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

GRATES AND GENERATOR BASE

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

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 Very soon stationary grates were used, originally made up of water-cooled beams, but the water-cooling was soon found to be unnecessary and even undesirable; these were replaced by fire-brick, but these were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

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

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

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

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

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

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

THE FUEL BED

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

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

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

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

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

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

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

COMPOSITION OF THE BLAST

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

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

SECONDARY OXYGEN

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

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

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

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

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

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

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

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

GENERATOR BRICKWORK

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

WASTE HEAT RECOVERY

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

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

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.