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INDEX - MICROFILM REEL 227
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AUTHORS

HOLLINGS - WITHERS (B.I.O.S.)
BOGUE - MADLE (FIAT)

	B.I.O.S. Final Report Number	Item No.
HOLLINGS, H., HOPTON, G. U., SPIVEY, E. Lurgi high pressure gasification. (1946?) 75 p., incl. illus. diagrs.	521	30
HOWES, D. A. Interrogation of A. Bollhorn, E. Grages, and Dr. Gross of Deutsche Erdöl A.G., Berlin. (1946) 31 p. tables (part fold.).	326	30
HOWES, D. A. Kaiser Wilhelm-Institut für Strömungsforschung Abteilung Reibungsforschung, Berlin. Interrogation of Dr. Ing. G. Vogelpohl. August 11th - 14th, 1945. (1946) 16 p.	325	30
JONES, H. F., WEST, H. L. Wirtschaftliche Forschungsgesellschaft m.b.H., Hitzacker Depot. Investigation of the installation and interrogation of the personnel. July 8th-11th, 1945. 41 p., incl. illus., diagrs. (part fold.)	120	30
MINISTRY of Fuel and Power and British Intelligence Objectives Sub-Committee. Technical report on the Ruhr coal field, by a mission from the Mechanisation Advisory Committee of the Ministry of Fuel and Power... London: His Majesty's Stationery Office, 1946. Vol. I - (Vol. I: vi, 61 p., XXI tables (part fold.))	394	
MORLEY, R. J. Winkler generators for manufacture of water gas, etc. (1946?) 40 p. illus. diagrs.	333	30
MURRAY, C. A. Chemische Fabrik Weyl A. G., Sandhoferstr. 96 - 106, Mannheim - Waldhof. 20th September 1945. 10 p. diagrs.	332	30

	B.I.O.S. Final Report Number	Item No.
PERRYCOSTE, W. B. C. German carbon electrode manufacture at Griesheim (I.G.F.) 1946. 14 p.	338	21,22, 31
PERRYCOSTE, W. B. C. German graphitising furnaces at Meitingen (Siemens Plania). 1946. 10 p. diagr.	337	21,22, 31
PURDON, F. F. Carbon electrodes, I. G. Farben, Griesheim. (1946) 8 p.	258	22
RANKINE, A. O. Developments of geophysical prospecting in Germany during the war. (1946) 7 p.	334	30
ROSE, J. D. Cyclopolyolefines. Miscellaneous report compiled from interviews with Dr. Reppe, Dr. Schlichting and Dr. Kroper (I.G.Farben, Ludwigshafen.) (1946) 6 p.	352	22
ROSE, J. D. Preparation of 5-diethylaminopentanol-2 by the Reppe process. Translation of a report by Dr. Hecht and Dr. Gassenmeier, Ludwigshafen. (1946) 6 p.	353	22
ROSE, J. D. Products formed by interaction of acetylene and amines. (1946) 5 p.	359	22
ROSE, J. D. Propargyl alcohol dehydration and oxidation to hexadiinediol. Interview with Dr. von Kutepow, Haup laboratorium, I. G. Farben, Ludwigshafen - 19th November, 1945. (1946) 7 p. diagrs.	357	22
ROSE, J. D. Recent advances/in the chemistry of carbon monoxide. Translation of lecture by Dr. W. Reppe, Ludwigshafen. (1946) 18 p. diagrs.	355	22
ROSE, J. D. The synthesis of intermediates for polyamides on an acetylene basis (Translation of a report by Dr. W. Reppe, Ludwigshafen). (1946?) 19 p., incl. diagrs. (part fold.) ("Summary Report by Dr. W. Reppe, Ludwigshafen, 18.10.41," cf. p. 4)	350	22
SABEL, "Ten years of oxygen - gasification at Leuna" by Oberingenieur Sabel. Translated by D. G. Fraser and R. J. Morley. 1945. (1946) 36 p. diagrs.	199	30

	B.I.O.S. Final Report Number	Item No.
THOMAS, W. H., WITHERS, J. G. Deutsche Gasolin A. G., Hamburg - Germany. Lubricants. October 2nd - 10th 1945. (1946) 50 p.	524	30
THOMAS, W. H., WITHERS, J. G. Schlafhorst Chemische Werke G.m.b.H., Hamburg - Germany. Lubricants. October 2nd-10th (1945). (1946) 17 p.	512	30
WALLER, C. J. Dr. F. Raschig, G.m.b.H., Chemische Fabrik, Ludwigshafen: Coal tar distillation; chlorinated phenols; phenol-formaldehyde resins; synthetic phenols. (1946) 25 p. diagrs.	507	22, 30
WALLER, C. J., MURRAY, C. A. Gesellschaft fur Teerverwertung m.b.H., Duisberg - Meiderich, and Castrop - Rauxel. (1946?) 58 p. illus., diagrs.	450	30
WATT, W.; CLEWS, F. H.; MILLER, R. B.; WALKER, J.; WHEATLEY, C. H. High temperature refractories and ceramics. (1946) 53 p.	465	21, 22
WEST, H. L. Wirtschaftliche Forschungsgesellschaft m.b.H. Interrogation of Herr Helmut Plote of the Construction Department (evacuated to Hitzacker), July 8th - 11th, 1945. 22 p.	122	30
WITHERS, J. G., THOMAS, W. H., ROBINSON, E. B. Samples of petroleum products collected from the Hamburg, Hannover, Bremen and Kiel areas. September 31st - October 29th, 1945. (1946) 40 p.	510	30
WITHERS, J. G., WEST, H. L. Ruhr-Chemie A. G., Sterkrade, Holten. Interrogation of Dr. O. Reolen at Wimbledon, November 15th and December 20th, 1945. (1946) 27 p. diagr. (Contents: "Translations of three documents prepared by Dr. Roelen," translated by K. G. C. Kirkpatrick.)	511	30

	FIAT Final Report Number
BOGUE, L. E., HOERTZ, Norman. Air filters and oil filters for engines. 1946. 15 p. diagrs.	600

	FIAT Final Report Number
COPELAND, N. A., YOUKER, M. A. German techniques for handling acetylene in chemical operations. 1946. 235 p., incl. Exhibits A, B, C, D, and E. illus., diagrs. Exhibit D contains 14 drawings.	720
McBERTY, Ford H. Ferrocyanides and sulfur from gas work residues. 1946. 14 p.	809
MAILE, A. M. Fuel injection without injection pump. 1945. 14 p. diagrs.	621

Copy 1

BIOS Final Report No. 521
Item No. 30

LURGI HIGH PRESSURE GASIFICATION

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LONDON—H.M. STATIONERY OFFICE

LURGI HIGH PRESSURE GASIFICATION

Reported by

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of

Ministry of Fuel and Power

BIOS Target Numbers
C30/6.06(a), 30/6.06.

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TABLE OF CONTENTS

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LIST OF ILLUSTRATIONS

INTRODUCTION

In high temperature carbonisation processes as generally practised coal is heated in the absence of air, when a limited part of the coal substance is converted to gas which, mainly because of its high content of methane, has a calorific value of about 500-600 B.Th.U's per cu.ft. Coke remains as a solid residue, and in fact the weight of coke may represent as much as 73% of the weight of the coal carbonised. Some of this coke is used for heating the retorts, so that the quantity of coke for disposal amounts to about 60% of the weight of coal carbonised. Thus for every 1,000 cu. ft. of coal gas made, there is produced about 0.9 cwt. of coke. Gas and coke production are inter-dependent, and the proportion of gas to coke is nearly the same for all carbonisation processes. But the relative demands for gaseous and solid fuels vary, and this variation in demand is commonly met by gasification of some of the coke to give water gas.

Considerable interest has been aroused by methods for the direct gasification of coal in which no solid fuel remains as residue. If coal is completely gasified in a continuous process with air and steam, the gas produced has a low calorific value of 130-180 B.Th.U's per cu.ft. The calorific value may be increased by using oxygen instead of air, but the value at 300-350 B.Th.U.'s per cu. ft. is still far lower than what is required for towns gas. If however the gasification of coal with steam and oxygen is carried out under a pressure of several atmospheres, the proportions of the gaseous constituents formed are altered, the most striking feature being the increase in the formation of methane, so that the calorific value of the gas is increased.

The gasification of coal with steam and oxygen under pressure to produce directly gas suitable either for towns supply or for synthetic processes was developed by the Lurgi Gesellschaft fur Warmetechnik, Frankfurt-am-Main, from proposals made by O. Hubmann and F. Danulat. It is intended in this report to review the published literature on the subject, to report information supplied by the technical staff of the Lurgi Company, to describe the plant visited, and to make a critical examination of working results.

REVIEW OF THE LITERATURE

Three articles on the Lurgi process of high pressure gasification have been published by F. Danulat. Metallgesellschaft Periodic Review, No. 13; Gas and Wasserfach, 1941, <u>84</u>, 549; 1942, <u>85</u>, 557). An earlier booklet ("Die restlose Vergasung fester Brennstoffe mit Sauerstoff unter hohem Druck", published by Schack at Frankfurt in 1936) gives a full theoretical treatment and the first experimental results. The reactions involved are as follows:-

$$CO + H_2O \rightleftharpoons CO_2 + H_2 + 9.81 \text{ k.cals.per g.mol}$$
$$C + CO_2 \rightleftharpoons CO \quad -41.87$$
$$CO + 3H_2 \rightleftharpoons CH_4 + H_2O + 49.5$$
$$CO_2 + 4H_2 \rightleftharpoons CH_4 + 2H_2O + 39.56$$
$$C + 2H_2 \rightleftharpoons CH_4 \quad + 18.07$$

Consideration of these reactions shows that the proportion of methane formed on gasification increases with increasing pressure, and decreases with increasing temperature, as shown in Figures 1 and 2, which are taken from the second of the two papers cited. In Figure 1 the effect of pressure is shown, and comparison of the curves with those of Figure 2, showing the effect of temperature, indicates that the first figure refers to a constant temperature of 1000°K (°C absolute) while the second figure refers to a constant pressure of 20 atmospheres. Danulat then deduces the composition and calorific value of the gas after removal of water vapour and carbon dioxide, as shown in Figure 3, which also shows the theoretical consumption of oxygen. It is seen that by gasification at a pressure of 20 atmospheres it is, ideally, possible to produce a gas with a calorific value of about 5000 k.cals. per N.Cu.m. (measured at 0°C and 760 mm.), that is, 562 B.Th.U's per cu. ft. at N.T.P. dry, or 523.5 B.Th.U's per cu. ft. at 30" and 60°F wet (Standard Temperature and Pressure, or S.T.P.), assuming that the normal cubic metre refers to dry gas.

In actual practice the composition of the gas does not agree exactly with the theoretical values shown in Figure 3. The more reactive the fuel gasified, the nearer does the gas approach the ideal. This is shown in Figure 4, which gives the calorific value in relation to the gasification pressure for the ideal case and for brown coal and hard coal. The difference in behaviour of brown coal and hard coal, which is due to the lower reactivity and lower content of volatile matter of the latter, is shown in the following table.

TABLE 1

Gasification of fuels under pressure

Source	Brown Coal Middle Germany	Hard Coal Ruhr
Size m.m.	2-10	3-10
inches	0.08-0.39	0.12-0.39
Gross calorific value k.cal.per kgm.	4,950	7,600
B.Th.U.per lb.	8,900	13,700
Combustible material %	70.9	88.4
Carbon %	-	81.2
Water %	18.5	6.6
Ash %	10.6	5.0
Tar (Fischer test) %	14.4	-
Gasification pressure, atmospheres gauge	20	21
Generator load, kgm.per.sq.m.per.hr.	770	310
lb.per sq.ft.per hr.	158	63
Oxygen consumption, Vol.% of purified gas	15.0	19.8
Steam consumption, kgm. N.cu.m.gas	1.35	1.40
lb.per cu.ft.N.T.P. of gas	0.084	0.087
lb.per.cu.ft.S.T.P. of gas	0.079	0.081

Composition of gas:-		Crude	Purified	Crude	Purified
CO_2	%	31.5	3.6	27.2	1.0
H_2S	%	1.4	0.0		0.0
C_nH_m	%	0.8	0.8	0.2	0.3
O_2	%	0.1	0.1	0.1	0.1
CO	%	14.1	20.2	20.4	27.8
H_2	%	35.6	51.9	38.8	52.4
CH_4	%	15.5	22.0	12.3	16.9
N_2	%	1.0	1.4	1.0	1.5
Gross calorific value, K.cal.per N cu.m.		3100	4390	3010	4100
B.Th.U.per cu.ft.N.T.P.		349	494	339	461
B.Th.U.per cu.ft.S.T.P.		325	460	315	429
Specific Gravity (Air = 1)			-		0.432
Gas Yield N.cu.m.per tonne of coal		640		1570	
cu.ft. N.T.P.per ton		23,000		56,300	
cu.ft. S.T.P.per ton		24,600		60,400	
Tar Yield, % of coal content		83.3		-	

The composition of the gas is also influenced by the period of reaction, that is, by the generator load. Increased throughput at constant oxygen-steam rates results in a lower proportion of methane and a lower calorific value. Under the most favourable conditions an increase of 50% in the rate of throughput of fuel will lead to a fall in calorific value of about 200 k.cals per N.cu.m. (22.5 B.Th.U's per cu ft. N.T.P. dry, or 20.9 B.Th.U's per cu.ft. S.T.P.).

The process of gasification is described as follows. The fuel is fed into the top of the generator, where it is dried by the hot gases leaving. The hot crude gas passes through the top layer of fuel with a considerable content of water vapour, and leaves at a temperature of 300 to 600°C depending on the water content of the fuel. At saturation the exit gases at 20 atmospheres have a partial pressure of water vapour of 8 to 10 atmospheres, corresponding to saturation at 170-180°C. The saturation temperature at atmospheric pressure would be 75 to 80°C. Hard coal presents no difficulties in the drying zone, but the water content of brown coal must be limited to 20 to 25% in order to avoid condensation. The dried fuel passes down the generator and is carbonised by contact with the hot gas with a high yield of tar, comparable to that obtained in atmospheric low temperature carbonisation. It is necessary that the fuel does not cake or stick during carbonisation under pressure. Caking causes resistance to gas flow and uneven distribution of gas through the fuel. Brown coal is in general non-caking even under pressure and is readily gasified. With hard coal it is necessary to select those coals which do not cake at the pressure and under the conditions of movement in the generator, and this can be tested only in actual operation. Some coals which do not cake at atmospheric pressure develop marked caking properties at high pressure. On the other hand, a gas flame coal from Upper Silesia which was weakly

caking at atmospheric pressure could be gasified satisfactorily, because pressure did not increase the caking appreciably and the movement in the generator prevented the caking from becoming effective. In general it was found that lean hard coal could be gasified under pressure satisfactorily, while gas flame coals usually required pre-treatment to reduce the caking properties. Coals with a high ash content, up to 30 or 40%, can be gasified satisfactorily.

After carbonisation the fuel passes further down through the gasification zone to the combustion zone at the base of the generator. When steam and oxygen react with the fuel there is first formed a gas practically free from methane. As this gas rises through the fuel bed its temperature falls and reactions occur leading to the formation of methane. Figure 5 shows the effect of temperature on methane formation according to Traustel and Reuter (Feuerungstechnik, 1941, 29, 159). The amount of methane obtained from fuels by high temperature carbonisation at atmospheric pressure as compared with pressure gasification is shown in Table 2.

TABLE 2

METHANE FORMATION FROM COALS

Lignitic Brown Coal		Lean Hard Coal	
Combustible Substance	63.7%	Combustible Substance	92.8%
Ash	22.3%	Ash	6.0%
Water	14%	Water	1.2%
Tar	11.6%	Tar	-

	Lignitic Brown Coal: Atmospheric Carbonisation		Gasification at 20 atm.		Lean Hard Coal: Atmospheric Carbonisation		Gasification at 20 atm.	
	%	N.cu.m.t.	%	N.cu.m.t.	%	N.cu.m.t.	%	N.cu.m.t.
CO_2	22.8	42.1	30.15	304.5	1.8	3.8	27.0	580.5
H_2S	2.4	4.5	0.45	4.5	0.1	0.2	0.0	0.2
C_nH_m	1.5	2.7	0.6	6.0	0.6	1.3	0.2	4.3
O_2	0.4	0.7	0.1	1.0	0.3	0.6	0.0	0.6
CO	15.8	29.2	16.5	166.7	3.6	7.6	20.3	436.1
H_2	32.4	60.1	34.0	343.5	68.4	144.3	38.5	827.5
CH_4	20.7	38.3	16.3	164.6	19.7	41.6	12.3	264.3
N_2	4.0	7.4	1.9	19.2	5.5	11.6	1.7	36.5
Total		185.0		1010.0		211.0		2150.0

The temperature in the combustion zone is dependent on the melting point of the ash, below which it is necessary to operate. The temperature is controlled by the relative amounts of steam and oxygen admitted, and experience has shown that there is a most favourable ratio which can be found only in actual operation. Any deviation from this ratio is accompanied by a decrease in performance. Thus increase in temperature reduces methane formation, while decrease in temperature lowers the reactivity of the fuel. A low melting point of the ash by limiting the highest permissible temperature of operation causes a reduction in the highest attainable calorific value of the gas and reduces the rate of production because of the lower reactivity. The combustion is very complete and the ash is discharged with at most 5% of combustible material.

Two further working results given in Danulat's papers are reproduced in Table 3. These may be compared with the results given in Table 1.

TABLE 3

Gasification of Brown Coal at 20 atmospheres pressure

Source of Brown Coal	Lausitz	Mid. Germany
Size m.m.	2-10	2-10
inches	0.08-0.39	0.08-0.39
Combustible Material	67.5	72.5
Water	27.4	16.9
Ash	5.1	10.6
Tar	10.2	14.8
Gross calorific value k.cal.per kgm.	4730	5030
B.Th.U. per lb.	8,520	9060
Generator load, kgm.per sq.m.per hr.	750	890
lb.per sq.ft.per hr.	153	182
Oxygen consumption, Vol.% of purified gas	15.0	14.7
Steam consumption, kgm.per N.cu.m.gas	1.10	1.30
lb.per cu.ft.N.T.P.of gas	0.069	0.081
lb.per cu.ft.S.T.P.of gas	0.064	0.076
Composition of purified gas:-		
CO_2 %	3.0	1.7
C_nH_m %	0.5	0.8
O_2 %	0.1	0.2
CO %	22.8	21.9
H_2 %	48.7	50.4
CH_4 %	22.6	22.9
N_2 %	2.3	2.1
Specific Gravity (Air=1)	0.448	0.426
Gross calorific value, k.cal.per N.cu.m	4280	4510
B.Th.U.per cu.ft.N.T.P.	482	507
B.Th.U.per cu.ft.S.T.P.	448	472
Gas Yield N.cu.m.per tonne of coal	760	680
Cu.ft.N.T.P. per ton	27,300	24,400
Cu.ft.S.T.P. per ton	29,300	26,200
Tar yield % of coal content	72.0	84.3

Figure 6 is a flow diagram of the process. This will be amplified later when describing the plant visited. Plant results have shown that the efficiency of steam decomposition in the gasification process is 65 to 70%. (Note:- The Böhlen results given later disclose a much lower efficiency.) The tar obtained from brown coal contains a higher proportion of the lower boiling constituents than is the case in low temperature carbonisation at atmospheric pressure and less dust and creosote. The content of material boiling below 180°C amounts to 18% by volume. The bitumen and paraffins originally present are cracked but slightly and non-destructively, and hydrogenation of the tar does not take place.

As a result of using a high gasification pressure which favours the exothermic formation of methane, the oxygen consumption is reduced, as shown in Figure 7. The energy requirement of the process is correspondingly reduced; it is shown in comparison with other processes in Figure 8, which gives the energy required to manufacture gas to be delivered at 20 atmospheres pressure. Danulat does not complete fully the diagram for atmospheric gasification followed by atmospheric catalytic conversion to a higher calorific value, but indicates the compression and pressure washing requirements. Figure 9 is a heat balance for gasification at 20 atmospheres. This gives the calorific value of the gas and tar as 76.5% of that of the coal and steam, or 85.1% of that of the coal alone. The calorific value of the gas is given as 62.2% of that of the coal and steam, which corresponds to 69.2% of that of the coal. This value may be compared with the working results given in Tables 1 and 3, as shown in Table 4.

TABLE 4

THERMAL EFFICIENCY OF GASIFICATION

Coal	Mid Germany	Ruhr	Lausitz	Mid Germany
Calorific value of coal, k.cal. per kgm.	4950	7600	4730	5030
Gas yield, N.cu.m. per tonne of coal	640	1570	760	680
Calorific value of gas, k.cal.per N. cu.m.	4390	4100	4280	4510
Thermal efficiency, gas to coal; %	57	85	69	61

It is seen that the result for Lausitz brown coal agrees with the diagram, but that the values for the Middle German brown coals are lower. The thermal efficiency of conversion from coal to gas is much higher in the case of hard coal and in fact is equal to the conversion of brown coal to gas plus tar. It will be noted that no figures are given in Table 1 for the tar yield from hard coal, and the evidence of Table 4 points to the fact that no appreciable quantity of tar was formed from the Ruhr lean coal.

All solid non-caking fuels are suitable for pressure gasification, such as brown coal, lean hard coal and their carbonisation products. Lurgi have gasified hard coals from Wiesche, Concordia and Karsten-Zentrum, as well as Amalie coal after ageing. Artificial ageing can be used to reduce the caking properties of coals which are unsuitable without treatment. A high gas content of the coal is not necessary, but has the advantage of increasing the calorific value of the gas produced on gasification by 100-200 k.cal.per N.cu.m. (112-225 B.Th.U. per cu. ft. N.T.P. or 105-209 B.Th.U. per cu. ft. S.T.P.). The yield of gas depends on the quantity and nature of the combustible material in the fuel. With fuels rich in bitumen, as for example Middle German coals, which give a high yield of tar, the gas yield falls off, as shown in Figure 10. The reactivity of the fuel has a great influence on the calorific value of the gas, fuels with greater reactivity giving at the same gasification pressure, gas with a higher calorific value. Increase in gasification pressure raises the calorific value but there are technical limits to this increase. Wiesche lean coal gave on gasification at 20 atmospheres a gas of calorific value 4100 k.cal. per N.cu.m. (461 B.Th.U. per cu.ft.N.T.P. or 429 B.Th.U. per cu.ft. S.T.P.), and it is calculated that at 30 atmospheres the calorific value would be 4300 k.cals per N. cu.m. (484 B.Th.U. per cu.ft. N.T.P. or 450 B.Th.U. per cu.ft. S.T.P.). With less reactive fuels, such as high temperature coke, the calorific value on gasification at 30 atms. would be 4000 k.cal. per N.cu.m. (450 B.Th.U. per cu.ft. N.T.P. or 419 B.Th.U. per cu.ft. S.T.P.). The calorific value of the gas obtained from various fuels at different pressures is shown in Figure 11.

Fuels with a low ash melting point require a high consumption of steam and oxygen because of the low operating temperature. The ash content may be as high as 30-40% without causing difficulty. The sulphur content can be high, because most of the hydrogen sulphide formed is removed in the pressure water wash, and does not over-load the oxide purifiers. The size of the fuel must not exceed 25 m.m. (1 inch) owing to the construction of the coal feed mechanism, and must not be below 2 m.m. (0.08 inch) to avoid excessive resistance to gas flow and carry over of dust.

Of the costs of gas production by gasification and carbonisation Danulat states that whereas in carbonisation the return for the coke is of great importance, in gasification it is the actual gas production costs which are decisive. Calculations have shown that pressure gasification is cheapest for Middle German brown coal, because of the low price of the coal and the high return for tar. With regard to hard coal, Danulat points out that the coke obtained on carbonisation is a high quality fuel; if however the coke is converted to water gas so as to give a mixed gas and no solid residue from the coal, then the costs are dearer than in pressure gasification of lean coal. Reference may be made to an article by Traenckner (Gas and Wasserfach, 1939, 82, 590) from which Figure 12 is reproduced; the figures used by Traenckner are taken from the working of the Hirschfelde plant.

The information given in this section is abstracted from published articles in the German press, and serves as an introduction. The first high pressure gasification plant rated at 3.5 million cu.m. per annum was put to work on the A.G. Sächsische Werke at Hirschfelde (near Zittau) in 1936, using 2 generators of 1.15 m. internal diameter each capable of producing up to 15,000 cu.m. per day. This has been described by Drawe (G.W.F. 1937, 80, 806). Larger plants with generators of 2.5 m. internal diameter were put to work in 1940 on the A.G. Sachsische Werke at Böhlen (near Leipzig), and in 1942 on the Sudetenlandische Treibstoffwerke at Brux (Czechoslovakia), with capacities of 150 and 80 million cubic meters per annum or 430,000 and 230,000 cu.m. per day respectively. The Societa Italiana Carburanti Sintetici proposed to erect a hydrocarbon synthesis plant at San Giovanni Valdarno (near Florence), in which synthesis gas was to be made from lignite by the Lurgi process, using 8 generators of 2.5 m. internal diameter working at 24.5 atmospheres pressure. Site preparation was not far advanced at the time of Italy's defeat. The plant at Bohlen was visited on May 4-13th, 1945.

DESCRIPTION OF THE BÖHLEN PLANT

Adjacent to the Sächsische Werke is a large hydrogenation works (Brabag 1, owned by the Braunkohle Benzin A.G.), and it is an important part of the activities of the Sachsische Werke to supply low temperature tar for hydrogenation. The large low temperature carbonisation plant used for this purpose is of the Lurgi 'Spulgas' design, and carbonises brown coal briquettes. Brown coal is delivered from Böhlen mine with about 52% water. It is dried in order to reduce the moisture content of the finer material to about 15%, although the lumpy coal still retains up to 25% water. The dried fine material is then briquetted without binder into 2½ inch cubes. These cubes are delivered to the low temperature carbonisation plant, and in the handling a considerable quantity of material is broken off from the corners. The broken briquette pieces, together with the larger lumps of the dried brown coal which are not suitable for briquetting, are gasified in the high pressure plant. Additional briquettes are often brought in from Espenhain. In general the briquette pieces and dried lumps are gasified in the proportion of 1 to 2 but it was stated that broken pieces alone or dried lumps alone can be used successfully. The size of the material is from 3 to 10 m.m., with a maximum of 20 m.m., and the amount of material below 2 m.m. must not exceed 8-10%. The material is transported to the plant by rail in special containers holding about 4 tons each. The container has an automatic valve at the bottom which opens when the container is lowered by the travelling crane into the bunker.

The gasification plant has a capacity of 150 million cubic meters (5,700 million cu.ft. at S.T.P., that is, 30" and 60°F wet) of towns gas per annum, which is supplied at a pressure of 19 atmospheres to the grid serving Leipzig and Magdeburg. The plant is in two parts, consisting of 5 older generators (1940) and 5 modern (1943) housed in one building. Figure 13 is a view of the generator house which is 31.4m.(102 ft.) long by 17 m. (56 ft.) wide, and 32 m. (105 ft.) high. The projecting structures at the top are for coal elevation to the bunkers which occupy the topmost floor of the building. The modern generators differ from the older type in the design of the charging pouch, grate drive mechanism, and arrangement for scraping the generator dome. Each generator is rated at 3,000 cubic metres (114,000 cu. ft. S.T.P.) per hour and is normally operated at 2,500 cu.m. (95,000 cu. ft. S.T.P.) per hour, measured at 0°C and 760 m.m., the calorific value being 4,200 k.cals. per cu.m. (472 B.Th.U./cu.ft. at 0°C and 760 m.m., or, assuming that the German statement refers to dry gas, 440 B.Th.U./cu.ft. S.T.P.). War time difficulties had often resulted in the plant producing gas with a calorific value of only 3,900 k.cals. per cu.m. Attempts had been made to increase the calorific value to 4,500 k.cals. per cu.m. (471 B.Th.U. per cu.ft. at S.T.P.) but this had not been found possible at the normal working pressure of 20 atmospheres. The opinion was expressed that a calorific value of 4,500 k.cals./cu.m. might be maintained by gasifying at 25 atmospheres pressure, when methane synthesis would be promoted further.

The charging pouch on the modern generators consists of a chamber 2.75 m. (9.0 ft.) high by 2.0 m. (6.56 ft.) external diameter constructed of M.2 boiler steel of thickness 42 m.m. (1.65 ins.) with a capacity of 7.5 cu.m. (265 cu.ft.). It is fitted with two valves, one at the top communicating with the overhead fuel bunker of 50 to 60 tons capacity, and one at the bottom leading to the generators. Both valves are operated manually and are shown diagrammatically in Figures 14 and 15. The method of charging is as follows. The bottom valve is closed, and the gas in the pouch is blown off to a small holder. The rotary valve is then opened, allowing fuel to flow into the cylindrical sleeve. The conical valve is opened. As this valve falls, it permits a cylinder resting on it to drop to an extent limited by stops provided for the purpose, leaving the coal from the bunker free to flow through the cylinder and the space between the bottom edge of the cylinder and the valve. When the pouch is full the top valve is closed. In rising, the valve makes contact with the movable cylinder, thus shutting off the coal and leaving the valve surface clean when it meets the seating. Gas is then let into the pouch from the generator through a special pipe connecting them, and finally the bottom valve is opened. It takes 5 minutes to charge the pouch, and it was stated that only 2 men per shift are required on the charging stage of the new generators as compared with 5 men on the old generators. The quantity of coal in the pouch is indicated by the freedom or difficulty of movement of the bottom valve. When this valve closes freely the pouch is empty. Ventilators are fitted over the coal charging valves to remove any gas which escapes and to minimise dust nuisance (Figure 16), and the coal bunkers are purged continuously with nitrogen which is a by-product from the air separation plant. The upper explosive limit with brown coal was stated to be 15% oxygen, but it was customary to maintain the oxygen in the bunker at not more than 12%.

The total volume of gas blown off from the coal pouches represents 5-7% of the total gas made, and it is not included in the reported gas make. The gas is drawn from the holder and burned in a super-heater, which raises the temperature of the steam used for gasification from 380°C as delivered from the power station on the works, to 500°C.

The top valve of the pouch is composed of H.30.11 steel seating against a Buna S rubber ring dovetailed into the top flange of the pouch. The normal life of the Buna ring is 3 months. The bottom valve has a removable conical insert of hard "Panzer" steel which makes contact with a sharp edged seating of chrome alloy of 60.11 steel. The seating is usually renewed after one year of service, when the initial line of contact has widened to 7-8 mm. The free opening of both the top and bottom valves is 250 m.m. (9.8 ins.) diameter. As indicated in Figure 15, a metal ring of triangular cross-section filled with concrete is inserted at the bottom of the charging pouch to fill the acute angle in the neck.

The generator consists of a spherical ended cylinder of overall height 6.8 m. (22.3 ft.) by 2.8 m. (9.2 ft.) external diameter with walls 15 m.m. (0.59 ins.) thick, with a capacity of 35 cu.m. (1,240 cu.ft.). The cylindrical portion of the generator is brick lined from the top to within 1 m. (3.3 ft.) of the grate. It was stated that the bricks were dry set in contact with one another and with the steel, and that no difficulty had ever been experienced with expansion. The brickwork in the older generators has lasted over 4 years. The generator is enclosed in a pressure cylinder of external diameter 3.0 m. (9.8 ft.) with walls 47 m.m. (1.85 ins.) thick, the annular space constituting a water jacket which is connected to a steam drum, the small quantity of steam produced (60 kg. or 130 lbs./hr. at most) being led into the gas offtake. In this way the pressure inside the water jacket is maintained equal to the pressure inside the generator, so that the generator wall, which is exposed to the gases at high temperature, is not stressed with the difference between the gasification pressure and the atmosphere. The steam drum is 1 m. long horizontally (3.3 ft.) by 0.6 m. (2.0 ft.) in diameter and is connected to the top and bottom of the water jacket.

A skirt is provided around the coal inlet for the purpose of maintaining a gas space over the fuel bed. The skirt also serves as a support for a system of scrapers for the removal of pitch and carbon from the dome of the generator. These scrapers are electrically driven at 10 revolutions per hour through reduction gearing by a motor rated at 0.5 k.w. and are operated for 6 minutes every 2 hours. The position of these scrapers is shown in Figures 17, the drive being at K; an additional scraper projecting to the metal wall above the firebrick had been added at a later date. The generator shown is of the older type in which the coal pouch is closed by a flange which must be unscrewed for filling. Inside the skirt is suspended a conical ring and beneath it a double cone whose combined purpose is to avoid segregation of the fuel and to equalise the pressure across the fuel bed. 17b is a drawing of the generator.

The grate is operated continuously and its speed of rotation is determined by the quantity and character of the ash. The ash zone normally extends 300-500 m.m. (12-20 ins.) above the grate. The temperature of the fuel bed and condition of the ash are controlled by the relative amounts of steam and oxygen used for gasification. The temperature in the reaction zone was stated to be 1050-1150°C. The minimum permissible melting point of the ash is 1100°C, and fuels containing up to 30% of ash may be used. The carbon content of the ash is 5-6%. Figure 18 is a reproduction of a determination of the melting point by the Bunte-Baum method of a sample of clinker taken from the wall of a generator, and Figure 19 shows the results of a similar test on the fuel which was in use at that time. Both determinations were made by the laboratory staff at Böhlen, who commented that the sintering temperature of the coal was rather low.

The grate is slightly domed in form, and is composed of three sections, in each of which is fitted a detachable portion incorporating a plough arranged to direct the ash passing over the edge of the grate into a cylindrical space beneath the grate. Photographs are reproduced in Figure 20. It was stated that stationary ploughs above the grate were tried and abandoned. A vertical vane attached to the grate shaft then scrapes the ash into an opening leading to the ash pouch. The diameter of the grate is 1.6 m. (5.25 ft.), the centre being 150 m.m. (5.9 ins.) above the circumference. The grate sections are preferably cast from 25% chromium steel, and have a normal life of 3 years. The drive shaft of the grate is hollow to provide the inlet for the oxygen and steam mixture used to gasify the coal. The opening is covered by a cap of 0.8 m. (2.6 ft.) diameter supported to give an opening of 20 m.m. (0.8 ins.) between the cap and the grate (see Figure 17b). The grate is driven electrically by a 4.5 k.w. motor through reduction gearing and a ratchet device which affords adjustment of the speed of rotation. The mechanical parts are protected by shearing bolts. The shaft is packed with metal asbestos of square section with provision for lubrication. The grate and drive mechanism are supported from the generator shell.

The ash leaving the generator passes into the ash pouch through a valve which is exactly similar in construction to the bottom valve of the charging pouch except that its diameter is 300 m.m. (11.8 ins.) instead of 250 m.m. The ash pouch is 2.45 m. (8 ft.) high by 1.57 m. (5.2 ft.) internal diameter with walls 7 m.m. (0.28 ins.) thick and has a capacity of 3.5 cu.m. (124 cu.ft.). This thin metal wall is surrounded by a pressure wall 1.7 m. (5.6 ft.) external diameter with walls 40 m.m. (1.58 ins.) thick. The thin wall is only a lining designed to provide an insulating gas space between the ash and the pressure wall. The base of the pouch is closed by means of a disc clamped by four swing bolts. A thin Klingerite packing ring set into the disc forms the actual joint, and this is renewed after three discharges. The pouch is surrounded by a steam coil at the base to prevent condensation of water on the ash. The ash is discharged through a portable sieve into a water sluice at intervals of about 2 hours, the oxygen and steam released on reducing the pressure being allowed to escape to atmosphere. Alternatively the ash can be discharged into bogies and wheeled away. Gasification is not interrupted. Steam is used when increasing the pressure again to working level. The sluice water is sent to a settling pond where the ash is separated, and the clarified water is then returned to the plant. In order to avoid dust nuisance the sluice is fitted with a ventilator which maintains it under a slight vacuum.

It was stated that there have been no difficulties due to clinker formation except during periods of irregular operation, and the ash discharged is normally very fine. During air raid periods irregularities in operation led to clinker troubles necessitating 4 shut down periods in one year for each generator. In normal times a generator can be operated for 250 consecutive days, which include about 30 miscellaneous minor shut down periods totalling 90 hours. The total time lost for both major and minor repairs is about 2,000 hours in a year.

In order to maintain a high calorific value of the gas, the amount of steam used must be as low as possible, the limit being defined by the character of the ash. If sintering occurs, the generator must be cooled by the addition of more steam. Slag formation in the generator is to be suspected if the jacket temperature fluctuates, or the gas make varies with a rise in outlet gas temperature and an increase in the power consumption of the ash extractor.

The rate of extraction of ash is adjusted to the generator load. If too much ash is extracted, the ash contains too much combustible material, while if too little ash is extracted, the gasification zone moves upwards, as shown by a rise in the outlet gas temperature.

Temperatures inside the generator at the inner surface of the brickwork lining are measured at four points by thermocouples projecting through the steel shells and evenly spaced around the circumference 1.2 m. (4 ft.) above the level of the top of the grate. It was stated that these temperatures are not reliable as a means on control, and more importance is attached to the outlet gas temperature and to the character of the ash discharged.

Gasification is continuous, and the interval between charging the pouch depends on the relative sizes of the pouch and generator. The interval is 20 minutes with the old generator, and 35-45 minutes with the new generator.

A generator can be started up from cold in 12-18 hours using 25 cu.m. (88 cu.ft.) of ash with a thin layer of coal on the top, fired with wood and wood wool. Air is substituted for oxygen when starting up, and the poor quality gas is discharged to a stack at the top of which it is burned (Figure 17, No. 9), the gas outlet valve of the generator being shut and a spade inserted (4). Steam is then added, coal being run in at intervals. When the generator is hot gas making proceeds using oxygen and steam.

The oxygen is supplied by a Linde-Frankel plant housed in a separate building 53.5 m. x 31.8 m. (175 ft. x 104 ft.). It consists of 4 units, 2 of 1,000 cu.m. (35,300 cu.ft.) per hour and 2 of 2,000 cu.m. (70,600 cu.ft.) per hour free oxygen capacity. The oxygen is of about 95% purity, and is supplied to the generators by compressors at 23 atms. and 40°C. The installed power capacity of the oxygen plant is 4600 kw. It is not proposed in this report to describe the operation of the Linde-Frankel plant; full details are available elsewhere.

The gas leaves the generator at a temperature of about 300°C, passing through an offtake pipe which is provided with hand operated scrapers, shown at L in Figure 17. These are operated twice per shift. The offtake pipe also contains water sprays. The gas then passes into a spray cooler, F. It was clear that the design of this spray cooler had given trouble. The apparatus is dealing with water, gas, tar, and dust. It appeared that four or five different designs were in use on the plant, the general design in each case making use of changes in the direction of gas flow and the action of the water spray to wash out tar and dust. The overall dimensions were 2 m. (6.6 ft.) high by 0.5 m. (1.6 ft.) diameter, and the whole cooler was water jacketed for additional cooling. The tar is discharged through a trap and the water is re-circulated through an indirect cooler G to the sprays (7 and 8 in Figure 17.). A total of about 500 cu.m. (11,000 galls.) per day of water is discharged from the spray cooler systems. Dust is carried away in the water and in the tar. Troubles

due to emulsification of tar and water have been experienced. The gas leaving the spray coolers at about 150°C and 20 atms. is collected separately from each half of the house.

Each stream passes through two vertical water tube primary coolers, when the temperature is reduced to 100°C, then through a tar precipitator of the multi-baffle type, followed by three vertical water tube secondary coolers to condense light oils. Each primary cooler possesses 48 tubes 7.16 m. (23.4 ft.) long with 48 m.m. (1.9 ins.) internal diameter and walls 4.5 m.m. (0.18 ins.) thick and has a heat transfer surface area of 60 sq. m. (640 sq. ft.). Each secondary cooler possesses 174 tubes 7.16 m. (23.4 ft.) long with 23 m.m. (0.91 ins.) internal diameter and walls 3.5 m.m. (0.14 ins.) thick, and has a cooling area of 102 sq. m. The gas is then washed with oil in a Raschig ring scrubber 9.5 m. (31 ft.) high by 1.2 m. (3.9 ft.) diameter, to recover benzole. These units are shown in Figure 21. Referring to the structure with a common platform staging at the top, the two primary coolers can be seen on the left, and next to them a low vessel which is the tar precipitator. Then the three tall slim secondary coolers can be seen, and on the right the broader benzole scrubber. The somewhat shorter vertical cylinder just to the right of the structure is a separating tank. The second and similar stream can be seen at the back.

The cooling of the gas, removal of condensable products, and oil washing is followed by scrubbing under pressure with water to remove carbon dioxide and hydrogen sulphide. Each of the two gas streams is washed in two towers in parallel, 2.1 m. (6.9 ft.) in diameter and 21 m. (69 ft.) high, packed with two layers of 50 m.m. diameter x 50 m.m. high Raschig rings, the total packed volume being 52 cu.m. (1,820 cu.ft.) per tower. Water drawn from a collecting tank is pumped to the top of each tower, and led from the base to a turbine of the impulse type where its pressure is reduced from 20 to 2 atms. During this expansion carbon dioxide and hydrogen sulphide and other dissolved gases are evolved, and work is performed of which use is made by coupling the turbine to the high pressure water pump and the electric motor which drives it. The mixture of water and gases leaving the turbine is separated in a vessel whose gas space is connected to the turbine housing so that the rotors run in a water-free gas atmosphere. The gas and water are led separately under their own pressure to the top of the aeration towers shown in Figure 22 (one of the washers can be seen also behind the aeration towers). There are two aeration towers for each gas stream, 16 m. (52.5 ft.) high by 4 m. (13 ft.) diameter, packed with wooden boards on edge. It will be seen, however, that there are actually five and not four aeration towers in all, and similarly there are five pressure washing-towers. Plans had been made to add a sixth aeration tower and a sixth pressure washing tower. This may have been done in order to increase the efficiency of removal of carbon dioxide and hydrogen sulphide, or so as to have spare apparatus available as reserve. The aeration towers are divided into two parts. In the upper part which contains two layers of boards each 3,36 m. (11.0 ft.) high presenting together 3,000 sq. m. (32,500 sq. ft.) of surface, the water, now at atmospheric pressure, releases gas which together with the gas evolved from the separating vessel is led to the power house and burned to generate steam. The water then passes through a seal to the lower part of the tower containing two layers of boards each 3.12 m. (10.2 ft.) high presenting together 2,800 sq. m. (30,000 sq. ft.) of surface, where it is blown with air; this air containing hydrogen sulphide is sent to the base of the power house chimneys, where (it was said) hydrogen sulphide and sulphur dioxide react to give sulphur which is discharged to the atmosphere. This is believed to be the present system; but the plant documents describe a three stage aeration tower, consisting of (1) a top stage where gases are evolved by reduction in pressure, these gases being burned (2) a middle stage where air is drawn through by a fan and sent to the boiler stacks (3) a final stage where air is blown through the water and discharged to atmosphere. The aerated water returns to the collecting tank. The washed gas passes to a separator for removal of entrained water. The amount of water circulated in the pressure washing system is about 0.1 cu.m. per N. cu.m. of gas, or 580 gallons per 1,000 cu.ft. S.T.P.

Difficulties due to corrosion of parts of the plant by hydrogen sulphide and oxygen at 20 atms. pressure have been experienced. Chrome steel containing up to 23% of chromium has proved to be resistant.

After waterwashing the gas passes to the Lux purifiers, one stream of which is shown in Figure 23 viewed from the charging stage of the generator house, while both streams can be seen to the left of Figure 13. The purifiers consist of two parallel streams, each of four boxes, of which three are in use while one is being re-charged with oxide. The working life of a charge is about four weeks. The boxes were built by Klonne, and are 1.5 m. (4.9 ft.) in diameter by 7.5 m. (24.5 ft.) high, containing five trays each with two layers of oxide 16-18 inches deep, the gas flowing in parallel through the ten layers of a box while the three boxes of a stream are worked in series. The gas enters with 10-30 grm. of H_2S per 100 cu.m. (4-12 grains per 100 cu. ft. S.T.P.) and leaves with 0.1 grm. per 100 cu.m. (equivalent to 0.7 parts per million by volume). It was stated that 20 tons of Lux were used in a year.

Gas leaks were a very serious source of anxiety in the early days of the plant, but were finally overcome by care in the selection of jointing materials and in workmanship.

The total pressure loss in the whole cooling and purifying plant is about one atmosphere.

In operation there are three attendants and one technician per shift in the control room, which contains a panel for each generator, on which are mounted a recorder for the carbon dioxide content of the gas made, steam and oxygen flow meters, a gas pressure recorder, and a five-point temperature indicator. The total number of men assigned to the plant, including those on the Linde oxygen plant, is 207. This excludes boiler men and power house attendants. The men are distributed as follows:-

Supervision, including laboratory and office			12
Operation:	gas plant,	3 shifts x 29	87
	oxygen plant,	3 shifts x 10	30
	gas treatment plant	1 shift	35
	miscellaneous	1 shift	15
Maintenance:	repair crew	1 shift	20
	minor repairs	1 shift	8
			207

It was stated that the cost of the gas plant complete with oxygen plant, offices, land, railroad, sidings, roads, utility services, etc. totalled 11 million marks. Of this sum, the first five generators with all buildings and ancillary equipment and services amounted to 6.5 million works, and the second five generators with the additional buildings and equipment required amounted to 4.5 million marks.

Plant Results

From the documents taken from Böhlen it is proposed to quote some typical results of the working of the plant.

Table 5

Working results for the month of September, 1942

(5 older generators available)

Production		
Purified gas	6,566,771 N.cu.m.	248.7 mill.cu.ft. S.T.P.
Tar	654.07 tonnes	643.6 tons
Benzole	216.91 tonnes	213.3 tons
Gas liquor	8,154 cu.m.	1,792,000 Imp.galls.
Maximum daily gas production	268,041 N.cu.m.	10.14 mill.cu.ft. S.T.P.
Mean daily gas production	218,892 N.cu.m.	8.284 mill.cu.ft. S.T.P.
Mean hourly generator output	2,396 N.cu.m.	90,660 cu.ft.S.T.P.
Mean generator loading of dried coal per hour	0.794 tonnes/sq.m.	162.6 lbs.sq.ft.

Consumption

Coal:- briquette pieces, as delivered	4,297 tonnes	4,226 tons
dry, ash-free	3,218 tonnes	3,165 tons
lumps from drier, as delivered	6,593 tonnes	6,484 tons
dry, ash-free	4,081 tonnes	4,016 tons
total coal used, as delivered	10,890 tonnes	10,710 tons
dry, ash-free	7,299 tonnes	7,181 tons
Pure oxygen used	974,597 N.cu.m.	36.92 mill.cu.ft. S.T.P.
volume per unit vol.purified gas	0.149	0.149
Steam for gasification	9,355 tonnes	9,204 tons
per volume purified gas	1.42 kgm./N.cu m.	0.0826 lbs/cu.ft. S.T.P.
Total steam used	9,894 tonnes	9,737 tons
per volume purified gas	1.51 kgm./N.cu. m.	0.0878 lbs./cuft. S.T.P.
Electricity used in oxygen plant	1,244,340 kWh.	1,244,340 kWh.
per volume of pure oxygen	1.28 kWh/N cu.m.	0.0338 kWh/cu.ft. S.T.P.
Total electricity used	1,839,008 kWh	1,839,008 kWh
per volume purified gas	0.280 kWh/N.cum.	0.00739 kWh/cu.ft. S.T.P.
Water:- Plant water	147,767 cu.m.	32,480,000 Imp.gall.
Drinking water	1,027 cu. m.	225,900 Imp. gall.
Total per vol. of purified gas	22.6 litres/ N.cu.m.	0.131 galls/cu.ft. S.T.P.
Re-cycled cooling water	53,277 cu.m.	11,720,000 Imp.gall.

Analyses

Gas:-		Released gas	Crude gas	Purified gas
CO_2	%	87.3	32.9	6.3
H_2S		3.3	1.3	0.0
C_nH_m		0.5	0.9	0.8
O_2		0.1	0.2	0.1
CO		1.6	13.2	18.6
H_2		3.3	35.0	51.2
CH_4		2.9	15.4	22.0
N_2		1.0	1.1	1.0
Sp.gr.(air=1)		1.424	0.777	0.457

Calorific value(gross) of purified gas	4,339 k.cal.N. cu.m.	454 B.Th.U./cu.ft. S.T.P.
Tar: Density at 60°C	0.932 kgm/litre	
Dust content	0.17%	
Water content	0.46%	
Setting point	30.9°C	
Gross calorific value	9,486 k.cal./kgm.	17,080 B.Th.U./lb.

Benzole:	Density at 15°C	0.828 kgm./litre	
	Distillate to 180°C	81.6%	
	" " 100°C	85.4%	
	95% distilling at	218°C	
	gross calorific value	9,766 k.cal./kgm.	17,580 B.Th.U./lb.
Liquor:	Carbon dioxide	4.477 gm./litre	0.448% by wt.
	Ammonia	4.153 gm./litre	0.415% " "
	Phenol	4.723 gm./litre	0.472% " "
	Tar	27.912 gm./litre	2.791% " "

Coal, as delivered	Briquette pieces	Lumps
combustible material %	74.9	61.9
Water %	13.1	28.9
Ash %	12.0	9.2
Tar content %	14.8	12.3
Carbonisation water content %	18.9	33.9
Dry, ash-free C %	68.01	69.89
H %	7.81	7.51
S %	3.29	3.04
N + O %	20.89	19.56
gross C.V.	7,042 k.cal./kgm. 12,680 B.Th.U./lb.	7,069 k.cal./kgm 12,720 B.ThU./lb.

Yields

Yield of purified gas from coal	603 N.cu.m. per tonne	23,200 cu.ft. S.T.P./ton
Purified gas from dry, ash-free coal	900 N.cu.m. per tonne	34,630 cu.ft. S.T.P./ton
Tar plus Benzole calculated on basis of tar in coal by Fischer method	60.2%	
Proportion of benzole in Tar plus Benzole	24.9%	
Tar plus benzole Recovery from Gas	133 gm.per N.cu.m.	0.00774 lbs. cu.ft.S.T.P.

Thermal efficiency calculated on the Gross Calorific Value

$\frac{\text{Gas + Tar + Benzole}}{\text{Coal}}$ 71.6%

$\frac{\text{Gas}}{\text{Coal}}$ 55.3%

Miscellaneous

Oxygen purity	94.5%	
Steam decomposition (excl. jacket)	45.4%	
Oil consumption (869 kg. new charge)	1766 kgm.	3892 lbs.
Grease consumption	72 kgm.	159 lbs.
Tar loss in liquor	227 tonnes	223 tons
based on coal content	15.7%	
Quantity of released gas	3,530,030 cu.m.	124.7 mill.cu.ft.
	3,346,000 N.cu.m.	126.8 mill.cu.ft. S.T.P.

Table 6

Working Results for the Month of February, 1944

(Some of the new generators available)

Production

Purified gas	10,791,350 N.cu.m.	408.4 mill.cu.ft.S.T.P.
Tar	1,184.96 tonnes	1,166 tons
Benzole	503.46 tonnes	495.5 tons
Gas Liquor	15,962 cu.m.	3,510,000 Imp.galls.
Maximum daily gas production	426,496 N.cu.m.	16.15 mill.cu.ft.S.T.P.
Mean daily gas production	372,115 N.cu.m.	14.10 mill.cu.ft.S.T.P.
Mean hourly generator output	2,400 N.cu.m.	90,860 cu.ft. S.T.P.
Mean generator loading of dried coal per hour	0.770 tonnes/sq.m.	157.7 lbs. per sq.ft.

Consumption

Coal: briquette pieces, as delivered	4,825 tonnes	4,764 tons
dry, ash-free	3,657 "	3,598 "
lumps from drier, as delivered	9,399 "	9,246 "
dry, ash-free	5,921 "	5,824 "
coal from Espenhain, as delivered	3,108	3,058 "
dry, ash-free	2,064 "	2,032 "
total coal used, as delivered	17,332 "	17,050 "
dry, ash-free	11,642 "	11,454
Pure oxygen used	1,680,469 N.cu.m.	63.64 mill.cu.ft. S.T.P.
volume per unit volume purified gas	0.156	0.156
Steam for gasification	14,808 tonnes	14,580 tons
per volume purified gas	1.37 kgm./N.cu.m.	0.0796 lbs./cu.ft. S.T.P.

Consumption (Contd.)

Total steam used	18,435 tonnes	18,150 tons
per volume purified gas	1.71 kgm./N.cu.m.	0.0994 lbs./cu.ft. S.T.P.
Electricity used	2,866,404 kWh.	2,866,404 kWh.
per volume purified gas	0.265 kWh./N.cu.m.	0.00700 kWh./cu.ft. S.T.P.
Water: Plant water	194,784 cu.m.	42,840,000 Imp. gall.
per volume purified gas	18.4 litres/N.cu.m.	0.107 gall./cu.ft. S.T.P.
Drinking water	3,296 cu.m.	724,800 Imp.gall.
Re-cycled cooling water	55,680 cu.m.	12,250,000 Imp. gall.
Oil used (inc.900 kgm. old oil)	1,795 kgm.	3,958 lbs.
per volume purified gas	0.166 gm./N.cu.m.	0.00966 lbs./ 1000 cu.ft.S.T.P.
Grease used	82 kgm.	181 lbs.
per volume purified gas	0.008 gm./N.cu.m.	0.00047 lbs./ 1000 cu.ft.S.T.P.

Analyses

Gas	%	Released gas	Crude gas	Purified gas
CO_2		77.2	32.1	6.8
H_2S		3.8	2.0	0.0
C_nH_m		0.8	0.8	0.7
O_2		0.2	0.1	0.2
CO		3.4	12.9	18.3
H_2		7.5	35.7	52.2
CH_4		5.3	14.9	20.6
N_2		1.8	1.5	1.2
sp.gr. (air = 1)		1.319	0.771	0.463
Ott. Number				62

Calorific value (gross) of purified gas	4,231 k.cal./N.cu.m.	442.5 B.Th.U./cu.ft. S.T.P.
Tar: Density at 60°C	0.930 kgm./litre	
Dust content	0.06%	
Water content	0.65%	
Setting point	33.9°C.	
Gross calorific value	9,611 k.cal./kgm.	17,290 B.Th.U./lb.
Benzole: Density at 15°C	0.827 kgm./litre	
Distillate to 180°C	82.1%	
" 190°C	86.7%	
95% distilling at	214°C	
gross calorific value	9,976 k.cal./kgm.	17,950 B.Th.U./lb.
Liquor: Carbon dioxide	4.779 gm./litre	0.478% by wt.
Ammonia	4.069 "	0.407%
Phenol	4.291 "	0.429%
Tar	14.736 "	1.474%

Coal as delivered	Briquette pieces	Dried lumps	Espenhain
combustible material %	75.8	63.0	66.4
water %	14.0	28.7	19.3
ash %	10.2	8.3	14.3
tar content %	15.2	12.7	12.8
carbonisation water content%	21.0	35.2	25.7
dry, ash-free: C %	70.05	71.22	69.78
H %	5.28	5.27	5.51
S %	3.00	3.39	4.19
N + O%	21.67	20.12	20.52
Gross C.V., k.cal./kgm.	6807	6747	6884
B.Th.U./lb.	12,240	12,130	12,400

Yields

Yield of Purified gas from coal	623 N.cu.m./tonne	23,980 cu.ft.S.T.P./ton
Purified gas from dry, ash-free coal	927 N.cu.m./tonne	35,680 cu.ft.S.T.P./ton
Tar plus Benzole calculated on basis of tar in coal by Fischer method	72.7%	
Proportion of benzole in Tar plus benzole	29.8%	
Tar plus benzole recovery from gas	157 gm./N.cu.m.	0.00914 lbs./cu.ft. S.T.P.
Tar loss in liquor	235 tonnes	231 tons
based on coal content	10.1%	
Thermal Efficiency calculated on the Gross Calorific Value		
$\frac{\text{Gas + Tar + Benzole}}{\text{Coal}}$	78.6%	
$\frac{\text{Gas}}{\text{Coal}}$	57.7%	

Miscellaneous

Oxygen Purity	95.1%	
Quantity of released gas	4,816,376 cu.m.	170 mill.cu.ft.
Staff employed		13
Workmen employed German men	107	
German women	4	
Ukrainian men	44	
Ukrainian women	12	
Other men, foreign	25	
Total	192	
Average employed during month	188	
Number of man-shifts worked in the month	4,681	
Gas production per man-shift	2,302 N.cu.m.	87,180 cu.ft.S.T.P

The only figures available for daily production of gas are those for November, 1944, during which month bombing interfered only slightly with production.

Table 7

Daily Production During the Month of November, 1944

Day	Gas Produced		Calorific Value		Observations
	N.cu.m.	cu.ft.S.T.P.	k.cal./N. cu.m.	B.Th.U./ cu.ft.S.T.P.	
1	405,337	15,350,000	4160	436	
2	333,683	12,630,000	4170	437	
3	402,443	15,240,000	4210	441	
4	374,399	14,180,000	4060	425	
5	322,395	12,210,000	4070	426	
6	245,083	9,281,000	4095	428	Shortage of O_2
7	340,333	12,890,000	4150	434	
8	366,794	13,890,000	4080	427	Air Raid Warning
9	416,940	15,790,000	4020	421	
10	386,587	14,530,000	4070	426	
11	279,418	10,580,000	4020	421	
12	377,503	14,300,000	4050	424	
13	441,490	16,720,000	4030	422	
14	394,986	14,960,000	4085	427	
15	374,431	14,170,000	4130	432	Air Raid Warning
16	382,240	14,470,000	4130	432	
17	374,169	14,170,000	4065	425	
18	367,678	13,925,000	4120	431	Coal Shortage
19	309,973	11,730,000	4090	427	
20	369,065	13,980,000	4105	430	
21	299,842	11,350,000	4100	429	Air Raid Warning, Burst Water Tube
22	335,814	12,720,000	4150	434	
23	395,105	14,960,000	4050	424	
24	385,715	14,600,000	4095	428	
25	352,934	13,360,000	4100	429	Air Raid Warning
26	270,720	10,250,000	4120	431	
27	324,916	12,300,000	4100	429	Air Raid Warning
28	370,901	14,040,000	4160	436	
29	374,262	14,170,000	4130	432	
30	224,703	8,520,000	4150	434	Air Raid Warning
Total	10,600,850	401,400,000			

The latest results available are those for January 1945, just before bombing began finally to reduce production, not because the plant was damaged, but because the adjacent Hydrogenation plant was severely hit. The results were taken from the office records and are not so full as those given above from the engineer's file.

TABLE 8

WORKING RESULTS FOR THE MONTH OF JANUARY 1945

(10 generators available)

Production

Purified gas	12,365,904 N cu.m	468.4 mill.cuft S.T.P
Tar	1,101.32 tonnes	1,082 tons
Bensole	474.78 "	467.5 "
Maximum daily gas production	476,190 N cu.m	18.03 mill.cu.ft.S.T.P
Mean daily gas production	399,892 "	15.13 " " "
Mean hourly generator output	2,300-2,500 "	87,000-95,000 " "

Consumption

Coal:- briquette pieces as delivered	4,859 tonnes	4,782 tons
dry, ash-free	3,639 "	3,581 "
lumps from drier as delivered	8,101 "	7,974 "
dry, ash-free	5,347 "	5,264 "
from Espenhain, as delivered	6,640 "	6,536 "
dry, ash -free	4,343 "	4,274 "
total coal used, as delivered	19,600, "	19,282 "
dry, ash-free	13,329 "	13,119 "

Pure oxygen used	1,799,198 N cu.m	68.15 mill.cu.ft S.T.P
vol. per vol. purified gas	0.145	0.145
Steam for gasification	18,183 tonnes	17,890 tons
per volume purified gas	1.47 kgm/N cu.m.	0.0855 lbs/cu.ft.S.T.P
Total steam used	24,096 tonnes	23,700 tons
per volume purified gas	1.94 kgm/N cu.m	0.1128 lbs/cu.ft.S.T.P
Electricity used	3,402,865 kWh	3,402,865 kWh
per volume purified gas	0.274 kWh/N cu.m	0.00724 kWh/cu.ft.S.T.P
Plantwater used	247,200 cu.m.	54,380,000 Imp. galls.
per volume purified gas	20 litres/N cu.m	0.116 Imp.gall.cu.ft. S.T.P.

Analyses

Gas		Released Gas	Crude Gas	Purified Gas
CO$_2$	%	75.3	32.1	9.1
H$_2$S		3.6	1.6	0.0
C$_n$H$_m$		0.8	0.7	0.6
O$_2$		0.2	0.2	0.2
CO		3.5	12.1	16.7
H$_2$		9.0	37.5	52.3
CH$_4$		6.1	14.5	20.0
N$_2$		1.5	1.3	1.1
sp.gr. (air - 1)		1.288	0.753	0.499

Calorific Value (gross) of purified gas 4,048 k.cal. N.cu.m. x 424/B.Th.U/cu.ft. S.T.P.

Coal, as delivered	Briquette pieces	Dried lumps	Espenhain
combustible material %	74.9	66.0	65.4
water %	13.5	24.8	21.5
ash %	11.6	9.1	12.9
tar content %	15.5	13.6	13.4
Carbonisation water content %	20.1	31.3	26.2

x The low calorific value was ascribed to air raid interruptions.

Yields

Purified gas calculated on dried coal 632 N.cu.m./tonne 24,320 cu. ft. S.T.P. per ton

dry, ash-free coal 929 N.cu.m./tonne 35,770 cu. ft. S.T.P./ton

As a final example of the working results, the most important figures for the year 1943 may be of interest, since they show the very regular operation of the plant.

TABLE 9

Year 1943

Total volume of purified gas made 97,796,608 N.cu.m. 3703/mill. cu.ft.S.T.P.

Gas		Purified Gas	Crude Gas
CO$_2$	%	7.7	32.4
C$_n$H$_m$	%	0.9	0.9
O$_2$	%	0.2	0.2
CO	%	18.7	13.6
H$_2$	%	49.6	35.1
CH$_4$	%	22.1	15.4
N$_2$	%	0.8	0.8

gross calorific value 4,360 k.cal./N.cu.m. H$_2$S 1.6

456 B.Th.U/cu.ft. S.T.P.

sp.gr. (air = 1) 0.486

Ott.Number 62

Tar made	11,593 tonnes	11,400 tons
Benzole made	4,483 tonnes	4,408 tons
Calorific value (gross) of tar	9,549/k.cal./kgm	17,180 B.Th.U/lb.
Sp.gr. of Tar (at 60°C)	0.933	
Calorific value (gross) of benzole	9,751/K.cal./kgm	17,530 B.Th.U/lb.
Sp.gr. of benzole (at 15°C)	0.828	
Liquor made	108,180 cu.m.	23,790,000 Imp.galls.
Composition of liquor:- CO_2	0.485%	
NH_3	0.454%	
Phenol	0.499%	
Tar	1.125%	
Tar content of liquor	11.25 gm/litre	1.125% by weight
Maximum daily gas production	401,982 N cu.m.	15.22 mill.cu.ft. S.T.P.
Mean daily gas production	267,936 N cu.m.	10.14 mill.cu.ft. S.T.P.
Mean hourly generator output	2,495 N.cu.m.	94,440 cu.ft. S.T.P.
Mean Generator loading of dried coal per hour	0.794 tonnes/sq.m	162.5 lbs/sq.ft.
Total quantity of coal gasified,		
as delivered	156,244 tonnes	153,800 tons
dry, ash-free	106,319 tonnes	104,700 tons
Calculated composition of mixed coal:-		
combustible material	68.1%	
water	21.0%	
ash	10.9%	
tar content	13.6%	
carbonisation water	26.9%	
dry, ash-free:- C	69.49%	
H	5.85%	
S	3.08%	
N plus O	21.57%	

gross C.V. 7,014 k.cal./kgm = 12,620 B.Th.U/lb.

Gas yield based on coal as delivered	628 N/cu.m./tonne	24,180 cu.ft. S.T.P./ton
Gas yield based on dry, ash-free coal	920 N/cu.m./tonne	35,420 cu.ft. S.T.P./ton
Tar and Benzole yield based on content in coal	75.8%	
Tar loss in gas liquor	5.8%	

Thermal efficiency calculated from gross calorific value

$$\frac{\text{Gas plus Tar plus Benzole}}{\text{Coal}} = 78.0\%$$

$$\frac{\text{Gas}}{\text{Coal}} = 57.2\%$$

Quantity of released gas	42,780,295 cu.m.	1,511 million cu.ft.
Composition of released gas:-	CO_2 84.5. H_2S 3.9, C_nH_m 0.5, O_2 o.2, CO 2.2 H_2 4.6, CH_4 3.3, N_2 0.8%	
	Gross C.V. (Calc.) 860 k.cal/N cu.m.	90 B.Th.U/cu.ft. S.T.P.
Purity of oxygen	95.0%	
Pure oxygen used	14,083,721 N.cu.m.	533.5 mill.cu.ft.S.T.P.
per vol.of purified gas	0.144	
Steam used for gasification	127,022 tonnes	125,000 tons
per vol.purified gas	1.30 kgm/N.cu.m.	0.0756 lbs/cu.ft.S.T.P.
Total steam used	154,425 tonnes	152,100 tons
per vol.purified gas	1.58 kgm/N.cu.m.	0.0919 lbs/cu.ft.S.T.P.
Electricity used	25,010,256 K Wh	25,01 million K Wh
per vol.purified gas	0.256 K Wh/N.cu.m.	0.00676 kWh/cu.ft.S.T.P.
Plant water used	2,056,452 cu.m.	452 mill.Imp.Galls.
per vol.purified gas	21.0 litres/N.cu.m	0.122 galls/cu.ft. S.T.P.
Re-cycled cooling water	353,868 cu.m.	77.8 mill.Imp.galls.
per vol.purified gas	3.6 litres/N.cu.m.	0.021 galls/cu.ft.S.T.P.
Staff employed 15	Workmen employed 173	
Total man-shifts worked	50,259	
Gas produced per man-shift	1,942.N.cu.m.	73,560 cu.ft.S.T.P.

On inspection of the plant records, it is found that the only figures for the power consumed in producing oxygen are those for September 1942 (table 5), and for August 1943. In the other periods only the total electrical consumption is given. The figures for oxygen production are 1.28 and 1.13 k Wh per N.cu.m. giving a mean of 1.205 or of 0.0318 k Wh/cu.ft.S.T.P. It was stated in conversation that the power requirement for oxygen production excluding compression is 0.9-1.0 k Wh per N.cu.m., which is high because the turbo-compressors on the plant are inefficient. It was hoped by fitting new rotors to reduce the power consumption for uncompressed oxygen to 0.8 k Wh/N.cu.m. (0.021 kWh/cu.ft.S.T.P.). The power required to produce oxygen and compress it to 23 atmospheres was stated to be 1.1-1.2 kWh per N.cu.m., that is to say, the power for compression is 0.2 kWh/N.cu.m. This figure of 1.1-1.2 kWh/N.cu.m. agrees well with the mean consumption in September 1942 and August 1943 of 1.205.

The cost of electricity was stated to be 1.1 pfennigs per kWh, so that the power cost for the production of uncompressed oxygen was 1.0-1.1 pfennigs per N.cu.m., while the power cost for the production of oxygen compressed to 23 atms. was 1.2-1.3 pfennigs per N.cu.m. It was further stated that the total cost of oxygen production was 2.2-2.5 pfennigs per N.cu.m., of which total 40% represented capital charges, 40% power costs, and 20% chemicals.

repairs and maintenance etc. This would give the power costs of oxygen production 0.9-1.0 pfennigs per N.cu.m., which is in fair agreement with the costs calculated from the power consumption. Probably the figure of 40% is not very accurate.

The total consumption of electricity for gas manufacture including oxygen production was stated to be 0.22 kWh per N.cu.m. of purified gas. For the whole of 1942, 1943 and 1944 the plant records show an average total consumption of 0.270 kWh per N.cu.m. (0.00712 kWh per cu.ft. S.T.P.), and indeed in none of the plant records quoted above is the figure so low as 0.22.

The average wage rate at Bohlen was slightly under 1 mark per hour. Chemists employed in routine analysis were paid 1.50 marks per hour. There were only two qualified chemists on the plant, and their salaries were 800-900 marks per month.

Based on costs of fuel at 6.50 marks per tonne, water at 6 pfennigs per cu.m., electricity at 1.1 pfennigs per kWh., labour at 0.4 pfennigs per N.cu.m. of purified gas, maintenance at 0.4 pfennigs per N.cu.m. of purified gas, and oxygen at 2.2 pfennigs per N.cu.m., the total cost of gas was stated to be 3.8 pfennigs per N.cu.m. After deducting a return of 1.4 pfennigs per N.cu.m. for by-products, the net cost of gas production was stated to be 2.4 pfennigs per N.cu.m.

The manager and engineer in charge of the plant stated that the gasification plant operated smoothly and satisfactorily, and was a most successful unit.

Critical Examination of the Process.

Thermal efficiency

From the results for 1943 reproduced in Table 9 it is calculated the calorific value of the coal was 12.620 x 0.681 = 8,598 B.Th.U/lb. or 192.5 therms per ton. The tar yield was 166 lbs/ton of coal, and the calorific value was 17,180 B.Th.U/lb. or 28.5 therms/ton of coal. The benzole yield was 64.2 lbs/ton of coal, and the calorific value was 17,530 B.Th.U/lb or 11.3 therms/ton of coal. The gas yield was 24,180 cu.ft. S.T.P./ton of coal and the calorific value was 456 B.Th.U/cu.ft. or 110.2 therms/ton of coal.

The thermal efficiency was:-

$$\frac{\text{Gas plus Tar plus Benzole}}{\text{Coal}} = \frac{150}{192.5} = 78.0\%$$

The efficiency of gas production (E.G.P) was

$$\frac{\text{Gas}}{\text{Coal-Tar-Benzole}} = \frac{110.2}{152.7} = 72.2\%$$

The above figures take no account of the fuel required to raise process steam. It is shown in the next section that the use of released gases for steam raising should provide about 23% of the total steam used on the plant. The remainder, amounting to 0.77 x 0.0919 = 0.0708 lbs. of steam/cu.ft. of gas or 15.5 lbs./therm of gas, is supplied by burning brown coal in the boilers. If the same coal were used for this purpose as is used in the generator, 1 lb. of coal would raise

$$\frac{0.65 \times 8.598}{1.328} = 4.21 \text{ lbs. of steam.}$$

at 350 lb./sq.in. and 720°F, assuming 65% boiler efficiency and feed water at 80°F. Thus 3.68 lb. of coal are required for raising steam per therm of gas made, or 0.181 tons of coal per ton of coal gasified. The revised thermal statement with these assumptions is:-

	Per ton of coal used	192.5 therms
Coal gasified	0.847 tons	163.1 therms
Gas yield	20,480 cu.ft S.T.P. of 456 C.V.	93.3 therms
Tar yield	141 lbs.	24.1 therms
Benzole yield	54.4 lbs.	9.6 therms

Thermal efficiency $\frac{127.0}{192.5} = 66.0\%$

E.G.P. $\frac{93.3}{158.8} = 58.8\%$

The results of the pressure gasification of hard coal are given in Table 1. It is perhaps important to remember that these results refer to the smaller Hirschfelde generator. It is calculated that the thermal value of one ton of Ruhr lean coal was 307 therms, and that the gas yield was 259 therms. No tar or benzole is reported to have been formed.

Thermal efficiency = E.G.P. = $\frac{259}{307} = 84.5\%$

No figures are available in the case of hard coal for the calculation of the quantity of steam raised by burning the released gases. The steam requirement of the process is given as 0.081 lb/cu.ft. of gas (18.9 lb/therm of gas), but it is not certain whether this is steam for gasification only, although it probably is. It is therefore pointless to make more exact estimates. It will be assumed that as in the case of brown coal 15.5 lbs. of steam per therm of gas made must be raised by burning hard coal. Using hard coal of calorific value 13,700 B.Th.U/lb., the fuel requirement for steam raising is 1 lb. per 6.71 lbs. of steam, or 2.31 lb. per therm of gas, or 0.267 tons per ton of coal gasified. The revised thermal statement with these assumptions is :-

	Per ton of coal used	307 therms
Coal gasified	0.790 tons	242 therms
Gas yield	47,700 cu.ft.S.T.P. of 429 C.V.	205 therms

Thermal efficiency = E.G.P. $\frac{205}{307}$ = 66.8%

For comparison with carbonisation processes, calculations will be made based on data by F.B.Richards (Gas Journal, 1934, <u>208</u>, 339) for continuous vertical retorts.

1 ton of hard coal carbonised		305 therms
Gas yield (deducting 0.6 therms used on the works) at 450 C.V., 20,770 cu.ft.S.T.P.		93.4 therms
Tar yield 0.073 tons of 370 therms per ton		27.0 therms
Coke and breeze of 280 therms/ton		
For sale	0.456 tons	127.7 therms
for heating retorts	0.169 "	47.3 therms
for raising steam	0.023 "	6.4 therms

The above calculations are summarised in Table 10 together with figures for the carbonization of hard coal in coke ovens followed by the manufacture of water gas from all the saleable coke.

These figures may be compared with the heat balance diagram, Fig. 9. The assumptions made in the calculations for high pressure gasification in part (b) of Table 10 must be borne in mind.

Similar calculations may be made to take account of the fuel burned to raise steam to generate electricity for the oxygen plant and for other uses in the process.

From 1942-4 the total electricity consumption is 0.00712 kWh/cu. ft. of gas = 1.562 kWh/therm of gas = 172.0 kWh/ton of brown coal gasified. It may be estimated that 12.0 lbs. of steam are required to generate 1 kWh (steam at 350 lbs./sq. in. and 300°F superheat expanded to 28" vacuum with an overall efficiency of 64%). Thus steam required to generate electricity is 2064 lbs./ton of coal gasified, and considering for the purpose of the heat balance that the same fuel is used as is gasified (whereas in fact a much cheaper form of powdered brown coal was used), this needs $\frac{2064}{4.12}$ = 490 lbs. of coal or 0.219 tons. The statement including fuel required to raise process steam and to raise steam for generation of electricity then becomes:-

1 ton of brown coal gasified needs 0.181 tons of coal for process steam and 0.219 for generation of electricity, total 1.40 tons used.

per ton of coal used		192.5 therms	= 100%
Coal gasified	0.714 tons	137.3 therms	
Gas yield 17,260 cu.ft. S.T.P. of 456 C.V.		78.6 therms	= 40.8%
Tar plus Benzole 164.3 lbs.		28.4 therms	= 14.8%
Total thermal yield		107.0 therms	= 55.6%

E.G.P. $\frac{78.6}{192.5 - 28.4} = \frac{78.6}{164.1} = 47.9\%$

Table 10

Efficiency of Carbonisation and Gasification Processes

System	High Pressure Gasification				Carbonisation		Carbonisation water gas manufacture	
Fuel	Brown Coal		Hard Coal		Hard Coal		Hard Coal	
C.V. of gas. B.Th.U/cu.ft.	456		429		450		364	
	Therms	%	Therms	%	Therms	%	Therms	%
(a) Fuel reqd. for steam ignored								
Per ton of coal treated	192.5	100	307	100	305	100	305	100
Gas yield " " " "	110.2	57.3	259	84.5	93.4	30.6	187	61.3
Tar plus benzole " " "	39.8	20.7	-	-	27.0	8.9	10	3.3
Coke plus breeze " " "	-	-	-	-	134.1	44.0	-	-
Total thermal yield " "	150.0	78.0	259	84.5	254.5	83.5	197	64.6
E.G.P.		72.2		84.5		65.0		63.4
(b) Fuel reqd. for steam included								
Per ton of total coal used	192.5	100	307	100	305	100	305	100
Gas yield " " " "	93.3	48.5	205	66.8	93.4	30.6	182	59.7
Tar plus benzole " " "	33.7	17.5	-	-	27.0	8.9	10	3.3
Coke plus breeze " " "	-	-	-	-	127.7	41.9	-	-
Total thermal yield " "	127.0	66.0	205	66.8	248.1	81.4	192	63.0
E.G.P.		58.8		66.8		62.2		61.7

For hard coal it is stated in Table 1 that 19.8 volumes of oxygen were needed per 100 volumes of purified gas. From Table 5 and from the figures for August 1943 the electricity required for oxygen production is 0.0318 kWh per cu.ft. Thus electricity supplied to oxygen plant is 0.0318 x 0.198 x 60,400 kWh per ton of hard coal gasified = 380 kWh. Steam required for generation of this power is 4560 lbs. But this is not all the electricity required. From Table 5 it will be assumed that 594,668 kWh are required elsewhere per 248.7 million cu.ft. of gas = 144.5 kWh per 60,400 cu.ft. of gas or per ton of hard coal gasified. Thus steam required for total electricity consumed is 6,290 lbs. This needs $\frac{6.290}{6.71}$ = 938 lbs. of hard coal or 0.419 tons per ton of coal gasified. Thus for 1 ton of hard coal gasified there is needed 0.267 tons of coal for process steam and 0.419 tons for generating electricity, total coal used being 1.686 tons.

Per ton of coal used		307 therms	= 100%
Coal gasified	0.594 tons	182 therms	
Gas yield	35.800 cu.ft.of 429 C.V.	154 therms	= 50.2%
Thermal efficiency =	E.G.P.		50.2%

Released Gases

It was stated that the gas released when charging the coal pouch amounts to 6% of the total make; thus the quantity of gas discharged from the pouch amounted in 1943 to

$\frac{6}{94}$ x 3.703 = 236 million cu.ft. S.T.P.

Assuming a C.V. of 330, the thermal value of this gas was $\frac{236 \times 330}{10,000}$ = 0.78 million therms. It was used for superheating the steam for gasification. This amounted to 125,000 tons, and it was superheated from 380 to 500°C. The heat required was therefore $\frac{125.000 \times 2.240 \times 113}{100,000}$ = 0.316 million therms at 100% efficiency or 0.531 million therms at 60% efficiency. It is therefore assumed that 0.25 million therms of gas from the pouches were added to the gases released in the pressure washing process.

The quantity of gases released from the pressure washing was 1.511 million cu.ft. of calorific value 90 B.Th.U. per cu.ft., therefore amounting to 1.36 million therms. If this gas together with the gas from the pouches not needed for steam superheating was sent to the boilers it would raise

$$\frac{1.61 \times 10^6 \times 10^5}{2,240 \times 1328} \times 0.65 = 35,200 \text{ tons of steam,}$$

at 350 lbs. per sq.inch gauge and 720 °F assuming 65% efficiency of steam raising from gas heating, and feed water at 80°F.

This quantity of steam raised from released gases represents $\frac{35,200}{152,100} = 23\%$ of total steam used on the plant. It is not known whether this raising of steam was credited in the costs statement.

By-Products

This yield of tar from brown coal is high, amounting in 1943 to 166 lbs. or 17½ gallons per ton of coal, with a calorific value of 17,180 B.Th.U. per lb., and containing little dust and water. The yield of benzole is also high at 64 lb. or 7¾ gallons per ton of coal, although the quality (for example, 82% distilling at 180°C) is poor compared with that habitually produced in carbonisation practice (85-90% distilling at 160°C). The yields are much higher than those obtained in the carbonisation ofcoking coal, which are of the order of 10 gallons of tar and 3 gallons of benzole, but the entirely different nature of the coals must be borne in mind.

The sulphur recovery is extremely low. The sulphur content of the Bohlen coal was 3.08% on the dry, ash-free basis or 3.08 x 0.681 = 2.1% of the coal delivered to the plant. Thus the sulphur in the coal gasified amounted to 47 lbs. per ton.

Yet the quantity of Lux used in the purifiers was stated to be 20 tons a year, so that it is reasonable to estimate the sulphur recovery at 20 tons a year. As a check, consider 100 million cu.m. of gas containing 20 grm. of H_2S per 100 cu.m at inlet of purifiers.

$$\frac{0.2 \times 100 \times 106}{454 \times 2,240} \times \frac{32}{34} = 19 \text{ tons of sulphur.}$$

Accepting a figure of 20 grm. of H_2S per 100 cu.m. of gas (8 grains per 100 cu.ft.), and a gas make of 24,180 cu.ft per ton, the sulphur recovery is

$$\frac{8 \times 241.8}{7000} = 0.3 \text{ lbs. per ton of coal.}$$

The gases released from pressure washing contained 3.9% of H_2S and amounted to $\frac{1,511 \times 106}{153,800} = 9,850$ cu.ft. per ton of coal. Thus the sulphur present in these gases was $\frac{9850 \times 0.039 \times 32}{385} = 32$ lbs. (Assuming the lb.mol. to occupy 385 cu.ft. at the conditions of measurement). More sulphur is discharged to the atmosphere in the air sent from the aeration towers to the boiler stacks, and in the gas released from the pouch.

The sulphur balance is therefore as follows:-

Sulphur in coal	47 lbs.	per	ton
Sulphur recovered in purifiers	0.3	"	"
Sulphur in released gases from water wash	32	"	"
Sulphur in released gas from pouch Sulphur in air from water regeneration	14.7	"	"

The gas liquor amounted in 1943 to $\frac{23,790,000}{153,800} = 155$ Imp. gallons per ton of coal gasified, and it contained 0.454 x 155 = 7 lb. of NH_3 per ton of coal. It does not appear that this ammonia (which is roughly equal to that recovered in carbonisation practice) was recovered; no plant for the treatment of the liquor was seen, and the plant records make mention of the "tar loss" in the liquor. This tar amounted to 1.125 x 15.5 = 17.4 lbs. per ton of coal, which is $\frac{17.4 \times 100}{13.6 \times 224} = \frac{1740}{300} = 5.8\%$ of the tar content of the coal. The phenol in the gas liquor was 0.499 x 15.5 = 7.7.lbs per ton of coal. These losses of ammonia, tar and phenol are appreciable, but the difficulties in working up so large a volume of weak liquor are great.

In the abstract of Danulat's paper it was stated that the crude gas leaves the generator at a temperature of 300 - 600°C depending on the water content of the fuel, and with a partial pressure of water of 3-10 atmospheres. For a gas make of 24,180 cu.ft. S.T.P. per ton at 20 atmospheres and a water partial pressure of 9 atmospheres it is clear that the water vapour in the hot crude gas would amount to $\frac{9}{11} \times 24,180 \times \frac{18}{380}$ 940 lbs. or 94 gallons per ton of coal. Actually the water content of the coal gasified was 21% in 1943 or 470 lbs. per ton. The steam used for gasification was 1,820 lbs. per ton, so that accepting the only value known (for September 1942) of 45.4% steam decomposition, the undecomposed steam was 990 lbs. per ton. The amount of steam generated in the jacket was stated to be 130 lbs. per hour. For a generator loading of 162.5 lbs. of dry ash-free coal or 206 lbs. of coal used per sq.ft. per hour the coal gasified was 5.65 tons per hour per generator, so that the steam added to the crude gas from the jacket was 23 lbs. per ton. The total of the moisture in coal, undecomposed steam for gasification, and jacket steam is 47 + 99 + 2 = 148 gallons per ton. This does not agree with a partial pressure of 9 atmospheres, but agrees well with the liquor make. The quantity of plant water used in 1943 was 0.122 gallons per cu.ft. or 2,950 gallons per ton of coal, which includes all coolers and presumably make-up in the water washing plants and miscellaneous uses.

Carbon Dioxide Removal.

From the figures for 1943 it is seen that the crude gas contained 32.4% CO_2, which was reduced to 7.7% in the purified gas by washing with water under pressure. The quantity of carbon dioxide removed in the water wash was therefore

$$\left\{\left(32.4 \times \frac{92.3}{67.6} - 7.7\right)\right\} \times 24{,}180 = 8{,}820 \text{ cu.ft. S.T.P. per}$$

ton of coal or 278 lbs of carbon per ton of coal. The coal contained 69.49 x 0.681 = 47.3% of carbon or 1,060 lbs. per ton, so that 26.2% of the carbon in the coal was washed out as CO_2.

This loss of carbon dioxide is a consequence of the process of high pressure gasification in which internal heating occurs. It represents the combustion of part of the coal to supply the heat requirements of the gasification reactions.

In Table 1 are given comparable figures for the gasification of Ruhr hard coal. The CO_2 in the crude gas was 27.0% (see also Table 2) and in the purified gas 1,0%. The CO_2 washed out was

$$\left(\left(27.0 \times \frac{99.0}{73.0} - 1.0\right)\right) \times 60{,}400 = 21{,}500 \text{ cu.ft. S.T.P. per}$$

ton of coal, or 678 lbs. of carbon per ton of coal. The coal contained 81.2% of carbon, or 1,820 lbs. per ton, so that 37.3% of the carbon in the coal was washed out CO_2.

The size of Plant.

The generator house for a daily production of $\frac{467.8}{31} = 15$ million cu.ft. of gas (January 1945) occupies a ground space of 102 ft. by 56 ft. or 5,712 sq.ft. The oxygen plant occupies a ground space of 175 ft. by 104 ft. or 18,200 sq.ft. The total ground space occupied by the gasification units is thus 1,600 sq.ft. per million cu.ft. per day. These figures may be compared with a continuous vertical retort house producing 9 million cu.ft. of gas daily occupying a ground space of 207 ft. by 58 ft. or 12,000 sq.ft., that is, 1,300 sq.ft. per million cu. ft. per day. (The retort house also produces in addition coke which has a thermal value equivalent to 12-17 million cu.ft. of gas).

A closer comparison is probably that between the high pressure generator and a carburetted water gas generator. The high pressure generator working on brown coal gasifies 206 lbs. per sq.ft. of cross section per hour, producing $\frac{206 \times 24{,}180}{2240} =$ 2220 cu.ft. of gas or $\frac{2220 \times 456}{100{,}000} = 10.1$ therms per sq. ft. per hour. The figures for hard coal are 63 lbs. per sq. ft. per hour (Table 1) or $\frac{63 \times 60{,}400}{2240} = 1702$ cu. ft. of gas per sq.ft. per hour or $\frac{1702 \times 429}{2240} = 7.3$ therms per sq. ft. per hour.

A carburetted water gas generator will gasify 86 lbs. of coke per hour per sq.ft. of generator cross-section, producing 2740 cu. ft. of gas per sq. ft. per hour which after carburetting has a calorific value of 500 B.Th.U. per sq. ft., so that the output corresponds to 13.7 therms per sq.ft. per hour. Thus the rate of production is almost double that in the Lurgi generator.

The coolers are small in comparison to what is normally installed in carbonisation practice. Thus assuming that all the coolers at Böhlen were of the type using a large number of narrow tubes presenting a heat transfer surface area of 102 sq.m. each (whereas in fact some of the coolers possessed only 60 sq.m. each) the total cooling surface presented would be 510 sq.m. per stream of 7½ million cu.ft. a day, or 5485 sq.ft. This corresponds to an area of 730 sq.ft. per million cu.ft. per day. It is customary in the cooling of coal gas from continuous vertical retorts to allow 2,000 - 3,000 sq.ft. of heat transfer surface per million cu.ft. per day in the form of primary and secondary water-tube condensers.

The oxide purifiers are very small in comparison with the boxes used in carbonisation practice, because most of the hydrogen sulphide is removed in the pressure water wash. On the other hand, ground space is required for the washing and aeration towers and for the ancillary pumps and motors.

The benzole scrubber is 31 ft. high by 3.9 ft. diameter for a gas load of 7½ million cu.ft. per day. This is a smaller tower than would be allowed in good practice for benzole recovery from carbonisation gas at atmospheric pressure. No figures were given for the benzole content of the stripped gas, but it is known that in an experimental high-pressure Fischer-Tropsch plant operated at Böhlen the gas was passed through active carbon for removal of the residual benzole before passing to the catalyst.

The Böhlen plant is not laid out compactly. It appears from consideration of the individual plant units that a complete plant for the production of 15 million cu.ft. of gas per day could be laid out in a rectangular space approximately 750 ft. by 200 ft. This includes the oxygen plant, generators, coolers, washers and purifiers.

The Operation of the Plant.

The figures in Table 8 show that the plant was run at the rate of $\frac{468,400,000}{31 \times 24} = 630,000$ cu.ft. per hour. It is stated in more than one place that the average generator output is around 91,000 cu.ft. per hour, so that the number of generators in use in January 1945 appears to be $\frac{630,000}{91,000} = 7$.

In fact it was customary to aim at operating 4 new generators and 4 old generators at a time, while the other 2 generators were being overhauled. The plant was run as a base load plant, supplying gas directly into the high pressure grid at a very steady rate day and night, summer and winter, alike. Although a generator could be brought into operation in 12-18 hours from cold, there was no attempt to operate the plant with variable output. Since there was no gas holder on the works, fluctuations in demand were presumably met by the use of holders (probably installed previously by normal-type gas works) situated at convenient points in the towns where the pressure had been reduced for use in the consumers' services.

The desirability of operating at a steady rate is also due to the dependence of the gasification plant on the oxygen plant. The Linde-Fränkl plant contained 2 units each capable of making 35,000 cu.ft. of oxygen per hour, and 2 units each capable of producing 70,000 cu.ft. per hour. The average oxygen consumption in January 1945 was $\frac{68,150,000}{31 \times 24} = 91,700$ cu.ft. per hour, so that 1 large unit plus 1 small unit would have been sufficient for the duty. It was however more usual to work two-thirds of the plant, that is, 1 large plus 2 small units, or 2 large units, at decreased unit output. Sudden large variations in output are not desirable in the Linde-Fränkl process, and there was no storage holder for oxygen.

The control of the gasification appears to be satisfactory, depending on adjustment of the relative amounts of steam and oxygen used, and the rate of rotation of the grate. Manual labour is small in amount, and includes no arduous tasks such as rodding vertical retorts, charging ovens, or discharging coke. The charging stage is protected from dust and gas by the use of ventilators over the coal charging valve, and there is no nuisance in the house from the discharging and quenching of coke. The use of nitrogen in the coal bunkers eliminates risk of fire or explosion. Working conditions are probably considerably better than in most retort houses, but the risk from possible gas leaks is more serious, and smoking was strictly forbidden in the generator house. There are no producers and consequently no handling of coke for firing, and no risk of leakage of producer gas which is very rich in carbon monoxide. The labour of cleaning a large number of flues and adjusting the check tiles from time to time, with the control of

waste heat boilers, is abolished. All this represents a desirable simplification in gas making.

The loss of ammonia in the large quantity of very weak gas liquor discharged from the trap in the spray cooler circuit is not so serious in view of the alternative sources of ammonia as is the loss of phenol, which is of value as a starting material in organic synthesis. It is not surprising that no attempt was apparently made to work up the liquor, but in view of its content of 1% of tar there might be more difficulties in some situations in discharging it as an effluent than were apparently met at Böhlen.

The loss of sulphur in the water washing process is high. Of 47 lbs. of sulphur present in 1 ton of brown coal gasified, only 0.3 lbs. is recovered in oxide purifiers. Part of the balance of sulphur is present in released gases which are burned for steam raising or steam superheating, while the remainder is present in the air used for regenerating the wash water, and this polluted air is sent to the base of the boiler stacks where it was said to react with the sulphur dioxide in the waste gases to form elementary sulphur. This is a doubtful matter. In any case, 46.3 lbs. of sulphur were discharged to the atmosphere as sulphur dioxide with possibly some elementary sulphur.

Oxide purification is correspondingly lightened. There is no gas drying plant, and none is needed, because the gas becomes highly unsaturated on expansion to the low pressure required in the consumers' services.

With regard to the valves used in the charging pouch, it was learned that in the Lurgi high pressure gasification plant at Brüx a hydraulically operated valve is used to close the top of the charging pouch. A drawing of this valve was obtained, and Figure 25 is a sketch showing the essential features.

The Lurgi process of high pressure gasification of brown coal is now a proved success at Böhlen and Hirschfelde, and presumably also at Brüx. Information regarding the high pressure gasification of hard or black coal is not so positive. Three trials of hard coal were made at Hirschfelde, and the reports of these tests were obtained from Lurgihaus, Frankfurt. They are given in the next section. These seem promising, but the calorific value of the gas made is lower than that made from brown coal.

At Böhlen the Manager and Engineer were asked particularly for details of the use of hard coal. Their answer was that Silesian hard coal had been gasified in the plant for a short period only, apparently about two months, and that the best conditions of operation had not been found. It was stated that troubles due to sticking and clinkering in the generator, and dust blockage in the spray cooler, had been experienced during the trial of hard coal.

The behaviour of a hard coal in the Lurgi generator would depend on its caking properties under the conditions of temperature, pressure and movement, and the properties of the ash, which determine the operating temperature. Careful tests of the properties of a hard coal would have to be made before embarking on its use, and it is doubtful whether any tests have much value except those carried out in the actual generator. For district gas, the low calorific value obtained from hard coal is a disadvantage which might have to be countered by increasing the generator pressure; and here it must be emphasized that despite the charts prepared by Lurgi showing the effect of pressure in increasing the calorific value of the gas made, no plant has been run at pressures of more than twenty atmospheres, so that a plant at 30 or 40 atmospheres would be a new engineering undertaking. The very high steam pressure required is then a limitation to installation of the process. For gasification at 20 atmospheres it is necessary to generate steam at 350 lbs. per sq. inch. The installation of suitable boiler plant must be considered as part of the project of high pressure gasification.

When gas of the correct calorific value has been made at the high pressure necessary, the problem arises of how to reduce the pressure for the service of consumers. The high pressure is an advantage only when a high pressure grid is used, but in any case the pressure must be reduced at some point before reaching the consumers' services. There is further the question of whether to store the gas for meeting fluctuations in demand at the high or low pressure. For district use where no high pressure grid is in existence it would seem preferable to reduce the pressure in the Works and to store the gas in a low pressure holder feeding the district mains. The gas would be expanded through a turbine with recovery of the energy by the coupling of the turbine to the driving shaft of a convenient power unit. The following estimate is offered of the amount and value of the energy so recovered, it being assumed that waste heat is available for heating of the gas between the expansion stages of the turbine:-

Theoretical power from isothermal expansion, 19 atms. to 12 ins. W.G. = 0.092 kwh per N-cu.m.

Power recoverable as electrical energy (70% overall efficiency) = 0.064 kwh per N-cu.m.

Value of power recoverable (based on Böhlen cost of 1.1 pfg.per kwh) = 0.071 pfg. per N-cu.m.

Costs.

No costs are given in Danulat's two papers which have been

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abstracted in a preceding section of this report, but reference was made to an article by Traenckner from which Figure 12 is reproduced. It may be noted that the values shown in the figure do not agree exactly with operating results quoted in the article. From this figure the following costs may be read.

Table 11

Costs of Gas Production (from Traenckner)

	Pfennigs per N.cu.m.
Coal	1.00
Operating charges	1.00
Capital charges	0.90
Total charges	2.90
Credit for By-Products	0.60
Net cost	2.30

These figures may be compared with the statements made at Böhlen. The consumptions are taken for the year 1943 (Table 9)

Table 12

Costs of Gas Production at Böhlen

		Pfennigs per N cu.m.
Coal. 0.001598 tonnes at 6.5 marks		1.04
Operating charges:-	Electricity 0.256 kwh at 1.1 pfg.	0.28
	Steam 1.58 kgm. at 0.21 pfg.	0.33
	Water 24.6 litres at 0.006 pfg.	0.15
	Labour	0.40
	Maintenance	0.40
	Miscellaneous by difference	0.27
	Total	1.83
Capital charges.	11 million marks at 12.5% (assumed)	0.93

Total charges	3.80
Credit for By-Products	1.40
Net cost	2.40

In the above table steam has been valued at 0.21 pfennigs per kgm. for the following reasons:- power was stated to cost 1.1 pfg. per kwh, and assuming the power station to generate steam at 500 lb. per sq. inch and 700°F working with a vacuum of 28 inches, the overall efficiency of power production is estimated to be 68%. The steam consumption per kwh would therefore be 11.4 lb. or 5.2 kgm., whence the steam is worth $\frac{1.1}{5.2} = 0.21$ pfg. per kgm.

Oxygen costs do not appear individually in the calculations but are included in the operating and capital charges. This is because it would be necessary, in order to charge the known oxygen consumption at the stated cost of 2.2 pfg. per N.cu.m., to charge the capital costs of the plant exclusive of the cost of the Linde-Frankl plant, and this last figure is not known.

Capital has been charged at 12½%, and the gas production corresponding to the charges on 11 million marks is taken, not for 1943 (when the plant was not fully in action), but for January 1945, that is,

$$\frac{11,000,000 \times 12.5}{12 \times 12,366,000} = 0.93 \text{ pfg. per N.cu.m.}$$

The miscellaneous operating charge of 0.27 pfg. per N.cu.m. is inserted simply to make the operating charges add up to the stated figure of 3.80.

The main difference between the figures given by Traenckner and those quoted at Böhlen is the higher operating charger at Böhlen and the higher return for by-products. This difference may be due to war conditions.

The return for by-products at Böhlen includes tar and benzole and possibly sulphur, and it may include a credit for the steam raised by burning released gases. The credit for sulphur and steam could not in any case be large, as inspection of the quantity of sulphur and the total steam charges will show. Neglecting this possible credit, the return for tar and benzole amounts to 1.40 pfennigs for

$$\frac{15,808 \times 1000}{97,796,608} = 0.162 \text{ kgm. per N.cu.m., that is, a return of}$$

$$\frac{1.40}{0.162} = 8.65 \text{ pfennigs per kgm.}$$ If 14 marks be

considered equivalent to £1, this return corresponds to 0.67 pence per lb. or 6d per gallon, which does not seem unreasonable.

A further examination of the labour charge may be made. If the plant employed 173 men working 50,259 man-shifts in 1943 at about 8 marks per shift (it was stated that the average wage was 1 mark per hour), then the total labour charge was 402,000 marks for a production of 97,706,608 N.cu.m., or 0.41 pfennigs per N.cu.m. This estimate agrees very well with the statement made under interrogation.

The cost of oxygen was discussed in the section on "Plant Results". The evidence agreed that the power consumed in production was 0.9 - 1.0 kwh per N.cu.m. of oxygen at atmospheric pressure. It may be pointed out that these figures do not represent a high working efficiency. Figures as low as 0.5 kwh have been quoted for the production of 1 N.cu.m. of 95% oxygen in large modern Linde-Fränkl plants.

The Gasification of Hard Coal

On the occasion of a visit to the chief offices of the Lurgi Company at Lurgihaus, Frankfurt-am-Main, enquiries were made regarding the behaviour of hard coal in the Lurgi pressure gasification process. Reference was made in reply to the information published by Danulat. (The figures given in Danulat's papers have been reproduced in an earlier section of this report). Further information was obtained in the form of three reports, and it is proposed in view of their interest to countries possessing deposits of hard coal to give a translation of these reports, together with conversion of the figures to British units of measurements.

Experimental Production of Synthesis Gas from Hard Coal from the Karsten-Zentrum mine, Upper Sibesia

A. General.

An experiment to produce synthesis gas from hard coal from the Karsten-Zentrum mine, Upper Silesia, was carried out at the Hirschfelde works of the A.G. Sächsische Werke on the 17th and 18th of September, 1938.

The reserve generator of the works was available for the experiments. The oxygen plant was operated at maximum production. The proportioning of the oxygen between towns gas and synthesis gas production had to be adjusted to the demand for towns gas, so that only a limited quantity of oxygen was available for the experiment on synthesis gas. The experimental conditions were as follows:-

The coal, which was delivered with a size of about 3-10m.m. (0.12 - 0.39 inches), was gasified at a pressure of 5 atmospheres gauge with a mixture of oxygen and steam. Owing to the production of towns gas at the same time, the condensing and purification plant could not be used for the experiments, and so the gas cooling had to be limited to a preliminary cooling to about 100°C. These conditions prevented the carrying out of an exact measurement of the quantity of gas, as well as the complete recovery of the tar which was produced. The gas yield was arrived at from a carbon balance on the throughput. The tar yield obtainable is well known from previous experience. An attempt was made to bleed off a portion of the gas and to obtain a sample of tar by cooling this stream, but it was found that the lighter constituents of the tar were not fully recovered. For the same reason no satisfactory result was obtained in the determination of the benzole content of the gas sample.

The conditions described above had to be accepted because the production of towns gas was not to be hindered by the experiment.

The experiment had the object of testing the behaviour of Upper Silesian hard coal in the Lurgi pressure gasification process, and in particular of finding whether a synthesis gas of the required composition - CO_2/H_2 ratio 1:2 - could be produced directly without difficulties in operation.

B. Measurement and Sampling.

The coal used was weighed by crane. A combined sample was taken during the experiment for coal analysis.

The gas samples for analysis were taken at the outlet of the cooler.

Orifices were used to measure the quantity of steam and oxygen. The temperature of the superheated steam was about 470°C. The purity of the oxygen was determined at regular intervals; it could be altered by addition of air at the suction of the oxygen compressor.

C. Conditions.

After the generator had been running on hard coal for about 24 hours the test was commenced.

Owing to the limited amount of oxygen available for the experiment, the generator load amounted to only 290 kg. per sq.m. (59.4 lbs per sq. ft.) per hour. This limitation of the generator output resulted in unfavourable conditions for gas formation. A fundamental principle of the application of pressure gasification for the production of synthesis gas is the use of high generator loadings, amounting in the case of Upper Silesian hard coal to 600-800 kg. per sq.m. (123-164 lbs. per sq.ft.) per hour, since by this means the period of reaction for gas formation in the fuel bed is so much reduced, that methane formation is greatly suppressed. The results should therefore be corrected to correspond to normal working conditions.

Gasification proceeded smoothly. The ash was fine, well burned, and showed no signs of slag formation, although the generator was run comparatively hot. There was no difficulty due to caking of coal, even though the coal drawn out on emptying the generator showed signs in places of slight caking together of the coal particles. The emptying of the generator showed that no deposits had built up on the walls.

The ratio of $CO:H_2$ could be adjusted readily to 1:2

D Tests Results

1. Coal. Proximate analysis.	Ash	%	6.4
	Fixed C	%	54.1
	Water	%	7.2
	Volatile matter	%	32.3
			100.0
Ultimate Analysis	C	%	69.9
	H	%	4.56
	S	%	0.64
Low Temperature Assay Tar		%	9.0
	Liquor	%	5.4
	Coke	%	72.4
	Water	%	7.2
Gas (by Difference)		%	6.0
			100.0

Calorific value, gross 6,626 K cal/kg (11,920 B.Th.U./lb.)

Size analysis below 0.5 m.m. (0.02 ins) % 0.3

0.5 - 1.0 m.m. (0.02-0.04 ins)	%	0.1
1.0 - 2.0 m.m. (0.04-0.08 ins)	%	0.1
Over 2.0 m.m. (0.08 ins)	%	99.5

Raw coal gasified per 24 hours	8.31 tonnes	(8.18 tons)
Generator loading per hour	289 kg/sq.m.	(59.2 lbs/sq. ft.)

Ash and moisture free coal gasified per 24 hours 7.18 tonnes (7.06 ton)

Generator loading per hour, calc. on ash and moisture free coal 249 kg/sq.m. (51.0 lbs./sq. ft.)

2. Crude Gas Analysis

CO_2 + H_2S	%	26.4
C_nH_m	%	0.4
O_2	%	0.1
CO	%	21.5
H_2	%	41.9
CH_4	%	6.7
N_2 (by difference)	%	3.0
		100.0
H_2S	%	0.143

Yield per 24 hours 17,470 N.cu.m. (661,600 cu.ft.S.T.P)

3. Purified Gas Analysis

CO_2	%	1.0
C_nH_m	%	0.5
O_2	%	0.1
CO	%	28.9
H_2	%	56.4
CH_4	%	9.8
N_2 (by difference)	%	4.1
		100.0

Ideal Synthesis gas (CO + H_2) % 85.3

Ratio CO:H_2 1:1.95

Yield per 24 hours 12,200 N.cu.m. (46,200 cu.ft.S.T.P)

4. Oxygen. Quantity per 24 hours 2,720 N.cu.m. (10,300 cu.ft.S.T.P.)

Purity % 83.2

Pure oxygen per 24 hours 2,260 N.cu.m. (8,560 cu.ft. S.T.P)

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5. Steam. Quantity per 24 hours 11,880 kg. (26,190 lbs)
Temperature °C 465

6. Performance figures:-

Crude gas yield based on raw coal 2,100 N.cu.m./tonne (80,800 cu.ft.S.T.P/ton)

Purified " " " " " " 1,465 N.cu.m./tonne. (56,400 cu.ft.S.T.P/ton)

Oxygen consumption, Vol.per unit vol. crude gas 0.130
Vol.per unit vol. purified gas 0.186

Steam consumption, 0.680 kg/N.cu.m. crude gas (0.0395 lbs/cu.ft. S.T.P.)
0.975 kg/N.cu.m. purified gas (0.0567 lbs/cu.ft. S.T.P.)

E. Summary.

The experiments show that the required CO/H_2 ratio of 1:2 can be maintained without difficulty. Owing to local conditions the generator had to be operated at the relatively low load of about 290 kg. per sq.m. (59.4 lbs. per sq.ft) per hour whereas under normal conditions a throughput of 650 kg. per sq. m. (133 lbs. per sq.ft.) per hour is to be expected. The low load is the cause of the relatively high methane concentration in the purified gas of 9%. If the results are altered in accordance with these facts, the following values are obtained:-

1. Composition of Purified Gas:-

CO_2	%	1.0
C_nH_m	%	0.5
O_2	%	0.1
CO	%	30.3
H_2	%	60.6
CH_4	%	5.5
(by difference) N_2	%	2.0
		100.0

Gross Calorific Value 3370 k.cal/N.cu.m. (353 B.Th.U/cu.ft. S.T.P.)

Content of CO + H_2 90.9%

2. Gas Yield, based on raw coal 1,535 N.cu.m./tonne (59,060 cu.ft. S.T.P./ton)

3. Oxygen consumption, vols. per unit vol. of purified gas 0.186
4. Steam consumption (based on purified gas) 1.00 kg/N.cu.m. (0.0582 lbs/cu.ft.S.T.P.)

Due to the operation of making towns gas the experiments had to be carried out with oxygen of 83% purity. In independent operation of a synthesis gas plant it would be proper to use oxygen of 95% purity, so that the nitrogen content of the synthesis gas would be altered accordingly.

The gas yield is calculated from the carbon blanace, taking account of the reduced methane content. The result agrees with the thermal efficiency of gas and tar production found in normal working, namely 85%.

It may be concluded from the results that Upper Silesian hard coal from the Karsten-Zentrum mine is well suited from the point of view of yields and character of the products and of working conditions for the production of synthesis gas by the Lurgi pressure gasification process.

It is of advantage for the economics of the process that the cost of Upper Silesian hard coal is low and that the cost of production of gas is influenced by the simultaneous production of valuable low temperature tar.

Experimental Gasification of Concordia Lean Coal at 20 atmospheres by the Lurgi Process.

In conjunction with a synthesis gas experiment with Concordia lean coal, a gasification experiment was carried out with the same coal at 20 atmospheres gauge on the 6th and 7th of March 1939, with the object of ascertaining what calorific value may be expected.

The synthesis gas experiments were carried out from the 2nd to 5th March 1939, commencing at a gasification pressure of 5 atmospheres gauge. On the 4th March the pressure was increased to 10 atmospheres, and at noon on the 5th reduced again to 5 atmospheres. On the 6th it was found by poker exploration that the fuel bed was uniformly soft. The pressure was then raised to 20 atmospheres and gasification carried out at this pressure.

On the 7th March it was possible to use the condensing and pressure water washing plant for about 2 hours so that the calorific value and composition of the purified gas were determined directly. It was not possible, however, in view of the shortness of the period, to measure the gas quantity and so determine the output.

The Concordia coal was delivered with a size of 5 to 10 m.m. (0.20 - 0.39 inches). It proved to be very suitable for pressure gasification.

Coal Analysis

Water 2.66% Ash 4.03%
Gas content on heating to 1100°C, 400 - 420 litres/kg. with 75% H_2 (6.4 - 6.7 cu.ft/lb).
Calorific value, gross 8042 k.cal/kg. (14,480 B.Th.U/lb)
nett 7774 " (13,990 ")
Size analysis:- below 2 m.m. (0.08 inches) 7.0%
2 - 5 m.m. (0.08 - 0.20 inches) 19.6 %
over 5 m.m. (0.20 inches) 73.4%

Gas Analysis

		Crude Gas, 6/7 March.	Purified Gas, 6/7 March.	Purified Gas 7 March.
		determined	calculated	determined
CO_2	%	31.1	1.5	1.5
C_nH_m	%	0.1	0.1	0.1
O_2	%	0.1	0.1	0.1
CO	%	13.9	19.9	21.0
H_2	%	39.4	56.4	56.0
CH_4	%	12.8	18.3	18.6
N_2	%	2.6	3.7	2.7
Gross calorific value k.cal/N.cu.m.			4080	4130
B.Th.U/cu.ft. S.T.P.			427	432

The generator was run at about 50% of its maximum load. The oxygen was 84% pure.

From the results, gasification of lean coal at 20 atmospheres with normal loading of the generator may be expected to yield a purified gas with a gross calorific value of 4,000 to 4,100 k.cal. per N.cu.m. (419 - 429 B.Th.U. per cu.ft.S.T.P.) On discharging the generator no trace of caking was found. During the whole period of testing, gasification proceeded smoothly.

Experimental Gasification of Wiesche lean coal at the Hirschfelde Gas Works

A. General

At the request of the Mülheimer Bergwerks-Verein, Essen, a gasification test was made on July 24 - 26, 1939, with Wiesche lean coal (Stinnes) at the Hirschfelde Gas Works of A.G. Sächsische Werke. The test was also of interest in view of the gasification project of the Fried. Krupp A.G., Essen, since it was proposed that Wiesche coal should be exchanged for Amalie coal, which had been found in previous tests to be unsuitable owing to caking (Note: from Danulat's paper it appears that Amalie coal is suitable after ageing).

The Wiesche coal was delivered with a size of 3 - 10 m.m. (0.12 - 0.39) inches. A sample which had been tested previously in the laboratory had shown no signs of caking, so that no difficulties from this cause were expected.

The test was intended to show that Wiesche coal can be gasified by the Lurgi pressure process. At the same time it was intended to determine the composition and calorific value of the gas as well as the output, and to study the influence of pressure on the gas composition and calorific value.

B. Conditions

The test was carried out in the stand-by generator of the Works. Since there is no stand-by for the condensing and pressure washing plant in Hirschfelde, this plant can be used for any length of time on the test gas only when the calorific value reaches that required for the supply of Zittau, namely 4,200 k. cal. per N.cu.m. (440 B.Th.U. per cu. ft. S.T.P.)

After running in for about 40 hours the generator reached a steady condition, and measurements were commenced at 8a.m. on the 26th July. Observations and measurement during the running in period had already shown that the coal was gasified very smoothly, but that a calorific value of 4,200 k.cal. per N.cu.m. could not be attained at 20 atmospheres. Consequently the production of purified gas and the measurement of the quantity of gas had to be restricted to 2 hours. Before and after this period of measurement the generator was run for a considerable time with the same load and at 20 atmospheres, but the crude gas made was burned .

As part of the test, the operating pressure was reduced to 15 - 10 atmospheres gauge without altering the load or the ratio of oxygen to steam used for gasification. After reduction of the quantity of oxygen and steam, the pressure was raised again in stages. In this way the dependence of the gas composition and calorific value on the pressure was determined. Extrapolation may then be used to determine the behaviour at pressures above 20 atmospheres. The Hirschfelde plant can not be operated at pressures above 20 atmospheres.

C. Measurement

The quantity of coal gasified was weighed by crane over a period of about 11 hours during the test. Since small variations in output could not be avoided during this time and the period of complete testing was only two hours, the quantity of coal was proportioned over the period according to the load as measured by the oxygen rate, and so the amount of coal gasified during the short period of the actual test was calculated with sufficient accuracy.

The quantity of purified gas made was measured during the test period by means of an orifice and ring manometer with indicating and recording mechanism. The readings were corrected for pressure, temperature, and gas density. An automatic Junkers calorimeter was used to measure the calorific value and was checked against a hand calorimeter. The composition of the crude and purified gas was determined by individual analysis.

Oxygen and steam rates were measured by orifices and high pressure U tubes. The temperature and pressure were read at the same time as the differential pressure. Since the point of measurement of steam temperature was before the regulating value, about 5°C must be deducted for expansion through the valve and heat losses. The purity of the oxygen was determined regularly by analysis.

The charts of the recording instruments for the test period are attached to the report.

D. Experimental Results

1. Coal. Size Analysis.	Below 2 m.m.	(0.08 ins)	3.6%
	2 - 3 m.m.	(0.08 - 12 ins)	2.4%
	3 - 5 m.m.	(0.12 - 0.20ins)	10.4%
	5 -10 m.m.	(0.20 - 0.39ins)	83.6%
	Over 10 m.m.		0.0%

Proximate Analysis

Fixed C		81.24%
Volatile Matter		7.16%
Ash		5.04%
Water		6.56%

Low Temperature assay.

Coke	91.40%
Tar	0.11%
Liquor	0.38%
Water	6.56%
Gas (by difference)	1.55%

Hourly throughput of	raw coal	254 kg.	560 lbs
	dried	238 "	524 "
	Ash and moisture free	224 "	494 "
Generator load per hour,	raw coal	210 kg/sq.m.	43.0"/sq.ft.
	dried	197 "	40.3"
	Ash and moisture free	185 "	37.9"

2. . Gas Analysis

		Crude Gas	Purified Gas	Purified gas calculated from crude gas
CO_2	%	27.0	0.7	1.0
C_nH_m	%	0.2	0.2	0.3
O_2	%	0.0	0.0	0.0
CO	%	20.3	26.5	27.9
H_2	%	38.5	54.9	52.9
CH_4	%	12.3	16.1	16.9
N_2	%	1.7	1.6	1.0

Calorific value determined

		3920		k.cal./N.cu.m.
		410		B.Th.U./cu.ft.S.T.P.
calculated	3003	4050	4132	k.cal./N cu.m.
	314	424	432	B.Th.U/cu.ft.S.T.P.

Purified gas made 430 N.cu.m./hour (16,300 cu.ft.S.T.P.)

3. Oxygen purity 84.7%
   quantity (100%) 85.1 N.cu.m./hour (3,220 cu.ft.S.T.P.)

4. Steam Temperature (superheated) 490°C
   quantity 600 kg./hour (1,320 lbs).

5. Performance figures

Gas yield from raw coal	1690 N.cu.m./tonne (65,000 cu.ft.S.T.P./ton)
dried	1810 N cu.m./tonne (69,609 cu.ft.S.T.P./ton)

Ash and moisture free	1920 N.cu.m./tonne (73,900 cu.ft.S.T.P./ton)

Oxygen consumption, vols.per vol. of purified gas 0.198
Steam consumption,per vol.of purified gas 1.40 kg./N.cu.m.
(0.0814 lbs./cu.ft.S.T.P.)

6. Influence of pressure on Gas Composition.

Crude Gas		Pressure 10.1	15.0	21.0	30 atm ganage (extrapolated)	
CO_2	%	27.4	27.7	27.0	28.5	
C_nH_m	%	0.3	0.2	0.2	0.2	
O_2	%	0.2	0.1	0.0	0.0	
CO	%	17.6	18.2	20.3	22.2	
H_2	%	43.8	40.5	38.5	33.3	
CH_4	%	9.1	10.8	12.3	13.9	
N_2	%	1.6	2.5	1.7	1.9	
Gross calorific value		2800	2860	3003	3040	k.cal./N.cu.m.
		293	299	314	318	B.Th.U./cu.ft. S.T.P.
Ratio H_2/CO		2.49	2.23	1.93	1.5	
Purified Gas (calculated)						
CO_2	%	1.0	1.0	1.0	1.0	
C_nH_m	%	0.4	0.3	0.3	0.3	
O_2	%	0.3	0.1	0.0	0.0	
CO	%	24.3	25.6	27.9	31.2	
H_2	%	60.4	56.8	52.9	46.9	
CH_4	%	12.6	15.2	16.9	19.6	
N_2	%	1.0	1.0	1.0	1.0	
Gross calorific value		3866	4020	4132	4285	k.cal./N.cu.m.
		404	421	432	448	B.Th.U./cu.ft. S.T.P.

The extrapolation to 30 atmospheres gauge pressure was performed as follows:-

From equilibrium date and previous experience it is known that within the range of pressure under consideration, the methane content of the crude gas is directly proportional to the logarithm of the pressure. In this way the methane content is calculated with accuracy. Further, the ratio of H_2 to CO was plotted in relation to the pressure; and the other gaseous constituents were assumed from the analysis at 10,15 and 20 atmospheres. The crude gas so estimated was then used to calculate the purified gas and its calorific value. As a check the relation of the calorific value of the purified gas to the pressure was employed, where the calorific value should be almost directly proportional to the logarithm of the pressure.

E. Conclusions.

The Wiesche coal was gasified very smoothly. The ash was fine; signs of caking could not be detected. The gas yield was 1690 N.cu.m. of purified gas per tonne of raw coal (65,000 cu.ft.S.T.P. per ton) which is satisfactory. The oxygen consumption (0.198 volumes per volume of purified gas) and Steam consumption (1.4 kg. per N.cu.m. or 0.0814 lbs per cu.ft. S.T.P.) are higher than in the gasification of brown coal. This is to be ascribed partly to the lower content of volatile matter, and partly to the lower reactivity of the lean coal. A low reactivity influences unfavourably the steam decomposition and methane formation. Consequently the calorific value was also low at about 4000 k.cal.per N.cu.m. (419 B.Th.U. per cu.ft. S.T.P.) The calorific value and consumptions can be improved only to a slight extent by running the generator at a higher temperature because of the risk of slag formation.

The influence of pressure on gas consumption and calorific value was determined by reducing the pressure to 15 and 10 atmospheres. Extrapolation then gave a calorific value of 4285 k.cal.per N.cu.m. (448 B.Th.U. per cu.ft. S.T.P.) for purified gas resulting from gasification at 30 atmospheres gauge.

Alteration of the throughput was made at the conclusion of the test at all 3 pressures. It had no noticeable influence on the methane formation.

List of Documents taken from Böhlen in Bag 3500

Photographed by camera A. Reel 12.

Document No.	Description
26	Description of high pressure gasification plant.
27	Analysis of dried lumps of brown coal.
28	Analysis of briquette pieces.
29	Analysis of gas from high pressure plant.
30	Working results for January 1945.
31	Fusion point of slag.
32	Estimated costs of construction of plant.
33	File of descriptions, instructions and results.
35	Drg. Flow sheet of brown coal processing.
36	Drg. Plan of Sächsische Werke.
37	Drg. -do-
38	Drg. Lay out of Gas Plant.

39	Drg. Gas connections in gas plant.
40	Drg. Flow diagram of oxygen plant.
41	Drg. -do-
42	Drg. Diagram of high pressure generator.
43	Drg. Diagram of coal supply to generator.
44	Drg. Studs on generator.
45	Drg. Pressure vessel.
46	Drg. Brickwork of generator.
47	Drg. Coal distributor for generator.
48	Drg. Coal distributor (for another plant).
49	Drg. Charging pouch of generator.
50	Drg. Automatic valve for charging pouch (at Brüx).
51	Drg. Valve of charging pouch.
52	Drg. -do-
53	Drg. Discharging pouch.
54	Drg. Ash discharge device.
55	Drg. Steam and water pipes on generator.
56	Drg. Jig for regrinding faces.
57	Drg. Hoods for gases from charging pouch.
58	Drg. Temperature measurement points.
59	Drg. Scrapers in generator.
60	Drg. Off take elbow valve.
61	Drg. Primary cooler.
62	Drg. Secondary cooler.
63	Drg. Tar separater.
64	Drg. -do- arrangement of nozzle rings.
65	Drg. Benzole scrubber.
66	Drg. Pressure Water Washing - ground plan.
67	Drg. -do- general arrangement.
68	Drg. -do- pipe lines.
69	Drg. -do- -do-
70	Drg. Aeration tower (lower part).

List of Documents taken from Frankfurt in Bag 2708

Photographed by Camera A. Reel 36.

Document No.	Description
1	Report of test on Concordia lean coal.
2	Report of test on Wiesche lean coal.
3	Report of test on Karsten-Zentrum hard coal.
4	Drg. Assembly of generator.
5	Drg. Generator.

List of Documents taken from Böhlen in Bag 4182

Photographed by camera A. Reel 33.

Document No.	Description
9	Analysis of broken briquette pieces.
10	Analysis of fuel from Espenhain.
11	Analysis of dried coal lumps.
12	Plant log sheet of pressure water wash.
13	Plant log sheet of condensers.
14	-do-
15	Plant log sheet of refrigeration.
16	Sketch of coal feed to generator.
17	Drg. Parts of grate drive.
18	Drg. Disc crank of grate drive.
19	Drg. Suspension of ash pouch.
20	Drg. Aeration tower (upper part).
21	Drg. Insulation of generator.
22	Drg. Cooling water tank.
23	Drg. Pressure water washing plant.
24	Drg. -do-
25	Drg. Discharge section of bunker.
26	Drg. Wash oil tank.
27	Drg. Discharge section of bunker.
28	Drg. Pipe lines of pressure washing plant.
29	Drg. Pressure washing tower.
30	Drg. Ventilation of generator house (Brüx).
31	Drg. Lay-out of Brüx generator house.
32	Drg. Generator shell.
33	Drg. Pressure washing plant (Brüx).
34	Drg. -do-
35	List of jointing materials.
36	Drg. Klonne high pressure purifiers.

List of Documents taken from Frankfurt in Bag 3499

Photographed by camera E. Reel 8.

Document No.	Description
1	Comparison of 8 processes of synthesis gas manufacture.
20	Lurgi process for synthesis gas production.

Note:- Document No. 1 consits of one large sheet which gives flow diagrams, gas composition, consumption of coal, oxygen steam and electricity, with tar and benzole recovery, and estimated capital costs of the plant, for the following processes for the production of synthesis gas: pressure gasification with cracking of the rest gas; pressure gasification with cracking of the gas produced; atmospheric gasification with re-cycling of CO_2; slagging pressure gasification; pressure gasification with cracking of the gas produced, using regenerators; Koppers rest gas cracking combined with pressure gasification; pressure gasification with re-cycling of CO_2; and low temperature carbonisation followed by the Winkler Generator.

Document No. 20 gives data including estimated costs for a project for a synthesis gas plant of capacity 550,000 N.cu.m. per day for Rumoi coal in Japan; also similar data for a synthesis gas plant of capacity 81,800 N.cu.m. per hour using pressure gasification and cracking. At the end of the typed sheets are flow diagrams with quantities for the process to produce synthesis gas of H_2: CO ratio of 2.0, 1.25, 1.0 and 0.666. There is also a diagram of the water connections to the hydraulically operated valves of a charging pauch together with time table of operations.

Bibliography

1) Hubmann, O. "Erzeugung von wasserstoffreichem Gas für" "Städteversorgung und Synthese", Veröffentl. der Metallgesellschaft, 1933

2) Drawe, R. Gas und Wasserfach, 1933, 76, 541

3) Drawe, R. Gas und Wassfach, 1937, 80,806

4) Danulat, F. "Die restlose Vergasung fester Brennstoffe mit Sauerstoff unter hohem Druck" Schack, Frankfurt,1936.

5) Danulat, F. "Pressure Gasification of Solid Fuels with oxygen", off print from Periodic Review No.13 of the Metallgesellschaft.

6) Traenchner, K. Gas und Wasserfach, 1939, 82, 590.

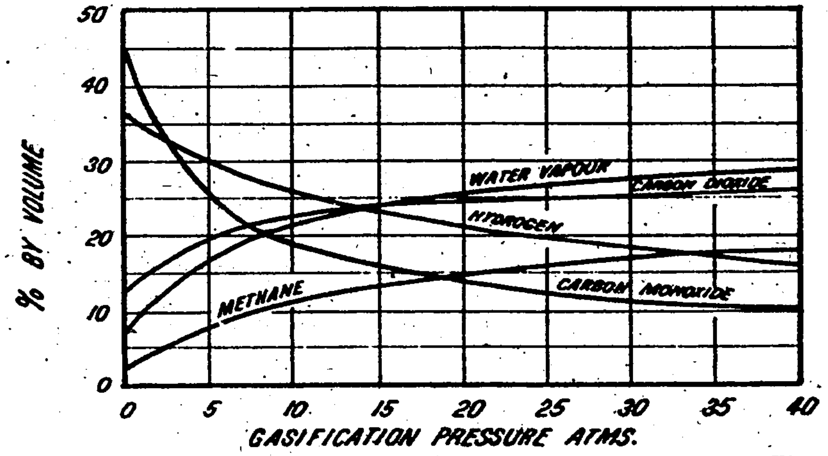
7) Danulat, F. Gas und Wasserfach, 1941, 84, 549.

8) Danulat, F. Gas und Wasserfach, 1942, 85, 557.

List of Conversion Factors employed

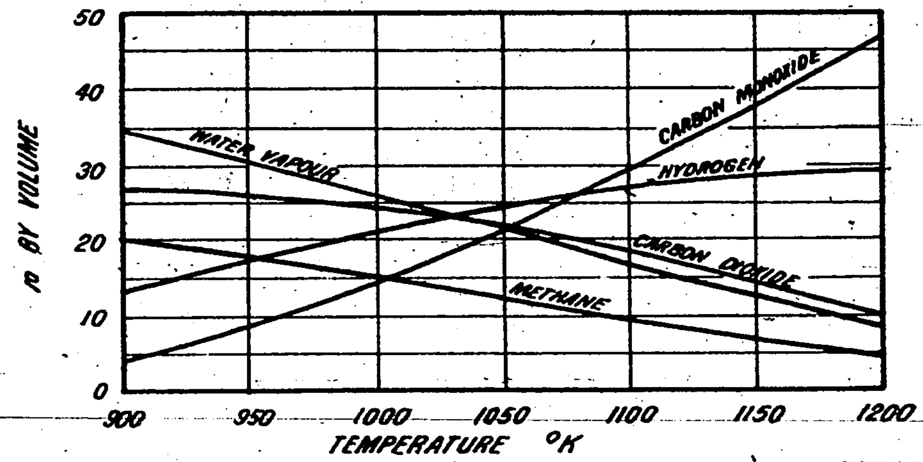
1 metre = 39.37 inches = 3.281 feet.
1 sq.metre = 10.76 sq.feet.
1 cu.metre = 35.31 cu.ft. = 219.97 Imp.gallons.
1 cu.ft. at 0°C and 760 m.m. dry = 1.073 cu.ft. at 60°F and 30 inches wet.
1 cu.metre at 0°C and 760 m.m. dry = 37.88 cu.ft. at 60°F and 30 ins.wet.
1 cu.metre of gas per tonne of coal = 35.88 cu.ft. of gas per ton of coal.
1 cu.metre at 0°C and 760 m.m. dry per tonne = 38.50 cu.ft. at 60°F and 30 ins. wet per ton.
1 kilogramme = 2.205 lbs. avoir.
1 kgm. per sq.m. = 0.2048 lbs. per sq. ft.
1 kgm. per cu.m. = 0.06243 lbs. per cu.ft.
1 kgm. per cu.m. at 0°C and 760 m.m. dry = 0.05818 lbs. per cu. ft. at 60°F and 30 ins. wet.
1 gramme per 100 cu.m. at 0°C and 760 m.m. dry = 0.4077 grains per 100 cu.ft. at 60°F and 30 ins.wet.
1 tonne = 0.9842 tons.
1 kilogramme calorie = 3.968 British Thermal Units.
1 k.cal.per kgm. = 1.8 B.Th.U. per lb.
1 1.cal.per cu.m. = 0.1124 B.Th.U. per cu.ft.
1 k.cal.per cu.m. at 0°C and 760 m.m. dry = 0.1047 B.Th.U. per cu. ft. at 60°F and 30 ins.wet.
1 litre per cu.m. at 0°C and 760 m.m. dry = 0.005806 Imp.gall.per cu.ft. at 60°F and 30 ins. wet.

FIGURE 1



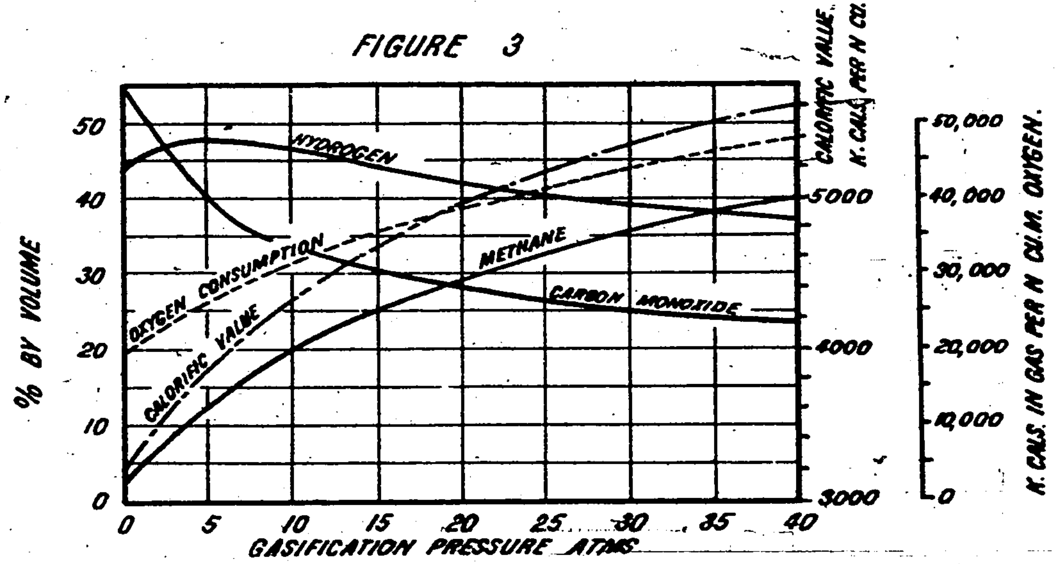
THEORETICAL GAS COMPOSITION IN RELATION TO PRESSURE

FIGURE 2



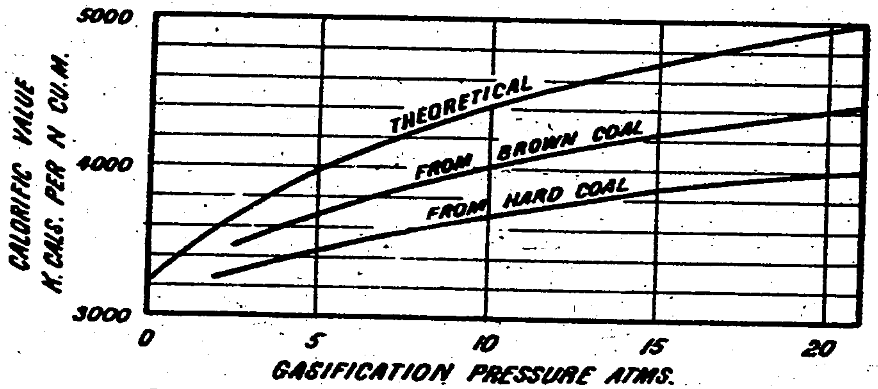
THEORETICAL GAS COMPOSITION IN RELATION TO TEMPERATURE

FIGURE 3



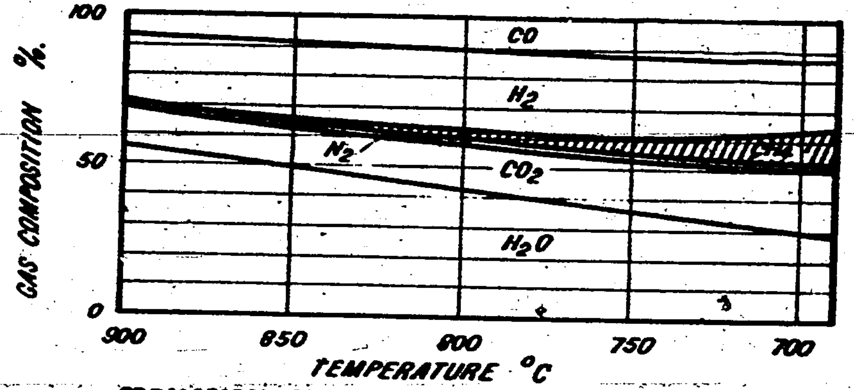
THEORETICAL COMPOSITION OF PURIFIED GAS, CALORIFIC VALUE, AND OXYGEN CONSUMPTION, IN RELATION TO PRESSURE

FIGURE 4



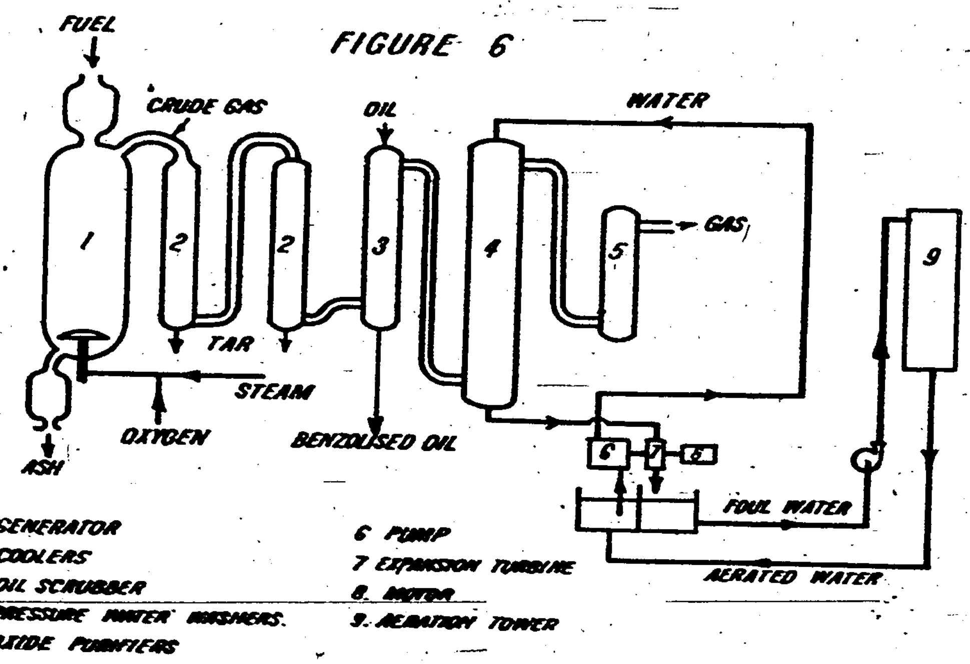
GROSS CALORIFIC VALUE OF GAS FROM BROWN COAL AND HARD COAL

FIGURE 5



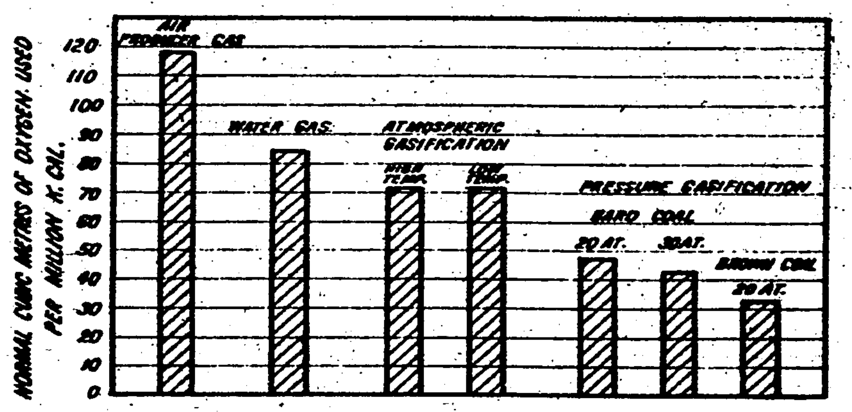
FORMATION OF METHANE IN PRESSURE GASIFICATION

FIGURE 6



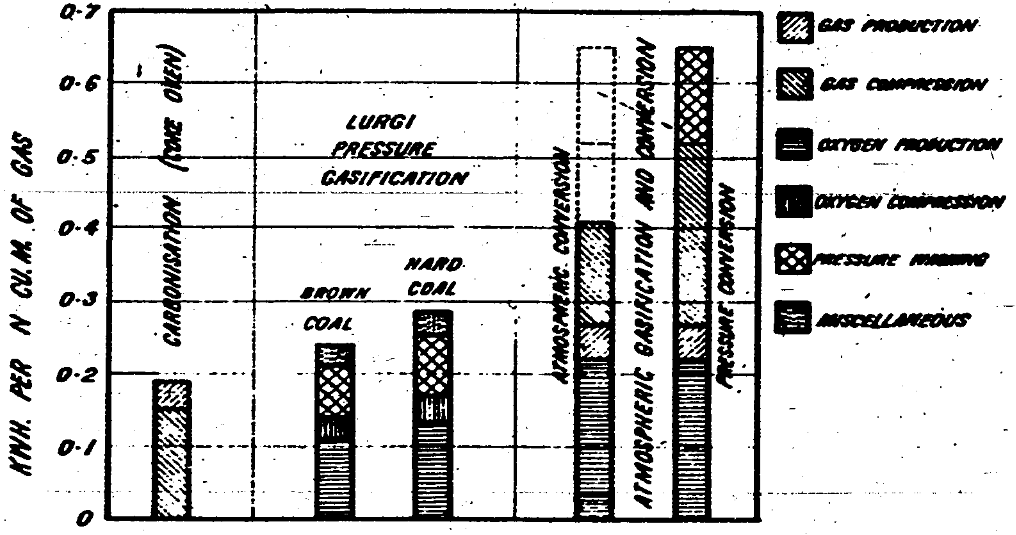
FLOW DIAGRAM OF PRESSURE GASIFICATION PLANT

FIGURE 7



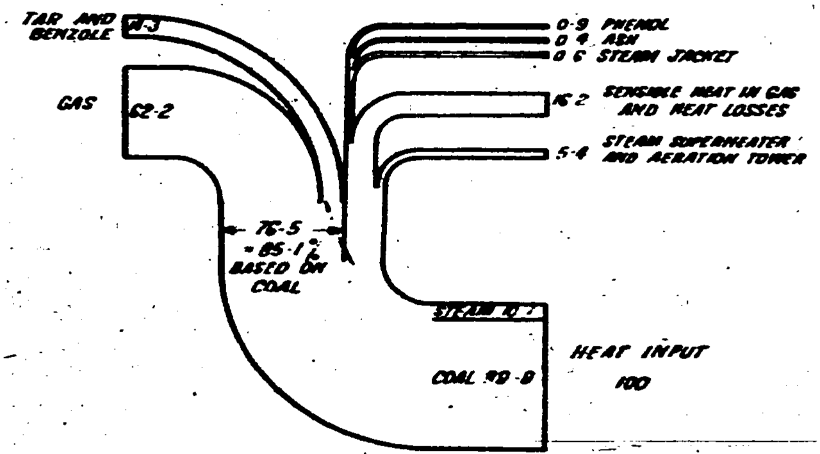
OXYGEN CONSUMPTION IN VARIOUS PROCESSES

FIGURE 8



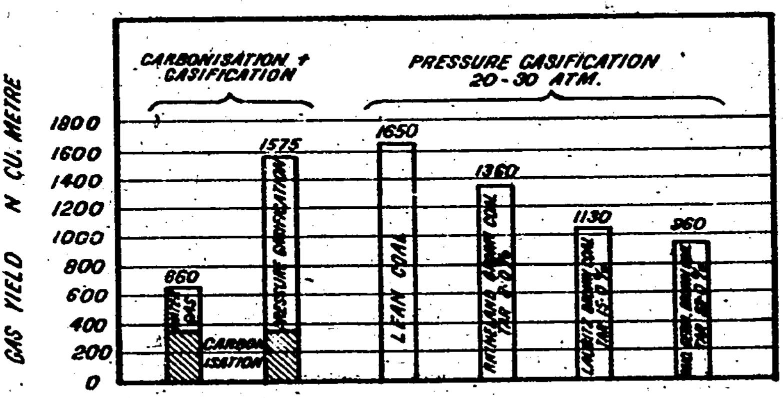
ENERGY REQUIRED TO PRODUCE GAS AT 20 ATMS.

FIGURE 9



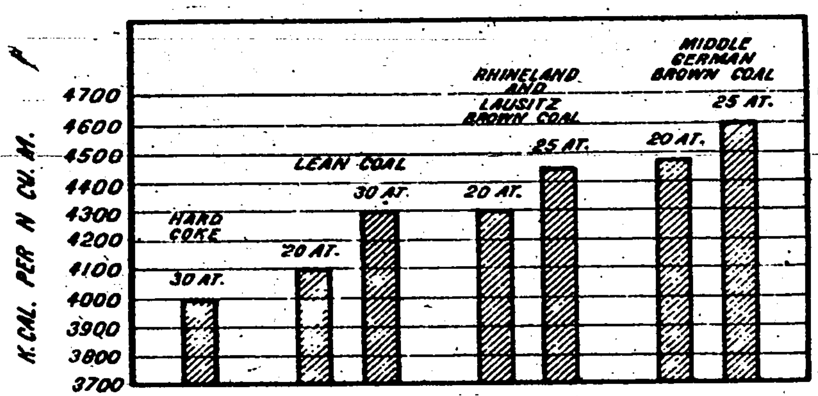
HEAT BALANCE FOR PRESSURE GASIFICATION

FIGURE 10



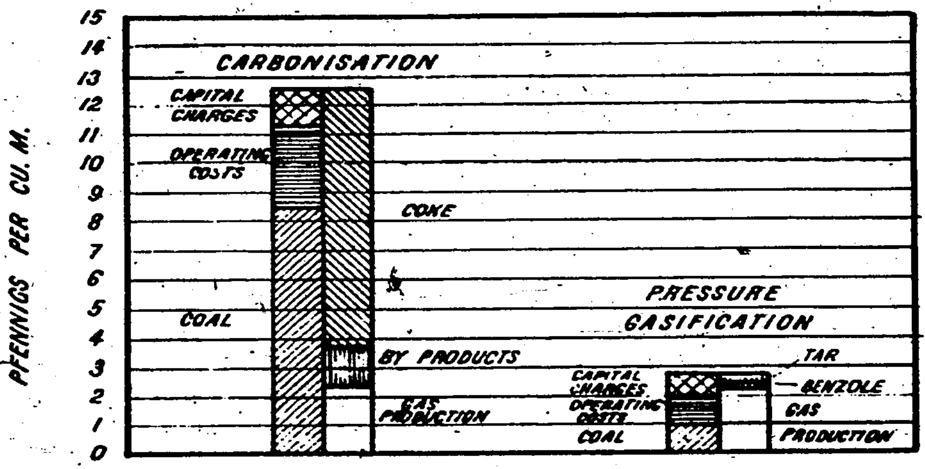
GAS YIELD PER TONNE OF DRY ASH-FREE COAL

FIGURE 11



GROSS CALORIFIC VALUE OF GAS
IN RELATION TO FUEL AND GASIFICATION PRESSURE

FIGURE 12



COSTS OF CARBONISATION AND GASIFICATION.

FIGURE 13

VIEW OF GENERATOR HOUSE

FIGURE 14.

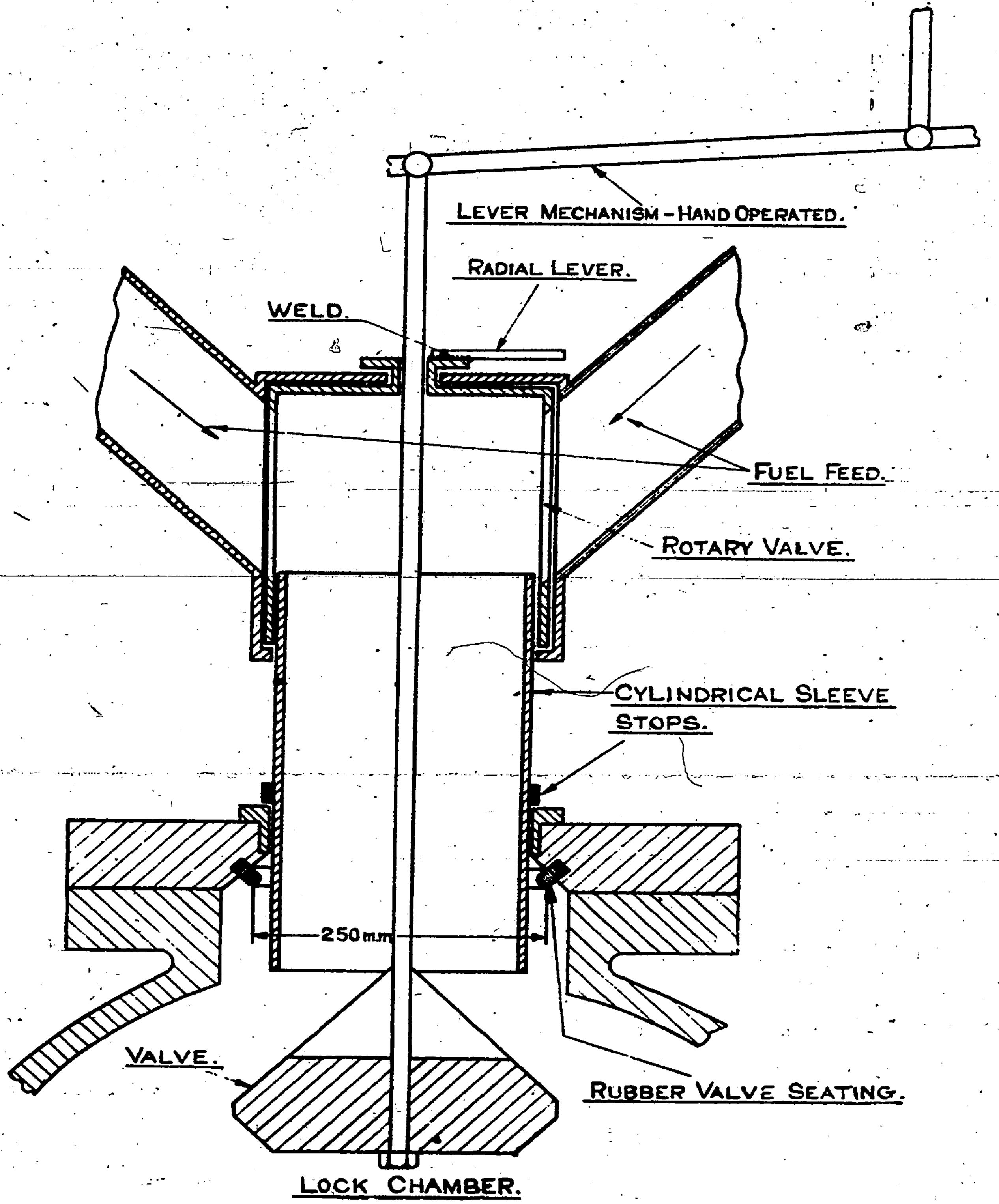


DIAGRAM OF FUEL FEED TO UPPER CHAMBER.
LURGI H.P. GASIFICATION PLANT - BÖHLEN.

FIGURE 15.

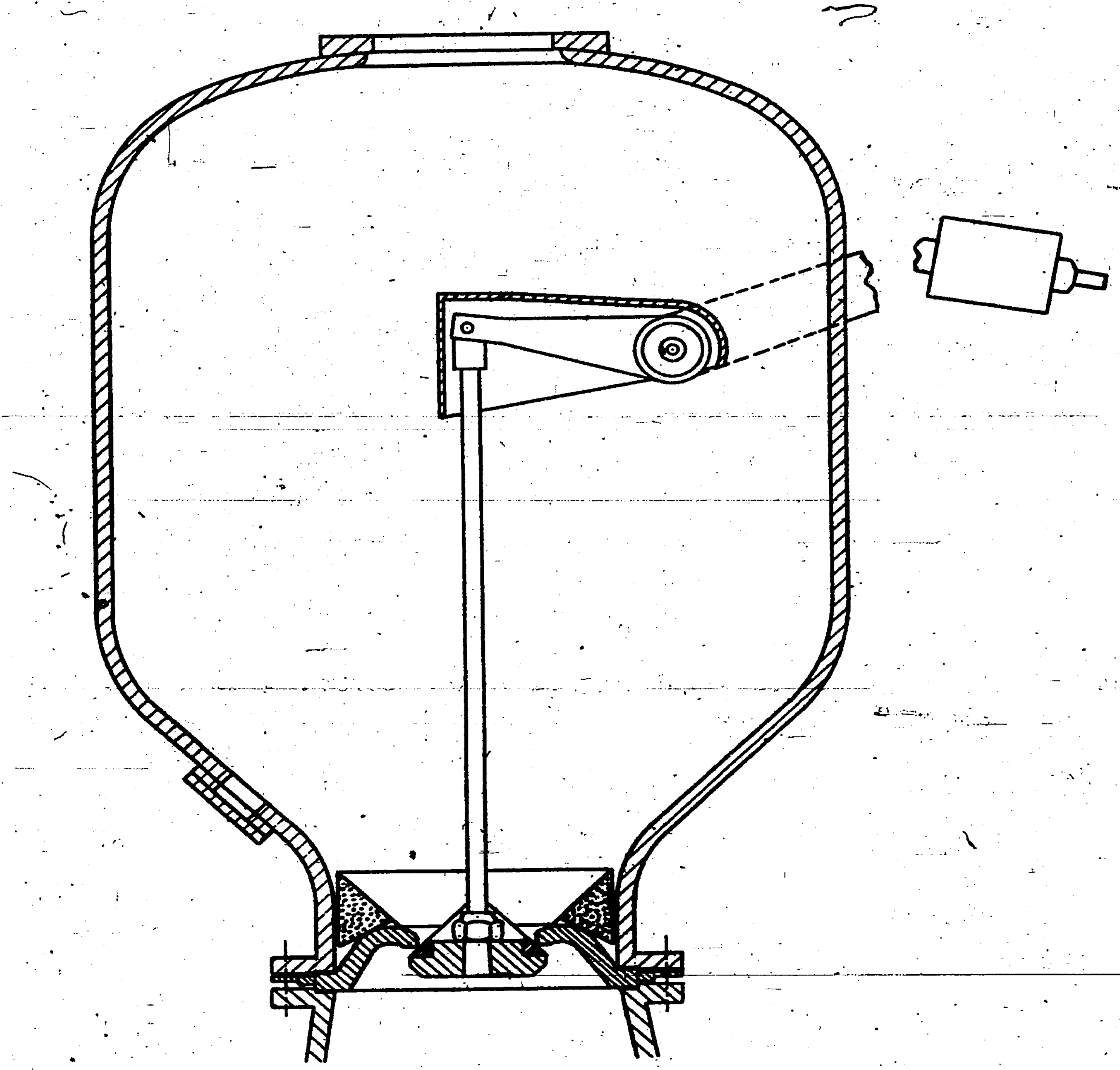


DIAGRAM OF BOTTOM VALVE OF UPPER LOCK CHAMBER
LURGI H.P. GASIFICATION PLANT - BÖHLEN.

FIGURE 16

VIEW OF CHARGING POUCH

FIGURE 17 A

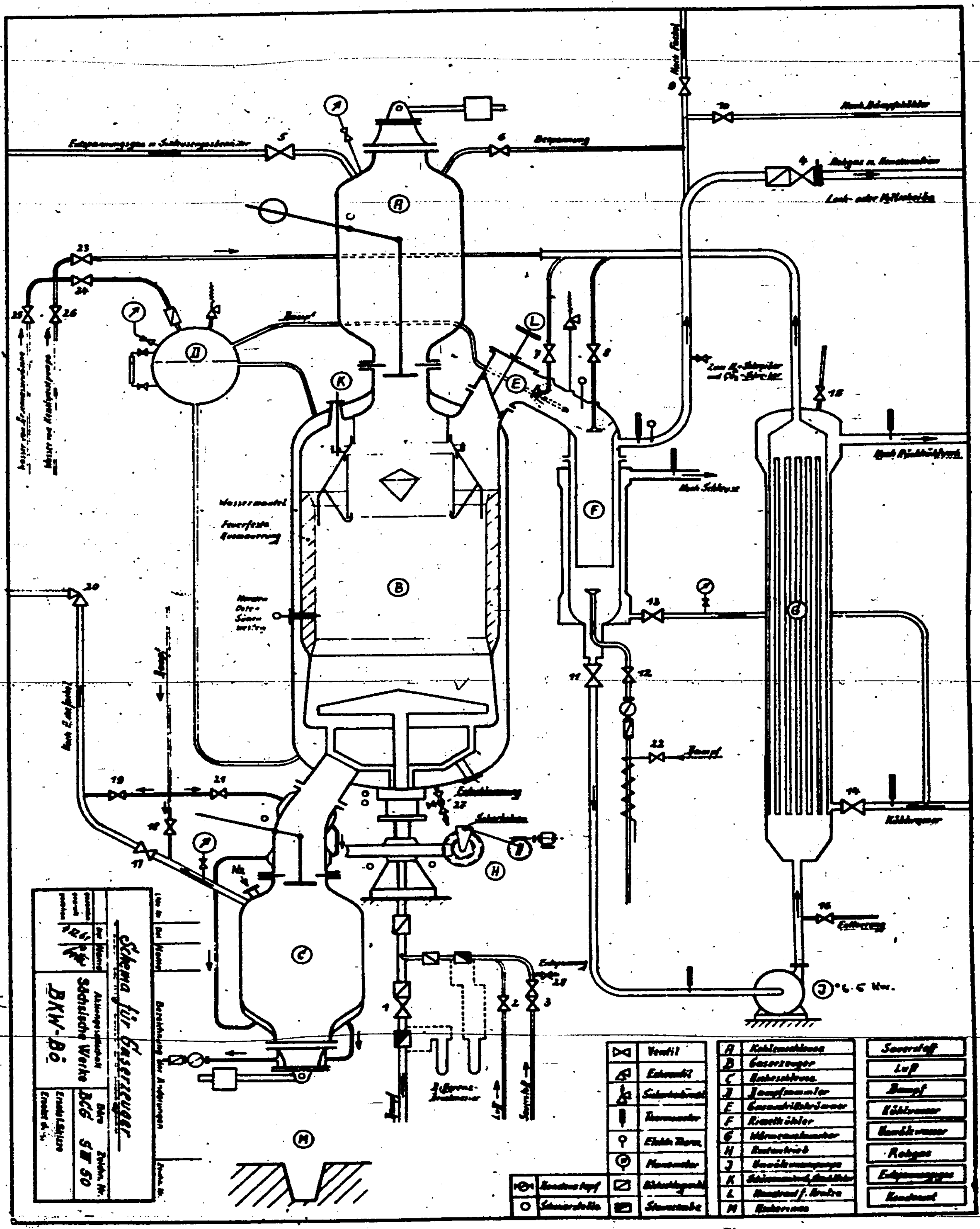
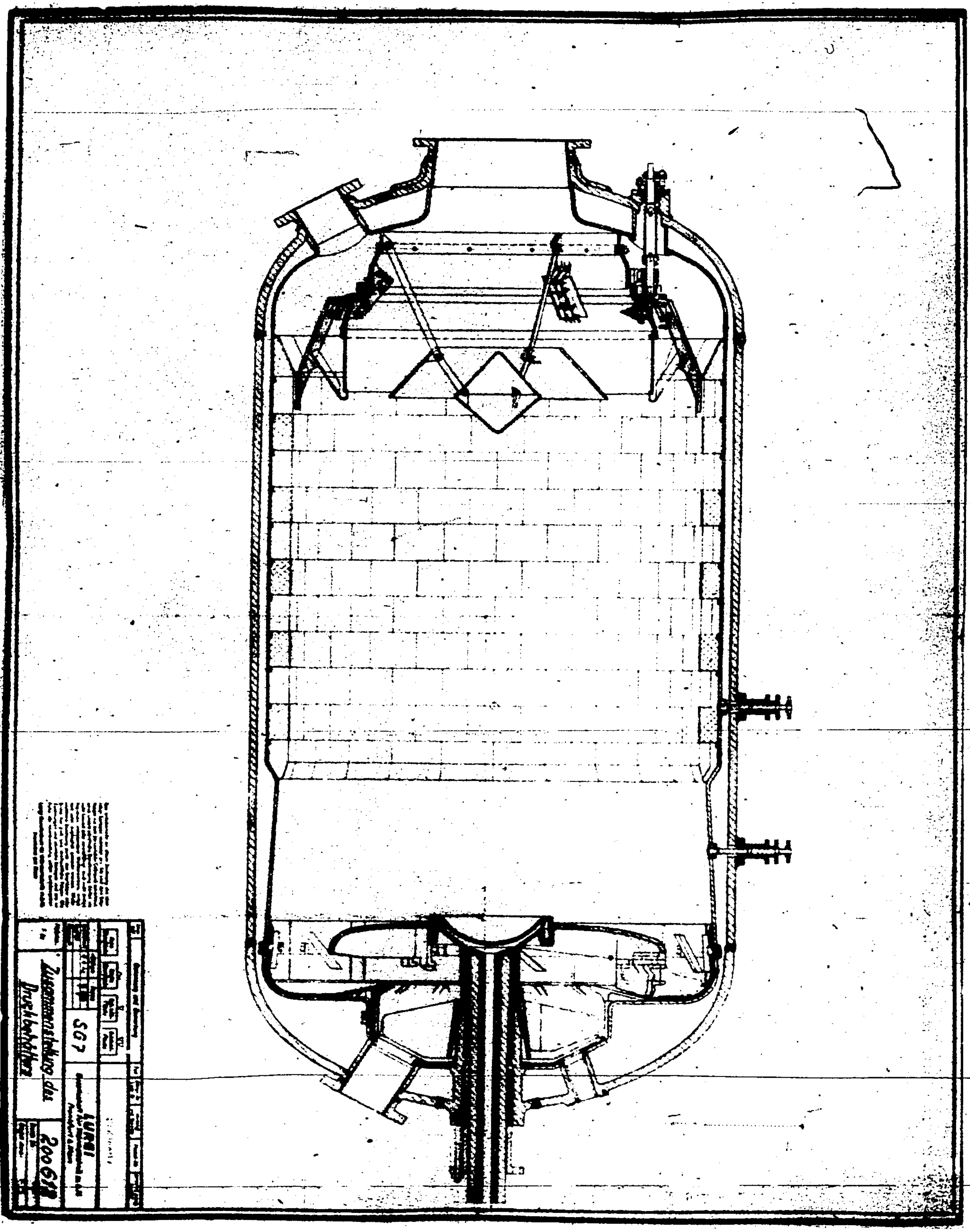


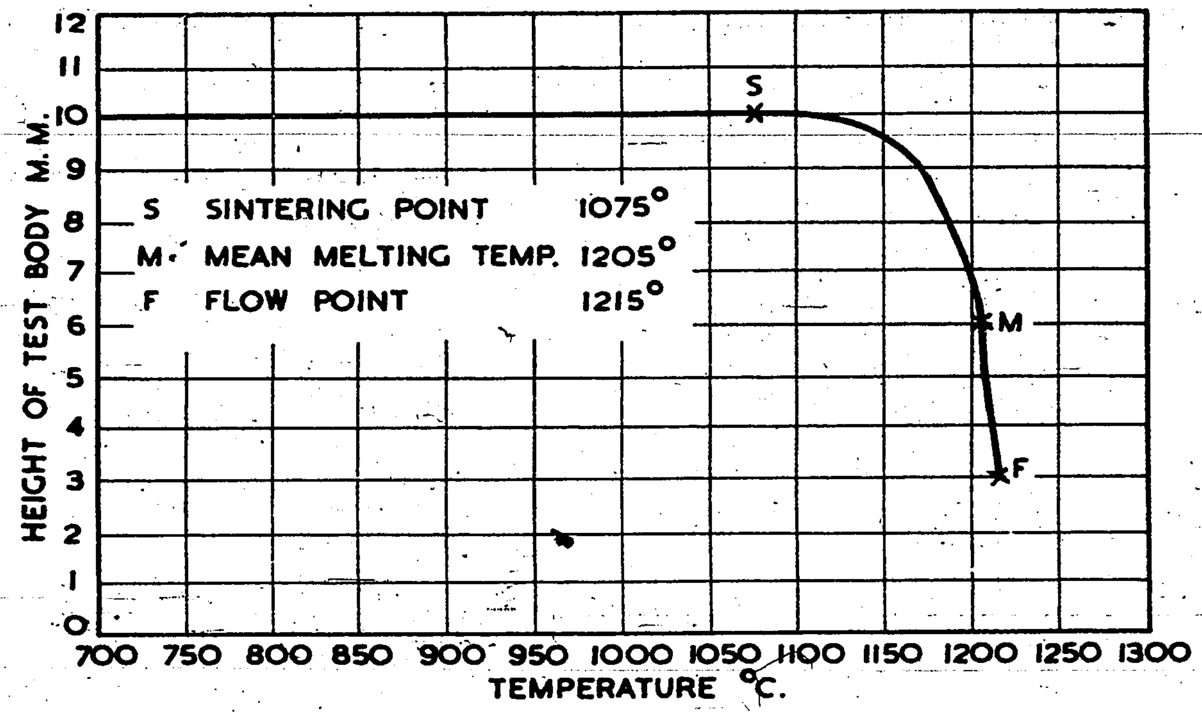
DIAGRAM OF GENERATOR

FIGURE 17 B



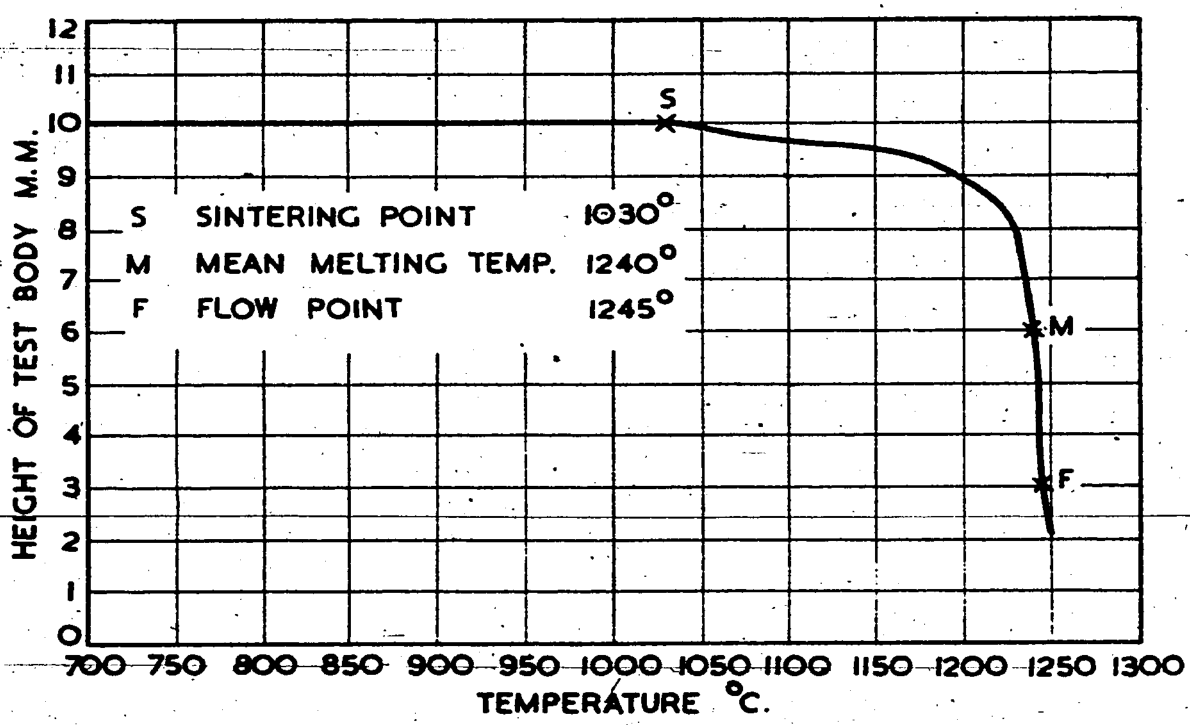
DRAWING OF GENERATOR

FIGURE 18



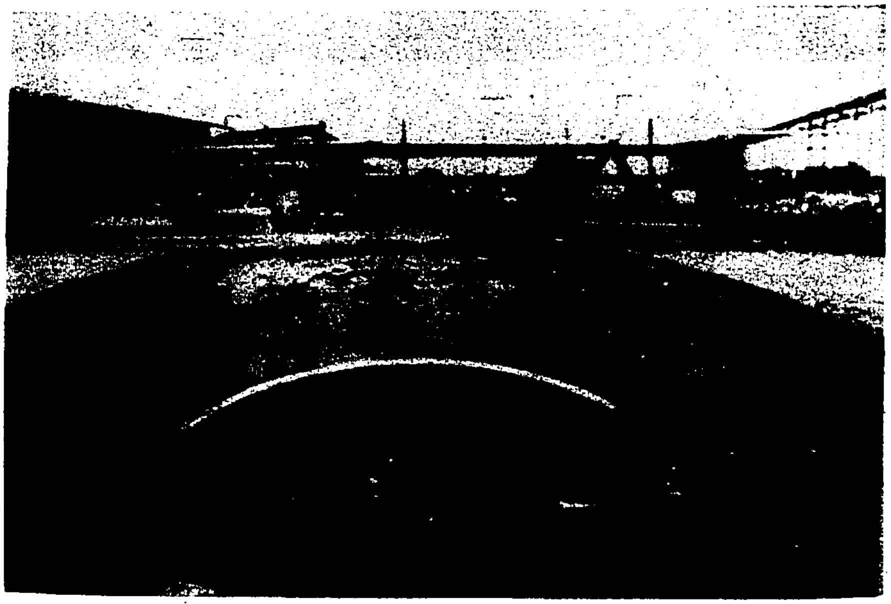
BUNTE-BAUM TEST OF CLINKER TAKEN FROM GENERATOR 9.7.42.

FIGURE 19.

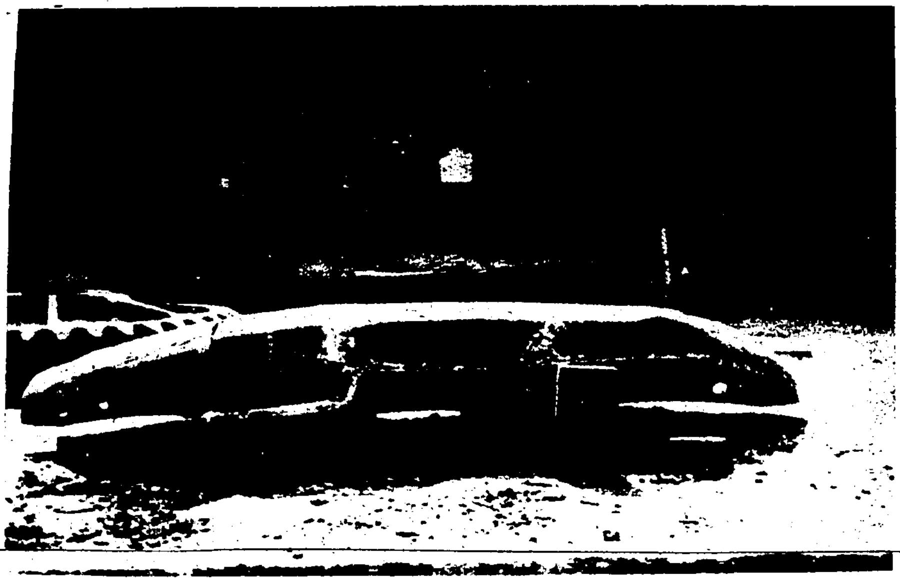


BUNTE-BAUM TEST OF COAL MIXTURE USED 27.6.42 – 6.7.42.

FIGURE 20



One of the three sections of the grate

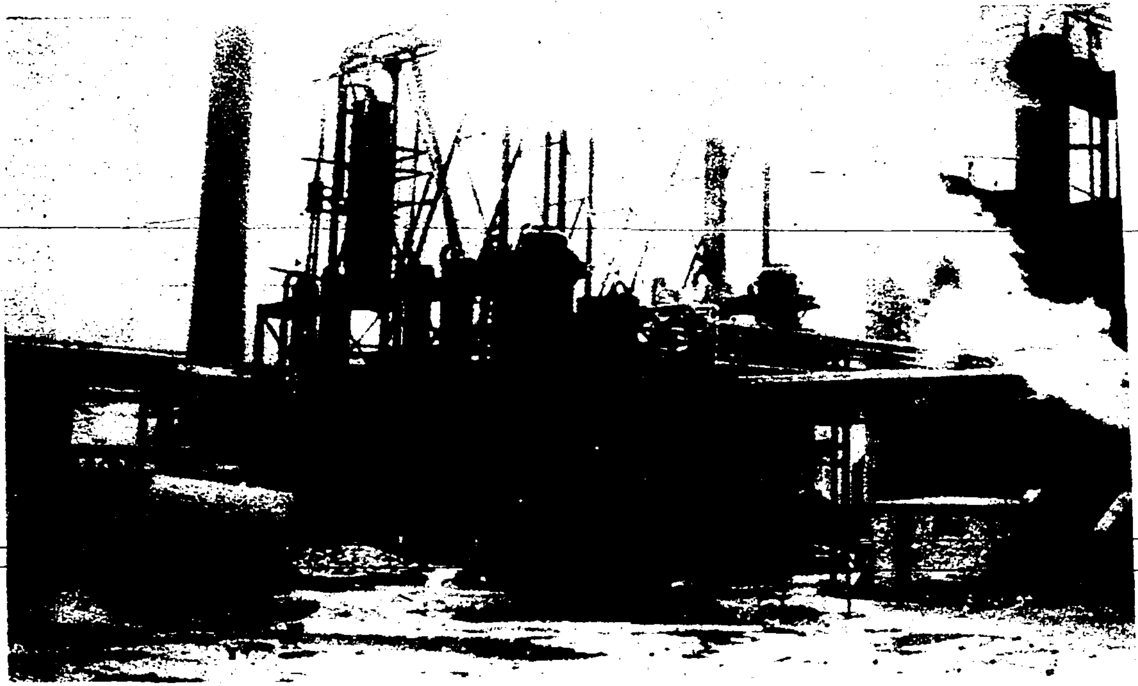


The same, viewed from the far side, showing the plough.

FIGURE 20 CONTINUED.

Close view of the plough, the section being turned face down. Note lft. mark on plough.

FIGURE 21

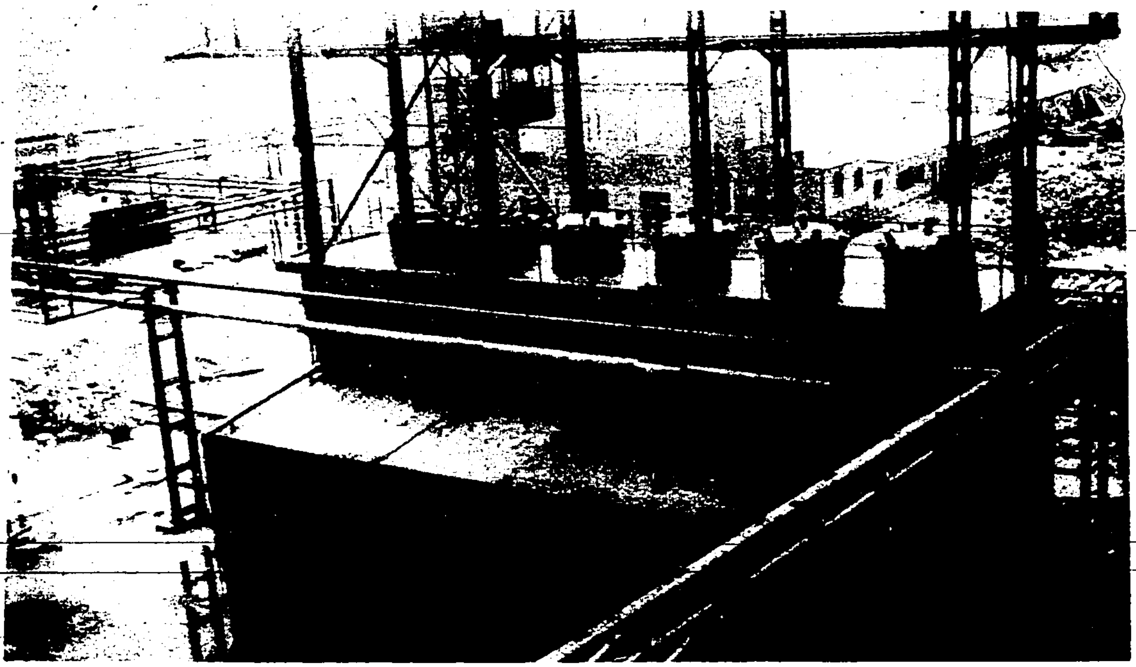


VIEW OF GAS COOLERS

FIGURE 22

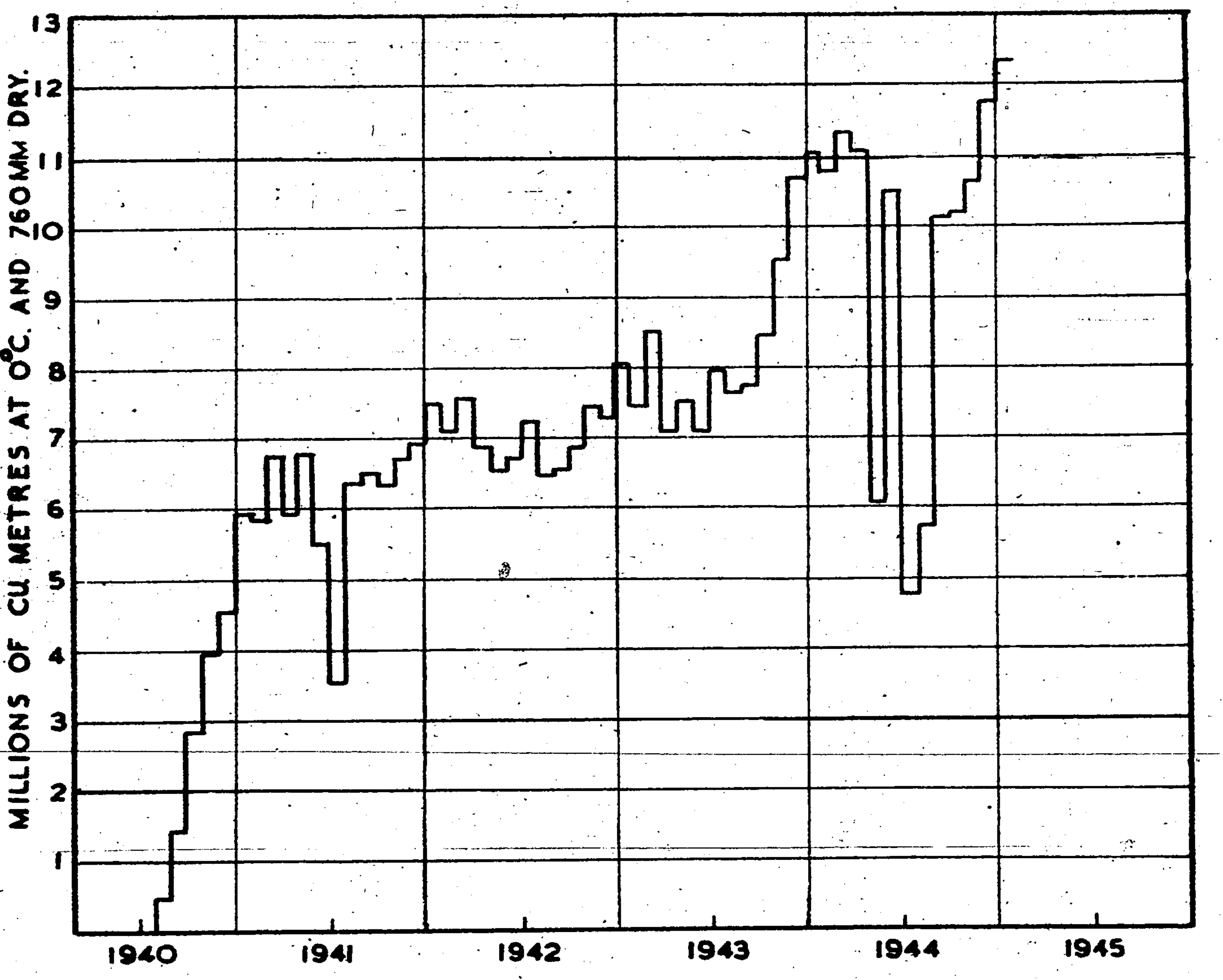
VIEW OF AERATION TOWERS

FIGURE 23



VIEW OF OXIDE PURIFIERS

FIG. 24.



MONTHLY PRODUCTION OF GAS AT BÖHLEN

FIGURE 25.

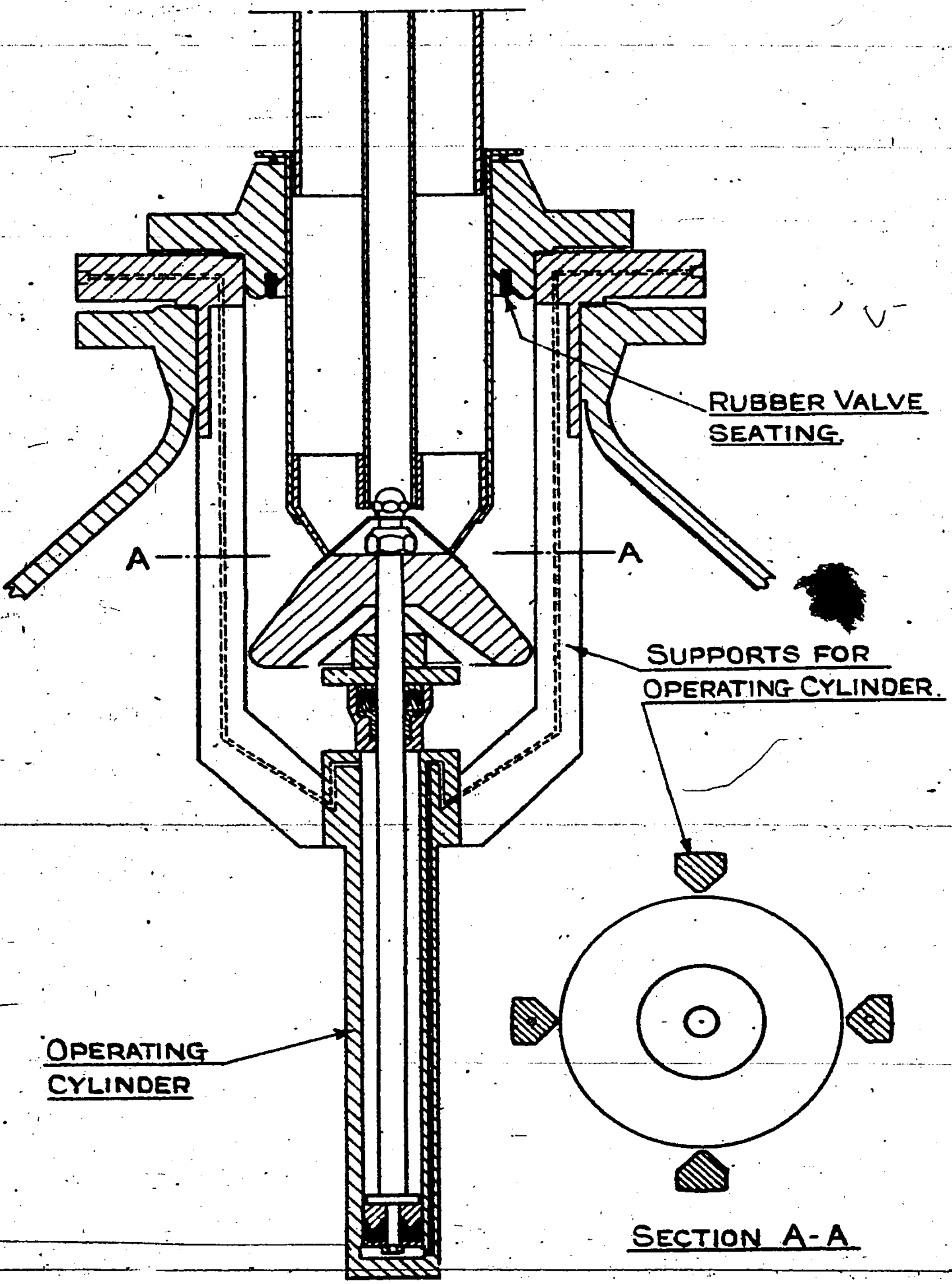


DIAGRAM OF HYDRAULIC TOP VALVE OF UPPER LOCK CHAMBER

LURGI H.P. GASIFICATION PLANT – BRÜX

Copy 1

FINAL REPORT No. 326
ITEM No. 30.

INTERROGATION OF
A. BOLLHORN, E. GRAGES and Dr. GROSS
of DEUTSCHE ERDÖL A.G., BERLIN

Howes, D.A.

"This report is issued with the warning that, if the subject matter should be protected by British Patents or Patent applications, this publication cannot be held to give any protection against action for infringement."

JUL [illegible] 1946
REC'D.
TIIC L.F. & L. S-C.

BRITISH INTELLIGENCE OBJECTIVES
SUB-COMMITTEE

LONDON - H. M. STATIONERY OFFICE.

INTERROGATION OF A. BOLLHORN, E. GRAGES AND DR. GROSS OF DEUTSCHE ERDÖL A.G., BERLIN.

Reported by:-

Major D. A. Howes, British,
Ministry of Fuel and Power.

BIOS Target No. C30/2.20
Fuels and Lubricants

British Intelligence Objectives Sub-Committee
32, Bryanston Square,
LONDON, W.1.

CONTENTS

4. RESEARCH STATION OF DEAG AT ROBLING STRASSE, BERLIN

PERSONNEL OF INTERROGATING TEAM

Major D.A. Howes, British, Ministry of Fuel and Power.

INTRODUCTION

August Bollhorn and Erich Grages are both directors of Deutsche Erdol A.G. and are located in the Head Office of this company at Martin Luther Strasse 61-66, Berlin-Schoeneberg. They were interrogated on various dates over the period August 5th to August 14th, 1945. Bollhorn was in charge of distribution while Grages was in charge of the plants and refineries. Thus, in the German Reich petroleum organisation they were responsible to REICHSTELLE FÜR MINERALOL and REICHS MINISTERIUM FÜR RUSTUNG UND KRIEGS-PRODUKTION respectively.

Dr. Gross is in charge of the Deutsche Erdol Research Laboratory at RÖBLINGSTRASSE 152-154 BERLIN. He was interrogated on August 12th 1945.

2. ACTIVITIES OF DEUTSCHE ERDOL AKTIENGESELLSCHAFT.

This company, often referred to as DEA or DEAG, was established in 1899 when it was called Deutsche Tiefbohr Aktiengesellschaft. Its name was changed in 1912. Up to 1916 the company dealt exclusively in mineral oil products, when it controlled about 95% of the petroleum production inside Germany and owned important oil interests in Galicia and Roumania. In 1918, when the company lost its foreign interests, it extended its activities to coal mining, including brown coal, coal retorting and the manufacture of various coal oils.

The present activities of DEA and its subsidiary companies are listed below:-

1. Deutsche Erdöl-Aktiengesellschaft, mines "Graf Bismark" and "Königsgrube" at Gelsenkirchen.

Coal mining and manufacturing of coke.
Total production per year .. .. .. 3,600,000 tonnes
Coal trading companies in Duisburg, Mannheim, Frankfurt on Main, Saarbrücken, Hamburg.

II. (a) Deutsche Erdöl-Aktiengesellschaft, management of the brown coal works at Borna, district Leipzig.

Brown coal mining and briquette production in Central Germany.
Production of raw lignite per year .. .. 11,000,000 tonnes
Trading companies in Leipzig, Kassel, Magdeburg and other small towns of Central Germany.
Production of briquettes .. .. 3,500,000 tonnes

(b) Deutsche Erdöl-Aktiengesellschaft, "Mineralölwerke Rositz" at Rositz, district Altenburg in the province of Thuringia.

Works for distilling lignite and refining of brown coal tar near Altenburg in the province of Thuringia.
Production of tar per year 240,000 tonnes
Processing of tar per year .. .. .. 300,000 tonnes

III. Deutsche Erdöl-Aktiengesellschaft, management of the mineral oil works in Berlin-Schoeneberg.

Production and processing of mineral oils with separate works as follows:-

(a) Crude Oil Production

Deutsche Erdöl-Aktiengesellschaft, "Erdölwerke Holstein" at Heide in the province of Schleswig-Holstein.

Production per year .. .. 120,000 tonnes

Deutsche Erdöl-Aktiengesellschaft, "Erdölwerke Wietze" at Wietze, district of Celle.

Production per year .. .. 80,000 tonnes

Deutsche Erdöl-Aktiengesellschaft, "Erdölwerke Ostmark" at Neusiedl/Zaya.

Production per year .. .. 350,000 tonnes
to 400,000 tonnes

(b) Refineries

Deutsche Erdöl-Aktiengesellschaft, "Erdölwerke Holstein" at Heide in the province of Schleswig-Holstein.

Processing of crude oil .. .. .. 180,000 tonnes
This plant is partly destroyed and is now operating at reduced capacity. Topping Plant

Deutsche Erdöl-Aktiengesellschaft "Erdölwerke Wilhelmsburg" at Hamburg-Wilhelmsburg.

Processing of crude oil.
Manufacturing of lubricating oils mainly 130,000 tonnes to 140,000 per year
This plant is destroyed and shut down.

Deutsche Erdöl-Aktiengesellschaft "Erdölwerke Nova" at Schwechat near Vienna.

Manufacturing of motor spirit, Diesel oil and lubricating oils.
Processing of crude oil .. .. .. 180,000 tonnes per year
This plant is partly destroyed, it is not known whether it has been put into operation again.

"Vaucefa" Vereinigte Chemische Fabriken Aktiengesellschaft at Brandenbrug on Havel.

Manufacturing of grease.
This plant is 70% destroyed and not yet operating again.

IV. Distributing companies for petroleum products

"Deutscher Mineralöl-Verkaufsverein" in Berlin-Schoeneberg
"Deutsche Viscobil Oil G m.b.H." in Berlin-Schoeneberg
including 10 selling departments in Germany.
Total turnover of the companies above .. .. 500,000 tonnes per year
value above .. RM 90,000 " " "

V. The DEA owns furthermore the "Edeleanu G.m.b.H." in Berlin-Schoeneberg.

This company designs and delivers whole plants for the Edeleanu process and plants for extracting and dewaxing mineral oils and brown coal tar oils, furthermore deasphalting of residues, using different kinds of solvents.

In the main office in Berlin the DEA and its branch company, the "Deutsche Viscobil Oel G.m.b.H.", are mainly occupied in distributing the available stocks of lubricating oil of different origins. The distribution is done in accordance with the requirements of the Occupation Forces and the Magistrate of Berlin.

Since February 26th 1945, the day on which the largest part of the office building was badly damaged, the greater part of the administration staff connected with the different works of the company, have been evacuated to the different works.

Thus the technical staff were sent to WIETZE near CELLE, including the leading technician of the company, GUNTHER SCHLICHT, a petroleum production engineer who was formerly responsible for DEA oilfields in Austria, Schleswig-Holstein and Hanover.

Information concerning other important personalities in DEA are as follows:-

Dr. SCHICK, the former Chief Chemist, is dead.
Dr. BANDTE is the Chief Chemist of DEA in Hamburg.
Director EUGEN BAUER was the head of DEA in Hamburg until he retired in 1944 but he is still in Hamburg.
The Chief Engineer of DEA in Hamburg was Ing LICHTNER who, when the Hamburg refinery was partly destroyed in July 1944, was evacuated to the small refinery at ELBINGERODE in the HARTZ mountains.

3. SPECIFICATIONS OF THE DEUTSCHE VISCOBIL OEL GESELLSCHAFT m.b.H.

This was the main distributing company for DEA and dealt mainly with lubricating oils and diesel fuels. The head office was at Martin Luther Strasse 61-66, Berlin-Schoeneberg, and sales offices were located at Berlin, Breslau, Braunschweig, Dresden, Essen, Frankfurt on Main, Hamburg, Hanover, Munich, Nürnberg, Rositz and Stuttgart. Storage depots were placed all over Germany.

The lubricating oils sold by Viscobil originated mainly from the DEA refineries at Wilhelmsburg and Vienna but before the war oils of foreign origin were purchased from Deutsch Amerikanische Petroleum Gesellschaft, Hamburg and other importers. The turnover in the Berlin area was about 2,000 tons in 1939 but by 1944 this was reduced to about 1,500 tons.

Average figures for the products marketed by Viscobil during the war are detailed below.

Cylinder Oils made at Hamburg - Wilhelmsburg Refinery.

	Saturated Steam	Superheated Steam Cylinder Oils	
	Cylinder Oil C	H.R quality	H.A. quality
Colour	Dark Green	Dark Green	Green
Sp. Gr. at 20°C.	0.950-0.960	0.950-0.960	0.940-0.950
Viscosity °E. at 100°C.	3-4.5	3.5-5.0	3-4
Flash Point °C.	270	280-290	280-290
Pour Point °C.	0 to + 10	+5 to +15	+10 to +20
Ash %	0.02	0.02-0.03	Below 0.01
Neutralisation No.	0.25	0.25	0.1
Asphalt %	0.1-0.4	0.2-0.4	Trace

RAILWAY (REICHSBAHN) AXLE OILS

	Grade S1		Grade D	
	RZA Specification	Average Properties	RZA Specification	Average Properties
Density at 20°C.	0.950 max.	0.920-0.930	0.950 max.	0.920-0.930
Flash Point °C.	160 min.	over 160	125°C min.	over 125
Viscosity °E. at 50°C.	8 - 10	8.5	3.5 min.	4
Hard Asphalt	0.2 max.	Below 0.2	1.0 max.	Below 1.0
Neut. No.	1.5 "	" 1.5	1.5 "	" 1.5
Water %	0.2 "	" 0.2	0.2 "	" 0.2
Ash %	0.3 "	" 0.3	0.3 "	" 0.3
Fluidity	Fluid at -5°C.	Satisfactory	Fluid at -25°C.	Satisfactory
% Gas Oil Added	-	-	10% max.	7 - 10

MARINE OILS

2

Designation	Z.d.M 2		Z.d.M 7		Z.d.M 11	
	ZdM Specification	Average Properties	ZdM Specification	Average Properties	ZdM Specification	Average Properties
S.G. 20° ca.	0.930	0.925	0.900	0.915/25	0.935	0.915/25
Flash Point °C.	215	220/235	213	205/220	200	205/220
Viscosity °E. 20°C.	-	75	-	55	-	55
" 50°C.	10-11.5	10.5	8 - 9	8.5	8 - 9	8.5
" 100°C.	-	1.95	1.90	1.8	-	1.8
Pour Point °C.	-5°	-15/-20°	-10°	-15/-20°	-10°	-15/-20°
Neut. No.	0.14	below 0.14	0.05	0.05	0.5	0.05
Ash %	0.02	" 0.01	0.01	below 0.01	0.05	below 0.01
Carbon Residue %	-	0.6	0.5	0.5	-	0.5
Emulsion test:						
a) with sea water	not emulsif.	Satisfactory	not emulsif.	Satisfactory	Special regulations	-
b) with dist. water	"	"	"	"	"	-
M.A.N. Test at 155°	-	-	traces	"	-	-

MOTOR OILS

	Motor Oil 6-8/50 Group A Viscobil D Winter	Motor Oil 9-12/50 Group A Viscobil DA and D		Motor Oil 15-20/50 Group A	Motorenöl der Wehrmacht
		Intermediate	Summer		
Sp. Gr. at 20°C.	0.915	0.920	0.925	0.935	0.900-0.905
Flash Point °C.	200/210	210/225	225/240	230	210/220
Viscosity °E.					
-15°C.					1800 max.
+20°C.	40	60-70	95	120	50
+50°C.	6.5	9	12	15	8.5
+90°C.					2.3
+100°C.	1.75	1.95	2.15	2.3	1.95
V.P.	2.4/2.5	2.4/2.5	2.5	2.5	2.0/2.1
Pour Point °C.	-25	-20	-20	-15	-20
Neut. No.	below 0.1	below 0.1	below 0.1	below 0.1	below 0.7
Sap No.					below 0.25
Conradson Carbon %	0.4	0.5	0.6	0.7	below 0.25

SPINDLE OIL RAFFINATES

	Grade 3.5/20		Grade 2.5/50		Transformer Oil Anti cold	
	Specification	Average Properties	Specification	Average Properties	Specification	Average Properties
Colour		Yellow		Yellow		Light Yellow
Sp. Gr. 20°C.		.885/.895		.900/.910	0.895 max.	0.890
Viscosity °E.						
+20°C.	3.5 ± 1	3.5		10		3.5
+50°C.		1.7	2.5 ± 0.5	2.5		
-30°C.					500 max.	250
Flash Point °C.	125 min.	150/160	140 min.	165/175	145 max.	155
Pour Point °C.	+ 5 max.	-15 to -20	+ 5 max.	-10 to -20		-45
Neut. No.	0.3 max.	0.05 max.	0.3 max.	below 0.05	0.05 max.	below 0.05
Water %	0.1 max.	below 0.05	0.1 max.	below 0.05		
Ash %	0.05 max.	below 0.01	0.05 max.	below 0.01	0.01 max.	below 0.01
Hard Asphalt %	nil	nil	nil	nil		
Sap. Value					0.15 max.	below 0.15

Designation	Spindle Oil Distillate 2.1/20 E.P. Oil - Distillate		Spindle Oil Distillate 3.5/20		Spindle Oil Distillate 2.5/50	
	Specification	Average Properties	Specification	Average Properties	Specification	Average Properties
Colour	-	dark	-	dark	-	dark
S.G./20°C. ca.	-	0.880/95	-	0.885/900	-	0.910/15
<u>Viscosity °E.</u>						
20 °C. "	2.1 ± 1	2.1	3.5 ± 1	3.5	-	10
50 °C. "	-	1.2	-	1.7	2.5 ± 0.5	2.5
Flash Point °C. "	not below 125°	120/130	not below 125°	150/160	not below 140°	160/170
Pour Point °C. "	not above +5	-15	not above +5	-15/-20	not above +5	-15/-20
Neut. No. "	not above 1.5	below 0.7	not above 1.5	below 0.7	not above 1.5	below 0.7
Water Content %	not above 0.2	below 0.1	not above 0.2	below 0.1	not above 0.2	below 0.1
Ash %	not above 0.2	below 0.1	not above 0.2	below 0.1	not above 0.2	below 0.1
Hard Asphalt %	not above 0.3	Traces	not above 0.3	below 0.1	not above 0.3	below 0.1

MACHINE OIL RAFFINATES

Designation	Machine Oil Raffinate light machine oil RZA 4.1/50		Machine Oil Raffinate compressor oil RZA 6.5/50		Machine Oil Raffinate 9/50		Engine Cylinder Oil RZA 5-6/50	
	RZA Specification	Average Properties	RZA Specification	Average Properties	Specification	Average Properties *	Specification	Average Properties
Colour	-	Orange	-	Orange	-	Orange	-	Orange
Sp. Gr. at 20° ca.	not above 0.95	0.910/0.920	not above 0.95	0.920/0.930	-	? —/0.930	not above 0.95	0.915/0.925
Visc. at 20 "	-	25	-	40/45	-	?	-	30/35
Visc. at 50 "	4.5 ± 0.5	4.5	6.5 ± 0.5	6.5	9 ± 0.5	?	5.5 ± 0.5	5.5
Visc. at 100 "	-	1.5	-	1.7	-		-	1.6
Flash Point "O.T." "	not below 170	185/195	not below 200	200/210	not below 170	205/ ?	not below 180	190/200
Pour Point "	not above + 5	-15/-20	not above + 5	-15/-20	not above + 5	-15/-20°	not above + 5	-15/-20°
U-tube "	flow at 0°	flow at 0°	flow at 0°	flow at 0°	-	flow at 0°	flow at 0°	flow at 0°
U-tube "	flow at -10°	flow at -10°	-	flow at -10°	-	flow at -10°	-	flow at -10°
Acid Value "	not above 0.3	below 0.3	not above 0.3	below 0.3	not above 0.3	below 0.2	not above 0.4	below 0.3
Water "	not above 0.1	below 0.1	not above 0.1	below 0.1	not above 0.1		not above 0.05	below 0.05
Ash "	not above 0.02	below 0.01	not above 0.02	below 0.01	not above 0.02		not above 0.02	below 0.01
Hard Asphalt "	0	0	0	0	0	0	0	0

* Some of the data in this column are missing.

MACHINE OIL DISTILLATES

Designation	Machine Oil Distillate 4.1/50 = RZA light machine oil distillate		Machine Oil Distillate 6.5/50 = RZA compressor oil distillate		Machine Oil Distillate 9/50		Machine Oil Distillate 15/50	
	Specification	Average Properties	Specification	Average Properties	Specification	Average Properties	Specification	Average Properties
Colour	-	dark	-	dark	-	dark	-	dark
Sp. Gr. at 20° ca.	-	0.915/25	-	0.925/35	-	0.925/35	-	0.935/0.945
Viscosity °E. - 20°C "	-	25/30	-	45/40	-	60/70	-	-
" 50°C "	4.1 ± 0.5	4.5	6.5 ± 0.5	6.5	9 ± 0.5	9	15 ± 5%	15.5
Flash Point °C. "	not below 160°	180/190	not below 160°	190/200	not below 170	200/210	not below 170°	205/220
Pour Point °C. "	not above + 5°	-15/-20	not above + 5°	-15/-20	not above + 5°	-15/-20	not above + 5°	-15/-20
U-tube 0° "	-	flows	-	flows	-	flows	-	flows
U-tube 10° "	-	flows	-	flows	-	flows	-	flows
Neut. No. "	not above 1.5	below 1.0	not above 1.5	below 1.0	not above 1.5	below 1.0	not above 1.5	below 1.0
Water content % "	not above 0.2	below 0.2	not above 0.2	below 0.2	not above 0.2	below 0.2	not above 0.2	below 0.2
Ash % "	not above 0.3	below 0.1	not above 0.1	below 0.1	not above 0.3	below 0.1	not above 0.3	below 0.1
Hard Asphalt % "	not above 0.3	below 0.15	not above 0.3	below 0.15	not above 0.3	below 0.15	not above 0.3	below 0.2

DARK OILS

Designation	Dark Oil 5 - 6/50 = Axle Oil "W priv."		Dark Oil 9 - 11/50 = KR = Axle Oil S priv.		Dark Oil 3 - 6/10 = Dearat.	
	Specification	Average Properties	Specification	Average Properties	Specification	Average Properties
Colour	-	black	-	black	-	black
Sp. Gr. at 20° ca.	-	0.920/40	-	0.920/40	-	1.0
Viscosity °E.						
50°C. "	5-6 ± 0.5	5.5	9-11 ± 0.5	8.5/10	-	-
100°C. "	-	-	-	-	3-6 ± 10%	4-6
Flash Point °C "	-	above 150°	-	above 170°	-	240/260
Neut. No. "	not above 2.0	below 1.5	not above 2.0	below 1.5	-	up to 0.5
Asphalt % "	not above 1.0	below 1.0	not above 1.0	below 1.0	-	0.5/1.5
Ash % "	-	below 0.3	-	below 0.3	-	below 0.3
Water % "	-	below 0.2	-	below 0.2	-	below 0.2
Pour Point °C "	-	-15°	-	-5/to -10°	-	0°

BENZINES, PETROLEUM RAFFINATE, GAS AND CLEANING OILS

Designation		Benzine	Petroleum Raffinate	Gas-Oil	Light Mineral Oil (cleaning oil)
Colour		water-clear	water-clear	yellow	light
Sp. Gr. at 20°C.	ca.	0.715-0.750	0.800-0.815	0.835-0.855	0.835-0.850
Viscosity °E. at 20°C.	"	-	-	1.25-1.5	1.35
Pour Point °C.	"	-	below -30°	-10 to -45	below -10°
Flash Point (Abel) °C.	"	-	above 25°	60 to 80 P.M.	-
Flash Point °C.	"	-	-	75 to 100°	80 to 100°
Ash %	"	0	0	below 0.01	below 0.01
Acid Value	"	0	0	0.1 to 0.5	below 0.05
Octane No.	"	45-50	-	-	-
Cetane No.	"	-	-	45-55	-
Sulphur	"	-	-	0.1 to 0.5	-
I.B.P.	"	40°	170°	200°	200°
up to 100°C.	"	10-30 Vol.%	-	-	-
" " 175°C.	"	75 "	-	-	-
" " 185°C.	"	-	not above 50 vol. %	-	-
" " 240°C.	"	-	not above 8 vol.	-	-
" " 300°C.	"	-	complies with requirements for exemption from fuel addition(?) regulations. (Versprittungspflicht).	70 vol.%	75 vol.%
" " 350°C	"	-		95 "	95 "
F.B.P.	"	180°		-	-
Zn Corrosion Test		-	-	below 1 mg.	-
Conradson Carbon Residue %		-	-	below 0.03	-
Aniline Point °C.		-	-	55-70°	-
Index No. (Kennziffer)		-	-	200-290	-

TYPES OF CRUDE PARAFFIN ("GATSCH")

Designation		"Gatsch" I "Mineralöl Salbe" I	"Gatsch" II "Mineralöl Salbe" II
Colour		dark	dark
S.G. 40°	ca.	0.825-0.855	0.860-0.880
Viscosity °E. 50°C.	"	1.5/2.5	-
" " 60°C.	"	-	3.0/4.5
Solidification Point °C.		30/40	45/55
Neut. No.		below 0.2	below 0.2
Wax	%	40-50%	40-50%

4. RESEARCH STATION OF DEAG AT ROBLING STRASSE, BERLIN.

Interrogation of Dr. Gross, August 12th, 1945

Research activities during the war have included the following main items :-

(a) Cracking of lignite tar oils and petroleum oils for diesel oil production.

(b) Lubricating Oil/water emulsions.

(c) Production of vaseline from Fischer-Tropsch Wax.

(d) Solvent refining of lubricating oils and diesel oils.

and these are briefly commented on below :-

(a) Cracking

Diesel oil was the main product required and the experimental work carried out was in connection with the day to day activities of the commercial plants at:-

Vienna - 150,000 tonnes input capacity per year of petroleum residues.

Rositz near Altenburg in Thuringia - 100-140,000 tonnes input capacity per year of lignite tar.

No information of a novel nature was obtained. No work had been carried out on thermal reforming or on olefine production.

(b) Lubricating Oil/Water Emulsions.

DEAG have used these emulsions for the lubrication of steam engines and slow running machinery since 1920 but they are useless for the lubrication of internal combustion engines. The DEAG emulsions are 50/50 water in oil emulsions emulsified with 1-2% Montan wax. The oil employed varies with the properties required, for example to make an emulsion having a viscosity of 6-7°E. at 50°C. the lubricating oil portion has a viscosity of 2.5°E. at 50°C. The emulsions were stated to be stable for several months and when cylinder stock is emulsified the product is stable for nearly a year.

It was stated that Rhenania make lubricating oil emulsions containing Voltol using soaps as emulsifiers but DEAG claim that their emulsions are superior in that their ash contents are lower. The DEAG patents expire in about two years time.

In making the DEAG emulsions they are allowed to stand for 24 hours after mixing and then the mineral and ash constituents of the montan wax are settled out and removed.

(c) Production of Vaseline from Fischer-Tropsch Wax.

An inferior grade vaseline has been made experimentally by DEAG by dissolving F.T. wax in liquid paraffin. The wax is first of all dissolved in ethylene dichloride and the fraction of the required melting point obtained by fractional crystallisation, it is then refined by treatment with sulphuric acid at 160-180°C. until water white.

(d) Solvent Refining of Lubricating Oils and Diesel Oils

In particular this process has been applied to the production of high cetane number (60-70) diesel oils from cracked lignite tars. Phenol has been preferred to furfural as the latter is said to change in use to the aldehyde whereas phenol is very resistant to chemical change. No information of a novel character was obtained on this subject.

DEAG have an experimental solvent refining plant at WILHELMSBURG which has an input capacity of about 5 tonnes per day. A small pilot plant was also at Robling Strasse but this was of very poor design and appeared to be very old.

In their commercial lubricating oil production DEAG used Paraflow to improve Pour Point and Oppanol to increase V.I. Both were manufactured by I.G. but the former was only marketed by Deutsche Amerikanische Petroleum Gesellschaft. This was in line with pre-war agreements.

More than 50% of the research laboratories of DEAG in Berlin have been destroyed and much of the experimental equipment has been confiscated.

5. LIST OF PETROLEUM PRODUCING COMPANIES, OIL FIELDS AND REFINERIES IN GERMANY AND AUSTRIA

The following details were given in a document submitted to the writer by E. Grages, a full translation of which is reproduced.

(i) Petroleum Producing Companies in Germany and Austria and their Outputs.

(a) Elwerath Company - Hanover.

Capital: 1,000 blocks of shares (Kuxe), value per block RM. 30,000.

Concessions mainly in the province of Hanover at Lingen and in Austria.

Production in Germany:	1938 - ca.	170,000	tonnes/year.
	1944 - ca.	175,000	tonnes/year.
Production in Austria:	1944 - ca.	85,000	tonnes/year.

(b) Wintershall A.G., Kassel.

Capital: RM. 125,000,000.

Main subsidiary of the "Gesellschaft Kaligewinnung" (Potash Extraction). Occupied with mineral oil also since 1931. Main concessions in Hanover and in Austria.

Production in Germany:	1938 - ca.	100,000	tonnes/year.
	1944 - "	120,000	tonnes/year.
Production in Austria:	1944 - "	20,000	tonnes/year.

(c) Preussische Bergwerks - und Hütten A.G. (Prussian Mining and Smelting Works), Berlin.

Capital: RM. 80,000,000.

Chief activities:- bituminous coal, ore and potash mining, smelting, rock-salt mining, electricity-works and mineral oil.

The site of the mineral oil section was in Hanover but, after it was destroyed, was centred at Berkhöper near Peine. The concessions were in the Hanover area, in Reitbrook near Hamburg and in Austria.

Production in Germany: 1938 - ca. 40,000 tonnes/year.
1944 - " 40,000 tonnes/year.
Production in Austria: 1944 - " 20,000 tonnes/year.

(d) Deutsche Erdöl-Aktiengesellschaft, Berlin

Capital: RM. 100,000,000.

Activities: Hard coal mining (Ruhr), Central German brown coal mining, brown coal distillation and mineral oil production and processing.

Mineral Oil: Heide in Holstein, in the Hanover region and in Austria.

Production in Germany: 1938 - ca. 107,000 tonnes/year.
1944 - ca. 200,000 tonnes/year.
Production in Austria: 1944 - ca. 472,000 tonnes/year.

(e) Deutsche Vacuum Öl Aktiengesellschaft A.G., Hamburg.
(Vacuum Oil Co., New York.)

Capital: RM. 20,000,000.

Mineral oil concessions, principally in N.W. Germany, in the Hanover region and in Oldenburg.

Production: 1938 - ca. 50,000 tonnes/year.
1944 - ca. 45,000 tonnes/year.

(f) Several (more than 20) small works in N.W. Germany.

Production: 1938 - ca. 135,000 tonnes/year.
1944 - ca. 130,000 tonnes/year.

The 1944 production includes the following:-

Brigitta Co. (Shell and Standard Oil group)	61,000 tonnes.
Siegfried Co. (Vacuum Oil Co.)	45,000 tonnes.
Itag, Celle	10,000 tonnes.

In addition to the output of the companies named, the following companies produced the amounts shewn in Austria 1944:-

Rohöl Gewinnungs Aktiengesellschaft A.G. (R.A.G.) (50% Shell - 50% Vacuum Oil)	280,000 tonnes.
Erdölproduktionsgesellschaft (50% Wintershall, 50% privately owned)	120,000 tonnes.
Van Sickle	100,000 tonnes.
Itag, including Steinberg - Naphtha	100,000 tonnes.
Donauöl (I.G.)	15,000 tonnes.

Consequently, in Germany: 1938, total ca. 550,000 tonnes/year.
1944 " " 710,000 tonnes/year.
in Austria: 1944 " " 1,212,000 tonnes/year.

(ii) <u>Mineral Oil Production Centres</u>

(a) Reitbrook near Hamburg.

(b) Nienhagen, Hanover.

(c) Heide, in Holstein.

(d) Meckelfeld near Hamburg.

(e) Oberg, Hanover, Ölheim.

(f) Wietze and Thören, near Celle.

(g) Gifhorn, Ehra, Wesendorf (Hanover).

(h) Lingen, on the Dutch border.

(i) Lower Austria.

(iii) Refineries.

(a) Heide in Holstein.

Owned by: Deutsche Erdöl A.G.

Capacity: 180,000 tonnes of crude oil per year.
Topping plant only.

(b) Hamburg Area.
Rhenania-Ossag Mineralölwerke A.G., Hamburg (Shell Co.)

Large refinery at Harburg.

Capacity: 300,000 tonnes of crude oil/year.

Distillation plant, dewaxing with selective solvents, and refining.

Production of lubricating oil and engine oils of many kinds of asphalts.

Grasbrook Refinery (Rhenania-Ossag)

Capacity: 50 - 60,000 tonnes/year.

Lubricating oils of every kind and greases.

Eurotank, Hamburg - "Petroleumhafen" (oil-port)

Capacity: 300,000 tonnes/year.

Dubbs Cracking Plant, preparation of benzine and coke.

Ebano Asphalt Works A.G. (Standard Oil Co.)

Capacity: 300,000 tonnes/year.

Distillation of crude oil preparation of special asphalts.

Ölwerke Julius Schindler, Hamburg.
Schliemanns Ölwerke, Hamburg.
Mineralölwerke Albrecht, Hamburg.

Small works producing special oils, principally white oils.

Wedel Refinery, near Hamburg (Vacuum Oil Co., New York)

Capacity: ca. 80,000 tonnes /year.

Manufacture of special lubricating oils and greases.

Wilhelmsburg Refinery, near Hamburg.

Owners: D.E.A.G., Berlin.

Capacity: 130 - 140,000 tonnes/year.

Distillation plant, solvent dewaxing, sulphuric acid refining, production of topping products, lubricating oils and asphalts of all kinds.

(c) Bremen Area.- Raffinerie Oslebshausen.

Owners: Deutsche Vacuum Öl. A.G. (Vacuum Oil Co., New York)

Capacity: ca. 150,000 tonnes/year.

Propane de-asphalting, phenol refining, distillation plant, solvent dewaxing. Manufacturers of high quality lubricating and engine oils.

Mineral Oil Refinery, formerly August Korff, Bremen. (Standard Oil Co.)

Capacity: 50 - 60,000 tonnes/year.

Distillation plant and sulphuric acid refining. Manufacturers of lubricating oils and greases.

(d) Hanover Area. Deutsche Erdöl Raffinerie - D.E.U.R.A.G. Neue Erdol Raffinerie (Nerag)

Owners: Gewerkschaft Elwerath.

Deurag: One third of shares with each of following:-

Gewerkschaft Elwerath, Hanover;
Preussische Bergwerks und Hutton A.G.

and one sixth each with:-

Rhenania-Ossag, Hamburg (Shell);
Deutsch-Amerikanische Petroleum Gesellschaft (Standard Oil)

Nerag: 50% of shares owned by Elwerath Co. and 50% of shares owned by Preussische Bergwerks und Hutten A.G.

Deurag and Nerag form an industrial unit.

Capacity: more than 300,000 tonnes/year.

Dubbs cracking plant, distillation plant, solvent dewaxing, furfurol refining plant.

Manufacture of fuels and high quality lubricating and engine oils - also carbon for electrodes.

Dollbergen Refinery, near Hanover.

Owners: Deutsche Gasolin, A.G.
50% I.G. Farben.
25% Shell.
25% Standard Oil.

Capacity: ca. 60 - 70,000 tonnes/year.

Distillation plant and dewaxing. Manufacture of special lubricating oils.

(e) Central German Area.
Lützkendorf Refinery, Krumpa near Merseburg.

Owners: Wintershall A.G., Kassel

Capacity: ca. 300,000 tonnes/year.

Propane de-asphalting, solvent refining, solvent dewaxing.

Manufacture of all kinds of lubricating and engine oils.

(f) West German Area. Emmerich Refinery.

Owners: Deutsche Gasolin A.G.
50% I.G. Farben.
25% Standard Oil.
25% Shell.

Capacity: ca. 150,000 tonnes/year.

Distillation plant, manufacture of lubricating oils.

Salzbergen Refinery near Bentheim (Wintershall A.G., Kassel)

Capacity: ca. 35,000 tonnes/year.

Cracking plant, distillation plant. Manufacture of fuels and lubricating oil.

Monheim Refinery.

Owners: Rhenania-Ossag Mineral Oil Works A.G., Hamburg (Shell).

Capacity: estimated as 150 - 200,000 tonnes/year.

Distillation plant, solvent dewaxing, solvent refining plant. Manufacture of all kinds of lubricating oils.

(g) Vienna Area. Deutsche Erdöl A.G., Mineral Oil Works "Nova" - Schwechat near Vienna.

Capacity: 180,000 tonnes/year.

Manufacture of lubricating oil and fuels by cracking.

Shell - Floridsdorf Mineralölwerke A.G., Floridsdorf near Vienna (Shell)

Capacity: estimated at 70,000 tonnes/year.

Manufacture of all kinds of lubricating oil.

Kagran Refinery.

Owners: Vacuum Oil.

Capacity: estimated at over 70,000 tonnes/year.

Manufacture of all kinds of lubricating oil.

Vösendorf Refinery.

Owners: Aktiengesellschaft der Kohlenwertstoffverbände.

Capacity: estimated at 60,000 tonnes/year.

Kornenburg Refinery.

Owners: Deutsche Gasolin A.G.
50% I.G. Farben.
25% Shell.
25% Standard Oil.

Capacity: estimated at 60,000 tonnes/year.

Manufacture of all kinds of lubricating oils.

Moosbierbaum Refinery.

Owners: I.G. Farben.

Capacity: not known to us.

Manufacture of special products.

Lobau Refinery, Vienna.

Owners: 50% Shell, 50% Vacuum.

Capacity: 150,000 - 180,000 tonnes/year. Mainly topping plant.

Besides the works named, there are also a few unimportant, obsolete processing plants and a series of "replacement plants" (Ausweich-Anlagen), which are merely for topping and have a standard output of 5 - 6,000 tons/month. The refineries named have been more or less badly damaged in air-raids. Their present condition is unknown to us. In the last month of the war they were repaired for use as topping plants only as a matter of expediency.

All information regarding the Deutsche Erdöl A.G. is as accurate as possible, but it is not claimed to be absolutely free from mistake.

Signed: E. GRAGES.

6. WAR TIME ORGANISATION OF THE GERMAN PETROLEUM INDUSTRY

The following information was obtained from E. Grages.

Production

Up till 1944 the supreme authority for oil production was the REICHSWIRTSCHAFTSMINISTERIUM (RWM) ABTEILUNG FUR MINERALÖL but at this time the Spier Ministry, namely REICHS MINISTERIUM FUR RUSTUNG UND KRIEGS PRODUKTION ("MINRUK") took over and remained in power until the end of the war. The staff of the former body were taken by the Spier Ministry, which had its main office in SCHINKEL PLATZ 1. This was later moved to AM SANDWERDER 29 and 37, Berlin-Wannsee and in March 1945 was evacuated to BLANKENBURG (HARZ MOUNTAINS - NEUE KASERNE). VON DURING of this organisation is in Berlin at FISCHER HÜTTEN STRASSE 40a, ZEHLENDORF.

In RWM Abteilung fur Mineralöl, E.R. Fischer and Rosenkrantz held the main responsibility and these were assisted by P. Schneider, a chemist, who acted as secretary and general assistant. All these were later transferred to "MINRUK".

MINRUK made full use of "WIRTSCHAFTSGRUPPE KRAFTSTOFF - INDUSTRIE and FACHGRUPPE ERDÖLGEWINNUNG on all production matters. The former body was located at Dorotheenstrasse 35 Berlin N.W.7. and was a private organisation set up in response to a Government Decree by the various companies producing and selling oil. It decided priorities on raw materials required for new construction or repairs and also allocated labour. Each constituent company had a member on the board, which was constituted as follows:-

President	E. R. FISCHER
D.E.A.G.	SCHIRNER and SCHLICHT
Rhenania	Dr. BODER
D.U.A.G.	ENGEL
I.G.	Dr. BUTEFISCH.
DEUTSCHE GASOLIN	Dr. BRUNCK
GEWERKSCHAFT ELWERATH	BROCKHAUS
Full Time Managing Secretary	F.W. ZIERVOGEL.

FACHGRUPPE ERDOLGEWINNUNG was located in Berlin at LINDEN STRASSE 21-22 but in March 1945 was moved to MARTIN LUTHER STRASSE 61-66, Berlin-Schoneberg and later was evacuated to WIETZE, near CELLE.

Liaison was also maintained between "MINRUK" and the following bodies.

ARBEITSGEMEINSCHAFT ERDOL-GEWINNUNG UND VERARBEITUNG ("AEN") - Formerly at DOROTHEEN STRASSE 35, BERLIN and AM SANDWERDER 29 Berlin and in March 1945 partly evacuated to WESTER-CELLE.

ARBEITSGEMEINSCHAFT DER BENZOLERZEUGER ("ARBO") and

ARBEITSGEMEINSCHAFT FUR HYDRIERUNG, SYNTHESE UND SCHWELUNG ("ARSYN")
Formerly at DOROTHEEN STRASSE 35, Berlin and later evacuated to DOLKAU, SCHLOSS and other places.

Drilling Programmes were decided by SONDER-BEVOLLMÄCH-TIGTER FÜR DIE ERDOL-INDUSTRIE (INVALINDEN STRASSE 7, Berlin) after discussions with the various commercial interests. This organisation was evacuated to D.V.A.G. in Celle.

Distribution

For distribution the supreme authority was Reichs-Wirtschafts Ministerium acting through REICHSTELLE FÜR MINERALÖL (RFM) originally having offices at BEHREN STRASSE 8, Berlin W.8., KRAUSEN STRASSE 22-24, Berlin S.W.68., REICHSKANZLER PLATZ 7-11, Berlin Charlottenburg 9 and evacuated in March-April 1945 to Munich and Hamburg.

Personnel associated with these organisations included the following:-

Dr. Raab. was manager of Reichstelle fur Mineralöl before the war, He was followed by Dr. PAUL MOJERT, who was transferred from the Deutsche Bank and during the last few months of the war JEHLE was manager. Raab was formerly mining engineer with PREUSSAG. MOJERT is still in Berlin. Dr. BUDEZIES was a lawyer in the REICHSTELLE - he left Berlin in April 1945 and is believed to be in Hamburg.

All motor fuels and diesel oils were controlled by RFM during the war and were distributed for civilian use by Zentralbüro fur Mineralöl (ZB) and for Wehrmacht use by WIRTSCHAFTLICHE FORSCHUNGS GESELLSCHAFT (WIFO). The former had its main office at ADOLF HITLER PLATZ 7-11, Berlin until it was evacuated in 1944 to Berlin Gatow and Dresden, Weisser Hirsch and in 1945 to AUSSIG, MUNICH and Hamburg. All petroleum distributing companies were compelled to participate in ZB and all motor fuels and diesel fuels produced from petroleum and by synthetic processes were delivered to ZB. Straight run petroleum gasolines were distributed by TEST BENZIN GEMEINSCHAFT which was controlled by Rhenania in Hamburg under the direction of RFM.

Lubricating oils were distributed by the individual companies up to October 1942 when a loose pool known as SCHMIERSTOFF GEMEINSCHAFT (SG) was set up by RFM. In 1944 this was replaced by ARBEITSGEMEINSCHAFT SCHMIERSTOFF VERTEILUNG (ASV) which had its head office in SAALFELD ON SAALE until it was transferred to MUNICH and HAMBURG in March 1945.

Kontinental A.G.

This company was formed by the Reich Government in 1940 or 1941 to control all oil produced in Roumania, Poland, Russia and the Baltic States. Its initial capital was 80,000,000 RM and the leading and wholly German owned oil companies and banks were compelled to subscribe 50% of the capital, the remainder being provided by the Government. D.E. A. G. were compelled to subscribe 3,000,000 RM.

The President of the Board of Directors was FUNK and the directors were:-

KARL BLESSING	Formerly a director of the Reichs bank who resigned and transferred to the Margarine Union was later compelled to join KAG by Funk. Not a Nazi.
E.R. Fischer	A director of Deutsche Gasolin
Brockhaus	Formerly of DEURAG-NERAG and Gewerkschaft Elwerath.
Diehlmann	Previously of I.G.

The Head Office of KAG was at Martin Luther Strasse 61-66, Berlin.

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FINAL REPORT No. 325.
ITEM No. 30.

KAISER WILHELM-INSTITUT FÜR STRÖMUNGSFORSCHUNG ABTEILUNG, REIBUNGSFORSCHUNG, BERLIN

Interrogation of Dr. Ing. G. Vogelpohl

Howes, D.A.

JUL - 1946
REC'D. ....
TIIC I.F. & L. S-C.

BRITISH INTELLIGENCE OBJECTIVES
SUB-COMMITTEE

LONDON - H. M. STATIONERY OFFICE.

KAISER WILHELM-INSTITUT FÜR STRÖMUNGSFORSCHUNG

ABTEILUNG REIBUNGSFORSCHUNG, BERLIN

Interrogation of Dr. Ing. G.Vogelpohl

August 11th - 14th, 1945

Reported by:

Major D.A.Howes, British, Ministry of Fuel and Power

BIOS Target No.C30/362

Fuels and Lubricants

British Intelligence Objectives Sub-Committee
32 Bryanston Square,
London, W.1.

CONTENTS

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Personnel of Interrogating Team:

Major D.A.Howes, British, Ministry of Fuel and Power

A. Introduction:

On August 11th, 1945, Dr. Ing. G. Vogelpohl was interrogated at his private address at Zellerfelder Strasse 9, Berlin, and requested to prepare written statements concerning his war time activities. These were ready on August 14th and he was interrogated a second time. This report comprises translations of Vogelpohl's written statements, amplified by the results of interrogation.

B. Activities of Abteilung Reibungsforschung and the Scientific work of G. Vogelpohl:

Vogelpohl started work as an assistant in the Institut für Technische Stromung forschung of the Berlin Technische Hochschule on March 1st 1928 and on April 1st 1937 was appointed Chief Engineer there. After the beginning of the war it was suggested by Prof. Dr. L. Prandtl, director of the Kaiser Wilhelm Institut für Stromung forschung in Gottingen to the Generalverwaltung of the Kaiser Wilhelm Gesellschaft zur Förderung der Wissenschaften that a special and independent department for friction and lubrication research be set up under Vogelpohl's direction. This suggestion was approved and the new department became the Abteilung Reibungsforschung at KWl Berlin. On June 30th 1942 Vogelpohl therefore left the T.H. Berlin and took over his new department, which through Professor Prandtl was financed by the Forschungsführung.

However, shortage of assistants prevented any experimental work for a long time and up to the middle of 1943 only one female assistant was available. At this time mechanics and engineers were recruited but on November 26, 1943, the Institut was badly damaged in an air raid, and documents, drawings and reports, etc., were destroyed.

Previous to this, however, on April 17th, 1943, Vogelpohl was instructed to give a series of lectures at the Technische Hochschule, Hanover, on "Mineral Oil Physics and their Applications" and this enabled Vogelpohl to transfer part of his experimental equipment from Berlin to Hanover where it was erected in the Tensile Strength Laboratory which was in a cellar. He then began a series of lectures at Hanover on lubrication and friction and intended to remove completely to Hanover. This, however, proved to be a slow process and the final move was never made.

For these various reasons Vogelpohl did not carry out a great deal of research during the war and few finished reports were prepared. The following reports are in existence:-

1) The Integration of the Reynolds Equation for Bearings of Finite Width - Published in Ingenieur-Archiv Bd 14 (1943) pp.192 - 212.

2) An Investigation of Frictional Heat Transfer from the Lubricant layer to the Bearing Surfaces.
   Sent to the Press in Autumn 1944 as a VDI Research Booklet. Copies are at Hanover and Gottingen.

3) The Stribeck Curve as an Index of the General Frictional Behaviour of Lubricated Bearing Surfaces - Its Calculation and Experimental Confirmation.
   Vogelpohl is completing the proof of this from notes in Berlin.

4) Cavitation as a cause of lubricating oil frothing.
   Typewritten copies are in Hanover and Gottingen.

5) The Reliability of Results on measurements of Bearing Friction.
   This report is incomplete.

6) On new Frictional measurements and experimental Results which contradict the Hydrodynamic Theory of Lubrication.
   Nearly completed. Experimental data are partly in Hanover.

7) Experiments on Oil Supply to the Big End Bearing of Internal Combustion Engines.
   This interim report is in Hanover and Gottingen.

8) The Construction and Testing of an Oil Testing Machine for determining lubricant behaviour with exclusion of the effect of the bearing metal and

the deformation of shaft and bush.
This work is in progress at Hanover.

9) The Development of Pressure in Lubricant Films with Parabolic Cross Section and the Range of Applicability to Rotational and Sliding Surfaces.
In preparation in Berlin.

10) Change of Heating with time in a Couette viscometer at High Shearing Velocities.
This is a mathematical investigation.

Vogelpohl intends to publish all these reports when completed.

C) Friction Research:

A Statement by Vogelpohl

1. Field of Activity and Problems in Friction Research

Machine construction is distinguished from building construction by movement. Every motion involves overcoming the resistance of friction. Generally friction is accompanied by wear. Friction and wear determine to a large extent the economic possibilities, working safety and length of life of machines.

The introduction of a liquid or plastic substance between the surfaces sliding on one another diminishes friction considerably. This is what happens in lubrication.

Besides this usually unwelcome resistance (useful in brakes however!) there is a second form of friction - resistance to motion from rest, known as static or "cohesive" friction. This is useful in many ways. It is the physical basis of all the resolvable and unresolvable combinations in building and machine technology, of adjustable brakes, of the motion of all vehicles, of the standing and walking of human beings and animals as well as of all spinning, wearing and sewing.

The tasks of friction research are: to study the physical processes of friction in a moving machine, lubrication, wear and the causes of static friction.

2. The Present State of Friction Research:

Modern friction research began with the investigations of Amontons in the year 1699. In spite of extensive work throughout almost 250 years, even the simplest case of sliding friction has not been satisfactorily explained so far. Especially in the case of the bush-bearing, the most important machine component in rotational movement, there are no unambiguous measurements nor are there any for the friction of to and fro moving machine parts and even less for the wear occurring.

The main reason for this unsatisfactory state of affairs is that friction is often regarded as a property of one of the materials sliding in contact. Similarly, the power to diminish friction is usually regarded as a particular property of a lubricating compound. However, friction and the effect of lubricants are not properties of the materials involved but are physical processes dependent on a large number of changes. Of these, part are neglected in the vast majority of experiments, so that contradictory results are obtained.

In addition, there is as yet no apparatus which allows direct measurement of friction with a single bearing without tedious and difficult corrections. The large number of measuring installations in use have grave sources of error which are not very well known. The readings of such instruments are taken without comment as "the friction of the experimental bearing". These errors are not a matter of merely 10 to 20 per cent, but of hundreds per cent.

Such results make any theory of friction impossible; even a working approximation is not permissible.

Satisfactory results are possible through only one line of approach; the use of basic hydrodynamical equations in the consideration of the flow-process of the lubricant (always a viscous fluid). This yields mathematical results which are confirmed by dependable experimental observations. But even this hydrodynamic theory of "lubricant friction" is a subject of debate as regards practical application. Very often the faulty experimental results mentioned above are compared with the calculated figures; sometimes erroneous theoretical figures are used as a basis of comparison. In such cases, of course, no agreement can be expected and contradictions must arise.

It is also maintained that lubricants with the same physical properties but different chemical structure vary in their lubricant action. The measurements in this connection have been made mainly in oil-testing equipment where the surfaces sliding on one another are, in part, subject to quite different lubricating conditions than an actual machine. Thus the results with such test machines do not usually apply in practice.

The "sliding properties" of bearing metals remain as little explained as the lubricating power of oils.

3. Work of the Friction Research Department:

In our present state of knowledge in this field, all work, apart from some minor details, relates to basic research. The hydrodynamical theory of lubrication is being extended and all questions connected with friction, lubrication and wear in their thermodynamic, theory of elasticity and material technical aspects are being tackled theoretically.

The following groups are included in current or future research:-

(1) Friction and Lubrication:

(a) Measurement of Friction

The first aim is the creation of apparatus permitting an unequivocal measurement of the bearing friction. This is being attempted in various ways: measurements on a single bush, with corrections; two bushes pressed in opposition against the shaft; measurement of the total turning moment with elimination of the support bearing friction; four-ball test machines and special apparatus for the measurement of friction with a single bearing. This newly developed equipment differs little externally from that used previously, but avoids earlier mistakes by the alterations made and, above all, by the method of observation and measurement.

(b) Temperature Measurement

The estimation of temperature distribution in the lubricant film and the use of the temperature viscosity curve to follow variations of viscosity in the film is as important as the measurement of friction itself. Many incorrect statements on the process of friction and lubrication may be traced to faulty viscosity measurements at the point of sliding contact. There is little possibility of applying theoretical considerations as a basis for measuring procedure.

(c) Measurement of Roughness

It is very important to ascertain the geometric formation of the surface layers of the parts in sliding contact. The Institut has available for this purpose a measuring instrument developed in co-operation with Dipl. Ing.Forster. This apparatus renders possible the photographing of the state of a surface over a large area. In the friction experiments the roughness of the surface is regularly measured. A corresponding apparatus is being developed for borings.

(d) General Technique of Fine Measurement

The "roughness peaks" are of the order, μ (= 0.001 mm.); the calculated film thicknesses are of the same order, or still lower. Consequently, to compare experimental and theoretical figures, a measuring technique is necessary which can read to 0.1μ with heavily loaded (and consequently deformed) machine parts. Equipment available up to now is so sensitive at even 1μ, that minute temperature changes can affect the readings substantially. A technique allowing linear measurements of the order of wave lengths of visible light has not yet been developed for this type of work.

(e) Roughness and Static Friction

It is intended to use special equipment for pressing together surfaces with different degrees of finish. They will then be rubbed along one another and the superficial deformations measured microscopically using metallographic procedure. This investigation is necessary to gain deeper insight into static friction and to determine the forces produced by the deformed surface layers rubbing against one another.

The opinion is often expressed that static friction is mainly due to surface forces. These researches could thus give a decision whether the friction is due to surface forces or to roughness or to the forces involved in elastic and plastic deformation under pressure.

These experiments are of particular importance in connection with wear. For this reason an investigation of unlubricated and partly lubricated sliding friction is being made.

(f) Friction in a High Vacuum

Of especial significance is the study of friction between two clean surfaces where, partly in vacuo, the last adherence layers of gas have been removed. Previous experiments of this nature have always neglected the nature of the surface and must therefore be repeated.

(2) Experiments on Self-Acting Lubricant Supply to the Point of Sliding Contact

Many friction experiments are undertaken without attention being paid to maintaining the lubricant supply constant. The latter is delivered either by means of flooding with an oil-stream or results from the surface and capillary forces between the material and the oil. In this way, oils with different surface properties give a quantitatively different feed and therefore different friction. Neglect of these relationships has led to the assumption that the surface forces are the immediate cause of friction or that they influence it, and that they are decisive in determining the lubricating action. It is very probable that this is a mistake. Success has been achieved already at the Institut in introducing mercury and other non-wetting liquids under low pressure into the "lubricating gap" (Schmierspalt), whereby a quite definite lubricating action was obtained. The clearing up of these problems is of the greatest importance in technical lubrication, especially for cylinder lubrication. Here "wetting" oils are necessary which can maintain, by virtue of their surface tension, a sufficient quantity of lubricant on the walls — The lubricating process itself then proceeds under the same conditions as with a bearing. It is not possible to lubricate a piston with a non-wetting liquid like mercury, as can be done, by employing special equipment, with a bearing.

(3) Wear:

Friction and wear are, to some extent, closely related. Wear research is very little developed as yet and the theoretical basis is even less complete than that of friction. Chemical processes play an important part, for the effect of the surrounding medium is also to be considered.

In addition to continuing the development of previous wear testing methods, it is intended to study deformation with both "cohesive" and sliding friction at low velocities by means of microscopical and microkinematographical photographs of the wear process.

(4) Oil Testing Machines:

The collection of results on friction, lubrication and wear also renders possible the construction of testing machines permitting the unequivocal measurement of the lubricating tendencies of oils. Up to now the application of such machines has been either limited or actually misleading. Since such methods of test are urgently required in practice, machines which avoid previous imperfections are already being tested or are under construction.

(5) Oil Properties:

The line of attack taken by the Institut in the direction of a more fundamental explanation of the process of lubrication from the mechanico-physical angle renders necessary a more complete picture of the relevant properties of oil.

(a) Firstly, the viscosity behaviour at high shearing speeds must be determined. Here the heating effect of internal friction on the lubricant can no longer be neglected. Special viscometers are being developed for this purpose. A theoretical basis is already available from the theory of heat.

(b) In machine lubrication, any frothing tendencies of the lubricant must be carefully watched. Intensive research has shown that frothing is closely connected with cavitation phenomena. Research is under way to clear up this matter.

(6) Calculations for Sliding Bearings:

Friction research can be applied to machine design as well as in actual running. The method of calculation devised by Falz for sliding bearings is based on very incomplete foundations. The following is necessary:-

(a) Research on the heat loss of bearings

Up to now only a few results for single bearings have been available. These must be extended and also be made to include multiple bearings in machines. The dependence of heat loss on individual variables must be examined more closely than formerly. Theoretical development in this direction is also desirable.

(b) Research on the determination of the minimum permissible strength of lubricating film.

This important quantity has so far been derived solely from considerations of superficial roughness. This method gives values which are considerably above those with heavily loaded bearings and is partly responsible for an exaggerated degree of surface finish. A new method is available, when the determination follows from running trials with actual bearings.

(7) Machine Lubrication:

Lubricant supply to the various sliding surfaces of a large machine, e.g., a diesel engine, is now based purely on practical experience. However, although a working solution may be found it does not at all follow that it is the best solution. Any lubrication breakdown is usually attributed to the lubricant, so that to some extent poor oil feeding methods are balanced by high quality oils. What is aimed at, is a design permitting absolutely reliable lubrication with simple, good oils.

(8) Research on Bearing Metals:

The so-called "sliding properties" of bearing metals have been determined up to now only in a one-sided fashion whereby, in most published reports, the lubricant used is not even mentioned.

The assertion, that hydrodynamical theory does not lead to any possibility of judging bearing metals is incorrect. The minimum permissible lubricant film strength is a quantity which characterises the sliding properties. A corresponding extension of the experiments mentioned to include different bearing metals leads to a scientific, quantitative determination of these properties which have up to now been treated in a somewhat unscientific manner.

Different bearing metals, according to their tensile strength and depending on temperature, have in varying degree the property of forming a more or less smooth surface layer when pressed against a hard surface. These properties are known as "surface layer formation". Their dependence on tensile strength properties and on metallographic structure is decisive in determining the minimum permissible lubricant film strength.

(9) Literary Activities:

Besides the publication of individual reports in technical and research journals the compilation of a large work entitled "Theory of Friction" (Reibungslehre) is planned. It is intended to give a picture of the present state of knowledge and of the results of the Institute in a compact form. Part of the manuscript for the first impression of the book is already almost complete.

G. VOGELPOHL
Abteilung Reibung forschung
das K.W.I für Stömung forschung

D.— A LIST OF THE SCIENTIFIC PAPERS BY VOGELPOHL

(up to 30.6.45)

1. The Determination of Inlet Tube Flow from the Napier-Stokes Equations.
   Zschr. Angew. Math. Mech., Vol.13 (1933), pp.446/447.

2. Wind Tunnel Experiments on Railway Train Air Resistance. Z. VDl, Vol.78, (1934) pp.159/167

2a Reprint of 2. in the "Monatsschrift der Internationalen Eisenbahn - Kongress - Vereinigung" Vol.5 (1934) pp.717/735.

2b French translation of 2 in the "Bulletin de l'Association Internationale du Congress des Chemins de Fer", Vol.16, (1934) pp.766/785.

2c English Translation of 2. in the "Bulletin of the International Railway Congress Association" Vol.16, pp.939/957.

3. With M.Medici: Experimental Research on Air Resistance with Railway Trains (in Italian).
   II Monitore Technico, (1934) pp.143/148.

4. Fredrick Wilhelm Bessel - On the 150th Anniversary of his Birth. (22.7.1784).
   Rundschau Techn. Arb., Vol.14, No.29 (18.7.34)

5. Fredrick Wilhelm Bessel - From Apprentice to the Most Important Astronomer of his Time.
   "Das Werk", monthly journal of the "Vereinigte Stahlwerke A.G.", Vol.14 (1934) pp.375/376.

6. Does the Engineer need New Books on Mathematics?
   Rundsch. Techn. Arb., Vol.15,No.17 (24.4.35) p.4.

7. The Physical Nature of the Resistance to Motion of Railway Trains.
   Z. VDI, Vol.79 (1935) pp.851/860.

8. Wind Tunnel Experiments with Automobile Models,
   Rundsch. Techn. Arb., Vol.15,No.37 (11.9.35) p.3.

9. The Laws Governing the Air Resistance of Railway Trains. Forschg. Ing. Wes., Vol.6 (1938) pp.217/222.

10. On the Hydrodynamic Theory of Bearing Friction. Zschr. Angew. Math. Mech., Vol.15 (1935) p.378.

11. Hydrodynamic Theory and Semi-Fluid Friction. Oel u. Kohle, Vol.12 (1936) pp.943/946.

12. Advances in Flow Research using the Ultra-microscope. Zschr. Angew. Math. Mech., Vol.16 (1936) p.371. (short lecture report)

13. Hydrodynamic Bearing Theory and Semi-Fluid Friction. Zschr. Angew. Math. Mech., Vol.16 (1936) pp.371/372 (short lecture report)

14. On the Impulse Theorem in the Theory of Flow. Forsch. Ing. Wes., Vol.8 (1937) pp.35/41.

15. Jointly with D.Mannesmann: Flow Research with the Ultra-microscope. Forschg. Ing.Wes., Vol.8 (1937) pp.42/47.

16. New Experiments on Lubrication as a Basis for Sliding Bearing Measurement. Report of the meeting "Prüfen und Messen" of the VDI on 1 and 2.12.36, Berlin 1937 pp.173/180.

17. A Contribution to the Study of Lubrication Utilising Earlier Work on the Hydrodynamic Theory. Zschr. Angew. Math. Mech., Vol.17 (1937) pp.362/365.

18. A Contribution to the Study of Sliding Bearing Friction. VDI - Forschungsheft, 386, Berlin 1937

19. Oiliness as a Result of the Heating of Lubricants. Proceedings of the General Discussion of Lubrication and Lubricants. London 1937, Vol.2,pp.442/451.

20. Viscosity and Lubrication. Oel u. Kohle, Vol.14 (1938) pp.991/997.

21. A Contribution towards the Explanation of Sliding Friction. Oel u.Kohle (incorporated with Petroleum) Vol.35 (1939) pp.720/728 - also Vol.36 (1940) pp.249.

22. The Mathematical Treatment of the Problem of Bearing Lubrication.
Oel. u. Kohle (incorporating "Petroleum") Vol.36 (1940) pp.9/134: 34/38.

23. The Historical Development of our Knowledge of Friction and Lubrication, I.
Oel. u. Kohle (incorporating "Petroleum), Vol.36 (1940) pp.89/93 and pp.129/134.

24. Frictional Losses in Marine Shaft Bearings.
Schiffbau, Schiffahrt u. Hafenbau, Vol 42 (1941) pp. 343/348.

25. On the Nature of Friction and Lubrication.
Archiv. für Warmewertschaft u. Dampfkesselwesen, Vol.23 (1942) pp.11/14.

26. The Present State of Border Friction Research.
(Criticism and Outlook)
Oel u. Kohle (incorporating "Petroleum") Vol.38 (1942) pp.340/350.

27. Integration of the Reynolds' Equation for Bush Bearing of Finite Length.
Ing. Arch., Vol.14 (1943) pp.192/212.

28. An Investigation of the Transfer of Frictional Heat from the Lubricant Layer to the Surfaces in Contact (Temperature distribution and Thermal Gradient in Parallel Lubricant Layers with Heating by Internal Friction).
VDI - Forschungsheft; in the press.

29. A Contribution to Turbulence Research.
Forschg. Ing. Wes. Vol.4 (1933) pp.154/155

30. New Problems in Flow Research (from the 9th Meeting German Physicists and Mathematicians at Würzburg 1933).
Z. VDI Vol.77 (1933) p.1318.

31. The Determination of the Phenomena of Flow in Three Dimensions using the "Painting" Procedure (Farbanstrichverfahren).
Z. VDI Vol.78 (1934) pp.1332/1333

32. The Air Resistance of Express Trains as shown by Wind Tunnel Experiments.
Z. VDI Vol.82 (1937) pp.1386/1388.

33. Recent Measurements of the Displacement Curve of the Centre of the Shaft in Sliding Bearings.
Z.VDI Vol.82 (1938) pp.832/834.

34. The Frictional Resistance and Strength of a Bearing Shoe of Finite Width.
Z. VDI Vol.87 (1943) pp.370/372.

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FINAL REPORT NO. 120
ITEM NO. 30

WIRTSCHAFTLICHE FORSCHUNGSGESELLSCHAFT m.b.H.
HITZACKER DEPOT

Jones, H. F., and West, H. L.

BRITISH INTELLIGENCE OBJECTIVES SUB-COMMITTEE

LONDON — H.M. STATIONERY OFFICE

WIRTSCHAFTLICHE FORSCHUNGSGESELLSCHAFT

m.b.H.

HITZACKER DEPOT

Investigation of the Installation and
Interrogation of the Personnel

July 8th - 11th, 1945

Reported by:-

Lt. Col. H. F. Jones, War Office (ST2)
Mr. H. L. West, British Ministry of
Fuel and Power

BIOS Target No. C 30/1.19(c)
Fuels and Lubricants

BRITISH INTELLIGENCE OBJECTIVES SUB-
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CONTENTS

Personnel of Team

Lt. Col. H. F. Jones	British, War Office
Major L. Rosenfeld	British, Ministry of Fuel & Power
Mr. H. L. West	British, Ministry of Fuel & Power

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1. SUMMARY

1. The information obtained in this report was obtained by inspection of the installation and interrogation of some of the personnel; details of the standing of the latter and their party connections are given.

2. The depot was one of the Grosslager in the claim of WIFO installations handling, mainly, Luftwaffe fuels and lubricants and to a limited extent products for the Army.

3. General details of the plant design and operation are given as well as those of the new construction for increasing the storage and/or blending capacity. The fuel storage consisted of 30 tanks of 3,300 cu.metres and 78 tanks of 600 cu.metres for oils.

4. A complete list of incoming and outgoing blending components and finished stocks are given together with the test methods used for their quality control and inspection.

5. Practically no research was carried out at this installation but what little was uncovered is noted and described.

6. No documents of value were located as these were alleged to have been destroyed by the retreating armed forces.

2. INTRODUCTION

1(a). The team visited this target as part of a limited survey of the WIFO installations. This particular installation is noteworthy for the large volume of oil storage in relation to the total storage capacity, otherwise it is a standard Grosslager or Hauptlager used for storage and blending of petroleum products mainly for the Luftwaffe and to a smaller extent for the Army.

1(b). Although the plant was not in operation, a limited (German) staff was kept employed to enable Military Government to draw on and dispose of some of the stocks available. The original depot leader, Herr Zanner, had been deposed by a vote of the operatives and Herr Keiser elected in his place.

3. PERSONNEL INTERROGATED

2(a). Hans Keiser (45 years of age) (and a party member from 1932) was originally the commercial manager of the depot. When taken over by the occupation troops he had been voted by the employees to remain in charge of the Depot. He appeared very co-operative but did not speak English.

2(b). G. Zanner (43), a mechanical engineer, came to Hitzacker from Neuberg in 1936. He had previously been the Technical Manager and Deputy Works Leader (being deputy to Wehling who was nominally in charge of all depots). Since the occupation he had been voted out of his position and replaced by Keiser, thus having no further connection with the plant. He had been a party member since 1933, had no knowledge of the English language and, considering his position, did not appear remarkably intelligent or to have much detailed knowledge of the plant under his control. Altogether, the opinion was formed that he had obtained his position more on his party connections than on his ability or personality.

2(c). Dr. Rohrmann (42) the chemical technical manager was in charge of the laboratory and of quality control. Educated at T.H. Hanover he had been with Benzol Verbandt and had been assistant to a professor at Helsinki for five years. He spoke limited English and, again, considering his position, did not appear well informed. The opinion was formed, however, that he was not particularly co-operative and was probably holding back information.

2(d). Herbert Stolte (35) was deputy to Rohrmann. He had a fair knowledge of English and appeared co-operative and enthusiastic in his work.

2(e). Oskar Hausch (45) a mechanical and electrical engineer on the new construction work, had previously been with the I.G. Farbenindustrie and Krupps and joined WIFO in 1939 having been first at Derben and then came to Hitzacker in 1941; he had also been to Czechoslovakia. He was most anxious to co-operate, spoke excellent English and it was due to his help that some of the information gathered during this visit was obtained.

2(f). Gerhard Kerl (36) a constructional engineer, had been at Hitzacker for varying periods in 1936 and 1937, 1940 and 1943; he had also spent six months at Heiligenstadt. He was engaged with Hausch on the new construction work. Not particularly co-operative and not speaking English, he had apparently been senior to Hausch presumably more for his party affiliations than his ability, as Hausch appeared the better man.

2(g). The information given in this report was obtained by interrogation of all the above, but, as there is considerable overlapping of the information given it is treated as a whole rather than in individual interrogations.

3. DESCRIPTION OF THE INSTALLATION

3(a). Originally designed and built in 1935, this installation had, in the later years of the war, been enlarged and additional storage and blending, as well as water and rail loading and unloading facilities, had been installed.

3(b). The site was situated in a well wooded, hilly location N.W. of the town of Hitzacker, being flanked on the N.E. by the River Elbe and on the south by the Lüneburg-Dannenberg railway line, sidings from which served the installation. Road connections to Hitzacker, Bleckede and Tiessau branched and ran through the site. It will thus be seen that good transport facilities by water, rail or road were available and had obviously been used, there being one old and one new wharf for handling tank barges, and four separate sidings or "stations" one for oil, one old and one new siding for gasoline and one new siding for Sonderstoff. A schematic layout of the plant with the latest additions is given in Fig. 1 (No notice should be taken of the apparent layout in circular groups as this particular installation, in contrast to some of the others, is not arranged in this orderly fashion)

STORAGE AND BLENDING

3(c) GASOLINE.

The total storage for gasoline consisted of 30 underground tanks of 3300 cu.metres capacity each, giving a total capacity of 100,000 cubic metres.

3(d). Each tank is comparatively self-contained, having at one end a small pump house with pipe connections, valves, and a centrifugal pump of 60 cu.metres/hour capacity, which can be used either for circulating the contents of the tank or for pumping to other locations. Access to this pump station was by a vertical ladder down a shaft, ventilation being provided by an electric fan. Some distance from the end of the tank a separate manhole was located, this being used for dipping and other purposes such as cleaning, air venting, etc. Each tank had a pneumatic contents gauge calibrated in cubic metres and for fuels of 0.680 to 0.750 specific gravity. The layout of the tank farm is given in Fig. 2.

3(e). In the new type construction, which was being used for the new blending blocks, and which represents the latest WIFO construction methods, five tanks of 4,000 cu.metre capacity each were put into one group. Each group was provided with a common pumphouse, which normally had two pumps of 200 cu.metres/hr. The prospective group at

Hitzacker should have become blending groups, with a capacity of 40,000 cu.metres, and so have five pumps to facilitate mixing, filling and emptying of each tank independently. Besides the main pumps small ones were provided for the removal of residues. Instruments for the measurement of pressure, flow and contents of the tanks were provided, as was ventilation for petrol fumes and fire extinguishing equipment (carbon dioxide). The tanks were automatically safeguarded against overflow.

3(f). The construction of the tanks, either old or new, was essentially the same, experience gained in the use of the old variety being used to obviate difficulties in the new. The tanks were of bolted, cylindrical construction with dished ends and a nearly horizontal axis. The axis was inclined 1 in 100 towards the pumphouse to guarantee complete emptying: at the lowest part there was a dished shaped, so called, sump. This served also for collecting and for emptying residues, water, etc.

3(g). The tanks were constructed of 10 mm. iron plate, the diameter being 10 metres and the length, for the 4,000cu.metre tanks, 55 metres. As the tanks were laid horizontally it was necessary, during construction to have a supporting structure on the inside, which was removed as soon as the outside was covered with reinforced concrete and the same had set. One may therefore regard these as concrete tanks with a thin iron film on the inside as sealing. To prevent rusting, the inside of the tanks received a coating of cement, which was sprayed on as cement milk. Access to the inside of the tank was gained by a manhole and ladder; in the manhole cover was also a dip socket for determining the contents by dipping. In the new construction the manhole was reached via a corridor in the concrete and, on the pumphouse side, the tanks had two cupolas for pipeline connections. In the latest practice and judged by experiences gained during the war, the wall thickness (concrete) should be 2.5 metres.

3(h). All vapour spaces of the tanks were inter-connected presumably to avoid loss by evaporation. Each tank had a pressure gauge reading from -200 mm of water to +2500 mm. which is the maximum the tanks will stand. The average working pressure in the summer was 500 - 800 mm. Flame and explosion traps were fitted to all vents: these were described as "Kito sieves".

OIL STORAGE

3(i). The oil storage consisted of 78 individual, underground tanks of 600 cu.metres capacity, giving a total of $46,800m^3$.

The construction of the tanks was in general principles similar to that of the gasoline group outlined in 3f & g but, naturally, with the smaller size the difficulties were less pronounced and with oil storage, rusting was presumably not so acute.

3(k). As with the fuel tanks, each tank had a small pumphouse, to which access was gained by a vertical shaft. In the pumphouse, pipe connections, valves etc., were located, each tank being fitted with it's own pump for circulation or pumping to other locations, a small semi-rotary for removal of residues, sludge, water etc., contents gauge reading up to 600 cu.metres, thermometer etc. The layout of the oil tank farm is given in Figs. 3 & 4; tanks 74 & 75 are duplicated in these tank drawings and should be superimposed. The relation between the gasoline and oil farms can be seen by superimposing the main pumping line to the harbour.

4. PUMPHOUSES AND BOILERS

4(a) For the discharge and loading of barges on the Elbe there were two underground pumphouses, one for gasoline, the other for lubricating oil.

4(b) For handling gasoline two centrifugal pumps of 300 cu. metres/hr. capacity each were fitted, these being combined with an air pump to clear gas from pumps and lines and to prevent air locks on the suction side. Wire mesh filters were used to prevent the ingress of foreign materials which might damage the pumps. Balancing tanks of 50 cu.metres capacity were fitted for use in emptying barges and for fire prevention a conventional carbon dioxide system was used.

4(c). The pumphouse for lubricating oils was fitted with gear pumps of 80 cu.metres/hr. capacity, these being also fitted with wire mesh filters.

4(d). The underground boiler house nearby was equipped with two Lancashire type boilers (by Bamag) each with 72 sq.metres heating surface and capable of producing two tons of steam (maximum) per boiler per hour. These were arranged normally for coal firing but could be operated with a low pressure oil burner. The boilers operated at 10 atmospheres pressure.

4(e). For the loading and unloading of rail cars there were three sidings or stations, one for lubricating oil and two for gasoline.

4(f). The lubricating oil station had ten pumping pits and three 5 inch lines, two from the tanks and one to the barrel filling facilities. The pumps were motor driven through reduction gearing. For loading out aviation oil a filter press, one metre diameter and of 75 cu.metres/hr. throughput was used through which the oil was pumped after pre-heating.

4(g). The original gasoline siding had two pumphouses, each fitted with a centrifugal pump of 250 cu.metres/hr. capacity for each main, which connected to the gasoline tanks, the tanks being inter-connected by a ring pipe line.

4(h). The new gasoline station was also connected to the tanks but had been damaged by bombing and the layout was not readily discernible.

4(i). At the first station an underground boiler house, similar to that by the river, was located. Two small portable or temporary, vertical boilers of the Cochran type were also located at the oil station for the purpose of heating rail cars and for filling off barrels of lubricating oil.

5. HEATING

All oil tanks were heated by hot water, not by steam, the water being drawn from the Elbe and heated. The water pressure at the pumps was four atmospheres but at the tanks this was reduced to 2½ - 3 atmospheres. By this method water was circulated at a maximum temperature of 130°C, the normal operating temperature being, however 120°C. In this manner it was possible to heat the oils to between 40 to 80°C to reduce them all to the same viscosity regardless of type, thus facilitating the pumping, metering and blending operations.

6. ELECTRIC POWER AND LIGHT SUPPLY

The electric supply was normally by cable from Hannover but, as a stand-by, a diesel electric power plant was built into the side of a hill. The latter was operated by a M.A.N. 8-cylinder, supercharged, diesel engine giving 800 H.P. at 420 rpm. This engine was lubricated with "Einheitsöl" (approx.8°E at 50°C).

7. BLENDING

7(a). Each storage tank was a complete unit with its own circulating pump driven by an electric motor, this pump being used for blending, transferring or loading.

7(b). In contrast, the new construction mentioned in 3e above was arranged for each set of five tanks to operate as a unit and from the description of these blocks it would appear that it was intended to carry out most of the gasoline blending at these sites and probably use the existing tank farms for storage.

8. TETRA ETHYL LEAD BLENDING

8(a). The T.E.L. blending was unusual in that special portable units designed by WIFO and operated by specially trained crews were used. As and when a tank of gasoline was to be leaded these units were taken to the site and the blending operation carried out through the manhole of the tank. Fig. 5 gives a diagrammatic sketch of the unit to which reference is made in the description of its use, whilst photographs 1 and 2 show the plant itself.

8(b). The suction and delivery pipes are placed into the tank through the manhole, the delivery line reaching about 10 cm. lower than the suction line to avoid recirculation of the already T.E.L. rich gasoline. The ethyl plant is then connected to the delivery and suction pipes by flanges 1 and 2. The ethyl fluid barrel is placed on the scale, weighed, opened with all the necessary precautions and the flexible pipe inserted.

8(c). The contents of the tank having been accurately gauged, valve A in the suction line is opened, as is valve B in the delivery line: valve C is kept closed as well as the regulating valve and the pump switched on. This starts the gasoline circulating from the tank through the T.E.L. plant. After a short period, when the injector has created a sufficiently high vacuum, the regulating valve is opened, the ethyl fluid is sucked in and mixed with the petrol in the injector pump, the mixture reaching the tank via valve B through the delivery line. When the scale shows that sufficient fluid has been taken from the barrel, the operation is stopped.

8(d). To obtain the last drop of fluid from the barrel, if this is required, it is rinsed with gasoline. For this purpose valve A is opened, the regulating valve and valve B closed but valve C is opened. After the pump has been started, gasoline is delivered into the barrel via the rinsing arm, the pumping being stopped when the barrel is full. The blending procedure is then carried out and the whole process repeated until the barrel is clean. The tray in the base of the plant is kept full of kerosene (?) during the operation so as to catch and dilute any ethyl fluid leaking from the unit.

When not in use, this mobile plant was kept under a wooden roof near the tank manhole as a protection from the weather, particularly rain.

9. OTHER BUILDINGS

In addition to the main plant there were the usual office buildings, workshops, stores etc., suitable for an installation of this size. The laboratory was of a fair size and was well, but not elaborately, equipped; it will be dealt with in more detail later in the report.

10. TELEPHONE COMMUNCATION AND CONTROL

10(a). In the basement of the office by the main gate a complete, automatic, telephone exchange was installed. By means of this, direct communication was available between any part of the plant, each tank pump house being fitted with a telephone.

10(b). Above the telephone exchange was located a control room from which it appeared possible to control the operation of the plant.

11. OPERATIONAL DIFFICULTIES

11(a). Tanks.

The old type tanks, which were made of 10 mm thick iron plates, showed marked corrosion on the inside after 1-2 years service, the corrosion being more rapid in tanks which were alternately full and empty. Innumerable rust formations appeared on the iron, which, when removed, left cavities 3 mm deep. This process continued, and it was to be expected that with longer use the tanks would finally start leaking; this was obviated by a protective coating. A thin layer of liquid cement was applied to the plates with a spray gun and, after this had hardened, it was covered by a thin layer of Lithurin, and I.G. Farbenindustrie product. This measure prolonged the life of the tanks considerably and was apparently used as a standard procedure in new construction.

11(b). Measuring Instruments

Messrs. Schaefer and Budenbergs' pneumatic valve indicator was used to measure the gasoline content in the tanks. The air in the copper pipes, which lead from the bottom to the roof of the tank and from there to the dial indicator, is compressed by the liquid rising from below. This air pressure is transferred on to the indicator of the apparatus and so gives a measure of the contents. Even small leaks in these pipes result in incorrect measurements. The bottom end of the pipes was frequently blocked by rust or dirt and then the whole measuring device was out of order: they were accordingly only used for rough estimates. Exact measurements were made by dipping.

11(c). The contents of oil tanks were measured with the aid of floats: these had eyes at the side which were guided by iron rods. If the level of the liquid fluctuated violently, as, for instance, during pumping, the float frequently came into an oblique position and jammed by the eyes, no measurements then being possible. This was overcome by replacing the iron rods by ropes kept taut by springs. The guiding of the float was thus made elastic, and no more jamming occurred.

11(d). Slide Valves.

The spindle and the interior of the valves in the petrol lines were made of iron because of the shortage of bronze. After a short time they became so rusty that, with a period of inactivity, they became fixed and could not be moved. The valve had to be taken out and the spindle and other parts cleaned or renewed. This caused considerable operational difficulties.

11(e). Pumps.

For gasoline, centrifugal pumps made by Amag Hilpert of Munich, type PF90 (three stage) were used. Through the, at times, unavoidable wear of the packing of the stuffing box, gasoline reached the thrust ball bearing and destroyed the lubricant resulting in the seizure of the pump. Ordinary roller bearing grease immediately dissolved and the bearing washed out. The above firm supplied a so-called petrol resistant grease, which withstood the solvent action of the gasoline for a longer time. Latterly the grease could not be supplied and no sample could be obtained in the plant. As a substitute "Calypsol" made by the Calypsolwerke, Düsseldorf, was used, this grease proving suitable.

Pumps which were not used for a long time frequently stuck. To prevent this, the supervising personnel ran the pump every day for a short time, the pump thus resting in a different position every day.

11(f). Pipe Lines

Because of the hilly nature of the land the pipes could not always be laid with steady rises and falls: high and low points were thus created. After pumping was completed some oil or gasoline always remained in the low points. This residue had to be emptied into barrels and these had to be transported to the respective tanks, an operation which proved very cumbersome. This situation was partly overcome by laying a small diameter pipe line from the low point to the next highest tank. With the aid of this line and an intermediate pump, the low points could be emptied. The emptying of the low points was a great obstacle to smooth working, especially in the oil tank farm and it grew in proportion to the number of different oils supplied.

11(g). Flame Traps.

The "Kito sieve" was very effective against explosions but owing to the difficulty of cleaning - they frequently became choked with dirt, rust etc., - operational difficulties were frequently encountered.

12. MANAGEMENT AND STAFF

12(a). The management of all WIFO depots was nominally in the hands of Wehling the general director of the company. He could, however, appoint any one of the three managers to be the "depot leader" this man being responsible for the smooth running of the depot, its safety etc. In general, the latter would be the man most reliable, politically, from the Nazi standpoint. The distribution of the staff is given below.

12(b) Works Manager - General Director Baurat Wehling (in Berlin).

(1) Deputy Works Manager Technical Manager (Depot Leader)	(2) Commercial Manager	(3) Tech.Chemical Manager.
ZAMMER	KEISER	DR.ROHRMANN
Deputy	Deputy	Deputy
LASS (Ing)	BAARS (business-man).	STOLTE (Tech. Chemist)

12(b) continued.

Techn. employees	9	Clerical employees	26	Chem.Employees	6
Skilled workers	60				
Semi " "	86				
Non " "	22				
Works Guard	35				
Foresters	12				
Trainees	-		2		5
TOTAL	226		28		13

TOTAL STAFF 267

In addition the Air Force had a resident liaison officer Sgt. Herst Schwarze.

12(c). The duties of the respective Managers were:-

(1) The Technical Manager was responsible for the entire technical management of the depot.

(2) The Commercial Manager concerned himself with the following items:

(a) Administration of the office, including such matters as materials, contracts including despatch, stores, personnel and pay department, works book-keeping and cashier.

(3) The Chemical Manager's duties included the entire laboratory management and the responsibility for quality control.

13. ACTIVITIES (GENERAL)

13(a). All supplies of raw materials were ordered through department MLV of WIFO H.Q. Mohrenstrasse, Berlin. This department evacuated to Derben, near Magdeburg on the Elbe when the bombing of Berlin began but later returned to Berlin and remained to the end. The head prokurist was Hartung.

13(b) Orders and order numbers for supplies to be despatched from the depot were sent in from Berlin up to 10 days ahead of the delivery date. The co-ordination officer of the Luftwaffe (all Haupt or Grosslager had such an officer) would then inform Hamburg that the material was ready and the requisite transport would be called forward; Hamburg was the movement control centre for the Hitzacker district, the areas depending on the set up of the Reichsbahn. All trains bore reference numbers and were accompanied by an officer in uniform who probably received orders direct from the resident liaison officer.

The personnel of the depot did not know, in general, the location to which the delivery was going.

13(c). Occasionally this depot supplied finished products to the big distributing firms such as D.A.P.G. Rhenania, Olex etc. Such deliveries were made mainly by water and were addressed to the resident military representative.

13(d). The Grosslager, in general, also supplied finished and partly finished products to the smaller depots (Heereslager). It was also stated that the Wehrmacht had small forward depots which were taken over from WIFO about three years ago. No blending was carried out at such depots, as they only dealt with barrels, cans and 1 litre flasks: it was suggested that these were called Nachschublager Two such stores were alleged to be in the vicinity, one at Bleckede and the other at Metzingen although the latter may only have been a dispersal store for Hitzacker during bombing.

14. ACTIVITIES (TECHNICAL)

14(a). Gasoline

The incoming gasoline supplies are listed below according to type.

CODE NUMBER	SUPPLIER
(a) Aliphatic type (iso-octane and similar)	
ET100	I.G.Farben Ludwigshafen
ET110)	" "
ET120)	" Leuna
)	" Hydebreck
	Hydrierwerke Scholven
(b) Gasolines with low aromatic content	
VT702	I.G.Farben, Leuna
VT705	Hydrierwerke Scholven
VT706	Hydrierwerke Welheim
VT707	Gelsenberg Benzin A.G.
VT708	Hydrierwerke, Pölitz
VT810	Brabag Magdeburg, Brabag, Böhlen
VT811	Hydrierwerke, Wesseling
VT812	" Brüx ?.

(c) Gasolines with high aromatic content (former DHD gasolines)	
VT330	?
VT340	Moosbierbaum ?
VT342	I.G. Farben, Leuna
VT345	Hydrierwerke, Scholven
VT348	Hydrierwerke, Pölitz
VT350	Donauchemie ?
(d) Aromatics	
VT302	Benzol-Verband, Bochum
VT303	WIFO, Derben
(Kyböl)	I.G.Hüls and Schopau

The incoming low aromatic gasolines could vary between 68 and 76 octane number (motor method) but did not normally exceed the range 72 to 74 O.N.; the ET110 was alleged to have an octane number of 92 - 96 M.M. The incoming supplies were blended and leaded to make the finished aviation gasolines B4, C2 and C3; the blending instructions had been destroyed and could not be compiled from memory, but it was stated the following octane number requirements had to be met, B4 - 89 O.N., C3 95 O.N. Benzol and Kybol were only used occasionally being added when it was desired to increase the aromatic content. The maximum lead content allowed was 0.012 vol.% but this was increased towards the end of the war to 0.014 to 0.015 vol.%. One rail tank car of MAI had been prepared, this being an experimental blend containing 2% aniline and 0.016% TEL and was supposed to have been used by Fighter Aircraft.

14(c). The tests applied to both incoming and outgoing products were the same, namely, specific gravity at 15°C; refractive index at 20°C; iodine number; Reid vapour pressure; copper corrosion; composition - aromatics, naphthenes paraffins (BVM method); Aniline point; low temperature stability, turbidity and crystallisation; gum content (with benzol after aging); distillation (reaction of residue); lead content and octane number.

14(d). Asked about the use of the Research method of determining octane number it was stated that this method had only been used for Army fuels and that even for that purpose it had been abandoned in 1943. No reason could be given for this change.

14(e) Lubricating Oils.

The following aviation oil blending components were supplied to Hitzacker:

(a) Viscous Oils (Synthetic oils 42 - 45°E at 50°C).

SS906	I.G.Farben, Leuna

(a) Viscous Oils (continued)

SS906G	I.G.Farben, Schkopau
SS1006	Rhenania-Ossag, Hamburg
SS1106	Norddeutsche Mineralölwerke, Politz.

(b) Thin oils (Natural oils 7°E at 50°C)

SS407	Odenfurther Mineralölwerke Czechoslovakia (not used)
SS607	Rhenania-Ossag, Hamburg
SS807	Nerag-Misburg

(c) Aero-Engine Running Out Oil

T42 or Ul	Rhenania-Ossag, Hamburg

14(f). The lubricating oil components received were blended to produce S3 (formerly called Rotring), aviation oil the finished oil being made by blending 50% of SS906, 1006 and 1106 and 50% of SS407, 607 or 807. The blend was adjusted to 16.8 - 18.5°E at 50°C. The other tests applied to both incoming and outgoing oils were specific gravity at 20°C; refractive index at 20°C; Viscosity at 20°C, 50°C, 90°C, 100°C,m, pole height, VI; flash point; neutralisation number; saponification value; Noack test; ash; sediment; asphalt; rosin, pour point and water content.

14(g). Certain aviation oils were received already blended being usually proprietary products from individual companies; they are given below:

Aero Shell Heavy	Rhenania-Ossag
Aero Shell Medium	" "
Rotring	(in part from Nerag, Misburg)
Grünring	(probably Intava)
Intava 100	Intava

14(h). Lubricating Oils for the Army

The following oils were received as finished products:

(a) Forces engine oil (summer) from:
Rhenania-Ossag, Hamburg
Vacuum Oil A.G. Bremen
" " " Dzieditz
I.G.Farben, Ludwigshafen
Nerag, Misburg

14(h) continued.

Gasolin, Dollbergen
Raffinerie Apollo, Pressburg.

(b) Forces engine oil (winter) from:-

Rhenania-Ossag, Hamburg
Vacuum Oil A.G. Bremen
Nerag, Misburg
Gasolin, Dollbergen

14(j). Other oil components, with the supplying firms are given below:

Nerag Neutral	Nerag, Misburg
Synthetic oil 3500	Ruhrchemie, Sterkrade-Holten
Machine Oil ZM65	Brabag, Zeitz
" " ZH25	" "
Russian machine oil	Derop ?
" cylinder oil	". ?
Motor Oil ASV 12/50	Property of the ASV
Motor Oil ASV 8/50	Property of the ASV
Rumanian Spindle Oil Distillate.	For the firm Schindler, Hamburg.
Standard 10	?
Elsner 808	?
Raffinate L	?
Motor oil Yacco	?
Penna Brightstock (Italian)	

14(k). In addition to the above finished oils received from distributing companies a certain amount of the following oils were blended at the depot.

General purpose engine oil (not used later).
Forces engine oil (summer)
" " " (winter)
" " " (tropics)

The tests on the Army oils were the same as those given above for aviation oils.

14(1). In addition to the incoming and outgoing products given above large quantities of captured Italian stocks in barrels and cans was stored about the depot. It was stated that barrels with identical markings were filled with different oils and should not, therefore, be taken at their face value, a great number of the barrels wontained castor oil, glycerine, ethylene glycol. Several barrels were filled with German Aero engine oils which had been delivered to the Italian forces such as Aero Shell Heavy, Aero Shell MMSH and Intava 100.

15. THE LABORATORY

The laboratory occupied the whole of a fair sized, one storey building. It was divided into various sections dealing with fuels, lubricants, special products, an analytical department and an engine test section. Whilst it was well equipped for the work undertaken it could not be described as elaborate and obviously no research work of any note was carried out. The entire laboratory was inspected and test details sought of any test of significance.

15(a). Fuel and Oil Section.

The laboratory was equipped to carry out all inspection tests on fuels and lubricants most of the test methods being standard German practice. Where this differs from current British or American method brief details are given below.

15(b). Analysis of Gasoline

(1) Two methods were used for this purpose, the DVL and another, presumably the BVM method. In the latter 20 ccs. of fuel are placed in a 100 cc stoppered graduated tube (similar to a burette) with 60 cc of Kattwinkel acid, a mixture of sulphuric acid and phosphorus pentoxide. After shaking in a machine for 15 minutes the decrease in volume of the gasoline is measured, this giving the volume percentage of aromatics and olefines. The olefines were separately determined by the iodine or bromine number.

(2) Stability of Gasoline: This test was to all intents and purposes similar to that used in Britain and the U.S.A. but the interpretation of the results was somewhat different. 250 ccs. of gasoline were used, placed in a bomb and heated for 4 hours at 100°C under a pressure of 7 atmospheres of oxygen. The oxygen absorption curve was taken but little use was made of it, the gum being determined after oxidation as being of more significance.

(3) Low Temperature Tests: The benzol received should have a crystallization point below -10°C and the finished aviation fuel below -60°C. The method of test was not novel.

(4) Noak Vaporisation Test: This test, which was claimed to be more significant than the flash point, measures the volatility of the oil when heated under specified conditions, viz. 250°C for 1 hour under a reduced pressure of 20 mm of water vacuum.

(5) Water Estimation: A fair amount of work had been done on and with the Dietrich and Conrad magnesium nitride test; it was alleged that it was only used when difficulties arose. The method itself appears to give some trouble since it is essential, and apparently somewhat difficult, to determine a blank on the magnesium nitride.

(6) Four Ball Machine: The machine was a standard version of its type but was alleged to be the only one in any WIFO laboratory and was accordingly used to test products for any WIFO depot requiring this test.

15(c) Analytical Section

There was little if anything of special importance in this Section, the chief work being water analysis and lead determinations for which the T.E.L. was precipitated with bromine and determined as lead sulphate.

15(d). Special Products

This section of the laboratory was devoted entirely to work on T.Stoff (85% Hydrogen Peroxide) including corrosion tests on aluminium.

15(e). Engine Test Section

Originally this section contained the following engines:

2 x C.F.R. engines (one removed) *
1 x I.G. Prüfmotor
1 x DKW water cooled ring sticking test
1 x DKW air cooled (removed by U.S. tropps for use in a lighting set)
1 x BMW 132N ring sticker in course of erection *

* Parts of these engines were located in a barn near Herr Stoltes residence.

No details were sought on any of the above as sufficient information is already available.

16. RESEARCH AND CORRELATION WORK

Little in the way of real research work had been carried out but a certain amount of work outside the ordinary routine had taken place. The items are listed below:

16(a) Compiling a viscosity temperature chart.

16(b) The Influence of Oppanol on the viscosity-temperature behaviour

This work was carried out for the Army who had hoped to use Russian oils of poor viscosity index. The addition of Oppanol B15 was allowed up to 0.6% and work had been done to investigate this effect. A method was given in Army specifications for estimating such additions of polyisobutylene using ethyl acetate.

16(d) Correlation tests for viscosity determinations and Gasoline Test Methods.

16(e) Tests on the water content of lubricants at start of clouding.

16(f) Storage tests with motor fuels

16(g) Tests with the Indiana oxidation test apparatus.

It was stated that this test was found to be of little use.

16(h) It was alleged that the results of all the above work had been destroyed and details could not be given from memory.

16(j) Two pieces of apparatus found lying in a corner proved to be of interest. The first was a Kriegsmarine corrosion test, designed by Wellman in which oil or fuel was pumped round on to a suspended steel plate. This test had never been used at Hitzacker and little details of it could be obtained. The second piece of apparatus was of more interest, being an attempt by Rohrmann to design a laboratory ring sticking test. This consisted of a steel rotor, which was shaped like a very coarse, square-shouldered screw thread, and which fitted, with little clearance, in a steel cylinder. The rotor was mounted in small ball bearings in the lid and at the bottom of the cylinder. In operation the outer cylinder was heated to 250-300°C and oxygen was passed upwards through the spiral of the rotor. The test oil was allowed to drip on to the top of the spiral and flow counter current to the oxygen. The rotor was revolved by belt drive with a pulley at the top, and the torque measured on the outer cylinder. The time was taken for the torque to increase suddenly due to the rotor sticking to the cylinder by virtue of the oxydised oil products formed. This test appears to have possibilities but would need to be correlated with engine tests.

17. STOCKS AT HITZACKER

In Appendix I and II are given two stocktaking reports showing the stocks at the dates given.

18. POSSIBILITY OF RESUMING OPERATIONS

A translation of a report on this subject by Zanner is given in Appendix III.

19. DOCUMENTS

All documents relating to the operation of the plant were alleged to have been burned by the retreating German Army who had had control of the plant for about a fortnight. Also certain essential bearings from parts of the plant had been buried, and would not, apparently, be easily located. Such documents as were found are listed in Report No.2. These might prove of value if details are required of constructional methods for tanks and other facilities.

20. BOMB DAMAGE

The original plant was almost undamaged by air attack but the fields adjacent to the gasoline tank farm were well cratered. The extensions, including the new blending blocks - one of which had received a direct hit - and the new gasoline siding were badly damaged. It would appear that this new construction, being readily visible, had attracted most attention.

21. CONCLUSION

21(a) The whole plant was well built and situated to make most use of natural cover and transport facilities. It is noteworthy for the large lubricating oil storage and stocks. Certain non-petroleum stocks such as alcohol and amines were alleged to have been held for the I.G. Farbenindustrie and their use was not known.

21(b). If it was required, there is no doubt that the plant could be put into operation with little delay once certain repairs had been effected.

21(c). The investigation of this plant serves to confirm the importance of these WIFO depots in relation to supply of fuels and lubricants to the German armed forces but whilst information is now available showing the initial storage and blending set-up, little is yet known of the activities of WIFO in relation to supplies to the more forward areas.

21(d). Classification of Information

The type of information obtainable from the WIFO "Hauptlager" as at Hitzacker, is of significance as it illustrates and important part of WIFO activities, typifying the latter plant where handling of aviation products in bulk was the main activity as compared with the smaller WIFO "Heerestanklager" at Heiligenstadt and Eickeloh, etc., where preparation of packages and filling and packing of Army fuels and lubricants was the main activity.

The information on product utilization and performance is not, to any large extent, obtainable from the WIFO installations. In view, however, of the statements obtained on questioning WIFO representatives, primarily for the purpose of learning facts about German product quality, it became evident that much information was coming to light regarding WIFO activities and organization that would be of interest to the Army and Ministry of Economic Warfare; hence this report.

22. MISCELLANEOUS NOTES

22(a) British Admiralty Investigation

A representative of NID 30, namely Lt. N. Cameron, R.N.V.R., was visiting the WIFO Hitzacker plant and had arranged to remove WIFO laboratory and engine test equipment to the Admiralty Experimental Laboratories, West Drayton.

Some lack of co-ordination between CIOS investigations and the Admiralty was, therefore, evident. There is, however, much to be said in favour of an arrangement whereby one or more Service representatives continuously follow up investigations instead of relying on spasmodic visits by a variety of part-time representatives.

22(b). Wehrmacht Demolition

Explosive charges were still in place in many of the tank pits at Hitzacker, and a number of demolition stick bombs were noticed scattered about the plant. The attention of these was drawn to the Military Governor at Dannenberg.

22(c). Sonderstoff-Lager

A small installation, situated outside the main installation for Sonderstoff products, was not investigated by the party as its presence was only detected from a plan of the plant found, after the team had left Hitsacker, among the captured documents. Its locality may be seen on the plan accompanying this report.

HLW/BMO.

APPENDIX I

REPORT ON THE VISIT TO THE "WIFO" WIRTSCHAFTLICHE FORSCHUNGS GESELLSCHAFT m.b.H. HITZACKER INSTALLATION ON THE 26th. MAY, 1945

Discussion with the depot leader Herr Zanner.

Stocks on hand according to the position on 26.5.45

ET110	Aviation Gasoline	ca	50 Brls.
VT348	" "	ca	50 "

were exhausted on the directions of the German district (Kreis) committee, Leader Herr Kuhlmann, Dannenberg, for food transport. All remaining gasoline tanks are empty except for the container No.10 which contains test gasoline, ca 180 cu.metre, which likewise, on the direction of the Kreis committee will be used for blending with spindle oil for diesel fuel. One can reckon on a production of 1800 iron barrels.

Pure Methanol 1400 t.

used for the preparation of propellants, are useable for the production of Formamint (formaldehyde).

ENGINE OILS (must be put through the filter press as required).

Aviation Engine Oil S3 (18°E @ 50°C)	ca	2400 t.
" " " No.1 (tank buried)	ca	2800 t.
" " " (old T42) thin oil	ca	414 t.
" " " SS407 (thinnish oil) (mineral oil comp.)	ca	3100 t.
" " " SS1106		./.
Forces engine oil (summer)	ca	1000 t.
" " " (winter)	ca	1100 t.
" " " preblend L	ca	420 t.
" " " Yacco	ca	404 t.
Synthetic oil 3500	ca	3000 t.
Gear Oil (Engine oil for Vario gears preblend)	ca	360 t.
Penna Bright Stock	ca	432 t.
Mixed or blended oil	ca	300
Lead tetraethyl fluid blue	ca	350 brls
" " " green	ca	96 "
Fluorol (dye for gasoline)		?
Sudan yellow	ca	100 Kg.

A.S.V. STOCK

Engine Oil 8/50 26105	390.019 kg.
" " 12/50 26110	1.998.972 kg.
Spindle oil distillate 01235 (was used for the preparation of diesel fuel, perhaps 10 t.(?) is left).	(512.997 kg.)
Captured oil, viscosity 18°E @ 50°C	1.007.708 kg.
./. for the Navy ?	500.000 kg.
	507.708 kg.

More accurate stock can be established later.

Unsorted oil RLM	1.044.786 kg.
Aviation used oil concentrate	100.000 kg.

Further, some unimportant, captured lubricating oil in "Wittrese".

EXTRANEOUS GOODS

Optan 35 (container 26 estimated, perhaps leaking)	408 t.(?)
Roxyl G. (solvent benzol, synthetic)	1016 t.
Opthyl 70 (containing 30% anaesthetic ether)	190 t.
Opturan 60	173 t.

18 barrels of castor oil filled partly without bungs lie in the wood.

Ca 1000 barrels of glycerine and 80 barrels of benzene have run out due to shooting or breakage by the Wehrmacht or the Americans.

WIFO Hitzacker get a copy of this preliminary report in order to record alterations.

(sgd) Juling (?)

Hamburg the 30.5.45.
J/Ca. Distribution:

APPENDIX II

STOCK AT HITZACKER, WIFO

GASOLINE

1) Gasoline for the Air Force		-
2) " " " Army		-
3) " " " Industry		-
4) Test-gasoline		174.410 kg.
Total		174.410 kg.

OILS

1) For the Air Force

a. finished aero engine oils			
S3	2.594.954	2.594.954	
b. aero-engine oil components			
Thin oil SS407	3.159.244		
Thick oil SS1106	266.936	3.426.178	
c. aero-engine running out lubricant			
U1	423.276	423.276	
d. other oils			
Captured oil, visc. 18/50	799.903		
Not graded oils, Air Ministry	1.036.249		
used aero-engine oil concentrate	92.496	1.928.648	8.373.056 kg.

2) For the Army

a. Forces summer engine oil	860.635	860.635	
b. Forces winter engine oil	1146.148	1.146.148	
c. Components			
			2.066.783 kg.
carried on			10.439.839 kg.

carried forward			10.439.839 kg
c. Components (continued)			
Forces engine oil, Preblend	418.167		
Engine Oil Yacco	402.308		
Synthetic oil 3500	3.590.970		
Engine Oil, Preblend Vario	370.712		
Blended Oil	396.459	5.118.652	
3. For the Industry			
a. Own oils			
Penna Bright Stock	431.478	431.478	
b. Oil: not WIFO property			
engine oil ASV/8/50	382.256		
" ASV/12/50	1.961.147		
spindle oil ASV	422.351	2.765.754	8.315.884 kg.
TOTAL			18.755.723 kg.

Keiser & Dr. Rohrmann

Hitzacker 10th July, 1945.

APPENDIX TO STOCKTAKING

The viscosities are at 50°C.

Flugoel S3: Finished aero-engine oil 17-19°E, can be blended for industry as motor or machine oil. Component for it is the Spindle Oil ASV, and the appropriate thin oil component would have to be procured from other firms.

Flugoel U1: Thin oil component for machine oil.

Flugoel SS407: Former Flugoel component, ca 7°E, suitable as machine oils. Suitability for engine has yet to be practically proved.

Flugoel SS1106: Former Flugoel component, from 42-45°E. Blend with Thin oil for engine resp. machine oil.

Forces engine oil (summer): Suitable as summer engine oil.

Forces engine oil (winter): Suitable as winter engine oil.

Preblend L, Forces engine oil) Can be used as
Engine Oil Yacco) viscous
Preblend Vario, engine oil) engine or car oil.

Synthetic Oil 3500 : 6-7°E. Suitable as machine oil after blending with ca 50% straight oil of equal viscosity. Use not recommended. Also an engine oil component.

Penna Bright Stock: ca 35°E. Use for blending. Liable to duty, when used tariff to be paid.

Mixed Oil (Mischoel): Residues of different oils from pipes. Tank content not homogenous, will probably give a motor or machine oil of 6-7°E.

Engine oil 8/50) Engine oils,
" " 12/50) Property of the ASV

Spindle Oil - Distillate: Thin oil component, Property of the ASV.

Captured oil 18/50: Use only after blending.

Ungraded oils: 16-20°E: Use after blending as engine or machine oil.

Used aero-engine oil concentrate: Reclaimed aero-engine oil 18-20°E, can be worked up to engine resp. machine oil.

Test Petrol: Only for blending with Diesel fuel.

TRANSPORT FACILITIES:

Oil: Tanker, Barrel, R.T.W.

Petrol: " " "

Ciltank: 600 cu.m. capacity

Petroltank: 3300 cu.m.capacity.

HITZACKER, 29th June 1945, PLOTE (10 July 1945)

APPENDIX III

Wirtschaftliche Forschungsgesellschaft m.b.H.
Ausenstelle Hitzacker
Dost: Hitzacker a.d. Elbe.

To the:
Kreis Committee,
Dannenburg.

Subject: The Possibilities of Starting up the WIFO Depot for Fuel and Lubricant Storage at Hitzacker.

The Grosstanklager of the Wirtschaftliche Forschungsgesellschaft m.b.H. Berlin at Hitzacker lies some 3 km. west of Hitzacker between the Elbe and the railway line from Wittenberge - Lüneberg, thus possessing water and rail connections. The place is specially suitable for fuel and lubricant distribution. Sea transport can be transferred to lighter at Hamburg and can then be brought to Hitzacker.

The storage consists of 30 underground fuel containers of 3300 cmb. with barrelling facilities and 78 underground oil containers of 600 cmb content. For storage 20 fuel containers and 20 oil containers are available at present, the remaining containers are partly damaged or filled. Thus some 60,000 cmb of gasoline or diesel oil and some 12,000 cmb of oil can be stored.

A possibility exists at present, of transferring to and from storage only by water if large quantities are to be handled. Smaller quantities can be transferred in tank wagons or barrels. The filling and pumping facilities at the station, as well as the siding are completely destroyed by bomb attack. Each tank has a special pump, so that the transfer in or out of tank wagons, barrels and the like is possible directly from the tanks.

Near the storage, the carrying out of blending is possible. For the examination of the stored and worked up fuels and lubricants a laboratory exists with all necessary facilities available. In this laboratory, if necessary, other materials such as food and the like can be investigated.

With the installation of our mechanical and electrical workshops, machines etc., as well as automobiles and electrical apparatus can be repaired and also batteries can be charged.

A diesel plant can, in emergency, put 200 kw. into the public network, as soon as small repairs are made.

Wirtschaftliche Forschungsgesellschaft m.b.H.
Hitzacker Depot.

Fig. 1.

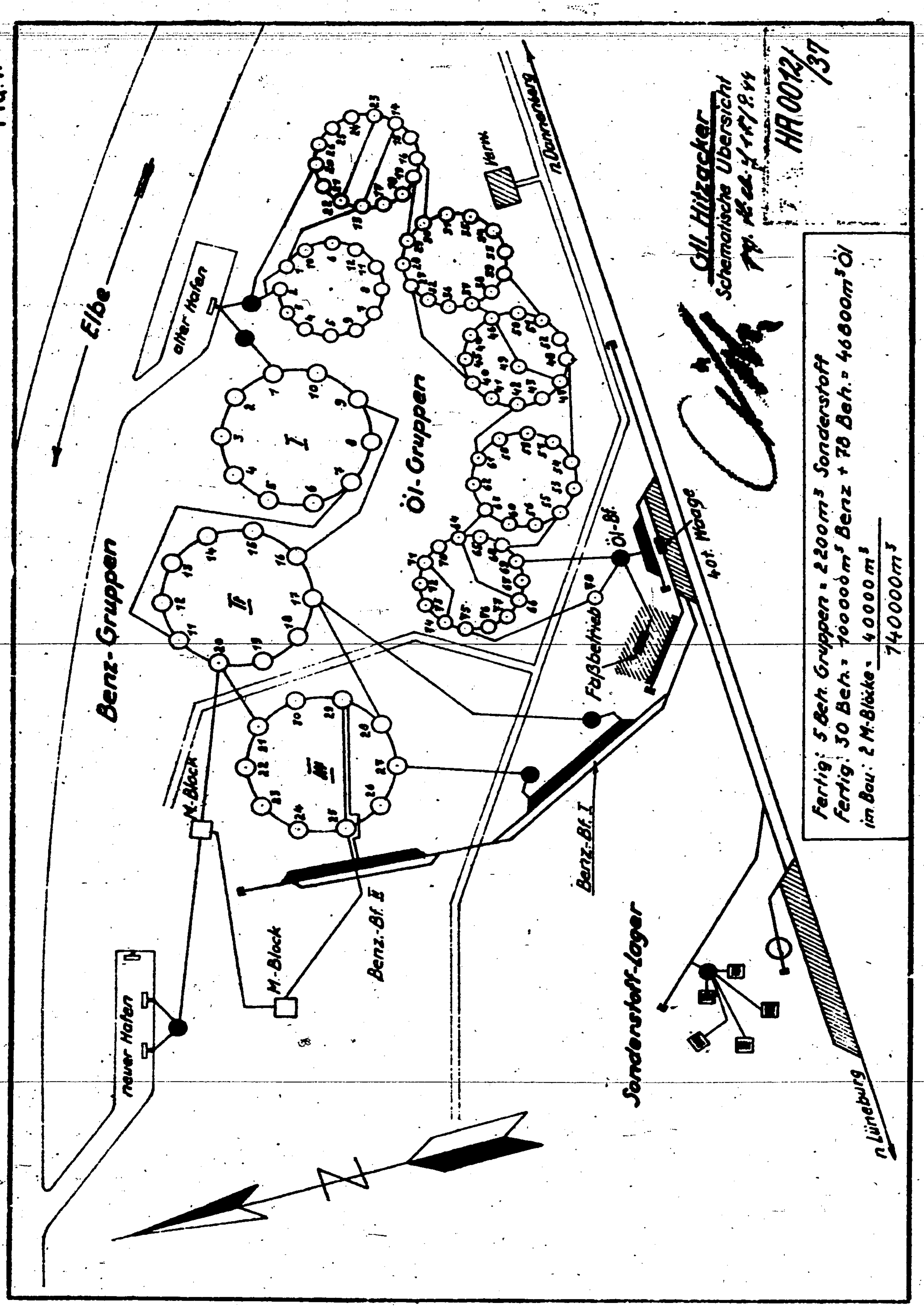
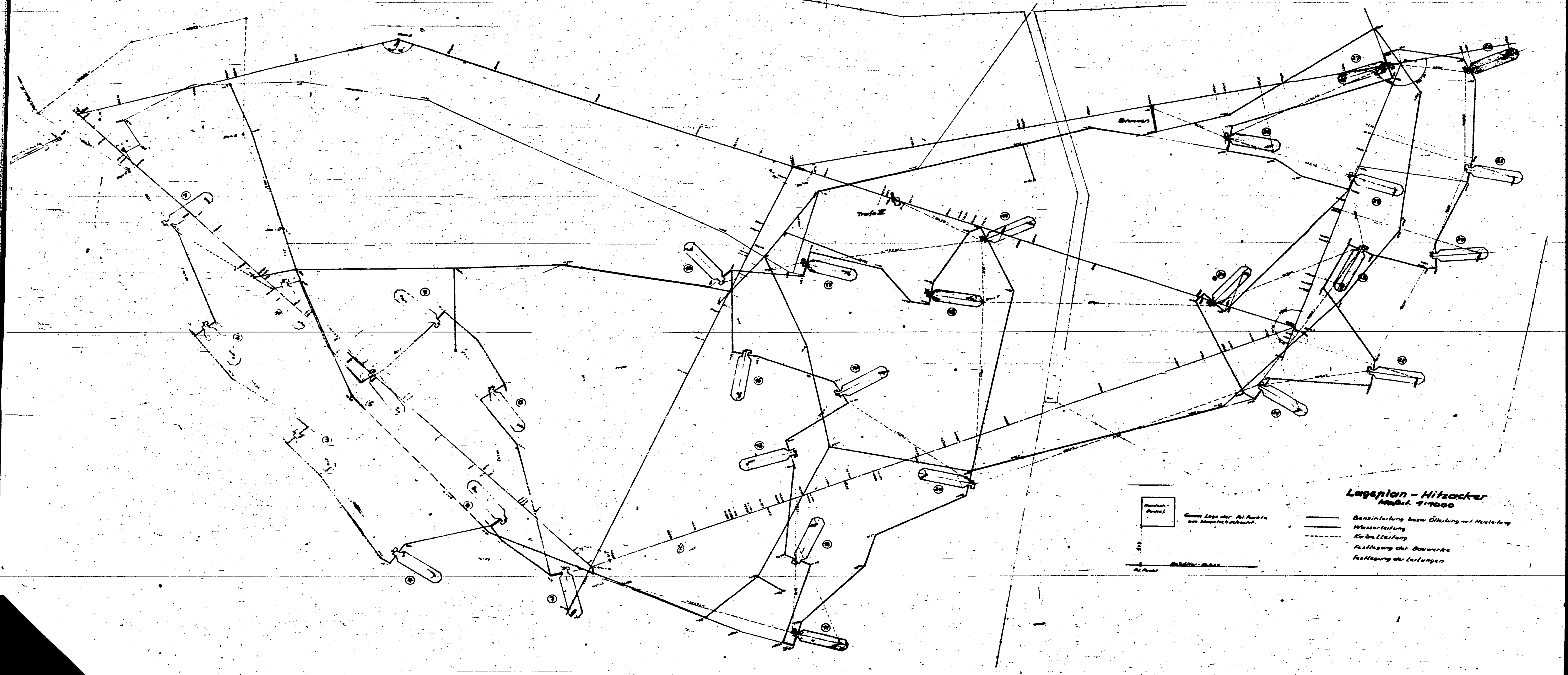
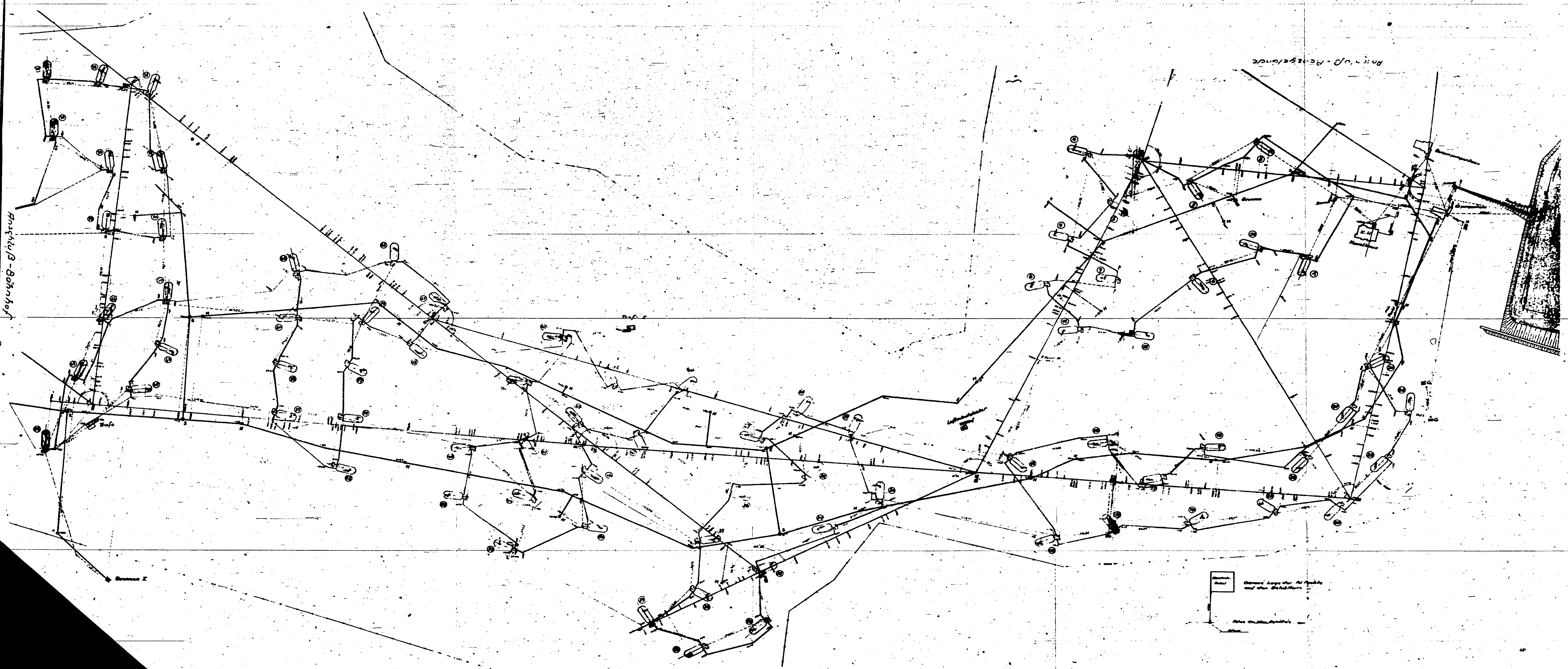


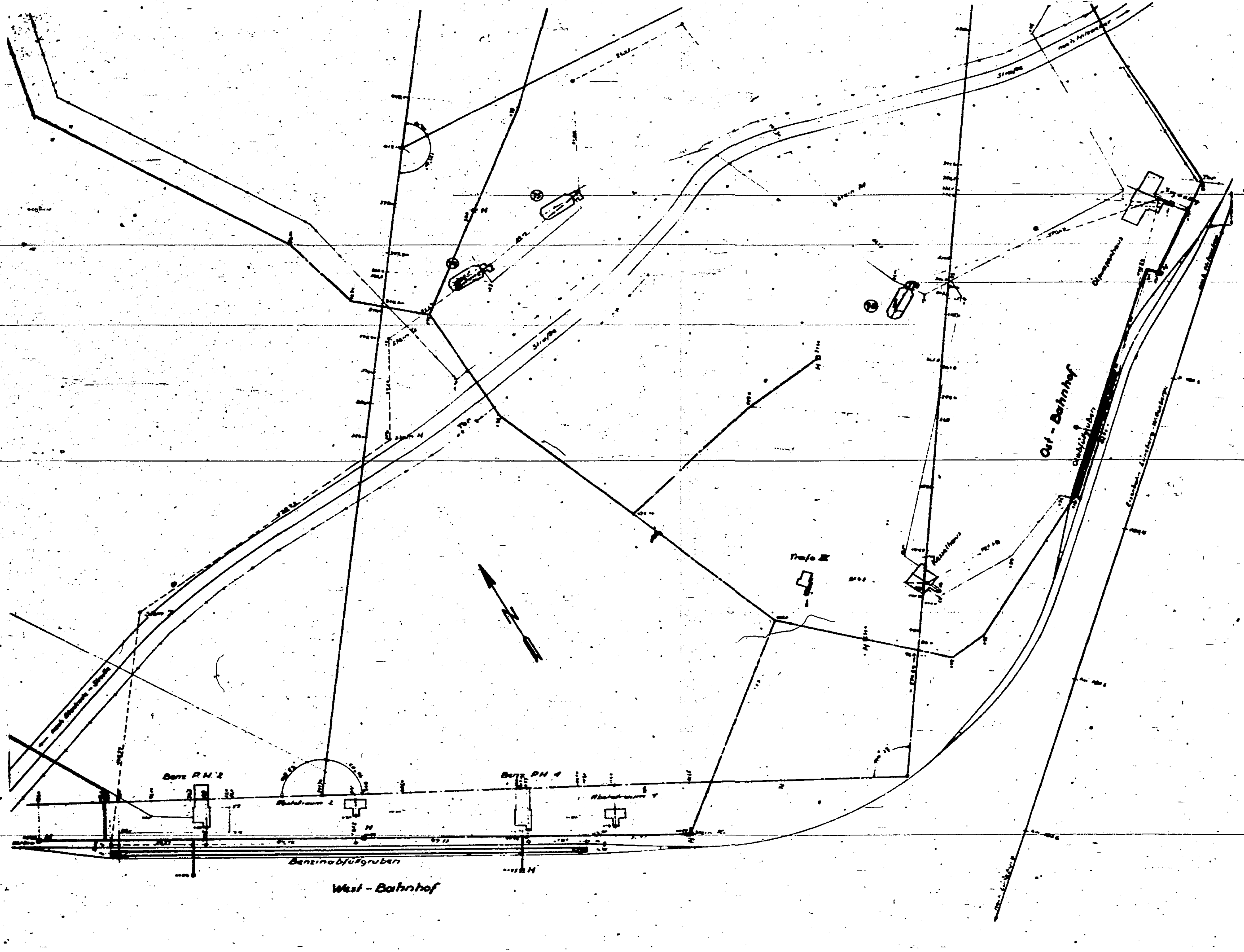
FIG. 2.



Lageplan - Hitzacker
Maßst. 1:1000

Fig. 3



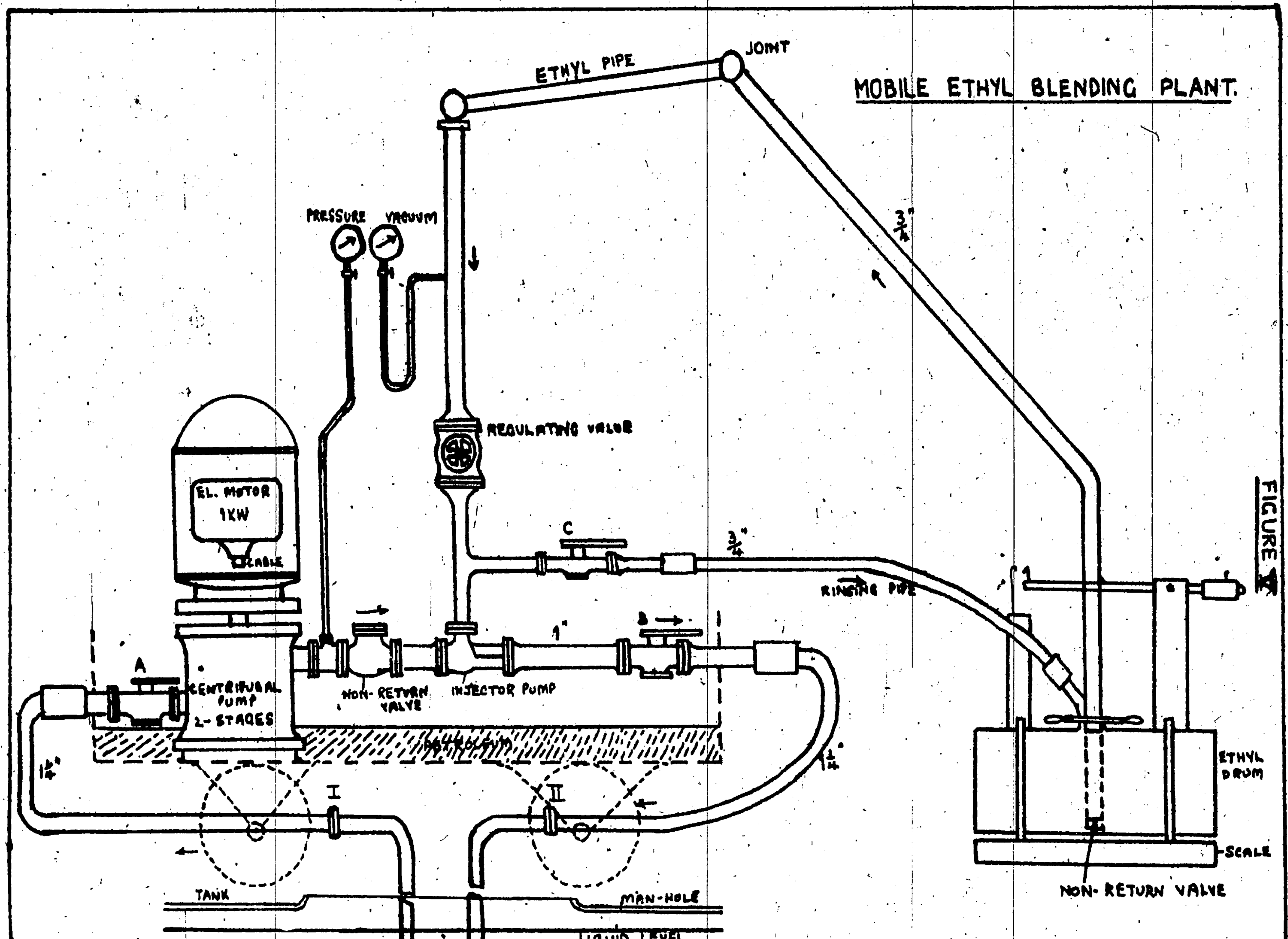


Ost - Bahnhof
Ölabfüllgruben
Eisenbahn
Trafo III
Ventilhaus
Benz. P.H. 2
Benz. P.H. 4
Abstellraum 2
Abstellraum 7
Benzinabfüllgruben
West - Bahnhof
Straße
N
H

FIG. 4.

Fig. 5.

MOBILE ETHYL BLENDING PLANT.



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MINISTRY OF FUEL AND POWER AND
BRITISH INTELLIGENCE OBJECTIVES SUB-COMMITTEE

Technical Report on the Ruhr Coalfield

BY A MISSION
FROM THE MECHANISATION ADVISORY COMMITTEE
OF THE MINISTRY OF FUEL AND POWER

Great Britain

VOLUME I

LONDON: HIS MAJESTY'S STATIONERY OFFICE
1946
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Report

TO THE RIGHT HON. EMANUEL SHINWELL, M.P.,

AND THE BRITISH INTELLIGENCE OBJECTIVES SUB-COMMITTEE

BY

A TECHNICAL MISSION TO THE RUHR COALFIELD

FROM THE MECHANISATION ADVISORY COMMITTEE

OF THE MINISTRY OF FUEL AND POWER

Members of Mission

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13th February, 1946.

Contents

VOLUME I

CHAPTER IV (Contd.)

✓ Volume II, containing Figures 1-195, will be published as soon as possible.

Volume III, containing Appendices 1-30 and Reports by investigating teams of specialists, organised on the basis of the Mission's recommendations, will be published later," A. p. v.

List of Tables

Report of a Technical Mission to the Ruhr Coalfield from the Mechanisation Advisory Committee of the Ministry of Fuel and Power

INTRODUCTION

1. WE were appointed to visit the Ruhr Coalfield with the following terms of reference :—

> "To examine and report upon new developments in coal mining technique in the Ruhr Coalfield, as under :—
>
> (*a*) Coal face Equipment, and in particular Power Loading devices for Longwall Faces and Coal face Lighting ;
>
> (*b*) The system of Driving Roadways in Stone ;
>
> (*c*) Underground Transport, with special reference to Locomotive Haulage ;
>
> (*d*) Winding and Shaft Layout, with special reference to Koepe Winding ;
>
> (*e*) Any Special features of Surface Arrangements generally."

2. The visit took place between the 11th August and 3rd September, 1945, when conditions for investigations in this Coalfield were difficult. During this period we also paid a very brief visit to the Dutch Coalfield where, owing to the recent German occupation, we found that there had been no important developments. We have, however, made use of certain drawings obtained in Holland to illustrate methods common to both Coalfields. In all, fourteen mines were visited and nine underground inspections were made.

3. The North German Coal Control put all the facilities of the research organisation of the BERGBAU-VEREIN (the former German Coal Owners' Association) at our disposal. The personnel of this organisation had been captured and their offices, together with the most important plans and technical data, had been discovered intact. Without this assistance we could not possibly have covered so much ground in so short a time, nor could we have secured the valuable drawings, technical documents and statistics upon which this report is based.

4. In our Preliminary Report, we recommended the formation of teams of technicians to report in detail on certain of the more important developments. The Reports of these further visits will form valuable appendices to this main report. Further, we recommended the evacuation to this Country of certain mining equipment for examination and test. We have since recommended that a few specified German technicians should be brought to this Country for interrogation.

5. This Report, together with numerous Appendices, describes, within our terms of reference, what seemed to us to be the best mining practice in the Ruhr, with particular reference to methods, equipment and technical developments new, or little known, to Mining Engineers in this Country. We are fully aware that the application of many of the Recommendations is only possible economically where there are sufficient reserves of coal available, and where mining conditions justify their adoption.

6. We should like to emphasise that, within recent years, very few mines have been completed or modernised in the Ruhr, and it should be understood beyond doubt that the mining practices chosen by us for description in this Report are not applied generally in the Ruhr.

7. We also desire to point out that, in the short time at our disposal, even with the masses of technical detail collected by us and aided by our individual prior knowledge of the Ruhr Coalfield, it was not possible to find confirmation in practice of all the detail given herein. The Report is, however, as comprehensive and as accurate as it can be from the information in our possession.

8. We found little in the Ruhr Coalfield which was not in keeping with the information given in the Report of the Technical Advisory Committee and, as will be seen, we were able to collect some details of the more important features recommended, which we believe will assist their implementation.

9. We are very grateful to the officials of the North German Coal Control for the advice given and facilities placed at our disposal, and also to our friends in Holland who received us in abnormal circumstances.

10. We wish to record our thanks to the numerous translators who have been most painstaking in their task of handling the large volume of German documents. Further, we owe our sincere thanks to the Staffs of the firms with whom we are individually associated for the excellence of their work in preparing numerous illustrations, tables and typescript, and also for their accurate transcription of text and metric measure so necessary to this Report. Finally, we wish to express our indebtedness to the various officials of the Ministry of Fuel and Power who have assisted us throughout our work ; particularly we would mention Mr. C. S. Stammers, who was seconded to us as Secretary and who has carried out a difficult and laborious task with commendable efficiency.

CHAPTER I

Physical Conditions

11. The Ruhr Coalfield extends for some 1,550 sq. miles, although part of this area is not coalbearing. The depths at which the coalbearing measures are tapped vary over the Coalfield. At the outcrops, the gradients are generally very steep. In some areas the coal measures are overlaid by thick beds of chalk, and in others, by running sand. In one case brought to notice, there was sand to a thickness of 130 yards in a total overburden of 370 yards. The present maximum depth of working and winding is about 1,100 yards, the average being about 760 yards.

12. It was stated that there is an average of 2.6 per cent. of coal in the strata, with 4 per cent. to 8 per cent. of coal in the coalbearing measures. The total thickness of workable coal to a depth of 1,100 yards varies from less than 10 feet at the Niederrhein Mine to 197 feet at another mine. The average thickness of

seam being worked is about 4 ft., the minimum being 2.3 ft.

13. The seams vary in hardness to a considerable extent, the Fat or Coking Coals (as well as some of the Gas Coals) being generally very soft, the Gas Flame or Steam Coal and anthracites being harder. The coal seams are classified in descending order as Gas Flame Coals, Gas Coals, Fat Coals and Anthracites. The Gas Flame Coals are house or steam coals, and the Fat Coals are, of course, of the coking variety. The roof strata associated with the Gas Flame and Gas Coals are generally softish clay and bind, the floor being reasonably hard. The Fat Coals have stronger strata, sometimes sandstone bands, and the Anthracites even better conditions.

14. As the pressure induced in the strata at depth cause face and road working conditions to deteriorate as cover increases, it can be seen that the best conditions usually occur in shallow anthracite and the worst in deep gas flame coal working. Considerable repair work is necessary to maintain long roadways in the seams, and maintenance difficulties have increased with depth.

15. A cross section on any line in the field shows considerable major and minor faulting and strata distortion with a resulting variation in seam gradients as in Fig. 1. The line of level course is generally winding and disjointed. For statistical purposes, and in order to compare mine with mine, the coal seams are divided by gradient into three categories : 0°–25° (described as the flat formations), 25°–35° and 35°–90°.

16. The division at these three gradients is based on the performance of the shaker conveyor.

17. At gradients 0°–25° power is required to convey material by shaker conveyor ; at gradients 25°–35° the coal slides on a shaker conveyor by its own momentum, but power is required to convey most kinds of packing material ; above 35° all material will slide and the conveyor is used as a chute. Of the Ruhr production, 73 per cent. comes from the first category, 9 per cent. from the second and 18 per cent. from the third.

18. No accurate conception was gained of the average quantity of water pumped per ton of coal produced. In the areas overlaid by running sand, great care is taken to seal the shafts and to leave sufficient barriers in the upper workings to prevent seepages or inflows. The natural drainage system resulting from the general layout of workings keeps the faces and roadways relatively dry.

19. The statement was made that the quantity of firedamp given off varied from about 130 cub. ft. to 1,600 cub. ft., with an average of about 1,000 cub. ft., per ton of coal. Roughly half of this quantity is emitted at the coal face ; the remainder comes into the air current in the roadways in the seams. It is not unusual to find water-gauges as high as 18″ due to ventilation restrictions in the main shafts, underground level drifts and staple shafts. A ventilation plan of the Friedrich Heinrich Mine is shown in Fig. 2.

20. It was gathered that spontaneous combustion was occasionally encountered in the wastes of longwall workings in certain seams. This was usually associated with the roof strata. No special preventative measures were noted.

THE HORIZON SYSTEM OF MINING

21. Coal mining in the Ruhr was begun in an area where the coal measures rose steeply to the surface. To the present day, this fact has had an abiding influence on the general layout of workings.

22. In earlier times, shafts were sunk to what was then considered to be an economic depth, and level cross-measure drifts were driven at right angles to the dip and rise, which cut the seams in proximity to the shafts ; thus, level haulage-ways were formed from which coal production was carried on to the rise. The coal lying at greater depth was eventually won by sinking small staple shafts of anything up to 130 ft. in depth, and cross drifting again, or by sinking new and deeper shafts from the surface.

23. This level working or horizon mining system is now practised in all Ruhr coal mines ; the distance between levels is commonly from 250 to 500 ft. and, in a few cases, as much as 650 ft. As far as could be gathered, the location of levels or horizons is not determined by any general rule. The deciding factors in this respect are the incidence of groups of seams, the quantity of coal available in a horizon, the quantity of gas expected, the gradients of the seams and seam conditions. It is obvious that the cost per ton to provide the necessary winding facilities in a pitbottom depends on the quantity of coal available to that level and on its rate of production ; economic reasons, therefore, tend towards ever-increasing distance between levels. Further, if the planned rate of production at a level is high, the resultant advantage in the cost of production makes it practicable fully to mechanise the pitbottom.

LATERAL MINES OR DRIFTS

24. Generally, lateral drifts wide enough at least for double track are driven at each level from either side of the pitbottom at an inclination of about 1 in 500 in favour of the coal load, and as straight as possible in the general line of level course of the strata. The position for a lateral drift relative to a seam is chosen, when possible, with due regard to suitable strata and, of more importance, to the effect which the working of seams in close proximity may have on its maintenance. The best position for a lateral drift is below the lowest workable seam. Such a choice, however, is only possible on rare occasions, and it is usually necessary to drive the lateral drifts between seams as in Fig. 3.

25. The lateral drifts at each level are commonly driven in the same vertical plane and are sometimes connected for ventilation purposes by staple shafts (as can be seen by comparing Figs. 3 and 4) ; otherwise ventilation difficulties may be met. Indeed, long drivages without air connections are seldom undertaken.

CROSS MEASURE MINES OR DRIFTS

26. Cross-measure drifts of double track width are also driven at about 1 in 500 at right angles to the line of level course at intervals along the lateral drifts. The distances between the cross-measure drifts vary from 1,000 to 4,000 feet and more, according to the strength of the seam strata, to avoid roadway maintenance in the seams prior to abandonment.

27. Where, as in most cases, the strata gradient is sufficiently great, these drifts usually intercept the seams. There are, however, instances where the gradient is small and the distance necessary to intercept the seams is relatively long ; in exceptional local cases where the seams are level, the drifts may not intercept the seams within the boundary of the leasehold. Figs. 3 and 4 show the lateral and cross-measure drifts on two levels at the Hannover Mine.

STAPLE SHAFTS

28. The lateral and cross-measure drifts on different levels are connected by staple shafts. As far as possible, these are only driven between cross-measure drifts and at intervals relative to the length of working faces. The longer the faces, the greater are the intervals between the vertical connections. Hence, whenever practicable, it is important to extend the length of the working faces in order to reduce the cost of driving staple shafts. A typical plan of staple shafts is given in Fig. 5, and a section along a cross-measure drift in the same mine is shown in Fig. 6. A plan and section of the Niederrhein Mine, where only about 10 ft. of workable coal is available in two seams 650 ft. apart, are shown in Figs. 7 and 8.

29. Staple shafts are used for the ventilation of workings, the raising and lowering of coal and materials, and the passage of men. Sometimes they are only driven up to the highest available seam in the horizon if this seam is a considerable distance below the next or higher level.

THE HORIZON SYSTEM

30. By the system of lateral and cross-measure drifts outlined above, panels of coal are blocked out ready for extraction, the uppermost workable seams being taken first. Ventilation is ascensional. During its productive period, each level is usually an intake airway ; subsequently, it may become a return airway. Water from the workings is drained naturally and led out to the shafts with the minimum of pumping, except where the growth is greater than normal conduits can take at the low gradient.

31. Most important of all, however, is the fact that at each level a system of locomotive transport can be provided for both coal and men. With roads between the main and staple shafts made for the purpose, such a transport service approaches the ideal in that increasing distance between these shafts, even to the boundary of the leasehold, is of little importance.

32. The system of drifts has the advantage, too, of providing some knowledge of the physical characteristics of the strata in each panel prior to the commencement of coal extraction.

33. Largely because of ventilation, it seems to be generally accepted that the output of a cross-measure drift is limited to a maximum of 2,000 tons per day of two shifts in moderately inclined strata, and to 1,500 tons in steeply inclined seams.

LAYOUT OF FACES

34. Most coal faces in the Ruhr Coalfield are laid out on the advancing longwall system ; only about 5 per cent. of the output is produced on retreating longwall faces. Reference has been made to the formation of panels of coal, usually bounded by two cross-drifts. The most common modern practice is to develop a single unit face on the strike between each pair of cross-drift staples. The coal produced is conveyed downhill on the face to a gate conveyor, which carries the coal to a staple shaft, or in some cases directly to a loading station on the cross drift. Staple shafts used in conjunction with conveyors are provided either with non-choking spiral chutes or with skips fed at the seam level from small bunkers.

35. A serious effort has been made for years to reduce the number of working faces by increasing their average length. This most important feature is discussed in Appendices Nos. 7 and 8. The effort has been particularly successful in the development of the long double-unit face advancing on the strike. For instance, in the example shown in Fig. 9, one third of the output is raised from the dip by the face conveyor to the gate conveyor. There are faces of up to 1,300 ft. and more in length on gradients up to 15° producing as much as 1,000 tons daily in two working shifts.

36. Longwall advancing to the rise is not commonly applied, although it has been very successful in some mines with gradients of up to about 15°. Figs. 10 and 11 show double-unit forms of face layout to the rise.

37. In the limited number of cases where longwall retreating is practised, it has been found that the roof weight is thrown forward on to the roads 90/120 ft. in advance of the face, thus necessitating heavy repairs. Accordingly, the cost of road maintenance and stone removal, when roadmaking, is high. From the ventilation aspect, the retreating system is considered an advantage at depths below 1,100 yds. in order to eliminate leakage of air through goaves. It also has advantages when power loading is adopted, especially in the present coal-plough form, which is described later.

38. Pneumatic picks are used almost universally for coal getting in the Ruhr. Their success depends largely on the natural friability of the coal, assisted to some extent by " controlled " roof pressure. When a new face is first put on production there is a lapse of time, running into weeks, before the " controlled " roof pressure becomes effective. This results in a temporary decrease in output per hewer shift. Further, as one face approaches the old waste of another, roof conditions often deteriorate seriously, causing abandonment, followed possibly by spontaneous combustion. For these reasons, efforts are being made to establish a system of continuous advancing longwall where, by previous drifting and the driving of staples, it will be possible, by connecting the face to the staples prepared in advance, to continue the working of a face through several panels cutting off the old gate roads. Fig. 12 shows the working plan of such a face in the Graf Bismarck Mine.

39. It will be noted that no reference has been made to barriers or pillars to protect drifts and staple shafts. Generally there are none. It is considered undesirable to leave coal pillars as they have been found to create areas of severe pressure both on the drifts and on the workings below ; this feature is said to be aggravated by depth. Extraction of the seams is continued through the staple shaft positions, but due care is taken to control subsidence in the area by uniform solid packing—an important precaution.

40. Pillars are prescribed, however, to protect the main shafts. It was stated that these are generally fixed at a radius of 162.5 ft. from each shaft on the surface, with an angle of 45° in quicksand and 65° in other strata.

THE RUHR COAL MINES

41. The normal annual output of the Ruhr Coalfield, produced by 41 companies from 137 mines, is 125,000,000 tons. The average annual output per mine is, therefore, about 900,000 tons. The total productive life of existing mines was given as varying from 50 to 100 years. The planned productive life of new mines, considered from the standpoints of capital expenditure and changing mining technique, was given as 75 years.

42. The capacity of a Ruhr mine is related to the area of the leasehold. Leaseholds are generally relatively small and depend on coal at depth rather than at a horizontal distance from the shaft. The average production per square mile was given as 750/1,050 tons per day. A figure of 1,800 tons per day was given as the most efficient, and 2,600 tons as the absolute maximum. A comprehensive description of mining practice in the Ruhr is given in Appendix No. 1, which is a translation of a paper by Dr. Vogel the chief mining technician of the German Coal

Owners' Association. Table 1, "The disposition of Manpower in the flat measures of the Ruhr Coalfield" has been reproduced from this Appendix.

43. A recent paper on planning the layout of an area is given in Appendix No. 2.

44. As far as could be ascertained, the annual output of a Ruhr mine is not any guide to its efficiency. Some of the small mines (reckoned by Ruhr standards) producing 1,500 to 3,000 tons per day are among the most efficient in ultimate cost of production, but these mines are relatively shallow with good physical conditions.

45. The majority of the mines are of so called medium size, producing 5,000 to 6,000 tons per day. Their efficiency varies; some of them, particularly the newer mines and those where depth and physical conditions are favourable, are very much more efficient than the others.

THE "COMBINED" MINE

46. Concentration of production in fewer mines was commenced in the years following the first European War. As a result, the average output per producing mine has been more than doubled since 1918. This concentration process still continues and, in the last ten or fifteen years, groups of independent two-shaft mines have been superseded by what are termed "combined mines." In such cases, a new central shaft with a capacity of 12,000 tons upwards has replaced several old shafts for coal-raising purposes. Some details of the Walsum Mine, an example of a "combined mine," are given in Appendix No. 3; a paper on the evolution of the combined mine (written as far back as in 1930) appears as Appendix No. 4. A further paper of recent origin is reproduced as Appendix No. 5.

47. It will be seen that the long established horizon method of layout of workings, described earlier in this Report, readily lends itself to the substitution of several coalwinding shafts by one centrally situated.

TABLE I

DISPOSITION OF MANPOWER PER 1,000 TONS IN FLAT MEASURES IN RUHR MINES IN 1941

SURFACE		140
UNDERGROUND		
(1) *Productive work.*		
Winning		137
(2) *Semi-productive work.*		
Gateroad transport	22	90
Staple transport	16	
Main gate	46	
Shift winding	6	
(3) *Unproductive work.*		
(*a*) *Development.*		
Preparatory	50	140
Preparatory including piercing faults	28	
Maingate driving	32	
Face conveyor shifting	30	
(*b*) *Work for ensuring continuity of working.*		
Stowage of goaf	51	132
Maingate maintenance	23	
Staple maintenance	7	
Main road maintenance Shaft maintenance	37	
Drainage	1	
Plant maintenance	6	
Mine safety ventilation, &c.	6	
TOTAL		639

48. Outputs of 10,000/15,000 tons per day of two working shifts are planned at a number of new deep mines in virgin leaseholds. If necessary, these mines will be provided with small-diameter auxiliary air shafts near the boundary of the leaseholds. Appendix No. 6 gives some details of Haniel, which is a large modern mine. Greater overburden and sinking difficulties have a bearing on the size of combined mines, but there is a feeling that the 10/15,000 ton mine is too large and unwieldy, particularly from the labour standpoint. Some authorities state that a mine with an output of 5/6,000 tons per day is large enough for the highest efficiency to be achieved, and that a production of 5,000 tons from steep measures is the maximum which should be aimed at.

49. The development of the combined mine was accelerated, if not initiated, as the result of the output-quota system adopted in the depression period in Germany following the first European War. At that time an annual quota of one million tons was the permitted maximum for two shafts. Later, an extra 500,000 tons were allowed for an additional ventilation shaft, and gradually the present idea of a three-million ton combined mine was developed.

DEVELOPMENT AND RESEARCH

50. A striking feature of the Ruhr coal mines is their similarity in equipment and mining practice. This similarity is due in no small measure to the activities of the development and research department of the Bergbau Verein (Coal Owners' Association).

51. Briefly, the department consisted of two series of study committees and sub-committees, under the general direction of two main committees, one dealing with production matters and the other with coal preparation and chemical matters. The Committees were composed of active mining engineers and technicians of various grades, each of whom specialised in one of the subjects dealt with by his particular committee. A member of the technical staff of the department was attached to each committee (each technician had several committees) to carry out research work under its direction in order to ensure that the work proceeded on practical lines. Indeed, much of the work was done at, or in close association with, the mines managed by the members of committees.

52. Full use was made of the scientific knowledge of the staffs of technical institutions and schools for testing and research planning, and the research carried out in this way was guided by the departmental committee concerned.

53. The staff was under the general control of a Secretary-General, a technically qualified mining engineer. The technicians were largely drawn from the Industry and had a practical background. The ability of those met, and their grasp of practical problems, was impressive.

54. The scope of research and development work carried out by the department, particularly in the war years, was very considerable. It was the department's task to make exhaustive enquiry into every suggestion advanced, from whatever quarter. The range of enquiry covered such diverse items as loading-machine designs and miners' houses and diet. In addition, the department scrutinised the German and foreign technical press for patents and new methods, and in consequence, British patents of recent origin were used as the basis of some of the present developments in the Ruhr.

55. The number of technical journals serving the industry was specially noteworthy. Chief among these were "Glückauf" and "Archiv." A series of secret papers descriptive of the work carried on by the department and its associates on coal-mining subjects were issued during the war. The department also kept in touch with research work carried out by manufacturers, many of whom published regular "House" journals describing their technical developments. The firms of Krupp and Demag, for instance, issued such publications.

56. One of the important functions of the department was to determine the standards for coal-mining equipment, and to pilot the specifications through the National standardisation machinery.

57. Many advantages may be derived from the operations of such a department; for instance, complete and up-to-date information on all aspects of mining is always readily available. Any development which promises to improve the efficiency of the Industry, or any difficulty which is retarding progress, is, therefore, spotlighted. Where such a problem is brought to light, it can be dealt with immediately by the appropriate organisation. Moreover, once the department is satisfied that its researches have disclosed a new practical application, no time is lost in putting it into effect, and making it widely known.

58. By taking full advantage of these factors the German Mining Industry has increased its efficiency as a whole, and very wide divergences in mining practice under similar physical conditions have been avoided. It should be clearly understood, however, that some mines are better planned and equipped and more efficiently managed than others.

59. As is natural, the older mines can show fewer examples of modern mining developments than the newer ones, and it is to the new mines that the visitor gives greatest attention in order to acquire the most up-to-date technical information.

CONCLUSIONS AND RECOMMENDATIONS

60. (i) The Ruhr Coalfield is faulted and distorted but the percentage of workable coal in the coal bearing strata is 4 per cent. to 8 per cent. The advantage of these rich measures, although partly offset by the average depth of working—which has now reached about 750 yards—is reflected in the large daily output obtained at many individual mines from relatively small leaseholds.

(ii) The horizon system of mining is ideally suited to the Ruhr conditions. This system is recommended for consideration in this country, particularly where the physical conditions are similar to those in the Ruhr.

(iii) The Ruhr modern coal mine with a capacity of more than 10,000 tons per day is a very large unit. Mines of such a daily output are not recommended in this country, because of complications of management, even where available coal thickness and other geological conditions are most favourable; and it should be pointed out that complete mechanisation as carried out in the most modern mines in the Ruhr can only be recommended where the reserves of coal and the daily rate of production justify the heavy expenditure involved.

(iv) Full co-ordination of research and development work has been achieved, and the organisation set up by the German Coal Owners' Association is worthy of close study. A similar co-ordination under the supervision of experienced and practical mining engineers would be of great value to the Mining Industry in this country.

CHAPTER II

Methods of Working and Coal Face Equipment

61. The number of working places in the Ruhr mines was rapidly reduced during the ten years ending 1937 by increasing the average quantity of coal produced from working faces, as described in Appendices Nos. 7 and 8. The methods of working were adapted to suit this concentration of production, and mining machinery was developed accordingly.

62. The improvement in output per underground manshift was progressive until it reached a figure of slightly more than 2 tons in 1936, after which there was a gradual decline (see Appendix No. 1). Efforts were made during the War to arrest this decline and to obtain a further increase in productivity by developing and applying power loaders.

METHOD OF WORKING

63. The method of working is longwall. As has already been stated, advancing faces predominate, only 5 per cent. of the coal being extracted on retreat.

64. The most important factor in favour of advancing longwall is the application of the pressure of the strata to facilitate the getting of the coal. These heavy pressures, inducing fractures in the coal at the working face, have an adverse effect on roadways serving retreating faces, and roadway maintenance has been found to be excessive from 20 to 50 yards ahead of the retreating faces. The difficulty and the cost of disposing of stone produced from rippings when forming roads in the solid in the seams have also a bearing on the subject, for this material is additional to the normal production of stone from the lateral and cross measure drifts.

65. Retreating longwall is adopted in the Ruhr at the present depth of the workings only where special factors throw the economic balance in its favour. For example, to maintain continuity of travel of an established production face across an area, the roadways in the goaf which serve the advancing face and connect it to a cross measure locomotive haulage drift may, at a particular point in the life of the panel or in the condition of these roads, be discarded in favour of roadways through the solid coal to the next parallel cross measure drift. It is considered important to maintain continuity of travel of faces producing high outputs, because it takes three months to tune a newly developed face to the highest production efficiency; that is, to stabilise roof control to assist the getting of the coal and to give the men time to get to know the face well and work together.

66. Consideration is being given to the application of retreating longwall for power loading faces owing to—

(*a*) the facilities immediately available in the existing roads for the storage of plant associated with the power loading application;

(*b*) the need in mechanical mining for complete exploration of the area to be worked; and

(*c*) the fact that with some methods of power loading the rate of advance of the face is greater than that at which roadways can be formed on advancing faces.

67. The view was expressed that longwall retreating will be essential for depths exceeding 1,100 yards owing to ventilation problems. It is considered that leakage of air through the goaves should be eliminated at these depths, and that solid packing of the retreating faces should be considered essential for minimising the area of warm surface exposed to the ventilating current, because the effective effort of a manual worker very rapidly diminishes with increase of working temperature.

Caving is classed as unsatisfactory for deep measures owing to the great area of warm rock surface which it exposes to the air current.

68. Nevertheless, at the present time, 95 per cent. of the coal is extracted longwall advancing, the roads being formed in the seams as the faces advance from the locomotive haulage cross measures drifts.

METHOD OF GETTING THE COAL

69. Approximately 85 per cent. of the coal in the Ruhr is mined by pneumatic picks with two coaling shifts per 24 hour cycle. The remaining 15 per cent. is machine cut, a small percentage being mechanically loaded.

70. The application of the pneumatic pick to the Ruhr coal seams has been very thoroughly analysed by ascertaining, under appropriate conditions of roof control, the man minutes required to break down a cubic metre of coal into a form suitable for shovelling on to the face conveyor. This figure is the basis for determining the method of working; for example, if it is proved that a cubic metre (1.3 cubic yds.) of coal in a seam of average thickness (i.e. 4 ft.) can be broken down in less than 10 minutes, it is definitely considered more economical to use pneumatic picks than any other form of coal getting, with the exception of power loading, which comes into a special category. This does not mean that the application of a coalcutter is profitable when the figure exceeds 10 minutes, because the physical characteristics of the coal and the cost of undercutting, which depends on the hardness of the holing material and the depth of the cut, must be taken into account. For instance, in a seam of average thickness the line of demarcation may be between 10 and 20 minutes, according to the characteristics of the seam.

71. According to the results of the analysis, coal cutting is not profitable under any conditions when the pneumatic pick figure is lower than 8.6 minutes, and is always economical when the figure exceeds 23.6 minutes. The figures for the majority of the coal seams in the Ruhr lie between 5 and 15 minutes.

72. It is said that shot-firing pays only when the pneumatic pick time exceeds 20 minutes per cubic metre (1.3 cu. yds.) and then only in combination with a coal cutter. (20 minutes per cubic metre is equivalent to an output per shift per hewer of 6 tons.)

73. Face work has been the subject of very close study. One analysis of the average of over 1,000 separate time studies of pneumatic pick work provided the following figures—

	Percentage of full shift (Including travelling time, etc.)	*Percentage of productive time at face*
(*a*) Using pneumatic pick	23	34.5
(*b*) Shovelling ..	30.6	46
(*c*) Supporting roof ..	12.9	19.5

Additional interesting figures from this same analysis are—

(1) Average time of interruption of face work from all causes ..	19 mins./shift
(2) Average man-minutes to load one cubic metre (1.3 cubic yds.) of coal on to conveyor ..	17.4 mins.
(3) Average man-minutes to set roof supports corresponding to cubic metre (1.3 cu yds.) of cleared space	7.3 mins.

This time study of work at the coal face is described in Appendix No. 9.

ROOF CONTROL

74. Roof control has been the subject of very careful study with a view to utilising the forces of strata movement to assist in getting the coal. The opinion is generally held that pressure fractures in the seam are more important from this point of view than are natural cleavages, and that, within limits, roof partings can be induced. Normal practice appears to aim at avoiding points of high stress by uniform packing and support within the pressure zone, which exerts its effect on the coal face.

75. German technicians have made an analytical study of the expenditure of energy in setting roof supports over a wide range of seams and conditions, and have compared various systems of supporting the roof on the basis of man minutes required per cubic metre of coal extracted. The details are given in Appendix No. 9.

PROPS

76. Approximately 75 to 80 per cent. of the faces in the Ruhr are supported by wood props at the present time, but steel supports are gaining favour. The development of steel supports for all systems of packing has been along the lines of the yielding friction grip type suitable for relatively high initial loads. The incidence of hard floors may have some bearing on the subject, for the floors of all seams inspected were definitely hard.

77. There is now a demand for a yielding steel prop which can be easily withdrawn, but which is capable of a much higher initial load setting than any at present available, and has a lower rate of yield under heavy pressures. Several designs have been produced, but a standard is not yet available.

CHOCKS

78. The type of quick release chock which is favoured for the breaking edge in caving practice is illustrated in Fig. 13.

PACKING

79. Solid packing is, with few exceptions, standard practice for seams inclined at more than 25 degrees. For seams of 25 degrees and under, the various methods of packing employed and the extent of their application and labour cost are as follows :—

	%	*Manshifts expended per 1,000 tons of coal produced*
Caving	37	45
Ripping dummy roads ..	15	73
Hand packing with material brought into face ..	23	62
Pneumatic stowing	13	34
Mechanical stowing ..	2	24
Compound system	10	—

The ascertained average figures of subsidence are—

Caving	90%
Strip packing	85%
Hand packing	60%
Mechanical packing—all types	50%

80. The low cost of pneumatic and mechanical packing, together with the control of the latent roof pressures on the getting of the coal which they make possible, is widening the application of these forms of packing.

(i) PNEUMATIC PACKING

81. Two examples of pneumatic packing with the "Beien" type of plant were seen, but as this principle is now well known it is not necessary to describe it in detail. The stowing material—maximum dimension 3 ins.—was tipped from the tubs in a locomotive haulage road on to a conveyor system which delivered it to the stowing machine in the vicinity of the face. The 6-in. diameter stowing pipes were lined with smelted basalt which was said to resist abrasion well, but not shock. The maximum length of piping used inbye of the stowing machine was 440 yds., which, for a face 220 yds. in length, is equivalent to moving the plant at intervals corresponding to an advance of the face of slightly less than 220 yds. Quick make and break joints were used on the face pipes.

82. Wire mesh, covered with thin fibre sheet, was used to form a retaining wall for the packing.

83. At the Graf Bismarck Mine, where pneumatic packing has been applied for a considerable time in workings immediately under the Rhein Herne Canal, 5 men were employed per shift on this work from the stowing machine inbye. The rate of stowing was 52 cu. yds. per hour; the normal volume packed per shift was 327 cu. yds. and the maximum 392 cu. yds. In one area, one of the seams thickened to about 10 ft. and was extracted in two layers. The top layer was worked first and the goaf packed pneumatically. When the lower stratum of coal was extracted the pneumatic packing above it proved to be a very sound roof and was considered better than the normal roof of the seam.

(ii) MECHANICAL PACKING

84. Visits were paid to two mines employing this system, the Jacobi Mine and the Pattberg Mine of Rheinpreussen.

85. The mechanical packing is done by a belt throwing or slinging machine called "Kreiselschleuder," which handles material up to a maximum dimension of 3 ins. The first design is illustrated in Fig. 14. The unit shown in Figs. 15 and 16 was later developed to increase the effectiveness of the throwing action by ensuring that the material attained the speed of the throwing belt, and this is the type now used. The machine is limited in its application owing to its overall height, and it is understood that another will be developed for the thinner seams, probably sited on the floor alongside the face belt conveyor.

86. At the present time, this packing machine straddles the face belt conveyor, which is of the troughed type without spillplates. The conveyor idler stools are so built that they also support rails on both sides to enable the packing machine to travel along the face. Pins, welded into the rails on the underside, register in corresponding holes in the idler stools and thus only a few pairs of rails are necessary. The rails are moved forward as packing proceeds. This packing machine, which is driven by an 8 H.P. motor, receives the dirt from a chute into which it is ploughed from the face belt.

87. Examination of the packs put in by these machines proved them to be uniformly built, but in neither case was the pack very tight to the roof at the face side. Uniformity in the quality of packing is considered more important than tightness at the face side.

88. At the Jacobi Mine, in a seam 5 ft. thick, with a face advance of 7.2 feet, 110 yds. of face, i.e., 440 cu. yds., are packed in a shift by the following personnel—

Operating machine	1
Preparing track ahead of machine	1
Withdrawing roof supports	2
Cleaning behind machine	1
On conveyor system from loco haulage road to face	3
At tub tipper station	3
Reserve for incidental duties	1
TOTAL	12

89. The three men at the tub tipper station are not required for the relatively simple job of tipping the tubs, but for the important reason that at this mine the tubs must be thoroughly cleaned of wet dirt before they are used to transport coal on the outbye journey.

90. At the Pattberg Mine the latest type of mechanical packing machine in use has a capacity of 157 cu. yds. per hour and a maximum, so far, of 650 cu. yds. per shift. The following personnel are employed—

Operating machine	2
Setting temporary roof supports	2
Withdrawing steel supports	3
Controlling packing	2
Inspection of belt conveyor system	1
Hand packer at roadhead adjacent to belt driving gear	1
At tub tipper station	2 to 3
For skip winding of packing material ..	2
TOTAL	15 to 16

91. (The packing material is lowered into the mine by special skips).

92. This example of mechanical packing is on a face where the Eickhoff Rheinpreussen cutter loader is in service. The layout of the face, including the roof supports and packing details, is illustrated and described later.

93. Opinion in the Ruhr is that mechanical packing will increase. One limitation at the present time is that the machine requires a face belt conveyor. The users of the system stress the importance of a very good organisation for the transport of the stone to ensure completion of the task in the shift allotted to it.

LAYOUT OF FACES

94. The best line of face for getting the coal by pneumatic picks is said to be approximately 20 degrees off bord, but little attention appears to be paid to cleavage, which is not generally well defined, and is considered by some technicians in the Ruhr to be less important than the pressure fractures induced in the coal by their system of roof control. The highly inclined seams in the early workings, and the ease of operation of compressed air driven shaker conveyors on the lower but favourable gradients, have led to the general adoption of faces on the line of dip and rise of the seam. These dip and rise faces are normally laid out with a slight inclination to the goaf in order to facilitate the filling of coal on to the conveyor and to prevent accumulation of water on the face.

95. Fig. 17 illustrates the standard arrangement of roadways serving a hand got face. The road for transporting the coal is usually ripped in the floor, but in the upper or supplies gateroad roof ripping predominates. All ripping work is done by hand, either by pneumatic picks or by shotfiring, according to the physical characteristics of the strata. An advance heading is formed only in the coal transport gateroad and then only when—

- (*a*) the coal is loaded direct into tubs from the face conveyor, or
- (*b*) when the application of gate conveyors or auxiliary face equipment is facilitated by the advance

heading. (For example, to accommodate the receiving or return pulley end of a gate conveyor in a thin seam where, otherwise, the height required for discharging the coal from the face to the gate conveyor would be unduly restricted.)

96. Suitable provision is made for taking materials from the locomotive haulage roads to the working faces. The circuit includes the staple shaft connecting the face with the winding level, and the type of equipment depends on the individual requirements of the face. Where solid packing by hand or mechanical means is adopted, it is customary to use gate conveyors in the top gate in order to complete the conveyor circuit, i.e. packing material in the top gate and down the face, coal down the face and out by the bottom gate. Fig. 18 illustrates the layout of the face at the Jacobi Mine where a mechanical packing machine is in use.

97. Fig. 19 is a sketch from a mine plan showing the layout of a large double unit, and is self explanatory. It is one of the few examples of a face advancing to the rise which, in this case, proved to be the best direction for getting the coal by pneumatic pick. When the faces are worked on the line of dip and rise at this mine, coal cutters are necessary to obtain the best results.

FACE CONVEYOR EQUIPMENT

98. The majority of the seams are inclined from 10 to 20 degrees, and compressed air driven shaker conveyors are normally used on the face. The air supply is obtained from a pipeline along the face which also feeds the pneumatic picks.

99. Troughed belt conveyors of both top and bottom carrying types are used on long faces in the thick flat seams and especially where mechanical packing is applied ; also, in some cases, for power loading. High cost of upkeep owing to short belt life (although spill-plates are not fitted) is said to have limited the use of this type of face conveyor.

100. The double chain scraper, which was previously used for conveying uphill, is now, owing to the development of the plough loader, also used downhill. This double chain conveyor, which runs at a speed of 140 ft. per minute and conveys at a rate of 150 tons per hour, can be extended to a maximum length of 260 yards under favourable conditions on hand filling faces, when it is fitted with two 50 H.P. drives—one at each end. Vertical plates are attached to the cross bars between the chains when the inclinations against the load exceed 23 degrees. The maximum inclination against the load on which the conveyor is used is 35 degrees. At this gradient, the maximum length is 130 yds. and only the top drive is effective ; it is understood that the 50 H.P. motor on the top can haul 80 tons of coal per hour uphill. No definite data were available with regard to the number of these conveyors in service, but Demag mentioned that they had supplied 15 to 20 for work on faces exceeding 110 yds. in length, and that there were from 200 to 300 in use on shorter faces.

101. Retarding conveyors of both double chain and button (or disc) types are used for conveying downhill on faces inclined at more than 20 degrees ; 20 degrees is considered to be the minimum gradient for satisfactory retarder service.

COAL FACE LIGHTING

102. Mains operated lighting is extensively used on the coal face in the Ruhr. This is undoubtedly due, to a great extent, to the almost complete absence of shotfiring on the coal face and of the disturbances connected with this practice. But it is equally obvious that the positive advantages of this form of lighting have played a big part in its development. It was claimed, for example, that the better visibility due to good face lighting resulted in improved pneumatic pick performances, a general quickening up of all face operations and an increased production of clean coal. It was further claimed that good lighting had also contributed to a reduction in the accident rate, and to an improvement in the general health of the miners, leading to reduced absenteeism due to sickness. It is somewhat difficult to decide whether these advantages would have the same value if shot-firing was generally practised at the coal face, but there is no doubt that men who have become accustomed to working on well lighted faces would strongly object to a return to the relatively dim lighting provided by battery-fed hand, or cap, lamps.

LIGHTING INTENSITY

103. Standards for all phases of underground lighting, which are based on practical experience, provide for illumination intensities varying from 0.5 to 7.5 ft. candles. The degree of intensity provided at the coal face varies so widely that an average figure would have little meaning. It can be assumed, however, that at the face the degree of intensity is seldom below 0.5 ft. candle, and in many cases much nearer 1 ft. candle. Moreover, at some faces, the figure is as high as 2 ft. candles. The standard of mains operated face lighting generally provided has an efficiency 10/30 times greater than that provided by hand lamps.

SOURCE OF SUPPLY

104. Two voltages are in common use for underground lighting, i.e. 110 and 220 volts ; about 74 per cent. of the lighting in use on the face and in gate roads is at the latter voltage. One reason for the higher voltage is undoubtedly the increase in the working area ; for example, the extension of faces up to 300 yds. or more.

105. The transformers used vary from 1.5 to 15 KVA, but the majority are about 4 KVA. All are of the dry type. About 40 per cent. of the transformers in use have secondary windings giving both 220 and 110 volts. The former voltage is used in some cases for lighting the gate roads, and the latter is used for lighting the coal face. In most face lighting systems it is usual to adopt a system of protection against earth faults, which involves the use of the low tension side mid-voltage point. This point is, therefore, usually earthed.

CABLES

106. Whilst rubber covered flexible cables are generally employed for the lighting actually on the face, a considerable amount of rubber insulated lead covered steel tape armoured cable is used in the gate roads and at loading points. The types of cable and voltage used in 1942 on faces, in gate roads and in some roadways is given in Table II. The two most common conductor sizes used are 0.0062 and 0.0093 sq. ins. ; the cables are usually four core.

CIRCUIT ARRANGEMENTS

107. Experience in seams of average height has led to the adoption of a more or less standard arrangement of cables and fittings. The circuit is split up into sections of about 80 ft. in length, each section containing 4/5 lamps, usually of 40 watts, so that the spacing is 16/20 ft. apart. In a few exceptional cases, a lamp of 60 watts is used ; in these cases the spacing is about 33 ft.

TABLE II

VOLTAGES AND LENGTHS OF CABLE USED IN FACE AND ROADWAY LIGHTING CIRCUITS IN 1942

Type of Cable	Working voltage				Combined Total	
	110 volts		220 volts			
	Miles	%	Miles	%	Miles	%
Armoured lead-covered ..	8.40	11.1	66.5	88.9	74.90	100.0
Rubber flexible	24.45	26.0	69.57	74.0	94.02	100.0
Total length	32.85	19.4	136.07	80.6	168.92	100.0

Note.—The total length of flexible rubber cable in use covers lighting on gate roads and coal faces.

108. Formulæ for determining the size and spacing of lamps at the face may be used for guidance, but every case must be decided on its merits and in accordance with the actual conditions at the face. It is claimed, however, that the standards given above will meet most cases.

109. The individual 80 ft. sections forming a link-up "plug-in system" are connected by means of 4-pin plug and socket couplers, which usually include a push-button switch for signalling purposes. A typical plug and socket of this description is shown in Fig. 20. With this device, signals to stop or start face conveyors or other remotely controlled face equipment can be made according to an established signalling code. The intervals of darkness are of very short duration and do not affect production.

110. The signalling system necessitates a switch lead to the farthest lamp in the circuit. This, with an earthing conductor, requires the use of a 4-core cable. The circuit arrangement which is illustrated in Figs. 21 and 22 gives a better voltage distribution throughout the face. It is not clear whether the signalling feature or the desirability of equalising the voltage led to this method of connection, but the latter is in itself sufficient justification for its adoption. It will be seen from Fig. 21 that the voltage of the lamps is related to the actual voltage on the face rather than to the rated voltage of the transformer secondary winding. This practice may shorten lamp life unless prompt action is taken to replace lamps that burn out or otherwise become defective.

111. Most face lighting circuits include a system of protection against faults either between phase leads or earth. The arrangements adopted vary from the simple mid-point to earth relay shown in Fig. 21 to the somewhat complicated Grümmer system shown in Fig. 23. The latter system provides against a broken live, or earth conductor, anywhere in the circuit, or against a short-circuit between these conductors. A full description of the system is given in Appendix No. 10, and typical flame-proof lighting distribution switches are shown in Fig. 24.

LIGHTING FITTINGS

112. The general appearance of the well glass fitting usually employed follows conventional lines, but the flameproof design is different from British types. For example, the terminal chamber and well glass enclosures are usually common, and direct cable entry into the former by means of a stuffing gland is accepted. The well glasses have a loose annular rubber ring, and are generally secured to the fitting by 2 wing bolts ; these have nuts with special heads, and require the use of a special key. A terminal block containing 2, 3 or 4 terminals is built into the unit with the lamp holder, which, in accordance with Continental practice, is of the Edison screw type. A selection of fittings is shown in Figs. 25 and 26.

113. The lamps are generally of the coiled filament gas-filled type, and little attention appears to have been paid to the use of special lamps with lower filament temperatures such as, for example, traction types.

114. Considerable research has been carried out on the prevention of glare ; this has included the use of pearl lamps and opal glass lamps, and the use of opal well glasses. Clear glass is recognised as unsatisfactory, and experiments with blue, blue-green and other coloured glass have met with little success. The best method of preventing dazzle is by the use of opal well glasses, with or without an opal or a pearl lamp. Hitherto, this form of glass involved a light loss of anything up to 40 per cent. but in the latest type it is claimed that the loss has been reduced to 8.5 per cent. Little information is available about this new opal glass, which is not of the toughened or armoured variety.

MAINTENANCE

115. It has already been said that the almost complete absence of shotfiring has greatly contributed to the successful application of mains operated coal-face lighting in the Ruhr. The absence of shotfiring has also lessened maintenance because there is no need to take down the cables and fittings or otherwise protect them against projected material. The daily move up of cables and the repair of defective cables, fittings or lamps is made easier by the link-up "plug-in" arrangement. A number of spare sections, complete with lamps, is kept in a nearby working level. These can be easily installed with safety by the one or more face-men specially authorised to do so. This system secures almost continuous operation with a minimum of calls on the services of the electrical staff. Because of the ease with which sections can be changed, it is not usual to carry out repairs, or even lamp replacements, at the face. When one or more lamps burn out, the section is removed and sent to the underground electrical workshop where it is thoroughly overhauled and tested before being returned to the face.

116. The advantages of coal-face lighting are referred to in Appendix No. 29.

GATE CONVEYOR EQUIPMENT

117. The troughed rubber belt is the most common type of gateroad conveyor. The maximum belt speed is 300 ft. per minute, and the maximum belt width is 2.7 ft. There are no developments in advance of British gate conveyor practice. Steel belt and steel plate conveyors are used but only as substitutes for the

troughed rubber belt, which is considered to be the best gateroad conveyor ; nevertheless, the characteristics of the steel belt and plate conveyors are worthy of note.

STEEL BELTS

118. The conveying performance of the steel belt, an example of which is given below, is satisfactory.

Maximum length on level ..	550 yds.
Capacity	120 tons per hour.
Width of belt	2.7 ft.
Speed of belt	160 ft. per minute.
Horsepower required at belt .. (on the level)	29 (This is equivalent to using, say, a 35 H.P. drive.)

119. Because of the lower co-efficient of friction of coal or stone on steel compared with rubber, the maximum inclination on which a steel belt can be used is 14 degrees. The equivalent figure for a rubber belt is 18 degrees.

120. Great care is necessary in setting a steel belt owing to its tendency to float. The conveyor must be absolutely straight, and the general practice is to suspend the structure on a readily adjustable suspension medium, such as narrow metal strips with holes at close centres. Wooden side boards are sometimes used to restrain the belt ; in other cases air operated self-centring idlers are fixed at intervals.

The minimum diameter of the driving pulley for the millimetre (approx. $\frac{1}{25}$") thick sheet steel is 3 ft., which, together with the difficulty of making a good joint underground with small rivets spaced at close centres, further restricts the application of this type of conveyor. The minimum length of extension is 27 yards, i.e. 54 yards of steel belt. The conveyor is not, therefore, suitable for day-to-day extension as a working face advances, and an auxiliary appliance is necessary to bridge the gap between the steel belt and the advancing face.

121. In one example the steel belt was used to obtain length, with a rubber belt in tandem for regular extension. To facilitate bye-work in the gate road during the single shift on which this was possible per 24 hours cycle, a 16 yd. long "Beien" scraper unit received the coal from the face conveyor and delivered it to the rubber belt. This scraper unit was mounted on wheels which ran on rails over the rubber belt so that the scraper unit could be readily withdrawn and reset as required. In this case, therefore, the gate conveyor plant consisted of a scraper unit telescoping over the rubber belt which was used for extension, which in turn delivered to the steel belt employed as the main gate road conveyor.

122. The steel belt is not considered suitable for handling wet stone.

STEEL PLATE CONVEYORS

123. These conveyors are used in gate roads for conveying coal outbye, or stone into the working faces for packing. The general details of the structure are illustrated in Fig. 27, and an example of the performance of the conveyor with this structure is given below—

Maximum length on level ..	550 yds.
Capacity	120 tons per hour
Speed	160 ft. per minute.
Horsepower of drive	60

124. With suitable vertical plates attached to the carrying plates at intervals, this type of conveyor can be used on gradients as high as 40 degrees in favour of, or against, delivery. The respective performances under these conditions of the 60 H.P. conveyor specified above are—

	Maximum Length.
40 degrees against	130 yds.
40 degrees in favour	240 yds. (40 H.P. to be absorbed by regenerative braking.)

125. The life of the carrying member of this conveyor appeared to vary, according to conditions, between 2 and 8 years.

STAPLE SHAFT EQUIPMENT

126. Owing to the importance of the staple shaft in horizon mining, the shaft equipment is described in detail in Chapter V (a)

LOADING STATIONS

127. The standard practice is to move tubs or cars through the loading station by power. Compressed air rams are used in preference to chains, which are almost universally used for controlling tubs and cars at the pit bottom. Chains require accurate setting for this type of work, hence the ram is used in the unsettled ground inbye. The flow of coal from the delivery chute at the discharge end of the conveyor system is also controlled by power.

128. One attendant, who operates both air valves, stands on a suitably placed platform overlooking the tub or car. He thus obtains an unrestricted view of the work, and a much better appreciation of the rate of filling, than is possible when the top of the tub or car is at eye level.

129. When the loading stations are on main locomotive haulage levels or cross cuts, the locomotive shunts a train of empties behind the loading station and picks up a train of full tubs outbye of the loading point. The sets of tubs are usually put through the station by the air rams without uncoupling.

130. One man thus controls the whole operation, and in one example with 3½ ton cars where the delivery chute had adequate storage capacity to permit a pause in the flow of coal (which completely avoided spillage between cars) he was the only attendant at the station. The maximum output filled per shift to date at this loading station is 1,225 tons, but the management are confident that they will be able regularly to handle 1,500 tons per shift with one attendant when this output becomes available. This loading station is illustrated in Fig. 28.

131. It is common practice to fill 1,000 tons per shift into one-ton capacity tubs with 2, 3 (and on occasion 4) men at the loading station. The number of men required depends on the amount of spillage, the marking of the tubs and, in some instances, the marshalling of sets.

132. Vibrators are used at some of the loading stations to increase the carrying capacity of small tubs. In one instance (the Jacobi Mine), spillage between tubs was prevented by coverplates taken round automatically on an endless circuit by the flow of tubs. Side spillage was eliminated by coverplates fixed over the edges of the tubs so that the coal could only go into the tub, and spillage could not occur except by overfilling the tub.

(Owing to the regular gradient on the locomotive haulage roads—1 in 400 to 500 in favour of the load throughout—the tub buffers are short and the distance between tubs is small, particularly when they are pushed through the loading station by air rams. This has an important bearing on spillage at the loading point.)

POWER LOADING

133. Much consideration has been given to power loading on longwall faces within the last five years. The technicians of the Mining Association in Essen (Bergbau Verein) appear to have approached the subject by making a very detailed analysis of the getting of coal on 135 faces in 58 seams at 41 mines. The data were summarized in a Paper by Vogel in 1940 (Appendix No. 9), from which the following are excerpts :—

> "It should not be forgotten that an unparalleled increase has only recently been achieved (rise in output per underground shift from 1.38 to 2.04 tons between 1927 and 1937, and fall in number of shifts per 100 tons from 72 to 49)."
>
> "Besides rationalisation and improvements in haulage, recent increased output has also been due to developments in packing."
>
> "The end of the rise in underground productivity in 1937 showed that the effects of the above factors were almost exhausted."
>
> "To achieve a further increase in productivity we must, therefore, turn mainly to such processes as have contributed little to previous increases, and, above all, to the actual getting of the coal which takes up 20 to 25 per cent. of all work underground. Here no considerable changes or improvements have taken place since the introduction of the pneumatic pick and the coalcutter."
>
> "The Association has therefore continued to give attention to this subject since the outbreak of war—
>
> (*a*) by a thorough examination of present mining methods ;
>
> (*b*) by deciding the proper fields for mechanical cutting, stripping, and shotfiring ;
>
> (*c*) by supporting development of new machines. . . . Coal getting must be split into its component operations, and the laws governing these must be sought. Time study is the only possible basis for such research."

134. There followed a very full analysis of 1,298 time studies from which valuable data on mining methods and conditions have undoubtedly been obtained, as the following extracts will show :—

> "Of the 350 productive minutes per shift, 35 per cent. go on actual coal getting, 46 per cent. on loading, and only 19 per cent. on support setting. These figures show how small is the scope for raising output by mechanising the breaking down of the coal. A considerable improvement can only be achieved when shovelling can be replaced by an efficient and suitable loading machine. This requires the mining of suitably sized coal."
>
> "It is clear that while a number of mines would be improved by the introduction of coalcutters, no sweeping improvement in output from this source may be expected . . . Only a mechanisation of loading can bring any appreciable improvement."
>
> "The present cyclical method of working, though an improvement on earlier methods, is not perfect. Only unfettered coal-getting, free of limitation from support setting, will permit full use of available productive power."

POWER LOADING COMPETITION

135. Following this survey of face work, in October, 1940, Bergbau Verein organised an attractive competition to stimulate development of power loading on longwall faces. The competition was on a very practical basis, as the effectiveness of any new appliance had to be proved by a saving of not less than 3 manshifts per 100 tons of coal produced over a minimum period of two months on a production face.

136. According to the report on the competition, more than 270 suggestions were received. The technical value of most of the suggestions was said to be slight in relation to the magnitude of the task, but nevertheless many important experiments were conducted, and at least five prizes were awarded after practical demonstration. The various methods of attacking the problem included—

(1) A coalcutter drawing behind it a plough with a powerful striking effect produced by an air cylinder at the back of the cut to loosen the coal.

(2) A coalcutter on top of a strong conveyor placed tight against the coal which pulled a loading element 10 to 12 yds. behind it. Shot holes were drilled prior to cutting, and the shots were fired between the coalcutter and the loader unit. This method was intended for hard coal, and the application appears to be the origin of the "Panzerförderer" or armoured conveyor.

(3) Undercutting the coal, shooting, loading, and conveying by a scraper arrangement of the "slusher" type.

(4) Using scraper buckets in tandem with picks or blades on the face sides to break off the coal. (This method appears to have achieved a considerable measure of success until overshadowed by the coal plough.)

(5) Cutter loaders, and

(6) The coal plough and its variants.

137. Practical experience over a relatively long period of service indicates that the two most important developments are the cutter loader and the coal plough. The official report of the competition states that the most interesting appliance which conformed to the competition standards was the coal plough.

PRODUCTION OF POWER LOADED COAL

138. The total quantity of coal loaded from production faces up to the end of 1944 was 2,093,000 tons.

139. The quantities produced by the different appliances were as follows :—

(*a*) by coal ploughs	998,000 tons
(*b*) by cutter loaders	830,000 tons
(*c*) by other types of loading, including oscillating machines ..	265,000 tons

140. The largest outputs from individual mines were : Friedrich Heinrich, by coal ploughs, 360,000 tons ; Rheinpreussen-Pattberg, by cutter loaders, 430,000 tons.

CUTTER LOADERS

141. The general principles applied in the German design of cutter loaders are basically the same as those in Britain, and indeed there is evidence that developments in British design have been closely studied—probably on the basis of patents—and that British mining machine practice has been followed to some degree.

142. There are two principal designs of German cutter loaders—

(*a*) Eickhoff for thick seams, and

(*b*) Demag for thin seams.

143. The Eickhoff is the basis of two improved models for thick seams. These are the Eickhoff Rheinpreussen and the cutter loader to the Bergbau Verein specification.

EICKHOFF CUTTER LOADER

144 The basis of this machine is an Eickhoff undercutting coalcutter with 50 H.P. motor. The coalcutter motor is the sole source of power for the complete loader.

145. The undercut coal is broken down by means of an intermediate cut by a cutter bar at the end of which is attached a shearing disc ; the bar revolves at approximately 200 revs. per minute, and the diameter of the shearing disc is about 20 ins. The height of the cutter bar and shearing disc above the floor can be readily varied, for the member is pivotally mounted and its position is controlled by hydraulic jacks driven by an oil pump on top of the coalcutter haulage. (Details of the arrangements may be seen in Figs. 29 and 31.)

146. As far as could be ascertained, the cutter bar with its shearing disc is maintained at a fixed height above the floor while the machine is travelling along the face. If vertical movement of the bar and disc is necessary to break down the coal, the forward travel of the machine is stopped.

147. The loading component consists of a flight conveyor which moves the coal sideways on to a scraper chain conveyor in line with the long axis of the machine. This scraper chain conveyor elevates the coal on to a cross band conveyor which, in turn, delivers it through the props to the longwall face conveyor. The cross band conveyor does not project through the props, and the spillage at this point has to be man-handled.

148. The scraper conveyor which receives the coal from the flight conveyor is carried under the coalcutter chain to clear the gummings. This entails the raising of the cutter jib, and in consequence coal is left on the floor.

EICKHOFF RHEINPREUSSEN CUTTER LOADER

149. The principal feature of this machine is the adaptation to load on to an underbelt conveyor in the same track as the loader. The carrying or underbelt is threaded through the machine structure, and receives the coal direct from the loader, which eliminates the difficulty of putting the coal through a line of props and gives more central loading of the conveyor belt. The drive to the folding flight loading conveyor is by chain from a sprocket underneath the sprocket driving the coalcutter chain. This, together with bringing the belt underneath the machine, raises the cutting jib above the floor, which is a considerable disadvantage.

150. The loader was seen at work in the Anna Seam at the Pattberg Mine under the following conditions—

Depth from surface	440 yds.
Inclination	5 degrees.
Thickness of coal	6½ ft.
Character of coal	Friable.
Nature of roof	16 ft. tender shale overlain by 50 ft. of hard sandstone. The immediate roof breaks with regularity every 66 ft. of face advance despite solid packing.
Timbering distance	See Fig. 29.
Nature of floor	Shale.

151. The face, which was about 200 yds. long in the line of dip and rise of the seam, was packed solid by the belt type dirt throwing machine " Kreiselschleuder."

152. An underbelt 2 ft. wide running at a speed of 200 ft. per minute was used to serve the cutter loader on the loading shift, and also the dirt throwing machine on the packing shift. (Details of both operations are illustrated in Figs. 29 and 30.) The conveyor had a 27 H.P. driving gear at each end, and its structure was adapted for supporting the rails on which the mechanical packing machine travelled along the face.

153. When seen in operation the loader was travelling at a rate of approximately 16 yds. per hour, and was performing satisfactorily with the help of two men with pneumatic picks who brought down the overhanging coal. This assistance is considered essential for the loader, and was most effective in bringing the coal down and in breaking the large lumps. It was seen that an appreciable amount of coal was left on the floor owing to the position of the cutter jib on the machine. Three men with pneumatic picks were lifting the floor coal, which was obviously a hindrance to speedy setting of the permanent supports. The cutter bar with its shearing disc was kept in a fixed position and was not being raised and lowered when seen.

154. A very simple and effective device was used for temporarily supporting the goaf ends of the roof straps as they were positioned in the new track behind the cutter loader. This temporary support was first rested on the lower and larger area section of the yielding type steel prop ; the roof strap was placed in position on the temporary support, and both were raised to the height required, where the temporary support was secured to the steel prop by tightening a wedge by hand.

155. The distribution of personnel during the loading shift is shown in Fig. 29, which also illustrates the timbering arrangement. When the loading of the face is completed, mechanical packing proceeds with the face belt conveyor in the same track. During packing the loader is dismantled and flitted to the other end of the face in the track adjacent to the coal face. Fig. 30 gives details of the packing operation.

156. The average distance cut and loaded per shift at the time of our visit was 65 yards. The performance in normal times was said to be 98 yards. The machine is credited with saving 2.5 manshifts per 100 tons in the Anna Seam, in which the normal production per pneumatic pick face worker is 10 to 12 tons per shift.

157. There are two Eickhoff Rheinpreussen cutter loaders at the Pattberg Mine. The second was on the surface for overhaul prior to being returned to service, probably in another seam where the coal is harder and where 4 to 5 manshifts per 100 tons of output had been saved in an earlier application.

CUTTER LOADER TO BERGBAU VEREIN SPECIFICATION

158. Following the earlier experiences with cutter loaders, the technicians of the Mining Association in Essen designed modifications which were incorporated in machines used in the Donetz Coal Basin during the period of occupation.

159. The problem of loading the coal on to the face conveyor through the row of roof supports adjacent to the machine obviously received much thought. The Eickhoff Rheinpreussen design with the carrying belt underneath the machine overcame this difficulty, but only one loader could be used for each face conveyor, i.e. two loaders could not work in tandem on to the face conveyor. This limited the length of the cutter loader faces.

160. The first Bergbau Verein modification included a telescopic endless belt immediately behind the machine to enable coal to be discharged through the roof supports on to any type of face conveyor, including the shaker, by a short cross conveyor. This short cross conveyor unit remained in a fixed position until the loader had advanced sufficiently for it to be moved forward to the next gap between supports.

161. This design was later discarded in favour of the arrangement illustrated in Fig. 31. A spiral gummer—following British practice—was fitted to deal with the holings from the undercut, and a larger spiral was used to convey the main body of coal sideways and push it up a ramp and through the props on to the face conveyor. This large spiral was driven at the face end to give maximum freedom of flow of coal at the discharge end ; it was also free to float within limits at the discharge end to accommodate irregularities of the flow of coal when passing roof supports.

162. This machine could not be seen in operation, nor were performance details available, but it was said to have given good results in a mine in the Donetz Coal Basin.

DEMAG CUTTER LOADER

163. This machine, illustrated in Fig. 32, was designed for use in seams varying from 3 to 4 ft. in thickness. It consists of a 40 H.P. coalcutter, approximately 16 ins. high, to which is attached a loading unit driven by a 20 H.P. motor. (A non-adjustable shearing jib, also driven by the 20 H.P. motor, cut to within 8 ins. of the roof in the example seen.)

164. The loading arms have a similar action to those on the British Hugh Wood loader. They push the coal up a short ramp on to the underbelt conveyor, which is an essential part of the installation. A flap gummer, which is fitted on the coalcutter, moves substantially at right-angles to the long axis of the machine, pushing the holings towards the face belt on the forward stroke, and folding up on the return stroke. The loader is unidirectional in operation, and has therefore to be flitted. A 20 ft. stable is required at the top end of the face, and a 13 ft. stable at the bottom end.

165. The machine was installed at the Niederrhein Mine in the Geitling Seam, which has the following characteristics—

Depth from surface	490 yards.
Inclination	3 to 5 degrees.
Thickness of coal	3′ 3″
Character of coal	Medium hard.
Output per shift per pneumatic pick	9 tons.
Nature of roof	Hard shale with at times a parting of 4 to 5 ins. above the coal. Roof straps are used.
Nature of floor	Hard shale with undulating surface.

166. The face, 148 yds. long, was loaded with regularity in a shift. Allowing for stable holes, the length travelled by the machine was 137 yds. and the output from the machine was 230 tons per shift. The rate of travel along the face was from 27 to 33 yds. per hour, and the following personnel were employed for the operation :—

Driver (behind machine)	1
Haulage (ahead of machine)	1
Setting catch props	1
Setting permanent roof supports	3
Cleaning coal along face conveyor	1
Handing props over conveyor	1
Cleaning floor coal behind loader. (Much coal was left owing to undulating floor)	3
TOTAL	11
Flitting machine on backshift	3

167. During the period in which it was used, the machine loaded approximately 30,000 tons with a saving varying from 3.26 to 3.41 manshifts per 100 tons. It is now out of service owing to shortage of labour at the mine, where all the available manpower has been concentrated in the more profitable 6 ft. seam. A visit was made, however, to the Geitling Seam to see a trial run of the loader in the stable hole at the bottom of the face. The action of the arms appeared to be very effective, but this may have been partly due to the angling of the arms at both ends of the loader element.

168. German technicians expressed the view that in the Ruhr conditions the three cutter loaders described can travel at a faster rate than that at which the roofs can be properly supported by the maximum number of men who can effectively work immediately behind the loaders.

THE COAL PLOUGH

169. This appliance consists basically of a cutting edge which is pulled along the face by rope haulage, and which shears a 30 cm. (11.8 in.) strip of coal off the solid. The coal so loosened is ploughed on to a robust chain conveyor which is held rigidly in a straight line parallel with the face ; the conveyor forms the guide for the coal plough. Fig. 33 illustrates the simplest form of coal plough in the present stage of its development. The rope pull is transmitted by means of the bar "A" to the main frame " B," which carries the shearing edge and the main plough. Unit " C," pivotally mounted on the main body " B " and free to float in the vertical plane, is an advance plough which guides the main plough and clears a 40 cms. (15.8 ins.) wide track between the face conveyor and the solid coal. This track is an essential part of the scheme, as is also the advance floating plough.

170. The height of the cutting edge or shear blade varies from a third to a half of the height of the seam, and thus the coal above the shear blade must either collapse as the plough travels along the face, or be brought down by other means. Hence the need for the clearance track of 40 cms. (15.8 ins.), and the floating plough unit " C," to load the coal which has been left behind the main plough in its previous passage along the face.

171. Experience has proved that the operation is most successful when the height of the shear blade is kept to a minimum consistent with effective getting of the coal. The higher the blade the greater is the outwards turning moment from the face which, above the conveyor structure, is counteracted only by the weight of the plough. The seam must, therefore, have a good roof parting, but it is claimed that up to a point the roof parting depends largely on the pressure fractures induced by the method of controlling the roof. Pneumatic picks are necessary for very sticky tops, but sometimes the trouble is overcome by taking 2 or 3 undercuts with the coal plough to induce the tops to collapse. When this is done, a cutting blade is required on top of the plough to prevent jamming under the overhanging coal, but the first expedient, where difficulty with roof coal is encountered, is to increase the height of the shearing edge.

172. The pull required to operate the coal plough varies. Figures as high as 45 tons have been recorded, but in the economic applications the maximum force measured for stripping 30 cms. (11.8 ins.) of coal is 16 tons, the normal being from 5 to 6 tons. When the force is 5 tons, there is an outward thrust against the conveyor of approximately 1 ton, but heavier outward thrusts can

develop in advance of the shearing blade if cleavages in the coal produce a piling up of the coal ahead of the blade. This is another reason for the 40 cm. (15.8 ins.) wide track between the solid coal and the conveyor, and for the advance floating unit " C."

173. Experience has shown that the pull required bears some relation to the natural cleavage planes in the coal, but this aspect of the application has not yet been fully analysed, and no definite information is available in regard to the best line of face. Nevertheless, a few data are known. The plough works best when striking the cleat in direction "A" in Fig. 34. In one test the comparative figures in directions "A" and " B " were 8 and 15 tons respectively.

174. It is thought that the best line of face may depend on the distance between the natural cleavage planes. For relatively large distances an angle of 45 degrees to the cleavage planes is suggested ; if the cleavage planes are close together a lesser angle is to be preferred, but this aspect of the application is certain to be the subject of early investigation.

175. In suitable conditions the rate of travel of the plough along the face is from 5 to 7 metres (16.4 to 23 ft.) per minute, which in a 6½ ft. thick seam is equivalent to loading coal at a rate of from 4 to 5 tons per minute. The plough loads in both directions, i.e. the right and left hand units are symmetrical (see Fig. 33). The two units are pivotally mounted at the centre, and the main frame portions " B " are made as heavy as possible to assist in holding the floor, and to counteract the outwards turning moment.

176. The shear blades—steel faced with hard alloy—are removable for sharpening, which in normal coal is required about every four weeks. For hard and difficult subjects manganese steel blades are suggested.

PERFORMANCE OF COAL PLOUGH

177. Following are three brief descriptions of coal plough installations :—

(1) *Hannover Mine : Rottgersbank Seam :*

Depth from surface ..	1,040 yds.
Inclination	25 to 30 degrees.
Thickness of coal ..	5′ 4″ including two thin variable dirt bands with good partings.
Character of coal ..	Friable.
Nature of roof ..	Strong sandy shale.
Timbering distance ..	Approximately 5 ft. each way.
Nature of floor ..	Hard shale—even surface.

178. The face was 263 yds. long, the top half being packed solid and the bottom half caved. The layout and disposition of the plant are shown in Fig. 35.

179. A Demag double chain conveyor was in use, the 50 H.P. drive being at the top end owing to the high inclination. Two 20 H.P. haulages pulled the coal plough up and down the face at a rate of 7 metres (23 ft.) per minute. The shear blade was approximately one-third the height of the seam, and the plough appeared to remove the 30 cms. (11.8 ins.) strip of coal with comparative ease (the coal was friable and there was a good roof parting). High goaf side spillplates were fitted to prevent spillage over the conveyor, which was moved forward, as required, by air cylinders.

180. Under normal conditions the results obtained on this face from the coal plough are said to be as shown in Fig. 36. Figures of pneumatic pick performances are included for comparison. These data—obtained officially at the mine—do not appear to be accurate, because the packers and rippers must have more work to carry out on the coal plough face owing to the increased rate of face advance. Nevertheless, a substantial economy per 100 tons of coal produced is indicated.

(2) *Hannover Mine : Blücher Seam :*

Depth from surface ..	1,040 yds.
Inclination	25 to 30 degrees.
Thickness of coal ..	5 ft.
Character of coal ..	Friable.
Nature of roof ..	Moderately tender shale.
Timbering distance ..	Approximately 5 ft. each way with straps both ways.
Nature of floor ..	Hard shale with even surface.

181. The face in this seam was also 263 yds. long with a double chain conveyor and 50 H.P. drive at the top end.

182. A Flottmann Kohlen-Hammer, which is a percussive edge type of machine (see Fig. 40) taking a 40 cms. (15.8 ins.) strip of coal, had just been installed. The shearing or cutting edge was slightly more than one-third of the height of the seam and the coal above was collapsing beautifully as the plough moved along the face at a rate of from 19 to 22 ft. per minute.

183. The machine has only recently been installed at the mine and no performance figures were available.

(3) *Friedrich Heinrich Mine : Präsident Seam :*

Depth from surface ..	490 yds.
Inclination	8 to 10 degrees (to the goaf on face inspected).
Thickness of coal ..	6½ ft.
Character of coal ..	Soft and friable.
Nature of roof ..	Good. : 3 to 13 ft. of shale with sandstone above.
Timbering distance ..	See Fig. 46.
Nature of floor ..	Hard and even.

184. The face was 218 yds. long advancing to the rise, and the soft friable coal tended to fall over in slabs even when the coal plough was a considerable distance away.

185. The face conveyor was a Westphalia Lünen double chain scraper with two 50 H.P. electric motors and one 50 H.P. air motor.

186. A rope pulled plough was in use with a special rope haulage system devised by the officials of the mine to avoid tensioning and other difficulties experienced with the standard arrangement. The arrangement is illustrated in Fig. 37.

187. A 33 H.P. haulage drives a surgewheel which pulls the plough backwards and forwards along the face and eliminates the inherent complications when two haulages are used for this purpose. Compressed air winches for maintaining tension on the two ends of the rope are at both ends of the face. These winches, which are always under air pressure and do not require manual control, act more or less as air cylinders by taking up slack and maintaining even tension in the ropes on the slack side of the surge wheel irrespective of direction of travel or reversal of the coal plough.

188. Small drums, with auxiliary ropes, are fitted on the shafts of the tension winches and can be used by means of clutches to pull the wedge (or sledge for moving the conveyor forward) through the last 33 ft. to the end of the conveyor. This is necessary owing to the length of the coal plough and the method of trailing the wedge behind it.

189. At Friedrich Heinrich the coal plough takes a 30 cms. (11.8 ins.) cut for only half the face, the cut on the remaining length being reduced to 10 cms. (3.9 ins.). On the return journey the figures are reversed, and thus the average advance per travel across the face is 20 cms. (7.9 ins.). The important point is that the 10 cms. (3.9 ins.) cut is taken from the middle to the end of the face in each direction, which means that the plough can be immediately reversed at the end of the face without waiting for the setting of roof supports. In the meantime the roof supports on the other half of the face are advanced 40 cms. (15.8 ins.) ; this in itself is an advantage because in any event the supports would require to be advanced for a 30 cms. (11.8 ins.) cut. More continuous operation is thus obtained. (It is also claimed that the taking of a thin cut on each alternate journey minimises the difficulties which may develop owing to the incidence of hard knobs of coal).

190. A saw tooth system of roof supports has been developed at Friedrich Heinrich (see Fig. 46) by which only every third prop is advanced each time the conveyor is moved forward. The distance between bars is adjusted according to the nature of the roof, and thus the system adapts itself to setting only the number of props required for the area of roof exposed despite the comparatively shallow cut of the coal plough.

191. Very good performances have been obtained with the plough at Friedrich Heinrich. Under normal conditions of labour in 1944 10 cuts were obtained in an 8¾ hour shift. In a small section cut off by a fault where the face was only 93 yards long, 16 cuts were recorded in one shift.

192. At the present time the output per shift from the 218 yds. face is 400 tons, the plough travelling across the face five times. The following manshifts are employed on a 24 hour cycle with one coaling shift :—

Forming top and bottom roads	15
Packing face	16
Moving heavy plant and adjustments on night-shift	7
Coaling on Dayshift :	
Plough haulage drive	1
Travelling face with plough	1
Working at top end of face with pneumatic picks	2
Working at bottom end of face with pneumatic picks	3
Roof supports	23
Removing stones from conveyor	1
TOTAL	69

193. This is equal to 69 manshifts for 400 tons or 5.8 tons per manshift. (It was said that in 1944 only 13 men were employed for the setting of the roof supports, and that the total number of manshifts employed on the 8¾ hour shift was 53 for an output of 850 tons, i.e. 16 tons per manshift. The output per pneumatic pick in this seam under normal conditions is 12 tons per shift.)

SPHERE OF APPLICATION

194. The initial success of the coal plough in the first competition obviously indicated attractive possibilities, and further development was encouraged by a supplementary competition to promote rapid introduction of the ploughing process, which was launched on the 1st June, 1944. Much practical work has been carried out on, and much thought has been given to, this form of power loading.

195. Experience has proved that good results are seldom obtained from the coal plough when a face is starting away from the solid. The pull required during this period is much greater than when the face has advanced sufficiently for the action of the roof to become normal. Rope pulls are higher on faces which are caved than on faces which are packed. Accurate observation has also shown that the rope pull increases as each cut is removed during the loading shift, which indicates that the best method is to take a few cuts per shift on a long face, and to control the roof by uniform packing to maintain pressure fractures in the coal.

196. So far, full scale tests have only been carried out in seams where the coal is not hard, the output per pneumatic pick is high, and pressure fractures can be induced in the coal by roof control. The application is satisfactory under these conditions, resulting in a saving of from 6 to 11 manshifts per 100 tons of coal produced, but only 5 or 6 units were in operation during the visit, although 12 were formerly in use. The extent of the economic application of the appliance is still under investigation, but the Bergbau Verein technicians expressed the opinion that ultimately this process could be applied to 20 per cent. of the coal in the flat formations in the Ruhr.

197. From the information so far obtained, it is thought that the coal plough can be economically used where the output per pneumatic pick is more than 8 tons per shift. Where the output is from 6 to 8 tons, the use of the plough depends on the prevailing conditions, but below 6 tons the use of the simple rope pulled plough is considered unsatisfactory. This figure is interesting, because it coincides with the point at which, in the opinion of the German technicians, coal cutting with shotfiring becomes an economic necessity.

FURTHER DEVELOPMENTS OF THE COAL PLOUGH

198. Apart from a brief description of a Flottmann Kohlen-Hammer in the Blücher Seam at the Hannover Mine, reference has so far been made only to the simplest form of coal plough (Fig. 33) which is pulled by rope, and shears or ploughs a 30 cms. (11.8 ins.) thick slab of coal off the face. This machine has been applied only under the most favourable conditions, but designs have now been developed for attacking harder coal and for taking slabs up to 70 cms. (2′ 4″) in thickness by the use of percussive action on the shearing, or wedging, edge of the plough.

OSCILLATING MACHINES

199. Two different machines (Figs. 38 and 39) were built to obtain this effect by running out-of-balance rotors at speed to oscillate the main body of the machine and so develop blows equivalent to pressures of from 100 to 200 tons on the cutting or shearing edges. The results have not been satisfactory on the whole despite the fact that one machine (Fig. 38) operated over a long period with a good performance.

200. A careful analysis of the performance of the machine illustrated in Fig. 39 (which weighs approximately 3 tons) proved that the effort was being almost wholly dissipated by the following losses :—

In bearings	20 to 30%
In friction on the floor	25%
Friction loss owing to oscillation against side pressure resulting from shearing blade	15%
Total approximately ..	70%

201. In addition there was the further loss of approximately 10 per cent. in the conical fastenings of the renewable picks on the shearing or cutting edge (as obtains in a pick hammer), and thus the effective percussive action of the large oscillating machine was only a very small proportion of the effort expended.

PERCUSSIVE EDGE MACHINES

202. Difficulties were experienced in the harder coals with jamming, climbing, tilting and heavy side pressures, and the view is now generally held that more effective progress will result from the machines which do not oscillate bodily but have shear blades or percussive edges independently vibrated by air cylinders incorporated in the structures.

203. Examples of these percussive edge machines are illustrated in Figs. 40 and 41. Both are designed for cuts of 40 cms. (15.8 ins.) and have the appearance of effective ploughing units. The machine illustrated in Fig. 41 was seen on test on the surface cutting through wood planks with a rope pull of 7 tons. These types of the percussive edge machine have the advantage that they cannot be drawn sufficiently far into the coal by the rope winch to suppress the oscillation in the manner experienced under certain conditions with the oscillating machines illustrated in Figs. 38 and 39.

CATERPILLAR TRACTOR MACHINE

204. Attention is also being paid to the elimination of the 21 mm. (0.8 inch) diameter or larger ropes used on the faces and the advanced headings necessary to accommodate the large haulages which must be situated in the gate roads. The heavy pulls experienced require special haulages and although very effective constant pull haulages have been designed they are very cumbersome. In addition, as each 30 cms. (11.8 ins.) or 40 cms. (15.8 ins.) strip of coal is ploughed off the face the pulling points at both ends of the face have to be moved forward. The secure setting of turn pulleys to withstand pulls up to 20 tons through a right-angle is a major task requiring well designed adjustable frames if the work is to be done expeditiously. For these reasons, the trend of progress is towards self-propelled ploughing machines.

205. Fig. 42 illustrates a design developed for this purpose by Knapp, but which has not yet been put into practice. The machine consists of caterpillars held by pressure against both roof and floor and, incidentally, it can accommodate a roof plough for bad roof partings. It is thought that difficulty might be experienced in guiding the machine, but in general it is considered that the principle is sound.

"RESONANCE TRACTOR" MACHINE

206. The problems here described have induced designers to explore a novel way of propelling the plough along the face. A new development which may be of major importance for this work is a "Resonance Tractor."

207. It is not possible to bring the coal itself into resonance because its resonance is very low and variable; also the damping effect of the mass is too high, and so far as is known, coal cannot be broken down by its own resonance. The designers, however, consider that the application of a "Resonance Tractor" to the coal plough will greatly broaden its sphere of operation.

208. The "Resonance Tractor" can achieve a pulling force which is a multiple of the weight of the machine; and, within limits, it is self-adjusting with regard to speed and force. As the built up energy is either transformed into speed of advance or increased pressure, the tractor travels fast when the resistance is low, but slows up and pushes harder when the resistance increases. This is a basic requirement of a good coal plough.

209. The Demag "Resonance" coal plough which is illustrated in Fig. 43 has not yet been given a practical test owing to the lack of certain components. Experiences with coal ploughs and some of the developments of the coal plough in the Ruhr are described in Appendices Nos. 11 and 12.

TESTING AND CORRELATION OF COAL SEAMS WITH REFERENCE TO THE COAL PLOUGH

210. The success achieved in soft coals, in which the pneumatic pick performance is already high and where fractures can be formed in the coal by controlling the latent roof pressure, coupled with the initial difficulties experienced in the harder coals, has clearly shown the necessity of a systematic investigation of the physical characteristics of the various coal seams to determine the sphere of economic employment of the coal plough. A testing unit (see Fig. 44) has been developed for this purpose, and its use may have far reaching results in analysing the expenditure of energy required to get coal in any seam. No experiments have yet been made with the appliance.

211. The appliance is a simple unit consisting of an oil cylinder with a piston fitted with a wedge shaped blade. Pressure oil is supplied from a power driven pump and a pressure gauge is included in the circuit for measuring the point at which the coal is split. The angle and line of fracture of the coal is to be recorded in each case, also a figure of hardness based on the speed of drilling with a rotary drill and a hard non-ferrous alloy bit at a pre-selected constant pressure.

212. The tests are to be made on each face in a stable hole prepared carefully by hand with a pick and saw so as not to disturb the remaining coal. Horizontal saw cuts are to be formed above and below the blade for the first measurements, which will be taken at various heights above the floor. Corresponding figures will be obtained without the saw cuts, and these will show the additional force required to shear the coal laminations.

213. Tests will also be made in regard to the angle of the blade, the depth of cut, and the relation of the direction of attack to the line of natural cleavage in order to establish a routine which will provide the necessary comparative data. When the testing routine is determined and correlated with the present production results on coal plough faces, a simple and definite method of ascertaining the economic sphere of application of the coal plough under any conditions will be established. Indeed, such a comparative analysis of the physical properties of coal seams may well provide valuable data for other purposes.

FACE CONVEYORS FOR POWER LOADING

FACE CONVEYORS FOR CUTTER LOADERS

214. The two cutter loaders inspected underground, i.e. the Eickhoff Rheinpreussen and the Demag, both work in conjunction with underbelt conveyors which, except for minor constructional details, are basically of the type used in this country.

FACE CONVEYORS FOR THE COAL PLOUGH

215. The most important item in the application of the coal plough is probably the face conveyor, which must have certain characteristics, e.g. :—

(1) The structure must be such that it can be held rigidly in a straight line to form a guide for the plough.
(2) The structure must be able to withstand the heavy side pressures from the plough.

(3) The joints must allow sufficient flexibility for moving the conveyor forward by power while it is running.
(4) High capacity, and
(5) Long length.

216. Heavy structures are used for this work, hence the name "Panzerförderer" or armoured conveyor. All the structures have similar characteristics, achieved in slightly different ways. A section through a typical trough is shown in Fig. 45. Strength of section is apparent.

217. The joints are relatively simple as, for example, in the structure shown in Fig. 45. In this case, wedge shaped pieces on the adjacent trough register in the recesses shown by "A." The two troughs are coupled together by bolts through holes "B," the bolts having a certain endwise tolerance. The centre plates are overlapped to suit the direction of travel of the chain to an extent which ensures that the overlap is maintained when the structure is being flexed towards the face by power. The limit of flexing is determined by the tolerance in the loose bolts.

218. Double chains are used with cross bars spaced at intervals of approximately 3′ 4″. 18 mm. (0.7 in.) annealed open link standard type is most common, although studded chains are also used. Chain speed is 200 ft. per minute, and the maximum rated capacity 250 tons per hour.

219. Two driving gears, one at each end of the conveyor, are always used in flat seams. Each gear is normally of 50 H.P. In the most modern installations for long lengths there are two 50 H.P. electric drives with fluid clutches, and one 50 H.P. compressed air motor which can be engaged by mechanical clutch. The air motor is used if there are overloads and starting difficulties, and for slow running and adjustment of the conveyor on the backshift.

220. The maximum length of this type of conveyor under favourable conditions is said to be 274 yds. for soft coal, and 197 yds. for hard coal.

221. There are two principal methods of advancing the conveyor by power :—

(*a*) by compressed air cylinders at intervals along the structure, and
(*b*) by pulling a wedge shaped sledge behind the plough and between the conveyor and the roof supports. This method is illustrated in Fig. 46.

222. Each method has its own peculiar advantages, and both appear to be satisfactory. In the case of the air cylinders with their own sprags there is no interference with the normal roof supports because these are not subjected to the outwards thrust of the coal plough transmitted through the conveyor structure. When the wedge shaped sledge is used, the face supports take the reaction of moving the conveyor structure forward, and also the stress of maintaining alignment of the conveyor against the outwards thrust of the plough. On the other hand, a supply of power is required along the face for the air cylinders, which require resetting at intervals. The cushioning effect of the air cylinders is of some importance, for it is at times advantageous for the coal plough to deviate slightly if an unduly hard irregularity is encountered.

223. A third method of advancing the conveyor by power has been contemplated—see Fig. 47. Suitably held racks, or ratchet strips, are stepped forward alternately by the action on levers of a member pulled by the plough along a guide rail on the goaf side of the scraper chain conveyor.

THE RESONANCE CONVEYOR

224. Owing to the difficulties inherent in the use of scraper conveyors on long faces (e.g. the great accuracy required in setting, and the high consumption of power and the limited length) an effort is being made to find an entirely different type of conveyor which will be more suitable for power loading on longwall faces.

225. The latest development in this direction is the so-called "Resonance" conveyor. Experimental units 6 metres (19.7 ft.) long, 260 mm. (10.2 ins.) high and 850 mm. (2.8 ft.) wide have been built, and have given very good performances on their initial trials on the surface.

226. A somewhat similar type of conveyor attached to a secure foundation is used on screening plants. In this new application the resonance is self-contained in the unit and the normally unbalanced forces are absorbed so that the conveyor can lie on the floor without any tendency to dance.

227. The main frame of the unit is 6 metres (19.7 ft.) long with a 2 H.P., 3,000 rev. motor drive in the centre. The driving gear can be changed to the other side, but the unit cannot otherwise be dismantled in underground service. The ends of the 6 metres (19.7 ft.) long units are built so that they register with other units in tandem. The joints permit a radius of curvature of 65 yds. in the horizontal plane; in the vertical plane, an undulation 30 cms. (11.8 ins.) high can be accommodated in 18 metres (19.7 yds.), i.e. by three 6 metres (19.7 ft.) sections.

228. The carrying portion of each 6 metres (19.7 ft.) section is divided in the centre into two conveying troughs each 3 metres (9.9 ft.) long which overlap and move in opposite directions when vibrating. The central drive is a torsion spring shaft oscillating on an axis and pushing the 3 metres (9.9 ft.) sections apart by means of levers, the movement being 10 mm. (0.4 ins.) to each side twelve times per second, i.e. 720 oscillations per minute.

229. The 3 metres (9.9 ft.) long carrying troughs, of 3 mm. (0.12 ins.) thick pressed steel sheet, are each attached to the tops of six levers set to a pre-determined angle. There are three levers on each side of the trough, and the bottom of each lever is rigidly fixed to a torsion bar. The torsion bar, which is supported at the lever end by a bearing in which it is free to rotate, is fixed to the frame on the opposite side at the other end in a rubber mounting. The rubber is vulcanised to the torsion bar and to its supporting journal in the main frame. Suitably disposed weights are attached to the oscillating levers for balancing the otherwise unbalanced vertical components of the angular motion of the trough.

230. The design appears to be such that the conveying members are vibrated at their own resonance or frequency.

231. The initial tests, which have been very satisfactory, indicate that it will be possible to convey at a high rate against a gradient of 12 degrees. The following results have been recorded :—

Gradient.	*Power consumed per 6 metres (19.7 ft.) section.*	*Oscillations per minute.*	*Rate of Conveying Tons/Hour.*
0°	1.79 H.P.	720	160
6° against	1.84 H.P.	720	150

232. The power required to convey the coal on the level was 0.86 H.P. per 6 metres (19.7 ft.) section. The rate of travel of the coal on the level was 48 cms. (1.58 ft.) a second.

233. It is thought that this type of conveyor will be much cheaper to maintain than either a scraper or a belt.

CONCLUSIONS AND RECOMMENDATIONS

234. (i) Longwall experience in the Ruhr provides no reliable guide to longwall retreating practice under British conditions. The view that longwall retreating will be advantageous in the Ruhr for depths exceeding 1,100 yds. appears to be sound from the aspect of ventilation, but is not in accordance with British experience of maintenance of roadways at depth.

(ii) The wide use of the pneumatic pick is basically due to the physical characteristics of the seams. The measurement of the effort required to break down a cubic metre of coal in each seam has defined the field of application of pneumatic picks in the Ruhr Coalfield.

(iii) Arrangements should be made to obtain first-hand knowledge of progress in the further development of the yielding type steel supports.

(iv) We recommend that mechanical packing, which is effective under Ruhr conditions, should be developed under suitable conditions in British mines without delay.

(v) The most important development in face conveyors for hand loading is the double chain scraper conveyor for long faces. We recommend that one of these conveyors should be brought to Britain for detailed examination and application under British conditions.

(vi) The provision of mains operated lighting at the coal face is common in the Ruhr and owes much of its success to the relative absence of shotfiring.

(vii) The standard of illumination provided at the coal face by mains lighting is much higher than has ever been attempted in this country.

(viii) The use of 40 or 60 watt lamps comparatively closely spaced has been made possible by reducing glare. Consideration should be given to the development in Britain of toughened opal glass with low light loss.

(ix) The circuit adopted has secured a fairly uniform degree of illumination throughout the whole length of face. This arrangement enables actual working voltage and lamp voltage to be more closely related.

(x) The link-up " plug-in " system of assembly removes many difficulties associated with the daily move up and maintenance of the installation. We recommend the adoption of the " plug-in " system in this country.

(xi) Gate conveyor equipment in the Ruhr is not up to British standards. The steel belt and steel-plate conveyors, which have been developed owing to the shortage of rubber, are not as satisfactory for gate conveyor service as the troughed rubber belt conveyor.

(xii) The layout and equipment of loading stations are sufficiently far in advance of British general practice to prove that the flow of coal into the tubs and the passage of the tubs through the loading station should be under mechanical control where large outputs are loaded.

(xiii) Despite the interest created by the power loading competitions, less than 0.4 per cent. of the total quantity of coal has been loaded mechanically during the last five years.

(xiv) The development of cutter loaders in the Ruhr has, to a degree, been on the lines initiated in this country, but is not so far advanced. The details of the Demag thin seam cutter loader are of interest because the loading action appears to be effective within the restrictions imposed by height limitations in thin seams, and we recommend that the drawings should be made available to the designers of cutter loaders in this country.

(xv) Experience in the Ruhr over the last three years has proved that the difficulties encountered in using the coal plough, and overcome under the most favourable conditions, progressively increase as the coal becomes harder. The forces to be mastered in the majority of seams are so little known, and the sphere of application of the plough is as yet so undefined, that the German technicians have requested permission to make a thorough investigation with the testing unit described. A parallel investigation is recommended in Britain. Such an investigation would :—

(*a*) Provide a valuable comparison of the physical characteristics of British coal seams, so far as the getting of coal is concerned.

(*b*) Ensure that full use is made of the experience already gained in the Ruhr.

(*c*) Eliminate the unknown factors in Britain and ensure the success of coal plough installations.

(xvi) We also recommend that a standard German coal plough complete with ancillary equipment should be obtained for practical test in a seam in Britain chosen after the investigation proposed under (xv).

(xvii) The development of the coal plough in the Ruhr should be closely studied, and complete control should be obtained of the resonance tractor.

(xviii) The removal of a narrow strip of coal from a longwall face by power (e.g. by using a coal plough as in the Ruhr) as a method of coal getting has been the subject of much thought and experiment in Britain during the last few years. The system is of great interest because the power loading operation can be made independent of the work of supporting the roof—even if this means increasing the number of manshifts for setting supports—which points the way to continuous power loading and to mechanising the work of supporting the roof.

(xix) We recommend that one of the special double chain conveyors developed for use with the coal plough should be brought from Germany for the application proposed under (xv).

(xx) The Resonance conveyor is worthy of the closest attention, and we strongly recommend that it should be further developed in Britain.

CHAPTER III

The System of Driving Roadways in Stone

235. A system of haulage arteries in stone at each winding level is an essential of horizon mining as practised in the Ruhr (see Chapter I). The progressive deepening of the workings entails the formation of a new horizon at a greater depth during normal coal production from the upper level, in addition to the extension of the workings on the production level. The driving of roadways in stone is, therefore, an important factor in horizon mining, and in the best practice the rate of development is adjusted to maintain the requisite number of stone miners in regular work.

236. The total length of roadways driven in stone in a leasehold mainly depends on the physical characteristics of the strata, including the inclination and the number and distances apart of the workable seams. The sizes of the roadways depend on their functions. The lateral drifts are generally 14 ft. wide by 9 ft. 6 ins. high or 15 ft. 9 ins. wide by 10 ft. high ; cross measure drifts are either 12 ft. wide by 8 ft. 6 ins. high, or 14 ft. wide by 9 ft. 6 ins. high. The longest mine normally driven without a staple shaft connection is of the order of 1,000 yds., although there have been isolated examples where the maximum length was 1,600 yds.

237. The average number of manshifts employed for the driving of stone mines and the handling of the rock from these mines is 40 per 1,000 tons of coal produced. 18,000 men, or 7.56 per cent. of the total underground personnel, are employed in this work. During a normal year, 380 kilometres (236 miles) of stone mines are driven, and as the output is of the order of 125,000,000 tons, approximately 530,000 tons of coal are mined per mile of stone mine driven, or 300 tons per yard.

238. Approximately 80 per cent. of the stone mines in the Ruhr are driven by hand methods, and indeed there appears to be a school of thought which favours low rates of advance with little expenditure on machinery. The small percentage of underground personnel required for the work may have had a bearing on this, especially as other phases of mining have, up to the present, provided greater opportunities for the saving of manpower. Nevertheless, the arduous nature of the work of hand drilling and of hand filling rock, particularly into the larger tubs, has focussed some attention on the problem, and considerable progress has been made in mechanising the driving of stone mines. The most important developments are in connection with drilling technique.

239. A comprehensive description of the driving of roadways in stone in the Ruhr is given in Appendix No. 13, and the following notes are based on observations of this practice and on discussions with German technicians.

MECHANISED STONE DRIFTING

240. An endeavour is made to select the depth of shot-holes to ensure that the cycle of work involved in advancing the roadway a full cut is completed in a shift. This enables shots to be fired between shifts. Thus the routine in any one shift consists of—

(*a*) Loading the rock,
(*b*) Setting supports and advancing track and ventilation tubes, and
(*c*) Drilling.

241. There is a certain amount of overlapping of the operations which include the forming of the finished road adjacent to the working face. Work proceeds on two shifts per day in all except the very long mines, in which three shifts are worked owing to the cost of the plant and of ventilation.

MECHANISED LOADING

242. The most common type of power loader in hard headings in the Ruhr is the scraper bucket or slusher, although other types have been adapted to suit particular conditions. On the whole, however, it may be said that loaders for stone mines are, as yet, only in the development stage.

243. The Eimco-Finlay type has been used in some of the smaller crosscuts, and the gate-end loader has been modified to facilitate hand loading in the larger roadways. The receiving boot of the gate-end loader has been so shaped that it can be forced by rope haulage into the pile of debris, which is then raked by hand on to the return end of the scraper chain conveyor. In one example (Fig. 48), a compressed-air operated rake is fitted.

244. The most important development along standard lines for the large locomotive haulage drifts is the " Stoss-schaufellader " (stone mine shovel loader), which is illustrated in Fig. 49. This machine consists of an exceptionally robust shaker 17½ yards long and an elevator to raise the material and deliver it in to the tubs. The shaker is fitted with a shovel 8 to 11½ ft. wide which rests on a roller and not on the floor. Two double-acting air engines drive the shovel and troughing, which is of heavy section abrasion resisting steel. The whole is fed forward as required into the pile of debris by an auxiliary rope winch mounted on the loader, the end of the rope being fastened to the rails. The rate of shaking is reduced when feeding into the pile and, when loading at full capacity, the complete unit is securely clamped to the rails by air-operated mechanism as illustrated in Fig. 49. An interesting additional feature is the use of compressed air to operate a ram to push the loaded tub from under the delivery head of the elevator, and the empty tub into position as required. A transverse roller carriage is used to transfer the empty tubs to the full track.

245. The " Stoss-schaufellader," which has a peak capacity of 100 to 120 tons per hour when handling rock in a level roadway, gives very good results except when the debris is wet. Under dry conditions, it is said to work satisfactorily against a gradient of 4 degrees. Average air consumption at a pressure of 60 lbs. per square inch is of the order of 570 cubic feet of free air per minute.

246. One of these loaders was seen in operation. It was effectively handling the rock, but it was noticed that the rock had been shot into small pieces and that, in addition, two men with pneumatic picks were continuously employed in breaking up the largest lumps.

TRANSPORT OF ROCK

247. Neither overhead wire nor Diesel locomotives can be used in a dead end heading. Therefore, tubs from a haulage road in a normal ventilation circuit are hauled to and from the working face of a stone mine by a compressed air locomotive (if available), or a battery locomotive (where permitted), or by rope.

SETTING SUPPORTS

248. The finished road is formed in the vicinity of the working face. (It will be noted in Fig. 52 that the platform of the drilling carriage is designed to facilitate the setting of girders close to the working face.)

DRILLING SHOT HOLES

249. Much attention has been paid to drilling technique with a view to eliminating the physical fatigue and strain of hand drilling with pneumatic machines in hard rocks, and to reducing the time taken to drill a round of shots so as to enable a full cycle of work to be completed in a shift, *i.e.*, loading, setting supports, etc., and drilling. A very important feature is that wet drilling is standard practice for hard headings.

250. Material progress has been made in wet drilling practice by the use of (*a*) " hard metal " (Widia class) tipped bits on percussive drills ; (*b*) drilling carriages, and (*c*) automatic vibratory feed for the drills.

251. (*a*) Tungsten carbide tips are now used on single chisel and cross bits for drilling 40 mm. (1.6 in.) diameter holes by percussive action. A typical single

chisel bit is illustrated in Fig. 50. A considerable advance must thus have taken place in the metallurgical development of these extremely hard, high-temper, abrasion-resisting metals, because the principal weakness of " Widia " in its initial form was its inability to withstand shock. In addition, drilling technique has been adapted to assist in overcoming the relatively low toughness of the hard metal by increasing the number of blows per minute and reducing the intensity of each blow, which enables the sharp edge of the hard metal effectively to drill the hardest rocks at higher speeds than is possible with steel. This has resulted in lighter drilling machines, greater flexibility in drilling practice, including selection of depth of hole, increased drilling speed, particularly in the harder rocks, lower power consumption and lower charges for the transport of drilling rods.

(*b*) The " Bohrwagen " or drilling carriage consists essentially of a wheel-mounted tubular screen with attachments to locate the drilling machines according to the pattern of shot holes selected for the particular conditions that obtain. Its use ensures accuracy in the placing of shot holes, and enables a large number of drills to be in operation at one time. The screen absorbs the thrust of the drilling, and each face worker can, therefore, easily supervise the running of at least two drills. In the earlier applications, the boring carriages ran on rails on the floor as shown in Figs. 51, 52 and 53, but the latest practice is to run the carriages on rails located at the sides of the roadway at a height corresponding to approximately the point of pivot of the screen. A drilling carriage was seen with 10 drills, fitted for wet drilling, operating simultaneously. The atmosphere at the face was remarkably clear of dust, and there were only 6 men in all in the heading.

Fig. 51 shows a carriage in position for drilling the holes. Two air cylinders at the top of the screen are used to fix the screen and carriage in position. The compressed air and water supplies are both brought to a central distributor, from which short length feeds are taken to the individual machines.

Fig. 52 is a profile of the same carriage, and Fig. 53 shows how the screen can be folded to minimise damage from shooting, and to facilitate the loading of the debris. The diagram of the shaking shovel in Fig. 53 shows a combination of the " Stoss-schaufellader " and the drilling carriage.

(*c*) Automatic vibratory feeding of the drill is obtained by using an appliance called a " Rapid-Boring Carriage." The guide rod of this carriage registers on a suitable attachment on the tubular screen drilling rig, and the carriage is fed along the guide rod by the pulsations of the drill. A spring-mounted roller clamp mechanism in the carriage provides free movement in the drilling direction and instantaneous locking in reverse. No tolerance is allowed on the backward thrust of the hammer drill, and thus incomplete, or loose, blows are avoided. This is said to be of special importance when drilling with " hard metal " tips. The spring-lever mechanism in the drilling carriage can be adjusted to give a tractive force (or drilling pressure) to suit the nature of the rock.

252. With a combination of (*a*) (*b*) and (*c*), 80 yards of 40 mm. (1.6 in.) diameter shot holes can be drilled in two hours in ordinary strata, and 70 yards in sandstone.

253. Compressed-air at a pressure of from 60 to 90 lbs. per square inch is at present used for drilling, the consumption per drill being approximately 70 cubic feet of free air per minute. Higher pressures are contemplated, and progress is expected in this direction. The higher pressures contemplated are of the order of 150 to 175 lbs. per square inch, which would be obtained by the use of inbye compressors ; the air would be taken from the existing mains at 60 to 90 lbs. per square inch and compressed to 150 to 175 lbs. per square inch. It was said that drilling pressures of from 175 to 200 lbs. per square inch are at present in use in Sweden.

SHOTFIRING

254. As has been stated, an endeavour is made to organise the work to enable shotfiring to take place between shifts. Simultaneous shotfiring is practised, and delayed action detonators (range of 10 delays) are used. In the case of mines in certain measures with no seams in close proximity, permission can be obtained to use unsheathed explosives with high nitro-glycerine content. This practice greatly assists in preparing the rock for loading.

255. Where a long mine is being driven and the explosive fumes have a nuisance value, the manholes which provide shelter when shotfiring are sometimes adapted to form air chambers which, by means of compressed-air, are kept at a slightly higher air pressure than the drift.

VENTILATION

256. Standard fans with 40, 50, 60 and 70 cm. (1.3, 1.6, 2.0 and 2.3 ft.) diameter blades are used, and these fans, which are mostly driven by compressed-air, deliver quantities varying from 3,540 to 7,080 cubic feet of air per minute through the tubing. The maximum length ventilated by a fan is 165 yds., and long roads have several fans in series. In the longer and more difficult drifts, two ventilating tubes are used, one for forcing and the other for extraction. The tubes are normally of galvanised steel of 1.5 to 2 mm. (0.059 to 0.078 in.) thick and have bolted flanges. Cardboard or other fibre packing is used at the flanged points, which are smeared with clay if they are to remain in service for a long time. Recently, rubber sleeves have been used to cover both ends of the pipes at the joint and thus eliminate air leakage ; the latest type is a rubber band tightened by a lever.

257. In one very long mine, two ventilating tubes, each 80 cm. (2.6 ft.) in diameter, were used. Both tubes were packed in cases filled with sawdust for heat insulation.

A ROTARY ROCK TUNNELLING MACHINE

258. So far, reference has only been made to current practice in the driving of roadways in stone. There is, however, a new development—a rotary tunnelling machine weighing approximately 18 tons—from which much is expected.

259. Fig. 54 shows in diagram form the principal details of the design of the machine, which has been used in a potash mine. The initial diameter of the tunnel was 2.4 yds., and an advance of 1.64 yds. per hour was obtained. The cutting head was fitted with " hard metal " bits which cut grooves consisting of approximately one-third of the total material, the remaining two-thirds being broken off the face by the action of the cutter head. The cuttings were delivered from the head to a belt conveyor, which had a loop take-up behind the tunnelling machine to facilitate the establishment of a semi-permanent tub loading station.

260. The incidence of a large quantity of fine dust probably caused much inconvenience, because an air suction system has been developed to replace the belt conveyor. The dust and cuttings can be removed by a

suction plant which, with suitable insulation, can also keep the temperature in the heading to a minimum by carrying away the heat energy expended in cutting. Heat dissipation is important in this operation. A 200-H.P. electric motor is required to drive the machine.

261. At the commencement of tunnelling in potash, difficulties were principally experienced in guiding the cutting head. These difficulties were overcome by using hydraulics to position the body of the machine, develop the forward thrust and guide the head. The horizontal axis was maintained by two grooves cut by discs in the sides of the road. Complete control was thus obtained, and it was claimed that the machine could be made to drive a curved tunnel, within certain limits.

262. The use of the machine in coal measures strata is contemplated, and it is thought that a 3 m. (3.3 yds.) diameter tunnel could be driven at a rate of 80 cms. (0.88 yds.) per hour in sandstone. A conventional shape of roadway to provide double track haulage would be made by blowing up the floor, the roof remaining undisturbed in a perfect semi-circle. The prohibition of electric power in a single heading is at present a limitation, and compressed-air for driving the machine is out of the question owing to the power required, *i.e.*, 200 H.P. It was understood, however, that a gas detector which would automatically cut off the electric power in the presence of methane was being developed by Siemens Schuckert, which, it was hoped, would enable an electric machine to be used in coal measures.

263. The prototype tunnelling machine cost about 300,000 marks (£25,000), which it was thought might be reduced to 100,000 marks (£8,000) in production. Such an expensive tunnelling machine would probably only be used by groups of collieries, or by tunnelling contractors. (A recent description of the machine and of its application is given in Appendix No. 13 (*a*).)

CONCLUSIONS AND RECOMMENDATIONS

264. (i) The co-ordination of loading, setting supports, drilling and shotfiring in mechanised stone drifting is most successful when the depth of the shotholes is adjusted to ensure that one full cut is completed in a shift.

(ii) The " Stoss-schaufellader " is an efficient loader, particularly when used in conjunction with the drilling carriage, but it is limited to level, or approximately level, roadways in which the rail track is laid close to the working face. It is doubtful whether, under these conditions, the " Stoss-schaufellader " loader is more effective than other loaders with a wider range of application.

(iii) Wet drilling in stone drifts is standard practice in the Ruhr, and we recommend that it should be used for driving roadways in stone in Great Britain, particularly where large numbers of drills are operated simultaneously.

(iv) " Hard metal " tips on percussive drills, the vibratory drill feed, and drilling carriages have materially speeded up the drilling cycle, and represent an important advance in the technique of driving roadways in stone. All three are worthy of further careful study with a view to applying the principles to our practice.

(v) The use of the rotary tunnelling machine in coal measures strata in the Ruhr should be encouraged, and the results should be carefully observed.

CHAPTER IV

Underground Transport with Special Reference to Locomotive Haulage

HAULAGE SYSTEMS

265. Underground transport in the Ruhr consists of three operations :—

- Main road haulage ;
- Staple shaft raising and lowering ;
- Gate road haulage.

266. The main road haulage system deals with coal, materials and men between the staple shafts and the pit bottom ; the staple shaft system deals with coal, materials and men between the levels and the roads in the seam ; and the gate road haulage system deals with coal and materials between the coal faces and the staple shafts.

267. The labour involved in these three haulage systems in 1941 was as follows :—

Main road haulage	46 manshifts per 1,000 tons
Staple shaft operation	16 manshifts per 1,000 tons
Gate road haulage	24 manshifts per 1,000 tons

The total shifts worked underground per 1,000 tons in 1937 (the most efficient period) were 499.

268. It is anticipated that during the next 15 years the new equipment now developed will result in a saving of 20 shifts per 1,000 tons in the three haulage systems.

269. The figures given above only apply to that 73 per cent. of the Ruhr output which is obtained from what is known as flat formations (0°—25°). In the steeper formations, the labour force per 1,000 tons is greater owing to the necessity of working smaller face units.

270. The development of underground transport in the Ruhr has been influenced by two factors : the economies to be obtained by concentrating the workings, and the economic necessity, at increased depths, of reducing to a minimum the number of shafts, levels and staple shafts.

271. As an example of the economies obtained from concentration of the workings, it may be mentioned that in the flat measures the output per working face per day increased from 50 tons in 1929 to 315 tons in 1941. The average depth in the Ruhr coalfield is about 760 yds. : up to 1944, the average increased at the rate of about 10 yds. per annum.

272. The influence of these factors has resulted in the following haulage requirements in the flat measures of the Ruhr :—

	Max. shift tonnage A	*Av. shift tonnage* A	*Max. transport distance* B	*Av. transport distance* B
Main road	1,000 T.	500 T.	3 miles	1½ miles
Staple shafts	1,000 T.	160 T.	750 ft.	110 ft.
Gate road	1,000 T.	160 T.	4,500 ft.	700 ft.

A. Main road haulage in working cross measure drifts only.

B. Main road haulage in working cross measure drifts and main levels (or lateral drifts).

273. It has already been stated in Chapter I that horizon mining was practised when coal was first worked in the Ruhr. The earlier methods of transport in operation show the same trends as those of other countries. A start was made with hand tramming; horse haulage quickly followed. Rope haulage and locomotives were introduced later, followed by mechanical haulage and conveying.

274. The horizon system of mining with its comparatively level roads readily lent itself to the introduction of locomotive haulage about 1880. This was the first mechanical aid to the transport problem, and it seems certain that it will continue for all time to be the basis of main road transport in the Ruhr. The next development in order of importance in the Ruhr was the large mine car; but this is comparatively new.

275. Staple shaft efficiency was increased by the skip and spiral chute. Developments whereby staple shafts are replaced by inclined drifts equipped with belt conveyors for coal and stowing material and with small hoists for other material have been tried out, but it was not possible to obtain definite information as to the potentialities of these developments.

276. The efficiency of gate road haulage has been increased by the introduction of conveyors which are often used in conjunction with spiral chutes in the staple shafts to maintain continuous haulage from the face to the cross measure drift.

277. The trend towards concentration of output and increased transport distances has necessitated very careful attention to ensuring the smooth running of the main haulage system. This has resulted in a high standard of tracklaying, continuous road lighting, good traffic control arrangements, mechanical loading of cars and mechanisation of working arrangements at the pit bottom. The introduction of the large mine car has emphasised the importance of these improvements.

278. Advantage has been taken of the consolidation of main haulage arrangements to establish standards for nearly all the equipment employed, and in particular for locomotives, mine cars and tracks.

MAIN HAULAGE

279. Main road haulage in the Ruhr is required to collect half a million tons of coal per day of sixteen hours from approximately 1,600 loading stations, haul the coal 1½ miles and deliver it to the main winding shafts; and in addition, to deal with development operations, and transport men and materials.

280. Transport in the main road haulage systems in the Ruhr is entirely by locomotives and tubs or mine cars: rope haulage is never used because of its complications and comparatively low speed. The use of conveyors on the levels is impracticable because the workings become very widespread with three systems of level roads always in operation, and because the cost is prohibitive owing to the small tonnage which would be hauled per yard of conveyor. Moreover, a conveyor system can only satisfactorily deal with traffic in one direction. This is a serious disadvantage where quantities of material have to be hauled in the opposite direction, and necessitates the installation of a secondary haulage system.

281. The main haulage roads in the Ruhr are all graded to 1 in 400/500 in favour of the load. This gradient was chosen to enable a locomotive to take the same number of empty tubs or cars into, and of full cars out of, the mine. The gradient was assessed for taper roller bearings on the cars. The roads are straight and have few changes in direction, and where a change in direction is necessary, the curves are well made and are of ample radius.

282. The roads are equipped with double track and in most instances they are steel arch supported. Straight girder supports are used only in settled ground. The height from ground level to the centre of the arch varies from approximately 8 ft. to 14 ft., and the width at the foot of the arch from 10 ft. 6 ins. to 20 ft. 6 ins. The junctions are all of arched construction, and those seen were of fine workmanship. Standards for arches of all sizes have been laid down.

283. The track is constructed as for surface railway practice. The rails are flat-bottomed and fish-plated, and the weights vary from 28 to 56 lbs./yd. The sleepers are nearly always of hardwood and vary from 3 ins. by 4 ins. to 4½ ins. by 12 ins. All underground tracks have been completely standardised.

284. Three standard gauges have been decided on, and a gradual trend towards these standards is apparent. The gauges are 1 ft. 11½ ins., 2 ft. 5½ ins. and 2 ft. 11½ ins.; the gauge commonly in use is 1 ft. 11½ ins.

285. Tubs are dealt with in detail later. Nearly all the tubs in the Ruhr are of between 15 cwts. and 30 cwts. capacity, but the advantages of large mine cars are fully realised. Mine cars of approximately 5 tons are now in use. Mine car standards for six sizes varying from 1.57 tons to 4.9 tons have been established.

286. The locomotives used in main road haulage are of three principal types: trolley wire, Diesel and compressed air. A total of 2,515 locomotives were in use in 1940. Of this number, 1,270 were trolley wire locomotives with an average H.P. of 41.6; 855 were compressed air locomotives with an average H.P. of 28.8; and 340 were Diesel locomotives with an average H.P. of 42.8. The maximum H.P. normally used for Diesel locomotives is 75, and for trolley locomotives 85. A speed of 7–10½ miles per hour is quite common. These easy haulage conditions have naturally led to some standardisation of locomotives, but this has been carried out by the manufacturers.

LAYOUT

287. Figs. 3 and 4 show the main haulage layout at the two working levels of the Hannover Mine, which was visited. The output from this mine in May, 1944, was 68,000 tons, of which 40,000 tons were obtained from flat formations (0°–25°), 9,000 from half steep formations (25°–35°), and 19,000 from steep formations (35°–90°). In this month the output per manshift was 31.2 cwts. overall, and 38.8 underground.

288. The mine has six shafts varying from 21 ft. 4 ins. to 14 ft. 9 ins. in diameter. Two of these are ventilation shafts (683 yds. 1 ft. deep) to the level above the level shown in Fig. 3. Two shafts for general purposes, coal and men winding are 850 yds. deep. Two others to the level shown in Fig. 4 are 1,058 yds. 1 ft. deep. One of these shafts is used for coal winding, and the other is being resunk. Ordinary cage winding is in operation. The reserves of coal above the 1,058 yds. 1 ft. level amount to 5½ million tons, equal to about 8 years' work.

289. This mine has been chosen as a good illustration of main haulage layout: only 23 shifts per 1,000 tons of coal were worked on main haulage during the month in question, compared with an average figure of 46 for the whole of the Ruhr.

290. At both the horizons shown in Figs. 3 and 4, one main level running East and West splits the leasehold approximately in two. Each leg is 3,166 yds. 2 ft. long and runs as near as possible on the strike of the seams. It should be noted that where the strike of the seams changes in direction the levels follow suit.

291. The cross measure drifts are turned off the main level at intervals of approximately 500 yds., and are laid out as far as possible to fit in with the faulting.

292. The main levels and cross measure drifts are exactly super-imposed on each other. The lowest horizon has not yet been fully developed to the West.

293. Staple shafts are driven from the cross measure drifts at intervals of 100 to 300 yds. to intercept the seams from which coal is conveyed by the main haulage system to the shafts.

294. Normally, at this mine there are twenty principal loading stations with daily outputs of between 50 and 500 tons. Further concentration is made difficult by the geological conditions. Details are not available of the amount of stowing material transported per day, but it must be considerable in an area of this inclination.

295. All the main line transport is carried out with 3,300 tubs of a capacity of 33 cubic feet on a 1 ft. 8$\frac{9}{16}$ ins. gauge (non-standard) with 16 Diesel locomotives aggregating 800 H.P. This haulage equipment deals with the coal, the materials and the man-riding in all three horizons.

CONSTRUCTION OF ROADWAYS

296. In constructing the main haulage levels regard must be had to the necessity of working out the coal above and below the level itself. It is impracticable to leave pillars to protect the levels, as the coal being worked can be as much as 250 yds. below the top level to be protected, and, therefore, the pillars would be too large. In addition, at the depths encountered the pillars would exert pressure on the workings below. The working out of the coal disturbs the road and the track, and in trolley wire installations interferes with the track bonding and trolley wire supports. The point at which this damage will ensue can be estimated fairly accurately from practical experience, and preventative and remedial measures taken.

297. The preventative measures comprise the solid stowing of the area from which support is being withdrawn and the use of stilts of various kinds in the construction of the supports. Flexible joints to allow for movement have also been tried with some success. These are illustrated in Figs. 55, 56, 57 and 58.

298. The remedial measures comprise the ordinary repair of damaged roadways. The work involved in this amounts to 34 manshifts per 1,000 tons produced, which is higher than the figure of 32 manshifts per 1,000 tons expended on making the levels in the first place.

299. Where trolley wire systems are in operation, experiments have been made with fire-proofing roadways, and in particular the roofs of the roadways, but wood lagging is now almost universal where this type of haulage is used.

300. Fig. 59 shows eight standard dimensions of roadway construction which have been adopted for the Ruhr coalfields.

301. The height from ground level to the centre of the arch varies from 8 ft. 8 ins. to 14 ft. 9 ins., and the width at the foot of the arch from 10 ft. 7 ins. to 20 ft. 8 ins.

302. It is more than probable that B.6 : 3 and B.8 are only used for roads in the seam itself, where single track is adequate. The car in B.8 is the largest standard car of 5 tons capacity on the maximum gauge of 2 ft. 11½ ins.

303. B.10 and B.12 : 5 are the normal main level and cross measure drift sections. The dimensions in this case are: height to the centre of the arch 11 ft., and width at the foot of the arch 15 ft. 7 ins., making a cross sectional area of 145 sq. ft.

304. B.14, 16, 18 and 20 are all sections of 3-track roadways and are used at loading stations and sidings near junctions and in the neighbourhood of the pit bottom; the 5-ton car is again shown in B.18 and 20.

305. In all these standard roadways there is a minimum clearance at one side of the road of approximately 2 ft. from the arch at a height of 5 ft. 10 ins. This is to allow men to travel.

306. The clearance between the cars is standard at approximately 8 ins., as is the clearance between the edge of the car and the near side of the road. This figure gives an indication of the high standard of tracklaying, road-making and maintenance.

307. The height of the trolley wire is also shown. The minimum height in B.6 : 3 is approximately 6 ft. above rail level.

VENTILATION

308. The horizon system of mining makes it necessary for sections of main haulage roads to be in return airways. As a new level is developed, a time arrives when sections of the old level must be used as the return airway for the new level. This could be avoided by a wide dispersion of workings, but this solution is hardly practicable where high outputs are produced from small areas. The present practice at many mines of winding coal at both shafts also makes it difficult to keep main haulages wholly in intake air. In any case, the top of the three levels in use is the main return airway for the mine, and it is the practice, where permitted, to use the haulage system originally installed for the purpose of conveying men and materials to the staple shafts.

309. Where trolley locomotives are used, the Regulations state that the firedamp content in the general body of the air must not exceed 0.3 per cent.

310. Where Diesel locomotives are used, the Regulations require that at least 215 cubic ft. of air per minute must be circulated for every H.P. of each Diesel locomotive using the circuit.

311. An additional ventilation problem is presented by the driving of new levels. These are driven as far as 1,000 yds. with auxiliary ventilation. The Regulations prohibit the use of both trolley and Diesel locomotives under these conditions, and compressed-air, battery or combined locomotives with both trolley and battery power units are therefore used.

312. In view of these ventilation difficulties, it says much for their efficiency and safety that trolley locomotives are used for hauling more than half the output of the Ruhr coal mines.

HAULAGE OPERATIONS

313. The steady process of concentrating production in the minimum number of faces and loading stations, to which reference has already been made, makes it imperative that there should be no delay in the arrival of tubs at the loading stations.

314. The ideal haulage system provides that the sidings at the loading stations are sufficient to hold a full train of loaded tubs, a full train of empty tubs, and an adequate reserve of tubs to provide for possible delay

in the arrival of the locomotive. In such a case, one locomotive can drop the empty tubs behind the loading station, pick up and take the full tubs to one of the pit bottom sidings, then pick up a full train of empty tubs and return to duty at another loading station. On the very easy gradients chosen, the locomotive can haul long trains and it is quite common for one locomotive to haul 150 small tubs or 60 mine cars. It is seldom practicable, however, to simplify haulage to this extent and at the same time utilise the locomotive to the fullest advantage.

315. Locomotives usually serve 3 or 4 loading stations, dropping empties off at each station and picking up fulls from each station on the way out. Locomotives always travel in front of the load.

316. Locomotives run direct from the loading stations to the pit bottom ; gathering locomotives are rarely used for building up trains. Pit bottom sidings are made sufficiently large to accommodate full trains.

317. Every effort is made to separate the different types of material hauled. Otherwise, a train of tubs filled with dirt and materials mixed with empty tubs would cause unnecessary shunting. Likewise, a mixed train of dirt and coal tubs might easily delay the winding operations. In the best practice to-day, one shaft or one winder in a shaft is confined to coal winding, and this has a considerable bearing on the problem.

318. The planning of a good haulage system is not enough in itself. Its smooth running depends on the maintenance of the road, track and rolling stock, on good road lighting, and, above all, on first class supervision and intelligent use of the telephone.

319. All large mines have a traffic control point, similar to a railway signal box, on each level. The telephone in conjunction with a simple signalling system forms the basis of control.

320. The economies to be made in future haulage operations are all bound up with the large mine car and the methods to be employed to control it at loading stations and pit bottoms. The introduction of large mine cars increases the pay load of the locomotive and enables the length of all sidings to be considerably reduced. The introduction of mine cars is usually only possible when new levels are being opened up, and consequently the full economies to be obtained by their introduction will not be achieved until a period of 20 years has elapsed.

321. Fig. 60 is a chart showing typical performances of a trolley locomotive serving three staple shafts over a period of 7½ hours. These staple shafts are respectively 3,280, 3,827 and 4,374 yds. from the pit bottom.

322. During the shift the locomotive completed six return journeys, delivered 655 empty cars and 5 man-riding cars to the staple shafts, and 431 tubs of coal, 13 tubs of stone and 21 man-riding cars to the pit bottom. Shunting operations at the pit bottom took 21 minutes ; inbye 145 minutes.

323. The locomotive travelled a distance of approximately 37½ miles during the shift at a speed which varied with the load. The maximum speed was reached at the end of the shift when 15 man-riding cars were taken to the shaft at a maximum speed of 18.6 m.p.h. The average speed during the shift, including shunting movements, but excluding the 83 minutes when the locomotive did not move at all, was 6.06 miles per hour.

MAN RIDING

324. The average time spent in travelling to and from work from the pit top is 120 minutes. This operation takes place in the ordinary haulage network for coal and materials. The tubs or mine cars are fitted with seats or slings hooked over the sides of the tub or car. These seats or slings may be of canvas for small tubs, or of wood for mine cars.

325. The high air velocities encountered can make travelling against the wind uncomfortable. Enclosed man-riding cars have been specially designed for these conditions, but even so the ordinary tub is commonly used. The height of the mine car enables a man to keep his head below the level of the side of the car without difficulty.

326. In large mines, the movement of men into and out of the mine is highly organised. All the men on one cross measure drift go down the mine at the same time, and are loaded into trains (despatched by time-table from the pit bottom) which take them to their respective sections with the minimum delay. This process is reversed at the end of the shift and probably creates certain difficulties when men are required to work overtime.

THE LINK BETWEEN MAIN HAULAGE AND HAULAGE IN THE SEAM

327. This link is arranged in two ways, either by staple shafts or by inclined drifts. Staple shafts are discussed in detail in Chapter V (*a*), and are referred to here only for continuity.

328. The task of the link is to raise and/or lower 500,000 tons an average distance of 37 yds. per day from the roads in the seam to the cross measure drifts. The maximum distance is 250 yds. The most economical method consists of raising the coal to the top level from the top third of the strata between two levels, and lowering it to the bottom level from the lower two-thirds of the strata between two levels. The link has also to carry out the task of raising and lowering the dirt, materials and men as and when required. The labour involved in this work amounts to 16 manshifts per 1,000 tons of coal produced.

329. Staple shafts are also used for lowering or raising coal from one level to another. This operation is necessary when a new level is being opened out and winding is required to be concentrated at the old pit bottom. It is also necessary when an old level is finishing and output is required to be concentrated at a new pit bottom.

STAPLE SHAFTS

330. Staple shaft haulage can be carried out by : single cage winding with a balance weight ; double cage winding ; skip winding ; using the staple shaft as a bunker, or for different types of elevating and lowering conveyors and spiral-chute conveyors.

331. Cage and skip winding each has the advantage of being flexible, and can therefore be used for all purposes in the same shaft. Each method, however, has the disadvantage that it is an intermittent form of haulage and requires tub standage or bunkering capacity, particularly at the seam level.

332. Staple shaft conveyors and spiral-chute conveyors have the advantage of continuous operation. Each method, however, has the disadvantage that separate arrangements must be made to transport men and equipment. Spiral-chute conveyors have many special advantages such as a continuous even flow of coal at even speeds ; they require no power ; their capacity is practically unlimited ; coal can be received at more than one place in the shaft ; maintenance is low because there are no moving parts ; the parts can be easily dismantled, transported and re-erected ; they have a high storage capacity ; and when totally enclosed are dust-tight.

333. The advantage of staple shaft continuous haulage is dealt with in conjunction with haulage in the seam.

334. Fig. 61 shows a working face connected to two levels by means of staple shafts. Both the staple shafts have three compartments and each shaft is used both for transport and ventilation purposes. Each centre compartment contains two spiral-chute conveyors, one to transport dirt into the seam and the other to transport coal on to the cross measure drift. One of the other two compartments in each shaft contains sets of ladders, and the other a hoist for the transport of both men and equipment. This is an example of a continuous operation.

INCLINED DRIFTS

335. It is quite possible to use drifts instead of staple shafts in the horizon system of mining, but whether it is economical to do so is doubtful. The fact that the method is used in only a very few cases in the Ruhr to-day tends to prove that it is uneconomical.

336. A drift is probably more expensive to construct than a staple shaft, particularly in the Ruhr where there is such a wide experience of staple shaft construction. A drift is more liable to damage by subsidence owing to its inclination and its length, and if used as part of a continuous haulage system the equipment required for conveying and haulage purposes would cost at least as much as the equipment for a staple shaft. Moreover, the saving in operating manpower (after discounting these possible disadvantages) would have to be effected from 16 shifts per 1,000 tons of coal produced, which is the average figure for staple shaft operations in the Ruhr. It is difficult to see how such an economy could be effected when the average output per staple shaft is only 160 tons per shift.

HAULAGE IN THE SEAM

337. Every day of 16 hours, the gate road haulage in the Ruhr is responsible for transporting 500,000 tons of coal from 1,600 coal faces an average distance of 700 ft. Gate road haulage is also responsible for the transport of stowing material and mining equipment, including roof supports : this material and equipment is usually brought from another set of staple shafts.

338. The work requires the expenditure of 24 manshifts per 1,000 tons of output ; developments are continually taking place with a view to reducing this expenditure by improving gate road haulage and by increasing the production from each coal face.

339. All known methods of underground haulage, adapted where necessary to local conditions, are used in the Ruhr gate road haulage system.

GENERAL

340. There has been an important change in haulage in the flat measures in the Ruhr since 1927. Whereas at that time no conveyors were in use in the gate road haulage system in flat measures, to-day 87½ yds. of conveyor are used for every 1,000 tons of coal produced.

341. The following Table sets out the incidence of the different types of haulage equipment in use in the flat areas of the Ruhr in 1941 :

TABLE III

Type of Haulage	*Planned Gate-Road Length* Yds.	*No. of Faces*	*% of Output*	*Av. Daily Output per Face*
1. Hand	203	41	1.23	75
2. Pony	323	28	1.20	106
3. Rope	339	133	9.69	181
4. Loco.	454	107	9.30	216
5. Main rope assisted by loco.	480	5	0.77	382
TOTAL BY INTERMITTENT METHODS ..	361	314	22.19	176
6. Shaker conveyor ..	230	32	2.40	187
7. Rubber belt conveyor	475	314	50.85	403
8. Steel belt conveyor ..	578	23	4.68	507
9. Plate belt conveyor ..	463	49	10.47	532
10a. Rubber belt and shaker	373	37	4.87	328
10b. Rubber belt and steel belt ..	723	16	3.39	527
10c. Rubber belt and plate belt ..	483	3	0.59	494
Total 10a, 10b, 10c ..	479	56	8.85	394
11. Scraper conveyor ..	287	3	0.56	462
TOTAL BY CONTINUOUS METHODS ..	461	477	77.81	406

342. The table shows that in 1941, 77.81 per cent. of the coal from the flat formations was transported by conveyor ; it is considered that had rubber and cotton been available all this would have been conveyed by means of rubber belts. Only 10 per cent. was dealt with by locomotives, and only 22 per cent. was transported in tubs.

343. The figures only refer to the 791 faces on full production in these mines representing 64 per cent. of the working points. The remaining working points, with the exception of reserve longwall faces, were mostly for preparation and exploratory purposes. Tub haulage is quite commonly used for these operations.

344. Of the 791 faces referred to, 713, which produced 97.2 per cent. of the output, were faces winning on the strike of the seam. This is an important consideration and shows that the introduction of the conveying system was not unduly influenced by difficulties of gradient.

345. In the steep formations, the smaller production per working point militates against the use of conveyors and locomotives owing to their capital cost. Tubs and rope haulage are commonly used in these steep measures.

346. A matter which has some bearing on the type of transport for gate road haulage is the prevalence of floor lift. Where this occurs, tub haulage, which facilitates the repair of the roadways, is preferred. Tub haulage also enables roadways to be kept cleaner. The figures show, however, that these two advantages are more than offset by the economic advantages of conveying.

347. The development of gate road conveying and the introduction in staple shafts of bunker storage, elevator conveyors and especially spiral-chute conveyors, resulted in the continuous transport system from the coal face to the mine car. This was a distinct advantage because skips with their complementary measuring chutes required considerable labour for installation and operation. Also, it seemed unnecessary to load the tub at the top of the staple shaft when it could be loaded at the bottom by fewer men.

348. The continuous transport system not only enabled great economies to be effected but also paved the way for the introduction of large mine cars in many mines where it was not possible to maintain sufficiently large seam roadways for mine cars.

349. The operation of transport of material to the face is a considerable operation. 38 per cent. of the faces in the flat formations are stowed with material brought in from the cross measure drifts, and solid

stowing is the general practice in the steep measures. In many of these cases conveyor systems can be economically justified, but even if this applied generally there would still remain the problem of moving up roof supports and machinery, both during the time the face was advancing and when it was being drawn off. This problem is aggravated by the fact that wooden props are still used at approximately 75 to 80 per cent. of the coal faces, and that the system of roof support restricts prop life. Consequently, small gate road locomotives are mostly used in the supply roads. There are 796 of these locomotives at work, or approximately one to every two working faces. 368, or 46 per cent., are compressed-air locomotives, 332, or 42 per cent., are battery locomotives, and the remainder are internal combustion locomotives. The average H.P. is about 10.

350. Locomotives for use in gate road haulage must be specially constructed so that they can be dismantled and taken through the staple shafts when they are moved from a worked-out face to a new face. It was seen that 88 per cent. of these locomotives were of types which require charging between shifts, and that charging stations were installed near the staple shafts for economical transmission of compressed air and electricity.

351. Special tubs have been designed for the transport of stowing material and equipment under certain conditions, and these are referred to in the section on car design.

CONSTRUCTION OF ROADWAYS

352. The construction of gate roads presents similar problems to those encountered in British mining. The roads in the flat formations have an average length of 700 ft. when the working of the face has been completed.

353. The rate of advance of the face is less than in this country and, in 1941, amounted to 3 ft. 6 ins. a day. This slower rate of advance has two effects; it is beneficial to general roof control, but it means that the road has to stay open longer for a given tonnage. The average life of a gate road is 200 working days, and during that period maintenance of the road accounts for 23 shifts per 1,000 tons of coal produced.

354. The German mining engineers in the Ruhr are satisfied that the methods adopted to relieve pressure on the gate roads are correct. Generally, these methods consist of supporting the roadway by a double packing system which leaves a roof pressure relief zone between the packs, thus, by allowing the roof pressure to act over a wider area, avoiding undue weight on the road itself. These mining engineers also consider that there is a danger in setting wood chocks of a too rigid type, and that for road support the pack walls must subside at the normal rate. Cambered girders or pointed arch supports are preferred. Examples of flexible arch joints are shown in Figs. 55, 56, 57 and 58.

355. Where conveyors are used, a track is always left in the same road for the purpose of repairing the road and for moving materials. Where strata conditions are suitable, double track is preferred throughout tub haulage gates as this eases the problem of shunting in the supply gate. Figs. 62 and 63 show typical methods of road construction in the seam.

VENTILATION

356. Haulage is necessary in nearly all the gate roads in the Ruhr, and as a result must take place both in the intake and return airways in close proximity to the coal face.

357. The two types of locomotives (the Diesel and the trolley) which are most economical in operating on the levels are unsuitable for flexible operation in the gate roads. The trolley locomotive is unsuitable because it is undesirable to bring the trolley wire system too near the coal face and because the locomotive cannot safely be used in moving ground. The Diesel locomotive is unsuitable because it can only be used in the return airways if the effect of its fumes is reduced to a minimum.

358. The ventilation factor was, therefore, the main factor in the decision to use compressed air locomotives and battery locomotives in the gate roads, and there is little doubt that this decision led to the extensive introduction of gate road conveyors between 1927 and 1941.

LOCOMOTIVE HAULAGE

GENERAL CONSIDERATIONS

359. Locomotive haulage is the standard form of underground transport used throughout the Ruhr Coalfield for main road haulage. It is recognised as being more flexible than rope or chain haulage, and is much less liable to breakdown with consequent stoppages. Its degree of flexibility cannot be compared with any other form of transport.

360. The number and sizes of locomotives can be adjusted to meet the varying conditions of haulage as may arise, for example, from the increasing or decreasing output of single levels. As a number of medium sized locomotives are generally employed, a breakdown usually affects only a small part of the mine, and a spare locomotive can soon be put into service. Curves present no difficulty to locomotives, and main roads need not necessarily be made straight, a factor which may be of considerable importance in secondary roads. A speed of 7–10½ m.p.h. can be employed because the tubs do not have to be attached to a moving rope, and the smaller number of tubs normally required enables a faster turn-round to be made. The proper distribution of supplies and stowing material is more easily achieved than is possible with rope haulage, and man-riding can undoubtedly be more successfully accomplished. The need for heavier and more expensive track is largely offset by subsequent freedom from derailment and the long and efficient service obtained. The increased amount of tub marshalling necessary in some circumstances is a disadvantage, but its effects can be reduced by good organisation.

361. As has already been said, the haulage problem in the Ruhr is considerably simplified by the horizon method of mining which provides level roads or roads having slight gradients favourable to the load. These roads, for which locomotives are particularly suitable, enable large tonnages to be hauled considerable distances at economic speeds by locomotives of moderate weight and horse-power. This has no doubt influenced the practice of using double roads throughout.

TYPES OF LOCOMOTIVES

362. Four main types of locomotives are employed, and the number and percentage of each in use at 1st January, 1940, are shown in Table IV.

363. In spite of the fact that the heavy high-powered electric locomotive (which is the principal advantage of the trolley system) is not employed in the Ruhr, the trolley system remains the most popular, and distinct economic advantages are claimed for it. Next in order of popularity is the comparatively uneconomic compressed-air locomotive; this is due to the fact that it is the safest locomotive in gaseous mines. The only danger of any consequence likely to arise from its use is through burst pipes or storage containers.

TABLE IV

UNDERGROUND LOCOMOTIVES IN USE IN THE RUHR COALFIELD AT 1ST JANUARY, 1940

Type of Locomotive	Number	Collective H.P.	Average H.P. per Loco.	Percentage	
				Main Road Locos.	Subsidiary or Gathering Locos.
1. (*a*) Trolley wire	1,270	52,742	41.6	50.9	
(*b*) Trolley wire—battery ..	24	1,362	56.8	0.96	
2. (*a*) Battery—main road ..	26	1,214	46.7	1.04	
(*b*) Battery—gathering	332	3,192	9.6		41.71
3. (*a*) Compressed-air—main road	855	24,110	28.8	33.46	
(*b*) Compressed-air—gathering	368	4,289	11.65		46.23
4. (*a*) Diesel—main road	340	14,542	42.80	13.64	
(*b*) Diesel—gathering	88	860	9.8		11.05
5. Benzol	8	144	18.0		1.01
Main road locos...	2,515				
Total gathering locos.	796				

364. The shortage of fuel oil and war demands for Diesel engines probably restricted the development of this type of locomotive. Mining engineers in the Ruhr, however, prefer the trolley locomotive, and in a number of cases there is no doubt that Diesel and compressed-air locomotives will be replaced by trolley locomotives as soon as the necessary equipment becomes available.

365. On the other hand, it is claimed that the initial installation cost of a Diesel locomotive is far lower than that of any other type.

366. As will be observed, benzol locomotives are fast disappearing.

367. Developments in the use of the various types of locomotives during the past 21 years are shown below :—

TABLE V

	1919	1933	1937	1940		
				All roads	*Main roads*	*Subsidiary*
	%	%	%	%	%	%
1. Trolley ..	38.5	49.0	43.5	39.3	51.9	—
2. Battery ..	2.4	7.5	9.1	10.9	1.0	41.7
3. Compressed-air	27.1	34.2	35.6	36.6	33.5	46.2
4. Diesel	—	3.3	9.4	13.0	13.6	11.1
5. Benzol.. ..	32.0	6.0	2.4	0.2	—	1.0
No. of Locos. ..	2,281	2,341	2,738	3,311	2,515	796

(The horse power and weight range of the various types of locomotives in use are given in Table XI.)

ELECTRIC LOCOMOTIVES

368. As will be observed from Table IV, electric locomotives fall into four main types, namely, trolley, combined trolley/battery, battery main road and battery gathering. The use of flameproof electrical equipment on all types, and of so-called flameproof battery containers on battery and combined trolley-battery locomotives, leads to further variations, each of which has its particular sphere of application.

369. For the purpose of defining parts of a mine in which electric locomotives may be used, danger spheres, or zones, which are based upon the firedamp content of the air, are laid down by the Oberbergamt (Inspectorate) as shown in Table VI. As will be seen, Zone 1 covers all areas in which the firedamp content does not exceed 0.3 per cent., which limits the application of trolley locomotives to this zone and also to intake airways up to approximately 55 yds. from the coal being worked. In Zone 2, where the firedamp content is in excess of 0.3 per cent. (the limit is specified by the Inspectorate in each individual case), combined trolley/battery locomotives or flameproof battery locomotives are generally employed. Provided flameproof electrical equipment is fitted and other safeguards are taken, such as the provision of at least four current collectors per locomotive, plain trolley locomotives may, in certain circumstances, also be permitted in this Zone. The third Zone covers areas where special hazards may exist, in which case only battery locomotives or combined trolley/battery locomotives with flameproof electrical equipment and flameproof battery containers are permitted. The effect of this zoning has led, on the one hand, to increased use of battery locomotives for gathering purposes, and on the other, to the development of main road battery locomotives which can satisfactorily perform the duties of gathering haulage in addition to main line haulage. This type of locomotive has thus been brought into direct competition with Diesel and compressed-air types. More will be said about this development later.

TROLLEY LOCOMOTIVES

(i) *General*

370. As shown by statistics, the trolley locomotive remains, by virtue of its higher operating efficiency, the most popular form of locomotive in the Ruhr.

371. Development in the application of trolley locomotives in relation to other types employed below ground may be seen from Table V, which also shows that although the percentage of trolley locomotives decreased in 1937, a substantial increase occurred in 1940. The 51.9 per cent. in that year accounted for a total of 1,294 locomotives, of which 24 were of the combined trolley/battery type.

372. At the end of 1942, 1,341 trolley locomotives, or roughly 64 per cent. of the total locomotives in use, were employed in about 83 mines in the Ruhr area. This involved the use of over 450 miles of underground electrified track. The number of trolley locomotives employed in each mine varies from 6 to 18, and the number of spares held in reserve from 1 to 3.

(ii) *Some Electrical Features of Trolley Locomotive Design*

373. As used in the Ruhr, this type seldom exceeds 10 tons in weight with motors totalling 85–100 H.P.: tandem application is very unusual.

TABLE VI

DANGER ZONES SPECIFIED BY THE GERMAN COLLIERY SAFETY OFFICE FOR ADMISSION OF ELECTRIC LOCOMOTIVES

	ZONE I. Where the firedamp content does not exceed 0.3 per cent.	ZONE II. Where the firedamp content exceeds 0.3 per cent. (Limits are laid down by the District Inspector).	ZONE III. Other atmospheres and all specially protected areas.
1. Trolley wire locomotive	——▷		
2. Unprotected battery locomotive, without plate protection.	——▷		
3. Battery locomotive, approved type (Sch.) without plate protection.	———	——▷	
4. Trolley compound locomotive, approved type, without plate protection.	———	——▷	
5. Trolley charging locomotive, approved type (Sch.) without plate protection.	———	——▷	
6. Battery locomotive, approved type, with plate protection.	———	———	——▷
7. Trolley compound locomotive, approved type (Sch.) with plate protection.	———	———	——▷

Note.—Sch.—Schlagwettergeschutzt = flameproof.
4. Trolley compound locomotive = combined trolley-battery locomotive with battery carried on separate bogie.
5. Trolley charging locomotive = trolley locomotive with directly attached battery which is charged from the trolley wire with an occasional boost in the charging station.

374. Design follows closely on conventional lines with two axle-slung motors, usually 220 volts direct current, at about 600 r.p.m., and no difficulty is experienced in accommodating these motors within suitable frames for the comparatively narrow gauges in use. Full load speed varies between 7 and 10 miles per hour for coal hauling, and speed control is obtained in the usual manner by series and parallel connection of the motors with resistances. The table below gives brief specifications of two war-time standard types of trolley locomotives which are in common use.

TABLE VII

	Type *KEL* 5	*Type* *KEL* 6
1. H.P. rating of motors (1 hour) ..	85	52
2. Draw-bar, pull (lbs.)	3,960	2,640
3. Gauge (inches)	1′ 9″–2′ 1″	1′ 9″–2′ 1″
4. Speed (miles per hour) ..	7.6	6.7
5. Wheel diameter	2′ 7″	2′ 7″
6. Wheel base	3′ 7″	3′ 7″
7. Working weight (tons)	13	8
8. Length overall	16′ 3″	15′ 11″
9. Height overall	5′ 3″	5′ 3″
10. Width overall	3′ 3½″	3′ 0½″
11. Working voltage	220	220
12. Smallest curve radius	26′ 3″	26′ 3″

Fig. 64 illustrates a modern electric trolley locomotive.

375. In the older type of locomotive the controllers are usually of the finger and segment (drum) type, but in later designs these have been largely superseded by cam-operated controllers and, more recently, by semi-contactor types. Although not generally adopted, it has been found advantageous to use air-break controllers with ventilated enclosures. This is usually achieved by fitting one or two circular plate venting devices to the door or cover, which is said to be sufficient to prevent accumulations of ionised air, thereby considerably reducing maintenance.

(iii) CURRENT COLLECTORS

376. Requirements laid down by the Inspectorate completely exclude the use of trolley poles with wheel or slipper collectors. For example, this form of current collector cannot easily be designed to provide more than one contact with the trolley line. In order to reduce the risk of open sparking, the Regulations provide for a minimum of two contacts which must be automatically reversible when the locomotive changes direction. These restrictions have resulted in the general adoption of collectors of the pantagraph or bow type with very satisfactory results. Many locomotives are fitted with two collectors each having two line contacts, with the result that arcing during normal running of the locomotive is almost completely eliminated. An example of this type of collector gear may be seen in Fig. 65. Even with these types of collectors, rolling contacts are not permitted in mines where firedamp is known to exist.

377. Contact devices for pantagraph or bow collectors fall into two main types :—

(1) Hard carbon blocks of triangular section, fitted to a copper rod, and

(2) Aluminium sliding plates used in conjunction with an oil soaked felt pad.

378. The former is undoubtedly the most popular type. The latter type appears to have come into greater use during the war period when suitable carbon was in short supply. In addition to carbon and aluminium sliders, copper, aluminium and steel rods have been employed as contact mediums with bow collectors.

379. It will be readily recognised that the adoption of pantagraph or bow collectors precludes the effective use of guard boards at the sides of the line, but since this form of protection against accidental contact is expensive to instal and maintain, it is claimed that a more satisfactory solution is to increase line height.

380. Among the advantages claimed for these types of current collectors compared with the trolley pole are :—

(1) Simplification of the overhead line layout at all junctions and crossings. (The use of special collector guide devices such as " frogs," with all the complications involved in their installation, is completely avoided).

(2) De-wirements, with the constant risk of mechanical and electrical damage to the trolley line and its supports, are eliminated.

(3) Arcing between collector and line is reduced to a minimum with a consequent reduction in line maintenance.

(4) All collectors of this type are, or can be, made automatically reversible.

381. Fig. 65 also illustrates a pantagraph having two aluminium slider plate contacts with a felt pad type oil lubricator fitted between them. Such lubricating devices obviously require careful handling on account of the fire risk. Graphite is an alternative to the use of oil or grease.

382. Fig. 66 shows a typical bow collector to which can be fitted various types of slider contacts including the triangular shaped carbon block, which is also largely used with pantagraphs. Three types of metal sliders having carbon or graphite inserts are also shown. Figs. 67 and 68 show more simple forms of bow collectors.

(iv) *Short Circuiting Switch*

383. One interesting electrical feature of the trolley locomotive, which is peculiar to most European coalfields in which this form of locomotive is used, is the short-circuiting switch which is required by paragraph 24—Locomotives—(*f*) of the German Instructions for the erection of electrical installations below ground. This instruction reads—

> " Trolley locomotives must be provided with switches for short-circuiting, the function of which must either be to cut off the current in the road by opening the automatic overload switch in the sub-station, or render the voltage drop in the trolley wire so great that the current at that point is not dangerous to life. The locomotive short-circuiters may be replaced by devices which actuate remote breakers which cut out the trolley wire automatic overload switch."

384. The short-circuiting switch provides ready means whereby the driver of the locomotive can make the trolley wire instantly dead in the event of any emergency such as a fire on the road, or if accidental contact is made with the line by the trip rider or any other person in the vicinity. Despite the apparently drastic nature of the method, it functions well and with complete safety. It must be remembered, however, that in the Ruhr mines the maximum load on the trolley line seldom exceeds 400 KW., and that a great deal is made of the point that the capacity of the generating plant must be closely related to the load demands of the locomotive.

385. The switches are robustly constructed with heavy contacts, and in one design are completely embedded in a slate block suitably slotted to provide blow out paths for the arc. Fig. 69 shows a typical contact arrangement, and Fig. 70 the position in which the switch is usually fitted on the locomotive. Its place in the electrical circuit is shown in Fig. 71.

(v) *Source of Power Supply*

386. Since the prohibition on safety grounds of the use of alternating current in any new installation, direct current at 250 volts has become the standard form of power supply for trolley locomotives, and in all but a few installations, the generating plant has taken the form of rotary converters. Motor generator sets are only used at a few plants, while a limited number of more recent installations are equipped with glass bulb or steel tank mercury-arc rectifiers.

387. The size of these generating units varies between 80 and 250 KW., the majority being round about 135 KW. Parallel connection of a number of machines is generally practised where the load demand exceeds this value.

388. Managements contemplating new installations or the provision of additional generating plant look with considerable favour on mercury-arc rectifiers of glass bulb and pumpless steel tank types, since experience in the Ruhr with this type of equipment has been extremely satisfactory from the point of view of high operating efficiency combined with low maintenance costs. Furthermore, costly foundations are avoided, and greater freedom of movement from site to site is obtained. As an example of good service, in one of the older installations in which glass bulb type rectifiers of 87.5 KW. capacity have been used, the bulb life has averaged 8,000 hours ; one bulb was said to have been in use for 12 years. A bulb life of between 3,000 and 4,000 hours is, however, more usual. The mercury-arc rectifier most commonly used is 125/150 KW.

389. The average distance covered by one power substation, which is usually situated at or near the shaft bottom, is about 1 mile, but in some cases is as much as 2½ miles. The cross-sectional area of the trolley wires provided and their supplementary feeders generally keep voltage drop to within a maximum of about 15 volts, although a drop of only 6 to 10 volts is not unusual. The size of trolley wire employed seldom necessitates supplementary feeders. It will be recognised that the apparent simplicity of power supply in the Ruhr is largely the result of using comparatively small locomotives, and that where the conditions demand the employment of heavier locomotives of much greater horse-power, the problem becomes more involved.

390. Figs. 72 and 73 show wiring diagrams of typical power supply installations for trolley locomotives. The former relates to mercury arc rectifier equipment, and the latter to motor-generators.

(vi) *Trolley Wire and Installation*

391. Except in a very few old installations the use of hard drawn copper wire of grooved section is standard practice, and the wire used, which is covered by a standard specification (DIN-VDE 3140 and 3141), is very similar in profile to that laid down in B.S.S. 23—1935. The German specification lays down four standard sizes, the minimum being 0.075 sq. in. and the maximum 0.155 sq. in. The most common size used is 0.124 sq. in., although a number of installations employ 0.186 sq. in., and a relatively few 0.235 sq. in., which, it will be observed, is outside the standard. This size is considered to be the practicable maximum. These trolley wire sizes are somewhat excessive when compared with the load demand of the locomotives employed, but it must be admitted that they reduce to a minimum, if not entirely eliminate, the need for supplementary parallel feeders in the road. At the same time, voltage drop is kept within the desired limits.

392. The height of the trolley wire from the top of the rails, as laid down by the Regulations, is directly related to the working voltage, and in the case of 250 volts direct current—the voltage commonly employed underground for trolley locomotive working—the minimum height specified is 5 ft. 11 ins. In the case of a very few installations which still use A.C. voltage, the minimum height is 7 ft. 3 ins.

393. Clearance between the trolley wire, or the current collector running on it, and any other metal in the roadway such as cables, pipes or support material, is specified in the Regulations, and must not be less than 1 ft. 4 ins., or alternatively, 4 ins. greater than the effective contact width of the current collector. The minimum clearance of 1 ft. 4 ins. is generally observed without difficulty.

394. Various methods of trolley wire support are employed, but the most common form is by means of span wires anchored to the roadside props. This, although apparently not directly specified by the Inspectorate, is used to secure flexibility in the support of the line. Where rigid brackets supported by the roof bars are used, either a flat spring or a loose link is inserted between the line and the insulator, or between the insulator and the supporting bracket, thus springing the line against the current collector. An example of the loose link type is shown in Fig. 74. The demand for this flexibility, which is provided automatically where the span wire method of support is employed, no doubt arises from the general use of current collectors of the bow or pantagraph type, which are not as sensitive as trolley poles to sudden changes in the height of the trolley wire. Whatever form of collector is used, however, the use of spring hangers serves to reduce sparking. The line is usually fixed rigidly to the insulators at the end of the track. To obviate sparking, an over-running switch, which is automatically operated by the locomotive if it inadvertently overshoots the line, is fitted about 10 yds. from the end of the track.

(vii) *Feeder Connections and Sectionalising Switches*

395. To comply with the Regulations, feeder cables to supplement the trolley wire must be provided with automatic circuit breakers at each end, except where practical and reliable arrangements can be made to isolate any section of the road at the supply source, in which case a switch at the line end of a feeder may be dispensed with.

396. The Regulations also provide that, where it may be advantageous to bridge the two trolley wires in double track roads for the purpose of equalising the voltage, insulated conductors shall be used. (In such a case, bare conductors would, to say the least, be inconvenient.)

397. Trolley line sectionalising switches, which are provided at approximately 1,000 yd. intervals, usually consist of a plain single or double pole air-break knife switch located in a conspicuous position at the roadside. The dead sections of the line to which these switches are connected are so arranged that the current collector on the locomotive cannot bridge the gap and so inadvertently restore the supply to the isolated section.

(viii) *Track*

398. Track standards and the weights of rails are discussed elsewhere in the Report. Here, it will be sufficient to refer to the additional track requirements for trolley locomotives. It is more or less standard practice to weld all rail joints, generally by welding the edges of the fishplates and the gaps between the ends of the rails. Welded-on copper bonds made from recovered scrap trolley wire are used for cross bonding, and sometimes to supplement the welded rail joint. The standard of conductance laid down requires that the resistance of the joints between the rails shall not exceed that of a standard length of solid rail. Cross bonds are required at 100 ft. intervals along the track, and at all switches and crossings. Welding is normally employed for these purposes.

BATTERY LOCOMOTIVES

399. Battery locomotives were introduced underground for main road haulage about 42 years ago. At that time the locomotives were equipped with motors of 6–8 H.P., powered from 80 cell batteries. Development was rapid, and by 1916, 36 H.P. locomotives (with the same power output as existing trolley locomotives) were in use. The advantage of the battery locomotive for gathering-haulage was not recognised, however, until about 1925. Up to about this time locomotives had not been used in the gate roads because of the risk of igniting fire damp. This ruled out the use of trolley locomotives, and battery locomotives, in which the electrical equipment could be made firedamp-proof, were, therefore, employed. Two distinct ranges were developed, 4–15 H.P. for gathering haulage, and 23–43 H.P. for main road haulage. As will be seen from the following table, generally from 1926 to 1938 the use of battery locomotives increased in gate roads and decreased in main roads. (Some of the reasons for this appear in Appendix No. 14.)

TABLE VIII

Year	*Number of Battery Locomotives in Main Roads*	*Number of Battery Locomotives in Gate Roads*
1926	161	63
1930	89	157
1931	32	156
1932	38	162
1933	26	145
1936	23	189
1937	23	227
1938	33	259

400. One of the main objections to the use of the battery locomotive for main road service was undoubtedly its extremely limited operating range. Considerable attention has been given to the production of higher capacity batteries, and to increasing the operating efficiency of the locomotives so as to increase their range. Much progress has been made in this direction by the use of lead-acid and nickel-cadmium cells, with the result that the present main road battery locomotives (most of which are now equipped with lead-acid batteries) can compete successfully with the Diesel and compressed air types.

401. A new type of main road battery locomotive which was developed before the war is described in Appendix No. 14. The main feature of this locomotive (see Figs. 75 and 76) is the eight step resistance-less control, which, it is claimed, saves 15–25 per cent. of the battery capacity. This locomotive is available in two sizes, one of about 13 tons and the other of about 17 tons. A specification of the larger size is given in Table IX.

402. Other features of the design are the tandem construction which permits the employment of four driving motors—each coupled to an axle—and facilitates the resistance-less control arrangement. The two parts of the locomotive are connected by a cardan shaft coupling. The two 60 cell lead acid batteries, which vary between 500–780 ampere hour capacity according to the size of the locomotive, have a discharge rate of 5 hours. The batteries are connected in parallel during the first three starting steps: thus, with the four motors in series, the voltage available for each motor is only about 28 volts. By series and parallel connection of the batteries, the motor groups and the motor fields, and with, in addition, field weakening, a steadily increasing voltage is imposed, which results in extremely smooth acceleration of the locomotive up to full speed. Fig. 77 shows in detail the electrical arrangement of this method of control.

403. As stated above, a saving of up to 25 per cent. in battery capacity is claimed for this arrangement. This saving, together with the high capacity batteries employed, has rendered possible double shift working with one charge. Batteries are usually charged on the

night shift and, as this normally takes 5–6 hours, the locomotive is available for work for not less than 17 hours in every 24 hours.

404. In assessing working costs, allowance is made for battery replacements on the basis of an estimated life of 350 charge-discharge cycles for the positive plates and 700 cycles for the negative plates, or about 18 months and three years respectively. This is reasonable. A higher figure of 450 to 500 charge-discharge cycles for the positive elements is claimed in other quarters.

405. As may be seen from the illustrations of this locomotive, both battery containers are fitted with venting devices in the top cover with the object of preventing flame from an internal ignition of hydrogen passing to the external atmosphere which may contain firedamp. The arrangement consists of 26 packs of plates pocketed behind louvres, which may also be seen in the illustrations. Each pack, which is readily removable, consists of a series of aluminium plates spaced 0.0197 ins. apart. The cover to which these plate vents are attached is secured to the battery case by means of a number of turreted projections alternately spaced on case and cover so that they interlock in the closed position and obviate the need for securing bolts. The mechanical fit is such that the cover can only be attached or removed with the aid of a mechanical drawing appliance.

TABLE IX

SPECIFICATION OF MAIN ROAD BATTERY LOCOMOTIVE

Type of locomotive	Fire-damp protected battery locomotive.
Maker	Heinrich Bartz, K.-G., Dortmund-Korne.
Date of manufacture	1940.
Dimensions.	
Length	29 ft. 4 ins.
Width	3 ft. 6 ins.
Height	6 ft. 3 ins.
Dia. of driving wheels	1 ft. 6 ins.
Wheel base	3 ft. 11 ins.
Track gauge	1 ft. 9½ ins.
Working Data.	
Weight	17.6 tons.
Horse power	47.2 H.P.
Speed	6.2 m.p.h.
Drawbar pull	2,650 lbs.
Motors	
Maker	A.E.G., Berlin.
Type	UKB 23.
Number	4
H.P. rating	11.8 H.P.
Speed	900 r.p.m.
Amperes	90 amps.
Gear ratio	1 : 7.73.
Batteries.	
Maker	Akkumulatorenfabrik A.-G., Hagen.
Type	AFA 12 Ky 380.
Number of cells	2 × 60
Capacity	780 ampere hours.
Mean battery voltage	113 volts.
Battery containers.	
Maker	Heinrich Bartz K.-G., Dortmund-Korne.
Type	B 10/60.
Protective device	Plate vents.
Length	10 ft. 11 ins.
Width	3 ft. 6 ins.
Height	2 ft. 7½ ins.
Total weight of batteries and containers	7.7 tons.

406. The experience gained from a number of ignitions has shown that plate protection is not a satisfactory means of confining flame from an internal ignition of hydrogen, and some time ago representations were made to the responsible authorities that this so-called protection should no longer be used. The general view is that not only are plate protection devices useless against hydrogen explosions, but that they actually encourage the accumulation of hydrogen within the enclosure. The alternative suggested in the Ruhr is that battery containers should be provided with large apertures to permit free ventilation of the enclosure.

407. In regard to battery locomotives in general, there is every indication that they will remain popular for gathering-haulage service in the Ruhr. When used in conjunction with trolley locomotives, the battery charging plant can be located in the underground substation which houses the generators for the trolley locomotive system, thus converting the sub-station into a compact all-purpose plant.

408. Alternative types of electric locomotives have not, so far, met with success. For example, the trolley battery tandem arrangement has not proved satisfactory because the addition of the battery unit lowers the efficiency of the locomotive. A modern example of this type of locomotive is shown in Fig. 78. A more efficient version is the trolley charging locomotive, in which a battery of medium capacity is added to the trolley bogie. When the locomotive is used as a trolley locomotive, the battery is automatically charged from the trolley wire, but this has not proved entirely satisfactory, and a boosting charge from a larger charging equipment is usually necessary every third shift.

DIESEL LOCOMOTIVES

(i) *General*

409. Diesel locomotives were not used underground in the Ruhr Coalfield to any appreciable extent until about 1930. In 1933, 77 Diesel locomotives, 3.3 per cent. of the total number of locomotives, were in use, and by 1937 this number had increased to 257. In 1940 (the latest year for which reliable information is available) the number had further increased to 428, of which 88 were employed for gathering haulage.

410. The six types of Diesel locomotive in use range from 9 to 75 H.P.; the latter is about 10 tons in weight and the largest so far available. Of these six sizes, standardisation has been effected in three, namely, the 9 H.P. (KML.8), which has a single cylinder engine; the three-cylinder 32 H.P. (KML.7); and the 75 H.P. (KML.6), which has six cylinders. The 10-ton Klockner-Humboldt-Deutz 75 H.P. (KML.6) six-cylinder locomotive (illustrated in Fig. 79) is used in large numbers in the Ruhr. This locomotive has a four-cycle engine in which the fuel is sprayed into an advance chamber; this method of injection is claimed to give cleaner burning, lower consumption with a higher power output, and lower oil pump and feed pressures than direct injection. It is also claimed that the engine is less sensitive to varying grades of fuel oil, a point of some importance during the war years. The fuel container has a capacity of about 18 gallons. The cylinders, which are cast *en bloc*, are fitted with liners which are easily renewable. Sensitive automatic regulation of the fuel pumps enables engine speed to be controlled over an extremely wide range from the driver's cab.

411. Cooling is effected by a radiator (constructed of seamless tubes) which is cooled by an eight-bladed belt-driven fan; a pump maintains constant circulation of water in the system. Starting is effected by a small compressed air motor, fed from air storage cylinders; the cylinders are charged by a small air compressor driven by the engine. Power is transmitted through a double plate friction clutch, and through a gear drive to side rods connected to the wheels. A four-speed gear box provides for speeds of 2.23, 3.73, 6.03 and 8.45 miles per hour.

(ii) *Intake Air and Exhaust Gas Conditioning*

412. Diesel locomotives are normally fitted with exhaust gas cleaners and intake air filters. The exhaust

TABLE X

Type	Vol. of containers cub. ft.	Length ft.	Width ft.	Height ft.	Weight tons	H.P.	Draw-bar pull lbs.	Miles per filling
Borsig (2 cylinder)	495	15′ 11″	3′ 4″	5′ 4″	9.3	33.5	1,980	4.95
Borsig (heavy design) ..	620	15′ 11″	3′ 7″	5′ 8″	10.6	44	2,600	
Schwartzkopff (piston drive)	460–600	13′ 10″	2′ 9½″–3′ 11″	4′ 7″–5′ 7″	6–9	30	1,980	3.2–6.85
Schwartzkopff (radial motor drive)	495–530	13′ 10″	2′ 8½″–3′ 4½″	4′ 7″–5′ 5″	7.5–9	35	2,650	3.73–5.6

cleaner usually takes the form of a water tank fitted with a series of baffles through which the gases are passed, and cooled and cleaned in the process. A plate vent composed of a pack of "Nirosta" steel plates spaced 0.0197 in. apart is fitted on the outlet side of the tank. After passing through this vent, the gases enter a mixing chamber where they are diluted by the admixture of approximately 30 times their volume of air, and are then passed out to the atmosphere.

413. In a more recently developed method of exhaust gas cleaning employed in Holland, a tray containing a number of Raschig rings is used. After passing through the water tank with its baffles, the cooled and wet gases pass through the Raschig ring filter. The rings, which are of porous earthenware and loosely packed, must be removed and cleaned at monthly intervals.

414. The conditions laid down by the Inspectorate for the design of Diesel locomotives provide, *inter alia*, that (1) at the highest engine speed, either light or at full load, the C.O. content of the undiluted exhaust gases must not exceed 0.12 per cent., and (2) in roads where Diesel locomotives are employed, the minimum ventilation shall be 215 cub. ft. per minute per locomotive horse power. In some locomotives, the gases are cooled off by sprayed water on leaving the cylinder and before entering the gas cleaner. Filtered water from a special container is used for this purpose, and the supply is automatically controlled so that in the event of a shortage of water the fuel supply is cut off and the locomotive brought to a standstill.

415. Some justification was found for the criticism that Diesel locomotives give off obnoxious fumes and so pollute the atmosphere, particularly in mines where several locomotives are used simultaneously. For example, in the Hannover Mine where several 70 H.P., 24 H.P., and 8 H.P. Demag Diesel locomotives were in use, the quantity of fumes present in the intake airways during the working shift was distressing. This was due to the general poor condition of the locomotives (the average age of the locomotives was 6 years) and, in particular, to the shortage of spare parts with which to keep the water scrubbers in good order. Of the 17 locomotives provided, 12 were out of service pending the arrival of spares, and it had been necessary to run some locomotives without exhaust gas scrubbers. Thus, the exhaust gases were passed almost direct to the atmosphere. At the Jacobi Mine, where 5 Klockner-Humboldt-Deutz 63 H.P. Diesels were in use, nothing more than a smell was apparent in the main haulage roads.

416. Manufacturers of Diesel locomotives have experimented with various methods of drive, and it is claimed that the side rod method has proved more satisfactory than the gear drive method. Experiments made with chain drives have not, so far, been successful.

417. The maintenance costs of Diesel locomotives are about the same as those for battery locomotives. Papers which deal with the experiences of actual users indicate that the energy and maintenance costs of Diesel locomotives are comparable with the cost of replacing batteries.

418. At a number of mines it is intended to effect a change from Diesel to trolley locomotives as soon as the necessary material becomes available.

COMPRESSED AIR LOCOMOTIVES

419. The number of compressed-air locomotives in use in 1919 amounted to 617 (27 per cent. of the total number of locomotives); by 1940 this figure had increased to 1,223, of which 855 were main road locomotives, and 368 were assigned to gathering duties.

420. The size range of this type of locomotive is not as wide as that of electric locomotives, and during the war only two standard models were produced, i.e. the 4.7 tons 40 H.P. (KDrL 2), and the 8–10 ton 40 H.P. (KDrL 1). Other types are, however, still in fairly common use. Particulars of four of these types are shown above.

421. High pressure compressed-air is usually produced on the surface by multi-stage compressors and conveyed underground—often for a considerable distance inbye—in special pipes of from 1½ in.–2 in. diameter at a pressure of between 150 and 200 atmospheres. Charging points from which the locomotives draw their supplies are arranged at suitable intervals along the roads. The air storage containers on the locomotives are in various forms and generally number three or four, although up to 9 are used in some cases. Container capacity varies from about 6,900 to 7,800 cub. ft. of free air at 150 atmospheres. The pressure is then reduced to 12–15 atmospheres at which the air is passed to the smaller working containers. Thence it passes to the high pressure cylinder and, through an inter-warmer, to the low pressure cylinder. The efficiency of this form of locomotive can be gathered from Appendices Nos. 15 and 16.

TABLE XI

H.P. AND WEIGHT RANGE OF PRINCIPAL TYPES OF LOCOMOTIVES USED IN THE RUHR

Type	*Designation*	*H.P.*	*Weight Tons*
Diesel	KML 8	9	
"	—	26	
"	KML 7	32	
"	—	45	
"	—	65	
"	KML 6	75	
Compressed-air	KDrL 2	14	
"	KDrL 1	40	
Trolley	—	36	7/8
"	KEL 6	52	8
"	KEL 5	85	10
Battery	KEL 9	15	
"	KEL 8	23	
"	KEL 7	43	

Fig. 82 illustrates two typical compressed-air locomotives. An economic comparison of the various types of locomotives in use underground in the Ruhr is given in Appendices 15 and 16.

SIGNALLING

422. The most common method of signalling in use on locomotive haulage roads in the Ruhr is by coloured lamps—a typical example of which is illustrated in Fig. 80. Two colours, red and green, are usual, but in some circumstances a third colour—yellow—is introduced. This is only used in single track roads where two locomotives may be travelling in opposite directions at the same time, and where the signals at the extreme ends of the section may have turned from green to red while one of the locomotives was passing the signalling point. By changing the light from red to yellow, the driver who first reaches the next signalling point is able to indicate his presence on the road. The driver of the opposing locomotive confronted with a yellow lamp reverses to the nearest junction out of the way.

423. The signal lamps are usually manually operated by the driver, the switches being mounted on the roof within easy reach. Automatic operation on the lines indicated in Fig. 81 is sometimes adopted, and in such a case the necessary supply is obtained from the trolley wire. An independent source of supply is, however, preferred in the majority of cases.

424. Except in the smaller installations, it is not customary to rely entirely on the telephone system, but rather to use it as an aid to visual lamp indication.

MINE CAR DEVELOPMENT AND DESIGN

425. The Ruhr mines carry a stock of tubs and mine cars capable of holding 70 per cent. of the gross daily output. In 1936, when the daily output was 475,000 tons, the count was 410,000 tubs with a total cubic capacity of 11,650,000 cub. ft. In 1941, the count was 450,000 tubs. The factories in Germany in 1941 had a capacity equal to 52,000 mine cars per annum. The life of a tub is approximately 8 years, and of a mine car 12 years.

426. The term mine car is used for all tubs, not manhandled, ranging from 25–37 cwts. upwards.

HISTORY

427. The history of the development of the German mine car may be summarised as follows. Originally, it had to be a tub low enough to be filled by hand and light enough to be trammed. The introduction of face conveyors enabled a small increase in size to be made, and this is reflected in the changes shown between 1914 and 1929. The size of the tub was still restricted, however, by the necessity of confining the tubs to the gate roads and staple shafts. The introduction of gate conveyors in 1926 gave an impetus to the demand for larger cars, but the restriction of the staple shaft remained. The introduction of continuous haulage and skip winding in staple shafts removed the disadvantage of the staple shaft in this respect, and the German mining engineers then began to assess the further limiting factors outlined in the next section.

428. The following table shows the distribution of tubs in the Ruhr in 1914, 1929 and 1936 :—

TABLE XII

	1914 %	1929 %	1936 %
9 –13 cwts.	98.09	78.49	31.60
13 –15½ cwts.	1.30	20.88	29.33
15½–17½ cwts.	—	.63	32.77
17½–35 cwts.	—	—	6.22
Over 35 cwts.	—	—	.08

(Appendix No. 17 sets out in detail the trend of sizes over this period.)

429. More recent figures are not available, but it is known that the mine car trend has continued. The economic advantages of a larger car have always been realised: the policy of concentration focussed attention on this type of car, the continuous conveying system from the coal face to the cross-measure drift facilitated its introduction, and, with the advent of the "Combined Mine" and the opening up of new levels, its general adoption in the flat formations seems assured. It is estimated that it will take 12 to 15 years to complete the change-over.

430. Appendix No. 18 is a translation of a paper on the subject of mine cars by Dr. Glebe, the haulage expert of the German Coal Owners' Association. Dr. Glebe's opinion of the technical advantages of the mine car are as follows: "Simplification of loading, reduction of deadweight and increase in useful load, with equal total weight per wind or train; reduction of the number of cars because of the larger capacity; reduction in the number of haulage mishaps because of better tracks essential for mine cars, and an increase in the capacity of the whole haulage system."

431. Dr. Glebe's analysis of the effect of substituting 63-cwt. mine cars for 13-cwt. tubs in a modern mine with steep formations, no conveying in the gate roads, and an output of 1½ million tons per annum, shows a financial saving of 34 per cent. made up as follows :—

	13 *cwts.* d.	63 *cwts.* d.
Stock of tubs	2.24	1.36
Haulage in subsidiary roads and main gates	5.24	2.82
Staple shaft winding	6.56	5.18
Main road haulage	1.84	1.10
Main shaft winding, including pit bottom haulage	6.02	3.98
TOTAL ..	1s./9.90d.	1s./2.44d.

LIMITING FACTORS IN CAR DESIGN

(i) *Two Winding Systems in One Shaft*

432. The development of horizon mining in the Ruhr led to the double winding system (*see* Chapter V) because of the need to wind from at least two levels.

433. It has been found quite practicable to design a mine car in such a way that one mine car takes up the maximum space on one deck of a cage. Therefore, the size of the mine car depends on the most efficient arrangement of cages in the shaft, and the length and width of the mine car are fixed within this limiting factor. (Shafts in the Ruhr are of varying sizes, and it was only recently found possible to reach some measure of standardisation for the newer and deeper shafts, which are about 6½ yds. in diameter.)

(ii) *Size of Roadways*

434. The size of the roadways and the different curves of the arches on the roadways limit the height of the car if adequate clearance is to be maintained. The German mining engineers came to the conclusion that it was safe to proceed within these limits.

435. The question then arose as to whether it was practicable, within these limits, to introduce maximum sized cars into the seam itself. Some German mining engineers hold the view that there are advantages in using the standard mine car for the purpose of taking material into the gate roads, and that the staple shaft and the gate road should each be sufficiently large to accommodate the standard mine car used. This is

advantageous in some cases, but not in steep seams and in weak ground. A further disadvantage is that the tipping of dirt at the rise side of a coal face requires elaborate machinery, as it is undesirable to unload cars containing four or five tons of dirt by hand.

436. It was to meet this difficulty that special material and dirt cars came into more general use. As far as possible, these cars are kept at a distance from the coal haulage so that mine cars of maximum size can be used for coal. (This is discussed more fully in Appendix No. 19.)

437. The question had then to be considered whether a further increase in the size of the mine car could not be brought about in conjunction with skip winding, and whether it would not be possible to have even larger mine cars which would run on the roads in the seam and not be taken up the shaft. After careful consideration, this scheme was abandoned for the following reasons.

(*a*) The Germans are by no means certain that skip winding is more economical than car winding in all cases, although the number of skip installations introduced during the last decade indicates that the Germans are fully aware of the economies which can be effected by this system.

(*b*) Skip winding in the Ruhr has the same disadvantages met with elsewhere in regard to breakage of coal, difficulty of winding dirt, and restriction of man-riding capacity. For these reasons alone car winding is still considered the best solution in many cases.

(*c*) Where dirt is removed from, or taken into, different levels at a mine, it is practically impossible to keep mine cars underground.

438. A compromise has been reached where skip winding plants are installed ; the GHH Company have invented a rolling tipper system for the purpose of feeding the skip. This system is fully described in Chapter V.

CAR DESIGN

439. The main requirements of the mine car in the Ruhr are that it shall be : of small tare for a good carrying capacity ; strong enough to withstand bumping ; dust and acid water proof ; of sufficient gauge to give stability ; easy running on curves and turns ; suitable for the working conditions, and fit the shaft cross section.

440. The first attempt to standardise the German tub was made in 1928, when standards Din 550, 551 and 552 were established for tubs of 13, 15½ and 17½ cwts. capacity. The next step was in December, 1944, when standard designs were published for six mine cars of 1.57, 1.96, 2.35, 2.94, 3.92 and 4.9 tons capacity. The publication of these standards was preceded in August, 1943, by a Law enforcing standardisation, where practicable.

441. The standards laid down took into account the limiting factors of shaft size and road height. As these factors are in themselves quite independent of the considerations normally given to the design of containers for carrying material on rail track, it was only to be expected that the standards would, to a certain extent, depart from normal haulage practice. The effect of basing the mine car on these limiting factors produced a long and narrow car with a long wheel-base and a high centre of gravity. The tare of the car when the capacity exceeds 3 tons is approximately half the pay load.

442. After steps had been taken to improve the track in the main levels and cross measure drifts and to ensure that the standards laid down for the track were adhered to, the new cars proved quite satisfactory in practice, and haulage mishaps were reduced.

443. The standard dimensions for cars are shown in Figs. 83, 84, 85 and 86. It will be seen from these diagrams that the capacity of the standard cars varies from 1.57 to 4.9 tons ; the width from 38.2 ins. to 48.8 ins. ; the length from 7 ft. 8 ins. to 10 ft. 2 ins. ; the height from 50 ins. to 53 ins. ; and the wheel-base from 39.3 ins. to 69 ins. : also, that the smallest radius curves which can be negotiated under gravity range from 21 ft. 4 ins. to 39 ft. 4 ins., or, when hauled by locomotive, from 32 ft. 9 ins. to 82 ft. The bodies are completely welded. Each body is fitted with leaf springs, single buffers and buffer springs. The wheels, which are of 13$\frac{25}{32}$ ins. diameter, are fitted with double taper-roller bearings. The couplings may be of the simple hook-and-eye type, or automatic.

444. These standard mine cars were not seen in operation, but large mine cars were seen at three modern mines, Pattberg, Niederrhein and Walsum. The capacities and measurements of these cars are given below :—

TABLE XIII

Dimensions	*Pattberg*	*Niederrhein*	*Walsum*
Capacity, cwts.	61.7	38.8	67.7
Total length	12′ 1⅛″	11′ 0″	12′ 9″
Height over rails ..	4′ 9″	4′ 2″	4′ 11″
Outside width	3′ 7⅛″	2′ 7⅛″	3′ 1⅛″
Gauge	23.62 ins.	23.62 ins.	29.52 ins.

CAR BODY

445. As has been mentioned, the car body is completely welded : the thickness of the plates varies from $\frac{3}{16}$ in. to $\frac{5}{16}$ in., and the body itself is welded to the frame. It is estimated that welding reduces the replacement and maintenance costs by 10 per cent. The car edges are thickened for the purpose of strength, to maintain rigidity, and to prevent distortion. Examples of different car edges, together with standard car edges, are shown in Fig. 87. The car bottom in the large mine car is flat, but in the three smaller sizes it can be round. The radius of the curves at the corners varies from 10 ins. to 1 ft. There have been three governing factors in this design. Firstly, it is considered desirable that the axle should be kept straight for reasons of strength : secondly, a great deal of wet dirt is transported in the Ruhr, and the bottom of the car is therefore designed in such a way that the dirt can be readily emptied : thirdly, it is considered an advantage to provide a clearance of at least 3 ins. between the bottom of the buffer and the top of the rail.

446. The car body is fitted with leaf springs seated on the axle. These springs are fitted outside the wheel on the three large sizes of cars, and inside the wheel on the smaller cars. The axles are square and the axle boxes have vertical guides (see Figs. 88 and 89). At present the larger sizes of mine car are not galvanised, but arrangements are being made to carry this out in the near future.

WHEELS, AXLES AND SPRINGS

447. The standard diameter for the wheels of cars of all sizes is 13$\frac{25}{32}$ ins. ; the width varies with the size of the car from 3$\frac{15}{16}$ ins. to 4½ ins. The tread width is increased as the weight of the car increases, and this is an important factor in stabilising the car. A play of ⅛th in. is allowed between the flange of the wheel and the rail head. The modern wheel is loose on the axle, which is a considerable advantage although it adds to the difficulties of braking the train. The wheels are spoked, and are of cast steel. (A standard wheel is shown in Figs. 90 and 91.)

448. The axles, which are of steel, are square in shape and support the body by means of leaf springs. Each spring contains 4 or 5 leaves.

449. Cars recently built have double taper roller bearings. Before the introduction of this new type of bearing, cars required greasing every 3 to 6 weeks, and careful records were kept of the dates on which this greasing was carried out. All cars were numbered for this purpose. Greasing was normally carried out by machine, the grease being forced from the cylinder by steam or compressed air. With the new type of bearing, it is considered quite safe to run a car for 12 months without greasing.

BUFFERS AND COUPLINGS

450. The comparatively high speeds at which the trains run, their length, and the rapid acceleration and deceleration possible with trolley locomotives, has directed considerable attention to the buffers and couplings with a view to absorbing shock and reducing the snatch. In the single buffer, which is used throughout the Coalfield, the coupling is led through a recess beneath the centre of the buffer. The purpose of this recess is two-fold : firstly, to enable the coupling to be attached centrally to the draw-bar or frame, and secondly to reduce the snatch between two cars coupled together. Two ordinary types of couplings are in use, the Kohlus and the Schulte. Both are similar, the only difference being that the Schulte has a smaller hole in the hook to assist in reducing snatch. The Kohlus coupling is shown in Fig. 92.

451. A new design of coupling, the Müthing, is dealt with in Chapter V. This is an automatic coupling, specially designed so that mine cars can be mechanically coupled and uncoupled for cage winding purposes. (One of the advantages claimed for large mine cars is a considerable reduction in coupling and uncoupling.)

452. Other types of automatic coupling are in use in the Ruhr, in particular the Scharfenberg (*see* Figs. 93 and 94), but these types were not seen.

453. In the standard mine car the spring of the buffer is seated on the frame (Figs. 95 and 96). Figs. 97 and 98 show various types of buffer and coupling springs in use. Attention is particularly drawn to Fig. 98 (*a*) in which the buffer spring is so designed that the shock is taken away from the car altogether and is passed on through the buffers of the next mine car. The buffer springs on the standard cars are generally of the simple coil or evolute type with a movement of from 1$\frac{3}{16}$ ins. to 2⅜ ins. A new design for use with mine cars is the friction or ring spring, shown in Figs. 97 and 98 (*a*). This spring consists of a series of single rings, inner and outer, fitted together to form a column of any desired length. When compressed, the outer rings expand and telescope the contracting inner rings. The shock is taken by the friction between the inner and outer rings, and by the actual compression and tension of the steel in the rings themselves. The working capacity of this spring is calculated to be 4 or 5 times as great as that of the evolute spring or the simple coil spring.

CARS FOR SPECIAL PURPOSES

454. These fall into three categories : man riding, dirt handling and materials handling.

455. In regard to man riding, the common practice is to hang slings on the sides of the tubs or cars. An example of this is shown in Fig. 99 (*a*), where the seats are staggered so that the men have more room for their legs. Mine tricycles which run on the track and carry three men are still used in old levels and in other places where normal traffic is light.

456. In regard to dirt handling, it is quite a common arrangement, where ordinary tubs are used, for the tubs to be emptied at the coal face by a portable side tipper operated by compressed air. When mine cars were introduced, this side tipper was too large to be used in gate roads, of which a number are relatively small. This difficulty has been overcome by designing special dirt cars which can be accommodated with the normal traffic. The container, which is mounted on the same undercarriage as for a mine car, can be pivoted by hand, and the side of the car is hinged at the top and opens at the bottom, as shown in Fig. 99 (*b*). An important consideration where the ordinary tub or mine car is loaded with wet dirt is the tendency of the dirt to stick to the bottom, thus reducing the useful load, and occasionally interfering with cleaning arrangements on the surface. At some mines, cleaning machines are installed on the surface to scour the car bottoms : the easy curves of the car bodies enable this work to be carried out with revolving brushes.

457. The cars for materials, an example of which is illustrated in Fig. 99 (*c*), are similar to some of the many types used in this country. It has proved advantageous to make the ends of the cars completely removable to allow for equipment such as shaker conveyor pans, and to adjust the sides and ends of the cars so that the height can be increased to accommodate bulky light material.

TRACK

458. Complete standards for tracklaying are laid down for all gauges and weights of rail in the Ruhr. These standards compare with good railway practice and are almost identical with the standard American recommendations for underground practice. A complete set of these standards was obtained, but it is considered unnecessary to publish them in this part of the report. (*See*, however, Appendix No. 20.)

459. The rails used in the mines are similar to those used on the German railways, *i.e.*, the flat-bottomed type. The profiles of the rails have been standardised.

460. There are five standard weights of rail : 28.20 lbs./yd., 36.35 lbs./yd., 40.35 lbs./yd., 48.45 lbs./yd. and 56.50 lbs./yd.

461. The first two weights are generally considered to be sufficient for tubs up to 17½ cwts. on gate roads, even with locomotive haulage. The 40 and 48 lbs. rails are used on levels, because of the heavier locomotives, and for mine cars in the gate roads. The 48 to 56 lbs. rails are used on the levels.

462. The 28-lbs. rail, unlike the heavier rails, can be laid without special tools. The standard specification requires good ballast for all rails except the 28-lbs. rail.

463. German technical literature lays great stress on the importance of good tracklaying, and of using special track gangs for laying rails over 28 lbs., particularly where high speeds will be used.

464. The rails are all fishplated and dogged on to wooden sleepers. Oak is considered the best wood for sleepers because it is hard and resists moisture, and does not split when nails are driven into it. In levels, it is considered essential to impregnate the sleepers with preservatives. For light tracks in gate roads, etc., rough cut sleepers of oak, beech and fir are used.

465. The wooden sleepers are made in three sizes. Sleepers of approximately 4½ × 12 ins. are used in the levels, of 4 × 5 ins. in gate roads where locomotives

are used, and of 3 × 4 ins. for horse and rope haulage. Steel ties are inserted at suitable intervals.

466. It is considered that there is no general case for steel sleepers in the mines. These sleepers corrode quickly unless galvanised, which increases the cost, and are less easily laid in the ballast. Consequently, they are only used in dry roads where the weight of traffic is light, or for rapid extension of the track in short lengths at the gate road heads prior to the installation of the permanent track.

ARRANGEMENTS AT STAPLE SHAFT LOADING STATIONS

467. Compared with main shaft winding, the arrangements for changing and standing room at the staple shaft are on a small scale because only small trains are brought in, and the working life of the staple shaft is relatively short. On the other hand, the work to be carried out requires adequate arrangements and suitable machinery such as graded tub runs with pulling-in haulages, swing-stages for loading, tub loading arrangements and automatic tub handling for skip-winding. Fig. 100 shows the plans and elevations of two examples of staple shaft stations. The top diagram shows an arrangement for an average output essentially from steep areas. Empty trains come from the main shaft on track I and over the switch " a " on to track III, where they are drawn by means of small haulers " b " and run down inclines to the onsetting point " c." The coal tubs run from the cage on to the creeper chain " d ", where they are picked up in trains from track II.

468. The next diagram shows an arrangement for a big output from a flatter area with an equally big demand for stowage material, for which a single skip is arranged. The balance weight runs next to the escape way in the shaft, and the coal passes down a spiral chute. Stowage tubs are tipped at " a " into the filling bunker for the skip. The empties which come from the main shaft over the switch at " b " into track IV are pushed through the staple shaft and under the spiral chute by the aid of a creeper, and are then loaded by means of a shaking chute " d." The tubs carrying wood, tools or machine parts on track III can be loaded on to the tub platform beneath the skip. Fig. 101 shows a spiral chute with, at the bottom, a hopper and shaker chute for side loading the tubs.

GENERAL TRAFFIC CONTROL

469. The problem of general traffic control in a level is to handle outbye traffic of coal, dirt and men, and inbye traffic of dirt, materials and men.

470. The whole of this traffic has generally to traverse two main arteries (the main levels) on its way from one or two pit bottoms to eight to thirty working points in four to eight cross measure drifts.

471. The main winding pit bottom may have as many as six full, and six empty, sidings for stock purposes, each of which may be 300/400 yds. long.

472. If the network is to operate efficiently, the loading stations must not wait for empties, the pit bottom must not wait for coal, and there must be no delay in the man-riding system.

473. The basis of the control system is nearly always a traffic control station, situated near the pit bottom, equipped with a very complete telephone system and, in addition, with various signalling systems. All the loading stations and main cross measure drift junctions are in communication with the control station by telephone. The controller at this station also organises the flow and direction of mine cars at the pit bottom.

474. As will be readily appreciated, the main level nearly always forms a bottleneck, and one of the principal tasks of the traffic controller is to fix the priorities for traffic from this level. Locomotives are often switched off the main level to the cross measure drift, but when proceeding in the opposite direction they are compelled to stop on the cross measure drift until the traffic controller gives permission to proceed.

UNDERGROUND WORKSHOPS

475. Spacious and well equipped underground workshops are provided at some mines in the Ruhr, and these are usually situated near the main shafts. The existence of these workshops is no doubt largely due to the use of locomotive haulage, and to the fact that the locomotives must often be serviced underground. Machine tools (including a lathe, shaping machine, drilling machines and grinders) are sometimes provided. This equipment enables major locomotive repairs to be carried out underground, and only wheel turning, axle repairs and motor rewinding are completed on the surface. A typical layout at a mine where both trolley and battery locomotives are in use is shown in Fig. 102. In this case, the fitting shop contains a good selection of machine tools, a substantial overhead crane and an electric welding outfit. About six tradesmen and labourers are employed per shift. Each shop is provided with at least one rail track to facilitate the easy movement of heavy equipment. The layout also includes the generating plant for the trolley locomotive system and for battery charging. It will be observed that the battery charging room is separately enclosed and is also provided with separate ventilation. Inspection pits, to enable underneath examination and repair of locomotives, are provided in the locomotive shop.

CONCLUSIONS AND RECOMMENDATIONS

476. (i) In the Ruhr the continuous system of gate road and staple shaft haulage and the use of the mine car show, in practice, a very satisfactory economy in costs and in manpower. We recommend that, where it is proposed to plan for horizon mining in this country, advantage should be taken of German experience in transport design and layout.

(ii) Locomotive haulage has become firmly established as the standard form of underground transport in the Ruhr because, compared with rope haulage, it has greater flexibility and breakdowns are less frequent.

(iii) The trolley locomotive remains by far the most popular locomotive in the Ruhr because of its higher operational efficiency compared with all others. There is evidence that some Diesel installations will be replaced by trolley locomotives as soon as the necessary equipment is available. We recommend that the trolley locomotive should be introduced into British coal mines, under suitable conditions, without delay.

(iv) The methods of trolley wire suspension and of current collection employed in the Ruhr are recommended from the point of view of efficient operation and low maintenance costs.

(v) Welding provides the most permanent form of track bonding. We recommend that the necessary facilities should be given to enable welding to be similarly carried out underground in British mines.

(vi) In view of the success achieved in the Ruhr, we recommend that mecury arc rectifiers should be provided in preference to rotary equipment in underground D.C. sub-stations for trolley locomotives.

(vii) The development of the Diesel locomotive has been retarded by war conditions and, to a certain extent, by its high maintenance costs as compared with the trolley locomotive. Fumes become a nuisance where several Diesel locomotives are simultaneously in use underground.

The German Diesel design is not, on the whole, as efficient as the British.

(viii) The compressed-air locomotive, which is comparatively low in horse-power, is generally acknowledged in the Ruhr to be less efficient than other types. We therefore do not recommend its use in British mines.

(ix) The efficient and attractive design of the undercarriage of the German standard mine car makes it particularly suitable for use with locomotives. This is of special importance in view of the increasing use of locomotives in British mines. Points worthy of particular study are the single buffer and buffer spring, the double taper roller bearings and the methods of springing and of suspending the car body.

(x) The efficiency of haulage operations in the Ruhr is, in general, greatly increased by the method of track-laying, which is of a very high standard.

(xi) The simple mechanical devices used at loading stations, together with the simple layouts, have enabled considerable economies to be effected in manpower, and add to the efficiency of large mine cars hauled by locomotives.

(xii) The underground workshops provided in some Ruhr mines have proved to be of considerable value, particularly for locomotive repairs. We recommend that similar accommodation should be provided underground in new large mines, and in older mines where a number of locomotives are serviced, in this country.

CHAPTER V

Winding and Shaft Layout

DEVELOPMENT OF WINDING

477. The first important factor to influence winding in the Ruhr was increasing depth. Over 50 years ago the deepest shafts were about 1,300 ft.; the cost of installing new winders to maintain output from deeper levels then led to the introduction of a single-rope groove-drum or pulley fitted with brake rims in place of the broad-drum winder. The inventor of this device was named Koepe, and the Koepe pulley remains to the present day. To increase winding capacity, rope speed was increased and an improvement in decking time was achieved by the introduction of cage-loading devices. Robustly constructed mine tubs to withstand the rough usage became necessary, and multi-deck cages were introduced together with, in some cases, simultaneous decking. To reduce decking time, larger tubs were designed and the same loads were carried by fewer decks.

478. In the larger diameter shafts, capacity was increased by the installation of double cage winding; this step facilitated the winding of coal, men and stowage material from more than one level in the horizon system of layout. More recently large cars were introduced which, in turn, led to the introduction of fully mechanised (and considerably more efficient) surface and underground circuits. (The latest development in the mechanisation of the operations connected with cage winding is the Müthing coupling which is described later in this Chapter.)

479. In a few cases, skip winding was applied as being more efficient than cage winding. This led to improvements in anti-breakage devices, and means were found to counteract the dust nuisance at the skip-loading level. The latest development in skip winding is the use of side-emptying cars in trains passing non-stop through a tipper with a limited roll, a system designed to eliminate coupling and uncoupling. The winding of stone has also received attention, and a special skip has been devised for this purpose.

480. It should be stated that the progress made in the mechanisation of winding practice is largely due to the concentration of winding in large capacity shafts where this is economically practicable. This trend has been greatly influenced by the rationalisation of the Ruhr mines which began in 1926.

481. It was noted that in 1941 (the most recent normal year in the Ruhr), 6 men, excluding those engaged in shaft maintenance, were employed each day at the pit bottom in winding 1,000 tons of coal from the flat measures.

482. The development of winder design and shaft equipment is largely in the hands of two outstanding and independent constructional engineering firms, Demag and G.H.H., who jointly own a skip-winder designing company. (It was noted that the Regulations required that the calculations and designs of every new winding equipment shall be submitted to a special technical branch of the Mines Inspectorate for approval.)

483. Winding practice in the Ruhr differs so fundamentally from British practice that it has been thought desirable to give the fullest possible information on the subject.

POWER FOR WINDING

484. Steam-driven winders predominate in the Ruhr, but in recent years there has been a definite tendency to adopt electric winders, particularly in new mines. (In the past, the choice of power was, to some extent, influenced by the general use of compressed air, which was used in all the mines with the exception of the Bonifacius.) Steam is preferred to meet the varying load on compressor drives of all types because it enables speed to be controlled with greater ease, and it has been retained for this purpose even where new central generating-plants of upwards of 100,000 KVA. have been installed.

485. The decision to instal steam or electric winders depends on individual conditions but, briefly, where it is cheap and plentiful, electricity is now chosen.

STEAM WINDERS

486. Only a few steam winders have been installed in the Ruhr during the last ten or fifteen years. These differ very little in external design from those of over a quarter of a century ago, but their efficiency has been increased by major improvements in speed control and in the shape of the cams, thus improving accuracy

of "cut off," and the valve gear employed ensures smooth and silent action. Steam pressures up to 18 atmospheres are used ; lower pressures are favoured, however, for slow running engines. The present maximum rope speed for steam winding was given as 59 ft./sec. A typical steam-winder is shown in Fig. 103.

THREE-CYLINDER STEAM-WINDERS

487. The development of large steam winders at potash mines has led to the introduction of three-cylinder high-speed, high-pressure, engines to drive the Koepe pulley by means of turbine gearing. In practice, it has been found necessary to provide the three-cylinder engine with a flywheel in an attempt to damp out the vibrations which are transmitted to the winding rope and produce harmonics of a destructive character. Despite the introduction of the flywheel, the rope life in some cases does not exceed six months. Fig. 104 is a plan of a three-cylinder steam-winding engine which, it may be noted, occupies little more than 50 per cent. of the space required for a slow-speed two-cylinder engine of the type shown in Fig. 103, and permits a corresponding saving in foundations.

488. Brief particulars of one installation are as follows :—Stroke 19½ ins. ; cylinder diameter 17 ins. ; superheated steam at about 715° F. ; pressure 470 lbs./sq. in. ; gear ratio 5.7 to 1 ; revs./min. 259/300 ; useful load 5 tons ; depth of wind 1,968 ft. ; rope speed 49 ft. per sec. ; steam consumption about 16.6 lbs. per shaft H.P. hour. Fuller particulars of multi-cylinder winding are given in Appendix No. 21.

489. The use of a multi-cylinder steam engine for winding is, to a considerable extent, experimental ; nevertheless, some experts have considerable faith in its development.

ELECTRIC WINDERS

490. The most common form of control in modern electric winders is the Ward Leonard, because it provides a wide range of speed control and, in certain conditions, is economical in power consumption.

491. The driving motor of a Ward Leonard winder is usually of between 400 and 1,000 volts, although motors of 700 to 800 volts are common. The speed is higher than the 40 to 50 revs. per min. of earlier practice, and, in general, the use of two motors has been discontinued because of the improved design and construction of single motors up to 3,000 KW. A typical example is shown in Fig. 105. The usual rope speeds of large Ward Leonard winders are 65.6 ft./sec. for coal and 39.4 ft./sec. for men, the maxima fixed by Regulation.

492. It is interesting to note that where two or more winders are installed at one mine, electric interlocking prevents simultaneous starting of the two winders and obviates a peak demand.

493. The large power plants now available are capable of dealing with peak loads which formerly had to be equalised by the Ilgner system, and winders operating on this system are no longer being installed.

494. There are one or two straight alternating-current surface installations of up to 1,400 H.P. These have a rope speed of only 33 to 50 ft./sec. with single- and double-reduction gears. Consideration has been given to this type of drive for automatic winding, but the additional maintenance costs are said to outweigh any saving in manpower.

WINDER BRAKE GEAR

495. The braking equipment of a modern winder consists of a main or hoisting brake and a safety brake, both operating on four common brake shoes of elm-wood mounted on steel brake posts. These posts are connected by two adjustable tension screws passing horizontally under the main winder shaft.

496. In one design, there are two brake cylinders with a common lever so arranged that the lever utilises the safety brake cylinder point as a fulcrum for the normal operation of the hoisting brake as shown in Fig. 106. This fulcrum is retained in position as long as an air pressure of about 60 lbs. per sq. in. is maintained in the safety brake cylinder by the special compressed air plant fitted to the apparatus. If the air pressure falls owing to lack of air, or in an emergency, a spring attached to the safety brake cylinder is released, and the hoisting brake cylinder piston becomes the fulcrum of the common lever and applies the brakes. In this way, braking action is always ensured. Pressure gauges indicate the air pressure in the receiver of the air system and in the cylinders.

497. This brake gear design incorporates a unique brake pressure regulator (*see* Fig. 106) which regulates brake pressure in direct proportion to the movement of the hoisting brake lever, or of the servo-motor system of the controller described later. The regulator consists of a casing (*a*) which houses a spring cylinder (*b*), spring (*c*) and balance piston (*d*), which is mounted on the same spindle as the piston valve (*f*) and works in the balance cylinder (*e*). The spring cylinder is coupled to the main brake operating-lever through the medium of pin (*g*).

498. The movement of the spring cylinder to the left moves the piston valve in the same direction through the spring and spindle, thus admitting steam or air into the main brake cylinder and, at the same time, by way of the balance ports, into the balance cylinder, where it forces the balance piston to the right against the spring and re-sets the piston valve in the neutral position. Thus increased travel of the spring cylinder requires increased pressure in the balance cylinder in order to compress the spring to a greater extent, and, in consequence, an increased pressure is set up in the hoisting brake cylinder. Movement of the spring cylinder to the right moves the piston valve in the same direction, thereby exhausting the brake and balance cylinders and releasing the brakes.

499. In an alternative design of safety-brake employing weights instead of springs, the weights are held in the off-position by the air pressure in the safety-brake cylinder. The post-brake design generally seemed too rigid and lacking in natural spring.

500. In addition to air-activated braking, regenerative braking is commonly applied to electrically-driven winders.

501. It has been found that the use of a number of short wooden shoes fitted with brake linings on a welded steel shoe path has eliminated most of the trouble associated with distortion of the old type large shoe caused by heating.

502. A point noted in the design of the brake rims was the flush surface which permitted ready inspection of the actual brake-shoe contact area.

503. The Regulations require that the brake shall hold the winding engine against normal load with a static factor of safety of three, and that under the least favourable conditions it shall produce a retardation of 6.6 ft. per sec. per sec.

WINDING ENGINE SPEED CONTROL

504. A modern development in safety equipment for steam and A.C. geared winders is the G.H.H. speed controller with patent oil flow regulator. The apparatus is a combined depth indicator and starting speed and overwind controller, and incorporates the following features.

505. The starting controller is so designed that it is impossible to move off in the wrong direction when the cage or skip is between the ground and banking levels, and a feature of the regulator is that it adjusts the power required, after one or two revolutions, to the minimum. If the speed limit is exceeded during the constant speed period, the regulator shuts off the forward power, applies reverse power, and the brake is applied with gradually increasing force. All these controls are removed, and the forward power is restored automatically, when the speed is reduced to within the limit. Further, if the speed during the retardation period is in excess of a predetermined retardation curve, the forward power is reduced and, if necessary, reverse power is applied. Should this be insufficient, the main or hoisting brake is gradually applied until the correct speed is attained. Thus the lower limit of speed control is greatly extended.

506. In the event of the cage or skip reaching a predetermined height above the bank, reverse power main and safety brakes are applied. When the brake pressure is released by the winding engineman, the reverse power continues until the cage or skip is lowered to the banking level.

507. The main feature of the controller is the oil flow regulator (*see* Fig. 106) which exerts maximum regulating forces throughout the entire range of winding speed and, owing to its dead beat characteristic, ensures a smooth action free from jerks.

508. The regulator incorporates two geared pumps driven direct from the winding engine ; one pump is required for each direction of wind in order to avoid the use of special reversing devices. The pumps are enclosed in a common casing, which is divided into suction and pressure chambers for each pump ; the suction and pressure chambers of each unit are connected by an orifice, the area of which is controlled by an adjustable needle valve. A weighted regulator piston which is incorporated in each pressure chamber ensures constant pressure.

509. During the forward movement of the winder, the forward pump delivers oil from the suction to the underside of the regulator piston on the pressure chamber, and thence back through the orifice to the suction chamber. If at any point of the wind the winder should exceed its safe speed, the pump will deliver more oil than the set orifice will allow ; the regulator piston will then rise and operate the slide valve of a servo-motor by means of a lever system which also controls the needle valve through an adjustable fulcrum. The adjustment of this fulcrum point is actuated by rods and levers from a speed cam or curved guide bar which is brought into action at the end of the wind by means of the nuts on the depth indicator, and which reduces the size of the orifice during acceleration and retardation. The movement of the slide valve of the servo-motor introduces pressure into the latter, which forces the engineman's control lever towards the neutral position, thereby regulating the steam or power consumption to an exact degree and automatically re-adjusting the speed of the winder. At the same time, the needle valve is raised and the area of the orifice is increased until a point of balance is reached between the lift of the regulator piston and the orifice area, thus preventing a rise in pressure in the pressure chamber or an excessive degree of regulation. In the event of an over-wind or a dangerous overspeed, the servo-motor will force the control lever past the neutral position into reverse and at the same time apply the main and safety brake.

510. *During the period in which the winder moves in a* forward direction as described in the previous paragraph, the reverse pump is out of action and simply pumps oil from its pressure chamber to its suction chamber via the orifice and needle, which is coupled direct to the needle valve of the forward pump. When, however, the winder is reversed, the reverse pump is brought into action and operates in the same way as the forward pump.

511. For man-winding, the adjustable fulcrum on the needle valve lever system is altered by means of a hand lever in order to reduce the area of the orifice so that lower speeds will be operative.

THE KOEPE WINDER

512. During the last 50 years, the Koepe winder has displaced other types of winder in the Ruhr, with rare and special exceptions, and has given great satisfaction in operation. It is a development due to the horizon system of mining and is less expensive to instal and operate than an ordinary drum winder. Its present state of perfection, particularly from the safety aspect, is due to years of experience in the Ruhr and elsewhere.

THE KOEPE PULLEY

513. All modern Koepe pulleys are of welded construction, as are the head sheaves and deflecting pulleys. This has resulted in a reduction of weight, and, consequently, of power requirements, which is a distinct advantage in electric winding. There is, however, an advantage in retaining weight in the rim of steam winders in order to obtain a flywheel effect so that the instantaneous accelerations, caused by the reciprocating moment which increase the tendency of the rope to slip, are reduced.

514. In only one case has a Koepe sheave been built up for use as a multi-layer single rope winch for sinking purposes. This is not advised in other cases, as it was stated that the interest on the capital cost of a permanent winder installation and the expense of alterations for permanent duty are greater than the hiring charges for a suitable sinking winch. The general practice in the Ruhr is to contract the work to an outside firm with the necessary plant.

515. The Koepe sheave can be used as a reel when changing ropes : there are, of course, other methods of rope changing (*see* Appendix No. 22).

KOEPE PULLEY LININGS

516. Various rope-groove linings are used on Koepe pulleys, oak and elm wood being common. Other linings with higher coefficients of friction, including leather, are also employed. These linings take the form of inserts in a dovetailed groove in shaped wood blocks bolted to the rim of the pulley as in Fig. 107.

The following coefficients were given :—

Wood (Oak or Elm)	0.25 to 0.4
Ferodo . .	0.3
Leather	0.45
Bekorite (Patent fibre)	0.45
Havorite (Patent fibre)	0.55
Aluminium	0.6 to 0.8 (Test not made under working conditions).

517. The use of leather cemented in alternate layers of soft and chrome leather appeared to be increasing. While aluminium has the highest coefficient of friction,

it is inclined to flake off. A minimum coefficient of .2 is required by Regulation, but the materials normally used as linings have a much higher coefficient. The statutory minimum coefficient of friction must be used in the basic calculations and designs for all Koepe winders.

518. It was stated that there is practically no slip when winding from 2,000 ft. or more with a coal load of 10 to 14 tons, although there is a very slight rope creep due to rope stretch, which is more or less nullified by each alternate wind when similar unbalanced loads are being raised. Slip is more apparent in shallower shafts with lighter loads, and becomes obvious when the emergency brakes are applied by the limit switches set on the headframe.

519 It is a fact that when winding is proceeding the depth indicator is used as a guide, and marks painted on the rope show the actual setting positions ; a brush and pot of white paint, to renew the markings, are always available. At the side of the Koepe pulley—and a few inches apart—there are two arrow indicators to show the setting levels between which the decking operation can be efficient. The depth indicator has a vernier for ready adjustment, and sometimes carries a drive to a speed recording device. In Koepe winder design, an acceleration rate of 2.64 ft. per sec. per sec. is used as an average, with a maximum of 3.94 ft. per sec. per sec. This limitation is imposed to prevent rope slip.

520. It is said authoritatively that for all practical purposes slip is eliminated in a Koepe winder which is properly designed and maintained. Good design incorporates slow running and heavy loads with low rates of acceleration and retardation.

Care is taken to use north lighting as far as possible in winder-house design, and the background area of the winder rope is painted black to give contrast to the white rope markings in use.

KOEPE ARRESTING DEVICES

521. No detaching hooks and bells are fitted in the headframes at Ruhr mines : their place is taken by other safety devices more suited to Koepe winding. The Regulations require that, when the winding speed exceeds 19.48 ft. per sec., a free distance of approximately 33 ft. must be provided between the normal decking level and the buffer girder platform.

522. The winder control is designed to operate within this distance, but should it fail to operate, the cage is carried past a set of catch pawls or automatic keps and on to a set of buffer girders which are sometimes spring-loaded. The wooden guides in this region, as well as those below the lowest winding level, are thickened or wedged inwards at 1 in 100 to act as a brake. (The maximum thickening amounts to 2 ins. per side.) This braking action causes the winding rope to slip on the Koepe pulley. If the winding load does not slip, and the residual force of the overwind is great enough—an almost impossible occurrence—the winding rope will break, and the cage, if not wedged securely by the guides, will drop back on to the catch pawls mentioned above.

523. The headframe often carries a limit switch to operate the emergency brakes when winding is continued past the normal maximum decking level. For obvious reasons, the use of keps for decking when man-winding with a Koepe winder is specifically forbidden by Regulation.

524. Fig. 108 shows a headframe with typical catch pawl and buffer girder platforms.

ARRANGEMENTS OF KOEPE WINDERS

525. The Koepe winder is arranged in three different forms as shown in Fig. 109.

GROUND LEVEL MOUNTED AT SOME DISTANCE FROM THE SHAFT : FIGS. 110 AND 111

526. This is the normal arrangement, the winder and motor generator being accommodated under one roof. The modern headgear for ground level mounting is of welded-plate girder construction, is very high and has pleasing lines. Fig. 112 shows a typical example of the new design for double-winding operating in one shaft. The main structure consists of four splayed main legs surmounted by two head sheave platforms one above the other. The frame carrying the shaft guides is divided into a short portion on light foundations, and a longer portion above which is hung from the main structure. The longer portion carries the catch pawl and buffer girder platforms (thereby reducing the weight of the structure and the area of the foundations of the shaft collar) and, in the event of an overwind serious enough to cause the winding rope to break, the weight of the cage is borne on the upper structure.

527. Fig. 113 shows a headframe for a single winder.

TOWER OR OVERHEAD MOUNTED (FIG. 114)

528. In this arrangement (which may be seen at the Minister Stein and Hannibal Mines), the Koepe winder is mounted on a headframe directly over the shaft, and has a deflecting pulley situated below the winder level. While there is a foundational advantage in tower mounting, it was stated that it requires 30 per cent. more steel than normal mounting. The arrangement does, however, result in an economy in the use of surface space, and consequently in the area required for the shaft pillar. A further feature is the weather protection afforded to the winding ropes by the enclosed type construction of the headframe. A tower-mounted installation is probably the best arrangement for multi-rope winding (described later), but it cannot be considered in weak ground. Access to the winder is provided by a small " self-control " type lift.

MOMMERTZ-LENTZ OR GROUND-LEVEL MOUNTED CLOSE TO THE SHAFT (FIG. 115)

529. The only instance of this arrangement is at the Walsum Mine. The foundations of the headframe and shaft collar are very complicated, but as they are merged together, there is a balance of stresses. Apart from a reduction in shaft pillar area, the main advantage claimed for this arrangement (as yet unproved) is that the ropes rise vertically (or nearly so) to the pulley sheaves, thereby minimising fatigue in the wires caused by oscillation due to rope sag.

530. Each of the three arrangements has three distinct platform levels. The lowest is the decking level ; the second is the catch-pawl level ; and the third is the buffer-girder level. Reference has already been made to the purpose of the latter two levels.

531. The angle of rope contact on the Koepe pulley varies a little in each arrangement, being greatest when the winding is tower mounted, but this is not regarded as of very great significance.

532. Opinions varied as to which of the three methods is cheapest to instal and operate, and individual experts agreed that there is little difference in initial cost, efficiency in operation, safety and maintenance. The choice of method must obviously depend on the particular circumstances in which it will be used.

MULTI-ROPE WINDING

533. As the depth from which coal is to be raised increases beyond 1,100 yds., the problem of winding heavy loads by cages to maintain output becomes more serious.

534. In an attempt to solve the problem, the first multi-rope winder has been installed at the Hannover Mine, although it is not yet in actual operation. The winder, which is tower-mounted, is designed for a depth of 820 yds. to 1,531 yds. The ultimate duty would necessitate the use of a single rope of $3\frac{9}{16}$ ins. diameter, which would be heavy, unwieldy to handle and require a very large rope-attachment gear. Apart from such serious practical disadvantages, it is considered that the twisting action of the rope in the shaft would have an adverse effect on the wooden cage guides.

535. In order to overcome these difficulties, the Koepe pulley is designed to use four winding ropes, two of which have a lay opposite to the others to eliminate the twisting action mentioned above. The winder shown in Figs. 116 and 117 is tower-mounted at a height of 164 ft. from floor level over the downcast shaft. A deflecting pulley of light welded construction with roller bearings is used for each of the four winding ropes, and the pulleys are aligned with four rope-grooves on the Koepe pulley, which is lagged with four sets of wood blocks curved to fit perfectly on its periphery. The wood blocks are each fitted with laminated leather inserts grooved to suit the ropes ; the grooves were cut *in situ* to ensure uniformity in pulley diameter at all four groove positions.

536. A load equalising gear is needed to equalise the load between the four ropes. This consists of a system of sliding and fixed sheaves as shown in Fig. 118. Ropes 1 and 4 are secured directly to cage 2 at one end, and to small sliding sheaves at the other. Ropes 2 and 3 are each attached to sliding sheaves at both ends. A roller link-chain passes over the two sliding sheaves connected to ropes 2 and 3, and round a fixed sheave on cage 2 ; two similar chains operate in the same way for ropes 1 and 2 and 3 and 4 on cage 1. On cage 2 are fitted two wedge-ring shock absorbers ; each of these devices carries an indicator with a suitably calibrated scale which shows automatically the respective loads on ropes 1 and 4. Further, the guide frames holding the sliding sheaves are designed to allow for an adjustment of about 2 ft. 6 in. each way. By these means, equalisation of the load between the four ropes is readily effected.

537. Particulars of the winder installation are as under :

	1,531 *yds.*	820 *yds.*
Output per hour	354 tons	471 tons
Weight of cage, etc.	16.9 tons	11.8 tons
Weight of tub	13.7 cwts.	13.7 cwts.
Capacity per tub (coal)	1 ton	1 ton
,, ,, (stone) ..	1.6 tons	1.6 tons
Tubs per cage	12	12
Coal per wind	12 tons	12 tons
Winding time	90 secs.	75 secs.
Decking time	30 secs.	30 secs.
Diameter of ropes	1.85″	1.45″
Weight of rope	5.4 lbs./ft.	3.7 lbs./ft.
Diameter of Koepe	16′ $4\frac{3}{4}$″	16′ $4\frac{3}{4}$″
Diameter of brake paths ..	20′ $6\frac{1}{2}$″	20′ $6\frac{1}{2}$″
R.P.M.	60	60
Acceleration	3.28 to 3.94′/sec.	3.28 to 3.94′/sec.
Motor	2 × 4,300 H.P.	4,300 H.P.

Ward Leonard Control.

538. The advantage of the multi-rope winder is that the employment of lighter ropes permits the use of a smaller Koepe pulley and smaller deflecting pulleys and, in consequence, the number of revolutions per minute is higher, the starting torque is lower and a motor of slightly lower horse-power and of smaller dimensions is required. The use of four ropes in place of one rope is an added safety feature. Further, lighter wires can be used in the manufacture of the ropes, which tends to ensure longer rope life, and provides a larger rope surface area for inspection. This installation will be watched with great interest in the Ruhr.

WINDING ROPES

539. Winding ropes of Lang's lay construction are commonly used for Koepe winding ; the flattened-strand type is occasionally employed. On the other hand, locked-coil winding ropes are never used because of their smooth surface, and the galvanising of ropes is not recommended.

540. Under the Regulations, ropes must be changed every two years : this period may, however, be extended to three years if a rope has been passed as satisfactory by the Mines Inspectorate. Nevertheless, it should be noted that although the maximum permissible rope life is relatively short only one rope is renewed at a time.

541. The static factor of safety enforced by Regulations based on men-load is 9.5, and in the case of coal 7.0, or even less in certain conditions. This is higher than the factors of 8 and 6 which would be allowed in drum winding in the Ruhr, principally because the Koepe rope cannot be recapped.

542. As there is no rubbing of the coils in Koepe winding, rope wear is less severe than in drum winding.

543. A careful external examination of winding ropes is made daily, and two engineers carry out a thorough examination of the ropes with the aid of calipers, etc. every fortnight.

544. Ropes are not externally lubricated, but when first fitted, they are often treated with a hot air blast to remove superfluous grease and varnished with shellac, or are painted with some other form of anticorrosive. This painting is repeated at periods varying from 4 weeks upwards, according to shaft humidity conditions.

545. It was stated that the diameter of the Koepe pulley should be 100 times that of the rope and 2,000 times that of one wire.

ROPE CAPELS

546. The rope capel is even more important in Koepe winding than in other forms of winding, because any damage caused to the rope either by a badly designed capel, or by negligence when the capel is fitted, is irreparable. The design of rope capels has therefore received much thought ; two notable modern forms made by G.H.H. and Demag respectively are illustrated in Figs. 119 and 120.

547. The G.H.H. capel consists of two main body plates, held together by bolts, incorporating a dead-eye and wedge-block. The rope is laced around this wedge, and is self-tightening as the load increases. The free end of the rope is secured to the body plates by two safety clamps, but these are not subject to any working load. The tension in the rope decreases gradually. It is progressively reduced by friction round the curved end of the wedge block, and finally it is completely relieved by the wedging action of the wedge block against the body plates. Major rope adjustment is relatively simple and can be made in less than an hour. There is also a packing-piece adjustment for

small amounts of rope stretch. The ready adjustment feature of this capel is important.

548. In the Demag design, the rope is led along the side of the eye and tightly secured by a hinged retaining arm lined with rubber. The rope is then turned round the eye and held in position by pressure exerted by a system of knee-action links. Pressure screws hold the links in position and, when tightened, are often covered by a shield. A screw adjustment permits of shortening the rope in a minimum of time. It is claimed that although this capel may be more complicated, it is relatively light in weight, short in length and provides adequate rope protection.

549. Rope adjustment through the medium of varying lengths of safety chains is not practised, and it is possible that the relatively smooth movement of the cages is due, in part at least, to the single-point suspension system employed. This form of suspension sometimes includes a shock-absorbing device mounted as shown in Fig. 121.

BALANCE ROPES

550. All Koepe winding equipment designs incorporate a balance rope as a load-equalising medium. The rope, which is normally of flat construction owing to the short distance between rope centres in shafts with four winding compartments, is suspended as shown in Fig. 122. When round balance-ropes are used, they are attached by a swivel and are guided at the return end.

SHAFT LAYOUT

551. For many years past, only round shafts have been sunk in the Ruhr ; there is no standard diameter, and shaft layout and fittings vary accordingly. Shaft diameters from 16 ft. 6 ins. up to 24 ft. 7 ins. were noted at the larger modern mines, the average being about 20 ft. These large shafts are equipped for double-winding, and the shaft accessories (which include large compressed air pipes, water pipes, cables, guides and buntons or guide beams, and shaft ladders with rest platforms) are carefully fitted into the remaining shaft space. Fig. 123 shows a well designed shaft layout.

SHAFT GUIDES

552. Large section wooden guides, generally of Karri Pine, are used in the Ruhr in preference to rail or other steel guides, largely because no satisfactory cage catching device has been invented for use with steel guides. In most cases, rigid guides are essential because of the small shaft clearances. Normally, a guide, which may be hinged at the levels, is placed at each end of the skip or cage. Auxiliary or spear guides are placed on the sides at these points (see Fig. 124). The shaft guides are sometimes bolted direct to steel bunton-frames formed of channel and girder sections set in the shaft walls, usually about 5 ft. apart.

SHAFT CLEARANCES

553. By the use of rigid guides, the clearances necessary to ensure safety in shaft operations are considerably reduced, which is a factor of particular importance in shafts accommodating two sets of winding equipment. The practice recommended is to allow a minimum clearance of 4 ins. between a fixed and a moving part, and of 6 ins. between two moving parts, the only major exception being where false deck edges come into contact with shaft airlocks. At these positions, winding speeds are normally low.

SHAFT AIRLOCKS AND CRANES

554. Airlocks, both at the surface and at intermediate levels, are formed within the shaft dimensions. Each cage or skip operating in a shaft with an airlock is provided with a false bottom or top, fitted with packing edges designed to fit as closely as possible against a specially constructed smooth-lined compartment at the airlock position. A false bottom is required in the case of surface airlocks. When the skip or cage enters this special compartment, the packing edges form an effective air seal so that the door or doors of the compartment can be opened without excessive air leakage. The doors are normally actuated by compressed air, but they can be operated manually in an emergency. Figs. 125, 126 and 127 illustrate surface and underground air locks.

555. An air vent with a folding door connects two airlock compartments, so that when a skip or cage is leaving one compartment, air is sucked into it from the adjacent compartment. When, however, a skip or cage is entering a compartment, pressure-relief ventilators prevent any building up of air pressure above.

556. To provide for an overwind, each compartment of an airlock is normally designed with a large loose cover or lid incorporating a small release cover (see Fig. 128), and the cage or skip has spring-mounted roof fittings to cushion the lifting motion. The small release cover is lifted by a special fitting either on the rope capel or on the cage.

557. The total loss of air in normal operation with the type of airlock described was given as less than 3 per cent., which is very good considering the high water gauges in use. A more detailed description of airlocks is given in Appendix No. 23.

558. Adequate means to handle skips, cages, rope capels, etc. at mines where shaft equipment is large and cumbersome is a necessity. The cage-decking level may be high enough to allow the installation of a jib crane and gantry below it (and with sufficient height to manipulate the longest plant required in the shaft), or at ground level with the crane overhead. The former arrangement is illustrated in Fig. 129.

559. At several mines the height of the decking level is a notable feature of the cage winding arrangements.

CAGE WINDING

560. The introduction of large cars has improved the efficiency of cage winding to a marked extent. Apart from the improved ratio of load to tare, these cars enable large outputs to be easily handled both at the surface and at the shaft bottom. This handling factor has an important bearing on the question of cage winding versus skip winding.

CAGE DESIGN

561. It appears that the four-deck cage (see Fig. 130) has been installed in most of the newer large mines. The cage is long and narrow in section in order to accommodate the long and narrow cars. As can be seen, every endeavour is made to save weight by the use of thin perforated plates, which are protected at car height by welded steel strips. The use of light alloy metals for weight-saving does not, at least for the present, seem popular.

562. A cage safety-catch device to grip the guides, should the winding rope break, is fitted at each end of the top of the cage ; details of this device are shown in Fig. 131. The safety catch is operated by a plate or carriage type spring (1), and the draw-straps (2) and the levers (3) are forced to follow the direction of movement of the spring which, with cross-bar (5), is gripped in the fork of the lifting-rod (4) by means of wedges (6 and 7). The levers (3) are keyed on shafts (8) and cause them, together with their toothed eccentric jaws (9), to effect a rotary motion through which the jaws clutch the guides. Owing to a slight slant of the teeth in relation to the vertical, the guides are drawn towards the middle of the cage, thus preventing the cage from leaving the guides.

563. The car-catching device commonly used in cages (shown in Fig. 132) consists of a movable spring-block loosely fitted over the cage rails—which is pushed forward by an oncoming car until it reaches its limit of travel—the fixed check pieces mounted on the floor of the cage inside the rail gauge—together with a flat bar welded on the surface of each cage rail and of a length equal to the distance between the wheel treads of a car. When decked, the flat welded bars act as wedges against the inner treads of the respective wheels. With such a device, empty cars enter and leave the cage at one side of the shaft and full cars enter and leave at the other side, a point to be noted when surface and shaft-bottom car circulation layouts are being considered.

564. The clearance allowed between the cage side and the tub or car is normally less than ⅜ of an inch, a fact which emphasises the rigidity of car construction. With such a small clearance it is not possible to provide the cage with a gate, and the difficulty has been overcome by providing a removable gate (see Fig. 133).

565. The weight of a four-deck cage with safety catch, tub-catching device and gates, is about 10½ tons.

566. It was noted that every cage installed in an upcast shaft where the main fans were situated carried on its roof a structure fitted with spring fittings which was designed to lift the detachable roof of the airlock compartment in the event of an overwind.

567. The number of men carried in a cage of four decks is about 70 ; the area per man required by law is about 2 sq. ft.

THE MÜTHING COUPLING

568. The coupling and uncoupling of trains of cars underground cannot be eliminated when cage winding is used, but a new form of coupling (the Müthing) may obviate manual operation, although, as far as is known, it has still to be fully tested. This automatic coupling, which may be put in or out of operation at will, is illustrated in Fig. 134. A complete coupling is fitted to each end of the car.

569. The coupling consists of a hook "A," which is pivotted at "B" and has lugs "C." These lugs are connected through links to springs "D." In the extended position, as shown in Fig. 134 (1), the hooks are held horizontally by the springs "D," but can deviate from that position (when forced to do so) by one hook overriding the other, as when two cars come together (see Fig. 134 (2)). The position of the parts when the coupling is completely engaged is illustrated in Fig. 134 (3).

570. Fig. 134 (4) shows the cars, buffer to buffer, with the hooks so placed that, if necessary, they could be uncoupled by hand. The hooks would remain in this position, owing to the action of the links and springs, until the cars were drawn apart, when they would automatically again become fully coupled.

571. When the cars are to be uncoupled, the hook is drawn back under the car by means of the lugs "C" on the hook bar (as indicated in Fig. 134 (5)), either by foot action or by an air operated mechanical device suitably placed for the purpose. Fig. 134 (6) is a view from the underside of the car, and indicates the hook in the forward position as in Fig. 134 (1). Fig. 134 (7), which is also a view from the underside of the car, indicates the hook drawn under as in Fig. 134 (5). Fig. 135 shows the Müthing coupling fitted to large cars.

572. The device is ingenious, but it may be difficult to maintain in operation.

CAR AND TUB CIRCULATION ARRANGEMENTS

UNDERGROUND

573. The car- or tub-handling arrangements seen at the shaft bottom are, for the most part, good. Careful grading to control speed and the judicious use of chain creepers and compressed-air rams saves manpower on the large roadways near the shaft, which are provided with storage accommodation in keeping with the output. (Rail-grading data is given in Table XIV.)

TABLE XIV

RAIL GRADIENTS

MINIMUM RAIL GRADIENTS FOR TUB AND CAR CIRCULATIONS

SMALL TUBS

(1) *Empty Tubs*
in the straight line about 1.0%—1 in 100.
on the curve ,, 1.3%—1 in 77.
at the switches ,, 1.3%—1 in 77.
at the brake stop in front of the shaft about 3.5%—1 in 28.6.

(2) *Full Tubs*
in the straight line about 0.8%—1 in 125.
on the curve ,, 1.1%—1 in 91.
at the switches ,, 1.1%—1 in 91.
at the brake stop in front of the shaft about 3.0%—1 in 33.

LARGE CARS

(1) *Empty Cars*
in the straight line about 0.8%—1 in 125.
on the curve ,, 1.1%—1 in 91.
at the switches ,, 1.1%—1 in 91.
at the brake stop in front of the shaft about 2.5%—1 in 40.

(2) *Full Cars*
in the straight line about 0.7%—1 in 143.
on the curve ,, 1.0%—1 in 100.
at the switches ,, 1.0%—1 in 100.
at the brake stop in front of the shaft about 2.0%—1 in 50.

In the more modern mines the switching of the cars or tubs (which in most cases is carried out by means of compressed air) is controlled from a central traffic station. Car and tub manipulation in front of and behind the shaft is very efficient in some instances.

574. The ease of decking afforded by the Koepe pulley winder is particularly noticeable, and the modern articulated, automatically reversing, cage-loading gear with long swinging platform is very effective (see Appendix No. 24). Fig. 136 shows the design of a modern electrically-driven cage-loading gear. The pushing device, which moves in a guide frame, is pulled by a rope or chain on a clutch-driven drum with an automatic fast-return action. A robust air-operated car stop-block, which usually acts on the car wheels or sides, is placed in front of the pushing device to control the oncoming full cars. A car stop, projecting from the floor near the swinging platform, holds the car to be cage loaded, and is automatically withdrawn when the car pusher moves forward. When multi-deck cages are in use, a selenium cell is sometimes placed in each compartment of the shaft at each decking level in such a position as to cause the cage-loading gear to lock when the cage is not at the decking level. Without this device mishaps might occur if the decks were miscounted.

575. Simultaneous decking is complicated and involves high capital expenditure. Decking times as low as 40 sec. for a 3 ton load on each of the 4 decks by the aid of electric or compressed-air driven cage-loading gear at one decking level were quoted. In these circumstances simultaneous decking does not appear to offer any substantial advantages, particularly when large cars are employed. A winding diagram for four deck cage winding is shown in Fig. 137.

576. Most of the shaft bottoms seen were spacious and well constructed, and the lighting arrangements were such as to facilitate safe and easy movement. Many, however, were dusty. Fig. 138 shows an example of a modern shaft-bottom layout of the continuous circuit type at the Walsum Mine.

AT THE SURFACE

577. The efficiency of car circulation at the surface of some mines is impressive, particularly where large cars are employed. Few men are required at the best installations—one at each winder at the shaft for changing cars and signalling, one or two at the tippers which are fully automatic, and one at the central circuit control-box. Also, a man is usually employed to supervise the tipping of stone, and another to attend to the cars loaded with wood, etc. as they come into the circuit.

578. The circuits are short, and normally chain creepers and carefully selected gradients are used to control the speed of the cars in circulation. The fact that the cars are of rigid design and therefore relatively heavy is an important factor in the mechanisation of car circuits. For instance, the air-operated side car-controllers which hold cars by the bodies, and much of the guide frame structure at curves and elsewhere, could only be usefully employed with cars which are likely to retain their true shape in service.

579. Other features of car circuits at the surface are the provision of mechanical car-cleaning plants, and automatic weighing and recording of the cars.

580. The use of large cars for large outputs reduces the numbers of tippers required, and the capacity of the rising backshunt used at either end of a modern tipper house to reverse the direction of car movement after tipping is thereby greatly increased. Fig. 139 shows a modern car circuit of the backshunt type. The loaded cars which are pushed out of the cage at the pit bank run automatically, after the switches have been placed in position, to the roadways B1, B2 and B3, where they are controlled by side acting stop blocks. In B1 and B2, the coal is unloaded by means of tippers K1 and K2. On the other hand, B3 only deals with stone, which is unloaded by means of tipper K3. All empty cars finally converge at the creeper B, which raises them to a position from which they run down and then climb a gradient of about 6° by their own momentum. This takes them to a second rising shunt where their direction of movement is again reversed, causing them to run back to the stop blocks Br. 4 and Br. 5.

581. Fig. 140 shows a complete circuit for two shafts on the same principle. An impression of one of the most efficient surface arrangements will be gained from Figs. 141 and 142.

582. There is no Regulation in the Ruhr prohibiting the siting of the tipper house and screening plant close to the downcast shaft. As suction fans are used, and the downcast shaft is normally the main coal-winding shaft, this freedom has an important effect on surface layout.

583. A new problem has, however, arisen in cage winding following the introduction of large cars, particularly as depth of winding increases. When a large loaded car is in a cage, the amount of rope extension is considerable ; with a three- or four-deck cage, the decking level of each deck must be calculated for correct rope marking to ensure proper setting. Fig. 143 shows an example of the necessary adjustments. The increased angle of the swinging platform at the shaft when loading cars involves points in cage-loading gear and car design to ensure clearance of the body and buffers at all stages. The action of the body spring must also be taken into account. Fig. 144 shows spring and car body curves relating to the movement of cars into the cage.

584. An important factor to be considered is that of man-riding. This can only be carried out during a limited period without causing disorganisation, even with the system used in the Ruhr where the men descend and ascend in rotation according to their place of employment, and where great care is taken to provide sufficient man-riding capacity in order to curtail the man-winding period, particularly when large bodies of men are involved. It was stated that the best practice allowed for about 70 men per cage wind and 35 per skip wind. At a number of mines, provision has been made for simultaneous decking for men in order to save man-riding time, and, in addition, the decking platforms at one side of the shaft, both at the surface and underground, can be moved so as to facilitate the transport of lengthy material.

SKIP WINDING

SKIP DESIGN

585. In the Ruhr, the few skips used for coal winding in main shafts are all of the bottom-emptying type, with an arrangement such as is shown in Fig. 145. This type is suitable for man-riding. The modern skip has two main features. Firstly, a curved chute is provided for unloading purposes. This chute is actuated by sliding arms, which engage in a guide path fixed at the loading and unloading positions as shown in Fig. 146. In the skip, there is a floating anti-breakage platform which minimises the fall of the coal and lowers it gently as the load accumulates. When the coal is unloaded, the platform is returned to its normal position by a self-contained air-pressure system, or by counter weights. The skip design usually incorporates two man-winding compartments, formed by folding platforms, which can accommodate 35 men (see Fig. 147). The weight of these two compartments, together with the guide-catching device required by Regulation for man-winding, is about 2½ tons. Improvements in design, without the use of light alloy metals, have reduced the weight of a skip of 15 tons capacity (including man-riding cages, cage safety device and capel) to less than 13 tons.

SKIP WINDING

586. As has been stated, only a small number of skip-winding equipments have been installed in the Ruhr to raise coal to the surface. This is probably due to the difficulty of hoisting a number of different qualities of coal from one level, such as is normal, and the naturally friable nature of much of the coal. The following advantages of skip winding, however, are claimed by the Skip Company : an increase of 30 per cent. in shaft capacity even where the same total load is carried, because of shorter loading and discharging times, and an average time of 15 secs. per load when discharging a 15-ton capacity skip as against 40 sec. when using large cars and four-deck cages with decking at only one level. The Company also claimed that the difference between

the pay load and the total load of skips and cages is between 13 per cent. and 18 per cent., and that skip winding involves fewer interruptions of the winding cycle. At greater depths, the total load may force the provision of skips, and experience indicates that to a depth of 1,650 yds., and with the present quality and construction of ropes, a single-rope system with a pay-load of 15 tons can be operated without using light alloy constructed skips. A typical winding diagram for a modern skip winder is shown in Fig. 148.

587. Details of the modern skip-winding system are fairly well known (see Fig. 149). The anti-breakage retarders for lowering the coal in the measuring chutes to the skips (an example of which is shown in Fig. 150) and the anti-breakage flap in each skip have largely eliminated the breakage disadvantages, although some authorities in the Ruhr are apprehensive about the " grinding " of soft coals. Nevertheless, skip winding is on the increase, although the saving in cost as compared with cage winding with large cars is not such as to give it a decided advantage in all cases. Indeed, cage winding with large cars may, in certain circumstances, be almost as economical as skip winding.

588. Skip winding was chosen, in one case at least, only because the seam gradients of the leasehold were very steep ; large dimensioned roads in the seam were, therefore, impracticable, and cars of only about 1½ tons capacity had to be used. At this particular mine, the Germania, the line of level course was far from straight and tubs were taken into the gate roads.

589. As has been previously stated, the largest tonnage of coal is usually raised at the downcast shaft of a mine. Until recently, skip winding in this shaft was associated with a dust problem at the tipper level and skip-loading positions. This difficulty has been lessened, if not entirely overcome, in the following manner : the tipper is equipped with a dust-extractor hood, and the measuring-chute compartment is sealed and fitted for dust extraction as shown in Fig. 151 ; the sliding air-operated gate or door arrangement normally fitted at the end of each measuring chute has been redesigned and fitted with an additional air cylinder to provide for the movement of a sealing frame towards the shaft and for a vertical movement of the gate, so that, when the skip is in position for loading, the sealing frame forms a close seal with the loading aperture of the skip. Thus, the air displaced from the skip on the entry of coal is passed into the measuring-chute compartment where the air-borne dust is extracted.

590. There is no doubt that skip winding simplifies the hoisting of coal by eliminating car circuits on the surface and, with suitably designed cars and tipping gear, reduces the numbers of men employed in the shaft bottom.

591. Normally, the cars of a train are uncoupled in front of the automatic tipper, and are then pushed mechanically by the car pusher (shown in Fig. 152) up a slightly rising gradient (in an uncoupled train) to the tipper. The cars enter the tipper one, or in the case of small tubs, two at a time, as the result of a single stroke of the pushing device ; the other cars fall back on to a catch stop and the leading car of the train is, therefore, cleared of the tipper frame. A second arrangement, in which a creeper is used, is shown in the lower portion of Fig. 151. In this case the train stops while tipping is proceeding. The tipper is electrically interlocked with the measuring-chute anti-breakage retarder and, therefore, only operates when there is space in the chute. In turn, the measuring-chute door is interlocked with the skip, and opens only when the skip is at the loading level. The capacity of the skip is a multiple of the car or tub capacity, and each measuring chute normally holds only a skip load. After ejection from the tipper, the empty cars gravitate away and are reassembled and recoupled into trains. Appendix No. 25 gives details of the proposed arrangements at the Germania Mine where the central shaft is designed for 12,000 tons per day.

THE ROLLING TIPPER SYSTEM

592. In order to obtain the greatest efficiency, the cars or tubs approaching the shaft in trains should not be manually uncoupled, and a continuous car circuit is desirable. A recent advance in design is the rolling tipper system, details of which are given below. (The general arrangement of the equipment of a roller tipping-plant used at a pit-bottom is shown in Fig. 153). The plant is designed for a certain output, on which are based the diagrams for the tipping plant and the skip-winding plant. The other phases of the operation (measuring-chutes, anti-breakage devices, reversing door and closing doors of the measuring-chutes) must be adapted to the main operation as shown in the corresponding diagram. Once the time for a skip wind has been fixed, the normal time for the tipping operations, in conjunction with the loading of a measuring-chute, is suitably adjusted.

593. Shown at the top of the diagram is the tipper, and beneath, the creeper. The creeper pulls the train at a constant speed, and the tipper operates at pre-determined intervals. In the case illustrated, four tippings are necessary to deal with the load of the measuring-chute. The loading of the measuring-chute begins with the tipping of the first car, and ends with the tipping of the fourth car ; the chute is unloaded when the front car has been brought into position. With a load of 12 tons, emptying lasts about 6 to 7 seconds ; the closing of the door takes a few more seconds.

594. The anti-breakage device lowers at a uniform pre-determined speed. It is an advantage to co-ordinate the speed of this device with the speed of the pulling creeper, either by means of a direct gear or an electric switch (Leonard switch). The diagram of the reversing door provides for these operations.

595. Full trains do not always arrive at the pit-bottom at regular intervals. In order to secure continuous operation of the pit-bottom equipment, the number of r.p.m. of the driving motor of the pulling creeper is regulated by the operator, who synchronises the speed of the creeper with the arrival of coal.

596. The skip, however, always winds at the prescribed speed, and any necessary adjustment is made by regulating the intervals in accordance with the speed at which the shaft bottom equipment works. The method of working is illustrated in Fig. 154. The cars, which are emptied singly without being uncoupled, are fitted with side-discharging doors and with couplings, each of which has an extra link ; unloading takes place by means of a roller tipper, situated above the measuring hoppers, which tips the cars at an angle of about 50°. During the tipping, the side-doors of the cars are opened mechanically, and after the cars have been unloaded and tipped back, the doors are securely closed. The rotation centre of the tipper is exactly in the middle of the coupling. The trains are drawn through the tipper at a uniform speed by means of an electrically-driven creeper. The driving motor of the creeper is of the variable speed type, i.e., its number of r.p.m. can be altered within certain limits. The tipper has no driving gear of its own. The plant is designed in such a way that, on the gradient, there is always one car in front of the tipper and two cars behind ; the rest of the track

rises 0.3 per cent. to, and falls 0.02 per cent. from, the tipper.

597. In the tipper, there is a rail-bridge contact which controls a safety device ; this allows the tipper to operate only when the car to be tipped is in its correct position. The plant has no special control gear : it automatically throws itself out of operation if the loaded measuring-chutes are not immediately emptied. After a chute is emptied, the plant is again automatically switched on. A push-button control stops the plant at once, should necessity arise.

598. Work at the pit-bottom proceeds as follows. A train consists, as a rule, of 32 cars. At the beginning of a shift, *i.e.*, when there are no cars in the tipper, the first train brings 38 cars. The locomotive, after having passed the pulling creeper 1, is uncoupled, and proceeds to a siding. Creeper 1 is then switched on from the operator's platform, and conveys car 1 to the tipper. The operator can reduce the speed of creeper 1 by switching the controller, and the plant can be operated with great precision. Creeper 2, as soon as it has caught the first car of a train, alone remains in operation. After car 1 is unloaded, cars 2 and 3 follow, while car 1 is caught by creeper 2. The operator then throws creeper 1 out of operation, and brings car 4 into the tipper by means of creeper 2 ; the first measuring hopper is then full (Drg. 2). The second hopper is loaded by cars 5, 6, 7 and 8.

599. The purpose of creeper 3 is to propel the train of empties further away ; this creeper has a constant continuous speed which is higher than that of creeper 2. In front of creeper 3 there is a rail-bridge switch which, when car 1 passes this point, operates a signal horn in the operator's cabin. The operator then knows that after tipping 4 more cars, the train of empties must be uncoupled. Creeper 2 is fitted with a counter which switches on a signal light after the 32nd car has been dealt with ; this signal signifies to the operator that he must at once uncouple behind the 32nd car (*see* Fig. 154, Drg. 3).

600. After uncoupling, the operator switches on the creeper which pulls away the first train of 32 cars. Between tipper and creeper 2 there now stand 6 cars, to which a second train of 32 cars is coupled. Uncoupling is done by the locomotive driver, who communicates with the operator by signs. The full train is pulled by creeper 1, which is switched on by the operator ; as soon as the train has been coupled to the six cars left over from the previous train, creeper 1 goes back into the rest position, and the work is taken on by creeper 2. The whole operation is then repeated, so that after the 64th car has been dealt with, the following train is coupled to the cars left over. The empty train 1 has already been taken away by creeper 3, which is returned to the rest position by means of a lever switch. Every locomotive driver who brings a full train to the tipping plant takes the tail lamp of the train standing in front of his train, and leaves it at the operator's cabin. The operator, when uncoupling the 32nd car of every train, fits a tail lamp to the rear of that car.

601. As creeper 3 runs at a higher speed than creeper 2, it is obvious that, shortly after 3 has been switched on, there will be a distance between the train in the tipper and the empty train.

602. Further details of a rolling tipper plant are shown in Figs. 155 to 158. A plant of this type is in operation at the Godulla Mine in Upper Silesia, and other installations are in preparation, including one at the Haniel Mine (Appendix No. 6). It was interesting to note that no development on the lines of the swivel coupling to permit continuous tipping had been made in the Ruhr, probably because this coupling is not suitable for cage winding or for use elsewhere where car loading devices or pushing devices contact the end buffers. The rolling tipper system uses side-emptying cars, which must be maintained in perfect order if delays in the plant and elsewhere are to be prevented.

WINDING STONE

603. The system of mining is such that stone is often raised to the surface from a lower level and then lowered to an upper level. Discard from the preparation plant is also taken underground. This can be done by means of cars, but in one instance a skip winder was specially set aside for this purpose, and the practice is likely to grow. Pipes to lower stowage material have been discarded. Theoretically, the hoisting of coal and the lowering of stone by means of the same skip is efficient practice, but objections are raised in the Ruhr to lowering washery discard in a coal skip because discard adhering to the skip spoils the appearance of the round coal. (In this connection, it may be noted that, with one solitary exception, washing of large coal is not carried out in the Ruhr.) In most cases, special winding provision has to be made for the lowering of stone in large quantities. The stone varies in size and, although it is possible to use the normal skip aperture dimensions, in at least one instance a new design (shown in Fig. 159) has been adopted to ensure smooth unloading. This type of skip is so built that the main body can be swung sideways, leaving the base stationary. The cost of maintenance is probably low, and the design seemed reliable and suited to the purpose for which it will be used.

EFFECTIVE USE OF SHAFT AREA FOR WINDING

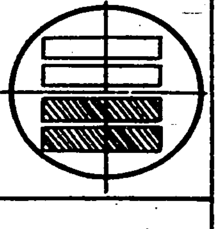
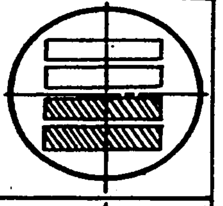
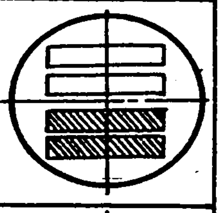
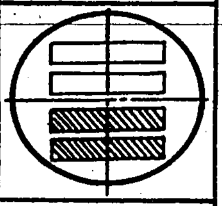
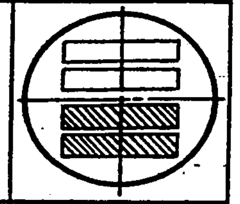
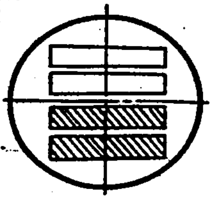
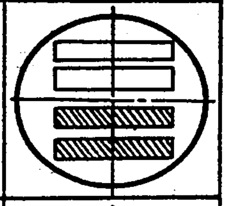
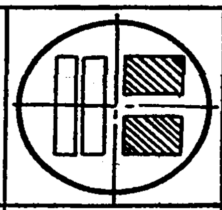
604. One of the notable features of shaft winding in the Ruhr is the endeavour to use the winding capacity of the shaft area to the greatest possible advantage. The effective shaft area is the total sum of the base areas of skips and cars at one deck. For instance, a double-winding system of 4 cages each with 3 decks to carry one car per deck would have an effective area equal to four times the base area of one car.

605. A careful investigation has recently been made into the methods of dimensional calculation of the relationship between cage and skip equipment and other shaft fittings, and their disposition in the shaft. (The results of this research are given in Appendix No. 26.) Figs. 160 and 161, which are based on these results, show the best distribution of cage equipment for double winding with the recently adopted standard series of medium and large cars.

DOUBLE WINDING IN ONE SHAFT

606. In a number of new installations, skip and cage winding is conducted in one shaft, and, in the majority of these cases, the skip and cage is of the same (or nearly the same) sectional area. Brief particulars and shaft arrangements of a few of these installations are given in Table XV. Fig. 162 shows an example of the usual tipping and skip-loading arrangements for side-by-side skips and cages, and Fig. 163 of the arrangements when the discharges of the skips are at right angles to the cages. It is understood that the side-by-side method is now preferred because it enables the shaft space to be utilized most efficiently and requires a simpler arrangement of shaft buntons and guides.

TABLE XV

	Colliery.	Andalusien	Johanna Süd	Lithandra	Hansa III	Auguste Vikto-ria	Wirek	Germania	Georg.
	Depth yds.	274·2	493·5	548·4	758·6	713	485·5	548·4	1142·5
Skip Winding	Useful load (Weight of coal) tons.	6,3	8	9	10	11	12	15	15
	Skip Weight (lbs)	15,400	27,280	24,640	25,740	28,820	30,140	33,000	25,520
Cage Winding	No. of Man platforms (cages)	2	2	1	2	2	2	2	—
	Cage Weight (lbs)	16,160	16,720	21,340	17,820	19,800	24,640	22,880	20,240
	Number of Decks.	4	4	3	4	4	4	3	3
	Shaft dia. ft.	21·31'	21'	21'	19·67'	21·31'	22·5'	25'	22·13
	▨ Skip Winding ☐ Cage Winding								

WINDING FROM VARIOUS LEVELS

607. The depths to which shafts are sunk beyond the first working levels in the first instance do not seem to be governed by any rule : the economic factors are calculated in each particular case. At a mine where the vertical exploitation of the coal in the leasehold is planned at the rate of 20 ft. of strata per annum, and where horizons of 450 ft. are fixed, the initial shafts would probably reach fully 900 ft. below the first level. In due course the shafts would be deepened to provide for development, and the downcast shaft would usually lead in depth.

608. During the life of a mine, the system of horizon mining described earlier generally results in the simultaneous production of coal from two or more levels. While coal production proceeds from the first level, a network of drifts is formed from the second level and air connections are made to the first level by staple shafts. As soon as these developments have reached the stage where coal production can be started from the second level, there arises the question of winding from the two levels. Ventilation, in best practice, is ascensional, and the downcast shaft is, therefore, sunk below the lowest producing level. The second, or upcast, shaft, which may or may not be sunk to the same depth, can be used to wind coal from the upper level. Both shafts may be used to raise and lower men and materials, including stowage material. As production gradually rises to a peak, and then diminishes throughout the life of each level, there is a shifting preponderance of output from the respective horizons. Therefore, at a mine equipped with only two winders, the equipment of each shaft must be capable of dealing with nearly the full output, personnel and materials. Such an arrangement requires the connection of both shafts to the screening plant by a " bridge."

609. In a shaft with only one set of cages there is, however, a limit to the time which can be allotted to winding men and materials, and if this limit were exceeded, coal raising time would be seriously reduced. This problem becomes more acute as the depth of winding increases, and skip winding adds to the difficulty.

610. In a discussion of this problem it was suggested that it would be necessary to provide a second winder in the downcast shaft in order to produce an output of 3,000 tons per day of two shifts.

611. Thus, with three winding mediums, the position would be that one winder in the downcast shaft would always raise coal from the lower level, the second winder in the same shaft would raise coal and men from the higher level, and the third winder in the upcast shaft would raise men from the lower level.

612. An example of winding in two shafts to deal with a production of 6,000 tons per day is given in Fig. 164. The downcast shaft, No. 1, which is the main producing shaft, is fitted with four four-deck cages, the winders hoisting from the second and third levels about 500 ft. apart. In the upcast shaft, No. 2, one winder for manriding and the handling of materials is at present installed in one half of the shaft, leaving the second half for a second winder (if required) when the working levels reach much greater depths and the winding of coal, men and stowage material becomes more difficult.

613. In very large and deep mines where such an arrangement would not provide adequate winding capacity for coal, men and materials, a second winder is installed in the upcast shaft. (In this case, also, skip winding increases the difficulty of providing adequate man-winding facilities.) All the large deep mines of 10,000 tons per day and over in the Ruhr have at least four winders to provide the hoisting capacity required.

614. From a winding-cost point of view, *winding from* various levels can be economically practicable only when large tonnages are raised and the advantage of concentration of production effort, as far as winding is concerned, is paramount.

CONCLUSIONS AND RECOMMENDATIONS

615. (i) The grouping of mines under the same ownership, increasing depth of working, and the universal development of the system of horizon mining have all influenced winding and ancillary operations in the Ruhr. In an endeavour to obtain greater economy in the use of man-power and of mechanical and/or electrical power, winding operations have become more concentrated, shaft capacity more fully utilised, and, in some instances, surface and shaft-bottom layouts have been modernised with great thoroughness.

(ii) In view of its record of reliable and efficient service in the Ruhr, the question of the use of the electrically-driven Koepe-winding system in British mining practice, particularly where the introduction of horizon mining is being considered, should receive renewed attention. In this connection, the advantages of the tower-mounted type of Koepe winder merit special attention.

(iii) It is believed that the problem of winding heavy loads from great depths in the Ruhr has been solved by the introduction of the multi-rope winder, which, however, is not yet in actual operation. This development should be closely studied in connection with the exploitation of our deeper seams.

(iv) The Ruhr type of air-lock can be used to advantage in many British mines where there is limited space at the shaft mouth. In addition to minimising surface air-leakage, it may facilitate modernisation of surface tub-circulation and thereby reduce man-power.

(v) The Müthing car coupling system for use in conjunction with cage winding is regarded with considerable confidence by some German technicians, but as it is only in the early stages of development no recommendation can yet be made as to its adoption in this country.

(vi) The simplification of car circuits, both above and below ground, made possible by modern cage winding with large cars has undoubtedly resulted in considerable financial savings in installation and in operation. In certain circumstances, therefore, cage winding with large cars can compete successfully with skip winding, and is recommended in this country in cases where a number of different qualities of coal are to be raised by the same winder.

(vii) The skip-winding appliances in operation in the Ruhr have proved to be reliable and inexpensive. The recent improvements effected in the design of skip winders to minimise the breakage of coal and to suppress dust should encourage the use of skip winding in this country, particularly in new mines or where an increase of existing shaft capacity is desirable.

(viii) The rolling tipper system for car-tipping underground is an outstanding achievement and should be studied by those responsible for the design of new mines where skip winding is to be used.

(ix) Whilst the results of recent study in the Ruhr of the effective areas of shafts and shaft-openings and their efficient utilisation are mainly applicable to shafts fitted with double-winding systems, nevertheless, the method recommended as a result of this study would appear to be an advance on the methods hitherto used in other countries in the allocation of shaft space.

(x) Double winding in shafts in which are hoisted more than 3,000 tons per day, particularly when winding has to be done from more than one level in the shaft, is another development which should be re-examined by British mining engineers. Where production can be reliably planned ahead for a lengthy period, the additional shaft capacity afforded by double winding will more than compensate for the extra cost of the second winder.

(xi) From a winding-cost point of view, winding from various levels can be economically practicable only when large tonnages are raised and the advantage of concentration of production effort, as far as winding is concerned, is paramount.

CHAPTER V(a)

Staple Shafts

616. The vertical staple shaft is an integral part of the horizon system of mining. It forms the shortest connection between levels and seams for the purpose of ventilation and for the transport of coal, men and stowage material. For such purposes, the vertical shaft connection is preferred to an inclined drift (and to the more complex system of connections between levels in each seam) because it is less likely to be seriously damaged or destroyed by subsidence even though coal extraction proceeds through the shaft at a coal level position. In such a case, production operations continue without interruption, and the shaft barring and the universally used wooden-guides are removed from the area which would normally be affected by vertical subsidence. The subsidence can be limited, however, by careful solid packing in the vicinity of the shaft. Shaft operations are continued in the meantime, and experience has shown that the shaft is disturbed to a surprisingly small extent.

617. A main staple shaft is sometimes driven for the purpose of raising coal from a development level to a level above which is fully equipped for surface winding. (The practice of raising coal from a development level to a surface winding level is quite usual.) The main staple shaft continues to be employed as a connecting medium with the development level until the sinking and fitting of the shaft and the construction of the shaft bottom are completed to the development level, or until the output from the development level justifies a reversal of the main-shaft winding arrangements so that the staple shaft is used to lower coal to the main shaft, and coal winding from the upper level to the surface is discontinued. For this purpose a staple shaft is normally sunk close to the main shaft so as to facilitate the transfer of coal from the staple shaft to the main shaft.

618. It was stated that 250 staple shafts, averaging 200 to 230 ft. deep, are driven annually in the Ruhr coal mines.

DRIVING A STAPLE SHAFT

619. As far as possible, staple shafts are driven from a roadway in one level to a corresponding roadway in another. When the purpose is to tap up to a seam, the staple shaft is driven upwards, a procedure sometimes adopted in staple shaft driving where the length is less than 330 yds. When this distance is to be exceeded, however, the shaft is driven downwards, and as horizon spacing is increasing, the downward method is beginning to replace the upward method, which, at present, is employed in about 50 per cent. of the drivages.

620. When a staple shaft is driven upwards, a vertical hole about 12 ins. in diameter is first drilled at the centre line to assist ventilation. Steel ventilation tubes are used. The cycle of work is so arranged that shot-firing is carried out at the end of the shift, and timbering proceeds as the drivage advances. Stone dust is a health hazard in the upward method, and is one of the chief reasons for the increasing use of the downward, or sinking, method : there is little difference between the two methods in the cost per yard. In the downward method, shaft timbering is completed in sections as the sinking goes on, or, if the strata is strong enough, is begun at the lower end on completion of the sinking. This method of drivage is used in the sinking of modern round staple shafts in the shaft pillar, and the shafts are brick lined. It may be noted that the problem of mechanising debris loading in staple-shaft sinking is being closely studied.

621. A further development in staple-shaft driving was shown in the construction of a model of a shaft-boring apparatus in which a conical boring head equipped with hard metal cutting bits is designed to rotate with a gyroscopic directional control to maintain a vertical cutting line, the cuttings being scraped towards the centre of the cone and elevated by bucket to the loading point. The idea for this apparatus was probably derived from the Schmidt-Kranz rotary tunnelling machine : the advance made in the technique of hard metal cutting-tool production gives it distinct possibilities.

STAPLE SHAFT DIMENSIONS AND LAYOUT

622. Staple shafts are normally employed for a limited period, and are, therefore, unlike main shafts which once made generally remain unaltered during the life of a mine. In the past, the limited life of staple shafts had some bearing on the standardisation of staple-shaft dimensions, and the standards were suited to small tubs of up to 60 cubic feet capacity. Consequently, the recent introduction of large cars and gate conveyors has led to changes in the dimensions of the shafts, and in layout and equipment.

623. The layout of a staple shaft is dependent on its dimensions, and these in turn depend, within limits, on the strength of the strata passed through. In weak strata the staple excavation is as small as possible, and a single cage with a back balance is employed. (In order to provide sufficient winding capacity, most staple shafts in the past had two compartments for cages and one for manway ladders : the latter were installed to avoid the need for the continuous attendance of a staple-shaft engineer, and to facilitate the examination of the special equipment required for manriding.)

624. Large cars are not raised in seam staple shafts, and as far as could be ascertained, only main staple shafts are fitted to receive such cars. Fig. 165 shows the suggested new standards for main staple shafts : one winding compartment is provided with a balance

weight, and sufficient space is allowed for a spiral chute conveyor to lower coal in the circumstances described earlier, and for a ladder system.

625. The rectangular design with wood lining is retained in seam staples but the advent of gate conveyors has rendered obsolete cage winding for lowering coal. Skips, or spiral chute conveyors, have replaced cages for this purpose.

STAPLE SHAFT WINDERS

626. The form of power employed to drive shaft winders was at one time mainly compressed-air, but the use of electric winders is becoming more frequent. Coal and stowage material are normally lowered in a staple shaft. The horse power necessary for raising purposes is relatively small, but braking power is higher in keeping with the load to be controlled.

627. Winders for staple shafts are commonly of the Koepe pulley type. There are some drum winders in use, but difficulties of rope lead are a serious disadvantage.

628. The staple winder is placed (as in Fig. 166) in one of three ways: on the high level, or over the shaft as in tower mounting, or on the lower level. The latter method of mounting does not suffer from the effects of subsidence as do the other two methods, and it has the advantage of being in intake air. An extra length of winding rope is, however, required, and difficulty has been experienced in fitting the rope in the shaft without guide pulleys. Fig. 167 shows the rope and sheave arrangement, now used at some mines, in which the Koepe pulley is placed under the ladder compartment and the rope rises in this compartment to sheaves of differing diameters set at an angle to suit the winding centres.

629. The modern staple winder is gear-driven by an A.C. motor, and maximum rope speed is usually controlled by an automatic speed-controller similar to that used in main winders. The maximum speed permitted for man winding is 13.1 ft. per sec., and the controller can be automatically set to this speed when man winding is signalled.

630. Winders rated as high as 860 KW. with rope speeds of 13 to 20 ft. per sec. and a useful load of 6 tons are now in operation in staple shafts. These relatively large powered winders are, of course, used mainly for raising purposes. It was stated that, normally, the average rating of winders for staple shafts was between 200 and 400 KW.

SKIP WINDING IN STAPLE SHAFTS

631. Skip winding is becoming increasingly common in staple shafts for raising and lowering coal and stowage material, which is a measure of the efficiency of this system of winding for outputs of considerably less than 1,000 tons per shift. Fig. 168 gives details of compartment arrangements and normal winding capacities, with a maximum rope speed of about 20 ft. per sec., for varying lengths of staples. Fig. 169 shows an arrangement for two skips. With an arrangement of this type (in one instance using 3-ton capacity skips) 1,000 tons per shift were lowered in a staple shaft 230 ft. deep by a winder driven by two 75 H.P. motors. Figs. 170 and 171 give skip winding particulars for stone. A feature of skips specially designed to wind stone is the side discharge-door which permits the passage of large pieces of stone. For skip winding with end-discharge in main shafts, the normal aperture is about 4 ft. 3 ins. by 3 ft.: whilst this aperture is normally regarded as sufficient for handling stone, the aperture in the side-discharging type of skip designed to deal with stone is about 5 ft. 3 ins. by 3 ft.

STAPLE SHAFT CONVEYING

632. Previous to 1930, staple shafts were sometimes used as bunkers, the coal being drawn off at the bottom. In such cases, the coal was usually of the coking variety. Breakage of this type of coal was of little consequence, but not so the grinding action in the bunker. Mild steel spiral-chutes and cast-iron wearing plates were used to counteract this grinding. The experiment was at first unsuccessful owing to the short life of the wearing plates caused by abrasion, which was finally overcome by providing a molten basalt wearing-surface. Spiral-chutes are made in three common diameters—3 ft. $5\frac{1}{2}$ ins., 4 ft. $1\frac{1}{4}$ ins. and 4 ft. 9 ins. These are said to be non-choking, and can be designed for damp coal, but they do not wholly prevent degradation. Fig. 172 gives some details of the design.

633. Spiral-chutes can be installed in main shafts where space is available. A spiral chute has been used with success in the coalfield of a neighbouring country for transferring the coal produced from an upper horizon to the skip-loading position at a lower winding level.

634. A second form of staple shaft conveying, which was seen in model form at one mine where it was in actual operation, consists of an endless chain driven electrically, or by compressed-air through gearing. Carrier plates are attached to the chain, which is suspended in a totally enclosed casing. The coal is loaded on to the carrier plates at the top, and the casing, which is fitted with rubbing strips, supports the free ends of the plates when under load. The coal is discharged at the bottom of the casing, where the plates leave the casing and are folded in their passage under a return pulley. The idea is ingenious and should obviate some of the breakage which normally occurs when coal is lowered vertically by a spiral-chute. The maintenance costs of the chain and carrier plates could not be ascertained, but they must be high. This conveyor is stated to be designed for staple shafts up to about 350 ft. in depth.

STAPLE SHAFT LOADING STATIONS

635. The efficiency of winding, and of spiral-chute capacity, largely depends on the design of the loading station. Considerable thought had obviously been given to the mechanisation of some of the loading stations which were visited, and the advantage of large cars was noted. Loading stations are described in Chapter II, and tub handling in Chapter IV.

CONCLUSIONS AND RECOMMENDATIONS

636. (i) Staple shafts are an essential part of the horizon system of mining as practised in the Ruhr, and have undoubted advantages for the passage of coal, men and materials. We recommend that the adoption of staple shafts in this country should be reconsidered in the light of the success of skip winding and spiral-chute conveying.

(ii) The success of skip winding in staple shafts clearly indicates the advantages of skip winding in main shafts in small mines where the tonnage raised per shift is relatively low.

CHAPTER VI

Special Features of Surface Layout and Equipment

SURFACE LAYOUT

637. The surface layout of every new mine in the Ruhr is designed before shaft sinking is commenced, and the design follows a somewhat common plan which may be modified according to variations in the planned output, the available land and other factors. Formerly, the various double-storey buildings were grouped so that the sides enclosed a space approximating to a square or rectangle, but this had the serious disadvantage that none of the buildings could be readily extended to meet new requirements. At the newer mines, the surface buildings still retain the characteristic square formation at the wings of the enclosure, but the layout is such that it permits building extensions in either direction away from the partially enclosed space. Some of the symmetry previously noticeable in surface layout has, therefore, disappeared, but the architectural lines have been retained.

638. An example of a recent layout at the Walsum Mine (which has a capacity of 12,000 tons per day) is shown in Fig. 173. The administrative building can be seen in the lower portion of the plan, with, on the right, the baths, material store and main workshops, which are connected by an enclosed manway above ground level to an assembly corridor or hall leading to the shafts. This covered manway is a notable feature. The men enter the manway through the baths building and, after calling at the lamproom and the store for working necessities, proceed to the assembly corridor (or hall) where places are taken according to working districts. On the left are the boiler plant, generator and compressor station, and the electricity sub-station. In the upper portion of the illustration can be seen the tippers and the screens near the downcast shaft (No. 1), the coal washer to the left of the upcast shaft (No. 2), and the coke ovens further to the left, all of which are in close proximity to the canal. The winder-towers are in line with the sidings. Fig. 174 shows some of the surface buildings at another modern mine.

THE ADMINISTRATIVE BUILDING

639. The administrative building or general office at a modern mine is generally large and commodious. Ample accommodation is provided for contact between officials and men prior to descending the pit, thus saving working time. The number of officials in a large modern mine is considerable, as is shown in Table XVI, and office accommodation is in proportion (Fig. 175).

BATHS AND CANTEEN ACCOMMODATION

640. Baths accommodation, though universally provided for both men and officials, is not up to modern standards. At some mines a few well-fitted bath cubicles for the use of senior officials and visitors are provided on the upper floor of the administrative building.

641. Canteen accommodation is rather primitive, hot soup being the main food served. Plans are in hand to incorporate more elaborate canteen buildings in the designs for new mines.

THE MATERIALS STORE

642. A very careful check is usually kept on the use of all materials, and detail costing is practised to a very considerable extent. Materials are issued from the store only on the authority of an official. Tools are supplied and maintained free of charge: this is thought to be an advantage to output. The systematic issue of materials and the keeping of records demand considerable space and, in consequence, many of the stores are large.

THE ASSEMBLY HALL

643. Generally, the winding of men is noteworthy for its orderliness. The assembly corridor or hall is marked off in districts or faces, and the men congregate accordingly. The men of each district or face have a definite time for descent and, eight hours later, for ascent. Such an arrangement permits the orderly dispatch of man-riding trains by timetable both inbye and outbye, which is a factor of very great importance in any scheme to insure that the maximum working time is spent at the face, particularly when dealing with large numbers of men. The arrangement is also fair to the men.

ENGINEERING WORKSHOPS

644. There is little of special note in regard to the engineering workshops. Fabrication and repair by welding is extensively adopted. In some cases, electric furnaces are used for treatment, particularly in connection with drill-steel sharpening. Repairs to heavy underground plant, particularly locomotives, are carried out in well equipped and well lighted underground workshops near the shaft bottom. It is understood that much of the major overhaul work is normally carried out by the machinery manufacturers.

CAR HANDLING AND TIPPING ARRANGEMENTS

645. As has been previously stated, some of the modern arrangements for car handling and tipping are most efficient. Fig. 176 is a plan of an installation at present under construction at the Haniel Mine. The shafts of this mine are connected by a "bridge" to facilitate the handling of materials. It is anticipated that the mine will produce some 12,000/15,000 tons per day of two working shifts. No. 2 Shaft will normally be used for coal winding, but No. 1 Shaft may also be used for this purpose in an emergency.

646. The so-called "shovel" tipper was particularly noted. This device consists of a power operated tipper with a specially designed anti-breakage trough which gathers the coal as it leaves the car and delivers it gently on to a large slow-moving jigger under the tipper, which is designed to ensure that the load of a large car is distributed evenly on the picking belt.

COAL-CLEANING PLANT

647. In only one plant—specially erected to deal with coal of particular value and for a particular use—is coal of more than $3\frac{1}{4}$ ins. size washed. De-dusting is a feature of some coal-cleaning plants, as is also the dehydration of washed fines. Froth flotation is increasing in its application to the treatment of fines.

648. Some modern mines have a smalls storage-bunker for use in an emergency, which is by-passed when the output is dealt with normally.

BOILER PLANT

649. With one exception, each mine in the Ruhr has its own boiler plant. The modern plant is of high-

pressure design; 1,175 lbs. per sq. in. producing 40/50 tons of steam per hour per boiler has proved most suitable. The effects of saturated steam at higher pressures has produced corrosion.

650. In order to encourage the use of inferior fuel in mine boiler plants, very careful study has been given to the effective use of low grade fuels with a large percentage of moisture and ash. A translation of a paper on this subject is given in Appendix No. 27.

651. At the Graf Bismarck Mine, two water-tube boilers are equipped to burn slurry with an ash and moisture content of up to 50 per cent. These boilers operate at 514 lbs. per sq. in., and have a capacity of 35 tons of steam per hour. The fuel is delivered on to the grate, which is sloped at 45°, by a curved chute with a short slow oscillating action. The grate is of the rocking-bar type with a short stroke; and the fuel is practically dry before it reaches the grate, owing to exposure to the heat of the grate. Two other boilers, which have a capacity of 40 tons of steam per hour, burn pulverised coal dust of varying ash content from a de-dusting plant. A further notable feature of this plant is that the economisers, which are built in sections, can be cleaned by steam. (Fig. 177 shows the constructional details of the plant.)

WAGON SIDINGS

652. In most cases, it was noticed that wagons near the preparation plant were drawn by rope (suitable ground sheaves were fixed where required) and that the extent of the sidings was small in relation to the capacity of the mine. Standage is usually limited to one day's output, but it was stated that the railway authorities normally give excellent service and provide the necessary extra accommodation in nearby marshalling yards. This is an important consideration in surface layout.

CONCLUSIONS AND RECOMMENDATIONS

653. (i) The recent developments in the surface layout of new mines in the Ruhr merit consideration by those responsible for modernisation schemes and for the design of new mines in this country, but there is an apparent extravagance in comparison with British modern layouts which, on the whole, are probably more efficient.

(ii) The covered manway to and from the shafts is an undoubted advantage in efficient organisation. It is recommended that future plans for pithead baths in this country should include a similar covered manway between the baths and the man-winding shafts.

(iii) While much has been done in this country, particularly during the war years, to effect economies by the use of low-grade fuels for power-raising purposes, nevertheless it is considered that the advance made in this direction in the Ruhr shows that further economies may be made without loss of efficiency. We therefore recommend that fuel efficiency and economy should continue to receive close attention.

(iv) The close liaison with the main railway authority in the Ruhr permits siding accommodation at coal mines to be limited to one day's output. Such a dependable working arrangement is highly desirable in this country.

(v) The efficient layout of both surface works and pit bottoms in the Ruhr has been greatly facilitated by the assistance provided by two very large engineering firms. These firms have staffs of mining technicians and are thus able to provide complete designs of general and mining engineering projects. Moreover, their manufacturing range is so very wide that, with the exception of coal cleaning and ventilation plant, they can supply nearly all the major equipment required. We recommend that the advantages to be gained by the transfer to this country of the mining equipment section of one or both of these concerns should be fully examined without delay.

CHAPTER VII

Supply and Use of Power

ELECTRICITY IN RELATION TO OTHER FORMS OF POWER

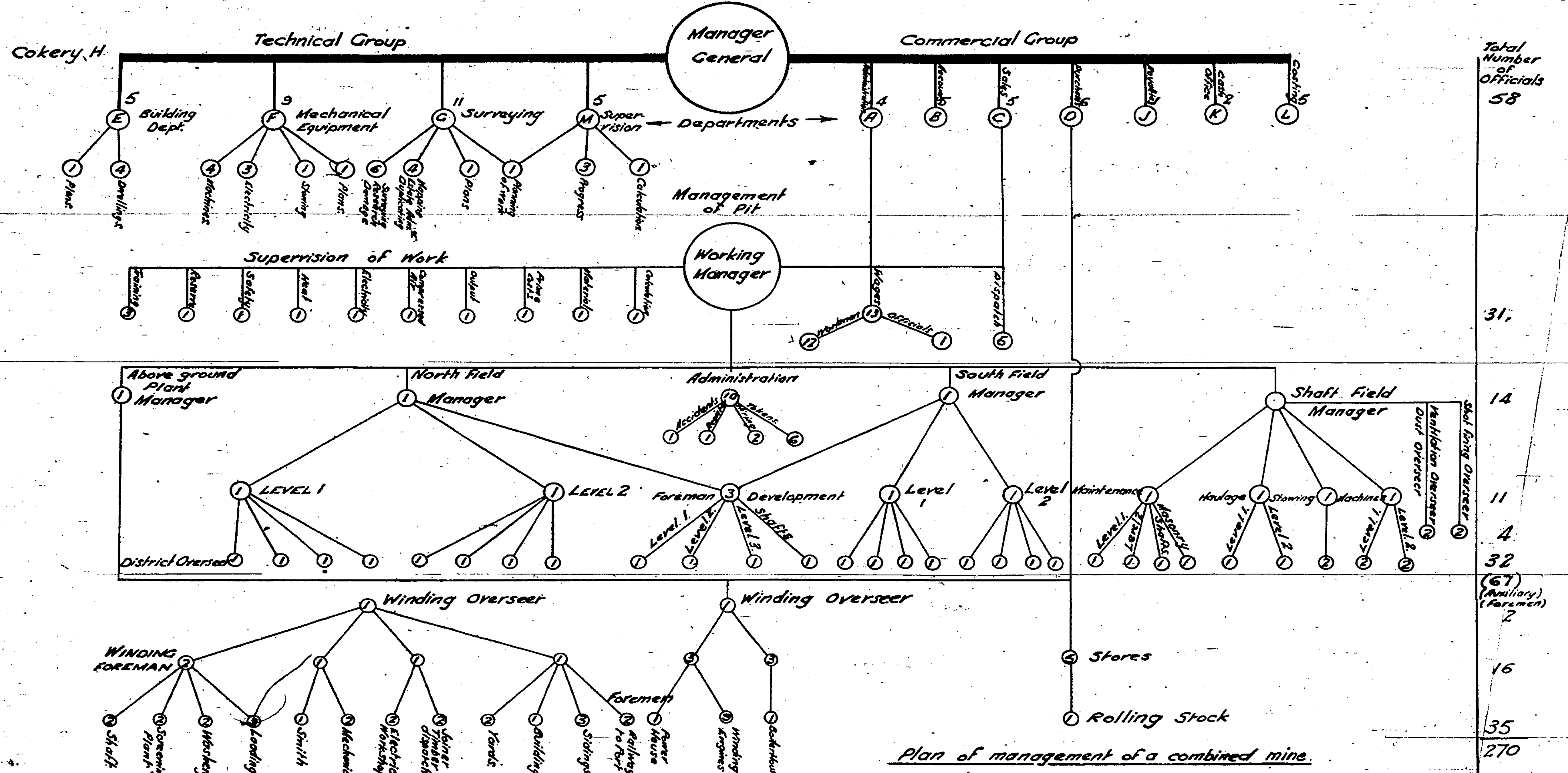
654. Electricity was first used in the Ruhr mines about 60 years ago, and was speedily recognised as a more efficient and more readily applied form of power than compressed-air or steam. Compressed-air continues to fill an important place, however, principally because of the widespread use of the pneumatic percussive pick and of the hammer drill, for which no satisfactory electrical alternatives have so far been found. The need for providing heavy compressing plant for these tools has also encouraged the continued use of steam on the surface, and has influenced the continued use of this form of power for winders and ventilating fans. The introduction at a later date of liquid fuels has not seriously affected the development of the other forms of power, because the liquid fuels are mainly used in the operation of locomotives.

655. The first known application of electricity to coal mines in the Ruhr was the introduction of a slope hoist in 1881, followed by a trolley locomotive installation in 1882, when electricity was first introduced in British coal mines. The application of the three principal forms of power advanced very evenly during the early part of the present century, and in 1929 the division was electricity 46 per cent., steam 32.6 per cent., compressed-air 21 per cent. and liquid fuel the odd 0.4 per cent. By 1937, electricity had advanced to 50.65 per cent. at the expense of steam and compressed-air. This somewhat slow development was due to the large number of small mines which were unable to afford the necessary generating plant and often lacked sufficient steam-raising capacity to operate such plant.

656. Moreover, until recent years, the public supply industry appears to have done little to develop the use of electricity in coal mines. In fact, the development was left to the larger groups of collieries who themselves provided central generating stations.

657. The trend of developments during the 9 years 1929 to 1937 is shown in Table XVII, and it will be observed that steam continued to be the most popular form of power for heavy plant. In the case of air-compressors, for example, there is no doubt that the high efficiency of the large turbo-compressor compared with the electrically-driven compressor with the same total capacity accounted for the continued use of steam.

TABLE XVI



Plan of management of a combined mine.

TABLE XVII

PERCENTAGE OF ELECTRIFICATION IN THE GERMAN HARD COAL MINES—1929 TO 1937

Type of Plant	1929			1937		
	Electricity	Steam	Compressed Air	Electricity	Steam	Compressed Air
	%	%	%	%	%	%
Cleaning Plant	95	3.7	1.3	100	—	—
Air Compressors	8.3	91.7	—	9.6	90.2	—
Ventilating Fans	62	38	—	64.6	35.4	—
Winders	18	82	—	22.4	77.6	—
Underground Plant ..	46.4	1.7	51.4	56.7	—	42.2

Note.—The small percentage of liquid fuel used for Diesel locomotives has been omitted from the above figures.

DEVELOPMENTS IN THE APPLICATION OF ELECTRICITY

ON THE SURFACE

658. Since 1929, electricity has dominated the field of power-driven machinery, particularly the smaller and medium-sized units used for screening and washing plants.

659. In view of the size of the plant usually required, and until the use of compressed air is abandoned, the steam engine will probably continue to be used as the prime mover for air-compressors, and in this respect steam is generally able to meet all requirements. The degree of electrification reached with winding plant is not high, and this is partly due to the existence of numerous old steam-driven plants which, as stated in Chapter V (in which is dealt with the merits of steam and electric winders) had their origin in the pre-electrification era. Preference is usually given to electric drive when new installations are considered. In some quite modern installations, however, the steam drive is still looked upon as a satisfactory solution of the problem.

660. The application of electric drives to ventilating fans proceeded smoothly from its inception, starting with variable speed motors in several forms, and settling down to synchronous motors with variable speed gears. The latter form has become more or less standard practice.

UNDERGROUND

661. At the coal face, the tremendous influence of the pneumatic pick and of the hammer drill has definitely retarded the development of the electric drive, and this state of affairs will undoubtedly continue until new and more efficient methods of winning coal, *e.g.*, by coal ploughs, or cutter or getter loaders, are developed. The tendency to use electricity for face and gate conveyors and to retain compressed-air for the picks is an indication that compressed-air will be eliminated when coal-getting machines to which electricity can be more easily applied are available. When the electric drive was introduced, attempts were made to develop an electrically operated percussive tool by using two A.C. operated coils with an oscillating iron core. The attempts ended in failure, and although since repeated have still not proved successful.

662. It is not, therefore, altogether from choice that compressed-air, which is generally recognised as inefficient compared with electricity, is retained. In fact, one authority has made the statement that steam consumption is about seven times greater for generating compressed air than for generating electricity. The second stumbling block to the unrestricted development of the electric drive underground was the danger of igniting firedamp, and it was only about 16 years ago that this hazard was considered to have been effectively counteracted by the introduction of flameproof equipment together with a code of stringent regulations.

663. Apart from the information given in Table XVII, few statistics are available to show the degree of electrification achieved in the Ruhr in terms of horse-power installed, but the following figures relate to the electrification of coal face equipment in the Ruhr district mines. The group of mines concerned, which have gradients of from 0–35 degrees, accounted in 1938 for an output of about 95,000,000 tons. In 1928, the group had only a little over 2,000 horse-power installed at the coal face, which by 1938 had increased to about 14,600 horse-power. Included in this total are cutting, slicing, notching, drilling and stowing machines ; face and gate road belt, shaker and chain, conveyors, together with a number of small main rope haulages employed for tub gathering. It will be obvious, therefore, that the application of electricity to the coal face in the Ruhr mines is, by comparison with Britain, very small.

664. No figures are available to show the total horse-power installed underground, including, in addition to face equipment, staple shaft hoists, pumps, locomotives and tub handling equipment, but some indication of this may be obtained from Tables XVIII and XIX which give details of transformers (including lighting transformers) installed underground. In 1928 the total capacity amounted to 63,328 KVA which, it is estimated,

TABLE XVIII

NUMBER OF TRANSFORMERS IN USE UNDERGROUND IN THE RUHR FROM 1928 TO 1932

Transformers	1928	1929	1930	1931	1932
No. of units	909	889	953	898	1,012
Total nominal capacity KVA ..	63,328	62,574	61,389	57,608	68,023

Estimated figure for 1938 = 1,500 units totalling 100,000 KVA.

TABLE XIX

ANALYSIS OF TRANSFORMER SIZES 1932

Item	No.	% of the Total	Nominal capacity KVA	% of the Total	Single Capacity KVA
Lighting transformers (Dry) ..	152	15.0	450	0.7	approx. 3
Oil-immersed transformers up to 20 KVA	286	28.3	2,558	3.8	9
Over 20 to 50 KVA	180	17.7	6,119	9.0	34
Over 50 to 100 KVA	142	14.0	11,465	16.8	81
Over 100 KVA	252	25.0	47,431	69.7	188
TOTAL	1,012	100.0	68,023	100.0	Mean 67

had increased to 100,000 KVA by 1938. Staple shaft hoists, which have motors up to 200 horse-power, account for a great deal of this load.

665. Table XX gives the total amount of electric cable in use from 1928 to 1933. No corresponding figures are available for the period 1934 to 1938, but it is estimated that the figure for low-tension cable in the latter year exceeded 1,200 miles. The investigation on which these figures are based covered all electrified mines in the Ruhr with gradients up to 1 in 1.43, and showed that the average length of L.T. cable per mine was 12.4 miles.

TABLE XX

LENGTHS OF ELECTRIC CABLE IN USE UNDERGROUND IN THE RUHR FROM 1928 TO 1933

Year	WORKING VOLTAGE	
	Up to 1,000 volts Miles	Over 1,000 volts Miles
1928 ..	428.4	385
1929 ..	510.0	382
1930 ..	640.1	393
1931 ..	558.2	380
1932 ..	908.4	364
1933 ..	885.1	390

666. The application of electricity to underground pumping was somewhat slow in the early days because of the difficulty of matching a high-speed motor to a slow-speed ram pump, but this was overcome by the advent of centrifugal pumps, and the electric drive is now largely standard practice. The saving in space and weight resulting from this change is significant. In one recent example quoted, a steam-driven ram pumping plant weighing 1,300 tons was replaced at a shaft bottom by an electrically-driven centrifugal set of equal output weighing only 25 tons.

667. The larger mines usually employ a number of staple shaft and incline hoists, mostly of moderate H.P., to which electric drive has been widely applied.

668. In regard to general application, there is every indication that electricity will supersede the other types of power of lower efficiency. The need for replacing compressed air by electricity has long since been recognised, and considerable attention is being paid to the development of machines to replace the pneumatic pick. This is largely due to the desire to increase output per manshift, and partly because of the difficulty of meeting the higher load demands of machines such as cutter-loaders with compressed air. Table XXI gives some interesting electrical details of an underground installation at a Ruhr mine.

TABLE XXI

DETAILS OF THE ELECTRICAL EQUIPMENT AT THE FACE AT A LARGE MODERN MINE IN THE RUHR

Supply 5,000 *and* 380 *volts* 3-*phase*, 50 *cycles*.

No. of motors .. .. = 32

Total capacity H.P. .. .. .. = 700

Average H.P. per machine (excluding auxiliary fans) .. .. = 22

No. of 200 KVA power transformers (excluding rectifier transformers for trolley locomotives) .. .. = 7 = 1,400 KVA

No. of 3 KVA lighting transformers .. = 20 = 60 KVA

1,460 KVA

No. of lamps in use on the faces and gate roads .. .. = 750

Length and size of cables :

H.T. Shaft cable = 2,500 yds. 3-core 0.0775 sq. in. (surface substation to seam switchboard).

H.T. Roadway cable = 700 yds. 3-core 0.0235 sq. in.

Medium pressure feeder cables = 6,800 yds. 3-core 0.0755 sq. in.

Short circuit rating of switchgear :

(1) at the surface bus bars .. .. = 130 MVA

(2) at the shaft bottom .. .. = 80 MVA

(3) at the medium pressure terminals of inbye transformers .. .. 30 MVA

Mean distances of inbye transformers from shaft .. .. 1,600 yds.

Mean distance of inbye transformers from face .. .. 540 yds.

Total underground current consumption 2.2 KWH/ton

Underground consumption exclusive of locomotive haulage and pumping .. 1.2 KWH/ton

Low pressure compressed air consumption (in addition) .. .. 5,650 cu. ft. free/air/ton

SUPPLY AND WORKING VOLTAGES

669. The usual generator and high-tension transmission voltage is 5,000 volts, the maximum being 6,000 volts, although in a few cases 3,000 volts has been adopted. Working voltage is fast becoming standardised at 500 volts, the alternative being the original standard of 380 volts which was favoured because of the 220-volt phase and neutral supply thus made available for lighting purposes.

670. In view of the tendency to increase face lengths to 200/300 and even 400 yds., the use of 380 volts brought about distribution difficulties and cables became somewhat unwieldy in size. In some cases the conductors were as large as 0.185 and 0.230 sq. ins. Apart from a reluctance to divide the faces into two or three units, it was generally more economical to step up the voltage to 500 volts, and this has largely been responsible for the change-over to this voltage. Only comparatively recently, the Germans decided to reduce the size of their inbye transformers and instal the smaller units, with built-in switchgear (transwitch units), closer to the face. A translation of a paper dealing with the reasons for the change-over from 380 to 500 volts appears in Appendix No. 28. In this paper, the author attempts to show that the higher voltage improves working conditions in the horizon system of mining, and that the change-over is well worth while on grounds of economy.

SHAFT AND ROADWAY CABLES

671. With the exception of shaft cables, feeder cables for all voltages employed in mining are nearly all paper insulated; lead covered, and armoured with single, or double steel, tape. Smaller cables employed inbye on medium pressure and low-tension lighting cables may be paper, lead, or rubber, insulated ; jute filled, lead-covered and steel tape armoured. The requirement that cables in vertical shafts must be self-supporting rules out the use of steel tape armouring in this respect, and double wire armouring is generally employed. All such cables are installed in wooden cleats in the conventional manner.

672. The almost universal use of steel tape armoured cable has resulted in satisfactory methods of attaching the tapes to joint boxes and to apparatus. The steel tapes are, in some cases, gripped against an underlying split ring by means of split clamps, and the lead sheath is secured mechanically against the inside wall of the box or casing. The sealing of all joint and terminal boxes with compound is always carried out. The cables, which are well supported on roadways at about 10 ft. intervals by means of light metal clips or straps usually attached to the roof bars, are very seldom damaged. This is not surprising in view of the common use of locomotive haulage. It is claimed that double steel tape armoured cable is less liable to damage from derailed tubs or falls of roof than wire armoured cable, but it must be pointed out that the Germans have little actual experience of the latter type for roadway feeders.

673. The shortage of copper during the war resulted in the introduction of aluminium conductors. As the conductivity of aluminium compared with copper is only about 80 per cent., the change involved an increase in the size of the cables and also proved much more expensive. The mixing of copper and aluminium conductors, particularly where this involved joining the two metals together, introduced electrolytic corrosion, particularly where moisture was encountered. Furthermore, the joining of aluminium to aluminium, either by hard soldering, or by welding or casting, had in most cases to be carried out by trained personnel supplied by the cable manufacturers. Attempts to overcome these disadvantages by using mechanical connectors were not wholly satisfactory.

674. Trailing cables will be dealt with later in connection with electrical equipment at the face.

TRANSFORMERS

675. Practice in the Ruhr is similar to that in British mines—except that there is a definite consensus of opinion in favour of the insulated neutral system, in spite of the Regulations of the VDE (Society of German Electrical Technicians) which recommend that the neutral point should be directly earthed. The Germans argue that given good maintenance, the insulated neutral system is safe, and they tend to look upon the application of, for example, core-balance leakage protection to the earthed neutral system as an admission that this system is somewhat unsafe.

676. In considering this view, the German mentality, particularly the reaction of the individual person to discipline and responsibility, must be borne in mind. Maintenance, generally, is of a high standard and, during the visit, when many transformers were seen, on only one occasion was a fault between one phase and earth found to exist, and this was on a small lighting transformer. It is usual practice to bring out the neutral point and to maintain it insulated from earth by means of an electrostatic earthing device (paper disc) or surge fuse, the function of which is to earth the neutral immediately a fault accompanied by a dangerous voltage rise occurs between any phase and earth. The presence of such a fault is generally indicated by a red lamp, and a second lamp is provided for the purpose of routine leakage testing. The recommendations contained in VDE 0118/1937 relating to the protection of transformers are as follows :—

(1) Direct earthing of the neutral point of the transformer low tension winding.
(2) Provision of a non-magnetic metal sleeve between the two windings on the transformer.
(3) Provision of fuses or automatic switches which, in the event of excessive voltage rise, will earth the low-tension neutral point or isolate the faulty cable or apparatus.

677. All power transformers are oil-cooled and are usually of the conservator type. The welded sheet steel tanks are generally fitted with deep fins instead of pipes for heat dissipation. Much has been said in the German technical press during recent years in favour of dry transformers, and considerable energy has been expended by the Electrical Industry towards securing this end, but so far little advance has been made. One of the major difficulties is to secure adequate ventilation, particularly where flameproof considerations must be taken into account. It should be pointed out that, in addition to equipment designed as flameproof, the German Regulations accept as flameproof any equipment in which open sparking does not normally occur. Thus, oil-cooled transformers are permitted to bear the "Sch"-flameproof mark. With air-cooling, it is considered that a higher standard of insulation is necessary both between individual coils and between windings, and this introduces another difficulty in the development of large air-cooled transformers, namely, that of space limitation. There are indications, however, that the Germans are departing from the practice of employing transformers of 3/400 KVA underground in favour of smaller units of 100 KVA or thereabouts, and it is claimed that this may help to dispense with the use of oil. The advantages of using two or three 100 or 150 KVA transformers in parallel, either in one location or spread over the area, rather than one unit of 3/400 KVA are now generally recognised. The greatest objection to the use of oil is the fire risk, but experience in the Ruhr has proved that this is not a serious hazard. Endeavours to substitute oil by non-inflammable agents such as Clophene have not, up to the present, met with success. The greatest objection to this type of substitute is, of course, the generation, under fault conditions, of chlorine gas, which, underground, may prove more hazardous than the fumes arising from burning oil.

678. Transformers are usually installed in fireproof rooms with efficient ventilation. Some of these rooms are fitted with thermostatically controlled ventilators which can be arranged to close and thus completely exclude air when the temperature exceeds a predetermined value.

8

The provision of Buchholz relays which provide protection against internal faults between windings in the transformer is standard practice. In this system, operation of the relay by bubbles of gas rising through the oil gives audible or visual indication of the presence of a fault by means of a buzzer or lamp. (Table XVIII indicates the development in the application of transformers from 1928 to 1932, and Table XIX is an analysis of the various sizes in use during the latter year.)

SWITCHGEAR

OIL-IMMERSED SWITCHES

679. Much of the high and low tension switchgear employed follows conventional lines and calls for no special comment. Oil-immersed switches are used on all voltages and for all services except at the coal face where flameproof enclosure is necessary, or where unsettled ground would render difficult the maintenance of the oil level in the switchgear. Investigations into the arc quenching properties of oil, particularly on higher voltages, led to the introduction of the so-called quenching chamber, or explosion pot type of contact arrangement, which is incorporated in an oil tank containing a much smaller volume of oil than is usually necessary. In this arrangement high pressure is applied to the oil in the confined quenching chamber by the gas produced by the arc, which forces cool oil at high speed down the hollow moving contact pin and quickly extinguishes the arc. Gases produced by the arc also pass out in this way. The chamber is usually provided with two or more spring-borne relief valves to limit the internal pressure. Oil-immersed push-button operated contactor switches are largely used underground for the control of staple hoist motors and pumps, and these are usually fitted with three thermal overloads backed up by one or two instantaneous short-circuit releases of the magnetic type. A typical oil-immersed push-button contactor switch is illustrated in Fig. 178, while Fig. 179 shows a manually operated oil circuit breaker.

EXPANSION SWITCHES

680. Various explosions and fires due to the use of oil switches led to the development of the expansion switch in which steam instead of oil gas is employed to extinguish the arc. The explosion pot with its moving pin contact and internal pressure chamber contains a small quantity of water. The water in the pressure chamber is converted to steam by the arc, and may reach a pressure of from 12 to 15 atmospheres. In one type, movement of the switch pin towards the " open " position opens a port in the chamber, thus releasing the pressure and so allowing the steam to condense quickly and cool the arc. For E.H.T. circuits, a long stroke for the contact pin is avoided by incorporating a single pole air-break knife switch externally and in series with it. While the arc is generally quenched in the expansion chamber with this arrangement, any small amount of current continuing to pass would be interrupted by the knife switch above.

681. A 10,000 volt 3-phase expansion switch is shown in Fig. 180, while Fig. 181 shows a cubicle housing for this switch. Fig. 182 illustrates a type with an additional air-break switch, and Fig. 183 an example of a flameproof expansion switch.

682. Because of exposed live metal, it is usually necessary to enclose this type of switch in a steel cubicle ; thus it is generally more bulky than other types.

FLAMEPROOF SWITCHGEAR

683. Flameproof switchgear for use at the coal face is in general use and covers a wide variety of types. Attention was first paid to the development of flameproof mining apparatus in 1903–5 by Beyling at the Experimental Station of the Westphalian Colliery Institute at Gelsenkirchen. In later years this work ran parallel with experiments in Britain, France and Belgium. A distinction is drawn between " Fire-damp protection " and " Fire-damp safe," for it is said that the latter can only be obtained when all parts of the circuit, and not only the apparatus covered by the " Approval," are safe. Under the Firedamp Protection Regulation V.D.E. 0170, all parts which in their normal operation are likely to produce sparks, flame, or dangerous temperatures, must be enclosed in " firedamp proof" casings. These include switches, starters, controllers and lighting fittings, but not motor and transformer windings and cable, which, it is argued, can be adequately protected against faults or excessive overloading by the provision of fuses or automatic circuit breakers.

684. Most of the alternatives to flange protection such as plate venting, or oil enclosure, have now disappeared, except that in some types of air-break reversing controllers for locomotive duty, plate vents are employed to safeguard against accumulations of ionised air. These, it is claimed, avoid the formation of nitric acid with its destructive effect on brass and copper contacts and connections. The main objection to the plate vent or other apparatus is the difficulty experienced in providing adequate protection against mechanical damage, and of keeping the apparatus clean. It is recognised that oil switches cannot be made flameproof because of the possibility of hydrogen accumulations within the enclosure, and, at the same time, that safety depends on the oil being maintained at the proper level, which, in practice, is not always easy. Most enclosures are fitted with internal flanges, which are machined smooth. Independent ventilation in which the enclosure is continuously fed with fresh air, slightly above atmospheric pressure, has been tried out, but is seldom used underground. All " firedamp protected " apparatus must be tested and passed by the official testing station at Dortmund-Derne, and must bear the sign " SCH " (" Schlagwettergeschützt "). In addition to flameproof tests, it is usual to submit the enclosures to a pressure test in order to safeguard against the use of enclosures with insufficient mechanical strength. In larger enclosures, explosion pressures of 6 to 7 atmospheres are provided for, and in the case of smaller casings of less than 6 cu. ins. the pressure generally met with is 4 to 5 atmospheres. During the early years of the war, trials were made with new methods of securing the doors of air-break switches and starters with the object of eliminating bolts, or of reducing their number to a minimum. This, it was claimed, would reduce the chance of bolts being left out, and of uneven closing of the door by the intervention of foreign material between the flanges. In one such design, which is now in common use, only one bolt is used, and the hinged door is fitted with a number of claws which engage with a shaft on the casing. The eccentrically mounted shaft is provided with flats to clear the claws and, when turned, engages the claws and draws the two flanges closely together. The single bolt is interlocked with the isolating switch so that the circuit cannot be made live until the door is properly closed. This particular design, illustrated in Figs. 184 and 185, is made up to 200 amps. capacity and is constructed of " Silumin," a light metal alloy which has about half the weight of cast iron or steel. Switches constructed of this light metal alloy have been in use for about 3 years and have given very satisfactory service in dry situations. Their behaviour in wet conditions is not known, but it is suggested that the presence of any corrosive agent in the water would be harmful. Some

difficulty is also encountered in maintaining good electrical conductivity between metal to metal faces. In another design, illustrated in Figs. 186 and 187, only one securing bolt is used, and the cover, which is hinged at the bottom, is provided with projecting wings on each side. These wings have tapered wedge-shaped slots on the inside which engage with projections on the sides of the switch casing, which also forms the flameproof joint. The weight of the door when closed tends to secure the joint, which is finally tightened by the single bolt located in a slightly downward direction. The operating lever for the isolating switch is carried on the door, and is mechanically interlocked with the single securing bolt. As considerable machining of cover and casing is involved, this design is probably somewhat expensive to manufacture. There is, however, a more simple design with the same principle of tapered claws on the door and projections on the casing. This design, which is semi-cylindrical in shape, is provided with flanges on the faces instead of at the sides, and again provides for only one bolt, which finally tightens the hinged side of the door and provides the necessary interlocking feature.

685. As open sparking does not normally occur in terminal or cable boxes, these fittings and attachments to circuit breakers are usually excluded from flameproof requirements except, of course, that flameproof bushings are required for the terminals into the main enclosure. Direct entry of armoured and incoming flexible rubber cables into such enclosures is therefore permitted, but this practice should not be confused with that in the U.S.A. which permits direct cable entry into main switch enclosures where open sparking normally occurs. Figs. 188 and 189 illustrate other types of flameproof air-break switches and circuit breakers.

ELECTRICAL LAY-OUT AT THE COAL FACE

GENERAL

686. The gate-end switches employed are of the air-break type. They are either manually operated circuit-breakers, or push-button, or remote-control, contactor switches, and usually conform to one or other of the designs previously described under " Flameproof Switchgear." Back or wall mounted switches, secured to a strip iron framework, and sometimes built up on a four-wheeled bogie, are preferred to bottom or floor mounting types as used in Britain. A gate-end assembly usually consists of one 200 and two 100 amp. switches for the cutter (or plough) and the face and gate conveyors, together with a 4–5 KVA lighting transformer and necessary switchgear. More elaborate arrangements are in use at many mines, and where the coal faces are completely electrified, for example, at the Rheinpreussen Mine, remote control is in general use. Fig. 190 shows the wiring diagram for a six-panel board for the remote control of an Eickhoff cutter loader, two belt conveyors and a lighting transformer. The fifth panel is used for grouping the conveyor remote control relays and push-buttons, and the sixth panel for the incoming feeder. It will be observed that a six-core trailing cable (with, in the example shown, a collective screen) is required to feed the cutter loader ; the additional core is for the local lighting on the machine. The screen is earthed through a low voltage relay (one side of which is earthed) at the gate switch end, and remains insulated throughout the remainder of its length. Thus contact with earth at any point operates the relay and clears the circuit. In some circumstances, two insulated pilots are employed with two small insulated conductors for the machine lighting, which involves the use of an 8-core cable, usually of 4–0.039 sq. in. and 4–0.0062 sq. in. cores. Such a cable with a collective screen, overlying canvas reinforcement and outer sheath is about 1.75 ins. in diameter. Figs. 191, 192, 193 and 194 show typical electrical lay-outs from the supply transformer to a double unit conveyor face, including the gate road and face lighting, at a modern electrified mine in the Ruhr. Fig. 195 shows the electrical lay-out for a coal plough installation.

FLEXIBLE TRAILING CABLES

687. Rubber sheathed flexible trailing cables are usually 3, 4, 6 or 8 core according to the service they are required to perform. It is usual to apply woven tapes to the rubber insulated cores before laying up on the customary cradle centre. The purpose of the woven tape is, apparently, to prevent adhesion between the cores and the outer sheath, which is often in two parts separated by canvas tapes. As already mentioned, the coal-cutter cables are usually 6 or 8 core, the cores in addition to the usual four being for the remote control circuit and for earth fault protection or machine lighting. Although some of the best material available was allocated to the German mining industry for the manufacture of trailing cables, the sheathing and insulating material produced from rubber and rubber substitutes was very poor. Experiments made towards the end of the war with conducting rubber with a view to reducing the resistance between the earthing screen and the conductor insulation met with little success. Very little Neoprene has been used, although a cable with a fireproof sheath known as "Flamex" was tested. "Flamex" had somewhat similar properties to Neoprene and, it was alleged, did not harden in use ; but its resistance to mechanical damage was extremely poor. The material from which it was made was not available during the later war years, and its manufacture was discontinued.

PLUG AND SOCKET COUPLINGS

688. Because of the small amount of shot-firing and the fact that few trailing cables are used on the coal face, damage to trailing cables is not as great a problem as in this country. Vulcanising is generally carried out with electrically heated clamp type vulcanisers, and the standard of workmanship is reasonably good. Very little attempt is made to repair severed conductors ; the usual method is to cut and re-join the cable by means of a plug-socket coupler. There is not the same objection to this practice as with portable machines like coalcutters, where the coupler is liable to be dragged about the face, because a very large proportion of the cables in use are connected to semi-portable gate conveyors. The Germans have definite objections to the use of detachable plugs, even on portable machines, and avoid using them by substituting, whenever possible, a form of bolted coupling or direct entry into a terminal box. Plug and socket construction becomes complicated with trailing cables with up to eight conductors, and, in most existing designs, defects quickly develop owing to vibration of the machine.

UNDERGROUND LIGHTING

689. The statement in Chapter II that coal face lighting is extensively used in the Ruhr applies equally to roadway lighting, and it is not uncommon to find continuous lighting of a high standard on roadways two miles or more in length. In the Jacobi Mine, which has an output of roughly 5,000 tons per day, the amount of electrical energy consumed for lighting underground amounts

to 15 per cent. of the total demand. In this particular case, nearly 2,000 lamps are in use underground including thirty 1,000-watt lamps around the shafts, 300-watt lamps spaced at 16-yd. intervals for a considerable distance on the main roads, and 200-watt lamps at 22-yd. intervals up to the gate roads, where 100 or 60-watt lamps at 6-yd. intervals are used. The faces have 40 or 60-watt lamps at 4½ to 6½-yd. intervals.

690. The number of roadway lighting installations increased rapidly up to the outbreak of the war. For example, in the four-year period 1934 to 1938, there was an increase of over 100 per cent. (Development was seriously retarded during the last years of the war by a shortage of metal filament lamps, and a number of lighting installations have fallen into disuse for this reason.) The same advantages are claimed for roadway lighting as for lighting on the coal face, and it is further claimed that good illumination at the shafts and in the roadways contributes to a higher standard of track maintenance, which, in turn, lessens transport breakdowns (see Appendix No. 29).

691. The equipment employed consists of single-phase or three-phase transformers of from 5 to 25 KVA with air-break circuit breakers, or, in the smaller installations, switches and fuses. The voltage normally used is 220 volts, although a few installations use 110 volts. Rubber insulated tape armoured cable, with three or four conductors, is standard, and the many types of well glass fittings employed include sizes for metal filament lamps of from 40 to 1,000 watts.

692. Apart from a few experiments with 40-watt 120-volt mercury vapour lamps, discharge lighting has not yet been introduced underground. The main objection to this type of lamp is that it cannot be used for signalling purposes on the face or in gate roads. It is admitted, however, that much can be said in its favour for shaft bottom, staple shaft area and main roadway lighting.

693. Shaft bottom areas are usually illuminated by 1,000-watt lamps placed sufficiently close together to maintain a good distribution of light even when one lamp fails. Some shaft bottom areas seen had twelve of these lamps installed at roof level, which, in some cases, was 30 ft. from the ground.

694. The size and spacing of the lamps in roadways vary with the size of the road. As a general rule, however, lamps of 200 watts are placed at 22-yd. intervals near the shafts, and of 60 watts at 5 to 6-yd. intervals at the face. Well glass fittings, with or without external reflecting shades, are used for all purposes. Many of these with a capacity of up to 1,000-watt have been certified flameproof.

695. Three-phase distribution is generally used for lighting roadways, and the numerous staple shafts where electricity is used for the hoists provide suitable locations for the transformers, which are thus able to cover long distances in both inbye and outbye directions.

696. In double track roads equipped for trolley locomotive haulage, the lights are usually installed in the centre of the road. The trolley wire D.C. supply must not be used for lighting.

697. The standard of mains lighting provided on roadways generally renders whitewashing unnecessary, and very little of it is to be seen.

POWER PRODUCTION

698. The scheme which is being carried out for centralising power production in large production plants in the Ruhr will eventually result in the elimination of obsolete and less economic units, and may even go so far as to cause the cessation of generation of electricity, despite the necessity to produce compressed-air power, at some of the smaller mines.

699. The following is a quotation from a paper by Philippi published in 1940 :—

> “ As the mines developed by concentrating output
> “ in a comparatively few shafts with large outputs, so
> “ also, to an increasing extent, is the generating of
> “ electric energy being taken away from the smaller
> “ mines and concentrated in one large plant.
> “ Naturally this change cannot take place overnight.
> “ It must proceed gradually and be carried on after
> “ the war. It is, therefore, necessary to decide which
> “ plants are to be developed into large central
> “ stations during the war, and which of them should
> “ be left till shortly after the war. Some of the im-
> “ provements have been made by converting to high
> “ steam pressures and temperatures, thereby reaching
> “ perfection in steam generation. These improvements
> “ have, of course, been made available in connection
> “ with the production of electric energy in mines, and
> “ as a source of energy, in addition to steam and com-
> “ pressed-air, for machines. The latter require some
> “ 2/3 of the boiler production, whilst only 1/3 goes
> “ to the generation of electrical power. After the
> “ war, it is expected that large plants powered by
> “ electricity will be used to volatize coal, and to
> “ produce artificial manure and other chemicals.
> “ These operations will be greatly facilitated by the
> “ present development. By the change-over to high
> “ steam pressures and temperatures, one is advancing
> “ with vision and foresight ; but it is essential that we
> “ remain within the limit, and that the cost per
> “ KWH does not exceed the allowance for sinking
> “ fund and service, but rather shows a profit.
>
> “ A sign of the development of the production of
> “ electric energy in the Ruhr area is the foundation of
> “ the Hard Coal Electricity A.G. of Essen by the
> “ members of the Rhine-Westphalian Coal Syndicate,
> “ with whom the hard coal mines of the Ruhr, Saar
> “ and Aachen districts have organised an important
> “ union for the economic production and distribution
> “ of electric energy.
>
> “ A proportionately larger number of machines and
> “ boilers are normally held in reserve at the small
> “ single unit plants than at large combined mines.
> “ When the circuits of several plants are connected
> “ together and it is possible for one to assist another
> “ in case of a breakdown, the system of interconnection
> “ is of great advantage.”

700. The formation of the Hard Coal Electricity Syndicate is a very important step towards increasing the supply of electricity to the Ruhr mines : it also will have an important bearing on utilisation of low grade fuels and may ultimately lead to power production at mines for general industrial use.

CONCLUSIONS AND RECOMMENDATIONS

701. (i) Few useful conclusions are to be drawn from German mining electrical practice largely because of the limited amount of electricity in use underground compared with Britain, and because of the retention of some obsolete practices.

(ii) Notable developments have, however, been made in the design of flameproof air-break switchgear with the object of dispensing with the use of bolts for securing doors, or of reducing their number to a minimum. British manufacturers of mining switchgear should be encouraged to consider similar designs.

(iii) The successful application of light metal alloys to the design of flameproof air-break switchgear is worthy of the attention of British manufacturers.

(iv) The lighting of shaft bottom areas and roadways in the Ruhr is generally of a very high standard.

(v) The movement to centralise the production of electrical power in large units, and the formation of the Hard Coal Electricity Syndicate would ultimately result in a considerable economy of man-power and fuel. Although the internal needs of the Ruhr mines are as yet unsatisfied, there is a distinct possibility that power may eventually be produced at these mines for general industrial use by utilising low grade fuel normally unsaleable on the market.

CHAPTER VIII

Summary of Conclusions and Recommendations

A. PHYSICAL CONDITIONS (Chapter I)

702. (i) The Ruhr coalfield is faulted and distorted but the percentage of workable coal in the coal bearing strata is 4 per cent. to 8 per cent. The advantages of these rich measures, although partly offset by the average depth of working—which has now reached about 750 yds —is reflected in the large daily output obtained at many mines from relatively small leaseholds.

(ii) *The horizon system of mining is ideally suited to the Ruhr conditions. This system is recommended for consideration in this country, particularly where the physical conditions are similar to those in the Ruhr.*

(iii) *The Ruhr modern coal mine with a capacity of more than* 10,000 *tons per day is a very large unit. Mines of such a daily output are not recommended in this country because of complications of management even where available coal thickness and other geological conditions are most favourable; and it should be pointed out that complete mechanisation as carried out in the most modern mines in the Ruhr can only be recommended where the reserves of coal and the daily rate of production justify the heavy expenditure involved.*

(iv) *Full co-ordination of research and development work has been achieved, and the organisation set up by the German Coal Owners' Association is worthy of close study. A similar co-ordination under the supervision of experienced and practical mining engineers would be of great value to the Mining Industry in this country.*

B. METHODS OF WORKING AND COAL FACE EQUIPMENT (Chapter II)

703. (i) Longwall experience in the Ruhr provides no reliable guide to longwall retreating practice under British conditions. The view that longwall retreating will be advantageous in the Ruhr for depths exceeding 1,100 yds. appears to be sound from the aspect of ventilation, but is not in accordance with British experience of maintenance of roadways at depth.

(ii) The wide use of the pneumatic pick is basically due to the physical characteristics of the seams. The measurement of the effort required to break down a cubic metre of coal in each seam has defined the field of application of pneumatic picks in the Ruhr Coalfield.

(iii) *Arrangements should be made to obtain first-hand knowledge of progress in the further development of the yielding type steel supports.*

(iv) *We recommend that mechanical packing, which is effective under Ruhr conditions, should be developed under suitable conditions in British mines without delay.*

(v) *The most important development in face conveyors for hand loading is the double chain scraper conveyor for long faces. We recommend that one of these conveyors should be brought to Britain for detailed examination and application under British conditions.*

(vi) The provision of mains operated lighting at the coal face is common in the Ruhr and owes much of its success to the relative absence of shotfiring.

(vii) *The standard of illumination provided at the coal face by mains lighting is much higher than has ever been attempted in this country.*

(viii) *The use of* 40 *or* 60 *watt lamps comparatively closely spaced has been made possible by reducing glare. Consideration should be given to the development in Britain of toughened opal glass with low light loss.*

(ix) The circuit adopted has secured a fairly uniform degree of illumination throughout the whole length of face. This arrangement enables actual working voltage and lamp voltage to be more closely related.

(x) *The link-up " plug-in " system of assembly removes many difficulties associated with the daily move up and maintenance of the installation. We recommend the adoption of the " plug-in " system in this country.*

(xi) Gate conveyor equipment in the Ruhr is not up to British standards. The steel belt and steel plate conveyors, which have been developed owing to the shortage of rubber, are not as satisfactory for gate conveyor service as the troughed rubber belt conveyor.

(xii) *The layout and equipment of loading stations are sufficiently far in advance of British general practice to prove that the flow of coal into the tubs and the passage of the tubs through the loading station should be under mechanical control where large outputs are loaded.*

(xiii) Despite the interest created by the power-loading competitions, less than 0.4 per cent. of the total quantity of coal has been loaded mechanically during the last five years.

(xiv) *The development of cutter loaders in the Ruhr has, to a degree, been on the lines initiated in this country, but is not so far advanced. The details of the Demag thin seam cutter loader are of interest because the loading action appears to be effective within the restrictions imposed by height limitations in thin seams, and we recommend that the drawings should be made available to the designers of cutter loaders in this country.*

(xv) *Experience in the Ruhr over the last three years has proved that the difficulties encountered in using the coal plough, and overcome under the most favourable conditions, progressively increase as the coal becomes harder. The forces to be mastered in the majority of seams are so little known, and the sphere of application of the plough is as yet so undefined, that the German technicians have requested permission to make a thorough investigation with the testing unit described.*

A parallel investigation is recommended in Britain. Such an investigation would :

- (*a*) *Provide a valuable comparison of the physical characteristics of British coal seams, so far as the getting of coal is concerned.*
- (*b*) *Ensure that full use is made of the experience already gained in the Ruhr.*
- (*c*) *Eliminate the unknown factors in Britain and ensure the success of coal plough installations.*

(xvi) *We also recommend that a standard German coal plough complete with ancillary equipment should be obtained* *for practical test in a seam in Britain chosen after the investigation proposed under* (xv).

(xvii) *The development of the coal plough in the Ruhr should be closely studied, and complete control should be obtained of the resonance tractor.*

(xviii) *The removal of a narrow strip of coal from a longwall face by power* (*e.g. by using a coal plough as in the Ruhr*) *as a method of coal getting has been the subject of much thought and experiment in Britain during the last few years. The system is of great interest because the power loading operation can be made independent of the work of supporting the roof—even if this means increasing the number of manshifts for setting supports—which points the way to continuous power loading and to mechanising the work of supporting the roof.*

(xix) *We recommend that one of the special double chain conveyors developed for use with the coal plough should be brought from Germany for the application proposed under* (xv).

(xx) *The Resonance conveyor is worthy of the closest attention and we strongly recommend that it should be further developed in Britain.*

C. THE SYSTEM OF DRIVING ROADWAYS IN STONE (Chapter III)

(i) *The co-ordination of loading, setting supports, drilling and shotfiring in mechanised stone drifting is most successful when the depth of the shotholes is adjusted to ensure that one full cut is completed in a shift.*

(ii) The "Stoss-schaufellader" is an efficient loader, particularly when used in conjunction with the drilling carriage, but it is limited to level, or approximately level, roadways in which the rail track is laid close to the working face. It is doubtful whether, under these conditions, the "Stoss-schaufellader" loader is more effective than other loaders with a wider range of application.

(iii) *Wet drilling in stone drifts is standard practice in the Ruhr, and we recommend that it should be used for driving roadways in stone in Great Britain, particularly where large numbers of drills are operated simultaneously.*

(iv) "*Hard metal*" *tips on percussive drills, the vibratory drill feed and drilling carriages have materially accelerated the drilling cycle, and represent an important advance in the technique of driving roadways in stone. All three are worthy of further careful study with a view to applying the principles to our practice.*

(v) *The use of the rotary tunnelling machine in coal measures strata in the Ruhr should be encouraged, and the results should be carefully observed.*

D. UNDERGROUND TRANSPORT WITH SPECIAL REFERENCE TO LOCOMOTIVE HAULAGE (Chapter IV)

704. (i) In the Ruhr, the continuous system of gate road and staple shaft haulage and the use of the mine car show, in practice, a very satisfactory economy in costs and in manpower. *We recommend that, where it is proposed to plan for horizon mining in this country, advantage should be taken of German experience in transport design and layout.*

(ii) Locomotive haulage has become firmly established as the standard form of underground transport in the Ruhr because, compared with rope haulage, it has greater flexibility and breakdowns are less frequent.

(iii) The trolley locomotive remains by far the most popular locomotive in the Ruhr because of its higher operational efficiency compared with all others. There is evidence that some Diesel installations will be replaced by trolley locomotives as soon as the necessary equipment is available. *We recommend that the trolley locomotive should be introduced into British coal mines, under suitable conditions, without delay.*

(iv) The methods of trolley wire suspension and of current collection employed in the Ruhr are recommended from the point of view of efficient operation and low maintenance costs.

(v) Welding provides the most permanent form of track bonding. We recommend that the necessary facilities should be given to enable welding to be similarly carried out underground in British mines.

(vi) *In view of the success achieved in the Ruhr, we recommend that mercury arc rectifiers should be provided in preference to rotary equipment in underground D.C. sub-stations for trolley locomotives.*

(vii) The development of the Diesel locomotive has been retarded by war conditions and, to a certain extent, by its high maintenance costs as compared with the trolley locomotive. Fumes become a nuisance where several Diesel locomotives are simultaneously in use underground.

The German Diesel design is not, on the whole, as efficient as the British.

(viii) The compressed-air locomotive, which is comparatively low in horse-power, is generally acknowledged in the Ruhr to be less efficient than other types. We therefore do not recommend its use in British mines.

(ix) *The efficient and attractive design of the undercarriage of the German standard mine car makes it particularly suitable for use with locomotives. This is of special importance in view of the increasing use of locomotives in British mines. Points worthy of particular study are the single buffer and buffer spring, the double taper roller bearings and the methods of springing and of suspending the car body.*

(x) *The efficiency of haulage operations in the Ruhr is, in general, greatly increased by the method of track laying, which is of a very high standard.*

(xi) The simple mechanical devices used at loading stations, together with the simple layouts, have enabled considerable economies to be effected in man power, and add to the efficiency of large mine cars hauled by locomotives.

(xii) The underground workshops provided in some Ruhr mines have proved to be of considerable value, particularly for locomotive repairs. We recommend that similar accommodation should be provided underground in new large mines, and in older mines where a number of locomotives are serviced, in this country.

E. WINDING AND SHAFT LAY-OUT (Chapter V)

705. (i) The grouping of mines under the same ownership, increasing depth of working, and the universal development of the system of horizon mining have all influenced winding and ancillary operations in the Ruhr. In an endeavour to obtain greater economy in the use of man-power and of mechanical and/or electrical power, winding operations have become more concentrated, shaft capacity more fully utilised, and, in some instances, both surface and shaft bottom lay-outs have been modernised with great thoroughness.

(ii) *In view of its record of reliable and efficient service in the Ruhr, the question of the use of the electrically driven Koepe-winding system in British mining practice, particularly where the introduction of horizon mining is being considered, should receive renewed attention.* In this connection, the advantages of the tower-mounted type of Koepe winder merit special attention.

(iii) It is believed that the problem of winding heavy loads from great depths in the Ruhr has been solved

by the introduction of the multi-rope winder, which, however, is not yet in actual operation. This development should be closely studied in connection with the exploitation of our deeper seams.

(iv) The Ruhr type of air-lock can be used to advantage in many British mines where there is limited space at the shaft mouth. In addition to minimising surface air leakage, it may facilitate modernisation of surface tub-circulation and thereby reduce man-power.

(v) The Müthing car coupling system for use in conjunction with cage winding is regarded with considerable confidence by some German technicians, but as it is only in the early stages of development no recommendation can yet be made as to its adoption in this country.

(vi) *The simplification of car circuits, both above and below ground, made possible by modern cage winding with large cars has undoubtedly resulted in considerable financial savings in installation and in operation. In certain circumstances, therefore, cage winding with large cars can compete successfully with skip winding, and is recommended in this country in cases where a number of different qualities of coal are to be raised by the same winder.*

(vii) *The skip winding appliances in operation in the Ruhr have proved to be reliable and inexpensive. The recent improvements effected in the design of skip winders to minimise the breakage of coal and to suppress dust should encourage the use of skip winding in this country, particularly in new mines or where an increase of existing shaft capacity is desirable.*

(viii) *The rolling tipper system for car tipping underground is an outstanding achievement and should be studied by those responsible for the design of new mines where skip winding is to be used.*

(ix) Whilst the results of recent study in the Ruhr of the effective areas of shafts and shaft-openings and their efficient utilisation are mainly applicable to shafts fitted with double-winding systems, nevertheless, the method recommended as a result of this study would appear to be an advance on the methods hitherto used in other countries in the allocation of shaft space.

(x) *Double winding in shafts in which are hoisted more than* 3,000 *tons per day, particularly when winding has to be done from more than one level in the shaft, is another development which should be re-examined by British mining engineers.* Where production can be reliably planned ahead for a lengthy period, the additional shaft capacity afforded by double winding will more than compensate for the extra cost of the second winder.

(xi) *From a winding-cost point of view, winding from various levels can be economically practicable only when large tonnages are raised and the advantage of concentration of production effort, as far as winding is concerned, is paramount.*

F. STAPLE SHAFTS (Chapter V (*a*))

706. (i) Staple shafts are an essential part of the horizon system of mining as practised in the Ruhr, and have undoubted advantages for the passage of coal, men and materials. *We recommend that the adoption of staple shafts in this country should be reconsidered in the light of the success of skip winding and spiral-chute conveying.*

(ii) *The success of skip winding in staple shafts clearly indicates the advantages of skip winding in main shafts in small mines where the tonnage raised per shift is relatively low.*

G. SPECIAL FEATURES OF SURFACE LAYOUT AND EQUIPMENT (Chapter VI)

707. (i) The recent developments in the surface layout of new mines in the Ruhr merit consideration by those responsible for modernisation schemes and for the design of new mines in this country, but there is an apparent extravagance in comparison with British modern layouts which, on the whole, are probably more efficient.

(ii) *The covered manway to and from the shafts is an undoubted advantage in efficient organisation. It is recommended that future plans for pithead baths in this country should include a similar covered manway between the baths and the man-winding shafts.*

(iii) While much has been done in this country, particularly during the war years, to effect economies by the use of low-grade fuels for power-raising purposes, nevertheless it is considered that the advance made in this direction in the Ruhr shows that further economies may be made without loss of efficiency. We therefore recommend that fuel efficiency and economy should continue to receive close attention.

(iv) *The close liaison with the main railway authority in the Ruhr permits siding accommodation at coal mines to be limited to one day's output. Such a dependable working arrangement is highly desirable in this country.*

(v) The efficient layout of both surface works and pit bottoms in the Ruhr has been greatly facilitated by the assistance provided by two very large engineering firms. These firms have staffs of mining technicians and are thus able to provide complete designs of general and mining engineering projects. Moreover, their manufacturing range is so very wide that, with the exception of coal cleaning and ventilation plant, they can supply nearly all the major equipment required. We recommend that the advantages to be gained by the transfer to this country of the mining equipment section of one or both of these concerns should be fully examined without delay.

H. SUPPLY AND USE OF POWER (Chapter VII)

708. (i) Few useful conclusions are to be drawn from German mining electrical practice largely because of the limited amount of electricity in use underground compared with Britain, and because of the retention of some obsolete practices.

(ii) *Notable developments have, however, been made in the design of flameproof air-break switch gear with the object of dispensing with the use of bolts for securing doors, or of reducing their number to a minimum. British manufacturers of mining switchgear should be encouraged to consider similar designs.*

(iii) *The successful application of light metal alloys to the design of flameproof air-break switchgear is worthy of the attention of British manufacturers.*

(iv) The lighting of shaft bottom areas and roadways in the Ruhr is generally of a very high standard.

(v) *The movement to centralise the production of electrical power in large units, and the formation of the Hard Coal Electricity Syndicate, would ultimately result in a considerable economy of man-power and fuel. Although the internal needs of the Ruhr mines are as yet unsatisfied, there is a distinct possibility that power may eventually be produced at these mines for general industrial use by utilising low grade fuel normally unsaleable on the market.*

13*th February*, 1946.

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ITEM NO. 30

WINKLER GENERATORS FOR MANUFACTURE OF WATER GAS, Etc.

Morley, R. J.

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BRITISH INTELLIGENCE OBJECTIVES SUB-COMMITTEE

LONDON—H.M. STATIONERY OFFICE

WINKLER GENERATORS

FOR MANUFACTURE OF WATER GAS ETC.

Reported by

R. J. MORLEY

on behalf of

Ministry of Fuel and Power.

BIOS Target No. C30/364

Fuels and Lubricants.

BRITISH INTELLIGENCE OBJECTIVES SUB-COMMITTEE,
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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Units of Gas Measurements

Throughout this report gas quantities are quoted in NM^3, measured dry at 15°C and 735.5 mms mercury; this is the normal practice at I.G. and BRABAG factories.

WINKLER GENERATORS FOR MANUFACTURE OF WATER GAS ETC.

SUMMARY

All the available information concerning Winkler generators, contained in C.I.O.S. reports and in documents brought back by C.I.O.S. missions to Germany in 1945, is collected together and combined with literature references to give a comprehensive account of the history and present status of the process. There are at least five large plants in Central Germany and Czechoslovakia using the process and possibly one plant in Japan. The process is technically sound and well-established but appears to be economic only where cheap fuel, e.g brown coal or brown coal coke, is available, which cannot be gasified conveniently in other ways.

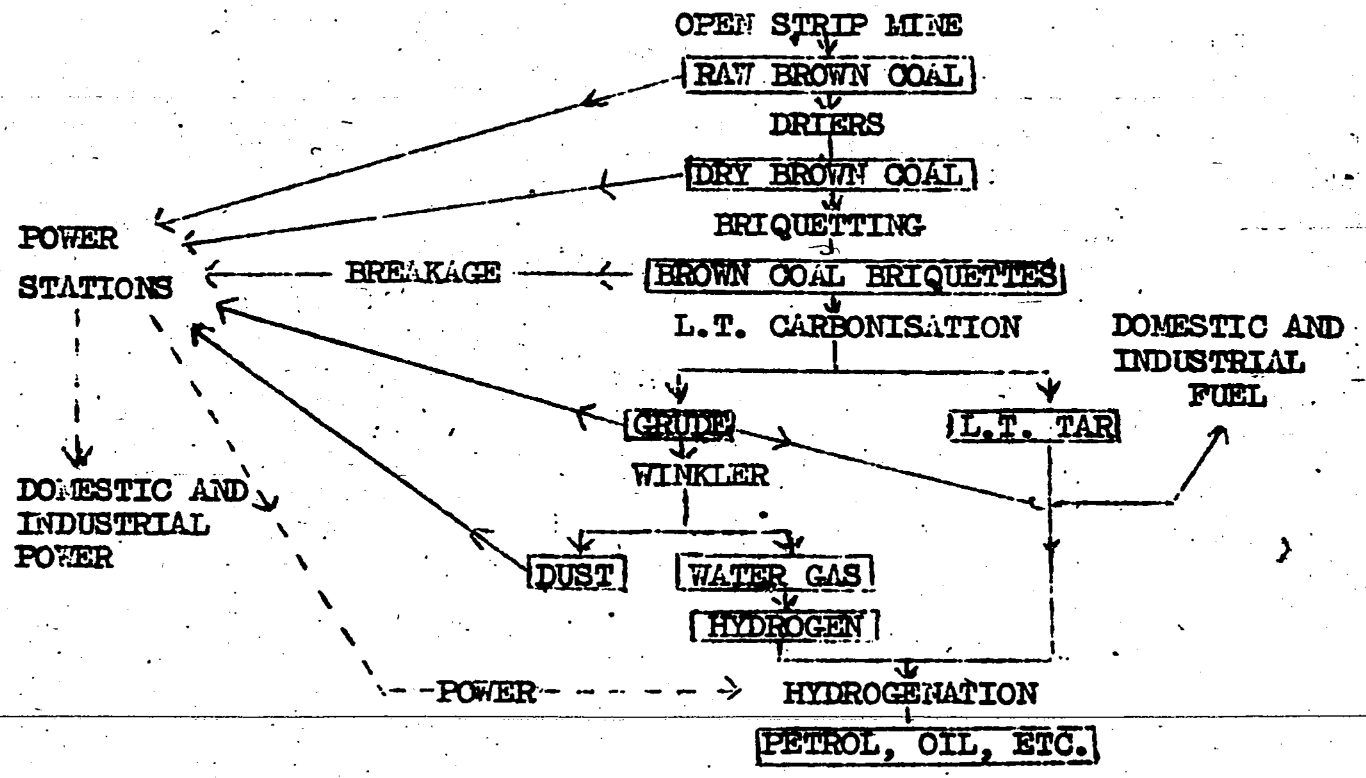
INTRODUCTION

The first large-scale Winkler generator for making power gas was put into operation at Leuna in 1926 and the first large-scale generator making water gas followed in 1930; the successful use of a "boiling" bed of fine fuel thus introduced a new process for the manufacture of power gas and water gas. Since then the process has become firmly established inside Germany and since 1936 has found considerable use in the large-scale production of hydrogen in plants manufacturing petrols, oils, etc., by the hydrogenation of brown coal and brown coal tar. For the manufacture of hydrogen the process requires large quantities of oxygen, and despite the fact that the Linde-Fränkl process, developed in the last 20 years, is a marked improvement over older processes, oxygen is still relatively expensive, so that its use, and hence the use of the Winkler process, can only be justified when it makes possible the use of a cheap fuel, which otherwise could not be satisfactorily gasified. This explains why all known Winkler generators are located near the brown coal fields of Central Europe; brown coal, as obtained by open strip mining, is very cheap, but it is difficult to get it into a form suitable for use in a conventional "make-and-blow" water-gas generator; on the other hand brown coal is an ideal fuel for a Winkler generator.

In recent years German economy has been such that it was advantageous to produce vast quantities of petrol and oil from indigenous coal. A particularly favourable process was to hydrogenate the tar obtained from the low temperature carbonisation of brown coal briquettes; this carbonisation produced several times as much brown coal coke, or "grude" coke, as it did tar, so that a use had to be found for the vast quantities of grude. The biggest use of grude was for firing the boilers of power stations, already existing in many cases and previously using raw brown coal, but it was also very convenient to use grude for making the hydrogen, required for hydrogenating the tar. Moreover since the Winkler process resulted in an appreciable fraction of the fuel being carried over as dust with the gas, it was also very convenient to be able to recover this dust and use it as boiler fuel.

Thus there has grown up in Central Germany, centred around Leipzig, a collection of large factories, all primarily based on the vast deposits of brown coal found in that region; these factories,

although carrying on different processes, are largely inter-related and are often located on the same or neighbouring sites. The diagram below sets out this inter-relationship.



The diagram shows up how the power stations can be used as a sink for unwanted products and how they can be used to keep a balance.

As far as we are aware there are no Winkler generators outside the Central European area, (possibly excepting Japan), and there are no large generators operating on anything but dry brown coal or brown coal grude. It is possible to operate Winkler generators on bituminous coals, L.T. coke from bituminous coal or even anthracite; operation however is not so satisfactory and in general it appears that the Winkler process is not economic for such fuels, where the alternative processes of coke ovens - water gas generators are available. Indeed even at Leuna, in the centre of the brown coal area, according to Ref. 1 Winkler gas cost approximately the same as water gas from ordinary water gas generators, operating on hard coke, brought 275 miles from the Ruhr.

The Winkler process is not suited to making town's gas, as the calorific value is low, and its field of application appears to be limited to the large-scale production of (a) water gas, to be used for manufacture of hydrogen, methanol or Fischer-Tropsch synthesis gas, (b) producer gas, to be used as a fuel gas or power gas, and (c) ammonia synthesis gas, but in all cases based on a cheap fuel, not otherwise easily utilisable. In the light of this it is easy to see why the process has not hitherto been used in Great Britain or the U.S.A. Nevertheless it is a technically sound process and economic in a limited field of application. Brown coal occurs extensively in the U.S.A. and Australia (but not in Great Britain) and there is no reason why the process should not eventually be operated in those countries at least.

WINKLER GENERATOR INSTALLATIONS

Table I is a list of known Winkler generator installations.

TABLE I

Plant	Started up	Operating Company	Units	Approx. Output/unit M^3/hr. water gas	Remarks	Ref.
GERMANY						
Leuna 20 m W Leipzig	1926 to 1930	I.G.	4 1	60,000 30,000	75,000 on producer gas. Only one unit works on water gas and one on producer gas at one time.	1
Böhlen 10 m S Leipzig	1938	Brabag	3	20,000		2
Zeitz 20 m SSW Leipzig	1939	Brabag	3	20,000		3
Magdeburg 50 m NW Leipzig	1939?	Brabag	3	20,000		1
CZECHOSLOVAKIA						
Brüx 80 m SE Leipzig	1942	Sudetenländische Treibstoffwerke A.G.	5 or 6	20,000		1

In addition there are small units at Oppau, nr. Mannheim, as well as at Leuna, operated by I.G. to test various coals. It is also possible that there are three generators in Japan (Ref.1).

HISTORICAL

The Winkler generator was developed by the I.G.; the development work was carried out at Oppau and large-scale plants were first erected at Leuna. The huge production of ammonia and methanol at Leuna was originally based on synthesis gases made from hard coke, brought from the Ruhr and gasified in conventional water-gas generators, operating on a make and blow cycle. The local cheap brown coal was used only for steam raising and for making producer gas, used as a power gas, but the power requirements of ammonia and methanol synthesis were so high that it paid to locate the factory on the brown-coal fields, rather than near a supply of hard coke, quite apart from any military reasons. In 1920-30 the I.G. were much concerned with the possibility of using brown coal, instead of coke, for synthesis gas manufacture. Before that time brown coal could be used for making producer gas, for power, only after submitting it to the relatively expensive process of briquetting; even so the producer gas contained up to 2% CH_4 and could not be used for ammonia synthesis, whilst the low ash m.p. and low strength of the fuel were additional obstacles; there was no satisfactory process for making water gas or producer gas from brown coal, suitable for ammonia and methanol synthesis.

Dr Fritz Winkler in 1921 (Ref.5) conceived the idea of using a "boiling" bed, i.e. using particles of fuel small enough to be almost gas-borne and hence comparatively mobile. Under such conditions the fuel bed behaves very much like a liquid; the gas passing through the fuel gives an appearance as if the bed were boiling, the bed finds its own level, as does a liquid, and circulation of particles within the bed is such as to give substantially equal temperatures throughout the bed. The first patent, DRP 437,970 was applied for on 28/9/22 and several others followed (Ref.7). The original work at Oppau was directed towards making power gas and the first Winkler producer (No.1) was put into operation at Leuna in 1926, having a capacity of 40,000 M^3/hr, equivalent to 3,300 $M^3/hr/M^2$ grate area. By 1929, four more producers had been added, each having a grate area of 25 M^2, double that of the first. During 1929 the whole plant often produced 200,000 to 230,000 M^3/hr power gas, and at times as much as 300,000 M^3/hr. One year afterwards, however, the slump hit Germany and requirements of power gas sank considerably, and normally only one or two producers had to be run.

After initial experiments at Oppau attempts were made at Leuna to make water gas from brown coal, coke or grude, by the "make-and-blow" method, without the use of oxygen, as described in DRP 437,970. It was expected that raw brown coal could not be used, because the presence of carbonisation products in the gases made would render them unfit for subsequent use, so grude was used. It was hoped that by blowing air alone through the boiling bed to raise its temperature and then passing steam through it, water gas could be successfully made, but the attempt failed for the following reasons. Particulate fuel, contained in a bed of fixed cross-sectional area, will "boil" satisfactorily only with gas velocities between certain fairly narrow limits; if the velocity is too low the bed ceases to boil and if it is too high entrainment occurs and the fuel is blown from the bed. A compromise had therefore to be made between air and steam rates. The steam rate had to be high enough to boil the bed, and the fuel bed deep enough so that too much undecomposed steam did not pass. The air rate had to be held below that which would cause entrainment, but it was desirable to have shallow fuel beds, so as to keep the time of contact between blow gas and fuel low enough to prevent excessive reaction between CO_2 and fuel. In practice it was found that with the highly reactive grude the CO content of blow gas was very high, and in fact blow gas approximated to producer gas, and this, coupled with the high exit temperature of blow gas, 1,000°C., gave an undesirably high ratio of producer gas/water gas, viz. about 5:1. This ratio was much bigger than the power gas/synthesis gas ratio for processes worked at Leuna and moreover water gas still contained 1% CH_4, which was still a drawback, although did not entirely prohibit its use. Theoretically the process could have been improved by preheating the air and steam with the hot waste gases, but this was not tried at that time.

In 1929 small-scale tests were commenced at Leuna, with the object of making NH_3 synthesis gas continuously from dry brown coal or grude, by using a continuous blast of steam and oxygen-enriched air. In 1930 the original No.1 generator was producing about 10,000 M^3/hr. of mixed gas for ammonia synthesis, but the CH_4 content was still an objection.

Also in 1930 Leuna began the production of nitrogen-free water gas, and profiting by previous experience, a satisfactory way was devised of using a continuous blast of pure oxygen with steam. Both grude and later dry brown coal were used as fuel, and three of the existing large Winkler producers were adapted for the purpose. In 1932-3 new Linde-Fränkl air separation plants were installed, specially to make oxygen for the Winkler generators. The introduction of part of the oxygen-steam mixture above the boiling fuel bed was useful in reducing the CH_4 content of the gas made, especially when using dry brown coal, but the content of 1 to 2% was now tolerated because of other advantages of the process and because Winkler gas provided only a part of the synthesis gas requirements.

Since 1933 as a rule one of the large Winkler producers at Leuna has continued to make 40,000 to 70,000 M^3/hr power gas, and one large generator to make up to 60,000 M^3/hr nitrogen-free water gas. It is to be noted that the old coke water-gas generators were still running in 1945, making several times as much gas as did the Winkler water gas generator. That a complete changeover was not made was due partly at least to the high brown coal demands of the factory as a whole on neighbouring mines (Ref 6, p.12); it is expensive to transport brown coal more than short distances, owing to its bulk, high water content and reactivity. It is also probable that Winkler water gas was not so much cheaper than coke water gas at Leuna, as to warrant the large capital expenditure required for the conversion.

In 1936 a large expansion of German synthetic petrol and oil industry was started, and Winkler generators, using oxygen to gasify grude, were chosen for manufacturing hydrogen at the BRABAG(Braunkohle-Benzin-A.G.) plants erected at Böhlen, Zeitz and Magdeburg; the plants

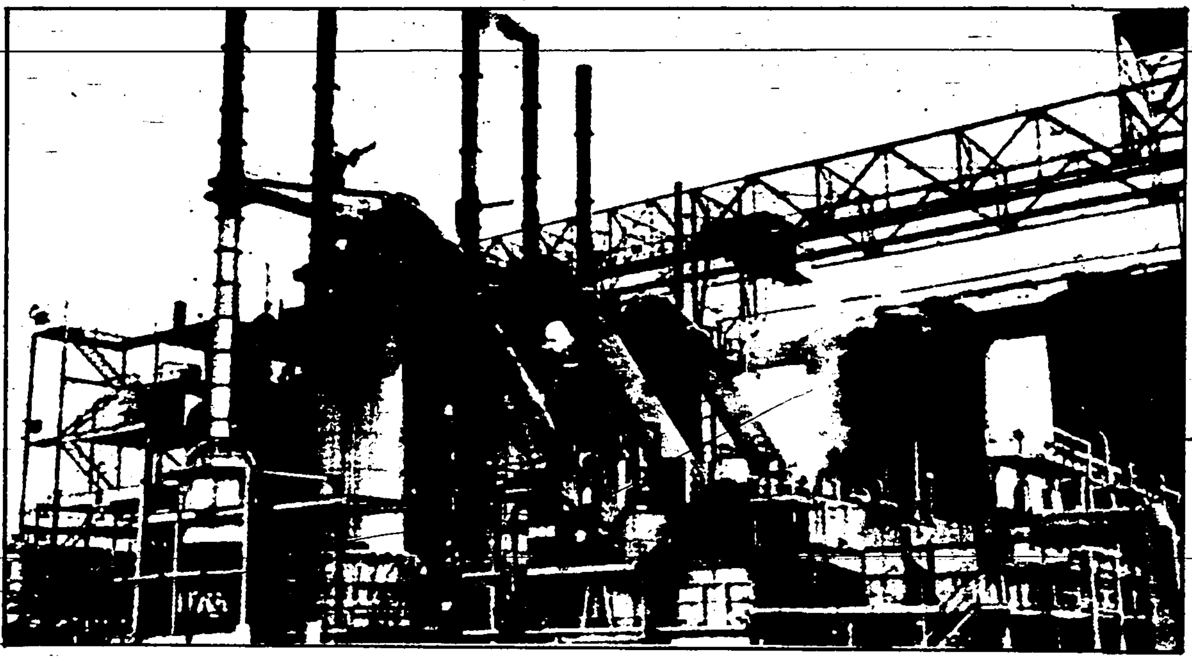


Fig. I General View of a BRABAG Plant
(believed to be Zeitz; from Oel u. Kohle)

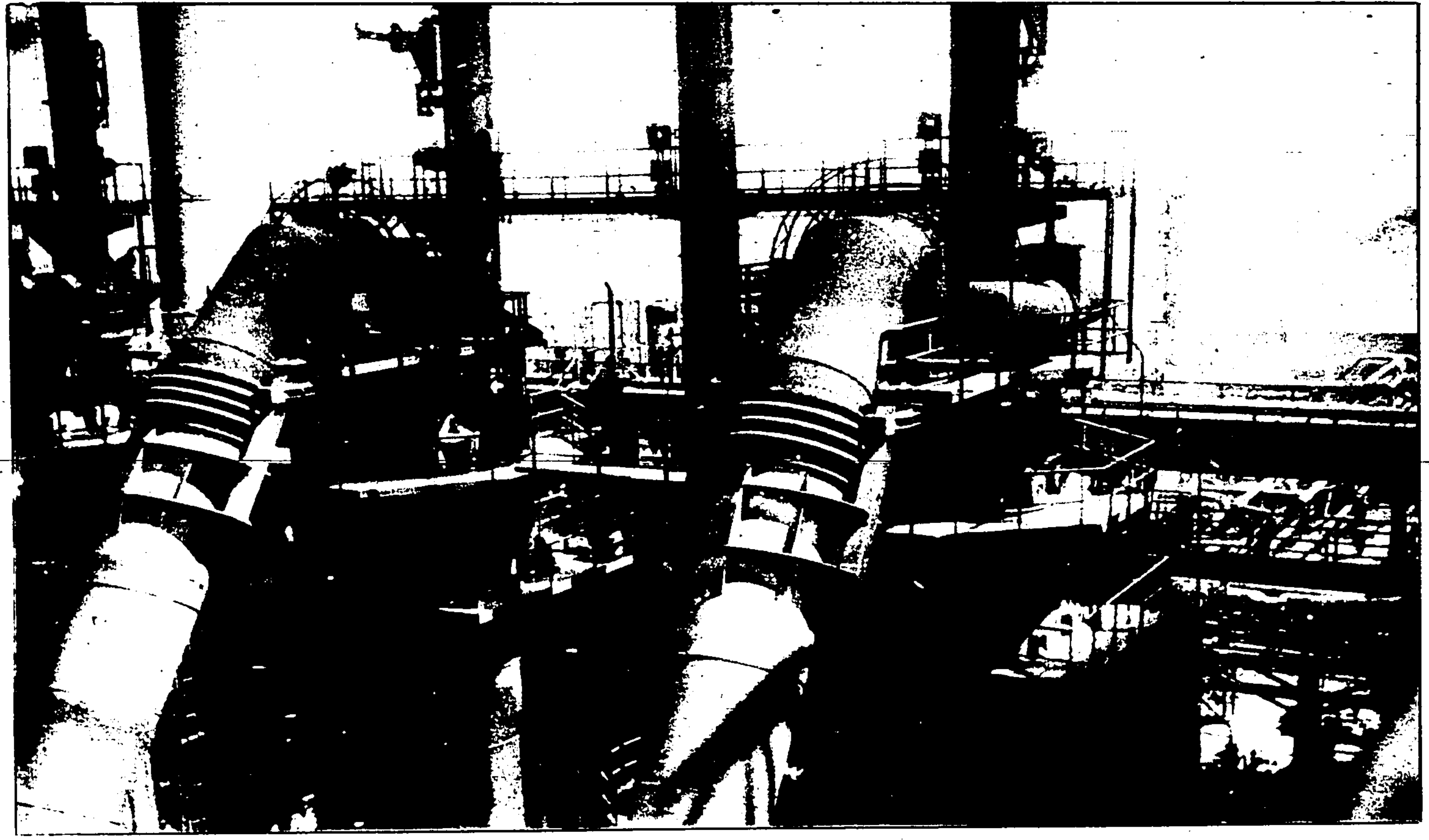


Fig. 2 View of Two Generators at Zeitz
(photographed by C.I.O.S. investigators)

Fig. 3 View of Waste Heat Boilers and Multicyclone at Zeitz
(photographed by C.I.O.S. investigators)

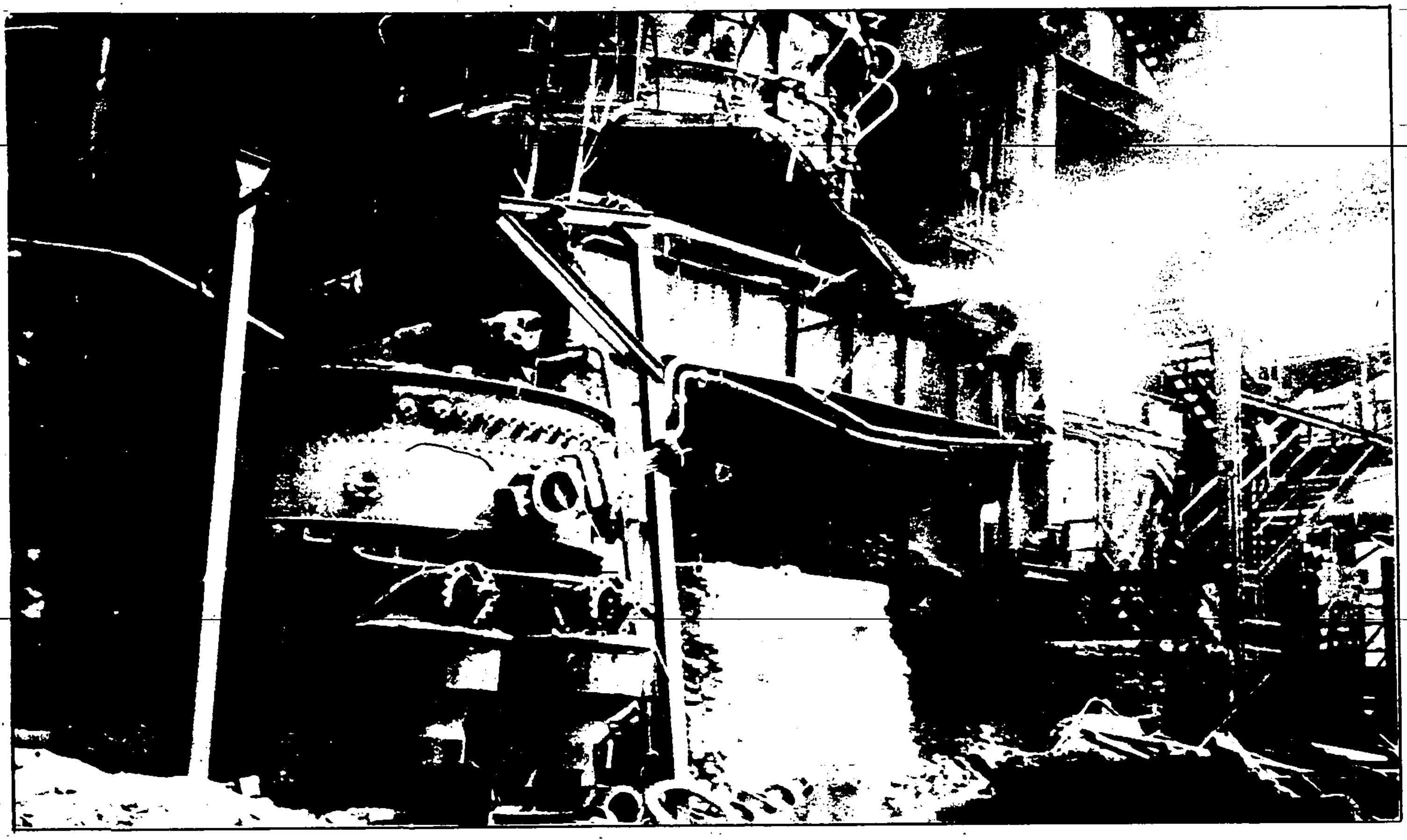


Fig. 4 View of Lower Portions of Generator at Böhlen

(photographed by C.I.O.S. investigators)

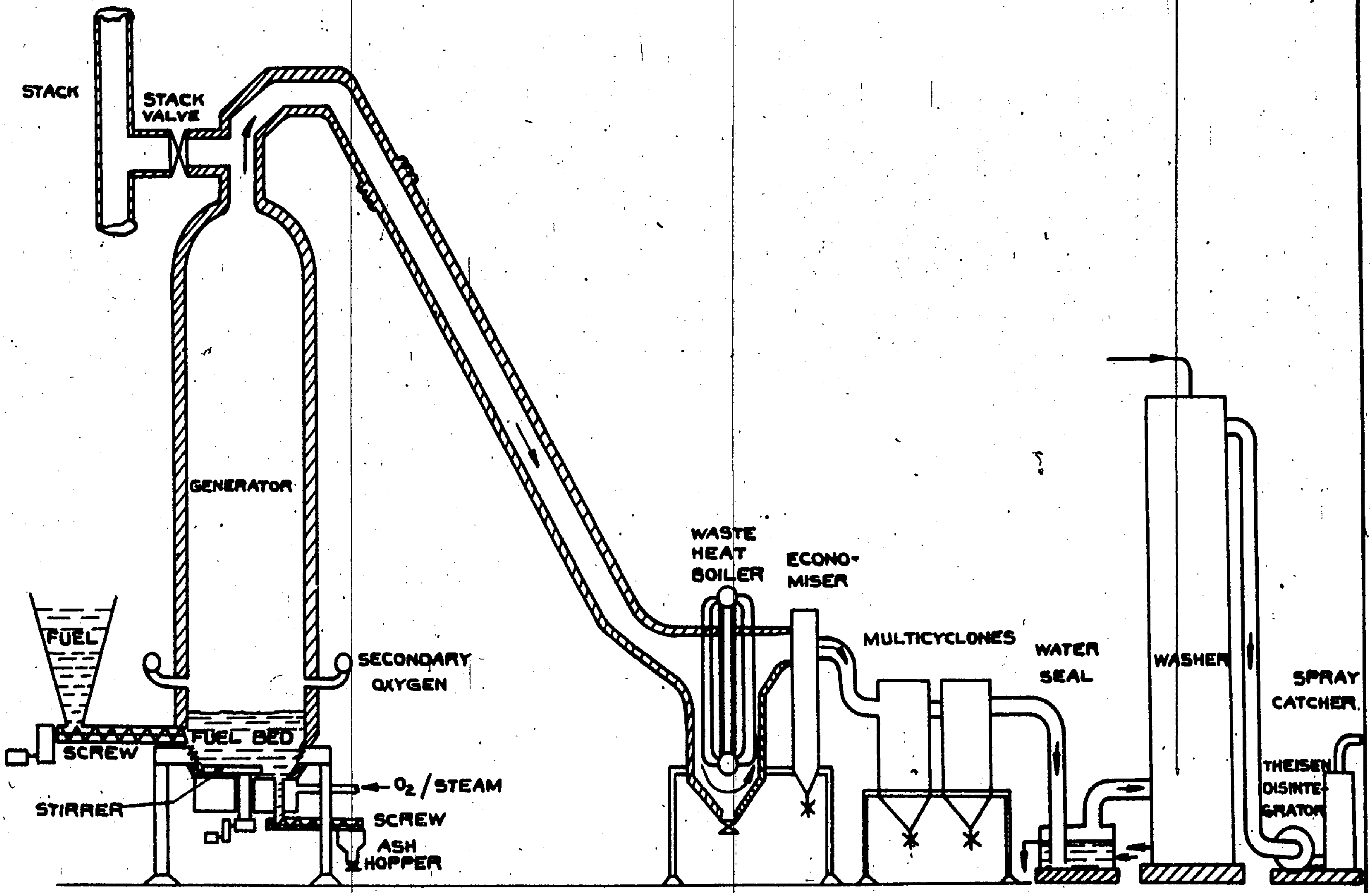
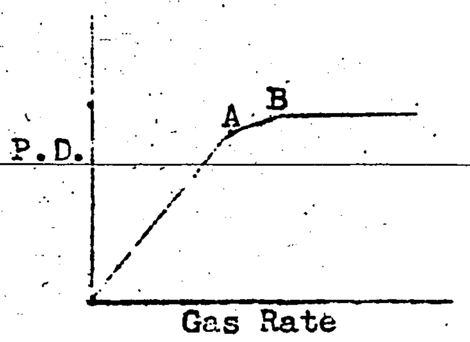


FIG.5. SKETCH OF TYPICAL INSTALLATION

were designed by Bamag under license from I.G., who, of course, were also involved. These were put into operation in 1938-9. After the outbreak of war a further hydrogenation plant was started at Brüx, in N.Czechoslovakia, and again the Winkler process was chosen and the plant was started up in 1942(?).

CHARACTERISTICS OF "BOILING" BEDS



The accompanying diagram illustrates a typical pressure drop-gas rate relationship of a bed of particulate fuel. At low rates the pressure drop increases almost linearly with increase in gas rate until a point A is reached, where pressure drop x area = mass of fuel. There is then a tendency for the bed to be lifted bodily like a piston, but at first the bed expands and the voidage increases; then at B the bed begins to "boil". From B onwards the pressure drop remains constant as the gas rate is increased. The particles are constantly in motion and as the voidage increases so the depth of bed increases. The bed becomes increasingly rarified as the gas rate increases, until eventually when the gas velocity reaches the free-falling speed of the particles (at least with a bed of uniformly-sized particles), the whole bed is carried away, i.e. true entrainment occurs.

The gas rates corresponding to points A and B are a function of particle size and density, moving to the right as these are increased. For the same fuel and air rate the pressure drop across the bed is proportional to the depth of bed and is in fact equal to the "hydrostatic" head, i.e. mass of fuel/unit area.

DESCRIPTION OF THE PROCESS

Whilst the principle of the use of a boiling bed remains in all plants, the details have changed considerably with the various installations. As these changes have not been made without reason, it is instructive to follow them.

The gasification chamber itself has always been a brick-lined vessel, of greater height than width, with the fuel bed contained in the lower part. It has apparently never been necessary to replace the brick lining by a water jacket, and this is understandable, because the temperatures are not too high, probably never above 1,050°C. The blast always enters through the base, but usually a portion is fed in through tuyères above the fuel bed. The hot gases are led off at the top, sometimes through waste heat boilers, and then dedusted in some manner before final cooling.

Photographs and sketches of various installations are shown in Figs. 1 to 7.

The various stages will now be considered in detail, with particular reference to the manufacture of water gas with a blast of steam and oxygen only, with no air.

OXYGEN PLANTS

These are adequately described elsewhere (Ref.8). All the plants installed since 1929 have been Linde-Fränkl units, each of capacity 2,000 to 4,000 M3/hr oxygen (97 to 99%).

FUEL SIZING AND STORAGE

Brown coal and grude are very reactive and are liable to spontaneous combustion, so that special care is necessary in handling. The fuel is milled and screened in inert atmospheres of nitrogen or CO_2, containing limited amounts of oxygen, and may be transported pneumatically by inert gases; the bunkers are likewise kept under inert gas pressure. The size range of the milled and screened fuel varies from plant to plant and a summary is given in TablesIII and IV. In general it can be said that the size range is between 0.1 and 10 mms., with the bulk in the range 0.2 to 4 mms. According to Ref.11 it is very desirable to keep out material $<$ 0.5 mms, since such material is liable to be blown through the bed unchanged. On the other hand, if the fuel is too large it tends to sink down to the grate, where the heat of combustion cannot be properly exchanged with the surrounding fuel, as is the case within the bed; consequently such larger pieces become overheated and clinkering results.

At Zeitz the milled grude is stored under nitrogen in two large bunkers each 7 m. diameter and 8 m. high, plus a conical base; the total storage volume is thus about 700 M3. In addition each generator has its own intermediate storage of about 125 M3.

At Böhlen the grude is blown over pneumatically with CO_2 from the power plant; the CO_2 from the bunkers is dedusted in Beth filters and cyclones.

PROPERTIES OF FUEL

Where dry brown coal is used the moisture content is normally reduced to about 8%, whilst grude usually has 2 to 3% moisture. Since during carbonisation brown coal loses water, tar and other volatile matter, the ash content of grude (22 to 28%) must always be greater than that (14 to 20%) of the dry brown coal, from which it is made. The calorific value of dry brown coal is about 5,200 T.cals/T net, and that of grude is between 5,400 and 5,800 T.cals/T net. The sulphur content is variable and this has a direct effect on the H_2S content of water gas.

In evaluating the Winkler process and especially when comparing with other processes in other countries, it is essential to remember (a) that dry brown coal and grude are both very reactive fuels, reacting with steam and CO_2 very quickly at comparatively low

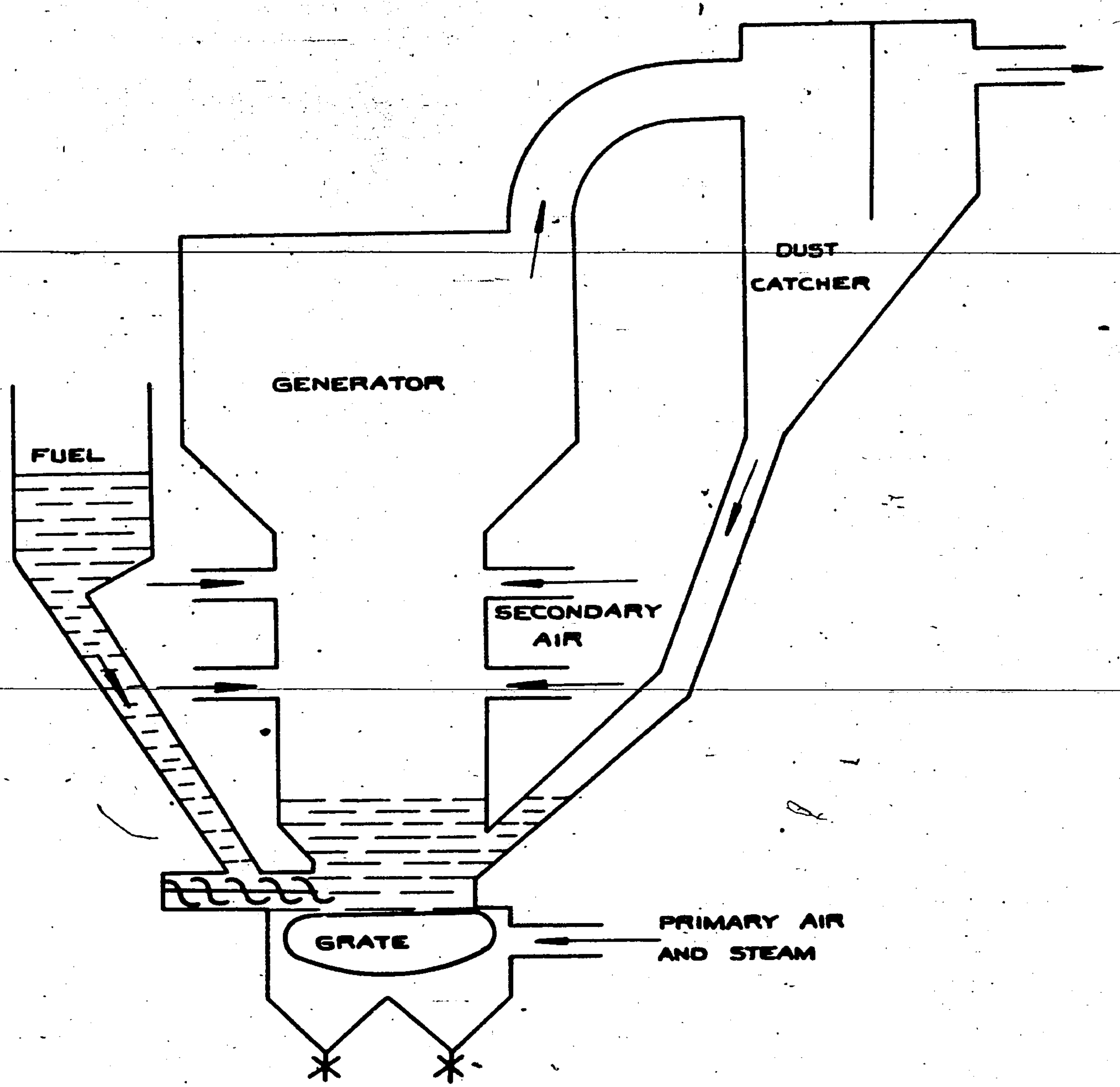


FIG. 6. ARRANGEMENT OF EARLY GENERATOR WITH TRAVELLING GRATE

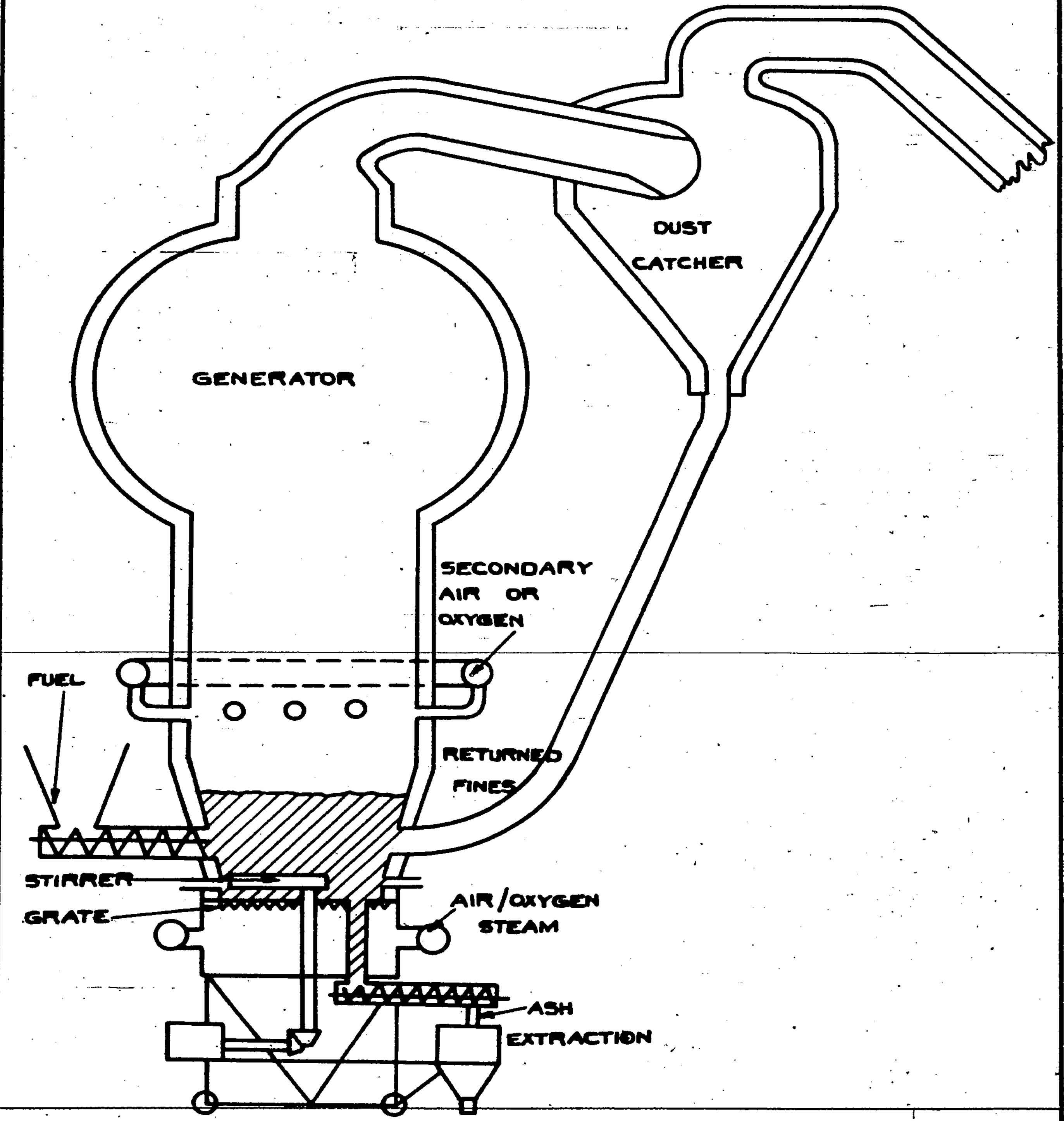


FIG. 7. ARRANGEMENT OF EARLY LEUNA GENERATOR WITH BULBOUS TOP

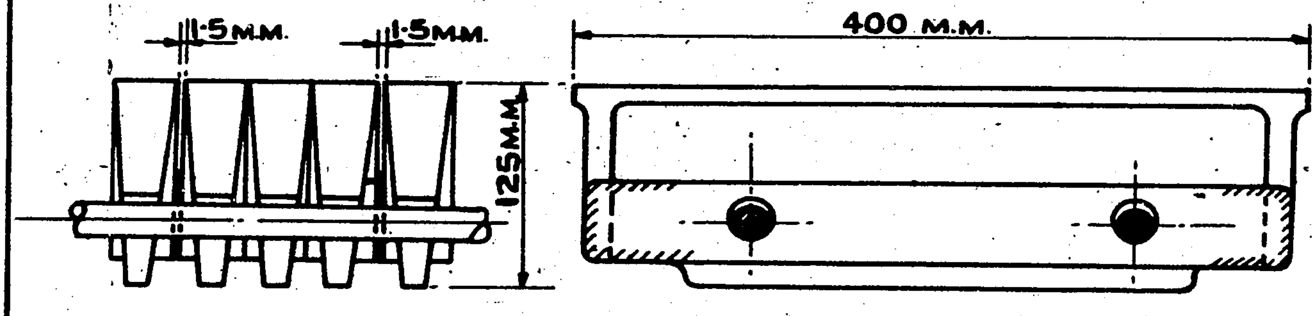


FIG. 8. SKETCH OF GRATE BARS

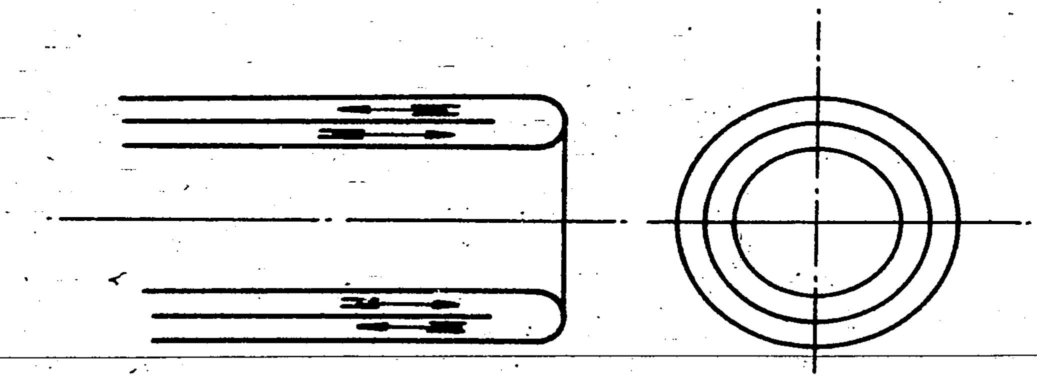


FIG. 10A. DESIGN OF WATER COOLED NOZZLE

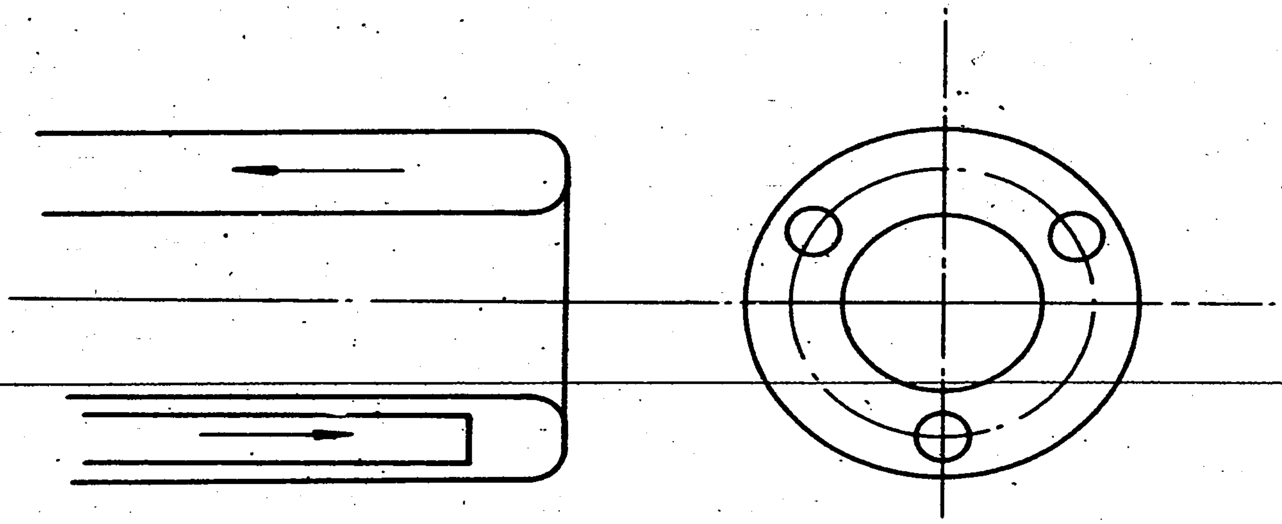
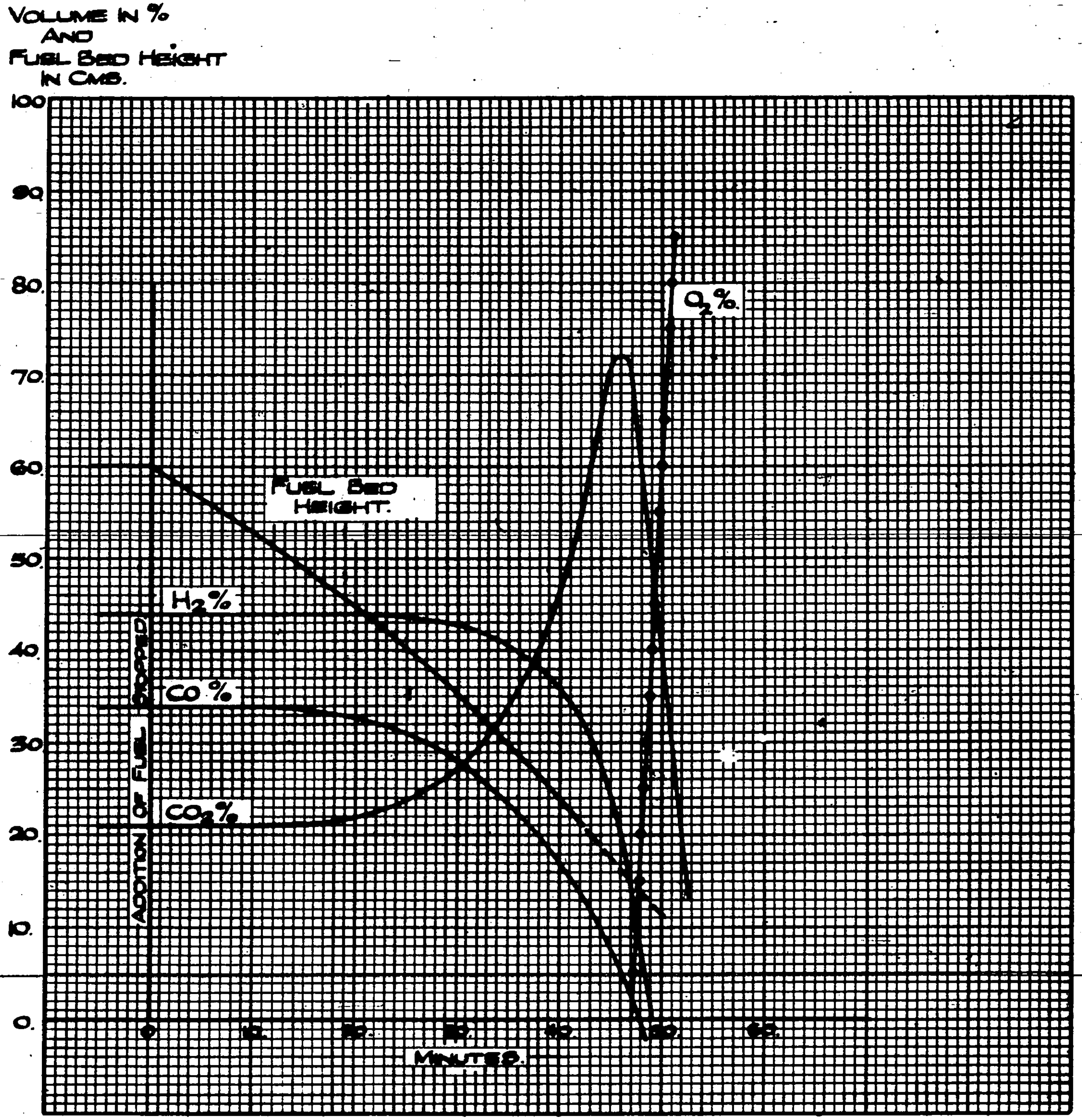


FIG. 10B. DESIGN OF WATER COOLED NOZZLE

FIG. 9.

CHANGE OF GAS COMPOSITION WITH AN OXYGEN BREAK-THROUGH.



temperatures (800° to 900°C), and (b) that dry brown coal and grude are both comparatively cheap fuels, so that a good carbon utilization efficiency is not so important, especially if any ungasified dust can be recovered and burnt under boilers at something approaching their full calorific value. Typical prices of raw brown coal are 1 to 3 RM/T at the mine, and about 4 to 9 RM/T for dry brown coal, after drying in neighbouring plants. Although the price of grude, sold as domestic and industrial fuel, might be around 20 RM/T, nevertheless in a combined factory, where large quantities of brown coal tar are required but where markets for grude are limited, so that grude has to be used as a boiler fuel, then the value of marginal grude is that of the cheapest alternative fuel, i.e. dry brown coal, at say 4 to 9 RM/T, and so grude can be charged to Winkler generators at such prices.

GRATES AND GENERATOR BASE

Fuel is introduced into the fire-bed by water-jacketed screw conveyors; there are three such screw conveyors on each Brabag generator. As far as we know fuel is nowhere introduced pneumatically, e.g. entrained with N_2 or CO_2, although there should be no difficulty about this. However, at some plants a current of CO_2 passes through the conveyor, to prevent steam passing backwards, to cause condensation and chokes. The feed rate is controlled either by the speed of the screw conveyor or else by the speed of the star-feeder, feeding into the screw-conveyor. The fuel enters the fuel-bed at points on the same side of the generator, about half-way up the fuel-bed; distribution of fuel within the fuel bed is left to the "boiling" action.

The development of the grate is interesting. The earlier Leuna generators had travelling chain grates (see Fig.6 and Ref.5). Since there is very little segregation of ash in the boiling bed, except as lumps of clinker, this arrangement must have caused a good deal of unburnt fuel to be drawn away at the base. Very soon stationary grates were used, originally made up of water-cooled beams, but the water-cooling was soon found to be unnecessary and even undesirable; these were replaced by fire-brick, but these were readily damaged by slag adhesion and mechanically by the stirrer. The present design of stationary grate appears to vary from plant to plant and because of this our information may be confused. At Leuna (Ref.10) the grate is made up of wedge-shaped cast iron bricks, 400 mms.long, 125 mms.deep, 35 mms.wide; these are packed in threes with 1.5 mms. spaces left between each set of three (see Fig.8). The grates at Böhlen are similar; Ref.2 says the bricks are about 300 mms.long, 50 mms.wide at the top, 25 mms.wide at the bottom; they are packed in threes, with very fine openings (1.5 mms or less) between every three. At Zeitz (Ref.3) similar bricks were used, about 75 mms. wide at the top, but these may have been made of fire-brick.

Above this grate rotates a water-cooled stirrer arm, driven from below via a shaft, passing up through the grate; at Zeitz this

is of square-section, about 6" x 6". This acts as a scraper, rather than as a stirrer, and its chief function is to sweep the larger pieces of clinker towards one or two holes in the grate, through which they can be withdrawn by means of two water-cooled screw conveyors. The speed of this stirrer arm is about 1 to 2 r.p.m. The grate-ash is dumped into a water channel at Böhlen and sluiced away, but at Zeitz it is collected in two small hoppers and emptied periodically by hand into small bogeys on rails. Such ash may be anything from 2 mms. to 100 mms. in size; it contains from 10 to 20% of the ash fed to the generator and contains from 30 to 50% carbon.

The pre-mixed blast of oxygen and steam enters the wind-box under the grate and passes up through the grate, thereby helping to keep it cool. Such a grate gives very good initial distribution of oxygen and steam.

The whole grate assembly, i.e. grate, stirrer mechanism, wind-box and ash conveyors, can be disconnected from the generator, dropped on to bogeys and wheeled away for maintenance, whilst a spare grate is inserted in its place. This greatly reduces time off for maintenance. A grate on its bogey can be seen in Fig.4.

Originally grates caused a good deal of trouble, due to slag-attack, burning out and leaking stirrer arm, but these have now all been largely overcome. Good pre-mixing of oxygen and steam reduced the troubles and the design improvements, as described above, with more careful operation, especially in avoiding excessive fuel bed temperatures, have done the rest. As an example of earlier troubles at Leuna in 1933 we quote Ref.6 p.20 : "Severe slagging at first caused a good deal of maintenance. The grate of No.1 generator was renewed at least three times between June and October 1933; in addition it underwent 5 major repairs". Again in 1935 at Leuna (Ref.10) No.3 generator was shut down for 5 weeks in January, whilst a new grate was installed, but in October the same year it was shut down for 3 weeks for grate repairs; No.4 generator was shut down for over 6 weeks in January for repairs to grate and stirrer and again for 3 weeks in April for repairs to stirrer; a new grate was installed in No.5 generator in March, but the generator was shut down for 11 days at the end of the same month for repairs to the stirrer. [The length of time taken for these repairs suggests that at that time the grates could not be readily removed and replaced.] It was in 1935 that Leuna changed over to the use of cast-iron bricks, with very satisfactory results.

At Zeitz it was claimed that the generators could be run for a week or two without any ash removal at the base; the ash or clinker merely built up at the base, but did not hinder gas-making.

An important improvement has been made recently at Leuna, in the development of a grateless generator. Although former troubles with grate and stirrer had been much reduced some still remained, notably at Leuna, due to relatively poor quality of fuel and to burning out of the stirrer; the grate and stirrer were also by no means cheap items of plant. This was the incentive for trying out a grateless type of generator. Unfortunately there are not many details of this development available, but it does appear to have been a success. It was tried out first on the smaller No.1 generator at Leuna in 1941 and the large No.5 generator was similarly modified in 1944. One of the generators built at Brüx in 1942(?) is also of the grateless type. The base of the generator is made conical and the oxygen and steam mixture is introduced through tuyeres in the side of this cone. One investigator reports having seen the base of one such generator at Leuna and judging by the number of patches the position of these tuyeres had been altered from time to time; it is believed that the final positions are at a number of points halfway up the sides of the cone. There is no stirrer, but two screw conveyors are fitted to the base, and can be run intermittently for removal of ash and clinker. Leuna claims (Ref.6) that the grateless generator uses 10% less oxygen and 10% less fuel than the generator with grate, but gives no explanation. The distribution of oxygen and steam in the fuel bed cannot be so good with the grateless type, but this would by no means necessarily adversely affect the efficiencies. Fuel can be saved if the ungasified dust carried away can be reduced or if less oxygen has to be introduced above the fuel bed, since this tends to burn CO and H_2 to CO_2 and H_2O, as well as burn the dust. It would be interesting to have more details of this development but unfortunately tentative explanations can be regarded only as speculative through lack of information.

THE FUEL BED

The depth of fuel in the boiling bed is kept at 1 to 1.5 m. It is controlled primarily by the rate of addition of fresh fuel, the control being by hand, the operator working to the pressure differential across the fire-bed, which is proportional to the depth of fuel. There are advantages in working with thicker beds but the additional pressure drop is an objection; with too thin a fuel bed there is too much danger of losing the level, with consequent oxygen breakthrough.

The temperature is maintained as high as possible, in order to keep down the CO_2 in water gas, but in practice a margin must always be maintained between the bed temperature and the softening point of ash. In general the softening point of ash derived from brown coal is low and this limits the bed temperature to about 900° to 1,000°. At Zeitz they claimed to be able to run to within 20°C of the ash softening point. The ash softening point varies from time to time, even when operating on coal from the same mine, and a practical way of ensuring the correct bed temperature is to examine the ash; if this is dusty the temperature can be raised but if it shows signs of clinker formation the temperature must be dropped. The temperature of the fuel bed is measured by sheathed thermocouples inserted through

the walls; in Ref.10, however, a test is described in which a bare couple was fixed to the stirrer arm and this showed a temperature 50°C greater than the normal couples.

Actual temperature control is effected by altering the blast composition; more oxygen gives higher temperatures and more steam gives lower temperatures.

In practice little trouble is experienced at any plant through clinker or slag formation, either as the result of large lumps collecting on the grate or as material building up on the sides of the generator. Sometimes some slag accumulates above the tuyeres, used to introduce oxygen above the fuel bed.

Ref.10 describes the formation of "bird - nests" on the walls and roof of the Winkler generator making power gas in 1935. Using dry brown coal from the Elise mine, with a fuel bed temperature of 950° and an exit temperature of 1,000°C, conglomerates of fly-ash, fused together, collected on the walls and roof; they were low in carbon content and somewhat sintered. When they became large enough they broke away and fell into the fuel bed; they were, however, so soft that they were easily broken up by the stirrer arm and the ash screw conveyors, and so their formation was not troublesome.

Failure to maintain a proper fuel bed level might be disastrous. According to Ref.6 on two or three occasions the level was lost, so that oxygen broke through the fuel bed and appeared in the exit gas; this led to serious explosions in subsequent portions of the plant. Fig.9, taken from Ref.6, shows the course of an oxygen break-through, as followed by analyses, as the fuel bed burnt away after addition of fresh fuel had been stopped. There is a rapid rise in the CO_2 content of the exit gases, just before free O_2 appears, and this interval is made use of to warn the operator; a sample of the exit gases is burnt continuously in a small flame placed in front of a photo-electric cell; when the CO_2 rises sufficiently the flame is extinguished and an alarm is sounded; the operator then immediately shuts off the oxygen supply.

Great care must also be taken to see that the steam rate does not fall below the required quantity. As an additional safeguard, an independent supply of steam is connected to the wind-box below the grate, which in emergency may be opened up.

COMPOSITION OF THE BLAST

At Leuna great stress (Ref.6) is laid on the necessity of obtaining adequate mixing between oxygen and steam, and it is recommended that this be done at least 10 to 15 m. from the generator, preferably with the incorporation of a restriction plate or bend. Failure to achieve good mixing leads to uneven heating and clinker formation in the fuel bed.

The % age of O_2 in the blast varies from 20 to 50%. The lower figures are used at Böhlen and Zeitz, and 40 to 50% at Leuna. This has a direct effect on the gas composition, the $H_2/(CO + 2\ CO_2)$ ratio being 0.57 to 0.59 at Böhlen and Zeitz and only 0.51 at Leuna; similarly the ratios $(H_2 + CO)/CO_2$ are about 3.0 and 3.8 respectively. This must mean that the Leuna generators are run at a higher temperature, but additional information is inadequate to prove or disprove this.

SECONDARY OXYGEN

The so-called "Uberwind" or secondary oxygen, added above the fuel bed, fulfils two functions: it is intended to burn off some of the finely divided fuel blown out of the bed and it is also intended to raise the temperature of the gases, so that further cracking of tar or hydrocarbons may occur and also so that steam and CO_2 may react with some of the finely divided fuel. Probably some oxygen reacts with water gas already formed, but there is no doubt that the net effect is beneficial. The necessity for decomposing tar and hydrocarbons is of course more important when using dry brown coal than when using grude.

The fraction of the total oxygen added above the fuel-bed varies from 33% at Leuna (at any rate with dry brown coal), to not more than 20% at Böhlen, down to 10% at Zeitz. It is probably significant that the dust content of the exit gases is least at Leuna and greatest at Zeitz. Nevertheless owing to the cheapness of fuel it is apparently still economic for Zeitz to blow over the dust and recover it for use as a boiler fuel, and use the oxygen to better purpose in the main blast.

Care must be taken to avoid too high temperatures above the fuel bed, otherwise liquid slag will collect on the walls; for this reason it is usual to mix steam with the oxygen, although often in smaller proportions than in the main blast.

The volume of the generator above the fuel bed is important, since it governs the time available for the completing the reactions of steam and CO_2 with carbon and for completing cracking of hydrocarbons and tar. This volume is some 15 times that of the fuel bed itself, giving an average actual contact time for the gas of the order of 7 seconds in passing through it.

The original Leuna generators had the upper portion of the generator enlarged to a bulb and some of these generators still exist. All modern generators, however, are straight-sided but heightened to give the same volume as the older design. It has been said that this change was made solely on the grounds of construction costs, although Dr Schairer at Zeitz stated that turbulence near the periphery of the bulbous portion led to uneven times of contact at different points of the cross-section.

At Zeitz the oxygen-steam mixture is introduced 2 m. above the fuel bed through twelve water-cooled nozzles or tuyeres; these end flush with the inside wall and point exactly towards the centre of the generator. It was found by observation through sight-holes, that a gas velocity of 8 m. per sec. through the nozzles was the optimum; at higher velocities the flames tended to strike and damage the far-side wall, whilst at lower velocities the flames tended to lick upwards on to the brickwork lining above the nozzles. In practice some clinker does build up on the wall above the nozzles, but it is of little consequence. In Ref.11 it is stated that at Böhlen the secondary oxygen is added at a point only 0.5 m. above the point of addition of fuel, which itself is only 0.7 m. above the grate; if the depth of fuel is 1.0 to 1.5 m., this, if true, means that the secondary oxygen is added at a point only just above or even at a point just below the fuel bed level.

According to Ref.10 the water-cooled nozzles at Leuna were very satisfactory in 1935. Originally they had been cooled with river water, but this led to deposits forming at the ends of the water passages, but from 1934 they were cooled with circulating condensate. The design at that time is shown in Fig.10A; they were in effect built up from three concentric tubes; mention is also made of an experimental design, shown in Fig.10B, to be tried out in 1936.

The temperature in the space above the fuel bed is quoted for various installations as between 900° and 1,000°C; this temperature is partly a function of the ash softening point, but in general it lies above the temperature in the fuel bed. There is also a fall in temperature towards the top of the generator, due to the endothermic reactions occurring.

GENERATOR BRICKWORK

The conditions as regard temperature are not very arduous and as long as attention is paid to gas velocities very little trouble is experienced with brickwork, either that lining the generator or in the rest of the plant.

WASTE HEAT RECOVERY

As the exit gases leave the generator at 900° to 1,000°C it is obviously economic to recover this heat as steam and in all plants there is an elaborate installation of high pressure boilers, superheaters and feed-water economisers, reducing the temperature to 200° to 300°C.

Gases pass from the top of the generator down to the top of the boiler through a long brick-lined pipe; at Böhlen this has an I.D. of 1.4 m., which corresponds with an actual gas velocity of about 19 m/sec; these pipes are characteristic features of Winkler generators, and are readily noticeable in Figs.1, 2 and 3.

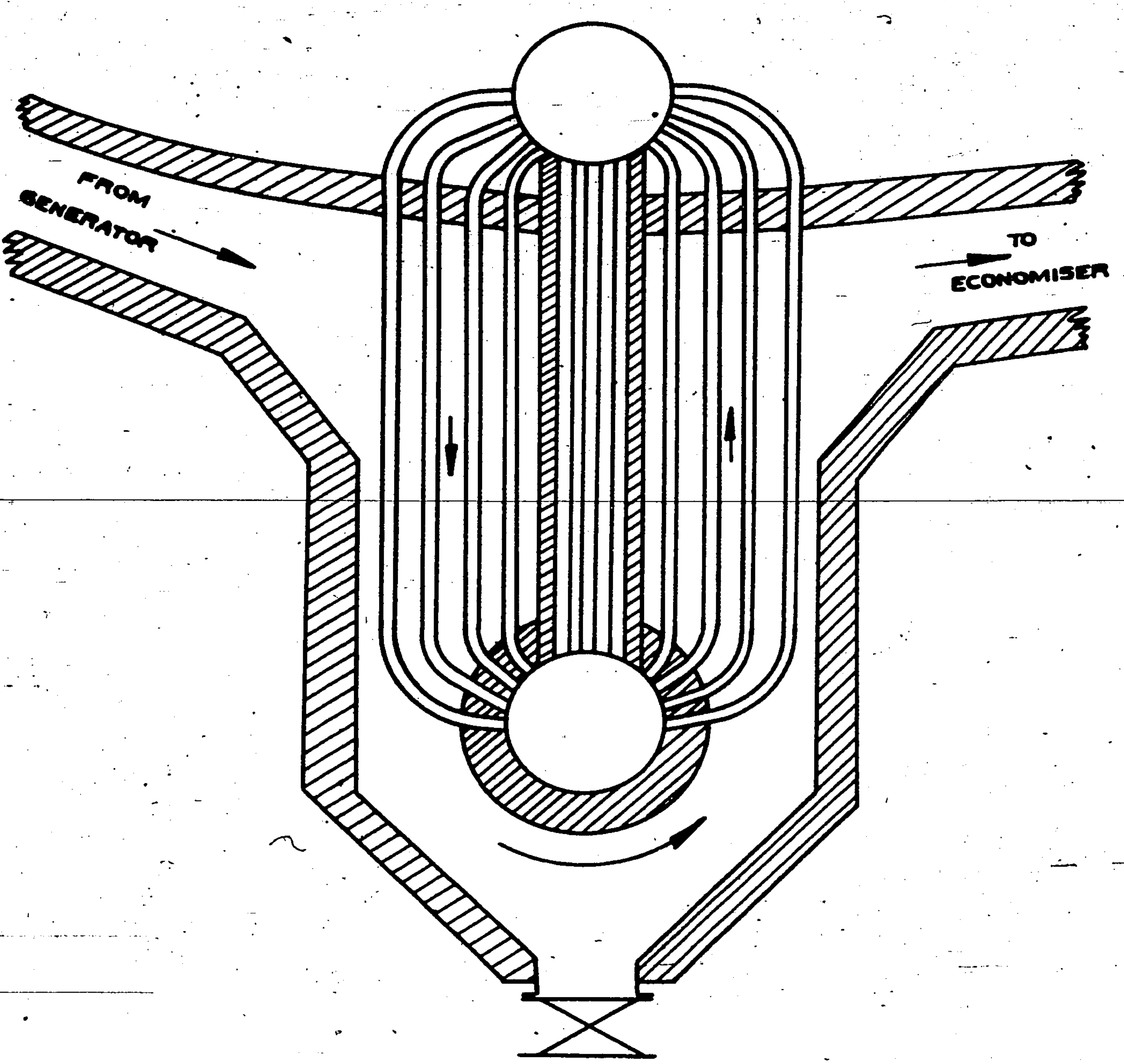


FIG. 11. TYPICAL ARRANGEMENT OF WASTE HEAT BOILER

At Böhlen and Zeitz two-drum water-tube boilers are used, raising superheated steam at about 18 ats (265 lb/sq.in.g.). A typical arrangement is shown in Fig.11. The lower drum is insulated and hangs in the gas space. Two baffle walls from drum to drum protect the cold down-flow tubes and also force the gases to take a U-shaped path. The gas leaves the boiler at about 400°C and passes through an economiser, pre-heating the feed-water to the boilers and being further cooled in the process. Dust builds up in the bottom of both the boiler and economiser, but this is not removed except during overhauls; after a certain amount has accumulated the gas velocities become high enough to prevent any more settling out. According to Ref.10 Leuna in 1935 had No.3 generator fitted with a 17 ats. boiler and No.4 generator with a 55 ats. boiler (800 lb/sq.in.g) each capable of raising 40 T/hr steam; some trouble was experienced in 1935 due to the sulphur-content of the gas and the high gas temperature, and on the 800 lb boiler, where they were attempting to run at a steam temperature of 460°C. the Sicromal 8 superheater tubes had to be replaced by zinc-coated Cr-Mo-steel, with better results.

Some trouble is experienced with erosion of tubes, and special attention must be paid at all points to gas velocities, which should be kept below 8 m./sec; velocities of 30 to 40 m/sec. cause serious erosion. In general, however, these troubles only occur if the generator output is so much increased that the gas velocities exceed the designed values; in most plants the waste heat boilers, as installed, were the limitation to output, due to this.

At all plants the weight of steam raised by the waste heat boilers is at least equal to the weight of steam introduced into the generator, but of course there is a net credit for steam, because the steam introduced into the generator is at low pressure, 10 to 25 lb/sq.in.g., whereas the steam raised is at elevated pressure and can be used as a source of power before being exhausted as low pressure steam.

DEDUSTING OF THE GAS

This is a most important aspect of the Winkler generator. An appreciable proportion (18 to 50%) of the solid material fed into the generator is carried away as a finely-divided dust with the exit gases, and adequate plant must be installed to separate out the dust. If possible the dust so recovered should be able to find some useful outlet, e.g. as a boiler fuel, the credit so obtained helping to offset the inefficiency of utilizing fuel in the generator and the cost of the equipment required for dedusting; according to Ref.11 Zeitz received a credit of RM.5.-/T for recovered dust.

The older Leuna generators had single cyclone dust-catchers installed between the generator and waste heat boiler and the recovered fines were fed straight back into the fuel bed; these single cyclones, however, were relatively inefficient and caused excessive quantities of dust to appear at the water seals.

In all later installations there is no attempt to remove dust from the gas before it has passed through the waste heat boilers: then when it has been cooled to 200° or 300°C it is treated by multicyclones. At Zeitz the gas passes in two parallel streams, each stream passing through two sets of multicyclones in series; the two sets of multicyclones in one stream are larger than those in the other, the object being to give a choice to suit the particular output; in practice hand operation of the necessary valves is found to be cumbersome and a nuisance, although this problem appears to be readily soluble by using hydraulically-operated valves. At Magdeburg electrostatic precipitators were originally used instead of multicyclones, but one day, due to faulty operation free-oxygen appeared in water gas and an explosion occurred; they now also use multicyclones. At Leuna electrostatic precipitators were also tried in the early days, but the dust content was so great that it was difficult to maintain the potential difference under such circumstances.

After the multicyclones the gases bubble through a simple water seal, which is really a safety device to prevent gas passing back from the main into a generator, which is not producing, but it also removes a certain amount of dust from the gas and cools and saturates it with water vapour at about 80° to 85°C; water has to be passed through this seal continuously, to cover the evaporation of water and to flush away the dust removed. The gas from all generators passes into a common main and thence through direct contact water scrubbers, which both cool and de-dust the gas and remove some H_2S; it is believed these are empty towers, fed with an excess of sprayed water. Finally the gas passes through Theison disintegrators, for final dedusting, and is then termed raw water gas, ready for H_2S removal and subsequent working up.

Water from the seals, coolers and disintegrators contains dust and H_2S and must be treated before being discharged to river or recirculated. At Zeitz the water is passed through two towers in series, with a common spare, all packed with wooden grids; CO_2 is blown through the first tower, to remove the bulk of the H_2S, which is subsequently treated in a Claus kiln for conversion to elemental sulphur, since it cannot be blown to atmosphere; air is blown through the second tower to remove the remaining H_2S, which is blown to atmosphere. Finally the water is sent to large settling ponds, where the bulk of the dust settles out, and the relatively clean water can then be discharged to the river; at Zeitz the final water contains about 20 mg/l of suspended matter, said to be not greater than that of the river water itself.

Occasionally the settled dust is recovered from the settling pits, dried and used as boiler fuel, but in general it is uneconomic to do so. However, the much larger amount of dry dust recovered from the multicyclones is normally used as boiler fuel, although it too may be wetted down and pumped as a slurry to dumps. At Zeitz dust from the multicyclones is collected in special fixed containers; when full these are isolated by remote-operated valves, the dust is roused by admission of CO_2 through a stand-pipe and the dust pumped away pneumatically to the boiler plant, using CO_2 as carrier gas.

The amount of dust carried over with the gas varies greatly from plant to plant, and increases notably with the output. Naturally unless clinker forms all the ash in the incoming fuel must be blown overhead; the ash particles must be considerably smaller than the average size of fuel particles, which fixes the linear velocity of the blast. In practice 80 to 90% of the ash passes overhead. In addition finely divided unburnt fuel must appear above the fuel bed, since some fines ($<$ 0.2mms) are fed in with the fuel and some fines are continually being produced as the result of combustion and attrition of larger particles in the fuel bed; only a portion of such fines is gasified in the space above the fuel bed. With higher outputs larger particles can be carried away and so the amount of fines in the gas increases with output. Also since the quantity of carbon gasified/M3 gas is relatively constant, then for a given fuel of fixed ash content the carbon content of dust carried away must increase with the dust content of the gas.

Under normal running conditions the dust contents, in gms/N M^3 gas leaving the generator, is variously reported (see Table III), as between 100 and 360, being lowest at Leuna and highest at Zeitz, with carbon contents of from 30 to 55%. This represents between 10 and 40% of the carbon charged to the generator. At Zeitz the 1944 average analysis of dust recovered from the multicyclones was :

C	54.3%
H	0.9%
ash	43.8%
moisture	1.0%
net C.V.	5,000 T.cals/T

The multicyclones at Zeitz and Böhlen (Refs.3 and 11) are about 80% efficient, so that at Zeitz gas leaves the multicyclones with about 60 g/N M^3 dust. At Zeitz the dust content after the direct contact coolers is reduced to about 2 g/N M^3 and finally after the disintegrators to 3 to 4 mg/N M^3. This must be considered as a very creditable overall dedusting performance, even though there are four stages of dedusting. According to Ref.12 the dust content of gas after the disintegrators at Böhlen was 2 to 5 mg/N M^3 for a generator output of 16,000 M^3/hr, but the dedusting train was overloaded at 19,000 to 21,000 M^3/hr and the dust content at this point rose to 40 mg/N M^3.

The higher dust content of gas at Zeitz may be a function of the fuel used, but as stated before it may be significant that at Zeitz appreciably less oxygen is introduced above the fuel bed.

We have been unable to find any data concerning the size of the dust at any stage, except that Ref.1 states the dust to have a maximum size of 0.3 to 0.4 mm; this also fits the statement made in Ref.11, that any material < 0.5 mms is liable to be blown out of the fuel bed.

STARTING UP

For starting up a small auxiliary Winkler generator is used; one such is shared between two generators and hence two have to be provided for three generators. One can be seen at the extreme left of Fig.1. This has an I.D. of 1.0 to 1.5 m but is always open to atmosphere through a wide open stack (0.5 to 1.0 m I.D.). A fire is started with wood and briquettes, air being blown through, whilst grude is run in slowly from a hopper. When hot enough the glowing grude is run by gravity into the large generator, standing full of N_2 or CO_2, with the safety valve open to atmosphere. A good rate of air is then blown through the grude and the level is built up by feeding in fresh grude in the normal way. The bed must be kept "boiling", otherwise the heat of combustion is not properly dissipated and clinkering results. The blast is then changed over to a mixture of steam and oxygen and when the gas made is of sufficiently good quality the safety valve is closed and gas making proceeds.

The reason why the generator cannot be lit up directly lies in the difficulty of ensuring a uniform fire-bed right across the grate. If part of the fuel-bed became hot, whilst the rest remained cold, then producer gas and unchanged air might accumulate above the fire-bed and lead to an explosion. Dr Schairer at Zeitz thought the generators there were not too large to start up directly on grude, but it would be dangerous to start them up with briquettes or dry brown coal, since the presence of carbonisation gases would make explosions more likely. No dangerous explosion can occur in the auxiliary generator because it is always adequately vented to atmosphere.

The valves on the outlets from the small generator are in contact with hot grude for only a short time whilst it is flowing into the large generator; at other times they are protected by a layer of cold grude.

A Winkler generator can be on line from cold within an hour or two, although longer is taken if possible to avoid damage to brickwork.

INSTRUMENTS AND SAFETY DEVICES

Temperature control is very important, since it is desired to work at as high a temperature as possible, but not so high as to cause slagging or clinkering difficulties. The temperature in the space above the fuel bed and the temperature within the fuel bed are both recorded continuously and fitted with alarms.

Mention has already been made of differential pressure manometers in duplicate, to measure the fuel bed depth, and also of the pilot flame, burning a sample of the exit gases before a photo-electric cell, fitted with an alarm. In addition, of course, there are the usual flowmeters, temperature indicators and pressure gauges.

There are bursting discs at strategic points, notably on the wind-box, whilst a large stack can readily be opened to atmosphere through the medium of a hand-controlled electrically or hydraulically operated valve.

There is a non-return water safety valve on the oxygen line to prevent gas passing back along the oxygen main, should the oxygen pressure fail; steam added to the secondary oxygen also performs a similar function. The water seal on the gas leaving the multi-cyclones, as already mentioned, prevents gas flowing back from the common gas main into a generator, which is not producing.

Mention has also been made of the emergency supply of steam to the wind-box, to guard against failures of the normal steam supply.

All these instruments and controls, together with controls for operating the fuel and ash conveyors and adjustment of the oxygen and steam rates, etc., are brought to a single control cabin, which at Zeitz and Böhlen controls all three generators; it is located about 5 m above ground level, i.e. approximately on the level of the fuel bed.

PRESSURE SURVEY

The following is a pressure survey at Böhlen (see Refs.2, 11) and Zeitz (Ref.13).

		Böhlen	Zeitz
	Generator output, M^3/hr water gas	20,000	15,000
		cms water gauge	cms water gauge
Pressures	Steam to Generator	1,950	1,450
	Oxygen to generator	-	-
	Wind-box	220	120
	Above grate	200	-
	Above fuel-bed	150	80
	After W.H.B., multicyclone	100	-
	After water seal	80	-
	After coolers	50	25
	After disintegrators	-	20

Pressure Drops:-	cms water	cms water
Across grate	20	40
Across fuel bed	50*	
Across W.H.B., multicyclone	50	55
Across water seal	20	
Across coolers	30	

Bearing in mind the difference in output, these two sets of figures are in reasonable agreement.

OUTPUT

The output of a given generator is, of course, fundamentally a function of the shaft or grate area and is roughly proportional to it. There are, however, other important considerations. A Winkler generator has one of the highest outputs/M^2 shaft area of any gasification process, and when making water gas from grude is normally of the order of 1,200 to 2,000 M^3/hr/M^2, although even higher outputs have been claimed. These high outputs are due primarily to the active nature of the fuel and the intimacy of contact of fuel with oxygen and steam, as a result of the finely divided nature of the fuel and the "boiling" motion of the bed.

For a generator of given shaft area, however, the output can be altered usefully only within a comparatively limited range. Below a certain output the bed ceases to "boil", although what blast there is will still find its way through the fuel bed. This immediately removes the means whereby heat is evenly distributed throughout the fire-bed. Consequently the lower layers, which the blast meets first, become overheated and slagging results. On the other hand, as the blast rate increases larger and larger particles can be carried away from the fuel bed and ultimately, of course, the whole bed is carried away, i.e. the fuel becomes fully entrained with the gas; long before this point is reached, however, the dust content of the gas becomes so high that the carbon losses become serious, whilst dedusting of the gas presents a formidable problem; moreover if velocities much exceed designed values, serious erosion will occur, especially in the waste heat boilers. The practical limits of output for generators, such as those at Böhlen and Zeitz, appear to be between 9,000 and 25,000 or possibly 30,000 M^3/hr water gas. Although limited this range, of course, is ample to permit two generators to cover all likely loads.

Thus the Winkler generator is capable of appreciable overload for a short time, provided one is willing to countenance the decreased efficiency and increased maintenance.

The figure of 50 mms given in Ref.2 should obviously be 50 cms.

Ref.10 comments on the effect of output on the performance of a generator at Leuna in 1935, making water gas from dry brown coal. The higher output was maintained for only one day, because of overloading of the waste heat boiler, but the comparison with normal running is given as follows :-

	Normal	High Output
Output, M^3/hr. water gas	30,000	42,000
Gas Analysis: CO_2	21.8	15.7
H_2S	1.5	1.5
H_2	38.5	36.0
CO	35.3	44.4
CH_4	1.8	1.6
N_2	1.1	0.8
C in fuel, kg/1,000NM^3 H_2 + CO	452	455
98% O_2, NM^3/ -	366	316
Steam, kg/ -	407	250
% C utilization	*86.5%	80%
% steam decomposition	33%	27%
% C in fly dust	31%	35%
% C in ashes	35%	40%
Fly dust, kg/1,000 NM^3 H_2 + CO	148	211
Ashes, -/ -	41	44

*Allowance was made in the high output for CO_2 introduced with the fuel; if the same allowance is made for normal output, the C utilization is reduced to 82.8%.

The report remarks on the better gas composition (80.4% H_2 + CO, as against 73.8%) at the higher output, and especially the appreciable reduction in oxygen and steam consumption; the carbon consumption is about the same, although the C losses in dust and ash increase, as does the amount of dust blown over. The report goes on to say that theoretically one might expect better performance at lower outputs, since this gives longer times of contact in the space above the fuel bed, and the only tentative explanation given for the reversed findings is that, despite the fact that recorded temperatures were kept the same, the actual temperature in the fuel bed at the higher output was in fact different (and presumably higher) since the thermocouples measure the temperature only near the walls.

Whether the above is reliable evidence may be open to doubt. Other figures given in Refs.1 and 6, however, tend to bear out the lower-oxygen requirements at higher outputs.

SERVICE REQUIREMENTS : EFFICIENCIES AND BALANCES

Because of the varying conditions it is difficult to give typical figures for service requirements and efficiencies, but perhaps the following list of ranges encountered might be a useful summary of known achieved results :-

	Per 1000 NM^3 $H_2 + CO$		Per 1000 NM^3 $H_2 + CO$
Grude	650 to 1000kg.	Dry brown coal	800 to 860 kg
Carbon	420 to 630 kg	Carbon	445 to 460 kg.
Oxygen (98%)	305 to 335 NM^3	Oxygen (98%)	315 to 360 NM^3
Steam used	350 to 900 kgs.	Steam used	300 to 400 kgs.
Steam decomposition	30 to 35%	Steam decomposition	27 to 33%
Carbon utilization	88 to 57%	Carbon utilization	86 to 80%

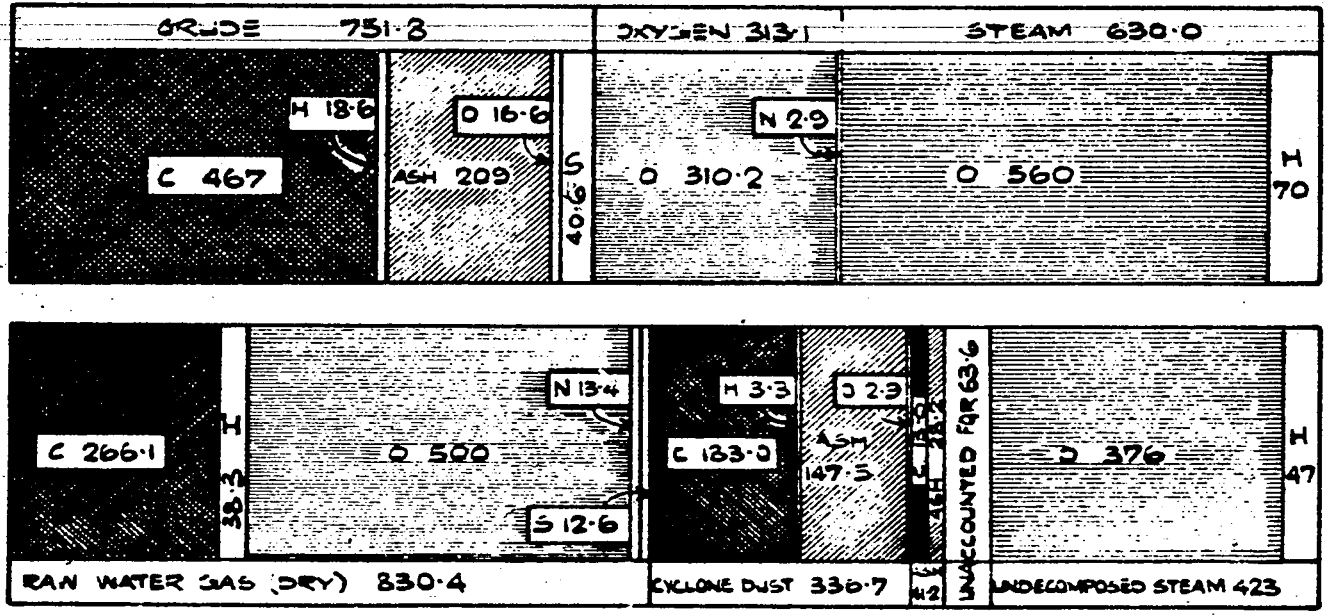
Data for various plants are collected together in Tables III (water gas from grude) and Table IV (water gas from dry brown coal) and these should be consulted for more detailed information, as far as it is available.

Material and heat balances will now be drawn up for one or two plants for which sufficient information is available.

MATERIAL BALANCE AT ZEITZ

Ref.14 gives a material balance for the whole of 1944, from which the following is taken.

INGOING MATERIAL IN KG/1000 NM^3 RAW WATER GAS.



OUTGOING MATERIAL

MATERIAL BALANCE AT ZEITZ.

NOTES

1. The actual balance given in Ref.14 shows 5.0 H and 300.6 H_2O as "unaccounted for". This obviously indicates an incorrect measurement of H_2O in or out, so in the above balance the measured steam in has been assumed to be correct and a hydrogen balance has been struck and hence the amount of undecomposed steam calculated. Comparing Ref.14 with the above chart, we then have :-

		Ref.14	Above Chart	
		kg/1000 NM^3	kg/1000 NM^3	% of component
"unaccounted for" :	C	4.9	4.9	1.05
	H	5.0	Nil (assumption)	
	Ash	33.3	33.3	15.9
	N	-	-10.5	
	S	28.0	28.0	
	H_2O	300.6	-	
	O	not given	7.9	0.9
Steam added + H_2O from grude		648.7	648.7	
Steam decomposed		345	222.3	
% steam decomposition		53%	34.4%	

2. The low value of "unaccounted for" oxygen, when a perfect H balance is assumed, indicates a satisfactory overall balance. The negative value of "unaccounted for" nitrogen does not arise entirely through neglecting N in grude: for balance 1.4% N in grude would be required, and it is unlikely to be so high. The high amount of "unaccounted for" S arises through neglecting the S content of dust and ashes.

3. The "unaccounted for" C and ash are presumably lost as dust passing the cyclones. Assuming the "unaccounted for" ash of 33.3 is correct and that dust has the analysis of cyclone dust, then this indicates that the multicyclones have an efficiency of $\frac{147.5}{147.5 + 33.3}$ or 81.6%, which is in good agreement with other information.

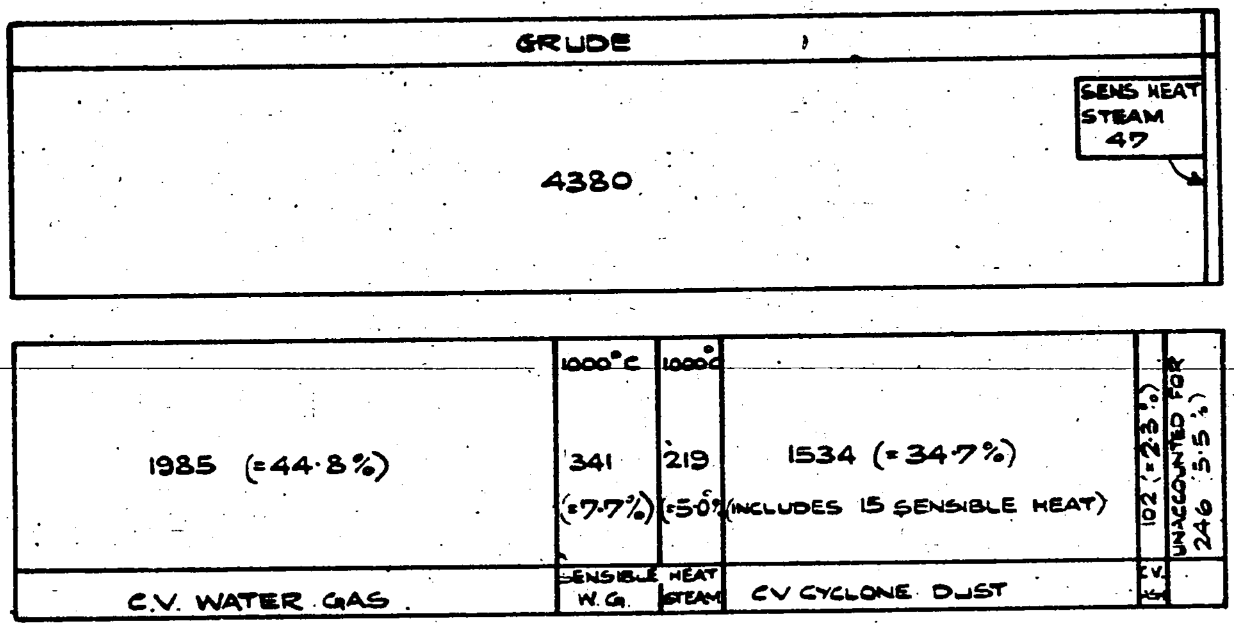
COMMENTS

The chart shows up clearly the poor carbon efficiency at Zeitz and the magnitude of the dust nuisance. The carbon efficiency, i.e. the percentage actually gasified, is 57% (Ref.14 from the same figures gives 49.25% and this error is repeated in Ref.3); the bulk of the ungasified carbon is blown over with the bulk of the ash as dust in the gas.

HEAT BALANCE AT ZEITZ

From the above data and Ref.14 the following heat balance of the generator itself (i.e. excluding waste heat boilers, etc.) has been drawn up for Zeitz :-

INGOING HEAT IN T.CALS/1000 NM³ RAW WATER GAS.



OUTGOING HEAT

HEAT BALANCE AT ZEITZ.

The above quantities are expressed in T.cals/1000 NM^3 raw water gas, using net calorific values and expressing sensible heats above 0°C.

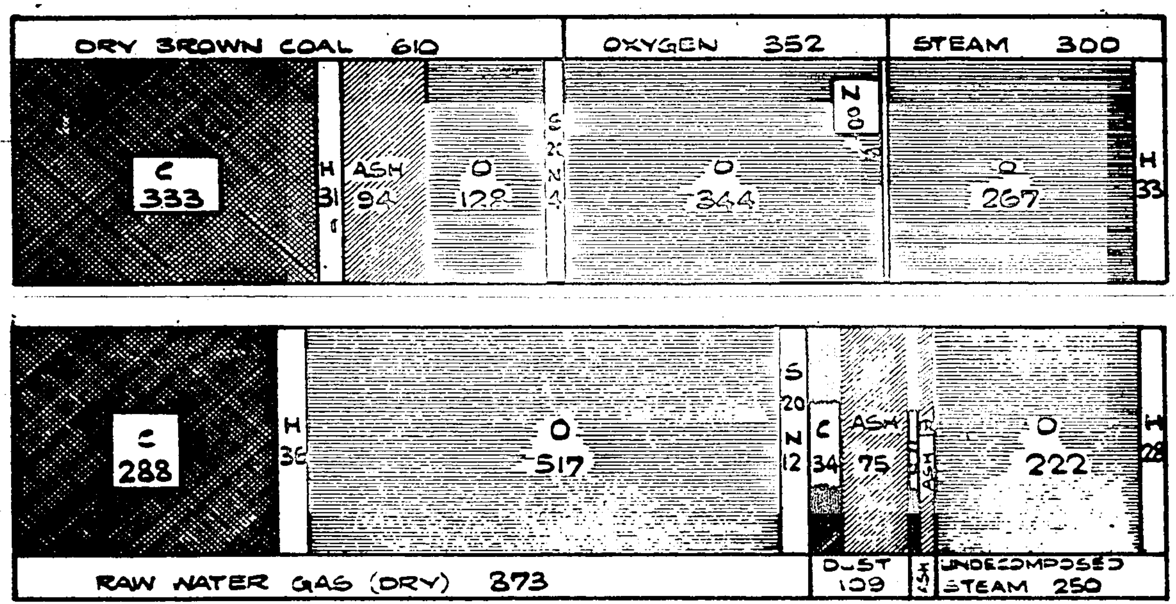
This chart shows much the same story as the material balance. The thermal efficiency of the generator itself (i.e. net c.v. of water gas divided by net c.v. of grude + sensible heat of steam) is 44.8%; the major inefficiency of 34.7% is as cyclone dust, whilst sensible heat of the water gas and steam at 1,000°C removes 12.7%. The "unaccounted for" loss of 5.5% has to cover c.v. of dust passing the multicyclones and losses by radiation, etc.

If all carbon in cyclone dust can be usefully recovered as a boiler fuel, then the net carbon efficiency is 93.5% and the net thermal efficiency is 70%, still however omitting waste heat recovery.

MATERIAL BALANCE AT LEUNA

The above balances for Zeitz, although representative of working at that plant, give a poor impression of the Winkler process; appreciably better efficiencies are obtained at Böhlen and even better at Leuna. Since we have available from Ref.10 the actual performance at Leuna over 12 months in 1935, material and heat balances are given below for Leuna, making water gas from dry brown coal. The output was relatively low, at 27,000 M^3/hr for a generator of 25 M^2 cross-sectional area.

INGOING MATERIAL IN KG/1000 NM³ RAW WATER GAS.



OUTGOING MATERIAL

MATERIAL BALANCE AT LEUNA

NOTE:

1. The above balance is exactly as given in Ref.10. The perfect balance of each component indicates that certain items have been estimated by difference; however, the overall picture is probably very near truth.

2. Of the ingoing H in fuel, 25 kgs are as H and 6 kgs as H_2O (49 kgs).

COMMENTS

The picture presented here is very different from that given for Zeitz. The carbon efficiency, i.e. the percentage actually gasified, is 86.4% (cf 57% at Zeitz). The carbon blown over as dust is only 34 kg/1000 NM^3, as against 183 kg at Zeitz.

HEAT BALANCE AT LEUNA

Using slightly different data Ref 10 gives the following heat balance :-

INGOING HEAT IN T.CALS/1,000 NM^3 RAW WATER GAS

Dry Brown Coal
3100

2050 (66%)	420 (14%)	470 (15%)	160 (5%)
C.V. Water Gas	Sens. Heat W.G.+Steam	Dust+Ash	Losses etc.

The thermal efficiency is 66% (compared with 44.8% at Zeitz), and dust and ash accounts for a loss of only 15% (compared with 37% at Zeitz.

If all carbon in cyclone dust can be usefully recovered as a boiler fuel, then the net carbon efficiency is 96% and the net thermal efficiency 74.5% (compared with 93.5% and 70% respectively at Zeitz). Thus so long as Zeitz can utilize the cyclone dust there is very little loss of carbon or thermal efficiency due to the high dust carryover at Zeitz; however, such high dust carryover does necessitate more expensive equipment to deal with it.

MANUFACTURE OF POWER GAS

At Leuna a number of compressors of the ammonia synthesis plant have always been driven by gas engines, fired by producer gas. Since 1926 the producer gas or power gas has been made mostly on one of the large Winkler generators.

Since a high CH_4 content of power gas is not objectionable, and may even be desirable, dry brown coal has been the normal fuel used. Hydrogen is an undesirable constituent of power gas, since in excess it causes too violent explosions in the engines, so that the blast used has been air alone, sometimes with the addition of CO_2, but never with the addition of steam. The water and hydrogen content of the fuel of course are the source of a certain amount of hydrogen in power gas.

The method of working is very similar to that of making water gas; in fact one generator at Leuna acts as a common spare to one water gas and one power generator. The air blast is split into

blast through the grate and secondary air above the fuel bed. The output of power gas from a large generator of 25 M^3 cross-sectional area is about 75,000 M^3/hr, which is somewhat greater than the output of water gas, 60,000 M^3/hr, from the same generator, since power gas does not carry with it any undecomposed steam.

Very complete data are available for Leuna for the whole of 1935 from Ref.10, and these are set out in Table V along with other published data. Figures in the first two columns, from Refs. 9 and 10 using dry brown coal, are in very good agreement, but published figures from Ref.9 using grude record too low a fuel consumption. The carbon utilization efficiency is about 82%.

The dust content of gases at Leuna is shown below, when working on dry brown coal :-

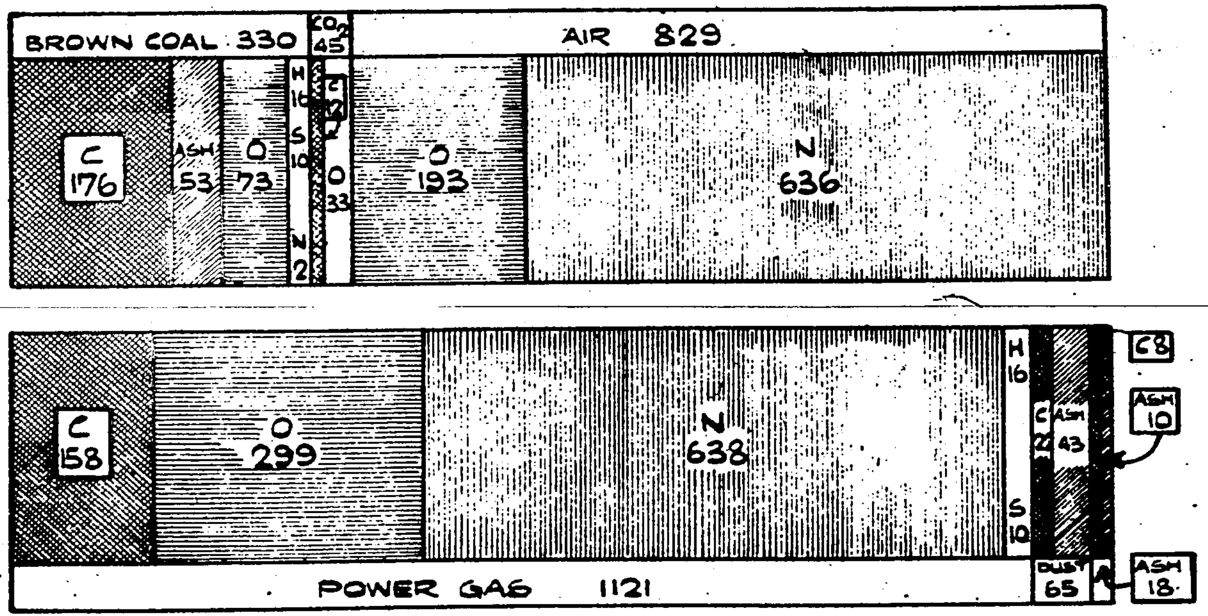
	Output M^3/hr.	Density Air = 1	Dust g/M^3
Water Gas			
(a) dry water gas	27,000	0.74	109
(b) water gas + undecomposed steam	36,000	0.72	81
Power Gas	50,000	0.91	65

At first sight it is difficult to see why power gas should contain less dust than water gas, since higher output and higher density would be expected to give more dust. However, evidently the main factor is the amount of fuel gasified, which controls the amount of fines brought in with fresh fuel and probably also the amount of fines resulting from attrition and gasification. Thus the percentages of dust in gas in terms of fuel used are 19.7% and 17.8% for producer gas and water gas respectively.

MATERIAL BALANCE AT LEUNA (Power Gas)

The following chart is based on Ref.10, giving the average for twelve months in 1935 :-

INGOING MATERIAL IN KG/1000 NM³ POWER GAS



OUTGOING MATERIAL.

MATERIAL BALANCE AT LEUNA

NOTE: Of the ingoing H in fuel, 13 kgs are as H and 3 kgs are as H_2O (26 kgs). Of the outgoing H in power gas, 12 kgs are as H and 4 kgs are as H_2O (35 kgs).

HEAT BALANCE AT LEUNA (Power Gas)

The following chart is also based on Ref.10, giving the average for 12 months in 1935 :-

INGOING HEAT IN T.CALS/1,000 NM³ POWER GAS

Dry Brown Coal
1660

1000 (60%)	330 (20%)	260 (16%)	70 (4%)
C.V. Power Gas	Sensible Heat	Dust & Ashes	Loss

The thermal efficiency is thus about 60%.

MANUFACTURE OF AMMONIA SYNTHESIS GAS

The only direct data available is published in Ref.9. Oxygen enriched air with steam is used as the blast, and the efficiencies, etc. are those to be expected from combining data for water gas and producer gas, to give a mixed gas of the right composition.

USE OF FUELS OTHER THAN BROWN COAL

Obviously the Winkler generator becomes of much wider application if it can utilize fuels other than dry brown coal or grude. Here information is not nearly so reliable, since as far as we are aware no large generator has ever run very long on such fuels. Ref.1 states that I.G. designed large-scale plants in Japan to run on a grain size mineral coal of a particularly active character, but we know nothing of their operation.

Most of the experimental work has been carried out on a small generator (0.8 M^2 shaft area) at Oppau, and some on a small generator (2 M^2 shaft area) at Leuna. There are also references in the literature.

As stated before O_2-gasification is a relatively expensive way of gasifying a fuel and may become economic only with fuels which cannot be gasified conveniently in other ways. Examples, which have been considered, are bituminous coal dusts, especially those whose ash content is high or whose ash has a low softening point, and hard coke breeze. Nevertheless, since these fuels can in general be used as boiler fuels, perhaps at some discount, they will in general have an appreciably higher cost than brown coal, near the brown coal deposits.

All the fuels mentioned are appreciably less reactive than brown coal or grude, and to obtain reasonable outputs from a given generator it is necessary to work at higher temperatures; this means higher exit gas temperatures, higher oxygen consumptions, higher CO_2 contents of water gas and possibly troubles with clinker formation. Moreover, because of the lower reactivity it is more difficult to gasify any dust in the space above the fuel bed, and the secondary blast tends to react with the gas rather than with the dust.

It is probable that fuels like young gas coals and low-temperature coke breeze could be gasified successfully in Winkler generators, with efficiencies and outputs only somewhat less than with brown coal or grude, but such fuels are rarely cheap.

Ref.6 (p.12) states that hard coke breeze cannot be gasified in Winkler generators at Leuna. Ref.10 briefly describes tests in the experimental generator at Leuna in 1935. Certain brown coals were unsuitable because of low ash softening point and high proportion of soluble salts in the ash (see also below).

Earlier tests at Oppau are described in Ref.5. Short tests on an American bituminous coal (Old Ben Coal Corporation, Mine 8, Chicago) gave promising results. This coal is described as fairly reactive, not strongly caking. Crushed coal, "about the size of peas to hazelnuts, containing some dust" was fed by screw conveyor into the boiling bed of coke; the coal was quickly distributed in the bed and no caking occurred. No gas analyses are given.

MISCELLANEOUS POINTS OF INTEREST

Ref.10 describes difficulties arising from the high sand content of Elise coal, sand being the chief cause of variable ash content. Sand caused chokes in the stack-lines and valves; it also led to the formation of volatile silicon sulphide (cf. Chem.Fabrik 1935, p.512), which after decomposition gave rise to finely divided silica, which was able to pass through the disintegrators.

It is desirable to keep low the content of water-soluble salts in the ash; such salts tend to be volatile and give rise to slagging difficulties. Thus Ref.10 states that Elise coal had a total ash content of 20%, of which 10% was water-soluble; on the other hand a grude which gave considerable trouble with slagging had an ash content of 22%, of which 20% was water-soluble.

The use of blast preheaters has often been suggested, but as far as we are aware they have not been successfully applied to

Winkler generator so far, although attempts have been made at Leuna. On theoretical grounds one would expect that preheating the steam and oxygen mixture would reduce the oxygen requirements. According to Ref.6 preheating the blast to 400°C would save about 25% of the oxygen required with no preheating. The most economic way of preheating, from the point of view of running costs, would be to interchange the heat in the hot exit gases with the incoming blast, but the capital cost of such preheaters is likely to be high.

COMPARISON WITH OTHER PROCESSES FOR MAKING SYNTHESIS GAS.

As stated before, the Winkler process has the great advantage of being able to use low-grade fuels, difficult to gasify in other ways, and this at once may give it a great local advantage. When, however, it is considered for coals which can be gasified in other ways or where it has to use fuels having enhanced value for other purposes, e.g. as a boiler fuel, then it becomes much less attractive.

The two great drawbacks to the Winkler process are its relatively poor thermal efficiency, which is no higher than that of a conventional coke water-gas generator, and the cost of oxygen. If fuel is at all expensive the poor carbon efficiency is a disadvantage, only partly mitigated if the dust can be collected and used as a boiler fuel. Even when made in modern Linde-Fränkl units oxygen is never cheap, and it is interesting that the I.G. consider (see Ref.6, p.10) that it is more expensive to use continuous oxygen-gasification of any fuel than to use a make and blow process with air, provided the same fuel can be got into a suitable form in both processes.

All processes using oxygen-gasification have an additional disadvantage in that any oxygen added must eventually appear as CO_2 in the synthesis gas; hence greater compression costs and water scrubbing costs are incurred to remove it, with corresponding increased capital costs.

Although the amount of gas produced per unit shaft area is relatively great (say 900 to 1,500 M^3/hr H_2 + CO/M^2, as compared with say 600 M^3/hr H_2 + CO/M^2 for make and blow coke water gas generators), and although the absence of distribution difficulties in a boiling bed enables very large units to be used (e.g. up to 50,000 M^3/hr H_2 + CO at Leuna, compared with say up to 8,000 M^3/hr H_2 + CO in the largest coke water gas generators), nevertheless all the auxiliary equipment required means that the output of Winkler generators per unit area of site is no greater than that of coke water gas generators. Thus at Böhlen and Zeitz the capacity of three generators was obtained for a site area of about 50 M^2 site /1,000 M^3/hr H_2 + CO installed capacity, including fuel handling, waste heat boilers, coolers, etc. but excluding the oxygen plant; the oxygen plant and its associated share of the boiler and power plant probably occupied an equal area. A coke water-gas plant, with all auxiliaries, would probably make the same amount of gas for a site area of about 40 to 60 M^2 site/1,000 M^3/hr

$H_2 + CO$ installed capacity. Moreover the large reaction space above the fuel bed, in terms of capital cost, largely offsets the advantage of a high output per unit area of grate.

CAPITAL COSTS

Available figures are of doubtful significance, but it is probably true to say that the capital cost of a Winkler plant, including oxygen plant, waste heat boilers, etc. is somewhat greater than that of a corresponding coke water gas plant, including coke ovens. The oxygen plant probably costs more than the Winkler plant it supplies.

PROCESS LABOUR AND MAINTENANCE COSTS

About four operators are required for each generator, but this depends to some extent on the size of generator. One man would be in the control cabin, which might however serve more than one generator, two men would be on waste heat boilers, dedusting and cooling equipment and dust handling, and one man on ash handling and miscellaneous labouring jobs. Labour additional to these four men would be required for fuel handling, especially if the preparation is done at the plant, and for machinery, such as oxygen blowers, boiler feedwater pumps, disintegrators, etc.

At Leuna in 1935 (Ref.10) 90 men and 11 chargehands were employed on the Winkler plant, running one power gas generator and one water gas generator. There would probably be one chargehand/shift for each generator and one for fuel handling, but if there were only four men/shift on each generator, this would leave about 60 men to cover fuel handling (but excluding drying) machinery, etc., as well as day labour; this figure seems excessive but it is not clear from the reference whether any maintenance labour is included. A rough figure for water gas might be taken as 0.4 man hours/1,000 M^3 $H_2 + CO$.

Also at Leuna over 1935 (Ref.10) maintenance costs for water gas averaged 1.75 RM/1,000 M^3 $H_2 + CO$, for an average output of 20,000 M^3/hr $H_2 + CO$. Maintenance costs for power gas averaged 0.46 RM/1,000 M^3 power gas, for an average output of 50,000 M^3/hr.

TABLE II

SUMMARY OF DESIGN OF WINKLER GENERATORS MAKING WATER GAS

Plant	Leuna		Böhlen	Zeitz	Magdeburg	Brux
Reference	1		2	3	1	1 & 4
Units	Small 1	Large 3(+1)*	3	3	3	5 or 6
Output NM^3/hr water gas :						
Maximum	40,000	80,000	25,000	22,000	-	-
Normal	30,000	60,000	20,000	18,000	ca 20,000	ca 20,000
Minimum	-	-	12,000	9,000	-	-
Fuel	Grude(formerly dry brown coal)		Grude	Grude	Grude	?
Grate	1 small & 1 large are grateless; others stationary grate.		Stationary grates			1 grateless; rest Stny.Gr.
Gasification chamber	Some bulbous at top, some straight-sided.		Straight-sided			
	Small	Large				
I.D. of fuel bed	3.9 m	5.5 m	4.5 m	4-4.5 m	4.5 m ?	
Cross-sectional area	12 M^2	25 M^2	16 M^2	12.5-16 M^2		
Depth of fuel	1 m	1 m	1.5 m	1.5 m		
Overall height	-	-	20 m	20 m	20 m	
Waste Ht. Recvy.	Waste heat boiler, superheater and economiser					
Dust removal; primary	Cyclone before W.H.B.		Multicyclones after W.H.B.		Originally electro-static, now multi-cyclones.	
final	Direct contact cooler and Theisen disintegrator					
Recovered dust used as:	Boiler fuel, returned to Winkler or for dephenolation.		Boiler fuel	Boiler fuel		

---

* 1 large generator now used experimentally for other purposes.

TABLE III

PERFORMANCE OF WINKLER GENERATORS MAKING WATER GAS FROM GRUDE

Plant	Leuna		Böhlen		Zeitz		?	
References	1		2	11	3 & 14 (Mostly 12 months 1944; some 2 months)			9
	Small	Large						
Units	1	3(+1)	3		3			
Actual output N M^3/hr. W.G./unit	-	50,000-60,000	20,000-25,000		16,600			
Fuel (Grude)								
: **Analysis** C	68.0		-	71	63.7			70.7
% on H	2.0		-	2.6	2.2			2.7
dry O	2.2		-	}	}			4.0
basis N	-		-	}1.1 ?	}5.5			0.0
Vol. S	1.3		-	}	}			0.6
Ash	26.5		-	25.1	28.5			22
H_2O	(2.0)		-	(2.1)	(2.6)			(6.4)
Cal.value, T.cals/ T.net as received	5780		5200-5400	-	5,650 to 5,850			5700
							mm.	%
Final grading	Av. 3 mms. with < 10% > 5 mms.		0.06-5 mm.	-	2-10 mms		0-0.2	20
							0.2-0.5	16
							0.5-1.0	20
							1-2	26
							2-3	8
							3-6	10
Gas Analysis CO_2	20		24.4	24.4	23.1			16.5
CO	37.5		27.6	28.8	29.6			42.6
H_2	39.5		45.3	44.4	43.8			39.0
CH_4	1.5		1.5	1.25	0.75			0.7
N_2	0.5		0.7	0.5	1.5			0.7
H_2S	1.0		0.5	0.6	1.25			0.5
Cal.value, k.cals/ N M^3 net	2150		1990	1982	1985			2195
O_2 in total blast	40-50%		21%	22%	21.5%			37.5%
Blast temp. °C	-		150°	-	160-180°			-
% O_2 as secondary O_2	33%		12-20%	-	10%	**Ref.13**		
Fuel bed temp. °C	850-900°		900°	800°	900-950°	960°		800-950°
Gas exit temp. °C	900-950°		900°	900°	900-1000°	980°		950-1,000°
Gas temp. after W.H. recovery	200°C		200-300°	300°	200-250°			250°
Dust content of gas, in g/N M^3 dry gas								
(a) before dust removal	100-200		200-250	225-250	300-360			-
(b) after primary dust removal			-	40-60	60			-
(c) after final dust removal			-	0.002-0.005	0.003-0.004			-

TABLE III (Cont'd)

		Leuna	Böhlen			Zeitz	-
References		1	2		11	3	9
% C in dust		50 to 55	40		43.1	54 -56	-
% C in ashes		-	40		54.1	30	-
Efficiencies							
per 1000 N M^3 H_2+CO			(1)	(2)			
grude	kgs	640	757	782	765	1023	630
carbon	kgs	427	-	-	534	635	417
oxygen	M^3	320 to 335	305	335	324	320	331
steam used	kgs	350	825	960	830	860*	405
steam raised	kgs	580	750	-	850	925	-
steam decomposition	%	-	-	-	-	35	-
carbon utilisation	%	88	-	-	68.6	57	86
dust blown over	kgs	130 to 260	-	-	-	500-550	-
dust recovered	kgs	-	-	-	245-270	458	-
grate ash	kgs	-	21	-	16.5	60	-
power (excl. oxygen production)	KWH	-	-	-	39	70	-
Cooling water	M^3	-	21	-	23	34	-

(1) Average of two days, 11th and 12th August 1938
(2) Average of 31 days, January 1940.

* In addition Ref.14 quotes about 230 kg/1,000 M^3 H_2 + CO as being used for "Apparateheizung", i.e. heating of items of plant, at least for the winter months, January to March; this use of steam is obscure.

TABLE IV

PERFORMANCE OF WINKLER GENERATORS MAKING WATER GAS FROM DRY BROWN COAL

Plant		Leuna				-
Reference		1	6	10 (12 months average)	10* (one day)	9
Actual output N M^3/hr. W.G.		-	-	27,000	42,000	
Fuel (Dry Brown Coal)						
Analysis % On dry basis	C	61.1	-	59.3	57.3	61.1
	H	4.7	-	4.5	4.4	4.7
	O	17.0	-	15.2	14.0	16.3
	N	0.1	-	0.7	0.6	0.8
	S	3.3	-	3.6	3.1	3.3
	ash	13.8	-	16.7	20.6	13.8
	H_2O	(6.0)	-	(8.7)	(8.1)	(8.7)
Cal.val., T.cals/T net as received		-	-	5170	5150	5270

TABLE IV (Cont'd)

		Leuna				–	
References		1 mm	6	%	10	9 mm	%
Final grading		0-0.6		9.6		0-0.2	20
		0.6-0.88		1.5		0.2-0.5	18
		0.88-1.0		9.0		0.5-1.0	17
		1-2		23.3		1-2	16
		2-5		16.5		2-3	12
		>5		0.1		3-6	17
Gas Analysis	CO_2	19	19	21.8	15.7	17.5	
	CO	38	38	35.3	44.4	41.8	
	H_2	40	40	38.5	36.0	37.2	
	CH_4	2	2	1.8	1.6	0.9	
	N_2	1	1	1.1	0.8	1.0	
	H_2S	?	?	1.5	1.5	1.6	
Cal.val., k.cals/N M^3 net		2162	2162	2117	2295	2195	
O_2 in blast		40%	-	40%	48%	40%	
Blast above fuel bed		33%	-	-	-	-	
Fuel bed temp. °C		-	-	-	-	800-950°	
Gas exit temp. °C		-	-	-	-	950-1,000°	
Dust content of gases in g/ N M^3 dry gas							
(a) before dust removal		-	-	110	170	-	
(b) after primary dust rem.		-	-	-	-	-	
(c) after final dust rem.		-	-	-	-	-	
% C in dust		-	-	29	35	-	
% C in ash		-	-	42	40	-	
Efficiencies per 1000 M^3 H_2+CO							
coal	kgs	800	800	830	855	790	
carbon	kgs	461	-	452	455	444	
oxygen	M^3	320- 335	330	366	316	342	
steam used	kgs	370	-	407	250	384	
steam raised	kgs	-	-	600	-	-	
steam decomposition	%	-	-	33	27	-	
carbon utilisation	%	80.5	-	86.5*	80*	84	
dust blown over	kgs	-	-	148	211	-	
grate ashes	kgs	-	-	41	44	-	
power	KWH	-	-	48	-	-	

* See also page 20

TABLE V

PERFORMANCE OF WINKLER GENERATORS MAKING POWER GAS

Plant		Leuna	-	-
Reference		10 (12 months av.)	9	9
Actual output, N M^3/hr.		50,000	-	-
Fuel		DRY BROWN COAL	DRY BROWN COAL	GRUDE
Analysis on dry basis	C	57.8	61.1	70.7
	H	4.3	4.7	2.7
	O	16.5	16.3	4.0
	N	0.6	0.8	0.0
	S	3.3	3.3	0.6
	Ash	17.5	13.8	22
	H_2O	(8.5)	(8.7)	(6.4)
Cal. val. T.cals/T net as received		5190	5270	5700
Gas Analysis	CO_2	9.8	7.7	4.3
	CO	21.7	22.5	32.7
	H_2	11.7	12.6	7.6
	CH_4	0.7	0.7	0.5
	N_2	55.3	55.7	54.6
	H_2S	0.8	0.8	0.3
Cal.val. k.cals/N M^3		984	1020	1140
Blast above fuel bed		25%	-	-
Fuel bed temp.		950°C	-	-
Gas exit temp.		1000°C	-	-
Dust content of gases in g/N M^3 dry gas				
(a) before dust removal		65	-	-
(b) after primary dust rem.		-	-	-
(c) after final dust rem.		-	-	-
% C in dust		33-55	-	-
% C in ash		34-44	-	-
Efficiencies /1,000 M^3 gas				
fuel	kgs	330	ca 330	ca 285
carbon	kgs	176	ca 186	ca 190
air	M^3	700	ca 720	ca 720
CO_2	M^3	25	-	
steam raised	kgs	450	-	
Carbon utilisation	%	83	ca 82	ca 97*
dust blown over	kgs	65	-	
grate ashes	kgs	18	-	-

*This appears very high and is probably in error: the fuel consumptions should be greater than shown.

References

1. C.I.O.S. Report Item No.30; XXXII - 107 by R. Holroyd
I.G. Farben. A.G. Works, Leuna

2. C.I.O.S. Report Item No.30; XXXII - 92 by J.F. Ellis
Brabag I Plant, Böhlen

3. C.I.O.S. Report Item No.30; - by J.F. Ellis
R.J. Morley. Brabag Works at Troglitz - Zeitz

4. C.I.O.S. Report Item No.30; XXX-103 - by R. Holroyd
I.G. Farbenindustrie A.G. Works at Ludwigshafen and Oppau

5. Third International Conference on Bituminous Coal, 1931, 1, 874, H.G. Grimm

6. B.I.O.S. Report : 199 Translated by D.G. Fraser
and R.J. Morley "Ten Years of O_2 Gasification at Leuna"

7. Winkler Patent Numbers; the following is an incomplete list.

DRP.437,970 (1922) and its equivalent B.P.214,544 (1923)
DRP.484,093 (1924)
DRP.487,886 (1926)
DRP.494,240 (1927)
DRP.496,343 (1928)
DRP.535,535 (1928)
U.S.1,687,118 (1928)

8. Another report in this series, shortly to be published: Large-scale Production of Oxygen, by A.M. Clark

9. Oel u. Kohle, 8.6.42, A. Thau

10. C.I.O.S. Document. BAG 3041, Target 30/4.02. Document 6.
Annual Report for 1935 of Leuna Winkler Plant.

11. C.I.O.S. Document. BAG 2719, Target 30/6.12. Document 1.
Correspondence between Koppers and Zeitz, April 1942

12. C.I.O.S. Document. BAG 3500, Target 30/4.05. Document 34.
Record note of 14.10.42.

13. C.I.O.S. Document. BAG 4182, Target 30/4.07. Document 1.
Zeitz data.

14. C.I.O.S. Document. BAG 4182, Target 30/4.07. Document 2.
Zeitz data.

Copy 1

FINAL REPORT NO. 332
ITEM NO. 30

CHEMISCHE FABRIK WEYL A.G.

Sandhoferstr 96-106
Mannheim - Waldhof

Murray, C.A.

BRITISH INTELLIGENCE OBJECTIVES
SUB-COMMITTEE

LONDON — H.M. STATIONERY OFFICE

CHEMISCHE FABRIK WEYL A.G.

Sandhoferstr. 96 - 106,

Mannheim - Waldhof.

Reported by

C.A. MURRAY, JNR.,

Ministry of Fuel and Power

BIOS Target No. C30/363

Fuels and Lubricants

20th September, 1945.

BRITISH INTELLIGENCE OBJECTIVES SUB-COMMITTEE
32, Bryanston Square, London, W.1.

13 p.

TABLE OF CONTENTS

Personnel of Team

C.A. Murray, Jnr.	Ministry of Fuel & Power
C.J. Waller	Ministry of Fuel & Power

Report on visits to

20th, 21st and 22nd
September, 1945.

CHEMISCHE FABRIK WEYL A. G.
Sandhoferstr. 96-106
MANNHEIM - WALDHOF

Personnel:

The Aufsichtsrat, in Berlin, consists of :-

Director - J. Fabian
" - Dr. Strauss
" - Dr. Taeger

The Vorstand consists of :-

Director - C. Müller
" - Dr. K. F. Lang
" - Dr. Bellwinkel

The management of the Works at Mannheim consists of :-

Werkleitung: Director Dr. K. F. Lang, Technical
Dr. Croy, Commercial
Ober-ing E. Heinemann, Chief Engineer

There is also a Works at München-Pasing, of which the management consists of :-

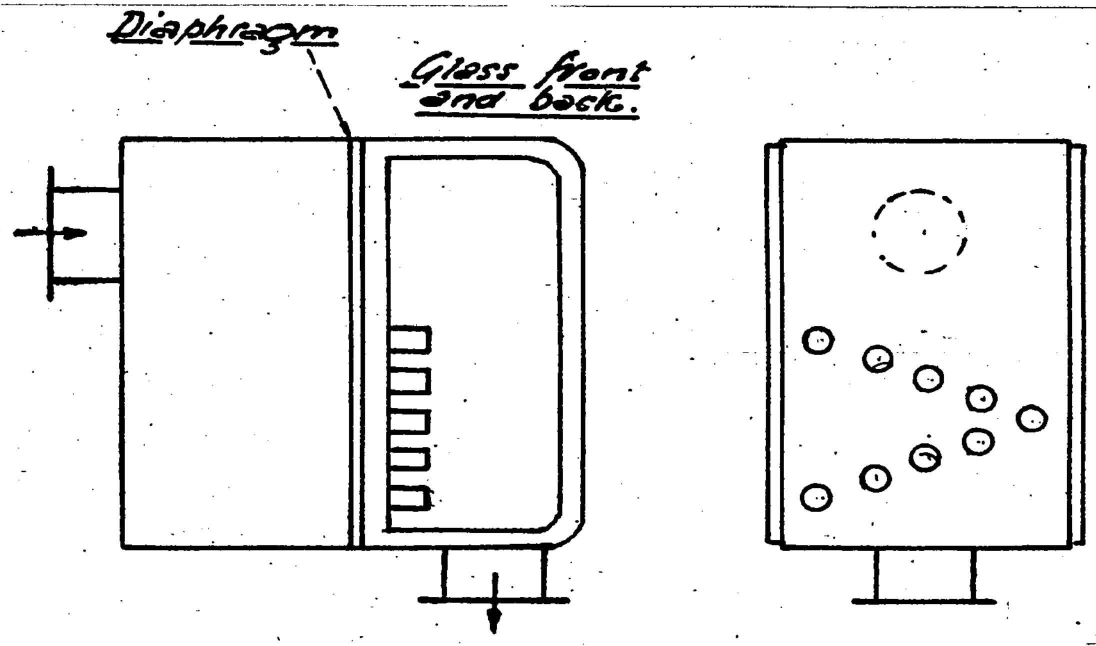
Dr. M. Ambré	Technical
Dr. Feick	Commercial

There is a close financial connection with the tar firm of Rütgers, which has works at Duisburg, at Castrop-Rauxel and in Berlin (Erkner).

Dr. Lang showed us round the Works.

General:

The present personnel of the Works, including office staff, is approximately 90. The normal complement on full



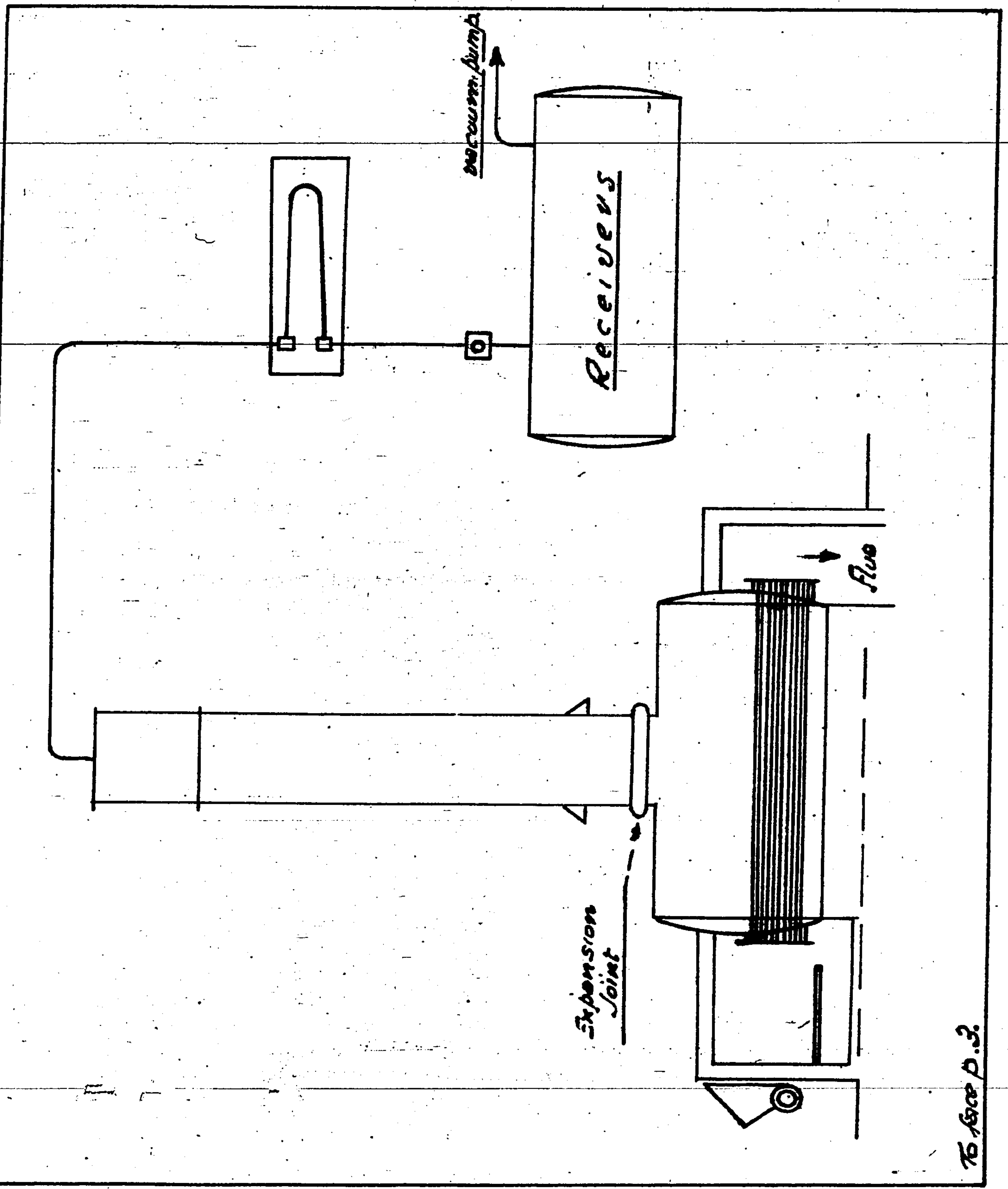
To face p. 2.

production is 130-140. The Works normally operates on two shifts, 6-2 and 2-10, on a six day week.

The Works distils the coke oven tar produced at the coke-oven plants in the Saar coal field and also the tar produced at the gas works in the former provinces of Baden, Hessen, Württemberg and a part of the Rhineland. The proportion is about 1/3 gas works' tar, from some 75 gas works whose productions vary from 50 tons per month upwards, and 2/3 from three smallish and two large coke oven plants. A little water gas tar is also received from time to time. A complete resumé of the figures for 1943 is attached (Appendix A).

Tar is received both by rail tanks (approx. 15 tons capacity) and by barge. The available storage for Crude Tar was 4 x 3,000 ton tanks, 2 of which have been practically destroyed by fire after bombing.

<u>Tar Plant</u>: The crude tar is dehydrated continuously, and the tar minus light oil and water is distilled in batch stills. The plant contains six stills, all of the same design. The first two are worked without columns, as dehydrating stills, and the other four are fitted with cast iron bubble cap columns, lagged, 2 m. in diameter and 40 trays high. The trays contain about 16 bubble caps per tray, and are about 20 cm. apart, so that the columns are 8 m. high. A dephlegmator, 2 m. high, is fitted direct on the top of the column, with the cooling water round the tubes and the vapour through them. The vapour passing over is condensed in coolers after the fashion of a superheater lying on its side in a rectangular tank of water. Both dehydrating stills operate under vacuum. The column head pressure is about 160 mm. Hg.; it is about 100 mm. Hg. more at the bottom. Vacuum is obtained by horizontal electrically driven piston type vacuum pumps, which are claimed to be more economical than the steam ejector type, especially as the Works generates its own electric power (380 v: 3 phase: 50 cycles) by horizontal steam engine and uses the pass-out steam for process. The vacuum is applied at the receivers. Measuring instruments consisting of a series of tubes projecting horizontally from a vertical diaphragm (see sketch opposite), the flow being calibrated according to the number of tubes through which liquid is flowing, are



To face p.3

fitted to each coil end.

The tar still column capacity is 7 tons/hour total boil-up. The normal reflux ratio is about 1.2:1, and the normal make is therefore 3 tons - say 600 g.p.h. Sight glasses are fitted into the columns approx. every 4 trays.

The stills are of a special construction developed by the firm, consisting of a horizontal cylindrical vessel 6.7 m. long x 3.6 m. diameter containing about 70 fire tubes, 4" in diameter, passing through from front to back and expanded into tube plates at each end. A dutch-oven type of furnace is built out in front of the still, fitted with a normal Lancashire boiler type of twin mechanical stoker burning washed smalls, and a similar oven construction at the rear collects the flue gases - outlet temperature said to be about 350°C - and conducts them to the chimney via a common flue (see sketch opposite).

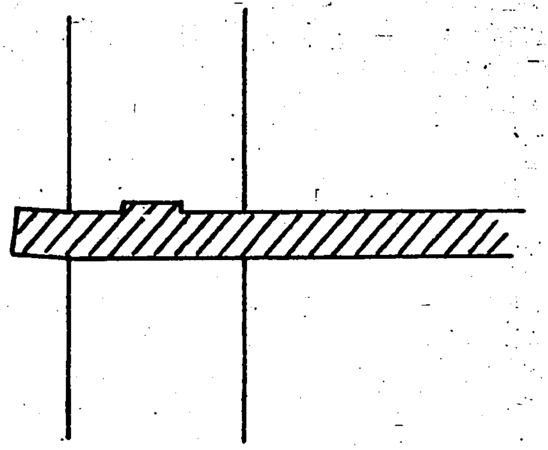
The labour at the Tar plant is 1 stillman, 2 stokers and 1 coal and ash wheeler per shift. The stills work 1 charge per day normally, but could do more if pressed. Coal consumption is said to be 40-60 Kg. coal/ton for distilling tar, and 22-30 Kg. coal/ton for dehydrating.

The fractions - taken are (a) from the crude tar, water and light oil (range 100°-240°C), and (b) from the dehydrated tar,

(i)	Carbolic Oil	170-215°C.
(ii)	Naphthalene Oil	195-230°C.
(iii)	Benzole Absorbing Oil	230-275°C.
(iv)	Anthracene Oil	270-315°C.
(v)	Pitch	softening point 40-62°C.

Carbolic Oil - shipped as such to Rütgerswerke, Castrop-Rauxel, for the extraction and refining of phenol, cresols and pyridine.

Naphthalene Oil - worked up at Mannheim to Naphthalene, pure (flake, crystal, ball), hot pressed and crude (fire lighter quality). The plant is almost entirely destroyed by bombing and fire but had been of the usual type. The cooling pans were apparently much deeper in relation to their width than usual.



To face p 4

The presses were of the usual rotating Harburger type with hydraulic accumulator and conveyors for crude and pressed naphthalene. The washers are lined with acid resisting tiles.

Benzole Absorbing Oil - sold to the various coke ovens and gas works.

Anthracene Oil - is blended for fuel oil, impregnating oil, heavy diesel oil, etc.

Anthracene - oil is cooled, put through Nutsch filters, and residue washed with oil and whizzed for 40's. This plant also destroyed.

Pitch - largely used for briquetting purposes in the Ruhr area. Run from stills into special type of tipping pan for cooling - in 'Pechhalle'. Also into forms for 2-3 cwt. blocks.

The still is made of approx. $\frac{7}{8}$" plate. The approx. life is 2,000 charges per still and 700 charges per set of tubes. The 70 tubes are approx. 4" in diameter, of drawn seamless tubing and about $\frac{1}{4}$"-$\frac{3}{8}$" thick. A groove is cut in the centre of the tube plate into which the tube is expanded. This prevents the tube slipping out of the plate due to the breathing of the still (see sketch opposite) which used to occur previously. Normally a firebrick protecting nozzle is fitted into and over the entry end of each tube to minimise the effect of the hot flue gases. The stills are stopped and cleaned and examined after every 14-20 distillations. If a tube begins to leak the ends are simply welded up. When 12-14 tube ends have gone then the whole still is stopped and re-tubed.

The dephlegmator tubes are about 2" bore and last about two years. Deposits from the water round the tubes are removed at intervals by inhibited hydrochloric acid solution.

Benzole Plant - This is an oldish plant with no special features. It is operated on the batch principle and distils the light oil obtained from the tar distillation plant and also crude benzole. The stills are of various sizes, approx. 20-25 cb.m. content, the charges being about $\frac{3}{4}$ of this. The usual distillation speed is 300-500 l./hour.

The steam consumption is said to be 0.5 ton/ton benzole per distillation. The products are :-

Motor Benzole
90's Benzole
90's Toluole
Various Solvent fractions
Dark Coumarone Resins from still residues

The labour is 1-2 men per shift, including washing. The washers use a 'Torpedo agitator', which fits low down in the cone and consists of a double entry impeller, turning at about 40 r.p.m. The lower eye sucks in acid and the upper benzole, and the mixture is thrown out of the periphery. The material is cast iron and the makers Kühnle, Kopp u. Kausch, of Frankenthal near Mannheim.

Steam Plant:

	2 - Babcock & Wilcox water-tube boilers.	2 - Steinmüller water-tube boilers.
Capacity:	9 tons/hour each = 20,000 lbs/hour	2-3 tons/hour each = 5-7,000 lbs/hour
Pressure:	19 atm. = 285 p.s.i.	15 atm. = 225 p.s.i.

Feedwater: Drawn from Rhine - treated with Permutit base exchange, and condensate.

Fuel: Washed Smalls

Evaporation figures: Approx. 8 lbs/lb.
Steam production: Approx. 3,000 tons/month
Steam temperature: Approx. 300°C.

Babcock steam reduced to 12-15 atm. and all put through horizontal steam engine to generate current at 380v. 3 phase: 50 cycles. Pass-out steam at 3 atm. = 45 p.s.i. used for process.

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APPENDIX A

Chemische Fabrik Weyl A. G., Mannheim-Waldhof.

Throughput and Production - 1943 (a normal year)

	Input tons	Products tons
Crude Tar received	75,302	
Crude Tar dehydrated	76,829	
Dehydrated Tar distilled	71,365	70,935
Light Oil distilled	2,271	1,649
Crude Benzole distilled	2,762	2,186
Crude Benzole washed	2,678	2,592
Washed products distilled	2,733	2,395
Coumarone Resin	404	205

Produced	tons
Pitch	19,514
Special Pitch	42
Refined Tar of all grades including Road Tar	38,743
Black Varnish, etc.	102
Crude Naphthalene	2,568
Cresylic Oil	1,503
Hot Pressed Naphthalene	1,862
Washed Naphthalene	1,222
Pure Naphthalene, crystals	1,067
do. flakes	112
Filtered Anthracene Oil	943
40's Anthracene	91
Crude Anthracene	111
Winter Wash Emulsion	113
Various grades Finished Oils	7,341

Appendix A - continued

Yields and Losses, 1941 - 1942

		1941 %	1942 %
Tar Dehydration	Light Oil	2.01	2.20
	Ammonia Water	4.13	3.34
	Loss	0.39	0.43
Distillation of Dehydrated Tar	Carbolic Oil	3.56	4.95
	Naphthalene Oil I	7.14	7.36
	do. II	5.59	4.89
Throughput, 1941 - 67,594 tons	Wash Oil	7.08	6.66
	Anthracene Oil I	4.10	3.26
	do. II/III	8.71	6.22
Throughput, 1942 - 68,941 tons	Column drainings	2.25	1.78
	Soft Pitch	6.24	10.50
	Briquette Pitch (M.S)	41.93	32.97
	Distilled Tar	12.95	20.95
	Loss	0.47	0.46

Benzole Plant

	1943 tons	tons	tons
Throughput		1,592	2,372
Production	2,395	1,275	1,912

	Washing loss	Acid Resin	Distn. loss
Raw Benzole I	0.50%	2.30%	1.0%
Raw Benzole II	0.40%	2.70%	

Naphthalene Plant

		1941 %	1942 %
Naphthalene Pans: Capacity of plant - 3,600 tons Pure Naphthalene (7.4% naphthalene Oil I reckoned on crude tar)	Drained Salts	68.9	64.7
	Cresylic Oil	30.7	34.6
	Loss	0.4	0.7
Naphthalene Presses: (capacity 1 ton/hour)	Pressed Naphthalene	73.1	71.6
	Expressed Oil	26.0	27.4
	Loss	0.9	1.0

Appendix A - continued

		1941 %	1942 %
Naphthalene Washers: (capacity 3,000 tons/year)	Washed Naphthalene	96.0	96.8
	Loss	4.0	3.2
Sublimation: (capacity 600 tons/year)	Sublimate (flakes)	97.0	92.8
	Residue	2.3	6.5
	Loss	0.7	0.7
Naphthalene Distillation: (capacity 1,280 tons/year Pure Naphthalene)	Pure Naphthalene	91.2	91.1
	Washed Naphthalene	4.6	4.0
	Residue	3.6	4.1
	Loss	0.6	0.8
Naphthalene Ball Presses: (capacity 720 tons/year)			
Summary:	Drained Salts	68.9	64.7
	Pressed Naphthalene	50.3	46.3
	Washed Naphthalene	48.3	44.8
	Pure Naphthalene	44.0	40.8

Total throughput of materials, 1943 - 86,056 tons
Total production - 81,622 tons

		per tonne RM.
Production costs, 1943 (exclusive of transport costs)	Total	- 9.42
	Naphthalene Plant	- 68.0
	Benzole Plant	- 33.50
	Remaining Tar Plants	- 8.31

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COPY 1

FINAL REPORT No. 338.
ITEM Nos. 21, 22, 31.

GERMAN CARBON ELECTRODE MANUFACTURE at GRIESHEIM (I. G. F.)

Perrycoste, W. B. C.

"This report is issued with the warning that, if the subject matter should be protected by British Patents or Patent applications, this publication cannot be held to give any protection against action for infringement."

BRITISH INTELLIGENCE OBJECTIVES
SUB-COMMITTEE

LONDON - H. M. STATIONERY OFFICE.

GERMAN CARBON ELECTRODE MANUFACTURE AT GRIESHEIM (I.G.F.).

Reported by

W.B.C. Perrycoste, M.A.P.

February, 1946.

Metallurgy.

BIOS Target Numbers
C21/793, C22/1(t), C31/804

BRITISH INTELLIGENCE OBJECTIVES SUB-COMMITTEE
32, Bryanston Square, W.1.

14p.

TABLE OF CONTENTS

SUBJECT PAGE NO.

PERSONNEL OF TEAM

F. N. Goss, M.A.P.
W. B. C. Perrycoste, M.A.P.

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1. OBJECT OF VISIT

The I.G.F. Carbon Electrode Factory at Griesheim (a suburb of Frankfurt, A.M.) was visited on 19/20th September, 1945. It was a "target of opportunity" selected as a result of information obtained during visits to other Factories.

2. INTRODUCTION AND SUMMARY

(a) The inspection was made by members of the Team which was investigating alumina and aluminium production in Germany. This field included the manufacture of the pre-baked anode and cathode blocks and Soderberg paste carried out in ancillary buildings. It was learned that some Reduction Works obtained some of their carbon blocks from Griesheim, so arrangements were made to investigate the part of the process carried out there which related to this supply. The Carbon Factories directly associated with Reduction Works are covered by the Report dealing with these later; but it seems more convenient to describe this Griesheim Carbon Factory separately.

(b) This Report deals with the raw materials, plant and process for the preparation of the paste which is used for all the Griesheim carbons. It includes a description of an interesting self-firing calciner. The Report also covers the pressing and baking operations for large sections, and includes a description of the largest extrusion press there. This Team did not investigate the plant and process involved in the manufacture of small carbon electrodes and sections.

3. PERSONNEL INTERVIEWED.

Dr. Engelbertz (Manager); Dr. Peter (Process Superintendent); Dr.-Eng. Gesses (Chief Engineer).

4. BOMB DAMAGE

There had been very extensive bombing at Griesheim, but the buildings and plant concerned with carbon manufacture did not seem to have been materially affected. Some of the processes were in actual operation at the time of our visit.

5. GRIST PREPARATION

(a) Raw Materials. The following cokes are used as the raw materials; pitch coke; petroleum oil coke; shale oil coke; and specially treated brown coal cokes known under the names of Baessweiler and 'S coke'. The two last-named cokes are a fairly recent development in German industry. They are manufactured by flotation and/or acid treatment, with, we understand, in one case the addition of pitch before coking. They are characterised by ash contents of 0.9% down to 0.6%.

(b) Preliminary Crushing. The coke is hand-shovelled from rail-trucks to a jaw crusher and reduced to 30 mm. in size in the older train; and in the case of the more recent train reduction is effected to 15/20 mm. in a "three-high claw" mill. This mill takes the form of three fixed-arm hammer mills mounted one above the other, with clearances between the spider arms and the body of the mill decreasing progressively. This crusher was supplied by Klocker Hambold, Deutz, of Cologne, and it was stated that for crushing oil and pitch coke this form of mill required less power and made less dust than the jaw crusher installed in the older train.

The coke is fed to the calciners to a given level from overhead bunkers fitted with segmental feeders. Each type of coke is separately bunkered so that mixtures of coke can be charged to the calciners in the correct proportions and with a view to the overall volatile content.

(c) Calcination

(i) Description of Plant. Two calciner houses were seen, the first containing three calcining units - two for pitch and oil cokes, and one for anthracite - installed in 1937, and the second containing six units for the calcination of pitch coke and oil coke, and installed in 1941 and 1942.

The calciners themselves were supplied by Reidhamer, of Nuremberg, and the conical water-jacketed discharge hoppers sub-contracted to Klocker Hambold, Deutz, of Cologne, and in principle both installations are the same and consist of groups of ovens, each group consisting of six vertical muffle cells working as a unit. Essentially each muffle consists of an oval-shaped fire-brick chamber measuring approximately 5 metres high x 160 cm. x 40 cm., fitted at the top with a charging hopper (directly sited beneath the segmental feeder outlet of an overhead bunker) and offtake pipes for the gas evolved from the coke during calcination, and at the bottom with a conical water-cooled mild steel discharge equipped with a rotary discharge table (drum type in the latter installation) for feeding the calcined material on to a plate conveyor. Each muffle is surrounded by gas-burning flues, the flues of the six muffles comprising a calcining group being arranged in parallel. The gas offtakes from the top of each muffle are led to a main and then introduced to the gas-burning flues at the top of the calciner system together with pre-heated air, piped from a recuperator system below the calciners. The burning gas then follows a downward zig-zag path from top to bottom of the calciners, and is finally passed through the air pre-heating recuperator before being exhausted to atmosphere through cyclones and a wet washer.

Suction on the calciners is provided by a 30 metre high chimney and this is sufficient without any additional pressure boosting of the gas. The only precaution necessary to maintain the draught is that periodically it is found necessary to clear out the gas escape ports at the tops of the calciners.

(ii) Dust Precipitation. The calciners in each house are provided with a dust precipitating unit, these units being separate and distinct from the Lurgi electrostatic precipitator serving the remainder of the process. The calciner precipitators each take the form of two cyclones followed by a wet washer, and the efficiency of these cyclones and wet washers was stated to be 98%, although it was admitted that the discharge effluent dust from the stack could be seen clearly. The precipitated dust is thrown away.

(iii) Method of Operation. Calcination is carried out whether the cokes are of high or low volatile content. With the calciners described above trouble ensues if the volatile content of the coke to be calcined exceeds 10%, owing to the binding and consequent withdrawal difficulties of the coke within the calciner, and therefore high and low volatile content cokes are mixed. Additionally, there is the insurance that even allegedly low volatile-containing cokes do, in fact, contain only a small amount of volatile matter before being fed to the further processes. In this connection stress was laid on the desirability of attaining uniformity in the volatile contents of the cokes to be processed. As an example of the above, Baessweiler coke (brown coal coke), which by normal standards would not require calcination, is mixed with pitch or oil coke so as to give an over-all mixture with a volatile content of less than 10%. In the event of only high volatile-containing cokes being available then previously calcined material is used as a diluent, and any excess gas still then available is used for steam raising elsewhere; and conversely, if only low-volatile cokes are on hand, insufficient in gas content to effect self-calcination, then means are available for introducing a supplementary supply of coal gas from the Ruhr Grid main. (This supplementary gas supply also provides a means for starting up of the calciners).

The calcination loss is that to be expected theoretically, i.e., the loss amounts to the moisture and volatile contents of the coke as charged.

Given sufficient volatile content in the coke, the calcination process operates at 1200°C., is self-supporting, and is worked continuously. The volatile content of the cokes after calcination was given as .3% maximum, and the output was stated as being at half-a-ton per hour for each calciner group of six muffles.

Temperature measurements during the calcination process are made by direct reading high temperature bulb thermometers inserted through sight holes built into the body of the calciner. (Thermometers of this type are well-known in Germany, and one was evacuated from an Aluminium Reduction Works and is being reported on separately).

There is no doubt that the calciners were looked upon as efficient and easily-worked units, and that in the event of greater calcining capacity being required at Griesheim further units of the same type would be installed.

No repairs had been necessary during the first five years of operation, and thereafter only minor repairs to the linings of the muffles. Four prints giving details of the calciners were evacuated.

(d) Grinding Plant. The grist production plant consists essentially of two pairs of roll crushers, several sieving machines, a fine grinding pendulum-type mill and a Lurgi electrostatic precipitator plant. All the plant appears to have been supplied by Klocker Hambold, Deutz, with the exception of the electrostatic precipitator and the pendulum mill.

The rolls of both the coarse and fine roll crushers were of size 80 cm. long x 40 cm. diameter. Normally the rolls on both crushers have plain surfaces, but for the coarse crusher rolls with serrated faces have been tried. We understand, however, that little advantage was to be obtained from these serrated faces as compared with the plain faces. Rolls were made of manganese steel, and the nominal setting for the distance between rolls was:- for the coarse crusher, 8-10 mm.; for the fine crusher, 1-2 mm.

The output capacities from these roll crushers, and on the types of coke processed at Griesheim, were given as follows:- Coarse crushing, 5/6 tons per hour; fine crushing, 2/3 tons per hour.

The screens were of the double-deck type and were vibrated mechanically. The following meshes were in use:- 3, 1, .5, .3 and .2 mm. It was stated that they found the screening below .2 mm. to be inefficient on a production scale.

We were told that they had little trouble with wear on the coarser steel sieves, but that with the finer sieves made of bronze occasional replacements were necessary on account of fatigue failures. It was also mentioned that, in order to reduce the wear and to obtain greater accuracy of sieving, all sieves had been enlarged from the supplied size of 2.7 M x 1.1 M. to 4 x 1.5 M.

The fine grinding mill was of the air-swept (classification) pendulum type and was supplied by Meumann and Essen, of Aachen. Although we understood wear-and-tear on this mill was high, we were told that it was considered a satisfactory unit, bearing in mind the duty, and that it consumed less power, had a greater capacity, and produced a more uniform product than a ball mill. Questioned on the point as to whether their comparison of a ball mill against a pendulum mill for the production of fines was on the basis of actual experience with both types, the reply given was that this was so, and that the ball mill used was of the short barrel type. It was confirmed that the ball mill used was not of the multi-stage tube type.

The following working details were given for the pendulum mill:-

Power consumed	27 KW. for the mill itself and 15 KW. for the air classification unit.
Output	500/600 Kg. per hour when fed with pitch/oil cokes of sizes 3/5 mm.
Size of product	96% less than .1 mm. and of this 80% of less than 60μ 4% between .1 and .2 mm.

For the collection of dust, multitudinous offtake ducts from the various items of plant were first led to four cyclones arranged in series which preceded a Lurgi precipitator. This dust precipitating plant was stated as having an overall efficiency of 99.8%, and it was said that the effluent dust was the merest haze. The cost of the dust-collecting system, including the ducting, was given as 45,000/50,000 Marks.

(e) Processing Procedure. The grist production procedure for the plant described above is that the coke from the calciners is delivered to the first roll crusher via plate conveyors and bunker and table feeder, of feed size 15/20 mm. or 30 mm., depending on whether the coke emanates from the old or from the recently installed calciners. The product from the first pair of rolls is passed through the various sieves enumerated above - the oversize from the first 3 mm. sieve, which is mostly 3/5 mm. in size, being either returned to the mill or passed on to form the feed for the second roll crusher or for the fine grinding mill. The undersize is separated into the various fractions by the remaining sieves and bunkered for ultimate re-compounding into the final grist. Similarly, the product from the second pair of rolls passes through the same series of sieves and the various fractions obtained bunkered in one or other of the five bunkers fed by the screens. The product from the fine grinding mill is fed as discharged (without screening) direct to the sixth bunker, together with the dust collected by the electrostatic precipitator plant.

For grist compounding, therefore, six fractions as follows are obtained:-

a. 1-3 mm.
b. 0.5-1.0 mm.
c. 0.3-0.5 mm.
d. 0.2-0.3 mm.
e. Pass .2
f. 96% Pass .1

and the next stage in the process is the drawing from the six bunkers of the various grist fractions in weighed amounts according to the recipe for the final grist for the particular type of electrode to be produced. Each of the six hoppers is equipped with its own weighing machine and is fitted with motor-driven inlet and outlet valves of the slotted drum type to allow steady flow of the material. The weighers are nowadays manually operated, although previously attempts have been made with automatic weighing devices. Automatic weighing, however, was found to be too complicated to be worth-while. The wieghing machines discharge into a 400 Kg. -capacity travelling hopper via a quickly-fastened canvas jacket which acts as a dust seal, and the travelling hopper is then hand-operated along a rail track to a mixing room. Discharge of the travelling hopper to the mixers is by means of an overhead crane.

6. BINDER

Soft pitch was employed for the larger type of electrodes, whether of the pressed or extruded kind. Specification of the pitch was as follows:-

S.P.	50°- 55°C. (K. & S.)
Coking residue	35 - 50%
Solubility in benzole	25 - 30%
Solubility in anthracene	12 - 13%

An additional empirical test is to coke the material insoluble in benzole, and then to examine this visually for structure. For a good pitch, a fine-pored structure is expected - contrariwise, the structure with coarse pores is taken as indicative of a poor binder. This test was one agreed upon some two years ago as the result of the pooling of the experiences of the Association of Carbon Electrode

Manufacturers and in their endeavour to standardise tests for binders. The test was not found to be 100% infallible at Griesheim but we were told that, generally speaking, they had come to look upon it with favour. For smaller carbons, such as brushes, binders with a somewhat lower softening point were used, and they were compounded from pitch and tar, sometimes with the addition of anthracene oil.

7. MIXING

Four mixers of the tilting Werner Pfleiderer type were seen. All were electrically heated and were equipped with 'Sigma' blades. It was confirmed that Griesheim had no experience with blades other than of the 'Sigma' type.

Large side dust offtake ducts were fitted, and as seen on similar mixers at other German Carbon Factories.

After mixing, the green mixture is discharged into a steam-heated hopper, and is then either carried direct to the extrusion plant tamping machine, or, if it is to be made into pressings, is lifted by crane to a second steam-heated vessel equipped with a table feeder serving a 60 Kg. auto-weigher.

8. PRESSING

The weighed green mixture is next passed on to the table of the three-container "Hydraulik" press supplied by Wien. The press is of the fixed anvil floating cylinder type, and is capable of pressing blocks of cross section 30 x 30 cm. and with a pressure of up to 1200 atmosphere. Pressing is single-ended and follows the normal cycle of filling, pressing, and discharging.

We were told that, in the case of anode blocks for Aluminium Reduction Factories, the shapes of the block head and of the contract recess were made to the particular whim of the customer. The anode blocks actually seen were approximately 14" deep, were dome-topped, and equipped with screw-type contact recesses. It was noted that the screw recesses were not undercut. The extraction of the die head was by means of a hand block and tackle, although the blocks themselves were fully discharged and were swept from the table on to roller conveyor by means of a

hydraulically-operated arm swinging horizontally across the table. The rotation of the press table itself was accomplished electrically.

9. EXTRUSION

(a) <u>Description of Press</u>. The range of extrusions at Griesheim extends from dry-battery carbons to electrodes of 14" diameter. They have a number of presses of both horizontal and vertical type. The largest is a horizontal press of 2,800-tons capacity, though they had on order at the time of the German collapse a vertical 5,000-ton unit of which part of the foundation work had been done. We confined our attention to the 2,800-ton horizontal press, which we saw at work on some small sections.

The motions of the press are hydraulic. It was made by Eumeco, with Ardelt, of Berlin, as sub-contractors for the tamping gear. It provides (a) continuous preliminary tamping during filling; (b) pre-pressing; (c) extrusion; (d) cutting off.

There are two electrically-heated containers which traverse independently and tilt from vertical to horizontal. In addition, they can float against hydraulic "springs" in the direction of the axis of the press. These containers measure 800 mm. internal diameter and 1.8 m. long, to hold a normal charge of 1,050 Kg. Over them is a structure in which are two filling funnels. This structure which is itself mounted on rail-tracks on the floor to permit its complete removal for repairs or servicing to the main press, carries the tamping machine, which can traverse from one funnel to the other to permit the alternate filling of the containers. A movable pressure plate is provided in front of the die entry to allow for pre-pressing.

The die is electrically-heated, and, of course, can be changed to suit the section. The discharge runs on to a roller conveyor over sliding plates, and there are flying shears. There is no provision for for cooling the extrusions, but they told us that they had planned to instal water sprays.

(b) <u>Operation of Press</u> The mixture is brought from the Werner Pfleiderer mixers by bucket hoist to a steam-heated hopper which runs on gantry rails fixed to the roof above the tamping platform. The discharge is off-set to feed under the body of the tamping machine