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LURGI HIGH PRESSURE GASIFICATION

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BRITISH INTELLIGENCE OBJECTIVES SUB-COMMITTEE

LONDON—H.M. STATIONERY OFFICE

LURGI HIGH PRESSURE GASIFICATION

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of

Ministry of Fuel and Power

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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 Wärmetechnik, 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, 84, 549; 1942, 85, 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	-

	Atmospheric Carbonisation		Gasification at 20 atm.		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. Sächsische 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 2½inch 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.	7,069 k.cal./kgm
		12,680 B.Th.U./lb.	12,720 B.Th.U./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
Benzole	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_2S		3.6	1.6	0.0
C_nH_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_nH_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_2S 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 0.2, 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, 208, 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%

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

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%

<u>Released Gases</u>

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

$$\frac{6}{94} \times 3,703 = 236 \text{ million cu.ft. S.T.P.}$$

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 of coking 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.

$$\frac{0.2 \times 100 \times 10^6}{454 \times 2,240} \times \frac{32}{34} = 19 \text{ tons of sulphur.}$$

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 $\frac{1,511 \times 10^6}{153,800}$ = 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 $\frac{17.4 \times 100}{13.6 \times 2240} = \frac{1740}{300}$ = 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

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

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

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

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 ofsulphur 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 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 II

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 charges 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.)

Sieve 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.o - 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)

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 + H2 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 blaance, 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/1b)
	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, determined	Purified Gas, 6/7 March, calculated	Purified Gas 7 March, 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 s ame 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 gauge (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 generafor.
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 genemator.
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) Traenckner, K. Gas und Wasserfach, 1939, 82, 590.

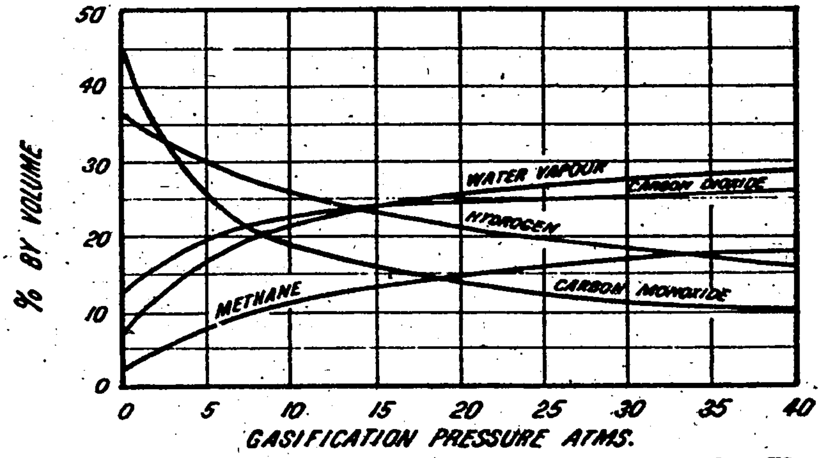
7) Danulat, F. Gas und Wasserfach, 1941, 84, 549.

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

List of Conversion Factors employed

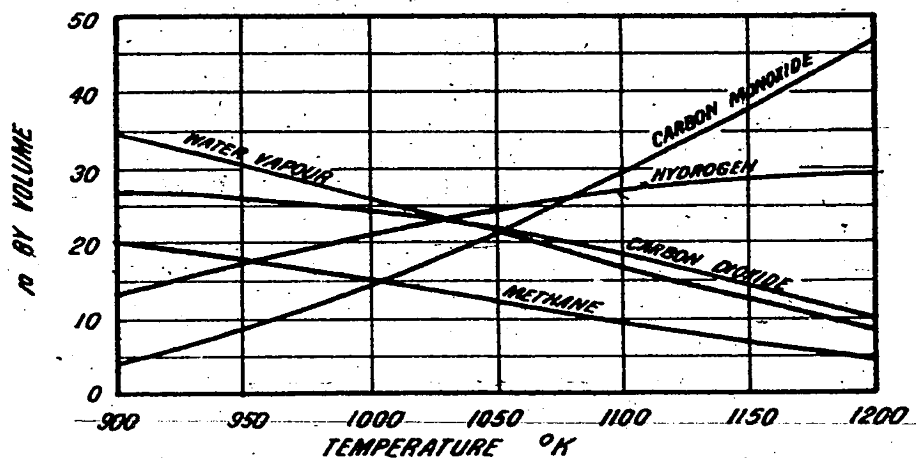
1 metre = 39.37 inches = 3.281 feet.
1 sq.metre = 10.76 sq.feet.
1 cu.metre = 35.31 cu.ft. = 219.97 Imp.gallons.
1 cu.ft. at 0°C and 760 m.m. dry = 1.073 cu.ft. at 60°F and 30 inches wet.
1 cu.metre at 0°C and 760 m.m. dry = 37.88 cu.ft. at 60°F and 30 ins.wet.
1 cu.metre of gas per tonne of coal = 35.88 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



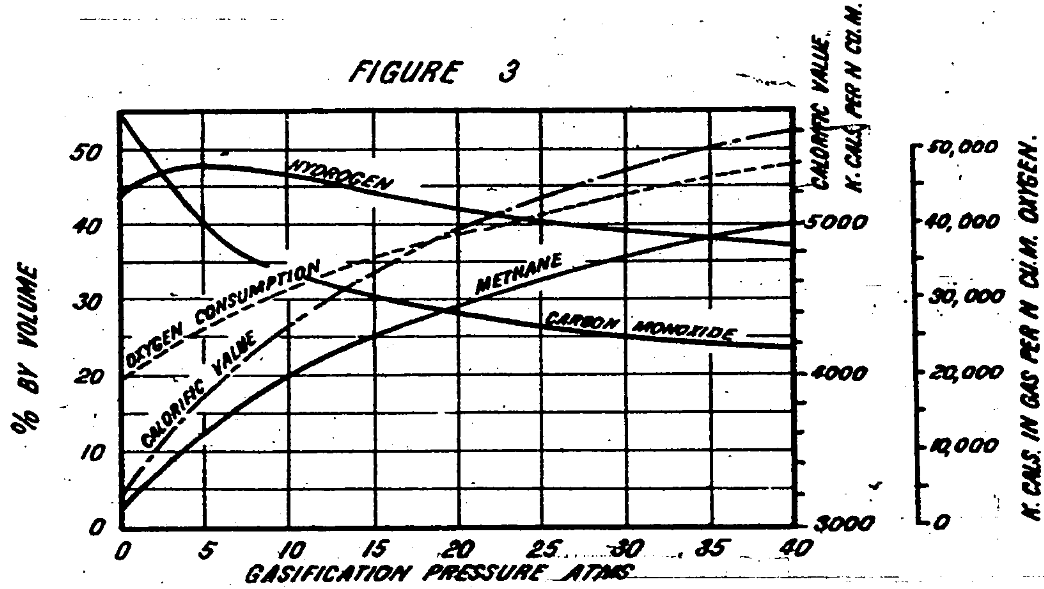
THEORETICAL GAS COMPOSITION IN RELATION TO PRESSURE

FIGURE 2



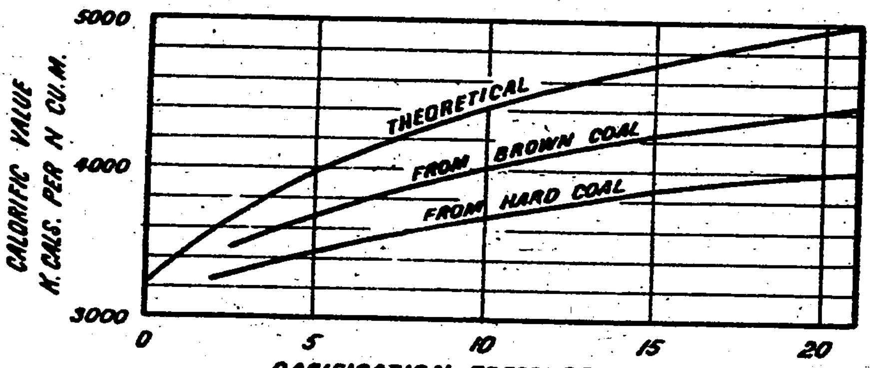
THEORETICAL GAS COMPOSITION IN RELATION TO TEMPERATURE

FIGURE 3



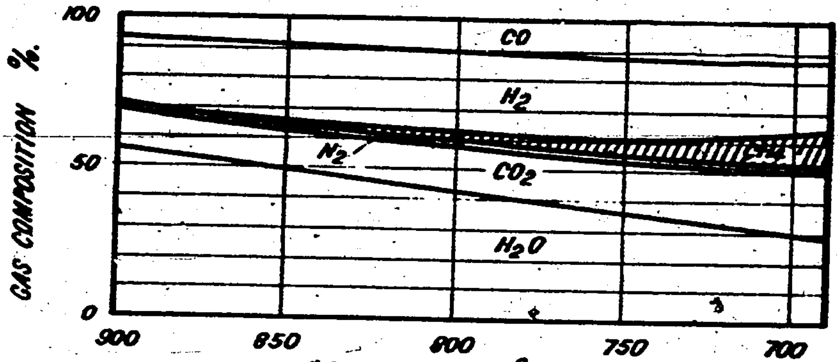
THEORETICAL COMPOSITION OF PURIFIED GAS, CALORIFIC VALUE, AND OXYGEN CONSUMPTION, IN RELATION TO PRESSURE

FIGURE 4



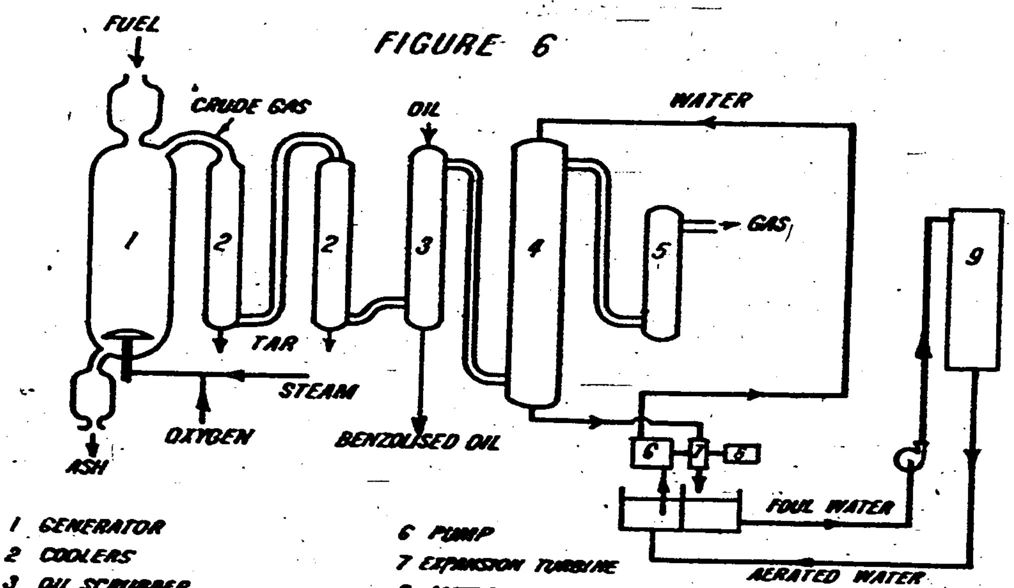
GROSS CALORIFIC VALUE OF GAS FROM BROWN COAL AND HARD COAL

FIGURE 5



FORMATION OF METHANE IN PRESSURE GASIFICATION

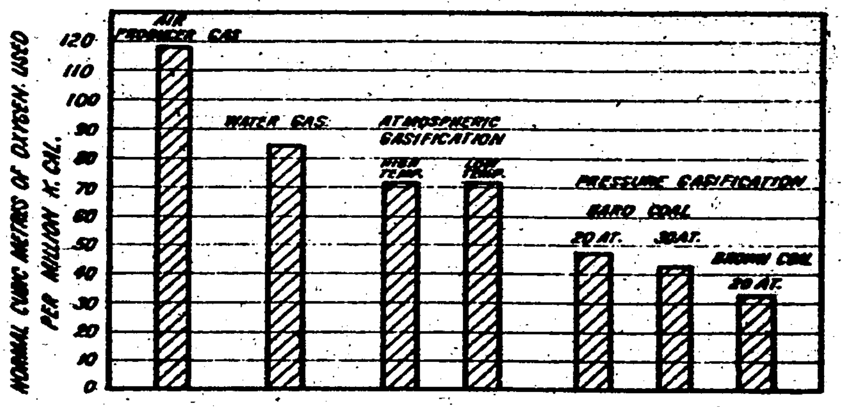
FIGURE 6



1 GENERATOR
2 COOLERS
3 OIL SCRUBBER
4 PRESSURE WATER WASHERS.
5 OXIDE PURIFIERS
6 PUMP
7 EXPANSION TURBINE
8. MOTOR
9. AERATION TOWER

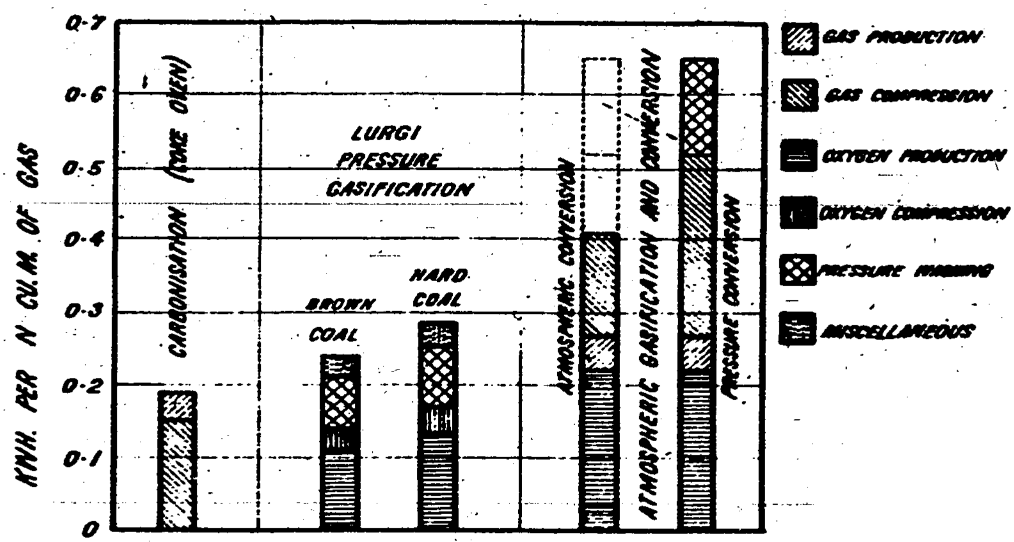
FLOW DIAGRAM OF PRESSURE GASIFICATION PLANT

FIGURE 7



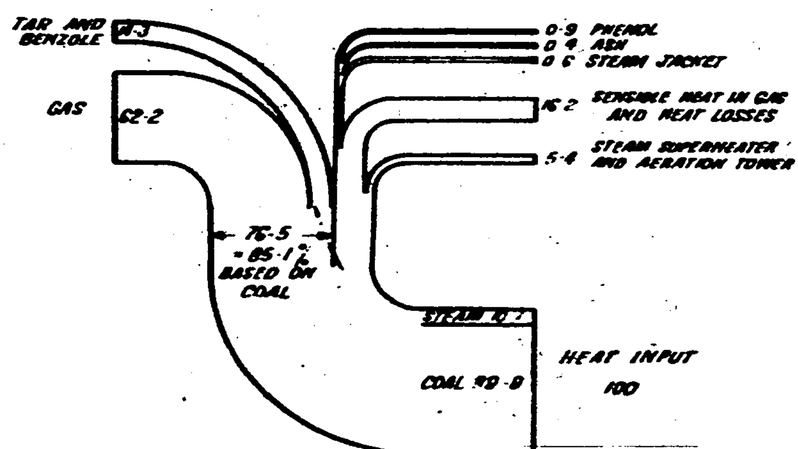
OXYGEN CONSUMPTION IN VARIOUS PROCESSES

FIGURE 8



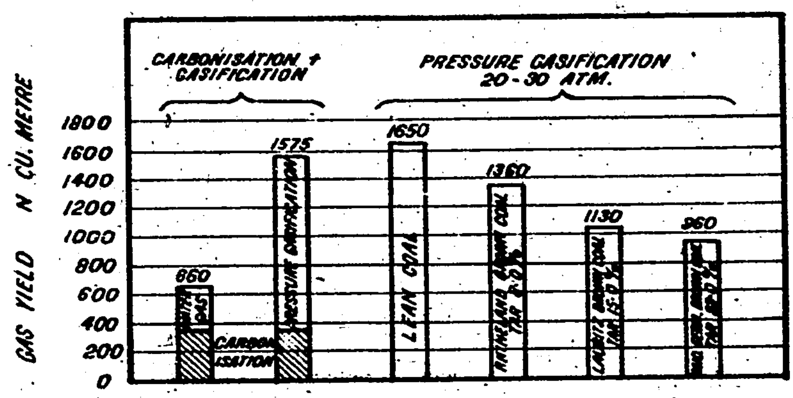
ENERGY REQUIRED TO PRODUCE GAS AT 20 ATMS.

FIGURE 9



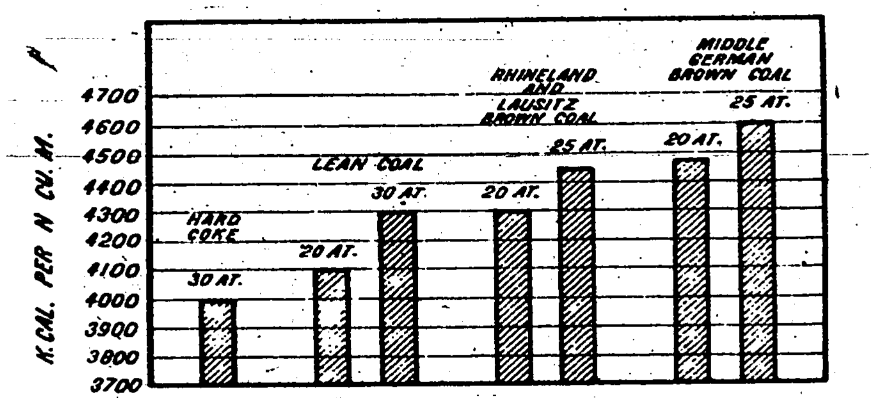
HEAT BALANCE FOR PRESSURE GASIFICATION

FIGURE 10



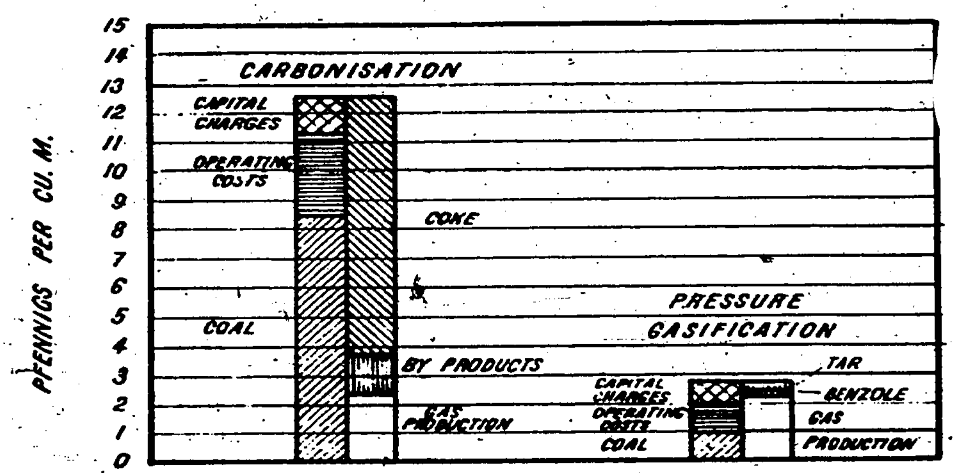
GAS YIELD PER TONNE OF DRY ASH-FREE COAL

FIGURE 11



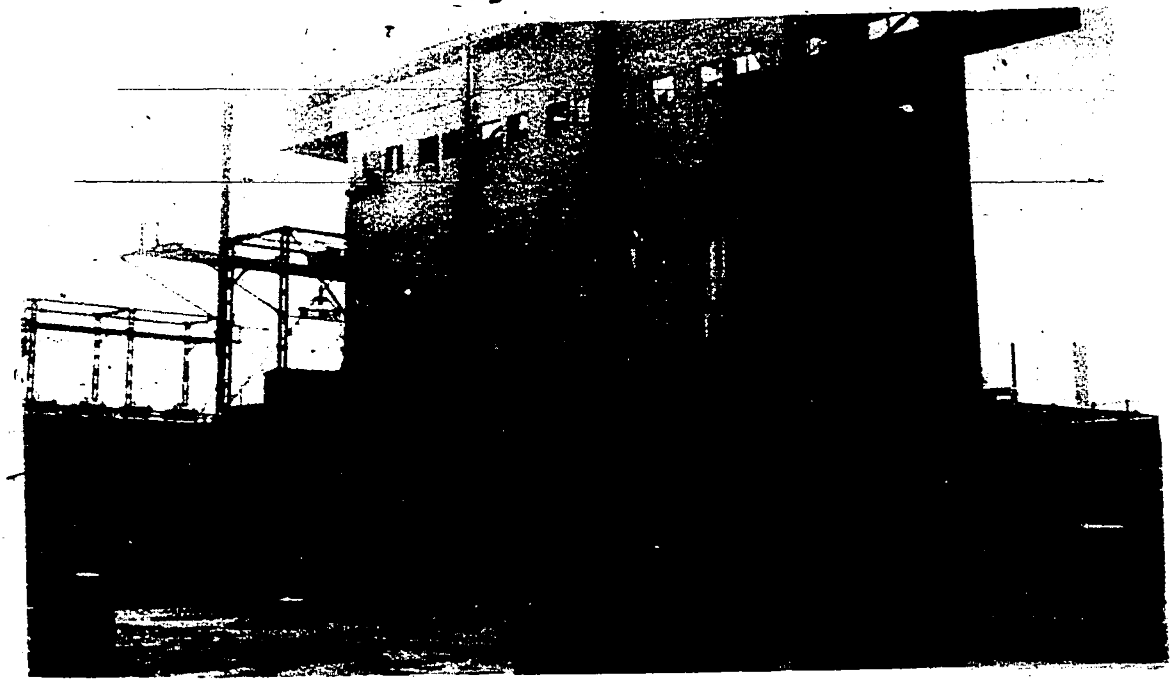
GROSS CALORIFIC VALUE OF GAS
IN RELATION TO FUEL AND GASIFICATION PRESSURE

FIGURE 12



COSTS OF CARBONISATION AND GASIFICATION.

FIGURE 13



VIEW OF GENERATOR HOUSE

FIGURE 14.

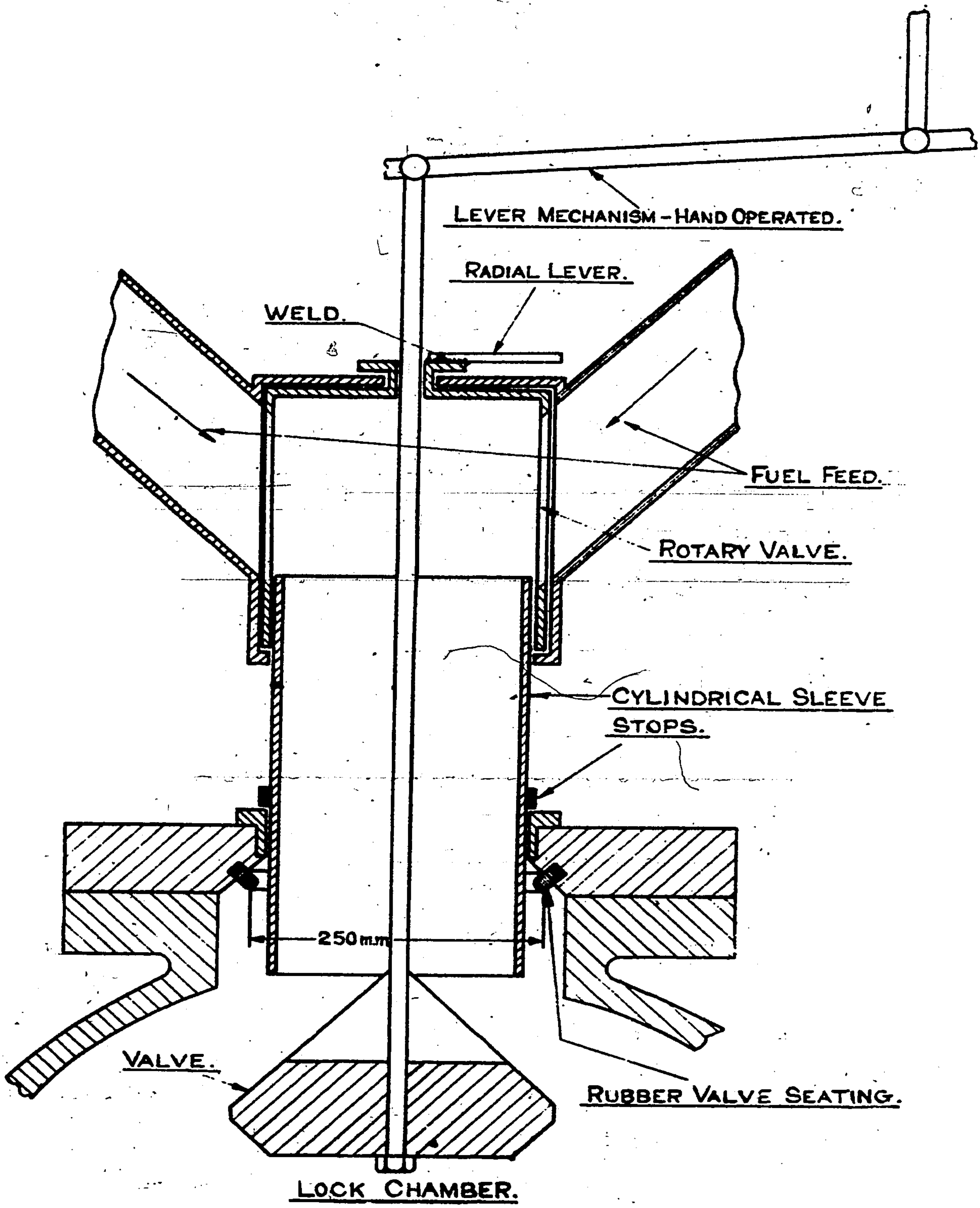


DIAGRAM OF FUEL FEED TO UPPER CHAMBER.
LURGI H.P. GASIFICATION PLANT-BÖHLEN.

FIGURE 15.

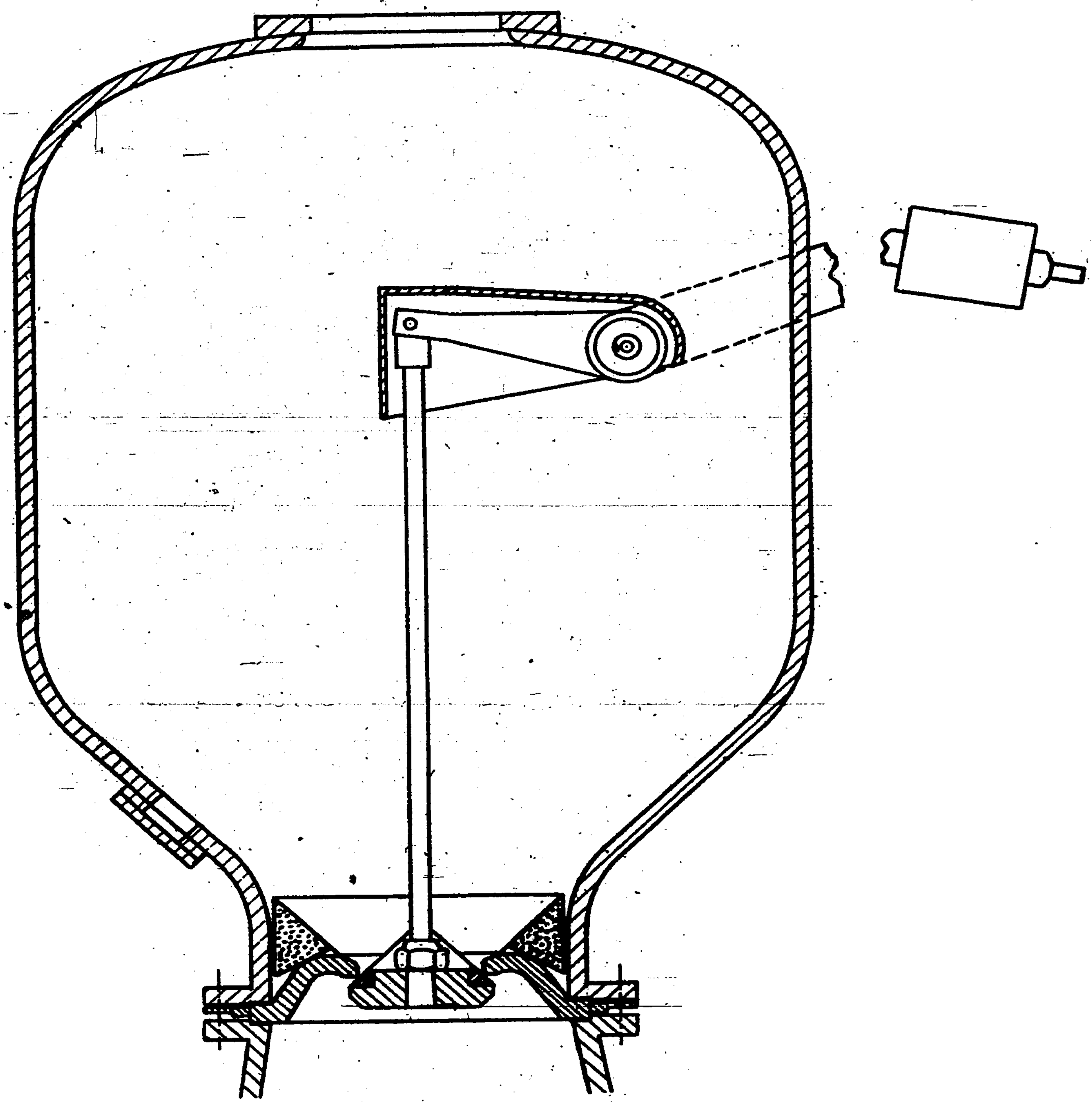


DIAGRAM OF BOTTOM VALVE OF UPPER LOCK CHAMBER
LURGI H.P. GASIFICATION PLANT – BÖHLEN.

FIGURE 16

VIEW OF CHARGING POUCH

FIGURE 17A

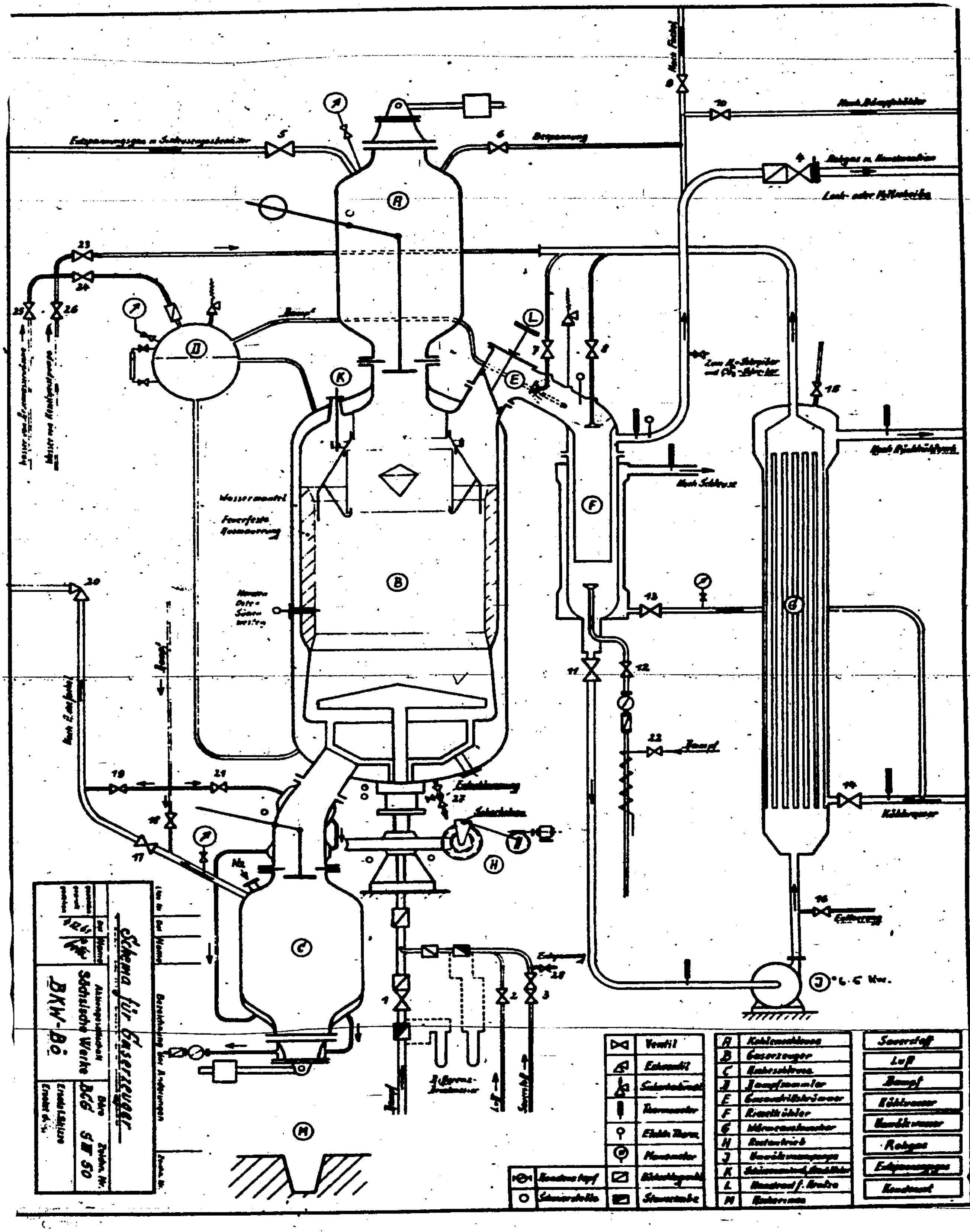
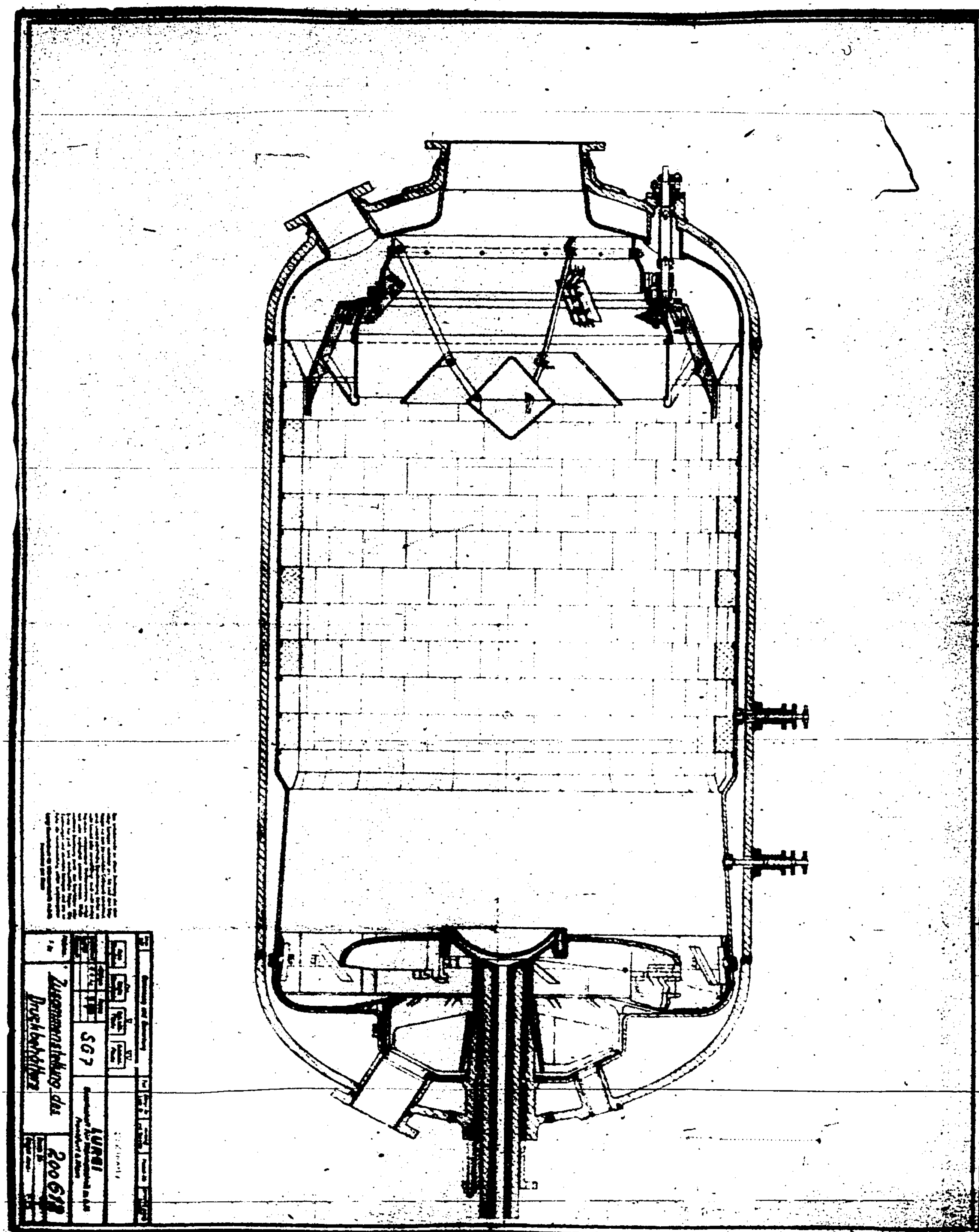


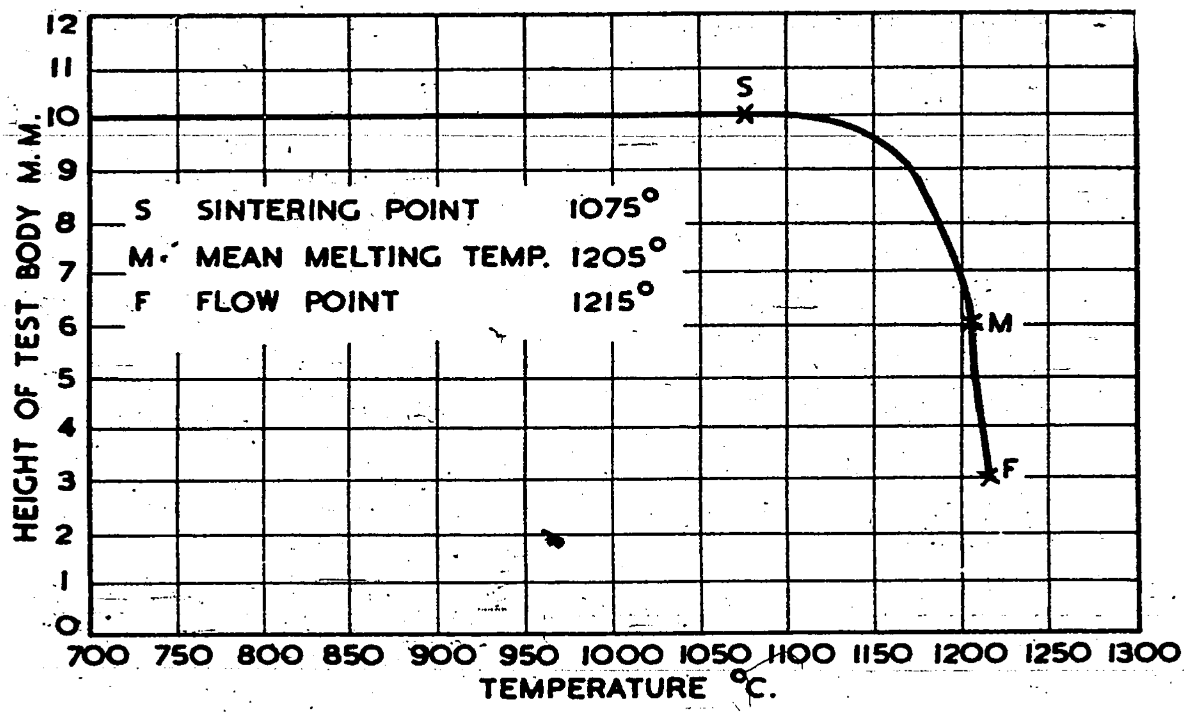
DIAGRAM OF GENERATOR

FIGURE 17 B



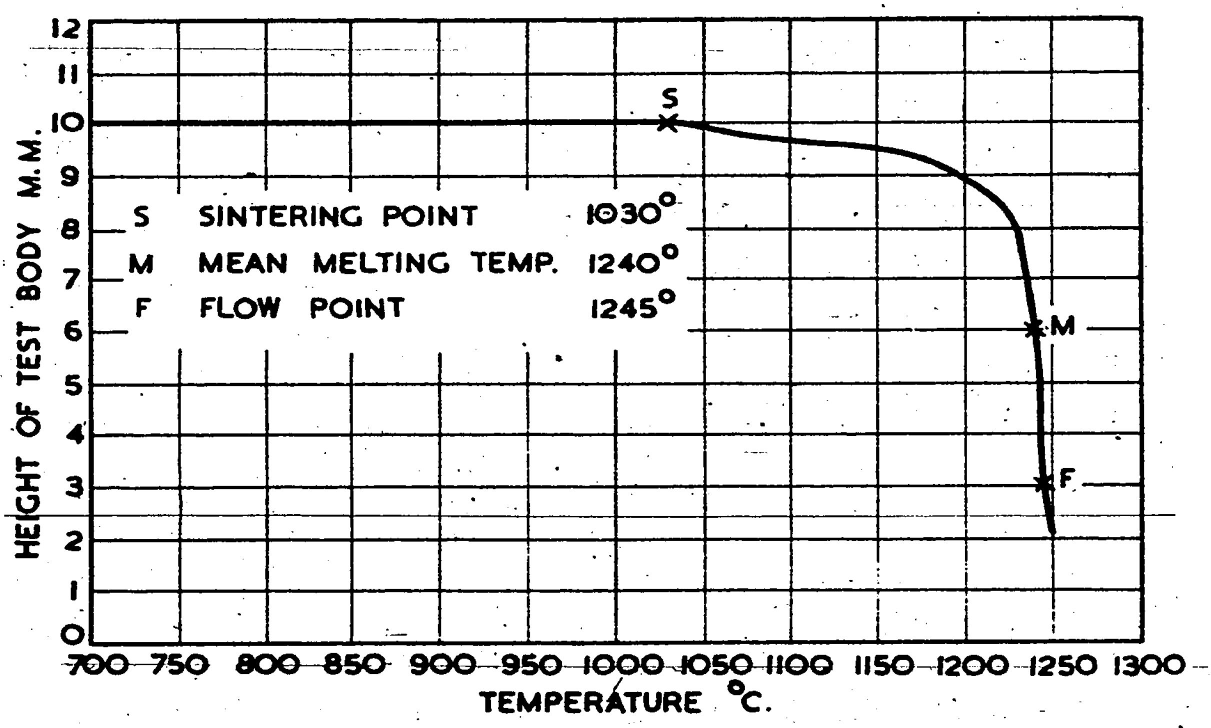
DRAWING OF GENERATOR

FIGURE 18



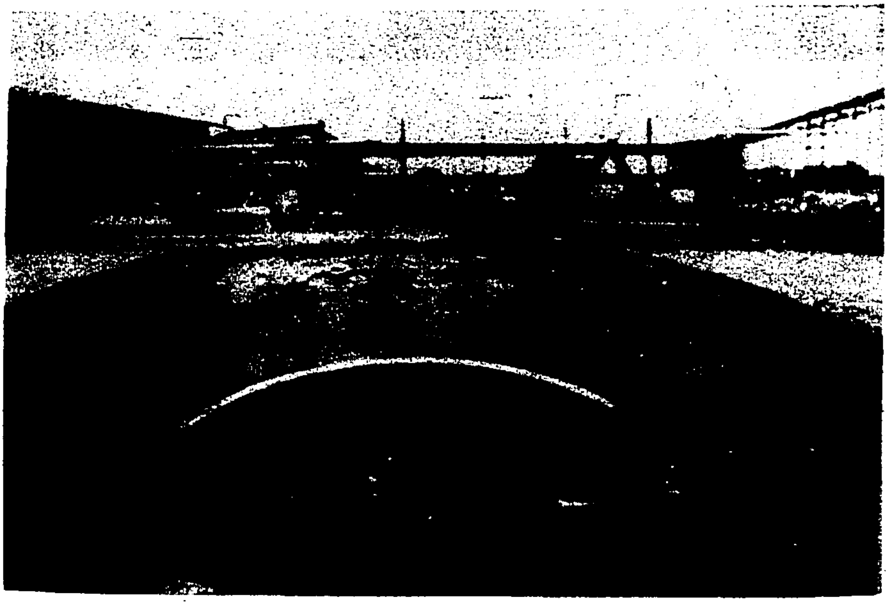
BUNTE-BAUM TEST OF CLINKER TAKEN FROM GENERATOR 9.7.42.

FIGURE 19.

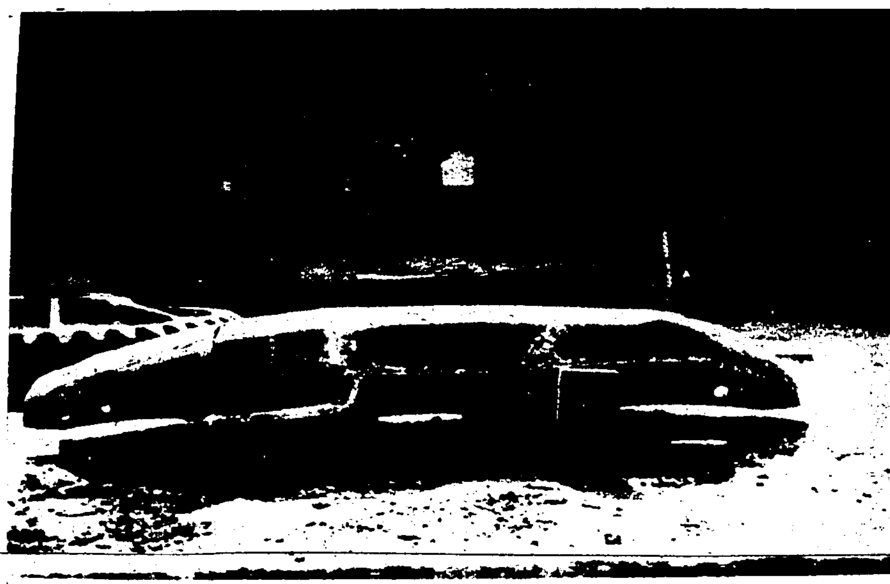


BUNTE-BAUM TEST OF COAL MIXTURE USED 27.6.42 – 6.7.42.

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.

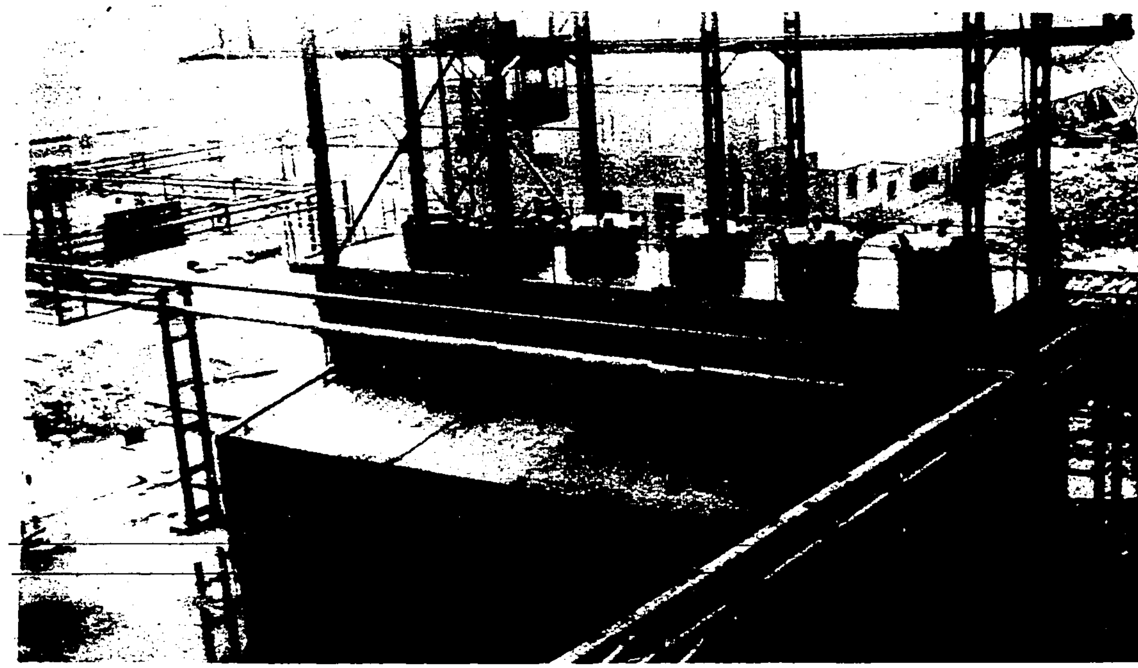
FIGURE 21

VIEW OF GAS COOLERS

FIGURE 22

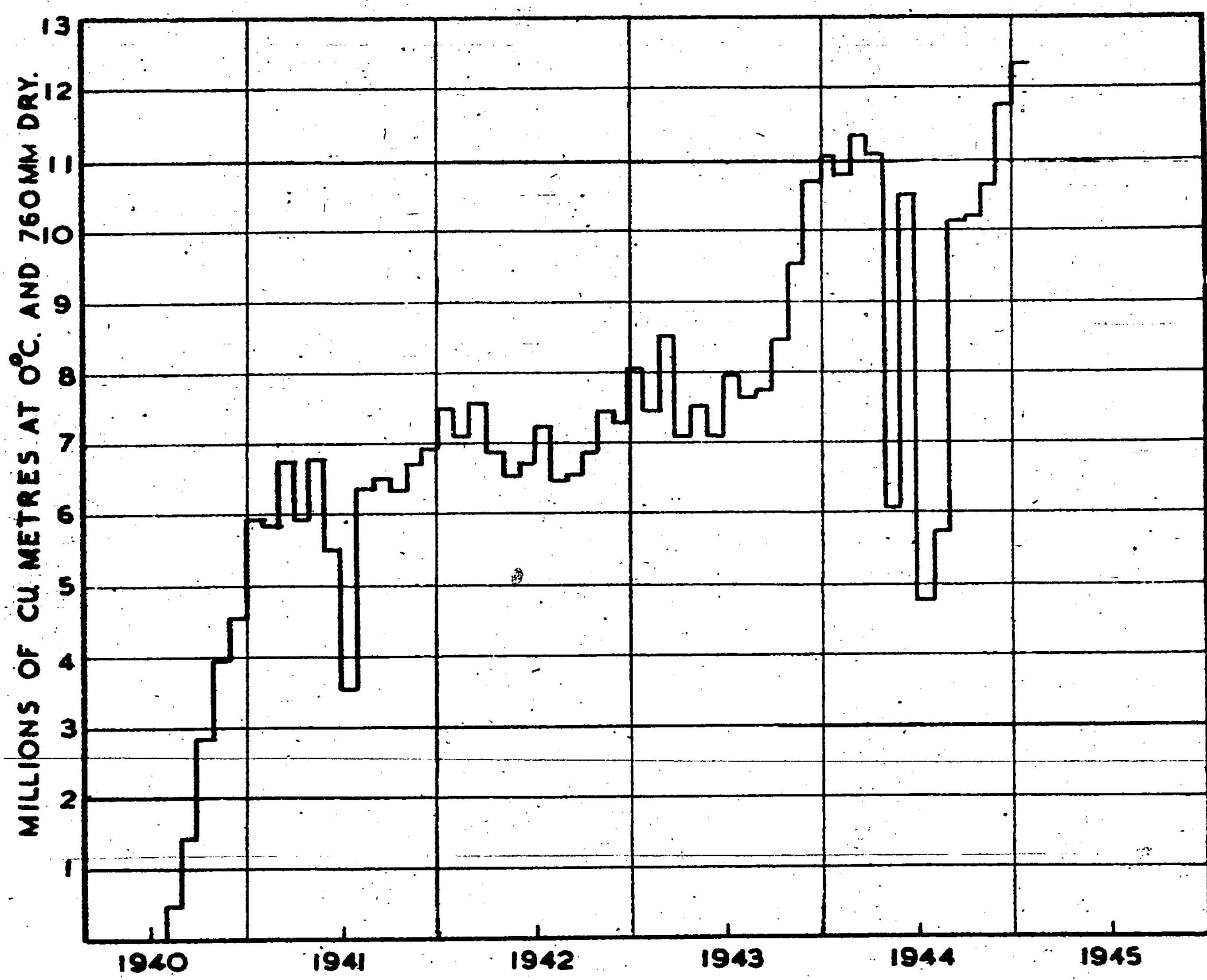
VIEW OF AERATION TOWERS

FIGURE 23



VIEW OF OXIDE PURIFIERS

FIG. 24.



MONTHLY PRODUCTION OF GAS AT BÖHLEN

FIGURE 25.

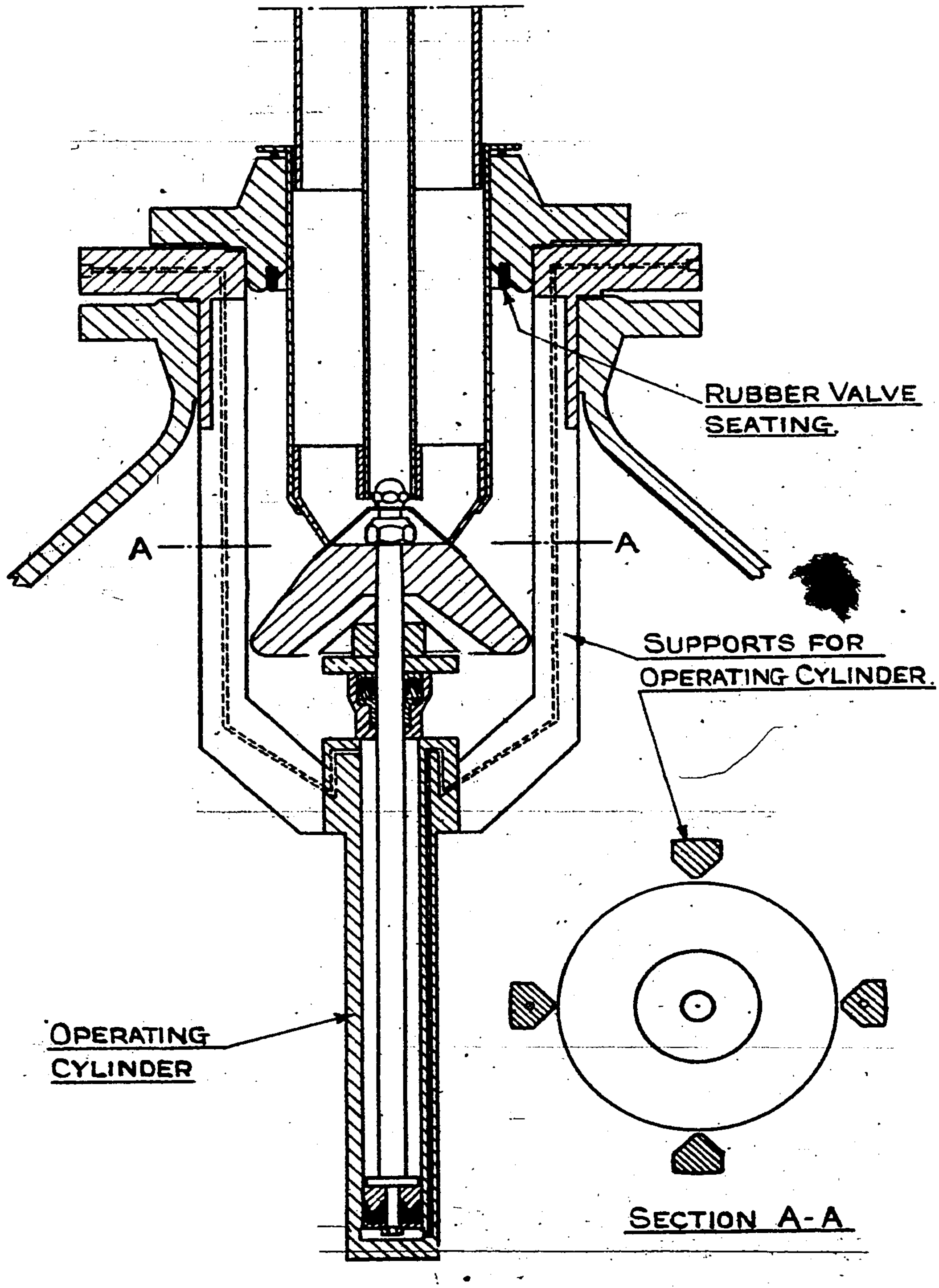


DIAGRAM OF HYDRAULIC TOP VALVE OF UPPER LOCK CHAMBER

LURGI H.P. GASIFICATION PLANT – BRÜX