# EXPERIMENTS ON BLAST FURNACE OPERATION IN YAWATA IRON AND STEEL WORKS(*)

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## 3 Ton/day Experimental Blast Furnace

Results of the experimental research carried out on a 3 ton-per-day blast furnace to improve operational efficiency can be briefly stated as follows:-

i) Effect of crushing and screening of raw materials:

Iron ores and metallurgical coke of four different sizes were successively smelted in the furnace. Optimum sizes for iron ore and coke were found to be 6.5 mm. and 17.2 mm. respectively.

ii) Trials with coke made of briquetted coal mixture including non-caking coal as the major component:

Two varieties of coke with high and low reactivity were prepared from briquetted coal mixture containing a major portion of non-caking coal and small amounts of anthracite, light and heavy caking coal and pitch. The operation data obtained with these cokes were compared with the normal data obtained with ordinary metallurgical coke.

The coke of lower reactivity was satisfactory while the one of higher reactivity somewhat hindered furnace operation. With constant ore/coke ratio, sulphur content of the iron produced was higher when using the coke of higher reactivity and silicon content was lower.

iii) Influence of coalite-coke on the productivity of the blast furnace:

Two sorts of coalite-coke containing 7 or 11% of coalite were prepared, and tried. It was found that the coke containing

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7% of coalite was suitable for use in the blast furnace; daily output of the furnace showed an increase when ash-content of the coke was sufficiently low. The coke containing 11% of coalite had a detrimental effect on the furnace production even when its ash-content was as low as 2%.

iv) Additions of some heating and desulphurizing agents into the metal bath in the hearth of the blast furnace:

Calcium-silicide, aluminium and some other materials were injected into the metal bath in the hearth of the blast furnace in order, either to raise the furnace temperature or to remove the sulphur in the metal inside the blast furnace. Si content of the metal being below 3% and S above 0.1% the injection of 2% by weight of calcium-silicide into the metal bath in the hearth had a remarkable effect. 78 to 86% of sulphur in the metal could be removed in this way. The temperature of the metal in the hearth could there be rapidly raised by blowing $O_2$ into the metal through a special nozzle provided in the furnace. Ferro-aluminium or aluminium could also be used as heating agent but they had a lower effect on the temperature of the metal. The injection of 1% by weight of calcium-silicide, calcium-carbide, ferro-manganese or soda ash into the metal bath in the hearth was found strongly effective for the desulphurization of the metal. Degrees of desulphurization thus attained were 54 to 66% for calcium-silicide, 55 to 67% for calcium-carbide, 35 to 49% for ferro-manganese and 40 to 66% for soda ash. These figures are not far from those obtained when the desulphurizing agents were added to the metal outside the blast furnace but when these desulphurizing agents were injected into the metal bath in the hearth, carbon and manganese contents of the metal as well as temperature of the bath were remarkably raised. The use of desulphurizing agents inside the blast furnace has therefore some advantages over the ordinary method of using them outside the blast furnace.

v) Smelting of nodular graphite cast iron in blast furnace:

Different iron ores were successively smelted and pit irons obtained were then treated with the same inoculant under the same condition to compare the degree of spheroidization of graphite in each case: Ores containing little S, P and Cu were found suitable for the production of nodular graphite cast iron. When these impurities were present in considerable amounts, the subsequent spheroidization of graphite was impaired to some extent.

Pig iron suitable for subsequent inoculation could also be smelted from an ore burden consisting of 10% of sinter prepared from pyrite cinder, iron sand, mill-scale with a low percentage of iron ore fines and 90% of high grade ores with low contents of impurities. However, the nodular graphite cast iron thus obtained was somewhat inferior to those obtained from 100% high-grade ore burden. An addition of 20% of the same sinter to the burden completely spoiled the quality of the iron produced.

vi) Lining of blast furnace with carbon bricks:

Carbon bricks when used in the bottom of blast furnaces have had a tendency to float up, due to deficiency in the pastes applied to the boundaries. Chemical properties of both carbon bricks and pastes were examined and a special type of carbon blocks was developed for bottom lining which did not show any tendency to float up the metal bath. The ordinary type of bricks were quite satisfactory for the side wall of the hearth; however, since carbon bricks are exposed to the oxidising atmosphere in the direct vicinity of the blast tuyeres, special care must be taken for the lining of this part of blast furnaces.

## LOW-SHAFT FURNACE OPERATION

* Experimental results obtained by the operation of the low-shaft furnace:

In 1954 a low-shaft furnace was built at the site of the former 3 t/d blast furnace. It was blown in December, 1954 and eventually blown out in August, 1956 after 21 months of operation. In the course of these months, a series of trials were carried out to solve the operational problems connected with production of not only basic pig iron but also foundry pig iron and ferro-alloys in the low-shaft furnace. The experimental work was carried out in five stages, as follows:

Campaign 1: Trial run to produce basic pig iron.

Campaign 2: Production of basic pig iron with soft coke.

Campaign 3: Production of ferro-alloys, and basic pig iron with soft coke, influence of coke-size on the operation of the low shaft furnace.

Campaign 4: Production of basic pig iron, foundry pig iron, high silicon cast iron and "Spiegeleisen" with soft coke.

Campaign 5: Production of ferro-manganese, high-silicon cast iron and ordinary foundry pig iron with an oxygen-enriched blast of 60% $O_2$.

From the results of these experiments it was concluded that:

1 ) The low-shaft furnace could satisfactorily produce basic pig iron with ore fines of -5 mm. and soft coke, with an oxygen enriched blast of 25 to 30% $O_2$.

2) When the blast was enriched with oxygen over 30%, ferro-manganese "Spiegeleisen" and high-silicon cast iron could be produced more efficiently in the low-shaft furnace than in blast furnace.

3) High oxygen content of blast, such as 60% is favourable for the production of ferro-manganese and high silicon cast iron, but in the case of ordinary foundry pig iron, the high oxygen content of blast had resulted in undesirable variations of the silicon content of the metal tapped. On the other hand when the furnace was run with blast of higher oxygen content, such as 60% a stronger tendency of the furnace to hang was observed than when it was run with blast of relatively low oxygen content, e.g. 30%. Further higher oxygen content of the blast increased the CO and $H_2$content of the top gas and the ratio of (CO and $H_2$)/$N_2$ could easily be raised so high as to utilise the gas for the synthesis of ammonia.

The results of the above experimental works ware reported in detail by Dr.Wada in a paper presented at the Symposium on "Iron and Steel Industry in India" held at Jamshedpur in February 1959, by National Metallurgical Laboratory, Jamshedpur.

## 250 KG/DAY EXPERIMENTAL BLAST FURNACE

Trials with the 3 ton-per-day blast furnace as well as with the low-shaft furnace proved very uneconomical. The experimental results of the physical properties of coke, e.g. its mechanical strength or average size of lumps, which were obtained from the operation data of the small furnaces, proved to be inapplicable to ordinary-sized blast furnaces for commercial production. On the other hand, it was felt that some of the experiments, e.g. these on the reduction of iron ores or others on the smelting of nodular graphite cast iron, could well be carried out in a still smaller furnace. These circumstances have resulted in the construction of a small experimental blast furnace with a capacity of 250 kg/day which replaced the former 3 ton/day unit. The blast furnace was put in operation in 1957. An investigation on the physical aspects of internal reactions of blast furnace was chosen as the theme of the experiment, for which the furnace was operated at first. It was concluded from the data obtained that the "flooding phenomenon" set a limit to the operation of blast furnace, which could be expressed by the following formula.

$$u_0 = 43.5 \times f \times d^{\frac{1}{2}}$$

where $u_0$ is the superficial velocity of ascending gas (m./sec.)

"d" is the average diameter of the lumps charged (m,)

"f" is a coefficient, which depends solely upon the size distribution of the coke charged. "f" is equal to 0.5 when all the lumps of coke have a definite size, and 0.35 when large and small sized coke are charged together.

In the course of the above experiments many improvements were made on the furnace to facilitate study of the chemical and physical aspects of blast furnace operation. The operation of this furnace with self-fluxing sinter deserves some special mention here. A special device provided in the furnace body was used to take some samples of charged ores partly reduced by the ascending gas. The ores and the coke thus obtained from the furnace were then examined.

Raw materials used in this experiment are shown in Table I. The furnace was first run exclusively on natural ores. Afterwards, 25%, 50% and 75% of the ore mixes were successively substituted by sinter. The furnace was finally run on 100% self-fluxing sinter burden.

These figures show that, with the use of self-fluxing sinter, the basicity of slag does not change so radically from bosh to tapping hole as with the use of natural ores. This fact is apparently due to the previous formation of calcium silicate in the course of sintering and consequently of fixed CaO. The comparatively low basicities of bosh slag, which always accompany the use of self-fluxing sinter, improve the fluidity of slag and ultimately exert a pronounced effect on the smooth formation of slag and metallic iron in the corresponding parts of the furnace, the conclusions thus drawn from these trials explain the excellent operation data obtained when No.3 Blast furnace of Kukioka Blast Furnace Plant was run on 100% self-fluxing sinter in November 1958. The possibility of total replacement of coke by briquetted coal fines was also examined at the experimental blast furnace. It was found that when the briquetted coal fines are charged into the furnace, individual fines are distilled in the furnace into coke breeze. The coke breeze thus formed in the furnace resulted in a high blast pressures and large amounts of flue-dust, causing the furnace hanging. Subsequent poor production rate and high coke rate of experimental operations have finally led us to the conclusion that operating blast furnaces on briquetted coal fines should be out of question for commercial production.

## EXPERIMENTAL RESEARCH AT THE BLAST FURNACE PLANTS

In parallel with pilot plant studies, the blast furnace plants have contributed a great deal towards additional knowledge and betterment of furnace operation. A number of trials were carried out in the actual plants, relating to diverse aspects such as new methods of blast furnace operation, physical aspects of blast furnace reactions, which lie beyond the reach of the experimental researches at the pilot plant and other phenomena, which can easily be observed on the ordinary blast furnaces for commercial production.

### 1. Oxygen-enriched Blast:

The daily output of any blast furnace, including those which are already in operation with high driving rates, can be remarkably increased by the use of oxygen without increasing coke rates. In other words, the use of oxygen eliminates the need of higher rates, which would be necessary in case the furnace production was increased by higher blowing rates. A test operation was made to get some quantitative data on the increase in production rates due to the oxygen enrichment of blast. No.5 blast furnace of Higashida Blast Furnace Plant was selected for the test; the furnace which had been in operation on the present lining since 27th June 1956, had a working volume of 578 $m^3$, a hearth diameter of 6.2 m. and 12 tuyeres. The oxygen enrichment started on 26th May 1959 and ceased on 11th July. Oxygen content of blast was raised from 22.1 to 23.5% in the five stages corresponding to the five periods of test operations. Operation data of the furnace in these trial periods and in the comparative periods, which preceded or followed the trial periods, are given in Table 2 and have enabled us to draw the following conclusions.

i) The furnace output was remarkably raised on good operational conditions. The highest driving rate then attained can be expressed by a daily coke consumption of 16.7 $t/m^2/d$ and by a productivity of the furnace of 1.25 $t/m^3/d$.

ii) Coke rates, ranging between 600 to 630 kg/t were affected neither by the oxygen enrichment nor by the humidification of the blast.

iii) The production rates at any stages were approximately proportional to the increasing quantity of oxygen (including that in the added steam and air) blown into the furnace in unit of time. The following formula was proposed for the calculation of production rates of blast furnaces:

$$P = \frac{0.324}{K \cdot C.R.} ( L+4.76 \quad .S + 0.00296 \quad .L \quad .W)$$

where P is the calculated production rate (t/d)
S :flow rate of oxygen for enrichment ($Nm^3$/min.)
L: blast rate ($Nm^3$/min.)
W: humidity of blast (grm./$m^3$)
C.R. coke rate (t/t)

K: ratio $\frac{\text{fixed carbon burnt at tuyeres}}{\text{coke charged at the top}}$

(this ratio was originally estimated to be 0.648 in trial periods)

iv) With one per cent of oxygen enrichment, the total volume of blast (i.e. the sum of the volumes of air, oxygen and steam), which must be blown into the furnace through tuyeres for the production of every one ton of iron, could be decreased by 3.4%. At the same time, the volume of top-gas per 1 ton of iron produced was decreased by 3.5%. The production rate of the furnace was increased by 6.3% for every one per cent of oxygen enrichment. However, only 4.8% and not 6.3% can be attributed to the oxygen enrichment itself, the rest (i.e. 1.5%) must be regarded as a result of the strong humidification of the blast during the operation.

The results thus obtained show that the enrichment of blast with oxygen is an efficient method to increase the productivity of blast furnace when higher blast rates have ceased to act.

2. Humidity-control of Blast:

Yawata Iron & Steel works has a long experience on the humidity control of blast. In 1915, a test operation with dry blast was made for the first time at Highashida Blast Furnace Plant. In 1943 a certain quantity of steam was successfully added to the blast of 1 t/d experimental blast furnace in the pilot plant. At Kukioka Blast Furnace Plant, the humidity of the blast has been regularly controlled since 1957 and kept at a certain level which is ordinarily the lowest one needed for the smooth operation of the furnaces; in some cases, however, blast of very high humidities, accompanied by higher blast temperatures, was used in order to increase the productivity. Humidity control of blast cannot completely make up for the insufficient qualities of ore burdens. Table 3 shows the operation data of No.3 blast furnace of 7.7 m hearth diameter, at Kukioka Blast Furnace Plant. In winter the furnace was in ordinary operation and in summer it was operated with extremely high productivity. The conclusions drawn from these data are:

i) High steam-contents of blast have a pronounced effect on the daily output of the furnace. This fact is due to the oxygen brought into the furnace as a constituent of steam. Quantitative analysis shows that 10 gm. of steam added to each cubic meter of blast has the same effect on the production rate as an increase in blast rate by 50 $Nm^3$/min. In other words, humidification of blast is similar to oxygen enrichment in that both promote production.

ii) Injection of steam into the blast mainly gives rise to the endothermic water gas reaction in the tuyere zone. The consumption of heat, which is thus inevitable when the steam is injected, results in a steeper temperature gradient from tuyere to bosh. Low blast pressures with little fluctuation, uniform descent of charged stocks and ultimately realised uniform furnace conditions which are observed with humidified blast, are a result of the steeper temperature gradient. And therefore, lower coke rates can be expected with the humidification of blast.

iii) Lower pressures of blast attained by humidification, eventually make it possible either to increase the driving rate of the furnace or to prevent, the coke rate from getting higher, since the lower pressures allow the uses of heavy burden and high blast temperatures as well as high blast rates. The increase in coke rates, which is due to the incomplete preliminary treatment of natural ores, can partly be compensated for by the humidification of blast. Finally it was concluded that, when the higher blast temperatures are available the higher steam contents of blast can be used to increase the efficiency of blast furnace operation. Since the theoretical explanation of the effect of added steam is not yet given, the investigation for this task is going on both at the Technical Research Institute and in the blast furnace plants. Utility of hydrogen, which forms a part of the products of water gas reaction, is one of the present topics drawing considerable attention.

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## TABLE 1

Chemical Analysis of Ores in Use

| | Size (mm) | Chemical Analysis (%) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | T. Re | Fe | $SiO_2$ | $Al_2O_3$ | CaO | S | Mn | $CO_2$ | $CaO/SiO_2$ |
| Goa | 5~1.5 | 58.14 | 1.43 | 2.23 | 5.28 | 0.04 | 0.047 | 0.85 | | |
| Self fluxing sinter | 5~1.5 | 53.65 | 13.08 | 8.32 | 2.40 | 8.48 | 0.104 | 0.84 | | 1.01 |
| Lime Stone | 5~1.5 | | 0.92 | 0.47 | 0.21 | 53.46 | 0.025 | | 43.71 | |
| Indian Mn Ore | 5~1.5 | 23.12 | | 7.06 | | 1.00 | | 29.43 | | |

| | Size (mm) | Ash (%) | Volatile matter(%) | Fixed carbon (%) | Sulphur (%) |
|---|---|---|---|---|---|
| Coke breeze | 20~10 | 13.17 | 4.12 | 82.71 | 0.567 |

## TABLE 2

Operating data of test periods

| | Item / Test Period | Production t/d | Coke rate Kg/T | Blast vol. (Calculation) $Nm^3/min$ | Blast temp. $^oC$ | Blast press $g/cm^2$ | Humidity of blast $g/m^3$ | Slip or Hanging | Blowing time Min/d |
|---|---|---|---|---|---|---|---|---|---|
| Oxygen enriched blast operation | I | 737 | 632 | 821 | 676 | 843 | 30 | 9.6 | 1440 |
| | II | 751 | 620 | 816 | 706 | 822 | 33 | 6.4 | 1440 |
| | III | 752 | 614 | 819 | 725 | 818 | 38 | 4.9 | 1428 |
| | IV | 803 | 601 | 826 | 768 | 777 | 42 | 0.5 | 1440 |
| | V | 805 | 626 | 822 | 713 | 819 | 46 | 2.3 | 1434 |
| Normal operation | Comparison | 698 | 637 | 826 | 735 | 853 | 36 | 0.2 | 1407 |

TABLE 2 (Contd)

Chemical Analysis

| Item | Test period | Pig C % | Pig Si % | Pig S % | Top gas $CO_2$ % | Top gas CO % | Top gas $H_2$ % | Top gas Temp °C | Slag CaO % | Slag $SiO_2$ % | Slag $Al_2O_3$ % |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Oxygen enriched blast operation | I | 4.49 | 0.68 | 0.028 | 15.4 | 26.4 | 2.6 | 199 | 40.5 | 30.4 | 15.2 |
| | II | 4.64 | 0.75 | 0.023 | 15.1 | 26.5 | 2.6 | 199 | 40.4 | 30.5 | 14.6 |
| | III | 4.54 | 0.72 | 0.025 | 15.7 | 26.4 | 2.7 | 202 | 40.4 | 30.6 | 15.5 |
| | IV | 4.54 | 0.90 | 0.030 | 15.2 | 26.2 | 2.6 | 218 | 41.1 | 30.3 | 16.4 |
| | V | 4.50 | 0.73 | 0.029 | 15.4 | 26.3 | 2.6 | 221 | 41.0 | 30.8 | 15.6 |
| Normal operation | Comparison | 4.48 | 0.63 | 0.028 | 14.9 | 26.3 | 2.7 | 249 | 40.4 | 31.1 | 15.3 |

Remarks : $O_2$ in Air (%)

| Test Period | $O_2$ in Air (%) |
|---|---|
| I | 22.1 |
| II | 22.6 |
| III | 22.6 |
| IV | 22.5 |
| V | 23.2 |

Table 3

Operating data in Kukioka No.3 Blast Furnace

| | Jan. 1959 | Aug. 1959 |
|---|---|---|
| Humidity of blast | 13.7 $gr/m^3$ | 33.2 |
| " of air | 4.6 " | 20.3 |
| Production | 1259 t/d | 1331 |
| Coke rate | 617 kg/t | 618 |
| Ore/Coke | 2.517 | 2.486 |
| No. of charges/day | 106 charges/d | 112 |
| Blast temp. | 668°C | 795°C |
| Vol. | 1459 $m^3$/min. | 1586 |
| Blast Press Average | 1084 $gr/cm^2$ | 1048 |
| " " (Max.-Min.) | 75 " | 37 |
| Blast Vol./Press | 1.35 | 1.51 |
| $CO_2$ in top gas | 16.8% | 16.2% |
| $CO/CO_2$ in top gas | 1.43 | 1.52 |
| Si in pig | 0.66% | 0.68% |
| S " | 0.031% | 0.027% |
| Hangings | 8 times | 1 |
| Proportion of Sinter | 34.8% | 41.0% |