FOREWORD

In the early part of 1945, as the Allied armies advanced, German laboratories and plants became available for investigation. Since German development work had been hidden from the eyes of the world by the Reich's national policy of secrecy, and by 5-1/2 years of war, it was obvious that much might be learned from such investigation. In particular, this was true in the synthetic-fuel industries deriving oil, gasoline, and a wide variety of chemicals from coal, for, owing to the scarcity of domestic petroleum, Germany had been forced into intense development of this field in contrast to the limited amount of similar development by the United States and Great Britain. Before the fighting ended in Europe, the United States and Great Britain organized teams comprised of experts in all fields to investigate the research and industrial operations in Germany. The teams investigating coal, oil, gasification, and allied chemical fields included more than 30 American investigators and about an equivalent number of British investigators during 1945 and functioned with a reduced staff into 1946. German work in the synthetic-liquid-fuels industries and allied fields was on such a large scale that even such extensive investigation could not possibly cover the subject in all detail. However, a great deal of information possible of direct application, and much information of a fundamental nature to help guide research work in this country for many years, was uncovered. Studies of the German industry are continuing, and it is hoped that such gaps in the information as now exist will be filled in by future work.

The primary fields that were covered in the oil and synthetic-fuels investigation were concerned with petroleum refining and the gas-synthesis and coal-hydrogenation processes for producing oil from coal. The related fields of coal gasification, oxygen production, alcohol manufacture, lubricating-oil production, and the production of waxes and edible fats, as well as a variety of other chemicals, were an inherent part of the investigation.

This report is one of a series which resulted from the investigations in Germany and other parts of Europe by the Technical Oil Mission, operating under the auspices of the Ministry of Fuel and Power for Great Britain and the Petroleum Administration for War and the Bureau of Mines for the United States. It is being published in accordance with the policy of the United States Government to make available to the interested public the results of the investigations of enemy research and industrial development.

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INTRODUCTION

The Leuna Factory of the I. G. Farbenindustrie A. G., situated near Merseburg, is the biggest heavy-chemical plant in Germany and produces a very wide range of products, mainly based on hydrogen or hydrogen and carbon monoxide. Its principal products are ammonia, synthetic petrol derived from the hydrogenation of brown coal, and synthetic alcohols made from hydrogen and carbon monoxide.

The plant was first visited on April 21, 1945, by a team including E. Cotton, V. Haensel, E. B. Peck, P. K. Kuhne, H. M. Weir, L. L. Hirst, W. W. Odell, G. U. Hopton, H. Hollings, J. F. Ellis, and H. G. Simpson. It was again visited on May 8-24, 1945, by a combined British and American team consisting of R. Holroyd, M. A. G. Banks, D. A. Howes, A. J. V. Underwood, R. A. Taylor, W. F. Faragher, H. Schindler, and J. G. Allen. This team was later joined by J. F. Ellis and R. J. Morley.

A third visit with particular reference to catalyst manufacture was made by W. F. Faragher and W. A. Horne, and the notes of these latest investigators have been taken into account in preparing the report.

This report was edited by Dr. R. Holroyd.

PERSONNEL OF VISITING TEAMS

1st Visit April 21 - 26, 1945.

Lt. Col. H. Hollings	)
Maj. J. F. Ellis	) British
Capt. H. G. Simpson	) Ministry of Fuel and
Capt. G. U. Hopton	) Power
E. B. Peck	) U. S. Petroleum
P. K. Kuhne	) Administration for War
H. M. Weir	)
V. Haensel	)
E. Cotton	)
L. L. Hirst	) U. S. Bureau of Mines
W. W. Odell	) Mines

2d Visit May 8 - 24, 1945.

Lt. Col. R. Holroyd	) British
Maj. M. A. G. Banks	) Ministry of Fuel and
Maj. D. A. Howes	) Power
Maj. A. J. V. Underwood	)
Maj. R. A. Taylor	)
Maj. R. J. Morley	)
Maj. J. E. Ellis	)
W. F. Faragher	) U. S. Petroleum
J. G. Allen	) Administration for War
H. Schindler	)

Among those visiting the plant later, the following submitted notes for inclusion in the present report:

L. L. Newman	) U. S. Bureau of Mines
W. A. Horne	) U. S. Petroleum
J. P. Jones	) Administration for War

Although not a member of any visiting team, Dr. H. Clough (British) has made a valuable contribution to the above report by studying evacuated documents and by his assistance in editing the final document.

I GAS PRODUCTION

The interrogation of Dr. Sabel (Engineer in charge of gas production) and Dr. Jeltsch (Chemist in charge of H_2S removal) was carried out by Hollings, Weir, Odell and Hopton on April 22nd and 23rd, 1945. Additional information was obtained by C. A. F. T. about the same time and by Ellis and Morley on May 16th. Newman interrogated Oberingenieur Ohler, Dr. Schroeter, Dipl. Ing. Stingl and Obermeister Heuer on May 14th and 15th, 1945, in regard to the detailed operation of the slagging gas producers (abstich-generatoren).

Gas Production

Water gas for NH_3 and methanol synthesis and for H_2 production was made in three distinct ways. The bulk was still made on water gas generators, of the usual design, working a cycle and using oven coke, and the rest was divided between Winkler generators, using O_2 and grude coke, and slagging producers, using O_2 and oven coke, or Rohschlacke (refuse from the Brassert generators). A rough summary of the plant can be seen in the following table:

Type	No. of Units	Unit Capacity M^3/hr Gas	Normal Output from Plant M^3/ hr. H_2 + CO
"Pintsch-Drehrost"	10	5,000)	240,000
"Pintsch-Brassert"		10-12,000?)	
Winkler	1	40,000)	55,000 (Limited by
	4	80,000)	(oxygen available: (a second Winkler (ran to make (producer gas for (power.)
Slagging producers	6	15,000(coke)	?
		8,200 (Rohschlacke)	30,000
Pintsch producers	10	?	Not used

Water Gas Generators

The original generators were of an old Humphreys and Glasgow design built by Pintsch (now referred to as "Drehrost-generatoren"), but most of them had been modified by Brassert (now referred to as Pintsch-Brassert-Generatoren). Very little attention was paid to this plant, as it was old and contained little novel. Only a few of the generators were seen, and as a number of changes had been carried out on various generators it was difficult in the short time available to get any clear idea of how many generators included each modification or indeed what was the effect of each modification. The following notes are therefore very incomplete.

All generators had concentric ring rotary grates, but whilst some were brick-lined others had jacket boilers. They had an I. D. of 3 m, so that the stated output of 10,000 to 12,000 M^3/hour must be considered very high and possibly in error. They were enabled to achieve high outputs without clinker troubles by extracting ash with a high coke content (50%C), the theory being that troublesome clinker could not form if ash were not allowed to accumulate in high concentration; the carbon in ashes was not lost, as it was used on the slagging producers. At least some of the generators actually in use were hand-operated.

The fuel used was oven coke, made from bituminous coal, and brought by rail from the Ruhr, a distance of 275 miles. The daily consumption of coke was 3,000 T/D.

We were told that until very recently the Winkler generators, using oxygen and local brown coal or grude coke, were more expensive to run than the coke water gas generators, despite the high cost of coke after its long haul and this had been the reason for the continued existence of the old method of gas manufacture. Only in the last years of the war, apparently, had the cost of Ruhr coke become high enough to make the Winkler generator cheaper to run. We do not know how far these arguments include considerations of the high capital cost needed for a new plant, remembering the old generators were in existence.

<u>Winkler Generators</u> (Site 279 on Works plan)

These generators were built in 1929-31 and since then have been subjected only to minor modifications. Since more modern installations were seen elsewhere (e.g. Zeitz) the plant was not covered in much detail. They have been used to gasify both dried brown coal and "grude" coke (brown coal low temperature coke), and have been used for the manufacture of power gas, producer gas for NH_3 synthesis and water gas. In recent years the fuel has been almost entirely grude coke, with one Winkler run to make power gas and one run to make water gas. Shortage of oxygen limited the plant output of water gas to one Winkler.

The principle of the Winkler generator is well known: particulate fuel was used, the most suitable size being 3 mm diameter, with less than 10% above 5 mm and the blast of air alone (when making power gas) or of a mixture of oxygen and steam (when making water gas) was sufficient to make the fuel "dance" or boil. As a result very high outputs could be obtained from a given cross-section in comparison with orthodox water gas generators.

There were five Winkler generators in all; the oldest and smallest one had an output of 40,000 M^3/hour water gas for a cross-section area of 12 sq.m. and the other four each had an output of 80,000 M^3/hour water gas for a grate area of 25 sq.m.

The change over from dry brown coal to grude coke probably took place because of the increased demands of hydrogenation for dry brown coal, thus causing a limitation of drying capacity, and also because of the availability of grude coke from various neighbouring brown coal L. T. carbonization plants, set up primarily to recover tar from the coal. Both fuels were quite satisfactorily gasified, although dry brown coal gave a higher CH_4 content of synthesis gas. The fuel was fed into the side of the conical base by four screw conveyors.

All the generators originally had stationary grates, over which swept a rotating water-cooled arm, to remove ash through an opening on one side. The blast passed through this grate. In recent years however the small generator (1943) and one large generator (1944) were modified and the grate and rotating arm eliminated, the oxygen and steam mixture then being added through tuyeres entering the side of the conical base; this successfully eliminated all shut-downs for repairs of the rotating arm, although by then the earlier rather serious troubles due to leaks from the arm, had been much reduced; more important however, it was claimed that the modification had reduced the consumption of fuel and oxygen by about 10%, although no reason was given. The grateless generator was fitted with two screw conveyors at the base, which could be run intermittenly to remove that ash, foreign material, etc., which was not blown over and had collected at the base. A grateless generator has been installed at Brüx.

In operation of generators with grates only about 10% of the ash was withdrawn at the base through screw conveyors: the remainder passed overhead. It was possible to run for 1 to 2 weeks without these screw conveyors, large material merely collecting slowly on the grate. The overhead ash contained 50 to 55% carbon and had a maximum size of 0.3 to 0.4 mm. It could either be returned to the generator or burnt on boilers: it had also been used as an active carbon for the dephenolation of effluents.

The blast, when making water gas, consisted of a mixture of 40 to 50% oxygen with 60 to 50% steam. About two-thirds of the oxygen was blown through the bed and one-third, mixed with 20% steam to prevent explosions in the tuyere main, was blown through tuyeres into the gas space about 3 to 4 m above the bed, with the object of gasifying carbon in dust entrained in the gas and cracking any tar and hydrocarbons. The original design had the top half of the generator enlarged to a bulb, designed to give a longer time contact for these reactions, but in later designs this was eliminated and the straight cylindrical portion heightened to give the same effect; the reason for the change was given as capital cost. Some of the generators at Leuna still had these bulbs, but some had not; the exact number of each was not obtained with any certainty. In all later plants the straight-sided generators were installed, e.g. three at each of the Brabag plants at Böhlen, Magdeburg and Zeitz, and five at Brüx (but including one grateless type as mentioned before). The most detailed account of this design is given in the report on Zeitz. Three such generators were also built by I. G. at Ludwigshafen for Japan, designed to work on a grain size mineral coal of particularly active character.

The whole generator was brick-lined and no trouble was obtained with clinker. The fuel bed temperature was about 900° C, but this depended on the nature of the fuel. The bed depth was about 1 m. and had a back pressure of about 0.5 m. water gauge.

With less reactive fuels, such as bituminous coal derivatives, the Winkler generator was said to be much less satisfactory. Much higher bed temperatures had to be used and the CO_2 in water gas was high.

Typical performance figures were given as follows:-

		Water Gas		Power Gas	
		Dry Brown Coal	Grude	Dry Brown Coal	Grude
Gas Analysis	$\%CO_2$	19	20	10	11
(H_2S free)	%CO	38	38	22	27
	$\%H_2$	40	40	12	7
	$\%CH_4$	2	1.5	0.7)	55
	$\%N_2$	1	0.5	55)	
Net C.V.T.cals/M		–	–	950	956
Fuel	kg/M^3	0.625	0.50	0.335	?
Oxygen	M^3/M^3	0.25-0.26	0.25-0.26	nil	nil
Steam	M^3/M^3	0.39	0.375	nil	nil

Typical analyses of the fuels, not necessarily corresponding with the above figures, were:

	Dry Brown Coal (dry basis)	Grude Coke (dry basis)
C	61.1	68
H	4.7	2.0
O	17.0	2.2
N	0.1	–
Volatile S	3.3	1.3
Ash	13.8	26.5
H_2O	(6.0)	(2.0)

The major thermal losses were as carbon carried away as dust and as sensible heat carried away in the water gas at about 900° C. The flue gas was passed through a cyclone to recover any coarse dust, was cooled to about 200° C in a waste heat boiler, and passed through a hydraulic seal; it was then dedusted in a direct contact water washer and a Theisen disintegrator. It was stated that unsuccessful attempts had been made to build recuperators and heat exchangers in the top of the generator, presumably to preheat the blast.

To avoid explosions when using oxygen-steam blasts it was essential to get good mixing; on the Winklers it was present practice to mix at a minimum distance of 30 to 40 m. from the point of entry into the generator, with several bends to promote turbulence.

Slagging Producers ("Abstichgeneratoren").

The original slagging producers at Leuna were three Würth producers, using coke breeze, "ashes" from the water gas generators or simply coke, blown with air only to make producer gas for NH_3 synthesis; the producers were completely brick-lined and ash was removed as molten slag. Steam or oxygen could be added as conditions permitted.

Owing presumably to brickwork failures the Würth type was replaced by another, in which the whole of the lower part of the producer was water-cooled. There were six of these producers, five of I. G. design and one by Pintsch. One had been built during the war. The producers were blown with oxygen and steam and the capacity of each unit was 15,000 M^3/hour of substantially nitrogen-free producer gas.

The producer was built of 1/2" to 5/8" iron plate, having a diameter of 2.5 metres at the tuyeres and 3.8 metres higher up, with the inside diameter of the brickwork 1.7 metres at the tuyeres and 3.3 metres at the top. The total height was 7 m. above the tuyeres and the fuel bed was 4 m. deep above the tuyeres. Only the top part, above the fuel bed, and the lower part, below the tuyeres were brick-lined; the rest was bare metal. In five generators the producer was water jacketed but in the last one built the jacket had been omitted and the metal was cooled merely by trickling water down over the outside. This modification had been carried out as the result of a serious accident on one of the old type; a piece of clinker became lodged just above a tuyere and as a result the incoming oxygen caused a very high local temperature, which burnt a hole in the jacket; the producer became flooded and quenched and before it was noticed oxygen had broken through, causing a serious explosion in the gas mains and gas coolers. This could not happen with the latest design; it was said that there was no trouble with evolution of steam as the water merely became warm.

It was very difficult to make power gas on these producers, using air only; the difficulty was presumably insufficiently high temperature to permit slagging, owing to heat abstracted through the generator walls, since the old brick-lined Würth producers could be run successfully on air.

When making producer gas, a mixture of oxygen and steam was introduced at the tuyeres and a temperature of 1,700° C was obtained, although the exit gas temperature was only 400° C. Limestone could be added to act as a flux for the liquid slag. Depending on the fuel, slag was run off at intervals of 20 to 60 minutes. One method of slagging was to run the liquid slag first into troughs, where any iron sank (and was dug out at intervals), and then into cold water; another method was to tap off molten iron from the extreme bottom of the generator and molten slag from a tap somewhat higher.

A wide variety of fuels could be used, but Rohschlacke (refuse) containing 50% carbon, from the Brassert generators was normally used. The fuel should be above 30 mm. and could be as large as 1 to 2 feet. When using metallurgical coke it was common practice to add 3% of limestone and 20% of solid slag from previous working to assist in the formation of slag. When using coke the blast mixture was 35% O_2 and 65% steam; when using Brassert Rohschlacke the mixture contained 50 to 58% O_2 and 50 to 42% steam.

Typical operating figures were:

		Brassert Refuse	Grude from Deuben	Met. Coke	Met. Coke with CO_2
CO_2	%	9.7	5.4	6.8	3.0
CO	%	66.5	62.4	61.4	92.5
H_2	%	22.9	31.2	31.0	3.0
CH_4	%	0.0	0.0	0.0	0.0
N_2	%	0.9	1.0	0.8	1.5
H_2S	g/M^3	2.7	13	4.3	2.2
O_2	M^3/M^3 H_2 + CO	0.347	0.276	0.262	0.310
H_2O	kg/M^3 H_2 + CO	0.207	0.266	0.346	nil
CO_2	M^3/M^3 H_2 + CO	nil	nil	nil	0.258
Fuel	kg/M^3 H_2 + CO	?	0.80	0.490	0.330
Carbon	" H_2 + CO	?	0.482	0.424	0.460
Fuel Analysis	C %	45-50	54	86.8	87.2
	ash %	55-40	16.9	9.1	11.8
	H_2O	0	22	1.8	1.0

The figures in the last column are interesting; here steam in the blast was replaced by CO_2, resulting in a very high content of CO in the gas made.

Smaller slagging producers were available and used for testing various fuels and various methods of running.

Pattenhausen Generator

This generator was not inspected, although the installation was seen from a distance. The principle of this generator was that all the heat of reaction was added in the form of highly preheated steam at about 900° C. A large excess (fourfold?) of steam was used and gasification of dry brown coal proceeded at about 600° to 700° C, a temperature only possible with a highly reactive fuel. We gathered that the plant was not a great success and certainly no other units had been built, although the original one started up in 1937.

Oxygen Plant

This consisted of Linde-Frankl units of conventional design and was not studied in detail. There were 9 units in all, having a total capacity of 23,700 M^3/hour of 98% O_2, the two oldest units producing 1,900 and the other seven 2,850 M^3/hour. The actual output over the five years 1938-42 averaged 22,000 M^3/hour 100% O_2. A somewhat smaller