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THE LIEGE EXPERIMENTAL FURNACE [1/]

by

A. Poos,
Belgium

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THE LIEGE EXPERIMENTAL FURNACE 1/

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SUMMARY

In 1951 an international committee for the direction of research on low-shaft furnaces, including organizations from seven different countries, decided to set up a low-shaft furnace at Ougrée, near Liège, which went into service in May 19[illegible].

The aims of research were first of all to use this furnace for the production of basic bessemer pig iron from low-grade raw materials, or, to be precise, refine and from fuels with low mechanical resistance and then to use it as a small experimental blast furnace for testing new techniques and collecting more complete information on the mechanism of pig iron production.

The installation, which first had an oval section furnace with [illegible] m² area and 24 m³ useful volume, now has a circular furnace with 1.4 m hearth diameter and a useful volume of 5.6 m³, and an installation for preparing charges with a Dwight-Lloyd sinter strand of approximately 10 m² useful area and very highly developed measuring and sampling equipment.

* This is a summary of a paper issued under the same title as ID/WG.1[illegible].

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[illegible]

[illegible] fifteen years of work, [illegible]. [illegible] years of experimentation with [illegible], [illegible] the advantages [illegible].

Since 19[illegible], the Liège furnace [illegible] furnace. It [illegible] for all kinds [illegible] furnace tests in industrial furnaces, [illegible] the phenomena observed in the Liège furnace are [illegible] the operation of industrial furnace.

First of all, an extensive [illegible] the injection of [illegible] gaseous hydrocarbons [illegible] — enriche[illegible]; the influence of [illegible] and the product[illegible] of the furnace was determined [illegible].

Enrichment of the blast with [illegible] was carried out, [illegible] with the injection of [illegible] pig iron. [illegible] series of tests [illegible] blast [illegible].

Since 19[illegible], the [illegible] programme [illegible] study of the [illegible].

[illegible] first of all [illegible] the [illegible] results [illegible] of the [illegible]. Numerous [illegible] the influence [illegible] growth rate [illegible]ation.

Simultaneously [illegible] out on the process, [illegible] were investigated. [illegible] carried out [illegible] these pro[illegible] the furnace.

By use of the experimental [illegible] possible [illegible] rapidly the optimum [illegible] and composition and burden behaviour.

Tests with coke shapes of carefully controlled size have given the spectacular productivity rate of 9.8 tonnes of pig iron per m^3 of useful volume and day.

As a result of all these tests, we have come to the conclusion that the low-shaft furnace does not seem to be an economically interesting proposition for countries that have steel works. However, under special conditions, the handicap of high labour costs that is due to the low capacity of the furnace can be counter-balanced by the saving in raw materials.

On the other hand, the Liège low-shaft furnace was completely satisfactory for experimental operations.

It can be used for applied research whose aim is the practical study of pioneering techniques or for basic research leading to more complete knowledge of the process.

Contents

Tables

1. HISTORICAL BACKGROUND

In 1950 the European Organization for Economic Co-operation set up a committee to promote the industrial application of oxygen.

The representatives of the iron and steel industry on this committee proposed the establishment of an international group to study the possibility of making pig-iron in small low-shaft furnaces using oxygen (1), (2).

The international committee for the direction of research on the low-shaft furnace set up for this purpose, which included organizations from seven different countries, decided in April 1951 to construct a low-shaft furnace at Ougrée, near Liège. This installation was put into service in May 1953.

On the expiration of the initial contract in December 1956, certain countries decided to withdraw, but the High Authority of the ECSC became interested in the research and agreed to provide very considerable financial aid. Sweden and a Canadian plant decided to participate in our research in 1967 and 1963, respectively.

2. THE AIMS OF RESEARCH

The aims of the research carried ou in the Liège experimental furnace have greatly developed over the course of the years, and this development has been closely bound up with that of technical and economic conditions in our courtries.

Originally, the chief aim was to operate the low-shaft furnace to produce basic Bessemer pig-iron, using raw materials that were not of high enough grade to be treated in a blast furnace of conventional design (1), (3), (4), (5).

At that time, owing to an alteration in mine-working techniques aimed at introducing more and more mechanization, the fines content of ore rose progressively; moreover, sintering and pelletizing procedures were far from the degree of perfection that we know today and were widely considered in the industry to be a necessary evil rather than a blessing.

The conventional blast furnace requires a charge whose particle size lies within clearly defined limits, and it is essential to avoid too high a content of fines in the ore if the operation of the installation is not to be upset.

Another disadvantage of the blast furnace is that its great height makes necessary a fuel with very high mechanical resistance, metallurgical coke. Metallurgical coke, which is expensive to produce and requires considerable capital investment, is obtained from coking fines, of which there was then an imminent shortage in many European countries, whereas non-coking coal was available in abundance.

It was hoped to solve most of the problems raised by the mediocre quality of ores and fuels by treating them in a much lower furnace, the low-shaft furnace. A considerable reduction in the height of the furnace might obviously impair its thermal efficiency, but the smaller particle size of the raw materials, the use of oxygen and the application of counterpressure at the throat might largely compensate for this.

More basic research on the process of making pig-iron in blast furnaces, phase-by-phase, which was carried on parallel to the main studies by means of a very complete system of probes and measuring instruments, fully confirmed our expectations that the Liège installation could be considered as a pilot plant in which blast-furnace phenomena could be reproduced on a sufficiently small scale to facilitate study and on a sufficiently large scale for the laws of similarity to hold. Accordingly, our research direction committee decided to use the Liège furnace as a pioneering installation, assigning it the aim of studying new techniques such as the injection of hydrocarbons, with or without oxygen enrichment of the blast, counterpressure operation, operation with very high blast temperatures, the injection of gas into the hearth to improve desulphurization, etc.

For obvious reasons, these techniques could not be studied in the laboratory, and their direct application to a full-scale production installation would have implied very great risks and considerable expense. Moreover, the conclusions that can be drawn from industrial tests are generally less precise and reliable than those obtained with a pilot installation, owing to the inevitable irregularity in the operation of an industrial blast furnace and the many limiting factors that condition its performance.

Finally, as previous tests had shown the paramount influence of charge quality on furnace performance, the research direction committee has since 1960 included in its programme the study of the chemical and physical properties of ore, agglomerates, pellets and coke. One aspect of this study, and not the least important, is the development of significant laboratory tests for assessing the quality of raw materials.

3. DESCRIPTION OF THE INSTALLATIONS

Detailed descriptions of the Liège pilot plant and the various improvements that have been made over the years have been given in many publications (1), (2), (4), (5), (6), (7), (8) and (9); we shall confine ourselves here to mentioning its main characteristics.

The plant includes a shop for the preparation of the charges, with storage yards, and the furnace with all ancillary installations, such as the equipment for charging, the hot blast stoves, the blowers, the preliminary gas cleaner and the installations for tapping the molten metal and the slag.

The furnace (figure 1) originally had an oval section hearth with a major axis of 3.2 m and a minor axis of 1.40 m, giving an area of 3.31 m^2. The useful volume above the tuyères varied between 22 and 24 m^3 according to the height of the charge (4.2 - 4.7 m). This geometrical shape was chosen because operation with a charge of small particle size requires relatively small distances between the tuyère pipes, in order to avoid forming too large a "dead man", with the result that large-capacity low-shaft furnaces cannot be circular. We consider that a circular cross-section might have been adopted for a furnace as large as ours, but the research direction committee wished to study the behaviour of the charges in a non-circular installation, so that the results could be extrapolated to installations of greater capacity.

To facilitate regular distribution of the charge over the whole cross-section of the furnace, two McKee rotary tops were fitted.

The uniformity of gas distribution over the whole cross-section of the furnace was still further improved by making the tuyères at the ends of the major axis of smaller diameter than those at the ends of the minor axis, and by altering the diameter of the tuyères according to the blowing rate and the nature of the charge.

When, in 1965, this furnace achieved a daily output of 138 tonnes of pig metal with a charge consisting of 100 per cent agglomerates, without reaching a metallurgical limit, some of the ancillary installations (for preparing the charge, handling, tapping, etc.) proved to be overloaded, so that it was necessary to replace the furnace by a smaller model.

The new furnace has the same height as the old one and its hearth diameter of 1.4 m is the same as the minor axis of its predecessor, so that conversion costs were reduced to a minimum. The new furnace, a vertical cross-section of which is shown in figure 2, has a useful volume of 2.6 m^3, is equipped with five tuyères and has a shell designed for a counterpressure of 5 kg/cm^2. However, as the hot blast stoves and the blower have not been replaced, we cannot at the moment achieve a higher counterpressure at the throat than 1.? - 2.0 kg/cm^2.

The hot blast stoves, which were originally planned for maximum blast temperatures of 900°C at the closed curcuit pipe line, were relined in 1962 with sillimanite bricks capable of withstanding temperatures of 1550 - 1600°C at the dome, giving a blast temperature of approximately 1250°C at the outlet. Nevertheless, since the reconstruction of the furnace, the hot blast pipe has been over-sized and the temperature at the tuyère pipes is scarcely above 1050°C.

As far as the preparation of the charge is concerned, it should first be noted that the pilot plant was fitted with a vacuum extrusion press in 1956, which was replaced in 1961 by a Dwight-Lloyd sinter strand 1.06 m wide and 10.55 m long, with seven wind boxes. Firing is by fuel oil burners. Before reaching the strand, the ore is measured out by means of extractor-weigher belts, then mixed in a homogenizer and granulated in a micropelletizer.

After sintering and hot screening, the agglomerate is cooled on a linear cooler fitted with three fans and then re-screened on a double screen with 5 and 25 mm mesh. The undersize passes into the return fines and the oversize is first crushed and then recycled on the cold screen.

The furnace is charged from three feed hoppers. The first, which now contains the agglomerate, has for some years been fitted with a screen for re-screening at 5 mm mesh which discharges into a weighing hopper. The other two hoppers still have their original dosing equipment, that is to say, metal extractor belts discharging on to weigher belts. One of these two latter hoppers, the one containing coke, has since 1963 been fitted with a neutron probe for continuous measurement of the humidity of the coke.

Finally, the two divisions of the pilot plant are provided with a vast range of measuring instruments shown diagrammatically in figure 3, so that the operators can very closely follow the functioning of the installations and very comprehensive investigations can be made. Among these instruments, special mention should be made of the many automatic and manual probes for measuring temperature and pressure or for taking samples of gases or solids at almost any point in the furnace. This equipment is supplemented by a very highly developed set of gas analysers. Figure 4 shows the present layout of the pilot plant and figures 5 and 6 give two views of the furnace.

The total staff of the pilot plant consists of about one hundred, including four professionals and fifteen technicians and workers assigned solely to special measurements and research.

4. THE RESULTS OF TESTS

The Liège experimental furnace has been in service for more than fifteen years and 166 series of tests have been made so far. It would be pointless to recapitulate all the results, which have been described in detail in the annual reports of the AIRBO and numerous publications (1-10).

Only the most outstanding of these tests will be mentioned here, as well as the conclusions drawn from them. We shall examine successively the following three aspects:

The results obtained in low-shaft furnace operation, consuming "mediocre" raw materials;

The results obtained by using the furnace as an experimental installation for pioneering tests;

The advantages of small furnaces.

4.1. The results of low-shaft furnace operation

In five years of operation, forty series of tests were carried out, corresponding to a production of more than 15,000 tonnes of pig metal.

We studied the influence of many factors on furnace operation, including:

The nature of the fuel:

Small-sized coke, semi-coke, dry steam coal or lean coal;

The nature of the ore:

Low-grade ore from the Grand Duchy of Luxemburg and Lorraine, acid or calcarlous, of varying particle size, with between 28.5 and 34.5 per cent Fe; extruded slugs of ore, of varying diameter; mixed agglomerates of ore and coal;

Counterpressure at the throat;

Oxygen enrichment of the last;

Blast rate.

The usual blast temperature was approximately 750°C and the height of the charge was generally maintained at 3.5 m.

The first tests with small-sized coke and 10/30 size ore immediately showed that it was possible to produce cold pig-iron in a low-shaft furnace from low-grade raw materials.

It was always possible to maintain a temperature of approximately 100°C at the throat, simply owing to the adoption of a sufficiently small particle size, and it was not necessary to use oxygen-enriched blast to control temperature, as had been expected.

In a low-shaft furnace, the particle size of the coke seems to play an extremely important role, as is shown by figure 7, which gives the FeO content of the slag and the carbon content of the pig-iron, by reference to the diameter of the coke. A fuel that is too large in particle size gives a refined iron, whereas one that is too small leads to irregular descent of the charge.

During these tests with small-sized coke, it was noted that for combustion rates of 50 tonnes of coke per day, a mineral charge with 40 per cent $<$ 10 mm including 10 per cent $<$ 5 mm, leads to considerable production of flue dust, of the order of 200-500 kg per tonne of pig-iron. On the other hand, with a charge of 5-25 mm screened ore, the production of dust at the same blowing rate, fell to 85 kg per tonne of pig-iron.

To make possible the consumption of greater quantities of fines, the pilot plant was equipped with a vacuum extrusion press for the agglomeration of ore in the 0-5 mm particle range. The extrusions were made either from pure ore or with the addition of fuel.

The operation of the furnace was thereby improved, but fuel consumption increased. This increase in the consumption of small-sized coke was the result of the poor reducibility of the extruded slugs, which were too compact, and was cut down very considerably by decreasing their diameter. Figure 8 shows the behaviour of the indirect reduction rate by reference to the diameter of the extrusion, and table I shows coke consumption.

TABLE I

Ore 0–25 mm	1300 kg of 10/20 coke per tonne of pig-iron
Extrusions, 33 mm diam.	1795 kg of 10/20 coke per tonne of pig-iron
Extrusions, 25 mm diam.	1502 kg of 10/20 coke per tonne of pig-iron
Extrusions, 16 mm diam.	1334 kg of 10/20 coke per tonne of pig-iron
Mixed Extrusions, 16 mm (ore + 10% coal)	1330 kg of 10/20 coke per tonne of pig-iron

The second purpose for which the low-shaft furnace was used was to employ fuels of lower mechanical resistance than conventional coke. This aim was fully achieved and it was possible not only to consume small-sized low-grade coke, but also semi-coke, dry steam coal containing 42 per cent volatile matter and devolatilized steam coal containing 12 per cent volatile matter. Table II gives the gross consumption of fuel and fixed carbon with various fuels and an identical burden of minette ore of 0–25 mm particle size containing 29 per cent Fe.

TABLE II

	Crude fuel	Volatile matter	Fixed carbon (kg per tonne of pig-iron)
(1) Screened coke			
Small-sized coke A	1556	2–3	1107
Small-sized coke B	1498	2–3	1062
(2) Coal			
Dry steam coal	3240	42	1651 (*)
Devolatilized steam coal	1799	12	1139
(3) Bruay semi-coke	1430	9–12	1022

(*) The relatively high consumption observed for steam coal is partly explained by the high particle size of this fuel (30–50 mm).

These results as well as the figures for the material balances seem to show that, under our experimental conditions, the volatile matter in coal plays hardly any part in reduction reactions as it is liberated at relatively low temperatures. On the other hand, with Bruay semi-coke, we must conclude that the rate of utilization of volatile matter is by no means negligible.

Pressurization considerably improved furnace operation, giving an increase in indirect reduction and a decrease in consumption. Thus, a counterpressure of 1.4 kg/cm^2 at the throat improved coke consumption so far as to equal, at a blowing rate of 5,000 m^{3}N/h, the performance of a conventional blast furnace working under the same conditions; with minette ore of 5-25 particle size giving a gross yield of 30 per cent, coke consumption is about 1,000 kg of coke (85 per cent carbon) per tonne of pig-iron.

It should be noted that the specific output of the installation is good, being of the order of 1.5 t/m^3 UV/24 h, and that the reduction of Si, P and Mn, desulphurization and carburization are very satisfying and obey the same laws as in the blast furnace, as was already pointed out at the beginning of this paper.

4.2. The Liège furnace as an experimental facility

Before using the furnace as an experimental installation, it was necessary to check again whether the mechanisms for the operation of small furnaces and industrial furnaces corresponded (5), (6), (7), (8).

This was done by parallel operations on the low-shaft furnace and a blast furnace with 5 m hearth diameter belonging to S. A. Cockerill-Ougrée (21). In both cases, the burden consisted of 100 per cent self-fluxing agglomerates with approximately 45 per cent Fe. The particle size of the agglomerate consumed in the low-shaft furnace was suited to its size, that is to say that particles over 25 mm were eliminated. In addition, the agglomerates were subjected to a dust-extraction process. Preliminary tests had shown the deleterious effect of fines of under 3 mm in the agglomerate, which would have been doubly apparent in a small furnace. The need to eliminate even small quantities of fines (less than 10 per cent) from a well prepared charge (100 per cent of agglomerates) was not very widely recognized at the time, but their elimination has since become current practice in most modern furnaces.

At the same time, we also noted the advantage of reducing the high quantities of limestone in the furnace.

Consequently, we were able to compare the operating results of our installation with those of an industrial blast furnace. The main operating results of the two furnaces are summarized in table III (8).

TABLE III

		Blast furnace No.7, Cockerill-Ougreé, Seraing	Low-shaft Furnace, Liége
Gross coke consumption	kg per tonne of pig-iron	688	890
Corrected coke consumption		687	673
CO_2/CO		0.48	0.46
Gas Temperature	°C	291	158
Dust	kg per tonne of pig-iron	30	9
Temperature of blast	°C	848	740
Blast pressure	kg/cm^2	0.56	1.48
Throat pressure	kg/cm^2	approx. 0	1.37
Output of pig_iron	t/m^3UV/day	0.89	1.98
Pig-iron Si	%	0.42	0.89
S	%	0.1	0.041
Quantity of slag	kg per tonne of pig-iron	820	780
CaO/SiO_2		0.90	0.90

Vertical measurement showed similar temperature gradients and gas composition in the two furnaces, corresponding to the pattern already noted by B.I. Kitaev (20). It was discovered that both furnaces had reserve capacity, by the use of which output could be raised still further without notably increasing coke consumption; this was done later (figure 9).

Having thus verified the validity of the results obtained in the low-shaft furnace and the possibility of direct extrapolation to the blast furnace, the research direction committee first wished to study certain new techniques capable of improving the technical and economic performance of the blast furnace, namely:

1. The injection of hydrocarbons;
2. Oxygen enrichment of the blast;
3. The use of very high blast temperatures.

Finally, it was necessary to study the influence of the chemical and physical properties of the ores, agglomerates and pellets on the operation of the blast furnace, to ascertain the best way of using these products and to alter the methods for the manufacture of agglomerates, and their composition, in such a way as to improve their quality.

Parallel to this research, it was also necessary to study laboratory quality tests on the ingredients of blast-furnace charges in order to establish a correlation with the results obtained in the furnace, and, where appropriate, to develop significant new laboratory tests.

4.2.1. The injection of hydrocarbons (4), (5), (6), (8), (13), (14), (15).

We carried out tests on the injection of blast-furnace gas containing 60 per cent CH_4, 13 per cent CO, 5 per cent H_2 and 14 per cent N_2. However, the most thorough study was made of the injection of liquid hydrocarbons, with or without O_2-enrichment of the blast.

In order to reduce capital expenditure, we worked with a light fuel oil, which required neither a re-heating installation nor heat insulation of pipes. Its composition was as follows:

C, 85.5 per cent; H, 14 per cent; S, approximately 1.5 per cent.

The oil was injected through the tuyères by pipes housed in the centre lines of the sprayers, with compressed air atomization, according to a technique described in various publications at the time (8), (14).

The injection of fuel oil and oxygen enrichment of the blast were carried to extreme values, which may be less interesting as far as industrial practice is concerned, in order to improve the validity of our conclusions and to increase the accuracy of the results. Accordingly, the quantities of fuel oil injected were varied between 0 and 200 kg per tonne of pig iron and the oxygen content of the blast was varied from 21 to more than 45 per cent.

In order to minimize the effect of interference factors, we took care to keep as constant as possible all factors that were not being investigated (coke quality, counterpressure at the throat, level of charging etc.) However, the diameter of the tuyères was suited to the operating conditions in each particular case, so as to ensure uniform distribution of the gas over the entire cross-section of the furnace, this being verified with the aid of two horizontal probes situated about 1 m below the charging level.

Before making the injections, and as a first approximation, we ascertained the theoretical quantity of fuel oil per tonne of pig-iron corresponding to a given figure of oxygen enrichment of the blast, so as to maintain unchanged temperature conditions, first, at the tuyères and, secondly, in the critical zone as defined by B. I. Kitaev (20) and J. Michard (22). In order to ascertain whether the combustion rate (in terms of the hourly flow of gas at the tuyères) could be increased by the injection of fuel oil combined with O_2-enrichment of the blast, all tests were made at various blowing rates.

The results of these tests may be summed up as follows:

Setting aside the advantages due to any increase in blast temperature the coefficient of equivalence of fuel oil is 1.2 kg of coke per kg of oil (see figure 10).

With a constant gas flow at the tuyères, output falls by 11-13 per cent for every 100 kg of fuel oil injected and tonne of pig-iron.

On the basis of our tests we cannot state that the injection of fuel oil actually makes it possible to increase the gas flow at the tuyères. In fact, we were not able to achieve limit operating conditions, as the limits were constantly receding and at the time were 3.2 t/m^{3}UV/day, with or without injection through the tuyères. Similar results were obtained with the injection of blast-furnace gas.

4.2.2. Oxygen enrichment of the blast

Oxygen enrichment of the blast brings an increase in productivity. Unfortunately, for the production of cold pig-iron, oxygen enrichment of the blast must be limited to 1 or 2 per cent additional oxygen, unless combined with the injection of a coolant to maintain the thermal balance of the furnace.

In our case, fuel oil was injected as a coolant, humidification of the blast being economically less advantageous under the conditions prevailing in our countries.

For every 1 per cent of additional oxygen, we noted that the increase in output due to oxygen alone was 2.5-3 per cent with constant gas flow, and 4-5 per cent with constant air flow. The necessity to combine oxygen enrichment of the blast with injection of fuel oil as a coolant reduces this increase in output to I.2-1.3 per cent (figure 11).

4.2.3. High blast temperatures

As was already mentioned above, the two hot blast stoves of the pilot plant were relined in 1961 with sillimanite refractories so that temperatures of 1200°C could be attained at the closed circuit pipeline.

Tests with increasing blast temperatures in the 800-1050°C range gave a gain in coke consumption of the order of 4 per cent and an increase in output (at constant gas flow) of approximately 6 per cent for every 100°C of increase in the blast temperature.

4.2.4. Study of burdens

Until the beginning of the sixties, the European iron and steel industry was largely based on poor ores from local deposits, improved by sintering.

The development of economic and technical conditions confronted us with the question of the advantage of increasing the Fe content of these agglomerates, either by the beneficiation of local ores or by the addition of rich ores, or even of consuming only imported ores. To be able to reply to this question, it was first necessary to ascertain the influence of the quantity of slag on the coke consumption and productivity of blast furnaces.

Certain problems that arose during this study prompted us to extend it to include a systematic investigation of the influence of the chemical and physical properties of the charge; this study was facilitated by the installation of a sinter strand in the pilot plant.

The Fe content of the agglomerate

We noted that when the Fe content of the agglomerate was progressively raised from 56 to 63 per cent, the gain in coke consumption, all other factors remaining equal (blast temperature, counterpressure, blowing rate etc.), was about 12 kg of coke (85 per cent carbon) per tonne of pig-iron at a blast temperature of 1150°C. We obtained a coke consumption of 504 kg (85 per cent carbon) per tonne of pig-iron with an agglomerate containing 62.7 per cent Fe, corresponding to 250 kg of slag per tonne of pig-iron.

The increase in the output of the furnace was 1.4-1.5 per cent for every 1 per cent of iron. During these tests, we achieved the record output of 138 tonnes of pig-iron a day, corresponding to a productivity of 5.96 tonnes of pig-iron per m^3 of useful volume and day, without reaching a metallurgical limit. In fact, the limiting factors on output were the handling, charging and tapping facilities. On the basis of this test, the oval furnace was replaced by a smaller circular furnace.

The reducibility of agglomerates

During the research on agglomerates, products of widely varying quality were tested. For example, the reducibility of the charge materials varied over a very considerable range (24-60 per cent) and we studied the influence of this factor on the operating results of the furnace. By keeping the particle size of the products constant, we eliminated an important interference factor.

We were able to establish a relationship between reducibility and the rate of utilization of the reducing gases, $\eta \frac{FeO}{CO}$, which is closely linked to the figure for parts per thousand of coke. This relation is given in figure 12.

This diagram shows that, for low reducibility figures, there is a linear relationship between the rate of utilization of CO and the reducibility of the agglomerate. At normal gas flows (approximately 4,500 m^3N/h) the rate of utilization of CO attains very high values (80-90 per cent) for reducibilities of 50 per cent; an additional increase in the reducibility of the agglomerate does not improve this figure further. At high flow, however, the rate of utilization of the reducing gas is distinctly lower and reducibility may also have an effect beyond this value.

Study of the behaviour of pellets

This problem has two quite separate aspects

(a) The influence of the physical and chemical properties of the pellet on blast-furnace performance;

(b) The most rational way of using pellets in blast furnaces:

100 per cent pellets + flux;

or pellets + self-fluxing agglomerate + flux;

or pellets + superbasic agglomerate.

These tests were made with six different types of pellet, three from industrial installations and three from pilot plants. The pellets differed either in chemical composition or properties, notably reducibility and rate of growth.

Table IV (see page 19) gives the characteristics of the pellets charged.

A graph of the operating results is given in figure 13, which shows for each type of pellet the change in coke consumption with reference to the gas flow at the tuyères.

In this figure we have also indicated, for purposes of comparison, the results obtained with a self-fluxing agglomerate of good quality containing 60 per cent Fe.

The information that we have drawn from these tests may be summed up as follows:

(a) Pellet growth has a great influence on the regularity of descent of the charge and on furnace operation in general. Pellets whose rate of growth is below 20 per cent have no effect, even at high blowing rates.

TABLE IV

Characteristics of the pellets

Pellets	A	B	C	D	E	F
Type	Commercial, rich, low silicon content	Commercial, rich, high silicon content	Pilot plant, self-fluxing	Commercial, rich, low silicon content	Pilot plant	Pilot plant, poor
Basic ores	Rich concentrates	Rich concentrates	Mixture of poor minette ores and rich magnetites	Rich concentrates	Mixture of hematite fines and rich magnetites	100 per cent fines of poor minette ores
Chemical Properties						
Standard analysis %						
Total Fe	65.80	64.45	53.35	64.96	63.13	41.44
CaO	0.70	0.59	9.67	0.58	2.01	16.48
Al_2O_3	0.70	0.47	3.09	0.91	1.82	6.72
SiO_2	2.62	5.61	6.49	3.80	5.42	13.89
Mean Reducibility % (CNRM method)	51	52	58	52	28	60
Physical properties						
Small particles "Micum" analysis 0-5mm %	2 - 3	3 - 5		1 - 2	0 - 2	15
Particle size analysis %						
5mm	99.0	98.6	96.8	98.7	98.8	95

A burden containing up to 65 per cent of pellets with a growth rate between 20 and 40 per cent gives satisfaction at low or medium blast and permits regular operation of the furnace. Operation with a burden containing 90-100 per cent of pellets is possible only at low blast, and results are mediocre.

Burdens containing 65 per cent of pellets with a growth rate above 40 per cent may be contemplated only at low blast; even then the operation of the furnace is unstable.

(b) It is not an ideal solution to have a bed consisting of 100 per cent of pellet plus fluxes directly charged into the furnace.

Furnace operation and operating results can be improved by charging at least some of the flux in the form of an agglomerate of high basicity.

The best results are obtained with a burden consisting of pellets and superbasic agglomerates, without additions in the furnace.

The differences between the three methods seem to be less with good pellets and to increase with a reduction in pellet quality. The question is whether that is due solely to the action of the fluxes in the charge or to the fact that the low-quality pellets are replaced by a superbasic agglomerate of excellent quality.

4.2.5. Tests with pre-formed coke

The problems of replacing metallurgical coke, which led to the tests in the low-shaft furnace, are arising again today, but in a different form. There is not only the problem of extending the range of coals that can be used for the manufacture of a blast-furnace fuel but also that of finding a substitute for an expensive, slow and discontinuous coking process, whose by-products are difficult to sell, and that of making a product of uniform particle size better suited to the operation of a modern blast furnace. Coke manufacturers hope to find a solution in pre-formed coke, and a wide variety of processes have been developed either at laboratory or pilot plant level.

Before undertaking large-scale capital investments for the construction of an industrial plant, these new products must be tested on a sufficiently large scale to ensure that test results are valid. Unfortunately, pilot installations have too small a capacity to supply a production furnace directly. Here again, our small experimental furnace was able to render important services and our research direction committee decided that these new products should be tested.

So far we have tested two types of shapes, manufactured from coals with 29 per cent of volatile matter but by different processes.

One of the chief aims of our tests was to study the effect of these products on the productivity of the furnace.

Figure 14 illustrates the two shapes. Their chemical analysis and physical properties are very similar but they differ very markedly in their bulk density and porosity, which is 38 per cent for the A type and 57 per cent for the B type.

Operating conditions in the furnace were identical in both cases; the burden consisted of screened agglomerate of 5-25 mm particle size, with a CaO/SiO_2 index of approximately 1.1, plus a small quantity of basic fluxes.

The two types of coke gave excellent results. A few hours after they were charged, the pressure drop in the furnace fell by 30 per cent from the figures obtained under the same operating conditions with our usual coke (0/25 mm). Vertical measurement indicated a marked improvement of permeability in the boshes.

Without going into further detail, it will merely be mentioned that with A-type shapes we achieved a combustion rate of 41 tonnes of coke a day, corresponding to a pig-iron output of 2.5 t/h, or 7.1 tonnes of pig-iron per m^3 of useful volume and day. That is the highest productivity figure so far achieved in our experimental furnace.

The results obtained with the B-type shapes were even better and must be considered as sensational. A combustion rate of 56 tonnes of coke a day was achieved, corresponding to more than 1,500 kg of coke per m^2 of hearth area and hour. The pig-iron output was 3.51 t/h, or 9.8 tonnes of pig-iron per m^3 of useful volume and day.

This operating limit was not imposed by the "furnace" factor but solely by the exhaustion of our stock of coke.

The figures that we have just quoted are obviously astounding. We do not wish by any means to suggest - and we do not believe - that the productivity figures in t/m^3 of useful volume can be extrapolated to other types of installation. It does not seem conceivable today that a 2,000 m^3 furnace - and there are many of them in the world - can produce 20,000 tonnes of pig-iron a day.

However, what seems to be less utopian and quite possible is the extrapolation of the results in kg of coke burned per hour and m^2 of hearth.

If we compare our maximum figure, 1,570 kg of coke, with world records, we obtain a 30 per cent increase in output. That would be quite sensational by itself.

4.2.6. Other tests

We could also quote many tests carried out with our furnace, such as the tests on the disintegration of agglomerates and ores in the course of reduction, studies on factors limiting the output of a blast furnace, the dynamic pattern of the process, the reduction of Si, P and Mn (19), desulphurization (with or without injection of gas into the hearth) and, more generally speaking, all kinds of theoretical studies aimed at a continuous improvement of our knowledge of the process, which is the basis of all progress. We should also mention technical tests such as the testing of new refractories (9).

However, that would take us too far from the matter in hand, and we wish to confine ourselves here to one last example regarding the evaluation of an ore of very special composition, whose behaviour was unknown.

4.2.7. Operation with Chichali ore

The United Nations was studying the possibility of building a steel plant in Pakistan to consume a local ore, Chichali ore.

This is a poor sedimentary ore, of unusual composition (30-34 per cent Fe, 23-28 per cent SiO_2, and a high alkali content of approximately 2 per cent).

After some initial difficulties caused by the special nature of this ore, particularly its high alkali content, we were successful in manufacturing a very good agglomerate with which it was possible to produce good quality pig-iron in the furnace with a coke consumption of 788 kg per tonne of pig-iron, a blast temperature of 978° C and more than 1400 kg of slag per tonne of pig-iron. These results far exceeded the most optimistic expectations of the experts who had evaluated this ore.

4.3 The advantages of a small furnace

With reference to low-shaft furnace operation for the production of pig-iron from non-agglomerated ore fines and low-grade fuel, we shall reproduce here the remarks made by the Chairman of our research direction committee at the international iron and steel congress held at Luxembourg in 1958 (3).

"The above considerations (productivity, fuel consumption, depreciation costs, etc.) show that the low-shaft furnace, considered as a production installation, cannot be categorically condemned, but that it would not be reasonable to expect it to transform the working conditions of the iron and steel industry. That is chiefly due to its low unit production, which exaggeratedly increases the cost of pig-iron.

This handicap may certainly be counterbalanced, and more, when it is possible to obtain granulated ore, small-sized coke or luminous-burning nuts at low price. On the other hand, for an output of less than 200 or 300 tonnes per day, the low-shaft furnace may quite often be an interesting solution.

While it is scarcely possible to say more for the moment with certainty, it is, however, not out of the question that our tests will later open up new avenues, for example, with regard to the production of synthesis gas. If a cheap method could be discovered for agglomerating coal fines, the advantages of low-shaft furnaces would be greatly increased.

With that proviso, it must be recognized that the low-shaft furnace has no place in the large plants of Western Europe, at the present stage of research. It is true that ore fines can be treated in such furnaces, but the process seems expensive, and small-sized coke is becomming too high grade a fuel in our countries for its use to ensure a sufficient advantage in general". (Unofficial translation)

These conclusions, which were stated in 1958 and were not so evident at the time, have been fully confirmed by technical and economic developments in the last decade.

For countries that have large-scale iron and steel plants, the low-capacity low-shaft furnace does not seem to be an economic solution at a time when furnaces are being built to produce 7,000 tonnes of pig-iron per day.

On the other hand, for countries in which the price structure is different from ours or where special local conditions prevail, this solution may be interesting, as is shown by the example of the very important plant of Kalbe in the German Democratic Republic.

Also, in regions at a low level of industrialization, where owing to the lack of markets for pig-iron or the lack of capital it has been impossible to construct large-capacity blast furnaces, the use of low-shaft furnaces has at least temporarily provided an interesting solution, as in the case of the Jose Panganiban furnace in the Philippines.

This solution is all the more interesting as it makes it possible, while producing the small quantity of pig-iron required, to train staff for a conventional iron and steel works to be constructed later. Afterwards, the low-shaft furnace can advantageously be used as a pilot plant and a research installation.

In fact, as an experimental plant, the Ougrée furnace has fulfilled its aims perfectly. It can operate under extreme conditions, and, when there is obstruction or re-lining is necessary, it is easy to stop the furnace, repair it and start it up again.

The furnace is suitable for applied research aimed at developing new techniques, whose direct application to industrial furnaces might be too risky, or for tests with new products available in only small quantities.

In all cases, a small experimental furnace allows research under very strictly controlled conditions, with the almost complete elimination of interference factors. Moreover, it is possible not merely to state results, but, by means of numerous research methods, often to explain them. A last and by no means negligible advantage is that the research costs of many tests are distinctly lower than with an industrial furnace (e.g. the Chichali tests, preformed coke etc.).

Finally, this furnace offers exceptional facilities for fundamental research whose main objective is to improve our knowledge of the physico-chemical reactions and the heat exchanges that take place in a shaft furnace as well as the dynamic pattern of the process. It was that type of research that laid the foundations for the impressive improvement in blast-furnace performance made during the last fifteen years.

5. CONCLUSIONS

Sixteen years ago, a number of iron and steel experts formed a group and decided to construct a low-shaft furnace in order to study (a) the possibility of employing low-grade raw materials, (b) new operating techniques, and (c) certain physico-chemical phenomena occurring in furnaces. Fifteen years of experiment have shown that many current calculations and theories on blast furnaces have lacked an experimental basis and have often had to be revised.

Valuable results have been achieved in 166 series of tests, both for practical improvements and for theoretical knowledge of the process. Experience has shown that it is possible to extrapolate the observations made in the Ougrée low-shaft furnace to full-sized industrial installations.

Conclusions were drawn that are now generally accepted regarding the advantage of a low-shaft furnace as a production installation. We investigated the advantages of new techniques and studied the behaviour of a very wide variety of raw materials in the furnace. Parallel to such research, we carried out more basic studies on the phenomena of reduction and fusion and made considerable progress in comparing quality tests conducted in the laboratory, showing their relation to the behaviour of a charge in a blast furnace.

We should not conclude this report without emphasizing that all our results were obtained through the active collaboration of all members of the executive and research direction committees in defining programmes and discussing results, and through considerable financial support at Community level, without which our work would have been impossible.

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We regret that some of the pages in the microfiche copy of this report may not be up to the proper legibility standards, even though the best possible copy was used for preparing the master fiche.

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