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WINKLER GENERATORS FOR MANUFACTURE OF WATER GAS,

Etc.

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BRITISH INTELLIGENCE OBJECTIVES SUB-COMMITTEE

LONDON — H.M. STATIONERY OFFICE

WINKLER GENERATORS
FOR MANUFACTURE OF WATER GAS ETC.

Reported by

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on behalf of

Ministry of Fuel and Power.

BIOS Target No. C30/364

Fuels and Lubricants.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Units of Gas Measurements

Throughout this report gas quantities are quoted in Nm^3, measured dry at 15°C and 735.5 mms mercury; this is the normal practice at I.G. and BRABAG factories.

WINKLER GENERATORS FOR MANUFACTURE OF WATER GAS ETC.

SUMMARY

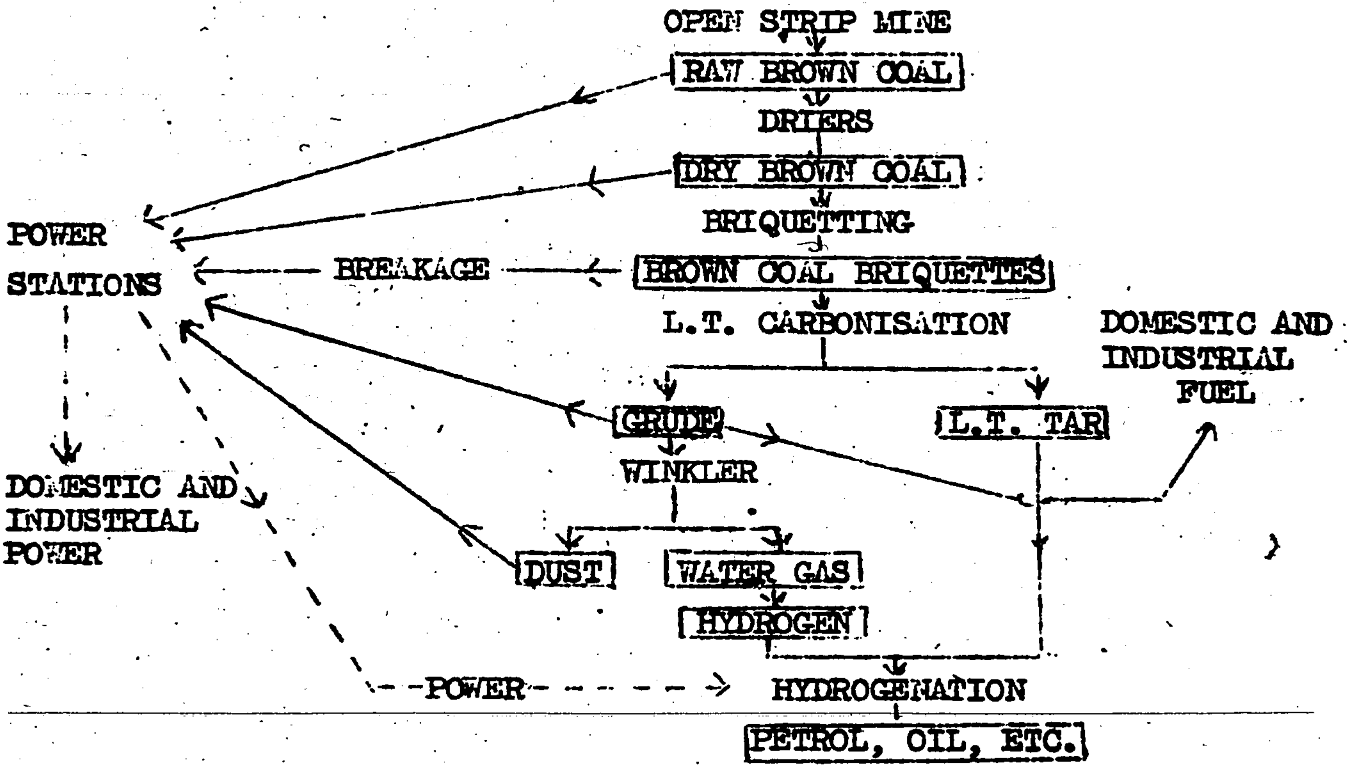
All the available information concerning Winkler generators, contained in C.I.O.S. reports and in documents brought back by C.I.O.S. missions to Germany in 1945, is collected together and combined with literature references to give a comprehensive account of the history and present status of the process. There are at least five large plants in Central Germany and Czechoslovakia using the process and possibly one plant in Japan. The process is technically sound and well-established but appears to be economic only where cheap fuel, e.g brown coal or brown coal coke, is available, which cannot be gasified conveniently in other ways.

INTRODUCTION

The first large-scale Winkler generator for making power gas was put into operation at Leuna in 1926 and the first large-scale generator making water gas followed in 1930; the successful use of a "boiling" bed of fine fuel thus introduced a new process for the manufacture of power gas and water gas. Since then the process has become firmly established inside Germany and since 1936 has found considerable use in the large-scale production of hydrogen in plants manufacturing petrols, oils, etc., by the hydrogenation of brown coal and brown coal tar. For the manufacture of hydrogen the process requires large quantities of oxygen, and despite the fact that the Linde-Fränkl process, developed in the last 20 years, is a marked improvement over older processes, oxygen is still relatively expensive, so that its use, and hence the use of the Winkler process, can only be justified when it makes possible the use of a cheap fuel, which otherwise could not be satisfactorily gasified. This explains why all known Winkler generators are located near the brown coal fields of Central Europe; brown coal, as obtained by open strip mining, is very cheap, but it is difficult to get it into a form suitable for use in a conventional "make-and-blow" water-gas generator; on the other hand brown coal is an ideal fuel for a Winkler generator.

In recent years German economy has been such that it was advantageous to produce vast quantities of petrol and oil from indigenous coal. A particularly favourable process was to hydrogenate the tar obtained from the low temperature carbonisation of brown coal briquettes; this carbonisation produced several times as much brown coal coke, or "grude" coke, as it did tar, so that a use had to be found for the vast quantities of grude. The biggest use of grude was for firing the boilers of power stations, already existing in many cases and previously using raw brown coal, but it was also very convenient to use grude for making the hydrogen, required for hydrogenating the tar. Moreover since the Winkler process resulted in an appreciable fraction of the fuel being carried over as dust with the gas, it was also very convenient to be able to recover this dust and use it as boiler fuel.

Thus there has grown up in Central Germany, centred around Leipzig, a collection of large factories, all primarily based on the vast deposits of brown coal found in that region; these factories, although carrying on different processes, are largely inter-related and are often located on the same or neighbouring sites. The diagram below sets out this inter-relationship.



The diagram shows up how the power stations can be used as a sink for unwanted products and how they can be used to keep a balance.

As far as we are aware there are no Winkler generators outside the Central European area, (possibly excepting Japan), and there are no large generators operating on anything but dry brown coal or brown coal grude. It is possible to operate Winkler generators on bituminous coals, L.T. coke from bituminous coal or even anthracite; operation however is not so satisfactory and in general it appears that the Winkler process is not economic for such fuels, where the alternative processes of coke ovens - water gas generators are available. Indeed even at Leuna, in the centre of the brown coal area, according to Ref. 1 Winkler gas cost approximately the same as water gas from ordinary water gas generators, operating on hard coke, brought 275 miles from the Ruhr.

The Winkler process is not suited to making town's gas, as the calorific value is low, and its field of application appears to be limited to the large-scale production of (a) water gas, to be used for manufacture of hydrogen, methanol or Fischer-Tropsch synthesis gas, (b) producer gas, to be used as a fuel gas or power gas, and (c) ammonia synthesis gas, but in all cases based on a cheap fuel, not otherwise easily utilisable. In the light of this it is easy to see why the process has not hitherto been used in Great Britain or the U.S.A. Nevertheless it is a technically sound process and economic in a limited field of application. Brown coal occurs extensively in the U.S.A. and Australia (but not in Great Britain) and there is no reason why the process should not eventually be operated in those countries at least.

WINKLER GENERATOR INSTALLATIONS

Table I is a list of known Winkler generator installations.

TABLE I

Plant	Started up	Operating Company	Units	Approx. Output/unit M^3/hr. water gas	Remarks	Ref.
GERMANY						
Leuna 20 m W Leipzig	1926 to 1930	I.G.	4 1	60,000 30,000	75,000 on producer gas. Only one unit works on water gas and one on producer gas at one time.	1
Böhlen 10 m S Leipzig	1938	Brabag	3	20,000		2
Zeitz 20 m SSW Leipzig	1939	Brabag	3	20,000		3
Magdeburg 50 m NW Leipzig	1939?	Brabag	3	20,000		1
CZECHOSLOVAKIA						
Brüx 80 m SE Leipzig	1942	Sudetenlandische Treibstoffwerke A.G.	5 or 6	20,000		1

In addition there are small units at Oppau, nr. Mannheim, as well as at Leuna, operated by I.G. to test various coals. It is also possible that there are three generators in Japan (Ref.1).

HISTORICAL

The Winkler generator was developed by the I.G.; the development work was carried out at Oppau and large-scale plants were first erected at Leuna. The huge production of ammonia and methanol at Leuna was originally based on synthesis gases made from hard coke, brought from the Ruhr and gasified in conventional water-gas generators, operating on a make and blow cycle. The local cheap brown coal was used only for steam raising and for making producer gas, used as a power gas, but the power requirements of ammonia and methanol synthesis were so high that it paid to locate the factory on the brown-coal fields, rather than near a supply of hard coke, quite apart from any military reasons. In 1920-30 the I.G. were much concerned with the possibility of using brown coal, instead of coke, for synthesis gas manufacture. Before that time brown coal could be used for making producer gas, for power, only after submitting it to the relatively expensive process of briquetting; even so the producer gas contained up to 2% CH_4 and could not be used for ammonia synthesis, whilst the low ash m.p. and low strength of the fuel were additional obstacles; there was no satisfactory process for making water gas or producer gas from brown coal, suitable for ammonia and methanol synthesis.

Dr Fritz Winkler in 1921 (Ref.5) conceived the idea of using a "boiling" bed, i.e. using particles of fuel small enough to be almost gas-borne and hence comparatively mobile. Under such conditions the fuel bed behaves very much like a liquid; the gas passing through the fuel gives an appearance as if the bed were boiling, the bed finds its own level, as does a liquid, and circulation of particles within the bed is such as to give substantially equal temperatures throughout the bed. The first patent, DRP 437,970 was applied for on 28/9/22 and several others followed (Ref.7). The original work at Oppau was directed towards making power gas and the first Winkler producer (No.1) was put into operation at Leuna in 1926, having a capacity of 40,000 M^3/hr, equivalent to 3,300 M^3/hr/M^2 grate area. By 1929, four more producers had been added, each having a grate area of 25 M^2, double that of the first. During 1929 the whole plant often produced 200,000 to 230,000 M^3/hr power gas, and at times as much as 300,000 M^3/hr. One year afterwards, however, the slump hit Germany and requirements of power gas sank considerably, and normally only one or two producers had to be run.

After initial experiments at Oppau attempts were made at Leuna to make water gas from brown coal, coke or grude, by the "make-and-blow" method, without the use of oxygen, as described in DRP 437,970. It was expected that raw brown coal could not be used, because the presence of carbonisation products in the gases made would render them unfit for subsequent use, so grude was used. It was hoped that by blowing air alone through the boiling bed to raise its temperature and then passing steam through it, water gas could be successfully made, but the attempt failed for the following reasons. Particulate fuel, contained in a bed of fixed cross-sectional area, will "boil" satisfactorily only with gas velocities between certain fairly narrow limits; if the velocity is too low the bed ceases to boil and if it is too high entrainment occurs and the fuel is blown from the bed. A compromise had therefore to be made between air and steam rates. The steam rate had to be high enough to boil the bed, and the fuel bed deep enough so that too much undecomposed steam did not pass. The air rate had to be held below that which would cause entrainment, but it was desirable to have shallow fuel beds, so as to keep the time of contact between blow gas and fuel low enough to prevent excessive reaction between CO_2 and fuel. In practice it was found that with the highly reactive grude the CO content of blow gas was very high, and in fact blow gas approximated to producer gas, and this, coupled with the high exit temperature of blow gas, 1,000°C., gave an undesirably high ratio of producer gas/water gas, viz. about 5:1. This ratio was much bigger than the power gas/synthesis gas ratio for processes worked at Leuna and moreover water gas still contained 1% CH_4, which was still a drawback, although did not entirely prohibit its use. Theoretically the process could have been improved by preheating the air and steam with the hot waste gases, but this was not tried at that time.

In 1929 small-scale tests were commenced at Leuna, with the object of making NH_3 synthesis gas continuously from dry brown coal or grude, by using a continuous blast of steam and oxygen-enriched air. In 1930 the original No.1 generator was producing about 10,000 M^3/hr. of mixed gas for ammonia synthesis, but the CH_4 content was still an objection.

Also in 1930 Leuna began the production of nitrogen-free water gas, and profiting by previous experience, a satisfactory way was devised of using a continuous blast of pure oxygen with steam. Both grude and later dry brown coal were used as fuel, and three of the existing large Winkler producers were adapted for the purpose. In 1932-3 new Linde-Fränkl air separation plants were installed, specially to make oxygen for the Winkler generators. The introduction of part of the oxygen-steam mixture above the boiling fuel bed was useful in reducing the CH_4 content of the gas made, especially when using dry brown coal, but the content of 1 to 2% was now tolerated because of other advantages of the process and because Winkler gas provided only a part of the synthesis gas requirements.

Since 1933 as a rule one of the large Winkler producers at Leuna has continued to make 40,000 to 70,000 M^3/hr power gas, and one large generator to make up to 60,000 M^3/hr nitrogen-free water gas. It is to be noted that the old coke water-gas generators were still running in 1945, making several times as much gas as did the Winkler water gas generator. That a complete changeover was not made was due partly at least to the high brown coal demands of the factory as a whole on neighbouring mines (Ref 6, p.12); it is expensive to transport brown coal more than short distances, owing to its bulk, high water content and reactivity. It is also probable that Winkler water gas was not so much cheaper than coke water gas at Leuna, as to warrant the large capital expenditure required for the conversion.

In 1936 a large expansion of German synthetic petrol and oil industry was started, and Winkler generators, using oxygen to gasify grude, were chosen for manufacturing hydrogen at the BRABAG(Braunkohle-Benzin-A.G.) plants erected at Böhlen, Zeitz and Magdeburg; the plants

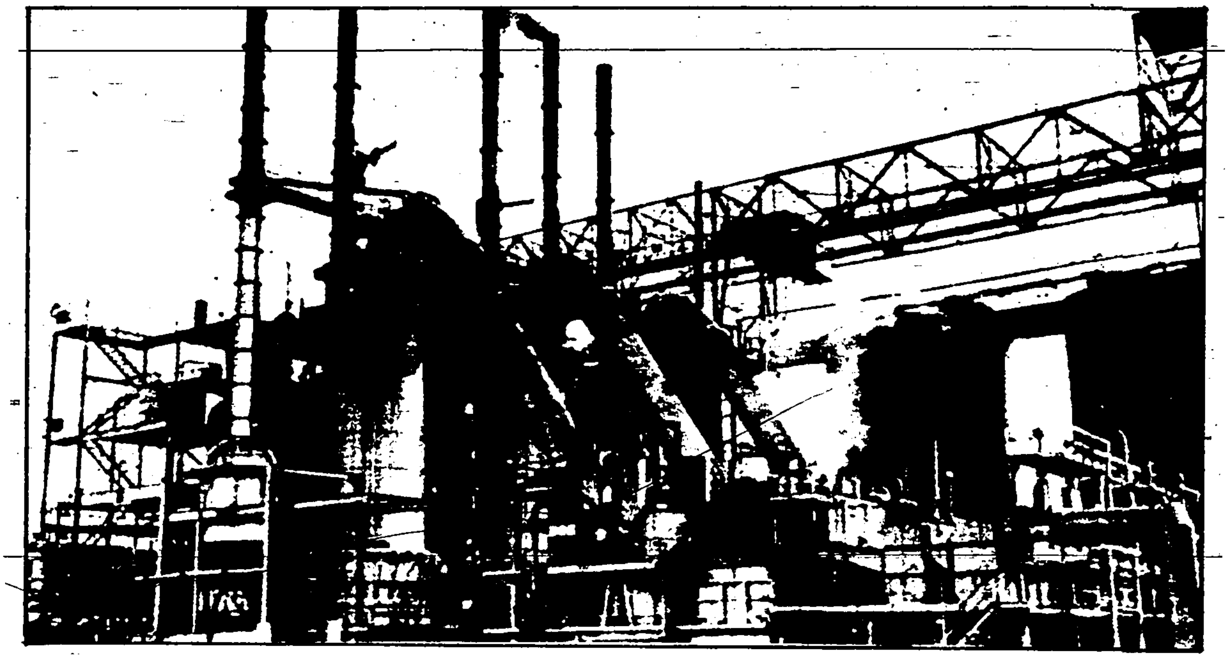


Fig. I General View of a BRABAG Plant
(believed to be Zeitz; from Oel u. Kohle)

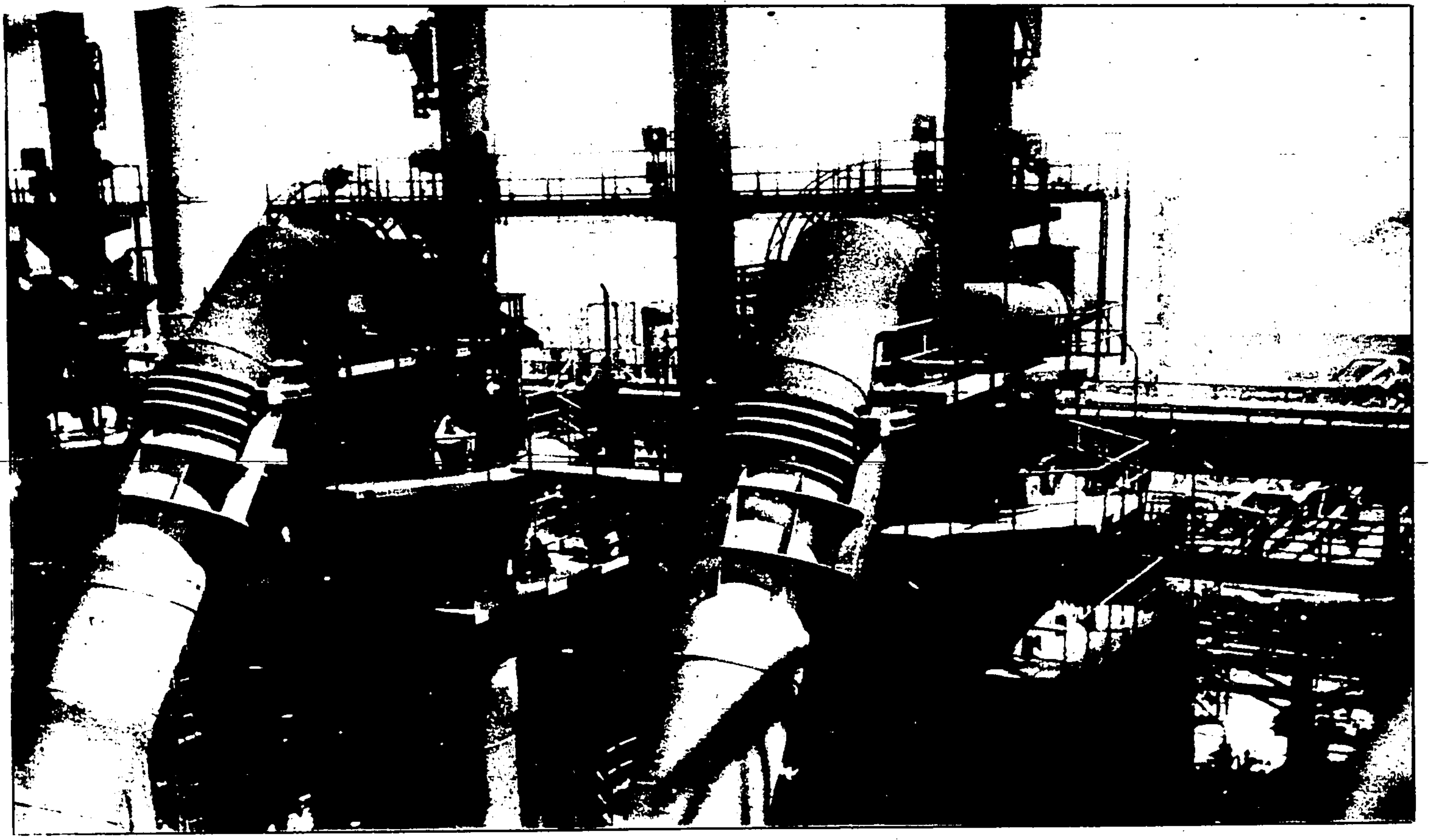


Fig. 2 View of Two Generators at Zeitz
(photographed by C.I.O.S. investigators)

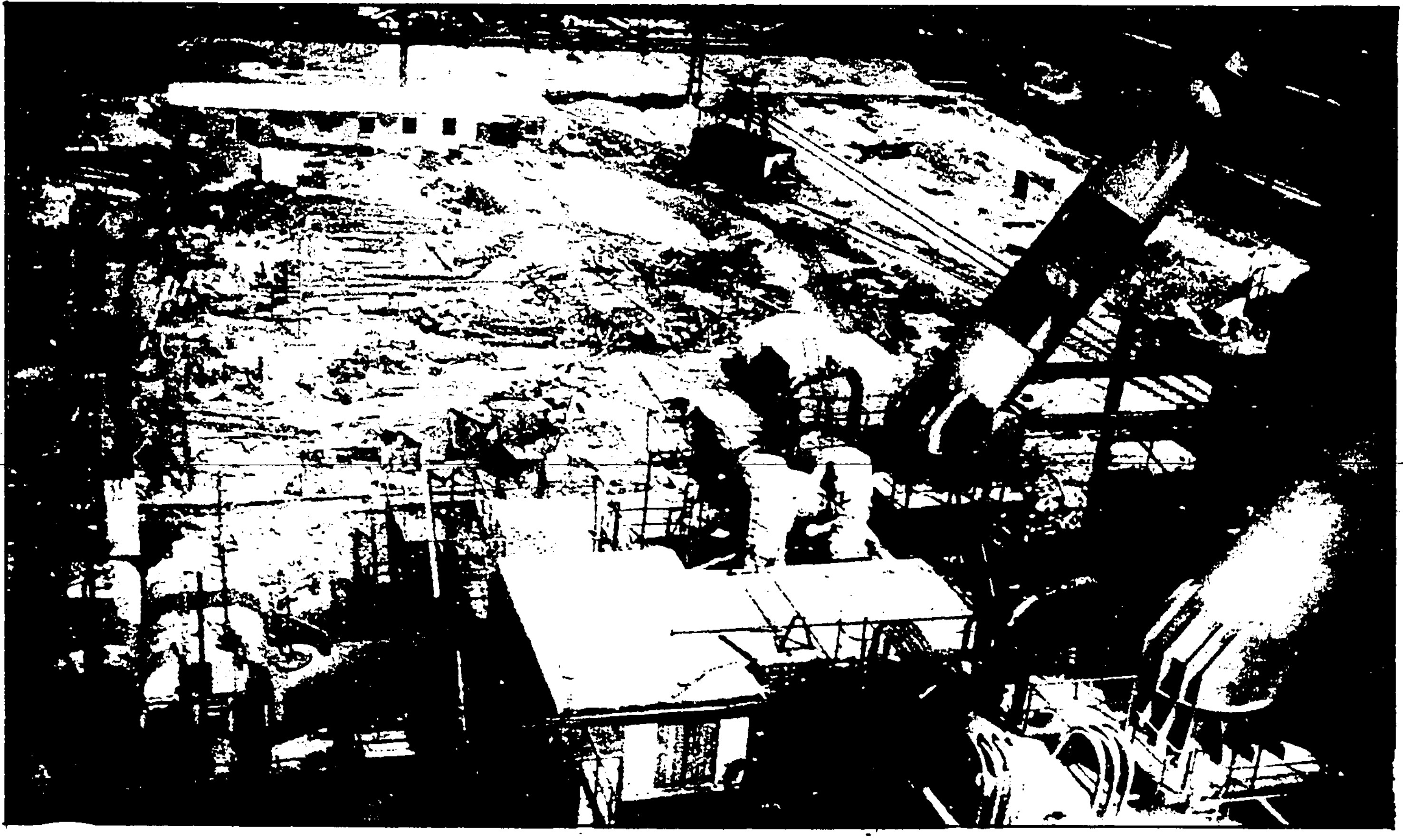


Fig. 3 View of Waste Heat Boilers and Multicyclone at Zeitz

(photographed by C.I.O.S. investigators)

Fig. 4 View of Lower Portions of Generator at Böhlen

(photographed by C.I.O.S. investigators)

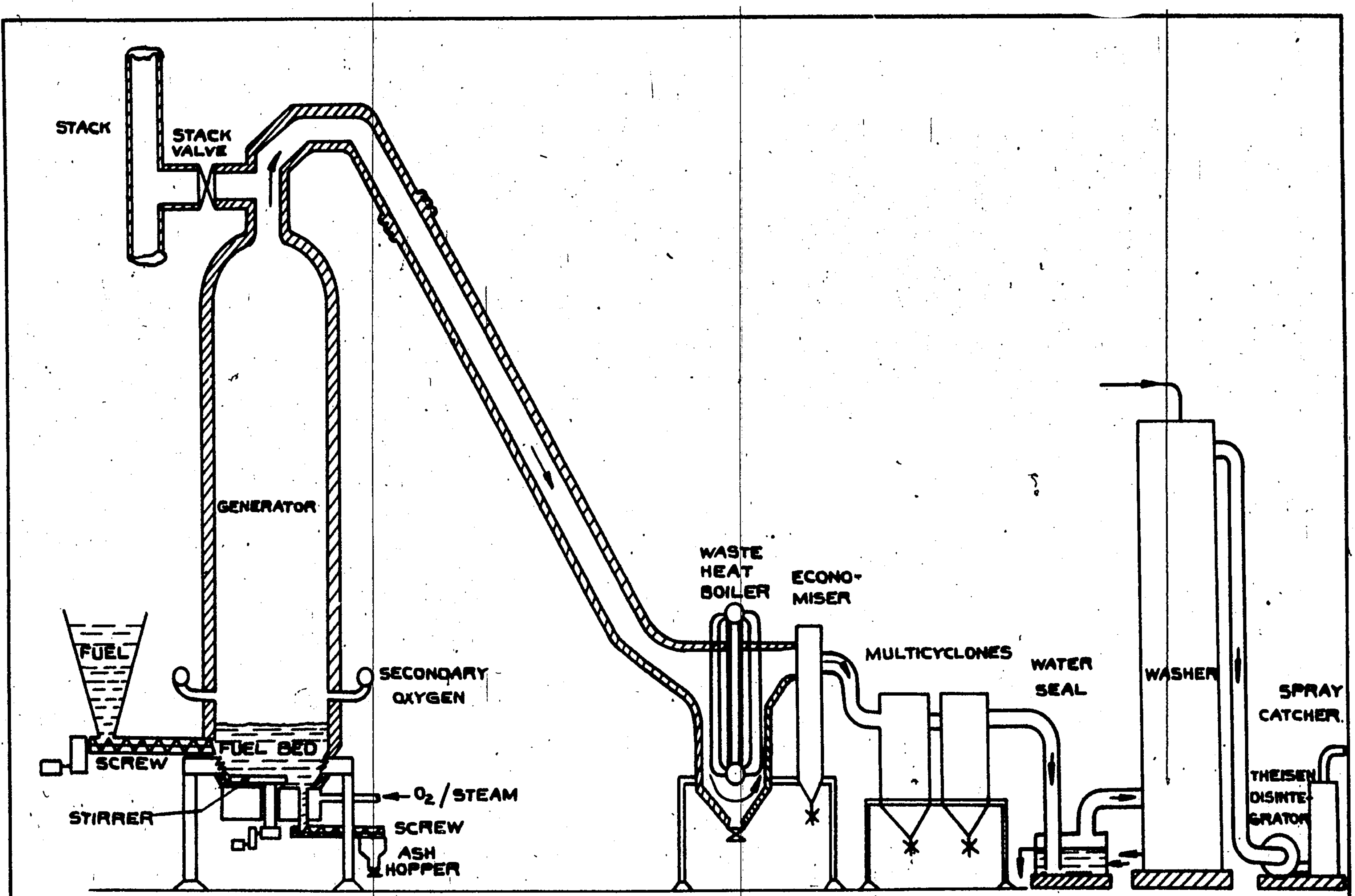
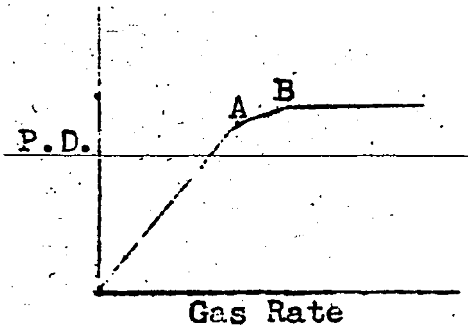


FIG. 5. SKETCH OF TYPICAL INSTALLATION

were designed by Bamag under license from I.G., who, of course, were also involved. These were put into operation in 1938-9. After the outbreak of war a further hydrogenation plant was started at Brüx, in N.Czechoslovakia, and again the Winkler process was chosen and the plant was started up in 1942(?).

CHARACTERISTICS OF "BOILING" BEDS



The accompanying diagram illustrates a typical pressure drop-gas rate relationship of a bed of particulate fuel. At low rates the pressure drop increases almost linearly with increase in gas rate until a point A is reached, where pressure drop x area = mass of fuel. There is then a tendency for the bed to be lifted bodily like a piston, but at first the bed expands and the voidage increases; then at B the bed begins to "boil". From B onwards the pressure drop remains constant as the gas rate is increased. The particles are constantly in motion and as the voidage increases so the depth of bed increases. The bed becomes increasingly rarified as the gas rate increases, until eventually when the gas velocity reaches the free-falling speed of the particles (at least with a bed of uniformly-sized particles), the whole bed is carried away, i.e. true entrainment occurs.

The gas rates corresponding to points A and B are a function of particle size and density, moving to the right as these are increased. For the same fuel and air rate the pressure drop across the bed is proportional to the depth of bed and is in fact equal to the "hydrostatic" head, i.e. mass of fuel/unit area.

DESCRIPTION OF THE PROCESS

Whilst the principle of the use of a boiling bed remains in all plants, the details have changed considerably with the various installations. As these changes have not been made without reason, it is instructive to follow them.

The gasification chamber itself has always been a brick-lined vessel, of greater height than width, with the fuel bed contained in the lower part. It has apparently never been necessary to replace the brick lining by a water jacket, and this is understandable, because the temperatures are not too high, probably never above 1,050°C. The blast always enters through the base, but usually a portion is fed in through tuyères above the fuel bed. The hot gases are led off at the top, sometimes through waste heat boilers, and then dedusted in some manner before final cooling.

Photographs and sketches of various installations are shown in Figs. 1 to 7.

The various stages will now be considered in detail, with particular reference to the manufacture of water gas with a blast of steam and oxygen only, with no air.

OXYGEN PLANTS

These are adequately described elsewhere (Ref.8). All the plants installed since 1929 have been Linde-Fränkl units, each of capacity 2,000 to 4,000 M3/hr oxygen (97 to 99%).

FUEL SIZING AND STORAGE

Brown coal and grude are very reactive and are liable to spontaneous combustion, so that special care is necessary in handling. The fuel is milled and screened in inert atmospheres of nitrogen or CO_2, containing limited amounts of oxygen, and may be transported pneumatically by inert gases; the bunkers are likewise kept under inert gas pressure. The size range of the milled and screened fuel varies from plant to plant and a summary is given in Tables III and IV. In general it can be said that the size range is between 0.1 and 10 mms., with the bulk in the range 0.2 to 4 mms. According to Ref.11 it is very desirable to keep out material $<$ 0.5 mms, since such material is liable to be blown through the bed unchanged. On the other hand, if the fuel is too large it tends to sink down to the grate, where the heat of combustion cannot be properly exchanged with the surrounding fuel, as is the case within the bed; consequently such larger pieces become overheated and clinkering results.

At Zeitz the milled grude is stored under nitrogen in two large bunkers each 7 m. diameter and 8 m. high, plus a conical base; the total storage volume is thus about 700 M3. In addition each generator has its own intermediate storage of about 125 M3.

At Böhlen the grude is blown over pneumatically with CO_2 from the power plant; the CO_2 from the bunkers is dedusted in Beth filters and cyclones.

PROPERTIES OF FUEL

Where dry brown coal is used the moisture content is normally reduced to about 8%, whilst grude usually has 2 to 3% moisture. Since during carbonisation brown coal loses water, tar and other volatile matter, the ash content of grude (22 to 28%) must always be greater than that (14 to 20%) of the dry brown coal, from which it is made. The calorific value of dry brown coal is about 5,200 T.cals/T net, and that of grude is between 5,400 and 5,800 T.cals/T net. The sulphur content is variable and this has a direct effect on the H_2S content of water gas.

In evaluating the Winkler process and especially when comparing with other processes in other countries, it is essential to remember (a) that dry brown coal and grude are both very reactive fuels, reacting with steam and CO_2 very quickly at comparatively low

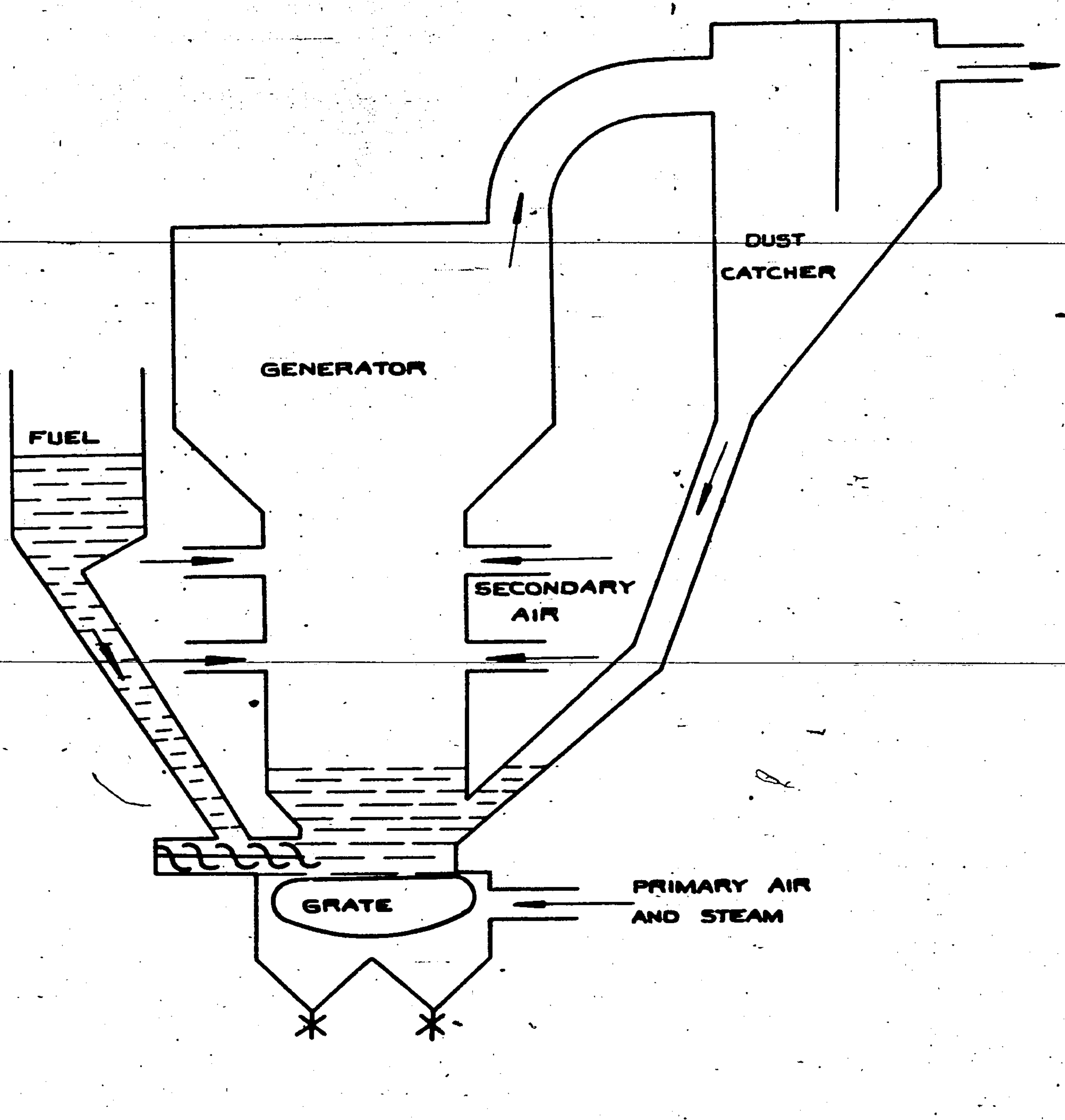


FIG.6. ARRANGEMENT OF EARLY GENERATOR WITH TRAVELLING GRATE

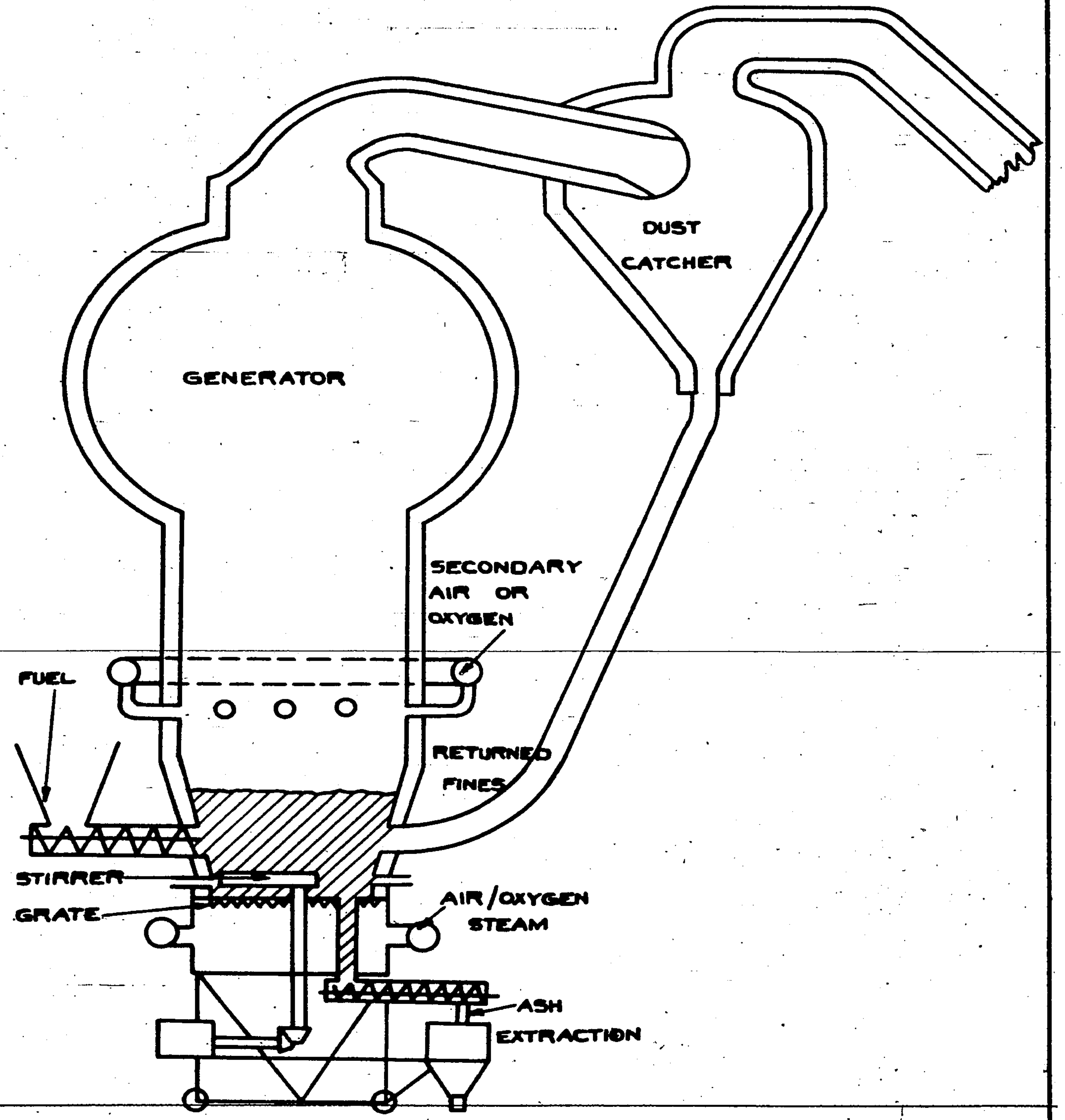


FIG. 7. ARRANGEMENT OF EARLY LEUNA GENERATOR WITH BULBOUS TOP

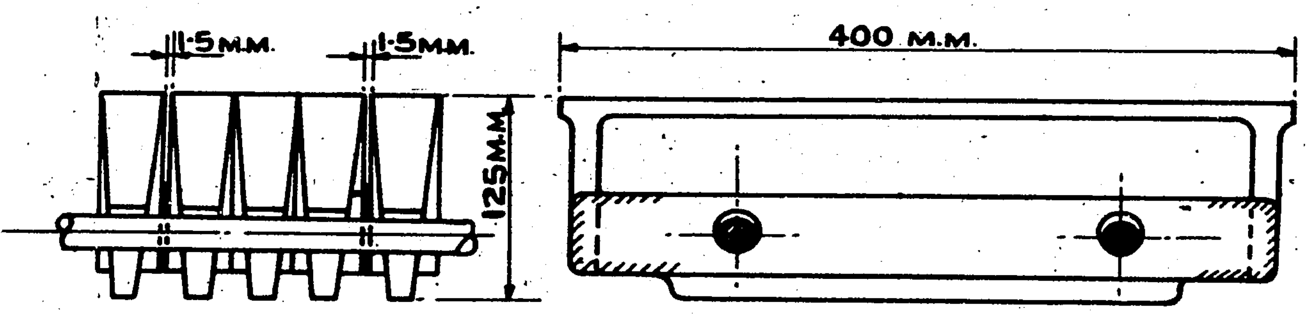


FIG. 8. SKETCH OF GRATE BARS

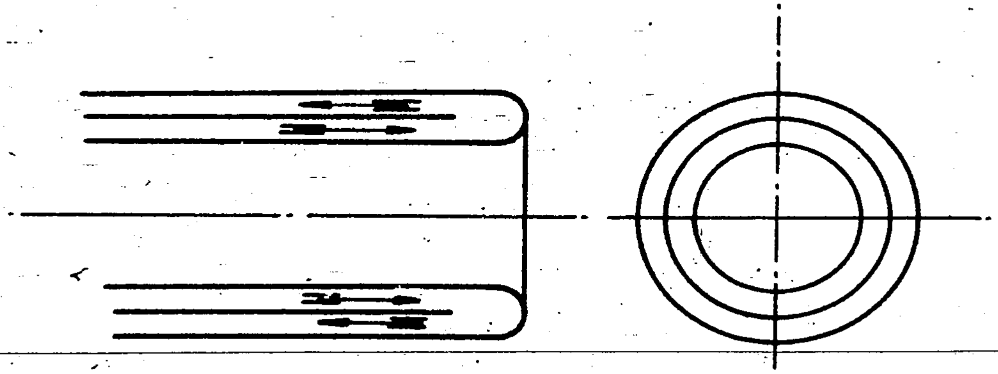


FIG. 10A. DESIGN OF WATER COOLED NOZZLE

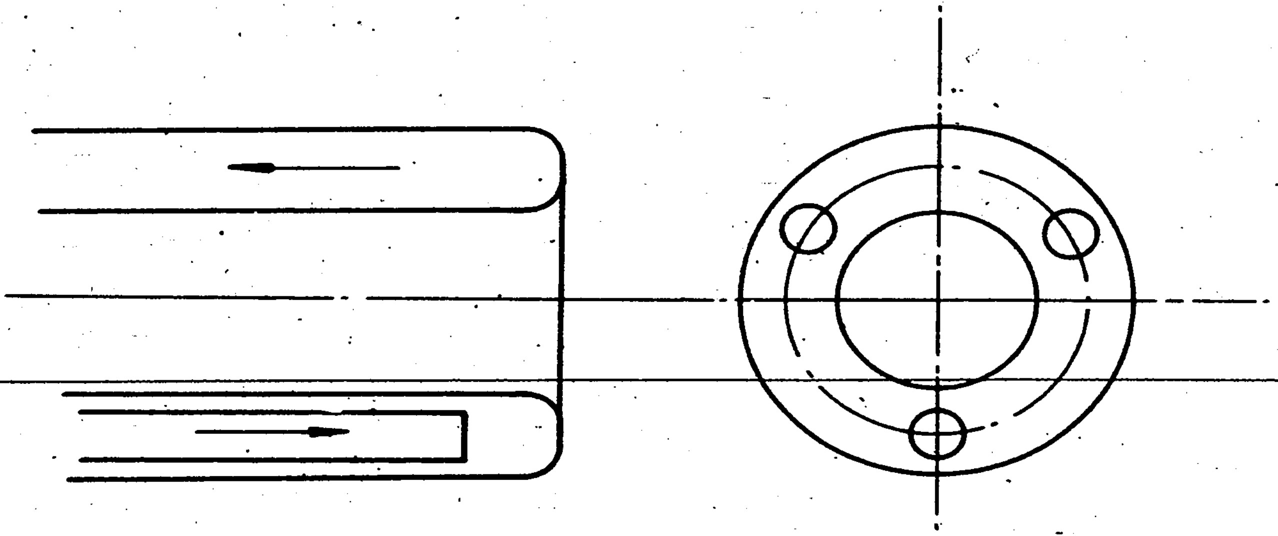
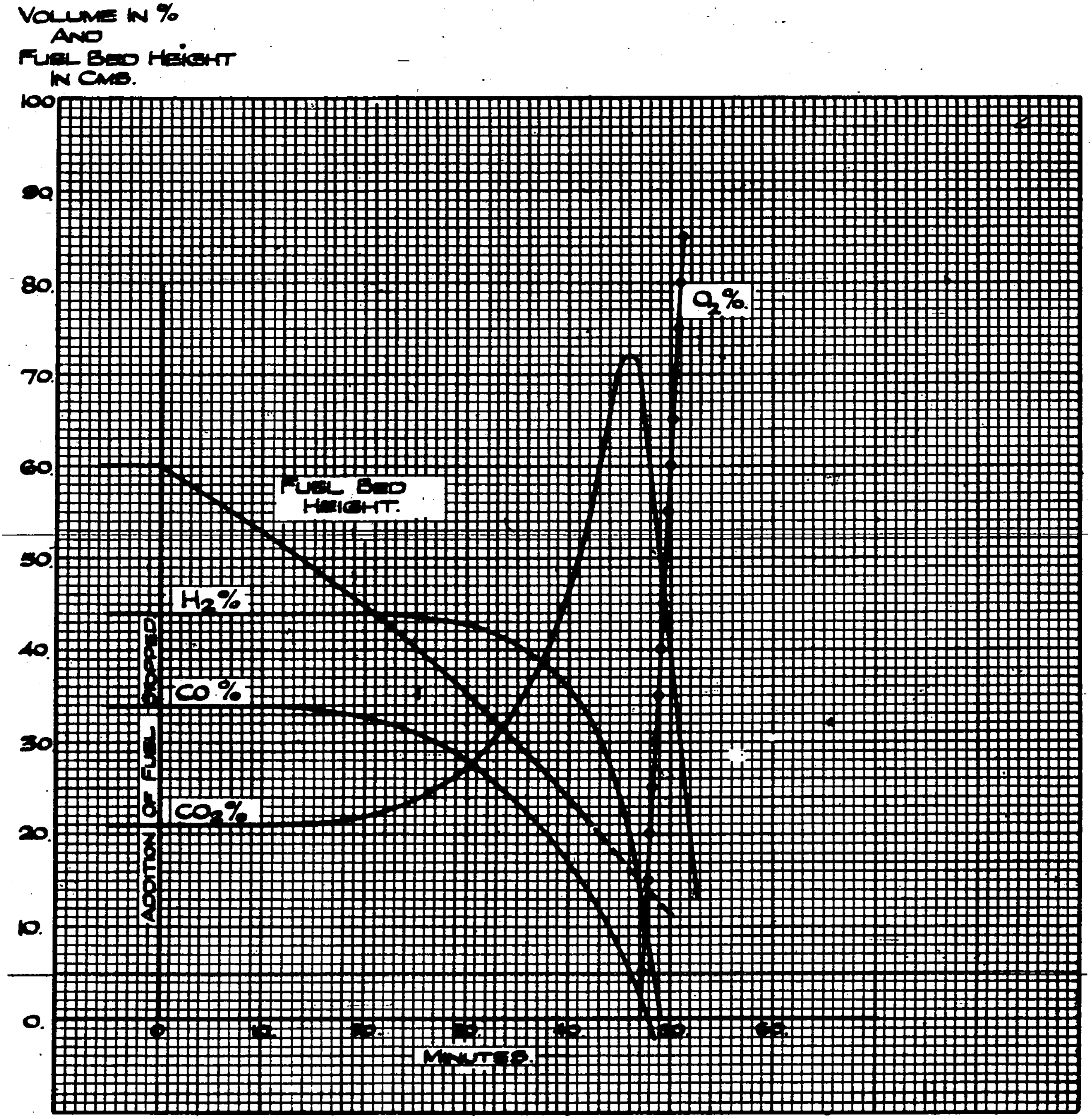


FIG. 10B. DESIGN OF WATER COOLED NOZZLE

FIG. 9.

CHANGE OF GAS COMPOSITION WITH AN OXYGEN BREAK-THROUGH.



temperatures (800° to 900°C), and (b) that dry brown coal and grude are both comparatively cheap fuels, so that a good carbon utilization efficiency is not so important, especially if any ungasified dust can be recovered and burnt under boilers at something approaching their full calorific value. Typical prices of raw brown coal are 1 to 3 RM/T at the mine, and about 4 to 9 RM/T for dry brown coal, after drying in neighbouring plants. Although the price of grude, sold as domestic and industrial fuel, might be around 20 RM/T, nevertheless in a combined factory, where large quantities of brown coal tar are required but where markets for grude are limited, so that grude has to be used as a boiler fuel, then the value of marginal grude is that of the cheapest alternative fuel, i.e. dry brown coal, at say 4 to 9 RM/T, and so grude can be charged to Winkler generators at such prices.

GRATES AND GENERATOR BASE

Fuel is introduced into the fire-bed by water-jacketed screw conveyors; there are three such screw conveyors on each Brabag generator. As far as we know fuel is nowhere introduced pneumatically, e.g. entrained with N_2 or CO_2, although there should be no difficulty about this. However, at some plants a current of CO_2 passes through the conveyor, to prevent steam passing backwards, to cause condensation and chokes. The feed rate is controlled either by the speed of the screw conveyor or else by the speed of the star-feeder, feeding into the screw-conveyor. The fuel enters the fuel-bed at points on the same side of the generator, about half-way up the fuel-bed; distribution of fuel within the fuel bed is left to the "boiling" action.

The development of the grate is interesting. The earlier Leuna generators had travelling chain grates (see Fig.6 and Ref.5). Since there is very little segregation of ash in the boiling bed, except as lumps of clinker, this arrangement must have caused a good deal of unburnt fuel to be drawn away at the base. Very soon stationary grates were used, originally made up of water-cooled beams, but the water-cooling was soon found to be unnecessary and even undesirable; these were replaced by fire-brick, but these were readily damaged by slag adhesion and mechanically by the stirrer. The present design of stationary grate appears to vary from plant to plant and because of this our information may be confused. At Leuna (Ref.10) the grate is made up of wedge-shaped cast iron bricks, 400 mms.long, 125 mms.deep, 35 mms.wide; these are packed in threes with 1.5 mms. spaces left between each set of three (see Fig.8). The grates at Böhlen are similar; Ref.2 says the bricks are about 300 mms.long, 50 mms.wide at the top, 25 mms.wide at the bottom; they are packed in threes, with very fine openings (1.5 mms or less) between every three. At Zeitz (Ref.3) similar bricks were used, about 75 mms. wide at the top, but these may have been made of fire-brick.

Above this grate rotates a water-cooled stirrer arm, driven from below via a shaft, passing up through the grate; at Zeitz this is of square-section, about 6" x 6". This acts as a scraper, rather than as a stirrer, and its chief function is to sweep the larger pieces of clinker towards one or two holes in the grate, through which they can be withdrawn by means of two water-cooled screw conveyors. The speed of this stirrer arm is about 1 to 2 r.p.m. The grate-ash is dumped into a water channel at Böhlen and sluiced away, but at Zeitz it is collected in two small hoppers and emptied periodically by hand into small bogeys on rails. Such ash may be anything from 2 mms. to 100 mms. in size; it contains from 10 to 20% of the ash fed to the generator and contains from 30 to 50% carbon.

The pre-mixed blast of oxygen and steam enters the wind-box under the grate and passes up through the grate, thereby helping to keep it cool. Such a grate gives very good initial distribution of oxygen and steam.

The whole grate assembly, i.e. grate, stirrer mechanism, wind-box and ash conveyors, can be disconnected from the generator, dropped on to bogeys and wheeled away for maintenance, whilst a spare grate is inserted in its place. This greatly reduces time off for maintenance. A grate on its bogey can be seen in Fig.4.

Originally grates caused a good deal of trouble, due to slag-attack, burning out and leaking stirrer arm, but these have now all been largely overcome. Good pre-mixing of oxygen and steam reduced the troubles and the design improvements, as described above, with more careful operation, especially in avoiding excessive fuel bed temperatures, have done the rest. As an example of earlier troubles at Leuna in 1933 we quote Ref.6 p.20 : "Severe slagging at first caused a good deal of maintenance. The grate of No.1 generator was renewed at least three times between June and October 1933; in addition it underwent 5 major repairs". Again in 1935 at Leuna (Ref.10) No.3 generator was shut down for 5 weeks in January, whilst a new grate was installed, but in October the same year it was shut down for 3 weeks for grate repairs; No.4 generator was shut down for over 6 weeks in January for repairs to grate and stirrer and again for 3 weeks in April for repairs to stirrer; a new grate was installed in No.5 generator in March, but the generator was shut down for 11 days at the end of the same month for repairs to the stirrer. [The length of time taken for these repairs suggests that at that time the grates could not be readily removed and replaced.] It was in 1935 that Leuna changed over to the use of cast-iron bricks, with very satisfactory results.

At Zeitz it was claimed that the generators could be run for a week or two without any ash removal at the base; the ash or clinker merely built up at the base, but did not hinder gas-making.

An important improvement has been made recently at Leuna, in the development of a grateless generator. Although former troubles with grate and stirrer had been much reduced some still remained, notably at Leuna, due to relatively poor quality of fuel and to burning out of the stirrer; the grate and stirrer were also by no means cheap items of plant. This was the incentive for trying out a grateless type of generator. Unfortunately there are not many details of this development available, but it does appear to have been a success. It was tried out first on the smaller No.1 generator at Leuna in 1941 and the large No.5 generator was similarly modified in 1944. One of the generators built at Brüx in 1942(?) is also of the grateless type. The base of the generator is made conical and the oxygen and steam mixture is introduced through tuyeres in the side of this cone. One investigator reports having seen the base of one such generator at Leuna and judging by the number of patches the position of these tuyeres had been altered from time to time; it is believed that the final positions are at a number of points halfway up the sides of the cone. There is no stirrer, but two screw conveyors are fitted to the base, and can be run intermittently for removal of ash and clinker. Leuna claims (Ref.6) that the grateless generator uses 10% less oxygen and 10% less fuel than the generator with grate, but gives no explanation. The distribution of oxygen and steam in the fuel bed cannot be so good with the grateless type, but this would by no means necessarily adversely affect the efficiencies. Fuel can be saved if the ungasified dust carried away can be reduced or if less oxygen has to be introduced above the fuel bed, since this tends to burn CO and H_2 to CO_2 and H_2O, as well as burn the dust. It would be interesting to have more details of this development but unfortunately tentative explanations can be regarded only as speculative through lack of information.

THE FUEL BED

The depth of fuel in the boiling bed is kept at 1 to 1.5 m. It is controlled primarily by the rate of addition of fresh fuel, the control being by hand, the operator working to the pressure differential across the fire-bed, which is proportional to the depth of fuel. There are advantages in working with thicker beds but the additional pressure drop is an objection; with too thin a fuel bed there is too much danger of losing the level, with consequent oxygen breakthrough.

The temperature is maintained as high as possible, in order to keep down the CO_2 in water gas, but in practice a margin must always be maintained between the bed temperature and the softening point of ash. In general the softening point of ash derived from brown coal is low and this limits the bed temperature to about 900° to 1,000°. At Zeitz they claimed to be able to run to within 20°C of the ash softening point. The ash softening point varies from time to time, even when operating on coal from the same mine, and a practical way of ensuring the correct bed temperature is to examine the ash; if this is dusty the temperature can be raised but if it shows signs of clinker formation the temperature must be dropped. The temperature of the fuel bed is measured by sheathed thermocouples inserted through the walls; in Ref.10, however, a test is described in which a bare couple was fixed to the stirrer arm and this showed a temperature 50°C greater than the normal couples.

Actual temperature control is effected by altering the blast composition; more oxygen gives higher temperatures and more steam gives lower temperatures.

In practice little trouble is experienced at any plant through clinker or slag formation, either as the result of large lumps collecting on the grate or as material building up on the sides of the generator. Sometimes some slag accumulates above the tuyeres, used to introduce oxygen above the fuel bed.

Ref.10 describes the formation of "bird - nests" on the walls and roof of the Winkler generator making power gas in 1935. Using dry brown coal from the Elise mine, with a fuel bed temperature of 950° and an exit temperature of 1,000°C, conglomerates of fly-ash, fused together, collected on the walls and roof; they were low in carbon content and somewhat sintered. When they became large enough they broke away and fell into the fuel bed; they were, however, so soft that they were easily broken up by the stirrer arm and the ash screw conveyors, and so their formation was not troublesome.

Failure to maintain a proper fuel bed level might be disastrous. According to Ref.6 on two or three occasions the level was lost, so that oxygen broke through the fuel bed and appeared in the exit gas; this led to serious explosions in subsequent portions of the plant. Fig.9, taken from Ref.6, shows the course of an oxygen break-through, as followed by analyses, as the fuel bed burnt away after addition of fresh fuel had been stopped. There is a rapid rise in the CO_2 content of the exit gases, just before free O_2 appears, and this interval is made use of to warn the operator; a sample of the exit gases is burnt continuously in a small flame placed in front of a photo-electric cell; when the CO_2 rises sufficiently the flame is extinguished and an alarm is sounded; the operator then immediately shuts off the oxygen supply.

Great care must also be taken to see that the steam rate does not fall below the required quantity. As an additional safeguard, an independent supply of steam is connected to the wind-box below the grate, which in emergency may be opened up.

COMPOSITION OF THE BLAST

At Leuna great stress (Ref.6) is laid on the necessity of obtaining adequate mixing between oxygen and steam, and it is recommended that this be done at least 10 to 15 m. from the generator, preferably with the incorporation of a restriction plate or bend. Failure to achieve good mixing leads to uneven heating and clinker formation in the fuel bed.

The % age of O_2 in the blast varies from 20 to 50%. The lower figures are used at Böhlen and Zeitz, and 40 to 50% at Leuna. This has a direct effect on the gas composition, the $H_2/(CO + 2\ CO_2)$ ratio being 0.57 to 0.59 at Böhlen and Zeitz and only 0.51 at Leuna; similarly the ratios $(H_2 + CO)/CO_2$ are about 3.0 and 3.8 respectively. This must mean that the Leuna generators are run at a higher temperature, but additional information is inadequate to prove or disprove this.

SECONDARY OXYGEN

The so-called "Überwind" or secondary oxygen, added above the fuel bed, fulfils two functions: it is intended to burn off some of the finely divided fuel blown out of the bed and it is also intended to raise the temperature of the gases, so that further cracking of tar or hydrocarbons may occur and also so that steam and CO_2 may react with some of the finely divided fuel. Probably some oxygen reacts with water gas already formed, but there is no doubt that the net effect is beneficial. The necessity for decomposing tar and hydrocarbons is of course more important when using dry brown coal than when using grude.

The fraction of the total oxygen added above the fuel-bed varies from 33% at Leuna (at any rate with dry brown coal), to not more than 20% at Böhlen, down to 10% at Zeitz. It is probably significant that the dust content of the exit gases is least at Leuna and greatest at Zeitz. Nevertheless owing to the cheapness of fuel it is apparently still economic for Zeitz to blow over the dust and recover it for use as a boiler fuel, and use the oxygen to better purpose in the main blast.

Care must be taken to avoid too high temperatures above the fuel bed, otherwise liquid slag will collect on the walls; for this reason it is usual to mix steam with the oxygen, although often in smaller proportions than in the main blast.

The volume of the generator above the fuel bed is important, since it governs the time available for the completing the reactions of steam and CO_2 with carbon and for completing cracking of hydrocarbons and tar. This volume is some 15 times that of the fuel bed itself, giving an average actual contact time for the gas of the order of 7 seconds in passing through it.

The original Leuna generators had the upper portion of the generator enlarged to a bulb and some of these generators still exist. All modern generators, however, are straight-sided but heightened to give the same volume as the older design. It has been said that this change was made solely on the grounds of construction costs, although Dr Schairer at Zeitz stated that turbulence near the periphery of the bulbous portion led to uneven times of contact at different points of the cross-section.

At Zeitz the oxygen-steam mixture is introduced 2 m. above the fuel bed through twelve water-cooled nozzles or tuyeres; these end flush with the inside wall and point exactly towards the centre of the generator. It was found by observation through sight-holes, that a gas velocity of 8 m. per sec. through the nozzles was the optimum; at higher velocities the flames tended to strike and damage the far-side wall, whilst at lower velocities the flames tended to lick upwards on to the brickwork lining above the nozzles. In practice some clinker does build up on the wall above the nozzles, but it is of little consequence. In Ref.11 it is stated that at Böhlen the secondary oxygen is added at a point only 0.5 m. above the point of addition of fuel, which itself is only 0.7 m. above the grate; if the depth of fuel is 1.0 to 1.5 m., this, if true, means that the secondary oxygen is added at a point only just above or even at a point just below the fuel bed level.

According to Ref.10 the water-cooled nozzles at Leuna were very satisfactory in 1935. Originally they had been cooled with river water, but this led to deposits forming at the ends of the water passages, but from 1934 they were cooled with circulating condensate. The design at that time is shown in Fig.10A; they were in effect built up from three concentric tubes; mention is also made of an experimental design, shown in Fig.10B, to be tried out in 1936.

The temperature in the space above the fuel bed is quoted for various installations as between 900° and 1,000°C; this temperature is partly a function of the ash softening point, but in general it lies above the temperature in the fuel bed. There is also a fall in temperature towards the top of the generator, due to the endothermic reactions occurring.

GENERATOR BRICKWORK

The conditions as regard temperature are not very arduous and as long as attention is paid to gas velocities very little trouble is experienced with brickwork, either that lining the generator or in the rest of the plant.

WASTE HEAT RECOVERY

As the exit gases leave the generator at 900° to 1,000°C it is obviously economic to recover this heat as steam and in all plants there is an elaborate installation of high pressure boilers, superheaters and feed-water economisers, reducing the temperature to 200° to 300°C.

Gases pass from the top of the generator down to the top of the boiler through a long brick-lined pipe; at Böhlen this has an I.D. of 1.4 m., which corresponds with an actual gas velocity of about 19 m/sec; these pipes are characteristic features of Winkler generators, and are readily noticeable in Figs.1, 2 and 3.

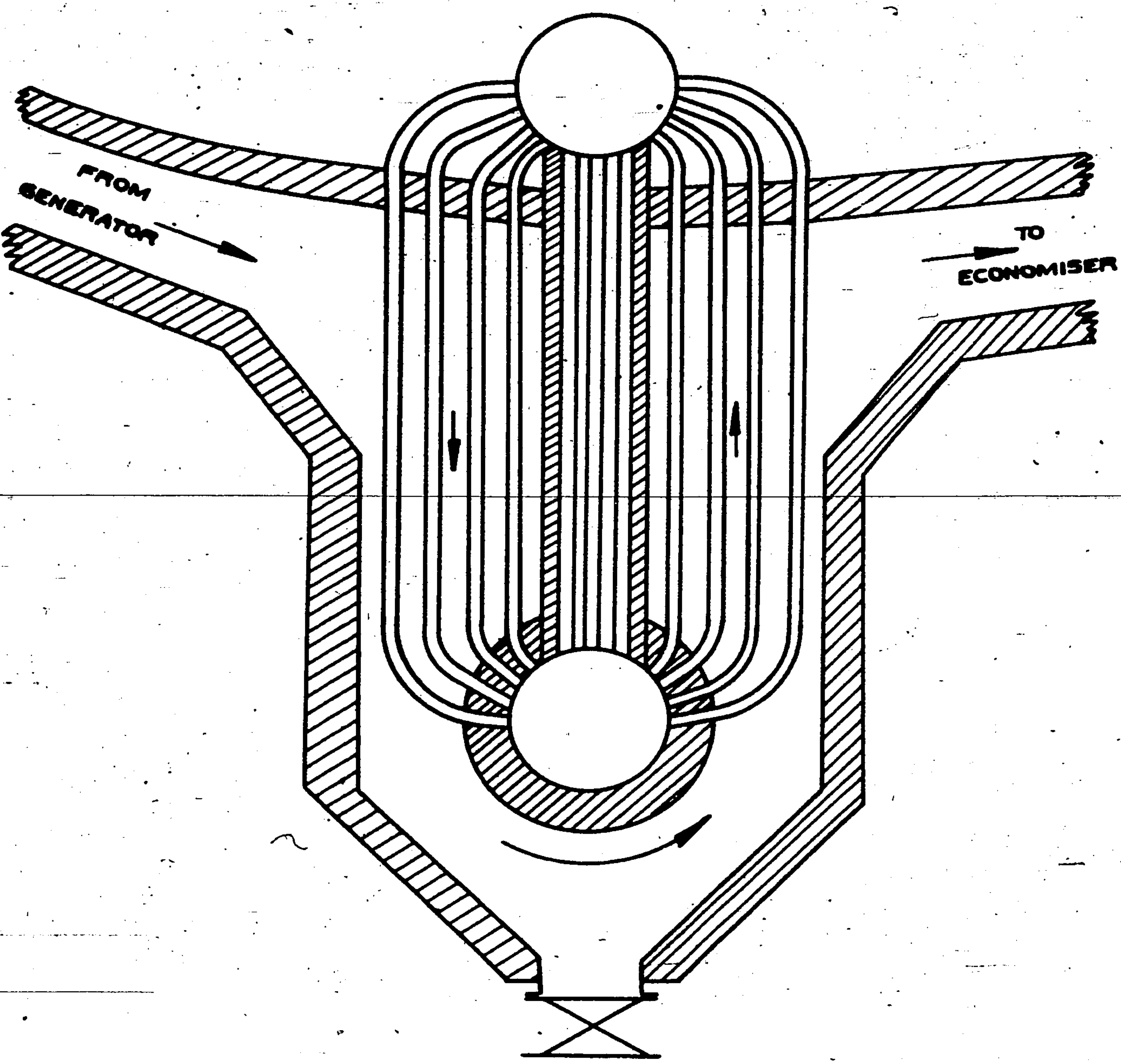


FIG. 11. TYPICAL ARRANGEMENT OF WASTE HEAT BOILER

At Böhlen and Zeitz two-drum water-tube boilers are used, raising superheated steam at about 18 ats (265 lb/sq.in.g.). A typical arrangement is shown in Fig.11. The lower drum is insulated and hangs in the gas space. Two baffle walls from drum to drum protect the cold down-flow tubes and also force the gases to take a U-shaped path. The gas leaves the boiler at about 400°C and passes through an economiser, pre-heating the feed-water to the boilers and being further cooled in the process. Dust builds up in the bottom of both the boiler and economiser, but this is not removed except during overhauls; after a certain amount has accumulated the gas velocities become high enough to prevent any more settling out. According to Ref.10 Leuna in 1935 had No.3 generator fitted with a 17 ats. boiler and No.4 generator with a 55 ats. boiler (800 lb/sq.in.g) each capable of raising 40 T/hr steam; some trouble was experienced in 1935 due to the sulphur-content of the gas and the high gas temperature, and on the 800 lb boiler, where they were attempting to run at a steam temperature of 460°C. the Sicromal 8 superheater tubes had to be replaced by zinc-coated Cr-Mo-steel, with better results.

Some trouble is experienced with erosion of tubes, and special attention must be paid at all points to gas velocities, which should be kept below 8 m./sec; velocities of 30 to 40 m/sec. cause serious erosion. In general, however, these troubles only occur if the generator output is so much increased that the gas velocities exceed the designed values; in most plants the waste heat boilers, as ~~installed, were the limitation to output, due to this.~~

At all plants the weight of steam raised by the waste heat boilers is at least equal to the weight of steam introduced into the generator, but of course there is a net credit for steam, because the steam introduced into the generator is at low pressure, 10 to 25 lb/sq.in.g., whereas the steam raised is at elevated pressure and can be used as a source of power before being exhausted as low pressure steam.

DEDUSTING OF THE GAS

This is a most important aspect of the Winkler generator. An appreciable proportion (18 to 50%) of the solid material fed into the generator is carried away as a finely-divided dust with the exit gases, and adequate plant must be installed to separate out the dust. If possible the dust so recovered should be able to find some useful outlet, e.g. as a boiler fuel, the credit so obtained helping to offset the inefficiency of utilizing fuel in the generator and the cost of the equipment required for dedusting; according to Ref.11 Zeitz received a credit of RM.5.-/T for recovered dust.

The older Leuna generators had single cyclone dust-catchers installed between the generator and waste heat boiler and the recovered fines were fed straight back into the fuel bed; these single cyclones, however, were relatively inefficient and caused excessive quantities of dust to appear at the water seals.

In all later installations there is no attempt to remove dust from the gas before it has passed through the waste heat boilers: then when it has been cooled to 200° or 300°C it is treated by multicyclones. At Zeitz the gas passes in two parallel streams, each stream passing through two sets of multicyclones in series; the two sets of multicyclones in one stream are larger than those in the other, the object being to give a choice to suit the particular output; in practice hand operation of the necessary valves is found to be cumbersome and a nuisance, although this problem appears to be readily soluble by using hydraulically-operated valves. At Magdeburg electrostatic precipitators were originally used instead of multicyclones, but one day, due to faulty operation free-oxygen appeared in water gas and an explosion occurred; they now also use multicyclones. At Leuna electrostatic precipitators were also tried in the early days, but the dust content was so great that it was difficult to maintain the potential difference under such circumstances.

After the multicyclones the gases bubble through a simple water seal, which is really a safety device to prevent gas passing back from the main into a generator, which is not producing, but it also removes a certain amount of dust from the gas and cools and saturates it with water vapour at about 80° to 85°C; water has to be passed through this seal continuously, to cover the evaporation of water and to flush away the dust removed. The gas from all generators passes into a common main and thence through direct contact water scrubbers, which both cool and de-dust the gas and remove some H_2S; ~~it is believed these are empty towers, fed with an excess of sprayed~~ water. Finally the gas passes through Theison disintegrators, for final dedusting, and is then termed raw water gas, ready for H_2S removal and subsequent working up.

Water from the seals, coolers and disintegrators contains dust and H_2S and must be treated before being discharged to river or recirculated. At Zeitz the water is passed through two towers in series, with a common spare, all packed with wooden grids; CO_2 is blown through the first tower, to remove the bulk of the H_2S, which is subsequently treated in a Claus kiln for conversion to elemental sulphur, since it cannot be blown to atmosphere; air is blown through the second tower to remove the remaining H_2S, which is blown to atmosphere. Finally the water is sent to large settling ponds, where the bulk of the dust settles out, and the relatively clean water can then be discharged to the river; at Zeitz the final water contains about 20 mg/l of suspended matter, said to be not greater than that of the river water itself.

Occasionally the settled dust is recovered from the settling pits, dried and used as boiler fuel, but in general it is uneconomic to do so. However, the much larger amount of dry dust recovered from the multicyclones is normally used as boiler fuel, although it too may be wetted down and pumped as a slurry to dumps. At Zeitz dust from the multicyclones is collected in special fixed containers; when full these are isolated by remote-operated valves, the dust is roused by admission of CO_2 through a stand-pipe and the dust pumped away pneumatically to the boiler plant, using CO_2 as carrier gas.

The amount of dust carried over with the gas varies greatly from plant to plant, and increases notably with the output. Naturally unless clinker forms all the ash in the incoming fuel must be blown overhead; the ash particles must be considerably smaller than the average size of fuel particles, which fixes the linear velocity of the blast. In practice 80 to 90% of the ash passes overhead. In addition finely divided unburnt fuel must appear above the fuel bed, since some fines (< 0.2mms) are fed in with the fuel and some fines are continually being produced as the result of combustion and attrition of larger particles in the fuel bed; only a portion of such fines is gasified in the space above the fuel bed. With higher outputs larger particles can be carried away and so the amount of fines in the gas increases with output. Also since the quantity of carbon gasified/M3 gas is relatively constant, then for a given fuel of fixed ash content the carbon content of dust carried away must increase with the dust content of the gas.

Under normal running conditions the dust contents, in gms/N M^3 gas leaving the generator, is variously reported (see Table III), as between 100 and 360, being lowest at Leuna and highest at Zeitz, with carbon contents of from 30 to 55%. This represents between 10 and 40% of the carbon charged to the generator. At Zeitz the 1944 average analysis of dust recovered from the multicyclones was :

C	54.3%
H	0.9%
ash	43.8%
moisture	1.0%
net C.V.	5,000 T.cals/T

The multicyclones at Zeitz and Böhlen (Refs.3 and 11) are about 80% efficient, so that at Zeitz gas leaves the multicyclones with about 60 g/N M^3 dust. At Zeitz the dust content after the direct contact coolers is reduced to about 2 g/N M^3 and finally after the disintegrators to 3 to 4 mg/N M^3. This must be considered as a very creditable overall dedusting performance, even though there are four stages of dedusting. According to Ref.12 the dust content of gas after the disintegrators at Böhlen was 2 to 5 mg/N M^3 for a generator output of 16,000 M^3/hr, but the dedusting train was overloaded at 19,000 to 21,000 M^3/hr and the dust content at this point rose to 40 mg/N M^3.

The higher dust content of gas at Zeitz may be a function of the fuel used, but as stated before it may be significant that at Zeitz appreciably less oxygen is introduced above the fuel bed.

We have been unable to find any data concerning the size of the dust at any stage, except that Ref.1 states the dust to have a maximum size of 0.3 to 0.4 mm; this also fits the statement made in Ref.11, that any material $<$ 0.5 mms is liable to be blown out of the fuel bed.

STARTING UP

For starting up a small auxiliary Winkler generator is used; one such is shared between two generators and hence two have to be provided for three generators. One can be seen at the extreme left of Fig.1. This has an I.D. of 1.0 to 1.5 m but is always open to atmosphere through a wide open stack (0.5 to 1.0 m I.D.). A fire is started with wood and briquettes, air being blown through, whilst grude is run in slowly from a hopper. When hot enough the glowing grude is run by gravity into the large generator, standing full of N_2 or CO_2, with the safety valve open to atmosphere. A good rate of air is then blown through the grude and the level is built up by feeding in fresh grude in the normal way. The bed must be kept "boiling", otherwise the heat of combustion is not properly dissipated and clinkering results. The blast is then changed over to a mixture of steam and oxygen and when the gas made is of sufficiently good quality the safety valve is closed and gas making proceeds.

The reason why the generator cannot be lit up directly lies in the difficulty of ensuring a uniform fire-bed right across the grate If part of the fuel-bed became hot, whilst the rest remained cold, then producer gas and unchanged air might accumulate above the fire-bed and lead to an explosion. Dr Schairer at Zeitz thought the generators there were not too large to start up directly on grude, but it would be dangerous to start them up with briquettes or dry brown coal, since the presence of carbonisation gases would make explosions more likely. No dangerous explosion can occur in the auxiliary generator because it is always adequately vented to atmosphere.

The valves on the outlets from the small generator are in contact with hot grude for only a short time whilst it is flowing into the large generator; at other times they are protected by a layer of cold grude.

A Winkler generator can be on line from cold within an hour or two, although longer is taken if possible to avoid damage to brickwork.

INSTRUMENTS AND SAFETY DEVICES

Temperature control is very important, since it is desired to work at as high a temperature as possible, but not so high as to cause slagging or clinkering difficulties. The temperature in the space above the fuel bed and the temperature within the fuel bed are both recorded continuously and fitted with alarms.

Mention has already been made of differential pressure manometers in duplicate, to measure the fuel bed depth, and also of the pilot flame, burning a sample of the exit gases before a photo-electric cell, fitted with an alarm. In addition, of course, there are the usual flowmeters, temperature indicators and pressure gauges.

There are bursting discs at strategic points, notably on the wind-box, whilst a large stack can readily be opened to atmosphere through the medium of a hand-controlled electrically or hydraulically operated valve.

There is a non-return water safety valve on the oxygen line to prevent gas passing back along the oxygen main, should the oxygen pressure fail; steam added to the secondary oxygen also performs a similar function. The water seal on the gas leaving the multicyclones, as already mentioned, prevents gas flowing back from the common gas main into a generator, which is not producing.

Mention has also been made of the emergency supply of steam to the wind-box, to guard against failures of the normal steam supply.

All these instruments and controls, together with controls for operating the fuel and ash conveyors and adjustment of the oxygen and steam rates, etc., are brought to a single control cabin, which at Zeitz and Böhlen controls all three generators; it is located about 5 m above ground level, i.e. approximately on the level of the fuel bed.

PRESSURE SURVEY

The following is a pressure survey at Böhlen (see Refs.2, 11) and Zeitz (Ref.13).

		Böhlen	Zeitz
	Generator output, M^3/hr water gas	20,000	15,000
		cms water gauge	cms water gauge
Pressures	Steam to Generator	1,950	1,450
	Oxygen to generator	-	-
	Wind-box	220	120
	Above grate	200	-
	Above fuel-bed	150	80
	After W.H.B., multicyclone	100	-
	After water seal	80	-
	After coolers.	50	25
	After disintegrators	-	20

Pressure Drops:-	cms water	cms water
Across grate	20	40
Across fuel bed	50*	
Across W.H.B., multicyclone	50	55
Across water seal	20	
Across coolers	30	

Bearing in mind the difference in output, these two sets of figures are in reasonable agreement.

OUTPUT

The output of a given generator is, of course, fundamentally a function of the shaft or grate area and is roughly proportional to it. There are, however, other important considerations. A Winkler generator has one of the highest outputs/M^2 shaft area of any gasification process, and when making water gas from grude is normally of the order of 1,200 to 2,000 M^3/hr/M^2, although even higher outputs have been claimed. These high outputs are due primarily to the active nature of the fuel and the intimacy of contact of fuel with oxygen and steam, as a result of the finely divided nature of the fuel and the "boiling" motion of the bed.

For a generator of given shaft area, however, the output can be altered usefully only within a comparatively limited range. Below a certain output the bed ceases to "boil", although what blast there is will still find its way through the fuel bed. This immediately removes the means whereby heat is evenly distributed throughout the fire-bed. Consequently the lower layers, which the blast meets first, become overheated and slagging results. On the other hand, as the blast rate increases larger and larger particles can be carried away from the fuel bed and ultimately, of course, the whole bed is carried away, i.e. the fuel becomes fully entrained with the gas; long before this point is reached, however, the dust content of the gas becomes so high that the carbon losses become serious, whilst dedusting of the gas presents a formidable problem; moreover if velocities much exceed designed values, serious erosion will occur, especially in the waste heat boilers. The practical limits of output for generators, such as those at Böhlen and Zeitz, appear to be between 9,000 and 25,000 or possibly 30,000 M^3/hr water gas. Although limited this range, of course, is ample to permit two generators to cover all likely loads.

Thus the Winkler generator is capable of appreciable overload for a short time, provided one is willing to countenance the decreased efficiency and increased maintenance.

The figure of 50 mms given in Ref.2 should obviously be 50 cms.

Ref.10 comments on the effect of output on the performance of a generator at Leuna in 1935, making water gas from dry brown coal. The higher output was maintained for only one day, because of overloading of the waste heat boiler, but the comparison with normal running is given as follows :-

		Normal	High Output
Output, M^3/hr.	water gas	30,000	42,000
Gas Analysis:	CO_2	21.8	15.7
	H_2S	1.5	1.5
	H_2	38.5	36.0
	CO	35.3	44.4
	CH_4	1.8	1.6
	N_2	1.1	0.8
C in fuel,	kg/1,000NM^3 $H_2 + CO$	452	455
98% O_2,	NM^3/ -	366	316
Steam,	kg/ -	407	250
% C utilization		*86.5%	80%
% steam decomposition		33%	27%
% C in fly dust		31%	35%
% C in ashes		35%	40%
Fly dust, kg/1,000 NM^3 H_2 + CO		148	211
Ashes,	-/ -	41	44

*Allowance was made in the high output for CO_2 introduced with the fuel; if the same allowance is made for normal output, the C utilization is reduced to 82.8%.

The report remarks on the better gas composition (80.4% H_2 + CO, as against 73.8%) at the higher output, and especially the appreciable reduction in oxygen and steam consumption; the carbon consumption is about the same, although the C losses in dust and ash increase, as does the amount of dust blown over. The report goes on to say that theoretically one might expect better performance at lower outputs, since this gives longer times of contact in the space above the fuel bed, and the only tentative explanation given for the reversed findings is that, despite the fact that recorded temperatures were kept the same, the actual temperature in the fuel bed at the higher output was in fact different (and presumably higher) since the thermocouples measure the temperature only near the walls.

Whether the above is reliable evidence may be open to doubt. Other figures given in Refs.1 and 6, however, tend to bear out the lower-oxygen requirements at higher outputs.

SERVICE REQUIREMENTS : EFFICIENCIES AND BALANCES

Because of the varying conditions it is difficult to give typical figures for service requirements and efficiencies, but perhaps the following list of ranges encountered might be a useful summary of known achieved results :-

	Per 1000 NM^3 H_2 + CO		Per 1000 NM^3 H_2 + CO
Grude	530 to 1000kg.	**Dry brown coal**	800 to 860 kg
Carbon	420 to 630 kg	Carbon	445 to 460 kg.
Oxygen (98%)	305 to 335 NM^3	Oxygen (98%)	315 to 360 NM^3
Steam used	350 to 900 kgs.	Steam used	300 to 400 kgs.
Steam decomposition	30 to 35%	Steam decomposition	27 to 33%
Carbon utilization	88 to 57%	Carbon utilization	86 to 80%

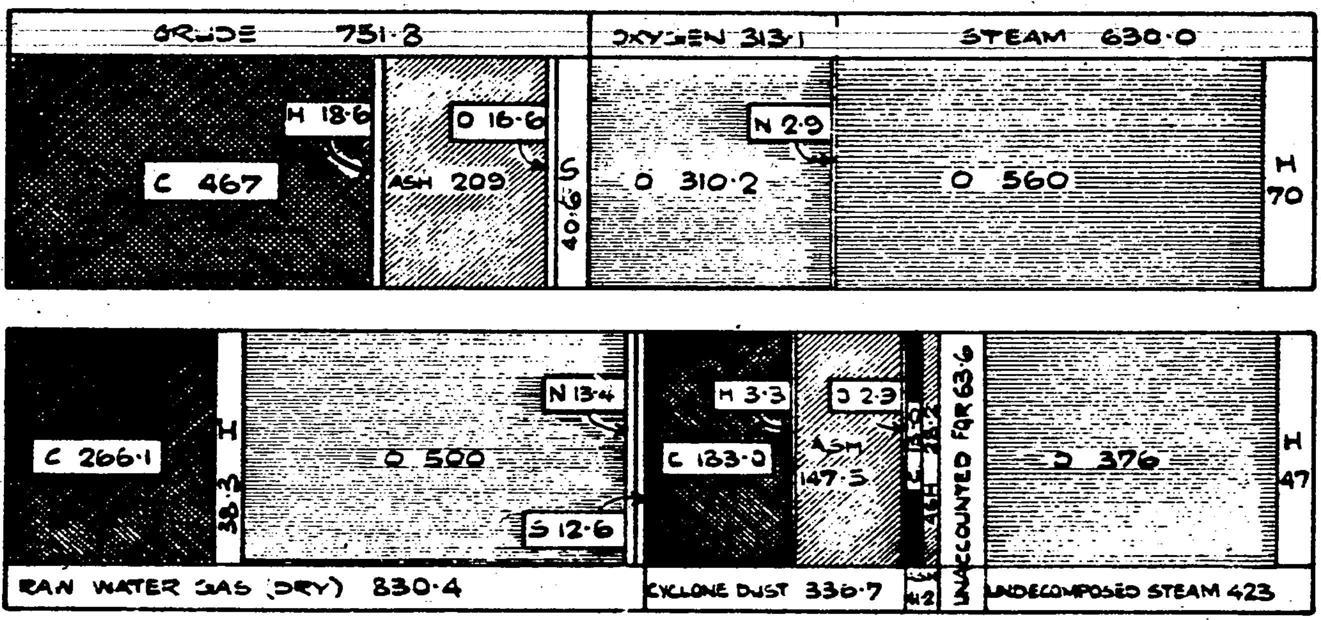
Data for various plants are collected together in Tables ~~III (water gas from grude) and Table IV (water gas from dry brown~~ coal) and these should be consulted for more detailed information, as far as it is available.

Material and heat balances will now be drawn up for one or two plants for which sufficient information is available.

MATERIAL BALANCE AT ZETIZ

Ref.14 gives a material balance for the whole of 1944, from which the following is taken.

INGOING MATERIAL IN KG/1000 NM^3 RAW WATER GAS.



OUTGOING MATERIAL

MATERIAL BALANCE AT ZEITZ.

NOTES

1. The actual balance given in Ref.14 shows 5.0 H and 300.6 H_2O as "unaccounted for". This obviously indicates an incorrect measurement of H_2O in or out, so in the above balance the measured steam in has been assumed to be correct and a hydrogen balance has been struck and hence the amount of undecomposed steam calculated. Comparing Ref.14 with the above chart, we then have :-

		Ref.14	Above Chart	
		kg/1000 NM^3	kg/1000 NM^3	% of component
"unaccounted for" :	C	4.9	4.9	1.05
	H	5.0	Nil	(assumption)
	Ash	33.3	33.3	15.9
	N	-	-10.5	
	S	28.0	28.0	
	H_2O	300.6	-	
	O	not given	7.9	0.9
Steam added + H_2O from grude		648.7	648.7	
Steam decomposed		345	222.3	
% steam decomposition		53%	34.4%	

2. The low value of "unaccounted for" oxygen, when a perfect H balance is assumed, indicates a satisfactory overall balance. The negative value of "unaccounted for" nitrogen does not arise entirely through neglecting N in grude: for balance 1.4% N in grude would be required, and it is unlikely to be so high. The high amount of "unaccounted for" S arises through neglecting the S content of dust and ashes.

3. The "unaccounted for" C and ash are presumably lost as dust passing the cyclones. Assuming the "unaccounted for" ash of 33.3 is correct and that dust has the analysis of cyclone dust, then this indicates that the multicyclones have an efficiency of $\frac{147.5}{147.5 + 33.3}$ or 81.6%, which is in good agreement with other information.

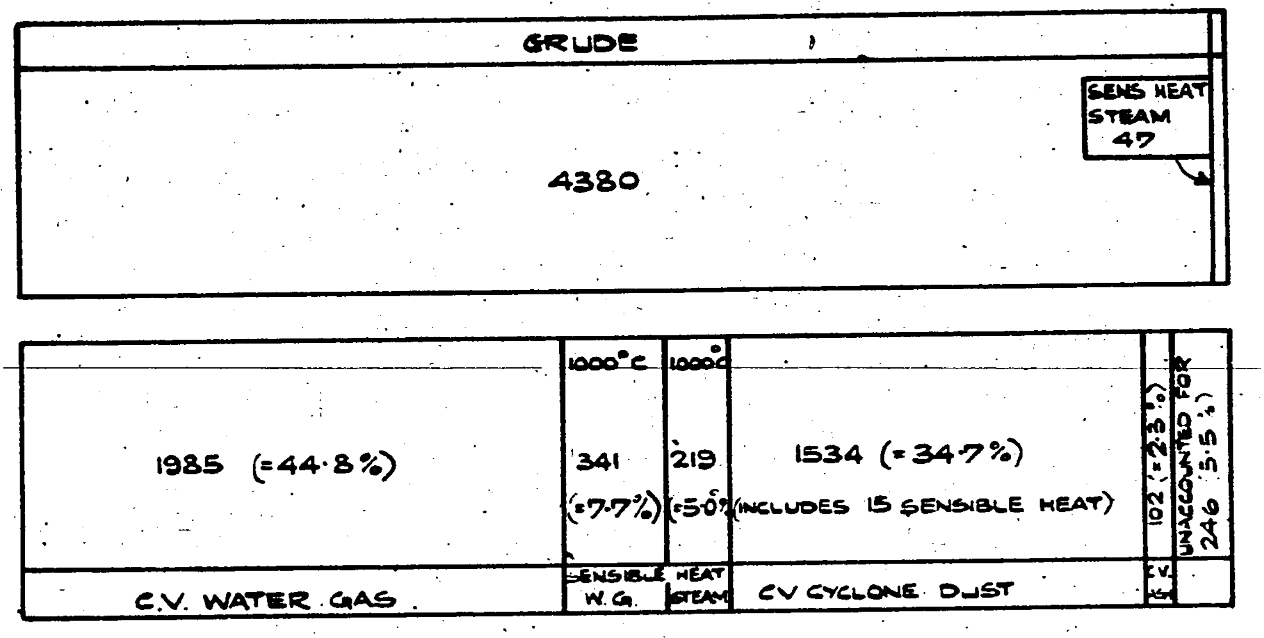
COMMENTS

The chart shows up clearly the poor carbon efficiency at Zeitz and the magnitude of the dust nuisance. The carbon efficiency, i.e. the percentage actually gasified, is 57% (Ref.14 from the same figures gives 49.25% and this error is repeated in Ref.3); the bulk of the ungasified carbon is blown over with the bulk of the ash as dust in the gas.

HEAT BALANCE AT ZEITZ

From the above data and Ref.14 the following heat balance of the generator itself (i.e. excluding waste heat boilers, etc.) has been drawn up for Zeitz :-

INGOING HEAT IN T.CALS/1000 NM³ RAW WATER GAS.



OUTGOING HEAT

HEAT BALANCE AT ZEITZ.

The above quantities are expressed in T.cals/1000 NM³ raw water gas, using net calorific values and expressing sensible heats above 0°C.

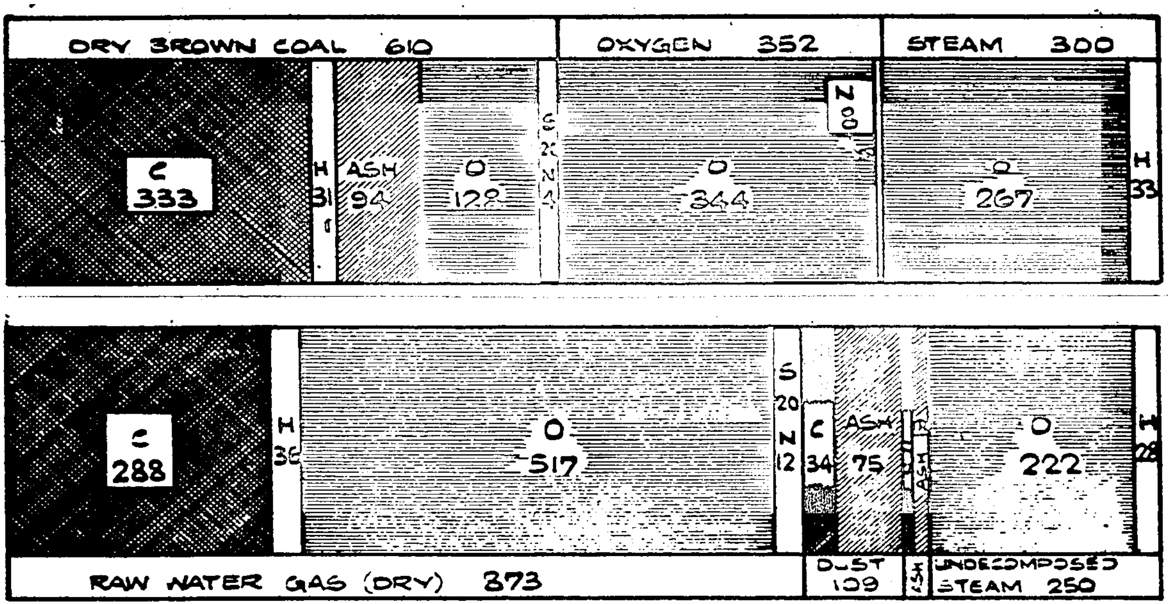
This chart shows much the same story as the material balance. The thermal efficiency of the generator itself (i.e. net c.v. of water gas divided by net c.v. of grude + sensible heat of steam) is 44.8%; the major inefficiency of 34.7% is as cyclone dust, whilst sensible heat of the water gas and steam at 1,000°C removes 12.7%. The "unaccounted for" loss of 5.5% has to cover c.v. of dust passing the multicyclones and losses by radiation, etc.

If all carbon in cyclone dust can be usefully recovered as a boiler fuel, then the net carbon efficiency is 93.5% and the net thermal efficiency is 70%, still however omitting waste heat recovery.

MATERIAL BALANCE AT LEUNA

The above balances for Zeitz, although representative of working at that plant, give a poor impression of the Winkler process; appreciably better efficiencies are obtained at Böhlen and even better at Leuna. Since we have available from Ref.10 the actual performance at Leuna over 12 months in 1935, material and heat balances are given below for Leuna, making water gas from dry brown coal. The output was relatively low, at 27,000 M³/hr for a generator of 25 M³ cross-sectional area.

INGOING MATERIAL IN KG/1000 NM^3 RAW WATER GAS.



OUTGOING MATERIAL.

MATERIAL BALANCE AT LEUNA

NOTE:

1. The above balance is exactly as given in Ref.10. The perfect balance of each component indicates that certain items have been estimated by difference; however, the overall picture is probably very near truth.

2. Of the ingoing H in fuel, 25 kgs are as H and 6 kgs as H_2O (49 kgs).

COMMENTS

The picture presented here is very different from that given for Zeitz. The carbon efficiency, i.e. the percentage actually gasified, is 86.4% (cf 57% at Zeitz). The carbon blown over as dust is only 34 kg/1000 NM^3, as against 183 kg at Zeitz.

HEAT BALANCE AT LEUNA

Using slightly different data Ref 10 gives the following heat balance :-

INGOING HEAT IN T.CALS/1,000 NM^3 RAW WATER GAS

Dry Brown Coal
3100

2050 (66%)	420 (14%)	470 (15%)	160 (5%)
C.V. Water Gas	Sens. Heat W.G.+Steam	Dust+Ash	Losses etc.

The thermal efficiency is 66% (compared with 44.8% at Zeitz), and dust and ash accounts for a loss of only 15% (compared with 37% at Zeitz.

If all carbon in cyclone dust can be usefully recovered as a ~~boiler fuel, then the net carbon efficiency is 96% and the net thermal~~ efficiency 74.5% (compared with 93.5% and 70% respectively at Zeitz). Thus so long as Zeitz can utilize the cyclone dust there is very little loss of carbon or thermal efficiency due to the high dust carryover at Zeitz; however, such high dust carryover does necessitate more expensive equipment to deal with it.

MANUFACTURE OF POWER GAS

At Leuna a number of compressors of the ammonia synthesis plant have always been driven by gas engines, fired by producer gas. Since 1926 the producer gas or power gas has been made mostly on one of the large Winkler generators.

Since a high CH_4 content of power gas is not objectionable, and may even be desirable, dry brown coal has been the normal fuel used. Hydrogen is an undesirable constituent of power gas, since in excess it causes too violent explosions in the engines, so that the blast used has been air alone, sometimes with the addition of CO_2, but never with the addition of steam. The water and hydrogen content of the fuel of course are the source of a certain amount of hydrogen in power gas.

The method of working is very similar to that of making water gas; in fact one generator at Leuna acts as a common spare to one water gas and one power generator. The air blast is split into blast through the grate and secondary air above the fuel bed. The output of power gas from a large generator of 25 M3 cross-sectional area is about 75,000 M3/hr, which is somewhat greater than the output of water gas, 60,000 M3/hr, from the same generator, since power gas does not carry with it any undecomposed steam.

Very complete data are available for Leuna for the whole of 1935 from Ref.10, and these are set out in Table V along with other published data. Figures in the first two columns, from Refs. 9 and 10 using dry brown coal, are in very good agreement, but published figures from Ref.9 using grude record too low a fuel consumption. The carbon utilization efficiency is about 82%.

The dust content of gases at Leuna is shown below, when working on dry brown coal :-

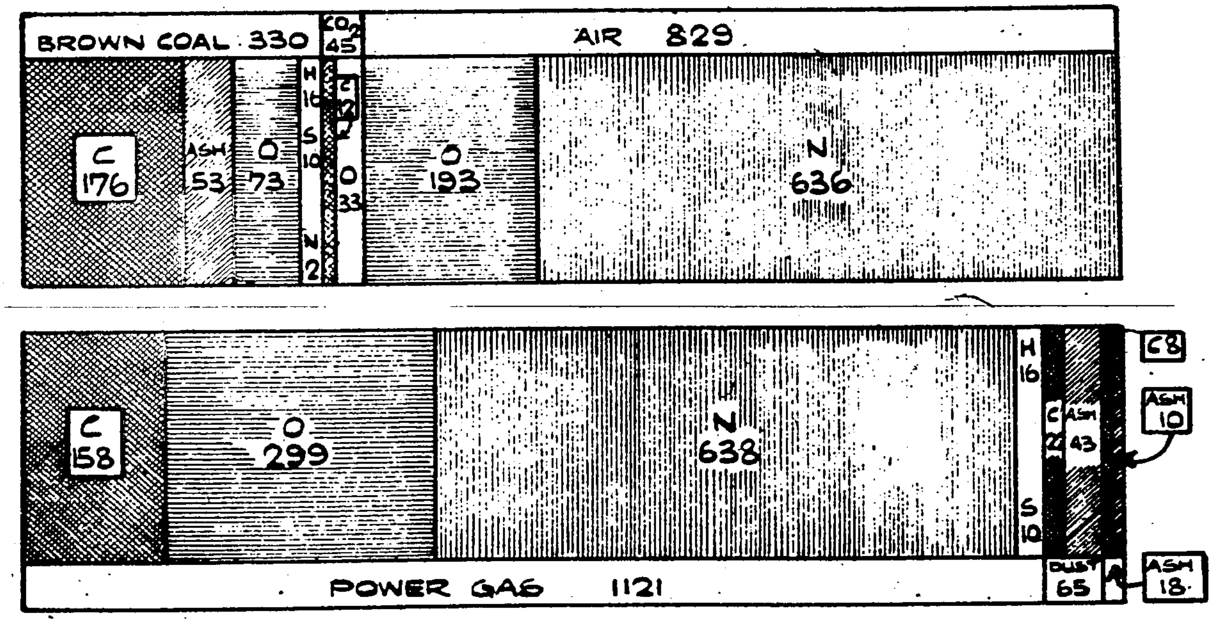
	Output M3/hr.	Density Air = 1	Dust g/M3
Water Gas			
(a) dry water gas	27,000	0.74	109
(b) water gas + undecomposed steam	36,000	0.72	81
Power Gas	50,000	0.91	65

At first sight it is difficult to see why power gas should contain less dust than water gas, since higher output and higher density would be expected to give more dust. However, evidently the main factor is the amount of fuel gasified, which controls the amount of fines brought in with fresh fuel and probably also the amount of fines resulting from attrition and gasification. Thus the percentages of dust in gas in terms of fuel used are 19.7% and 17.8% for producer gas and water gas respectively.

MATERIAL BALANCE AT LEUNA (Power Gas)

The following chart is based on Ref.10, giving the average for twelve months in 1935 :-

INGOING MATERIAL IN KG/1200 NM³ POWER GAS



OUTGOING MATERIAL

MATERIAL BALANCE AT LEUNA

NOTE:

Of the ingoing H in fuel, 13 kgs are as H and 3 kgs are as H_2O (26 kgs). Of the outgoing H in power gas, 12 kgs are as H and 4 kgs are as H_2O (35 kgs).

HEAT BALANCE AT LEUNA (Power Gas)

The following chart is also based on Ref.10, giving the average for 12 months in 1935 :-

INGOING HEAT IN T.CALS/1,000 NM^3 POWER GAS

Dry Brown Coal
1660

1000 (60%)	330 (20%)	260 (16%)	70 (4%)
C.V. Power Gas	Sensible Heat	Dust & Ashes	Loss

The thermal efficiency is thus about 60%.

MANUFACTURE OF AMMONIA SYNTHESIS GAS

The only direct data available is published in Ref.9. Oxygen enriched air with steam is used as the blast, and the efficiencies, etc. are those to be expected from combining data for water gas and producer gas, to give a mixed gas of the right composition.

USE OF FUELS OTHER THAN BROWN COAL

Obviously the Winkler generator becomes of much wider application if it can utilize fuels other than dry brown coal or grude. Here information is not nearly so reliable, since as far as we are aware no large generator has ever run very long on such fuels. Ref.1 states that I.G. designed large-scale plants in Japan to run on a grain size mineral coal of a particularly active character, but we know nothing of their operation.

Most of the experimental work has been carried out on a small generator (0.8 M^2 shaft area) at Oppau, and some on a small generator (2 M^2 shaft area) at Leuna. There are also references in the literature.

As stated before O_2-gasification is a relatively expensive way of gasifying a fuel and may become economic only with fuels which cannot be gasified conveniently in other ways. Examples, which have been considered, are bituminous coal dusts, especially those whose ash content is high or whose ash has a low softening point, and hard coke breeze. Nevertheless, since these fuels can in general be used as boiler fuels, perhaps at some discount, they will in general have an appreciably higher cost than brown coal, near the brown coal deposits.

All the fuels mentioned are appreciably less reactive than brown coal or grude, and to obtain reasonable outputs from a given generator it is necessary to work at higher temperatures; this means higher exit gas temperatures, higher oxygen consumptions, higher CO_2 contents of water gas and possibly troubles with clinker formation. Moreover, because of the lower reactivity it is more difficult to gasify any dust in the space above the fuel bed, and the secondary blast tends to react with the gas rather than with the dust.

It is probable that fuels like young gas coals and low-temperature coke breeze could be gasified successfully in Winkler generators, with efficiencies and outputs only somewhat less than with brown coal or grude, but such fuels are rarely cheap.

Ref.6 (p.12) states that hard coke breeze cannot be gasified in Winkler generators at Leuna. Ref.10 briefly describes tests in the experimental generator at Leuna in 1935. Certain brown coals were unsuitable because of low ash softening point and high proportion of soluble salts in the ash (see also below).

Earlier tests at Oppau are described in Ref.5. Short tests on an American bituminous coal (Old Ben Coal Corporation, Mine 8, Chicago) gave promising results. This coal is described as fairly reactive, not strongly caking. Crushed coal, "about the size of peas to hazelnuts, containing some dust" was fed by screw conveyor into the boiling bed of coke; the coal was quickly distributed in the bed and no caking occurred. No gas analyses are given.

MISCELLANEOUS POINTS OF INTEREST

Ref.10 describes difficulties arising from the high sand content of Elise coal, sand being the chief cause of variable ash content. Sand caused chokes in the stack-lines and valves; it also led to the formation of volatile silicon sulphide (cf. Chem.Fabrik 1935, p.512), which after decomposition gave rise to finely divided silica, which was able to pass through the disintegrators.

It is desirable to keep low the content of water-soluble salts in the ash; such salts tend to be volatile and give rise to slagging difficulties. Thus Ref.10 states that Elise coal had a total ash content of 20%, of which 10% was water-soluble; on the other hand a grude which gave considerable trouble with slagging had an ash content of 22%, of which 20% was water-soluble.

The use of blast preheaters has often been suggested, but as far as we are aware they have not been successfully applied to

Winkler generator so far, although attempts have been made at Leuna. On theoretical grounds one would expect that preheating the steam and oxygen mixture would reduce the oxygen requirements. According to Ref.6 preheating the blast to 400°C would save about 25% of the oxygen required with no preheating. The most economic way of preheating, from the point of view of running costs, would be to interchange the heat in the hot exit gases with the incoming blast, but the capital cost of such preheaters is likely to be high.

COMPARISON WITH OTHER PROCESSES FOR MAKING SYNTHESIS GAS.

As stated before, the Winkler process has the great advantage of being able to use low-grade fuels, difficult to gasify in other ways, and this at once may give it a great local advantage. When, however, it is considered for coals which can be gasified in other ways or where it has to use fuels having enhanced value for other purposes, e.g. as a boiler fuel, then it becomes much less attractive.

The two great drawbacks to the Winkler process are its relatively poor thermal efficiency, which is no higher than that of a conventional coke water-gas generator, and the cost of oxygen. If fuel is at all expensive the poor carbon efficiency is a disadvantage, only partly mitigated if the dust can be collected and used as a boiler fuel. Even when made in modern Linde-Fränkl units oxygen is never cheap, and it is interesting that the I.G. consider (see Ref.6, p.10) that it is more expensive to use continuous oxygen-gasification of any fuel than to use a make and blow process with air, provided the same fuel can be got into a suitable form in both processes.

All processes using oxygen-gasification have an additional disadvantage in that any oxygen added must eventually appear as CO_2 in the synthesis gas; hence greater compression costs and water scrubbing costs are incurred to remove it, with corresponding increased capital costs.

Although the amount of gas produced per unit shaft area is relatively great (say 900 to 1,500 $M^3/hr\ H_2 + CO/M^2$, as compared with say 600 $M^3/hr\ H_2 + CO/M^2$ for make and blow coke water gas generators), and although the absence of distribution difficulties in a boiling bed enables very large units to be used (e.g. up to 50,000 $M^3/hr\ H_2 + CO$ at Leuna, compared with say up to 8,000 $M^3/hr\ H_2 + CO$ in the largest coke water gas generators), nevertheless all the auxiliary equipment required means that the output of Winkler generators per unit area of site is no greater than that of coke water gas generators. Thus at Böhlen and Zeitz the capacity of three generators was obtained for a site area of about 50 M^2 site /1,000 $M^3/hr\ H_2 + CO$ installed capacity, including fuel handling, waste heat boilers, coolers, etc. but excluding the oxygen plant; the oxygen plant and its associated share of the boiler and power plant probably occupied an equal area. A coke water-gas plant, with all auxiliaries, would probably make the same amount of gas for a site area of about 40 to 60 M^2 site/1,000 M^3/hr

$H_2 + CO$ installed capacity. Moreover the large reaction space above the fuel bed, in terms of capital cost, largely offsets the advantage of a high output per unit area of grate.

CAPITAL COSTS

Available figures are of doubtful significance, but it is probably true to say that the capital cost of a Winkler plant, including oxygen plant, waste heat boilers, etc. is somewhat greater than that of a corresponding coke water gas plant, including coke ovens. The oxygen plant probably costs more than the Winkler plant it supplies.

PROCESS LABOUR AND MAINTENANCE COSTS

About four operators are required for each generator, but this depends to some extent on the size of generator. One man would be in the control cabin, which might however serve more than one generator, two men would be on waste heat boilers, dedusting and cooling equipment and dust handling, and one man on ash handling and miscellaneous labouring jobs. Labour additional to these four men would be required for fuel handling, especially if the preparation is done at the plant, and for machinery, such as oxygen blowers, boiler feedwater pumps, disintegrators, etc.

At Leuna in 1935 (Ref.10) 90 men and 11 chargehands were employed on the Winkler plant, running one power gas generator and one water gas generator. There would probably be one chargehand/shift for each generator and one for fuel handling, but if there were only four men/shift on each generator, this would leave about 60 men to cover fuel handling (but excluding drying) machinery, etc.; as well as day labour; this figure seems excessive but it is not clear from the reference whether any maintenance labour is included. A rough figure for water gas might be taken as 0.4 man hours/1,000 M^3 $H_2 + CO$.

Also at Leuna over 1935 (Ref.10) maintenance costs for water gas averaged 1.75 RM/1,000 M^3 $H_2 + CO$, for an average output of 20,000 M^3/hr $H_2 + CO$. Maintenance costs for power gas averaged 0.46 RM/1,000 M^3 power gas, for an average output of 50,000 M^3/hr.

TABLE II

SUMMARY OF DESIGN OF WINKLER GENERATORS MAKING WATER GAS

Plant	Leuna		Böhlen	Zeitz	Magdeburg	Brux
Reference	1		2	3	1	1 & 4
Units	Small 1	Large 3(+1)*	3	3	3	5 or 6
Output NM^3/hr water gas :						
Maximum	40,000	80,000	25,000	22,000	-	-
Normal	30,000	60,000	20,000	18,000	ca 20,000	ca20000
Minimum	-	-	12,000	9,000	-	-
Fuel	Grude(formerly dry brown coal)		Grude	Grude	Grude	?
Grate	1 small & 1 large are grateless; others stationary grate.		Stationary grates			1 grateless; rest Stny.Gr.
Gasification chamber	Some bulbous at top, some straight-sided.		Straight-sided			
	Small	Large				
I.D.of fuel bed	3.9 m	5.5 m	4.5 m	4-4.5 m	4.5 m ?	
Cross-sectional area	12 M^2	25 M^2	16 M^2	12.5-16 M^2		
Depth of fuel	1 m	1 m	1.5 m	1.5 m		
Overall height	-	-	20 m	20 m	20 m	
Waste Ht.Recvy.	Waste heat boiler, superheater and economiser					
Dust removal; primary	Cyclone before W.H.B.		Multicyclones after W.H.B.		Originally electrostatic, now multicyclones.	
final	Direct contact cooler and Theisen disintegrator					
Recovered dust used as:	Boiler fuel, returned to Winkler or for dephenolation.		Boiler fuel	Boiler fuel		

* 1 large generator now used experimentally for other purposes.

TABLE III

PERFORMANCE OF WINKLER GENERATORS MAKING WATER GAS FROM GRUDE

Plant	**Leuna**		**Böhlen**		**Zeitz**		?	
References	1		2	11	3 & 14 (Mostly 12 months 1944; some 2 months)		9	
	Small	**Large**						
Units	1	3(+1)	3		3			
Actual output N M^3/hr. W.G./unit	-	50,000-60,000	20,000-25,000		16,600			
Fuel (Grude)								
: **Analysis** % on dry basis C	68.0		-	71	63.7			70.7
H	2.0		-	2.6	2.2			2.7
O	2.2		-	1.1 ?	5.5			4.0
N	-		-					0.0
Vol. S	1.3		-					0.6
Ash	26.5		-	25.1	28.5			22
H_2O	(2.0)		-	(2.1)	(2.6)			(6.4)
Cal. value, T.cals/T.net as received	5780		5200-5400	-	5,650 to 5,850			5700
							mm.	%
Final grading	Av. 3 mms. with < 10% > 5 mms.		0.06-5 mm.	-	2-10 mms		0-0.2	20
							0.2-0.5	16
							0.5-1.0	20
							1-2	26
							2-3	8
							3-6	10
Gas Analysis CO_2	20		24.4	24.4	23.1			16.5
CO	37.5		27.6	28.8	29.6			42.6
H_2	39.5		45.3	44.4	43.8			39.0
CH_4	1.5		1.5	1.25	0.75			0.7
N_2	0.5		0.7	0.5	1.5			0.7
H_2S	1.0		0.5	0.6	1.25			0.5
Cal. value, k.cals/N M^3 net	2150		1990	1982	1985			2195
O_2 in total blast	40-50%		21%	22%	21.5%			37.5%
Blast temp. °C	-		150°	-	160-180°			-
% O_2 as secondary O_2	33%		12-20%	-	10%			
						Ref. 13		
Fuel bed temp. °C	850-900°		900°	800°	900-950°	960°		800-950°
Gas exit temp. °C	900-950°		900°	900°	900-1000°	980°		950-1,000°
Gas temp. after W.H. recovery	200°C		200-300°	300°	200-250°			250°
Dust content of gas, in g/N M^3 dry gas								
(a) before dust removal	100-200		200-250	225-250	300-360			-
(b) after primary dust removal			-	40-60	60			-
(c) after final dust removal			-	0.002-0.005	0.003-0.004			-

TABLE III (Cont'd)

		Leuna	Böhlen			Zeitz	-
References		1	2		11	3	9
% C in dust		50 to 55	40		43.1	54 -56	-
% C in ashes		-	40		54.1	30	-
Efficiencies							
per 1000 N M^3 H_2+CO			(1)	(2)			
grude	kgs	640	757	782	765	1023	630
carbon	kgs	427	-	-	534	635	417
oxygen	M^3	320 to 335	305	335	324	320	331
steam used	kgs	350	825	960	830	860*	405
steam raised	kgs	580	750	-	850	925	-
steam decomposition	%	-	-	-	-	35	-
carbon utilisation	%	88	-	-	68.6	57	86
dust blown over	kgs	130 to 260	-	-	-	500-550	-
dust recovered	kgs	-	-	-	245-270	458	-
grate ash	kgs	-	21	-	16.5	60	-
power (excl. oxygen production)	KWH	-	-	-	39	70	-
Cooling water	M^3	-	21	-	23	34	-

(1) Average of two days, 11th and 12th August 1938

(2) Average of 31 days, January 1940.

* In addition Ref.14 quotes about 230 kg/1,000 M^3 H_2 + CO as being used for "Apparateheizung", i.e. heating of items of plant, at least for the winter months, January to March; this use of steam is obscure.

TABLE IV

PERFORMANCE OF WINKLER GENERATORS MAKING WATER GAS FROM DRY BROWN COAL

Plant		Leuna				-
Reference		1	6	10 (12 months average)	10* (one day)	9
Actual output N M^3/hr. W.G.		-	-	27,000	42,000	
Fuel (Dry Brown Coal)						
Analysis %	C	61.1	-	59.3	57.3	61.1
On dry basis	H	4.7	-	4.5	4.4	4.7
	O	17.0	-	15.2	14.0	16.3
	N	0.1	-	0.7	0.6	0.8
	S	3.3	-	3.6	3.1	3.3
	ash	13.8	-	16.7	20.6	13.8
	H_2O	(6.0)	-	(8.7)	(8.1)	(8.7)
Cal.val., T.cals/T net as received		-	-	5170	5150	5270

TABLE IV (Cont'd)

		Leuna				-	
References		1 mm	6	%	10	9 mm	%
Final grading		0-0.6		9.6		0-0.2	20
		0.6-0.88		1.5		0.2-0.5	18
		0.88-1.0		9.0		0.5-1.0	17
		1-2		23.3		1-2	16
		2-5		16.5		2-3	12
		>5		0.1		3-6	17
Gas Analysis	CO_2	19	19	21.8	15.7	17.5	
	CO	38 -	38	35.3	44.4	41.8	
	H_2	40	40	38.5	36.0	37.2	
	CH_4	2	2	1.8	1.6	0.9	
	N_2	1	1	1.1	0.8	1.0	
	H_2S	?	?	1.5	1.5	1.6	
Cal.val., k.cals/N M^3 net		2162	2162	2117	2295	2195	
O_2 in blast		40%	-	40%	48%	40%	
Blast above fuel bed		33%	-	-	-	-	
Fuel bed temp. °C		-	-	-	-	800-950°	
Gas exit temp. °C		-	-	-	-	950-1,000°	
Dust content of gases in g/ N M^3 dry gas							
(a) before dust removal		-	-	110	170	-	
(b) after primary dust rem.		-	-	-	-	-	
(c) after final dust rem.		-	-	-	-	-	
% C in dust		-	-	29	35	-	
% C in ash		-	-	42	40	-	
Efficiencies per 1000 M^3 H_2+CO							
coal	kgs	800	800	830	855	790	
carbon	kgs	461	-	452	455	444	
oxygen	M^3	320- 335	330	366	316	342	
steam used	kgs	370	-	407	250	384	
steam raised	kgs	-	-	600	-	-	
steam decomposition	%	-	-	33	27	-	
carbon utilisation	%	80.5	-	86.5*	80*	84	
dust blown over	kgs	-	-	148	211	-	
grate ashes	kgs	-	-	41	44	-	
power	KWH	-	-	48	-	-	

* See also page 20

TABLE V

PERFORMANCE OF WINKLER GENERATORS MAKING POWER GAS

Plant		Leuna	–	–
Reference		10 (12 months av.)	9	9
Actual output, N M^3/hr.		50,000	–	–
Fuel		DRY BROWN COAL	DRY BROWN COAL	GRUDE
Analysis on dry basis	C	57.8	61.1	70.7
	H	4.3	4.7	2.7
	O	16.5	16.3	4.0
	N	0.6	0.8	0.0
	S	3.3	3.3	0.6
	Ash	17.5	13.8	22
	H_2O	(8.5)	(8.7)	(6.4)
Cal. val. T.cals/T net as received		5190	5270	5700
Gas Analysis	CO_2	9.8	7.7	4.3
	CO	21.7	22.5	32.7
	H_2	11.7	12.6	7.6
	CH_4	0.7	0.7	0.5
	N_2	55.3	55.7	54.6
	H_2S	0.8	0.8	0.3
Cal.val. k.cals/N M^3		984	1020	1140
Blast above fuel bed		25%	–	–
Fuel bed temp.		950°C	–	–
Gas exit temp.		1000°C	–	–
Dust content of gases in g/N M^3 dry gas				
(a) before dust removal		65	–	–
(b) after primary dust rem.		–	–	–
(c) after final dust rem.		–	–	–
% C in dust		33-55	–	–
% C in ash		34-44	–	–
Efficiencies /1,000 M^3 gas				
fuel	kgs	330	ca 330	ca 285
carbon	kgs	176	ca 186	ca 190
air	M^3	700	ca 720	ca 720
CO_2	M^3	25	–	
steam raised	kgs	450	–	
Carbon utilisation	%	83	ca 82	ca 97*
dust blown over	kgs	65	–	
grate ashes	kgs	18	–	–

*This appears very high and is probably in error: the fuel consumptions should be greater than shown.

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5. Third International Conference on Bituminous Coal, 1931, 1, 874, H.G. Grimm

6. B.I.O.S. Report : 199 Translated by D.G. Fraser and R.J. Morley "Ten Years of O_2 Gasification at Leuna"

7. Winkler Patent Numbers; the following is an incomplete list.

DRP.437,970 (1922) and its equivalent B.P.214,544 (1923)
DRP.484,093 (1924)
DRP.487,886 (1926)
DRP.494,240 (1927)
DRP.496,343 (1928)
DRP.535,535 (1928)
U.S.1,687,118 (1928)

8. Another report in this series, shortly to be published: Large-scale Production of Oxygen, by A.M. Clark

9. Oel u. Kohle, 8.6.42, A. Thau

10. C.I.O.S. Document. BAG 3041, Target 30/4.02. Document 6.
Annual Report for 1935 of Leuna Winkler Plant.

11. C.I.O.S. Document. BAG 2719, Target 30/6.12. Document 1.
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12. C.I.O.S. Document. BAG 3500, Target 30/4.05. Document 34.
Record note of 14.10.42.

13. C.I.O.S. Document. BAG 4182, Target 30/4.07. Document 1.
Zeitz data.

14. C.I.O.S. Document. BAG 4182, Target 30/4.07. Document 2.
Zeitz data.