Experience with Low Shaft Furnace at Ougree

Dr. H. Malcor

HEIGHT is of major importance in a blast furnace. Of late there has been a tendency to increase the height of blast furnaces and exceptional thermal efficiencies were thus attained as can be visualised by the fact that the top gases do not exceed 100 to 150°C in temperature. However the main disadvantage with higher furnaces lies in the necessity of a combustible of great mechanical strength: metallurgical coke, a product both rare and expensive. It would therefore be advantageous to reduce the height provided this measure is not too detrimental to efficiency. Use of oxygen was thought of in this connection and the idea of a collective study on the performance of a Low Shaft Furnace was formed in 1951 in the meetings of a Committee of the European Organisation of Economic Co-operation (*Office Europeen de Co-operation Economique*) which was to investigate the possible uses of oxygen in ferrous metallurgy.

Seven European countries were signed up for a 5-year mutual contract to form our International Committee for Research on the Low Shaft Furnace (*Comite International de Recherches sur le Bas Fourneau*). These countries were: Austria, Belgium, Greece, France, Italy, Luxemburg and Holland. The Batelle Memorial Institute (U.S.A.) joined subsequently. The United Kingdom participated in the Committee as an Associate Member. Moreover, renowned specialists from Germany, Sweden, Switzerland and Yugoslavia agreed to take part in the deliberations, as consultants.

Considering the economic conditions of the countries in Western Europe, the main object of the Committee was to study the possibility of producing a Thomas pig iron (i.e. a cold pig-iron) on an industrial scale, in the low shaft furnace, using raw materials considered as poor or unsuitable for blast furnace purposes, such as fine ore and especially, combustibles other than metallurgical coke.

The first contract expired in December, 1958 and while many of the original Committee Members discontinued their associateship, the High Authority of the European Community for coal and steel (*Haute Autorite de la Communaute Europenne du Charbon et de l' Acier*) agreed to match up the required funds for a period of three years provided the programme of work would mainly include investigations that could impart a better knowledge of the mechanism of the blast furnace process.

From the beginning, the research was guided by a "Directive Committee" assisted by one "Technical Committee" and one "Executive Committee". Financial dealings of the enterprise are being managed by the Belgian Institute of Research (IRSIA) and the execution of research is entrusted to the Belgian National Centre of Metallurgical Research (*Centre National Belge de Recherches Metallurgiques*).

Construction of the Low Shaft Furnace

The construction of a pilot low shaft furnace was the first job the Committee had to undertake and the plant was built at Ougree, near Liege in Belgium, in the immediate vicinity of an oxygen producing unit. The works started in July, 1952 and were completed by May, 1955.

Fig. 1 shows the general layout of the plant and we can see:

- the low shaft furnace,
- the Cowpers stoves,
- the turbo-blower,
- the casting, storing and burden preparation hall,
- the control room and the offices.

We have selected an oval section for the low shaft furnace. In fact, if ever low shaft furnaces are to be built with large capacities, they cannot be circular because opposite tuyeres would then be at too great a distance one from another, which would create a zone of lesser activity at the centre: this would cause a portion of burden to reach the hearth in an insufficiently conditioned state. As a matter of fact it was not necessary to take up the oval shape for a relatively small section as the one of our low shaft furnace but we thought it preferable to try this shape which would be necessarily adopted for high capacity industrial units.

We knew that numerous difficulties would be caused by this shape and for one year the performance of the furnace was indeed irregular, marked by serious blockings at the extremities of the major axis, numerous falls and high production of flue dusts.

Based on the experience acquired in the course of the first trials, the furnace underwent great alterations. We can mention in particular that the charging system was too simple and caused a bad distribution of the charges. The two charging boxes consisted of a chamber closed at the top by a valve

Dr. H. Malcor, President, Institut de Recherches de la Siderurgie (IRSID), France.

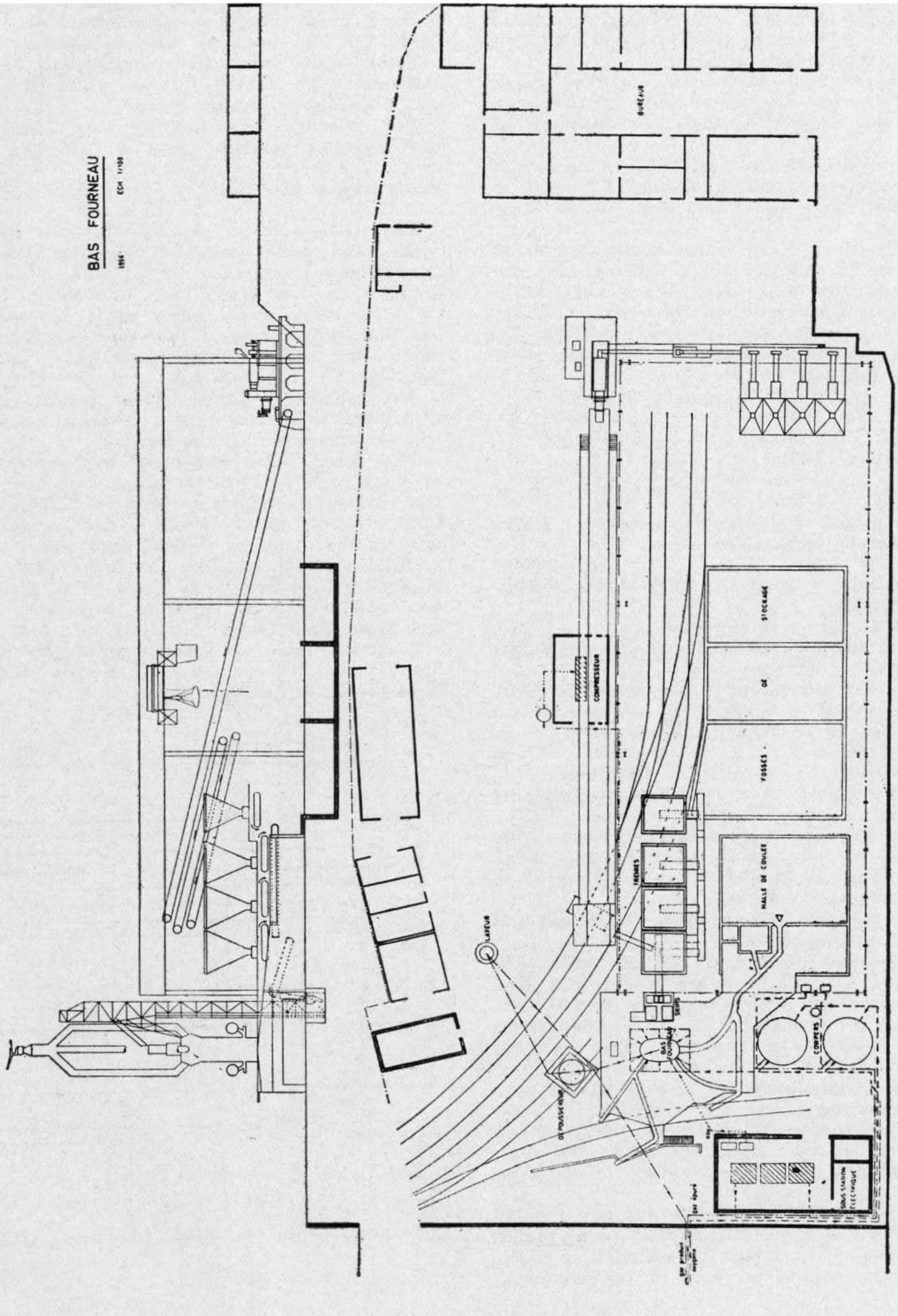


Fig. 1. — Plan schématique actuel de l'usine pilote.

which ensured tight closing when the bell forming the bottom of the chamber, was going down. This system has been replaced by a revolving double bell as for the standard blast furnaces.

In order to adapt the furnace to its oval shape, we also had to modify the distribution of the blast by changing the number, position and diameter of the tuyeres.

The profile of the furnace was also altered and the two horizontal gas outlets originally located at the ends of the minor axis were replaced by four vertical outlets.

These modifications have considerably improved the performance of the low shaft furnace and the stability and reproducibility reached are sufficient to draw definite conclusions from the trials. There, however, still remained a tendency for blockings.

The present main characteristics of the low shaft furnace are as follows :

- length : 3·20m (originally 3·00 m.)
- width : 1·40m (,, 1·20 m.)
- hearth area : 3·81m² (,, 3·06 m.)
- bosh area : 5·91m²
- stock area : 5·05m²
- total height : 7·40m
- maximum height of charge above tuyeres : 4·80m
- height generally maintained avove tuyeres ... ... : 3·50m
- refractory lining : silico-aluminous bricks carbonaceous lining
- number of tuyeres : 10 (originally 8)
- diameter of tuyeres : 60 to 80mm (originally 100 to 140mm).

Fig. 2 shows the dimensions of the actual furnace

The blast required is collected by a group of two blowers in series of 14,000m³/h capacity and it is injected at 4,000mm of water pressure. These blowers are worked by a motor, 6,000V–900 hp, which can be coupled to a turbo-blower (pressure 2·3 kg/cm²—discharge 9,000 m³/h).

The blast is conveyed into 2 Cowper stoves, 19m high and 6m diameter, capable of heating it to about 800°C. The whole installation is designed to stand a pressure of 2·5 kg/cm².

Pig iron is tapped about every 4 hours and removed in the solid state.

Raw materials are discharged and collected by a weigh bridge of 8 tons ; they are stored in 3 bins each having a capacity of 900 tons ore or 450 tons coke and are then charged on 3 feeding sieves screens of 100–150 tons capacity. The weighing system adopted is not a standard one (continuous system on 3 weighing belts) and it allows the intermittent weighing of all raw materials for both cases of standard alternative layers operation as well as mixed charges melting. The last belt distributes the materials in two skips of 800 tons each.

There was no provision originally for any special preparation of the charges but it was soon found difficult to use ores with high percentages of fines. We examined the various processes of agglomerating the fines in some not too expensive manner and as a result of our study, a vacuum cold extrusion press of 10 ton/hour capacity was installed in 1957.

Total costs of the installations at Ougree amounted to £ 470,000 of which £ 84,000 was spent for the extrusion press.

The expenses incurred by our Committee from the beginning totalled about £ 1,300,000.

Programme of trials

The trials were so planned that we may :

On one hand, achieve the objectives of the Committee : Production of a cold pig iron from ore fines and low grade fuels, in economic conditions ;

On the other hand, carry out a systematic study on the performance of the low shaft furnace to point out the factors likely to influence its behaviour ;

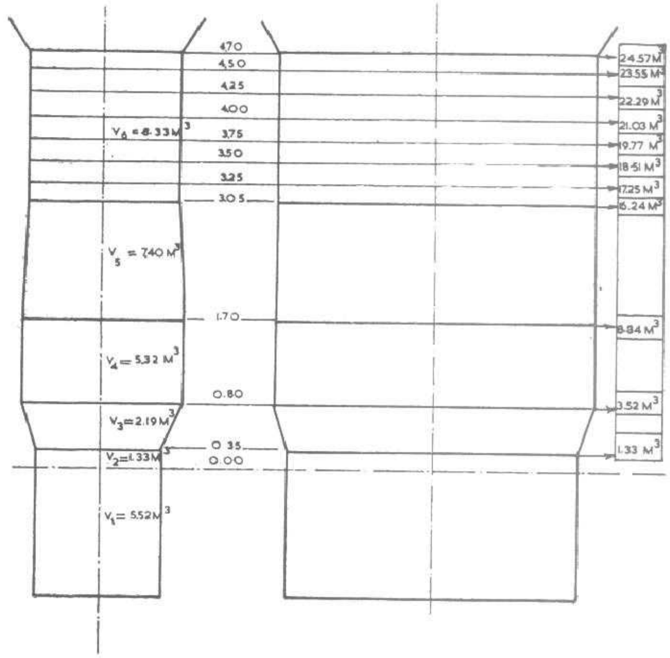
And finally, obtain such results as would contribute to increase our present knowledge on the performance of blast furnaces.

The trials were executed by metallurgists of of Liege with the collaboration of engineers from the various participating countries. While in operation the low shaft furnace has a staff of 70 workers and employees, and 5 engineers.

Metal was tapped for the first time in 1953 ; in a period of five years about 15 major campaigns were conducted each of 1 to 2 months' duration and more than 16,000 tons pig iron were produced.

Results of major importance during the most significant periods of operation of the low shaft furnace have been given in this paper.

PROFIL DU BAS FOURNEAU 1958



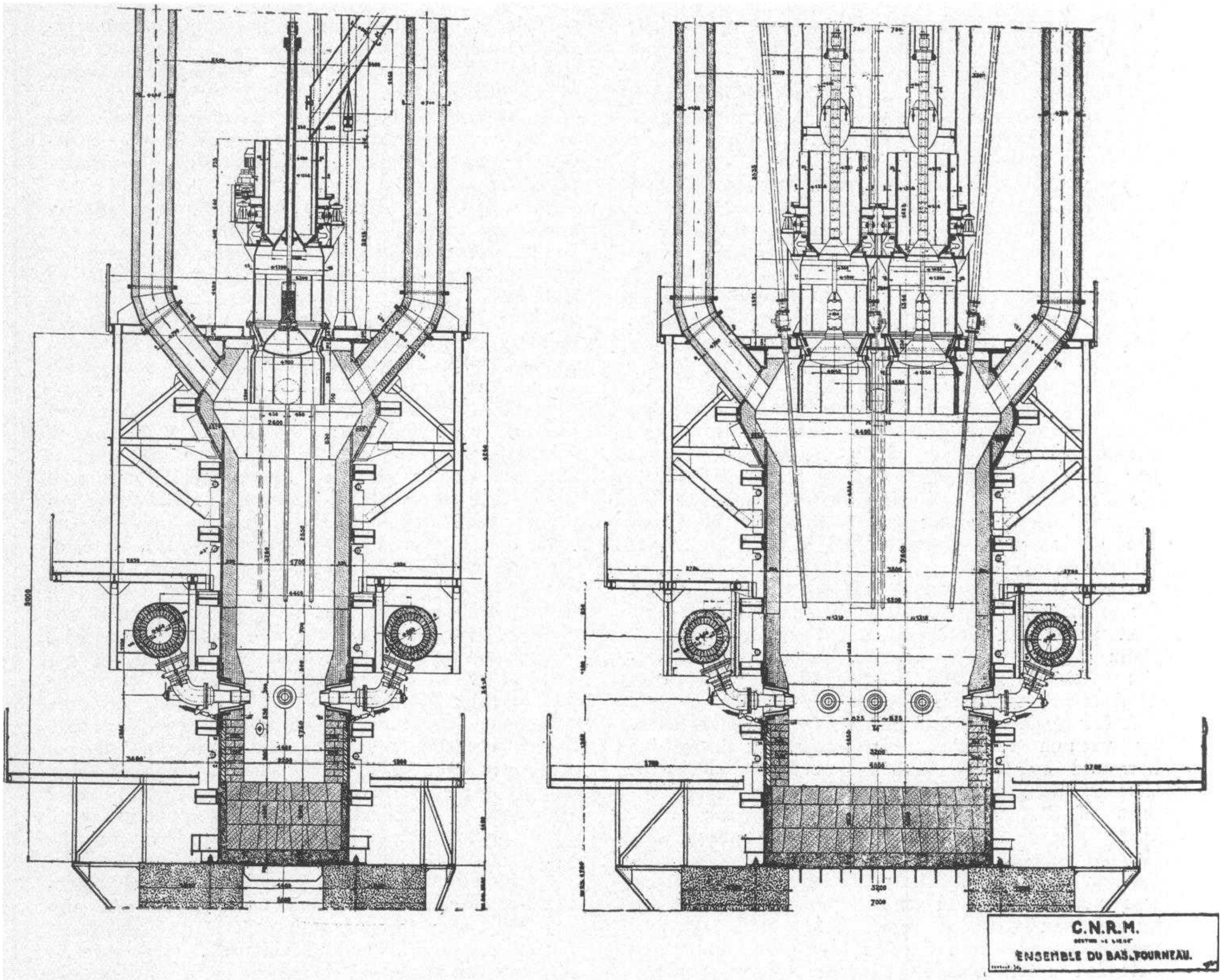


Fig. 2.—Coupe Vertical du bas fourneau actuel (8 tuyeres).

The objective of the first campaigns was to regulate the plants; certain constructional drawbacks were observed and as already mentioned amendments were made in 1954.

Low grade, siliceous Luxemburg ore was used, and then low grade calcareous ores with about 30% Fe, obtained from Luxemburg and Lorraine. These ores were of low grain size (0–30 mm) and all of them contained a large proportion of fines (20 to 40% and even 60% of 0–10 mm).

As combustible, we successively used various metallurgical coke breezes (0–30 mm) and then, French semi-coke (9–25 mm) with 15% moisture, 12% ashes and 9 to 12% of volatile matters. This semi-coke obtained from non-coking high volatile coals, gave excellent results.

These first campaigns were characterised by an irregular operation with numerous hangings, blockings and large quantities of flue dusts (200 to 500 kg per ton of pig iron) which were there in particular, due to the high proportion of fines in the ore. The use of oxygen enriched blast at 28% did not result in any improvement. The intensity of combustion could not be increased, without serious disturbances, beyond 55 tons per day with ordinary blast and 70 tons per day with oxygen enriched blast.

The fuel rates were high (calculated values of 1,200 to 1,600kg/tons pig iron) and the indirect reduction was poor, but it was a good surprise to note that the top gas temperature was low (below

200°C) and that thermal losses were only minor (7%), even with the low grain sizes and even without enriching the blast.

The silicon content of the pig was relatively low (1%) and the pig iron was in a fairly well carbonised state provided the combustible was not in too large pieces (<25 mm).

After modifying the low shaft furnace the first campaign of 1955 was fairly long and its main objective was to appreciate the improvements effected and to achieve stability in the operation of the furnace.

The campaign started with the same semi-coke and the calcareous Lorraine ore, as used previously. Later another Lorraine ore of 32% Fe was exclusively used in the low shaft furnace.

From the start, the performance was more regular and flue dust production had decreased; after trials with varying proportions of fines it was soon evident that at a rate of 40 to 60 tons of coke per day, the low shaft furnace functioned as an ejector, conveying all the fines charged, to the dust catchers. Neither use of enriched blast nor use of low top pressure (0·5 kg/cm²) had any favourable effect.

However, with screened or dust-free ore (3–25 mm for example), the conditions improved and flue dust production decreased to 85 kg/tons pig iron. From this, it was apparent to us that agglomeration of the fines should be done, if large quantities of fines are to be charged in the furnace.

A few agglomerating trials, at normal temperature by vacuum extrusion, were made on a machine borrowed by the Committee and these elucidated the question. Extruded materials made from ore fines of St. Pierremont 0–7 mm (pure or mixed with 50% of blast furnace dust) were consumed in the low shaft furnace along with the 7–20 mm fraction of the ore. The operation of the furnace was satisfactory and the Committee decided to purchase an extrusion press. Trials with extruded materials made from fines of lean coals, and mixed extruded materials gave, however, mediocre results.

At the end of 1955 there was a short campaign using as fuel a mixture of French semi-coke and dry Lorraine high volatile with 42% of volatiles (grain size 20–30 mm) but the run of the furnace was found difficult.

A new campaign in 1956 tried the use of high volatile dry nut coal (30–50 mm) and then of high volatile fat nut coal. The results were satisfactory and good quality pig was produced especially when using the dry high volatile variety. The absence of tar in the dust catchers and in the gas, proves that hydrocarbures were cracked in the hearth.

At the end of the year we carried out comparative trials with dust-free ore, Dwight-Lloyd sinters, and then with coke breeze and semi-coke; this was done in order to determine the behaviour of hydrogen in the hearth. When using sinter the furnace worked very regularly, without flue dust; the pig was of good quality but the top temperature was high (300°C) and so also the fuel rate (taking into account the high temperature reached in the fusion bed).

In 1957, we received the extrusion press, and we main'y concentrated our activities on the manufacture and consumption of various types of extruded materials.

The trials first related to extruded ore. Lorraine fines gave excellent results, provided a size of 3 mm was not exceeded. Addition of 4% water was necessary to increase plasticity and the product thus obtained contained 15% humidity. When fresh from the machine their crushing strength was of 2 kg/cm² and this reached 5 kg/cm² after hardening. Extruded products, 33, 25 and 16 mm diameter were tried in the low shaft furnace.

The 35 mm extruded materials were too big, and unsatisfactorily reduced; at the rate of 50 tons of coke/day, their use resulted in a poor performance and bad quality pig. We then decreased the rate to 35 tons of coke/day, and this considerably improved the furnace operation with 25 mm pieces; with the 16 mm size we could afford a rate of 50 tons coke/day. Flue dust production did not exceed 70 kg per ton of pig. Results were still better with re-sieved coke over 10 mm, but it was observed that the fuel rate was higher in the case of extruded material than when using sieved ore.

In order to confirm the influence of the coke rate, several trials were made with fine, raw ore 0–25 mm; at the rate of 40 tons of coke/day only the performance was found very stable and the pig of correct composition. The smelting zone rose up, indirect reduction increased and the fuel rate clearly decreased. There were however large quantities of dusts due to a high proportion of fines in the ore.

We have then tried to use mixed ore-coal agglomerates. We obtained good ones, of 25 mm size and 10% coal, from Lorraine fines (0–3 mm) and 0–2 mm, Ruhr, floated "Schlamms". Their use in the low shaft furnace together with coke breeze was however not satisfactory. Dust was produced in large quantities; the mixed agglomerates were rejected and choked the furnace.

Another trial was also made to study the behaviour of volatile matters in the low shaft furnace using 0–25 mm ore and Sarre high volatiles, freed of the major part of their volatile contents by heating at 650°C.

During the year 1958, we worked the low shaft furnace as an experimental blast furnace.

We first varied the coke rate between 50 to 30 tons of coke/day in order to determine the conditions in which the performance of the low shaft furnace would be most stable and most comparable to that of the blast furnace, even at the cost of lowering the productivity ore and coke breeze, re-screened on 5 mm were used. 40 tons of coke/day appeared to be the optimum rate.

Using the same raw materials, we proceeded to another trial where the top pressure was of 1·5 to 2 kg/cm². It was then observed that use of top-pressure considerably improved the working of the low shaft furnace; the fuel rate decreased by about 200 kg/ton of pig; the pigs obtained were well carburised and very fluid. On the contrary while working at the too low rate of 30 tons/of coke/day the blast could not penetrate well and the furnace cooled down.

We subsequently took up trials with Dwight-Lloyd sinter with or without top pressure, at the rate of 35 to 40 tons of coke/day.

The first trials with unscreened sinter and without top pressure gave deceiving results. Big pieces in an unreduced state passed in front of the tuyeres. To improve things we not only had to reject pieces larger than 35 mm but also to eliminate the 0–3 mm size. The performance became really satisfactory only after careful re-screening of the sinter on 3–25 mm. The pig was then of good quality, and the fuel rate was distinctly lower than with ore, but the top temperature remained higher than in the case of ore smelting.

A few trials with 30% enriched blast have given promising results; the top temperature appreciably decreased. However, a few unreduced pieces were still appearing in front of the tuyeres and the pig was not as good as usual. Our enriching of the blast was perhaps excessive and this might have caused excessive concentration of heat in the melting zone.

Trials without addition of flux, consequently with a lower basicity index than usual ($CaO/SiO_2=1{\cdot}09$ as against about 1·5) have improved the performance and decreased the fuel rate.

Finally, the use of top pressure (1·4 kg/cm²) gave the same favourable results in both cases of sinter as well as raw ore. The furnace was remarkably stable, and desulphurisation excellent in spite of the low index of basicity. The top temperature fell from 250 to about 150°C, the ratio CO_2/CO changed from 0·31 to 0·45 and the raw coke rate decreased to 890 kg/ton of pig, i.e. a corrected fuel rate of 673 kg. This figure is quite comparable to that of blast furnaces consuming 100% sinter. In proper conditions and with suitable burden size the low shaft furnace behaves as a blast furnace.

In the course of our trials to come we intend studying more closely, with ore sinter, the influence of top pressure oxygen and water vapour in the blast, as well as the effect of the blast temperature, which had always been maintained so far around 700–750°C except for a very short trial where it was only 500°C.

We are also setting up an apparatus which will enable us to inject liquid fuel in the tuyeres.

We will also continue our trials on the preparation of extruded materials from various materials—low grade iron ore, pyrite, dust from blast furnace working with ferro-manganese.

Results

What are we to infer from these five years of operation?

We had been handling a new type of plant, which was yet to be set to the point and which was unfamiliar to the staff. Moreover, we wished to carry out a number of different trials and therefore we frequently changed the operating conditions.

Now that the unit has been stabilised and that experience has been gained by our staff the performance has much improved and the results would be still better if the low shaft furnace worked without interruption.

Having said this, the author feels that ample experimental results have been collected during these five years. Many of the results are definite and undisputable while some others will have to be verified and completed by new trials.

In the last place we proved that the low shaft furnace can produce good quality pig on an industrial scale, provided certain conditions, that we are going to point out now, are fulfilled.

Influences of the grain-size of the burden: The low shaft furnace adapts itself, without too many difficulties, to raw materials of mediocre quality, provided they are small sized (say 35 mm) and do not contain excessive fines.

The advantages of such a grain size were evident throughout the trials: heat exchanges are rapid and it becomes possible to use a furnace as small as ours.

The ore (whether it is raw ore, extruded agglomerates or Dwight-Lloyd sinter) should also not be used in too large sized pieces as these would reach the hearth in an insufficiently prepared state. Extruded pieces of 33 mm dia. are, in particular, not satisfactorily reduced.

Consumption of ore fines: Conversely, if a high percentage of fines is contained in the ore (and this was one of the main aims of the Committee) the furnace operation is irregular, with blockings and very high quantities of dust. This is at least what we could observe in the working conditions initially set for our furnace i.e. 50 tons coke per day and without top pressure. 200 to 500 kg of dust per ton of pig were thus obtained with an ore containing about 40 to 60% of 0–10 mm size. Resieving the ore on 5 mm the productiou of dust fell to 85 kg/ton.

When coke rate is lowered, the furnace becomes more stable and there is a considerable decrease in the production of dust. At a rate of 30 ton/day a raw ore with 60% of 0–10 mm, gave only 50 kg of dusts per ton of pig and with a resieved ore this figure was 12 kg/ton pig (the coke breeze used was also resieved). This observation can be explained by the fact that with such burden size used, the charge is presumably put in partial fluidisation, when the coke rate reaches 50 ton/day.

We are trying to consume more fines by using top pressure. The last trials with a high top pressure of 1·5 kg/cm² have in fact given much more encouraging results than the first one.

Another way of utilising the ores rich in fines, is to agglomerate the fines by a relatively simple process; this is for example the case of 0–3 mm ore cold extruded under vacuum. While using 100% of such materials of 16 mm dia. the furnace runs well; the quantity of dust is less than 100 kg/ton pig but the fuel rate is found to be higher than with screened ore of the same size.

Consumption of lower grade fuels: As far as fuels are concerned, our trials have confirmed that the low shaft furnace can consume different types of combustibles less resistant and less expensive than the metallurgical coke, provided a proper size is ensured. It is desirable to eliminate the major portion of fuel fines. Various types of coke breeze, when the grains are hard, dried and properly dust-freed, gave the same results. A porous and friable variety however brought about some difficulties.

Semi-coke containing 10 to 12% of volatiles (mainly hydrogen) gives excellent results. The gross fuel rate is found to be of the same magnitude as in the case of coke breeze. This means that the rate of fixed carbon is lower by 10%. It is to be assumed from this that hydrogen contained in the semi-coke has special reactive properties.

Nuts of high volatiles (42%) behave very well in the blast furnace provided they are not too small sized (30 to 50 mm), otherwise they are partially rejected. Most of the tar seems to be dissociated in the smelting zone; they are found neither in the gas nor in the dust catcher. The gross fuel rate was unfortunately very high while using these nuts: it was more than twice the rate for coke breeze, i.e. an increase of 40% in the rate of the fixed carbon.

High volatile coals, devolatilised at 650°C cause hangings and falls; the carbon rate is comparable to that of coke breeze.

A few trials for use of anthracite mixed with semi-coke have given very encouraging results.

The use of raw coal fines in the low shaft furnace was found impossible. Extruded coal fines ore mixed extruded materials have not so far given any satisfactory solution to this important problem.

It would be useful to carry out further trials in this direction.

Quality of the pig: The pigs obtained are of the Thomas OM type, i.e. cold pig low in silicon; their average analysis is as follows:

3·5% C, 0·8% Si, 0·1% S, 1·7% P, 0·5% Mn.

Excepting for the very last trials where no flux was added and in which the basicity of the slag was 1·1 the slags were rather strongly basic:

$$45\%\ CaO,\ 30\%\ SiO_2,\ 15\%\ Al_2O_3,\ i=\frac{CaO}{SiO_2}=1{\cdot}5$$

We had feared that the short stay of materials within the low shaft furnace (3·2 hours as compared with 12 hours in the blast furnace) would cause an insufficient conditioning of the charge in the hot zone and that the ore would reach the hearth in an unsatisfactorily reduced state which would result in the refining of the pig and all other disturbances connected with it: Sulphured pig, scories, blocking of the hearth.

In fact, the low iron content of the slag (1%) and the rather normal sulphur content of the pig, prove that in our operating conditions, the charge does reach the tuyeres level in a sufficiently well prepared state. As already mentioned these conditions are: small grain size of the charge and a narrow horizontal section of the furnace to avoid dead zone. The larger size extruded materials and the raw agglomerates have thus given pigs with too low carbon and of high sulphur contents.

The first pigs tapped were rather low in carbon, so that we feared lest a certain refining should take place in the hearth. But since the operation was stabilised and fuel, well-sized, we obtain very fluid pigs, especially with use of top pressure. On the other hand, it was observed that addition of some coke breeze in the charge was effective in increasing the carbon content when necessary.

Temperature of top gases: Contrary to what could be expected, the temperature of the top gases is generally low, provided the charge is sufficiently low-sized. This temperature can be regulated and changed at will by altering the effective height of the charge. Charging raw Lorrain ore, and grain-size being 10–30 mm, the top gases are hardly 100°C when the charging level is of 3·70m above the tuyeres. When this level is of 4·70m the gas is too cold. It is therefore not necessary to adopt enriched blast when using raw ores.

The top temperature, however, reaches 250–300°C, when use is the made of sinter without top pressure and in this case oxygen proves useful.

Soundings to determine the temperatures at various levels have shown that the smelting zone is very concentrated in the low shaft furnace. In a normal run with ore, the temperature is found to be 1,100°C, 2m above the tuyeres; this falls to 500°C, 3m above the tuyeres and to 80°C at a distance of 3·70m above the tuyeres.

This heat concentration is essentially due to the small grain-size of the coke charged and the zone is more spread up when using sinter without top pressure.

This concentration of heat explains why the thermal radiation losses are lower in the low shaft furnace than in the blast furnace even though the ratio area/volume has a better value in a blast furnace. Thus, in the low shaft furnace the thermal losses amount only to 7–10% of the total calory-input. This fact, together with the low temperature of the top gases, ensures a higher thermal efficiency to the low shaft furnace than the blast furnace.

Indirect reduction: The reduced height of the furnace and of the smelting zone could act in such a way that the gases rising from the hearth do not have sufficient time of contact with the charge so that indirect reduction may be as good as that in the blast furnace.

At the normal rate of 50 ton/coke/day, the indirect reduction is in fact lower than in the

Operational Data of the Low Shaft Furnace at Ougree

Period No.	Fuel (Grain size in mm)	Iron Ore (Grain size in mm)	Tuyeres (No. & dia.)	Charging height (m.)	Blast Temp. (°C)	Blast % O_2	Top Pressure	Fuel consumption	Calculated weight of C	Total dusts	TOP GAS Temp. (°C)	TOP GAS CO_2/CO (gross)	TOP GAS % H_2	PIG IRON Production (ton/day)	PIG IRON % C	PIG IRON % Si	% S	Slag CaO/SiO_2
1	Cockerill Coke. 10/30	Luxemburg, 26% Fe 10/30 (20% 0/10)	8 of 140 mm	4.8	650	21	0	54.5	1263	262	167	0.33	2.6	29.2	3.24	0.32	0.146	1.42
2	"	"	"	"	724	28	"	52.2	1181	174	138	0.3	2.8	30.3	2.91	0.80	0.145	1.52
3	Esperance Coke 10/20	"	"	"	671	27	"	76	1303	362	137	0.28	2.9	39.9	3.24	0.48	0.154	1.44
4	Ougree Coke 10/30	Piennes, 34% Fe 0/20 (40% 0/10)	"	"	662	21	"	56	1127	562	214	0.35	2.9	33.7	3.16	0.48	0.214	1.42
5	"	"	"	"	719	27	"	72.5	1210	562	203	0.31	3.9	40.0	2.91	0.87	0.306	1.50
6	Zeebrugge Coke 10/20	"	8 of 80 mm	4.5	773	27	"	71.5	1116	288	185	0.26	3.4	43.1	3.49	0.86	0.131	1.45
7	Ougree Coke 10/30 + 20% Frasil 0/10	"	"	3.6	759	29	"	71.8	1193	637	185	0.24	3.3	35.4	3.47	0.59	0.174	1.54
8	Ougree Coke 10/30	"	"	4.6	752	28	"	70.8	1173	300	168	0.25	3.3	39.5	3.20	1.12	0.181	1.60
9	Zeebrugge Coke 10/30	"	"	4.3	788	28.5	"	66.8	1157	256	141	0:27	3.8	36.5	3.23	0.85	0.167	1.52
10	Cockerill Coke 20/40	"	"	4.8	799	28	"	65.5	1331	243	189	0.25	3.8	34.8	2.98	1.38	0.203	1.57
11	Gand Coke 5/20	"	"	4.1	789	27.5	"	68.3	1178	453	145	0.25	3.6	35.4	3.34	0.91	0.229	1.48

Trials for regularising the operation of the furnace (1953)

Period No.	Fuel (Grain size in mm)	Iron Ore (Grain size in mm)	Tuyeres (No. & dia.)	Charging height (m.)	Blast Temp. (°C)	Blast % O_2	Top pressure	Fuel consumption	Calculated weight of C	Total dusts	TOP GAS Temp. (°C)	TOP GAS CO_2/CO (gross)	TOP GAS % H_2	PIG IRON Production (ton/day)	PIG IRON % C	PIG IRON % Si	% S	Slag CaO/SiO_2
12	Zeebrugge Coke 10/30	Piennes 34% Fe 0/20 (40% 0/10)	8 of 80 mm	4.1	774	27.5	0	67.7	1125	357	96	0.25	3.3	35.9	3.49	0.92	0.165	1.55
13	Bruay Semi-coke 10/20 (10% MV)	Minette Ida 31% 10/30 (28% 0/10)	8 of 60 mm	3.2	767	28	"	66.9	1111	296	125	0.24	6.9	36.1	3.61	0.23	0.114	1.68
14	Bruay Semi-coke 10/30	"	"	?	682	21	"	45	1063	541	120	0.30	5.9	22.7	3.44	1.10	0.07	1.52
		(Operations stopped for altering the furnace)																

Use of semi coke (1954)

Operational Data of the Low Shaft Furnace at Ougree

Period No.	Fuel (Grain size in mm)	Iron Ore (Grain size in mm)	Tuyeres (No. & dia.)	Charging height (m.)	Blast Temp. (°C)	Blast % O_2	Top pressure	Fuel consumption	Calculated weight of C	Total dusts	TOP GAS Temp. (°C)	TOP GAS CO_2/CO (gross)	TOP GAS % H_2	PIG IRON Production (ton/day)	PIG IRON % C	PIG IRON % Si	% S	Slag CaO/SiO_2
15	Bruay Semi-coke 10/30 + coke 20/40	Minette Ida 31% Fe 10/30 (28% 0/10)	8 of 60 mm	?	657	21		53	1129	671	115	0.33	4.2	27.4	3.46	1.10	0.070	1.53
16	Bruay Semi-coke 10/30	"	10 of 60 mm	4.2	709	"		50.8	1097	326	86	0.30	6.4	24.6	3.47	0.98	0.067	1.52
17	"	"	"	?	775	"	29cm Hg	56.8	966	339	69	0.33	6.4	24.9	3.55	0.76	0.065	1.53
18	"	St. Pierremont 32% Fe 4/32	"	?	762	"	20cm Hg	52.6	1098	521	96	0.32	6.3	25.6	3.43	1.14	0.080	1.56
19	"		"	?	763	27.7		58.8	1007	466	62	0.27	7.5	30.7	3.26	1.24	0.083	1.54
20	"	St. Pierremont 4/32	"	?	705	21	26cm Hg	56.6	893	206	105	0.37	5.7	40.8	3.51	1.17	0.042	1.63
21	"	"	"	?	716	"	0	51.7	857	353	103	0.34	5.6	36.2	3.49	0.87	0.050	1.65
22	"	St. Pierremont 4/32 + 16% extruded material 33 mm dia.	"	?	726	"	"	55	927	304	84	0.33	6.1	34.3	3.47	0.72	0.072	1.64
23	"	St. Pierremont 4/32 + 47% extruded material 33 mm dia.	"	?	740	"	"	54	1218	387	125	0.25	6.6	?	3.38	1.51	0.062	1.49
24	30/50 Faulquemont/dry high volatile + Bruay Semi-coke	St. Pierremont 4/32	"	?	713	"	"	66.3	1341	452	142	0.26	7.4	?	3.69	0.80	0.076	1.63

Trials to obtain a regular furnace operation with use of Semi-Coke—Consumption of extruded materials and Coals. (1956)

Period No.	Fuel (Grain size in mm)	Iron Ore (Grain size in mm)	Tuyeres (No. & dia.)	Charging height (m)	Blast Temp (°C)	Blast % O_2	Top pressure	Fuel consumption	Calculated weight of C	Total dusts	TOP GAS Temp. (°C)	TOP GAS CO_2/CO (gross)	TOP GAS % H_2	PIG IRON Production (ton/day)	PIG IRON % C	PIG IRON % Si	% S	Slag CaO/SiO_2
25	Faulquemont 30/50 dry high volatile (42% volatiles).	St. Pierremont 4/32	10 of 60 mm	4.7	753	21	26cm Hg	50 0	1507	392	252	0.20	-	20.7	3.37	0 90	0.118	1 55
26	Ougree coke 10/30	St. Pierremont 5/25 rescreened	"	4.5	700	"	"	"	992	88	85	0.34	2 9	33.4	3.61	0 69	0.064	1 61
27	"	Dwight-Lloyd Agglomerates + Lime	"	4 6	735	"	"	54 3	833	18.4	275	0.16	1.9	34.6	3.48	0.56	0.046	1.52
28	Bruay Semi-coke 10/30	"	"	4.7	740	"	"	50	837	33.2	349	0.14	4.8	33	3.42	0.86	0.035	1 64
29	Ougree coke 10/30	St. Pierremont 5/25 rescreened	"	4.1	722	"	"	53.5	1073	80	69	0.28	3.5	31.8	3.41	1.21	0.062	1.57

Trials with high volatile nut-coals, baked agglomerates and rescreened ore. (1956)

Operational Data of the Low Shaft Furnace at Ougree

Period No.	Fuel (Grain size in mm)	Iron Ore (Grain size in mm)	Tuyeres (No. & dia.)	Charging height (m.)	Blast Temp. (°C)	Blast % O_2	Top pressure	Fuel consumption	Calculated weight of C	Total dusts	Top Gas Temp (°C)	Top Gas CO_2/CO (gross)	Top Gas % H_2	Pig Iron Production (ton/day)	Pig Iron % C	Pig Iron % Si	Pig Iron % S	Slag CaO/SiO_2
30	Ougree coke 0/20	33 mm dia. extr. mat. from 0/3 St. Pierremont fines	8 of 60 mm + 2 of 80 mm	3.9	765	21	26cm Hg	50	1370	?	111	0.22	3.1	24.2	3.12	1.52	0.168	1.25
31	" 10/20	Extr. materials 25 mm dia.	"	4.1	725	"	"	50.6	1345	95	153	0.22	2.9	25.1	3.00	1.54	0.132	1.39
32	"	"	"	"	700	"	"	34	1353	56	143	0.32	4.5	17.0	3.32	1.46	0.071	1.32
33	" 0/20	St. Pierremont small sized 0/25	"	4.4	630	"	"	31.7	1096	48	64	0.39	2.8	20.0	3.35	1.23	0.045	1.43
34	Loraine coke 10/20	Extruded materials 25 mm dia.	6 of 60 mm + 4 of 80 mm	4.5	700	"	"	47.1	1256	80	164	0.24	3.5	26.0	3.21	1.81	0.107	1.37
35	"	-do- 16 mm dia.	"	"	"	"	"	46.4	1084	70	175	0.28	3.8	28.9	3.18	1.78	0.122	1.34
36	"	Mixed extruded mat., 10% coal	"	3.9	"	"	"	44.6	1218	297	87	0.26	5.1	27.2	3.33	1.68	0.088	1.35
37	"	St. Pierremont small sized 0/25	"	3.7	"	"	"	39.4	995	390	76	0.42	3.6	25.3	3.50	1.20	0.047	1.58
38	Ougree coke 0/20 screened 10/20	Extruded materials 16 mm dia.	"	4.3	"	"	"	45	1127	50	90	0.36	3.9	27.3	3.32	1.49	0.106	1.31
39	Esperance coke 15/30	"	"	4.2	"	"	"	39.2	1070	35	80	0.40	3.8	24.8	3.39	1.22	0.079	1.21
40	"	St. Pierremont 0/25	"	3.6	"	"	"	39.1	1060	202	79	0.44	3.2	24.9	3.58	1.73	0.039	1.40
41	Devolat. coal 10/20	"	"	3.5	"	"	"	38	1143	537	65	0.35	5.5	21.2	3.27	1.80	0.056	1.50

Production and consumption of various types of extruded materials.
Influence of coke rate (1957)

Operational Data of the Low Shaft Furnace at Ougree

Period No	Fuel (Grain size in mm)	Iron Ore (Grain size in mm)	Tuyeres (No. & dia.)	Charging height (m.)	Blast Temp. (°C)	Blast % O_2	Top pressure	Fuel consumption	Calculated weight of C	Total dusts	TOP GAS Temp. (°C)	TOP GAS CO_2/CO (gross)	TOP GAS % H_2	PIG IRON Production (ton/day)	PIG IRON % C	PIG IRON % Si	PIG IRON % S	Slag CaO/SiO_2
42	Various cokes 10/25	St. Pierremont 5/25 rescreened	10 of 80 mm	2.9	750	21	26cm Hg	49.7	1001	38	90	0.31	2.1	34.6	3.57	0.74	0.036	1.45
43	Esperance coke rescreened	"	10 of 60 mm	2.9	"	"	"	42.4	998	25	79	0.36	2.9	29.5	3.55	0.58	0.075	1.35
44	"	"	"	2.9	"	"	"	30.6	946	12	50	0.37	2.7	22.3	3.62	0.56	0.043	1.32
44b	"	"	"	4.0	"	"	"	30.0	950	10	50	0.41	2.5	?	3.52	0.65	0.031	1.35
43b	"	"	"	4.0	"	"	"	38.9	960	20	50	0.38	2.7	?	3.51	0.67	0.068	1.30
45	"	"	"	4.0	"	"	1.4 Kg/cm²	47.2	880	59	62	0.40	2.9	37.3	3.73	0.36	0.051	1.44
46	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
47	"	"	"	4.0	"	"	"	39.3	822	39	50	0.42	2.9	32.8	3.79	0.57	0.029	1.46
48	Lorraine coke 10/25 non-rescreened	Dwight-Lloyd Aggl., non-rescreened cockerill + limestone 10/20	"	4.0	"	"	"	39.9	869	6	225	0.25	1.8	32.5	3.52	0.61	0.036	1.41
49	Rescreened Esperance coke 10/20	Rescreened Dw.-Lloyd Aggl., 3/35 + limestone	"	4.5	800	"	0	35.5	821	9	226	0.26	2.2	30.2	3.49	0.61	0.034	1.46
50	"	"	"	4.0	750	29.9	"	40.8	729	4	111	0.30	2.5	40.8	3.10	2.01	0.037	1.29
51	"	-do- but without limestone	"	4.5	"	21	"	39.8	752	13	288	0.28	2.0	37.6	3.24	1.12	0.049	1.09
52	Esperance coke 10/20 non-rescreened	Rescreened Dwight-Lloyd Aggl. 3/25	"	4.3	730	"	"	40.3	724	13	230	0.32	1.8	39.5	3.25	1.26	0.050	1.02
53	Esperance coke 10/20 non-rescreened	"	"	4.3	740	"	1.4 Kg/cm²	39.7	609	5	158	0.46	1.7	44.6	3.16	0.89	0.041	1.08

Low Shaft Furnace operated as an experimental Blast Furnace – Influence of grain size, coke rate and top pressure – Consumption of backed agglomerates. (1958)

blast furnace and with raw ore the ratio CO_2/CO of the top gases is only about 0·3, against about 0·45 in the case of the blast furnace.

By reducing the rate to 40 tons of coke day, there is a considerable increase in the indirect reduction and the ratio CO_2/CO reaches 0·44. This increase is partly justified by the fact the gases stay longer within the furnace, but it is also probably due to less fluidised state of the charge when operating at the rate of 40 tons of coke/day, than when operating at 50 ton/day.

Top pressure which increases the duration of passage of the gases, also increases the indirect reduction and the ratio CO_2/CO. Top pressure amounts to an increase in the effective volume of the furnace, and its use should prove to be a very favourable factor towards the industrial utilisation of the low shaft furnace, by achieving an appreciable increase in the production as well as ensuring a very good stability in the operation, a good carburisation of the pig and an economy in the fuel.

Fuel rate : Rates of raw fuel have varied between very wide limits according to the amount of dusts obtained and the carbon content of the fuel used. We shall therefore only refer to the rate of fixed carbon, i.e. quantity of carbon of the fuel charged, per ton of pig, deducing the carbon in the pig and dusts.

With the most frequently used raw materials, Lorraine ore with 31% Fe in small sized grains, and coke breeze, and for a 30% output of the fusion bed, the fuel rate is comparable with that of the blast furnace, i.e. 950 kg/ton pig iron, provided the coke rate is kept at 40 tons of coke/day maximum. This is well understandable as in these conditions other factors are also comparable : thermal losses, top temperature and rate of indirect reduction. But at a greater rate such as 50 tons of coke/day, which was generally maintained by us in the course of the first years, the fuel rate is higher, about 200 kg/ton pig and there is at the same time a decrease in the indirect reduction.

With top pressure, the fuel rate is lessened by 200 kg/ton pig, the charge rate being the same. We reached for example a corrected fuel rate of 600 kg/ton pig only, while using sinter.

Production of the rich gases : We have made only a few trials to obtain from the low shaft furnace a rich gas, by enriching the blast with oxygen. A few trials with 28% enriching gave a gas of 1,350 cal/Nm^3 (lower calorific value) as against the usual figure of 950. But the fuel rate had increased.

With devolatilided coals a gas of about 1,300 cal/Nm^3 is obtained (lower calorific value).

Conclusions

We have seen that the low shaft furnace can produce a good quality pig, from a charge composed of, on one hand low grade ore small sized or fines, cold extruded or sintered and on the other, coke breeze, semi-cokes, dry high volatile coals. It is also probable that many other types of raw materials would find use in this furnace.

Industrial production of pig iron by the low shaft furnace can however be thought of only if costs are competitive.

The great advantage of the blast furnace lies in its height which is the cause of its excellent thermal efficiency, the fuel rate is low and the charges reach the hearth in a well prepared state. The furnace runs with great regularity, can produce all sorts of pigs and can make up for eventual shortcoming in its charge, owing to its large capacity ; the unitary production is high and can reach 2,000 ton/pig per day. However, the blast furnace necessitates the use of metallurgical coke, a product rare and expensive, and does not adapt itself well to high quantities of fines in the ores.

Now as regards the low shaft furnace, most of the difficulties anticipated (i.e. high top temperature, high thermal losses, low indirect reduction, insufficient conditioning of charges before reaching the hearth) do not really exist or they can at least be counteracted under certain conditions. Its more serious drawback is therefore its low unitary production. Personnel costs per ton of pig iron are very high. In this connection it would be advantageous to increase the rate but, in our trials with ordinary pressure and 31% grade raw ores, we could not go farther than 500 kg coke per m^2 per hour. The only alternative left is to increase the section of the furnace. It would not be possible to increase the minor axis of the ellipse without causing the ore to fall in the hearth in an unprepared state. The major axis could be lengthened ; this may bring about more difficulties in the performance but the situation could perhaps still be handled. Use of top pressure would appreciably step up production.

In European countries where large plants industries are prevalent and where labour is very costly, low production capacity of the low shaft furnace is a serious disadvantage and this handicap will not be easily compensated by the fact that the furnace can consume cheaper raw materials.

In the countries where the price structure is different from ours, the handicap of increased labour costs per ton of pig can be compensated or even by-passed by the economy realised on the raw materials.

Moreover, the low shaft furnace is most suited to places where the construction of big blast furnaces is not possible either due to lack of suitable funds or due to non-availability of a suitable quality or quantity of ore, or due to lack of a large market for the finished products. A low shaft furnace producing 100 to 200 tons of pig per day would be ideally suited for countries with limited resources or for the regions where metallurgical industries have just started. Such a furnace would consume certain local raw materials of lower grade, which would otherwise go waste.

The low shaft furnace can also be recommended for places where it is required to produce a rich gas along with the pig. Our trials have not been conclusive in this connection but it appears that the enriching of the blast, which becomes necessary in this case, brings about no particular difficulties. Here again, all would depend on the price of the gas-calory as compared with the low shaft furnace.

In the end it should be said that the low shaft furnace is still far from having said its last word. We still have much research work to carry out. We are also at the disposal of countries or organisations willing to participate in our activities or desirous to have particular trials, of special importance to them, to be carried out by us. The National Shipyards and Steel Corporation, who are engaged in setting up a low shaft furnace in the Philippines, have for instance asked us to admit them as a member of our Committee.

DISCUSSIONS

Dr. C. V. S. Ratnam, Neyveli Lignite Corporation (Private) Ltd., Neyveli, Madras State : Did the investigators at Ougree use so far lignite or brown coal in any form, briquettes, carbonised briquettes or char in the low shaft furnace?

Have any magnetites been used with the low shaft furnace?

Have the investigators used agglomerates or briquettes containing non-coking coals and magnetites or other iron ores in the low shaft furnace?

What is meant by producing "richer gas" from the low shaft furnace? Is it high B.T.U. gas or synthesis gas for liquid fuels?

Dr. H. Malcor (Author) : We have not so far tried lignite or brown coal at Ougree.

Magnetites have not been used but we intend trying them in the near future.

We tried to use agglomerates made from a mixture of coal and lean iron ore (minettes), extruded in a vacuum machine. These researches are referred to in my paper; they proved unsuccessful; the furnace was blocked a few hours after the agglomerates reached the hearth; we assumed that they crumbled into dust and choked the fire. The coal used for these trials was a coking coal but we see no reasons why non-coking coals would do better; we therefore gave up the idea of trying them.

So far the trials with oxygen enriched blast gave a gas with a B.T.U. content 50% higher only to that of the usual blast furnace gas; we never tried yet to reach enrichments leading to the production of synthesis gas.