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DEVELOPMENTS IN BLAST FURNACE PRACTICE AND DESIGN[1]

by

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SUMMARY

The progress of ironmaking technology during the past 15 years in Japan in the fields of raw materials, operating practice, and equipment may be outlined as follows. In the field of raw materials, lump ores have been crushed to 50mm, and then fine ores have been removed by screening. After ascertaining the effect of these measures, the lump size was brought to 35mm, and -5mm fine ores have been completely eliminated. In some works, sizing has now been brought down to the very narrow range of 8-25 mm.

This, however, led to the generation of fine ore in larger quantities. Increased use of sinter and the production of self-fluxing sinter have become more popular for the treatment of such fines. A 10% increase in sinter ratio in the burden corresponds to a reduction of coke rate of about 10kg/t and to a production increase of about 2%. It has thus become usual practice to improve blast-furnace operating results by constantly supplying large quantities of sinter having a stable quality.

In operation, the adequate permeability guaranteed by good preparation of raw materials permitted achievement of higher blast temperatures: a 100°C increase in blast temperature led to a reduction of coke rate by about 20kg/t. The application of fuel injection required a constant theoretical flame temperature to be maintained at the tuyeres, thus resulting in a high blast temperature of about 1,100 - 1,200°C, and the reduction of coke rate to 447kg/t as the national annual average.

The remarkable progress of BOF steelmaking led to an increased demand for hot metal, and this has hastened the trend toward constructing larger blast furnaces. With a view to ensuring a high permeability in these large-capacity blast furnaces, high top pressure operation has been adopted, and various improvements have accordingly been made on the top charging systems.

In the casthouse operations to treat large quantities of hot metal, two casthouses are provided with three tapholes in Nippon Kokan's Fukuyama No.4 blast furnace, daily producing more than 10,000 tons on monthly average.

Production costs in large-capacity blast furnaces are relatively low, taking into account all the operating and investment costs. Capacity expansion is advantageous up to about 2,500m^3. In large-scale iron works directed toward a more favorable mass-production, therefore, the superiority of large-capacity blast furnace has been recognized, and there is an active move toward replacing small furnaces by large-capacity ones.

Research and development efforts have been made in raw materials, operations and equipment. There have not only been impressive developments in these individual fields, but also combinations of the results of progress in these different fields have made very significant contribution, as illustrated by the marked decrease in coke rate and increase in productivity, thus leading to the present success of large-capacity blast-furnace operation.

1. Progress of ironmaking technology in Japan

Ironmaking technology has recently made remarkable progress, an outline of which is as follows. The Japanese steel industry formulated the first rationalization plan during the period from 1951 through 1955 to reconstruct former facilities. Crushing of lumps applied for the preparation of raw materials considerably raised the productivity of blast furnaces. Iron production and coke rates, which had been 2.2 million tons and 912kg/t* respectively in 1950, had become 5.26 million tons and 713kg/t respectively in 1955.

In the second rationalization plan covering the period from 1956 through 1960, new blast furnaces were constructed (the working volume of the largest was raised from 1,300 to 1,700 m^3). Production was raised to 12.1 million tons, while the coke rate decreased to 617kg/t in 1960.

In addition, as shown in Fig.1, the coke rate was reduced to 507kg/t in 1965 and to 447kg/t in 1971 as an annual national average in Japan, through the application of oil injection, use of sinter in larger quantities, adoption of self-fluxing sinter, high top pressure operation, and other technical innovations.

In the meantime, BOF was introduced by Nippon Kokan K.K. and Japan Steel Corp. in 1957.

The HF converter process, employing a high pig ratio of about 80% at furthermore a very high efficiency, has demanded the stable supply of a large quantity of hot metal. To cope with this increasing demand, the trend toward constructing new and larger blast furnaces was further accelerated in addition to the efforts to modify existing furnaces and improve production techniques. A furnace having a capacity exceeding

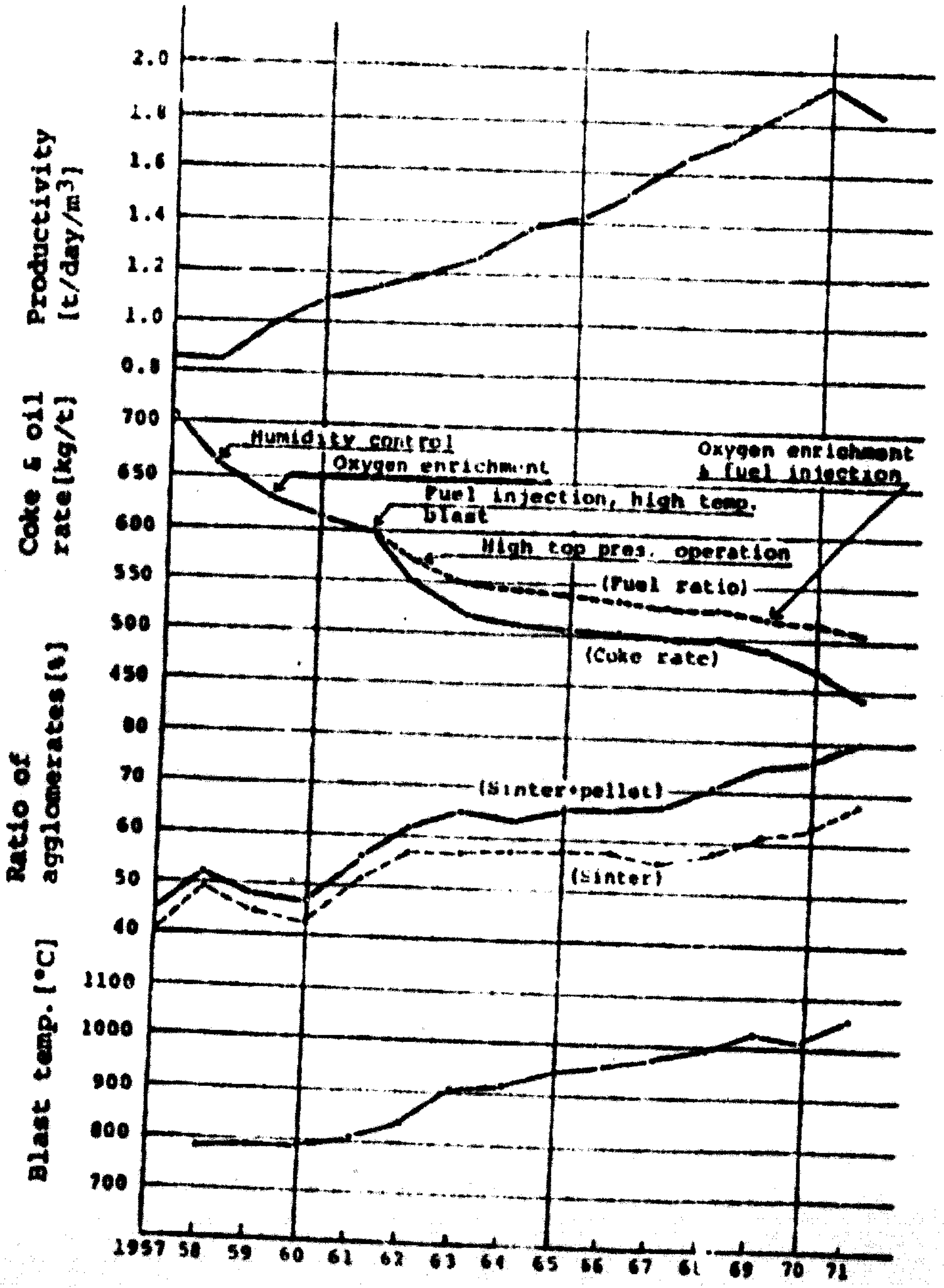


Fig.1 Progress of blast furnace operating results

2,000m^3 was built in 1964, and in 1971, 67 furnaces including three of larger than 4,000m^3 were brought into operation, about 60% of which are operating at a high top pressure, thus giving an annual production of 72.2 million tons, or 3,180 tons/day per furnace on average, corresponding to a productivity of 1.84 tons/day/m^3. Change in number of constructed blast furnaces is represented in Fig.2. This progress will be reviewed

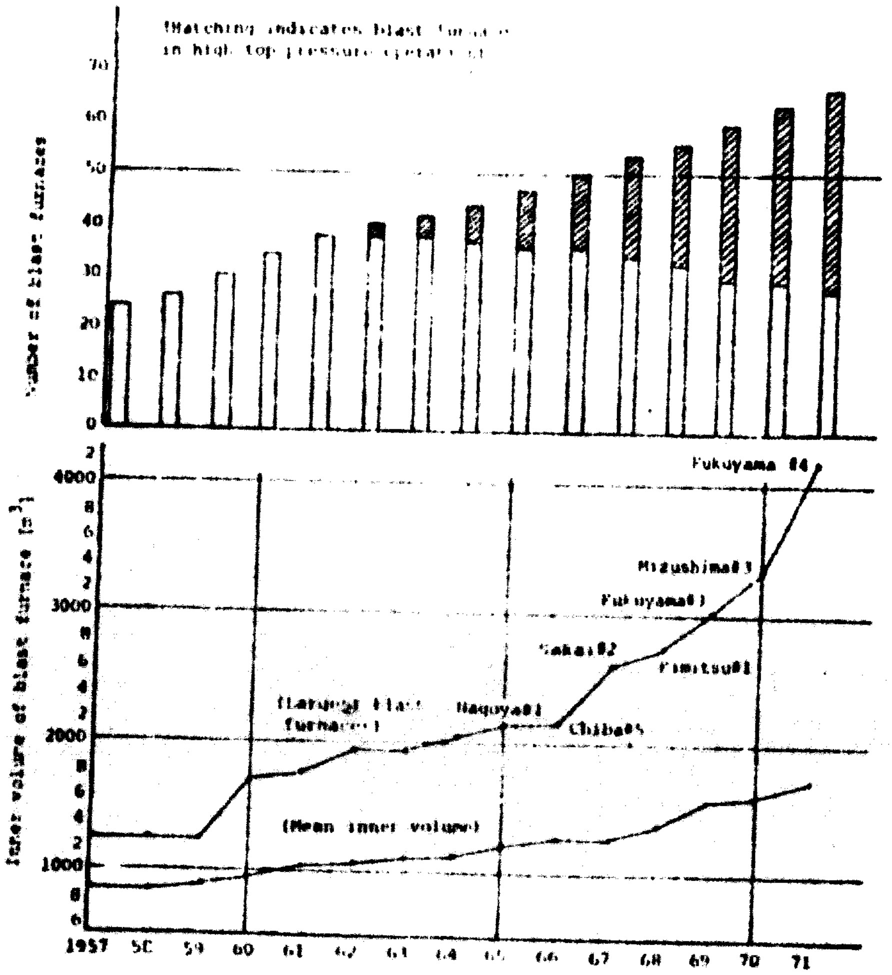


Fig.2 Progress of number of operating blast furnaces and inner volume

in detail in the following paragraphs from the point of view of operation and equipment.

2. Raw materials

2.1 Preparation of iron ore

Size control of ore by crushing and screening was at first slow in being applied in practice because of the uncertainty of the effect and difficulties in treating generated fine. From 1952 - 53, crushing of large lumps was first applied on an experimental basis to verify the effect of sizing. From 1957 to 59, raw materials preparation facilities have been modified into two-stage crushing type in many iron works in succession, with emphasis placed on bringing the ore size to 50mm. However, the removal of generated fines was still inadequate : fines were charged into blast furnaces in the form mixed with sized ore in most of the works. Later in 1959 - 63, tests were carried out in many works to ascertain the effect of sizing. This resulted in an intensified crushing: facilities were modified into those of the circulation type in which the fraction of a size over a certain limit in ores after the secondary crushing was recrushed to size ore to less than 40mm. Simultaneously, closer screening of -10mm fines has been applied in an attempt to ensure an adequate permeability in the furnace and to improve the burden distribution and reducibility. According to the results of tests carried out at that time at Nippon Kokan, a 1% decrease of lumps of larger than 35mm in charged ores corresponds to a decrease in coke rate of about 2kg/t, and a 1% decrease of -6mm fines leads to a decrease in coke rate of 1kg/t.

In the same period in which the sizing was intensified, furnace capacities began to expand from 1,300m^3 up to 1,700 m^3. Later construction of large furnaces exceeding 2,000m^3 resulted in sizing of ore to tight range of 8 - 25mm.

2.2 Sinter and its effect

Ore sizing was intensified for the improvement of the blast furnace productivity. This,however, led to the generation of fine ore in larger quantities at mine sites and in iron works. This led to an increase in sintering plant capacity.

Before 1950 - 1953, sinter accounted for 30% of the burden, but this percentage increased to about 40% in 1955, and more emphasis has been placed on the effect of sinter on the blast-furnace operation. Tests and research were conducted to find sinter qualities suitable for blast-furnace operation, while tests with more sinter were carried out in commercial furnaces to ascertain its effect on the operation.

Furthermore, progress has been made in the study of self-fluxing sinter mixed with limestone: tests with a high blending ratio of this sinter were conducted in many industrial furnaces from 1957 onwards. This revealed the remarkable effect of self-fluxing sinter on the improvement of gas permeability through the furnace, increase in production, and reduction of coke rate.

Burdens now in use in the present blast furnaces exclusively therefore consist of self-fluxing sinter, and efforts are directed toward increasing its blending ratio to ensure a sinter percentage of 70 - 80% in most modern works.

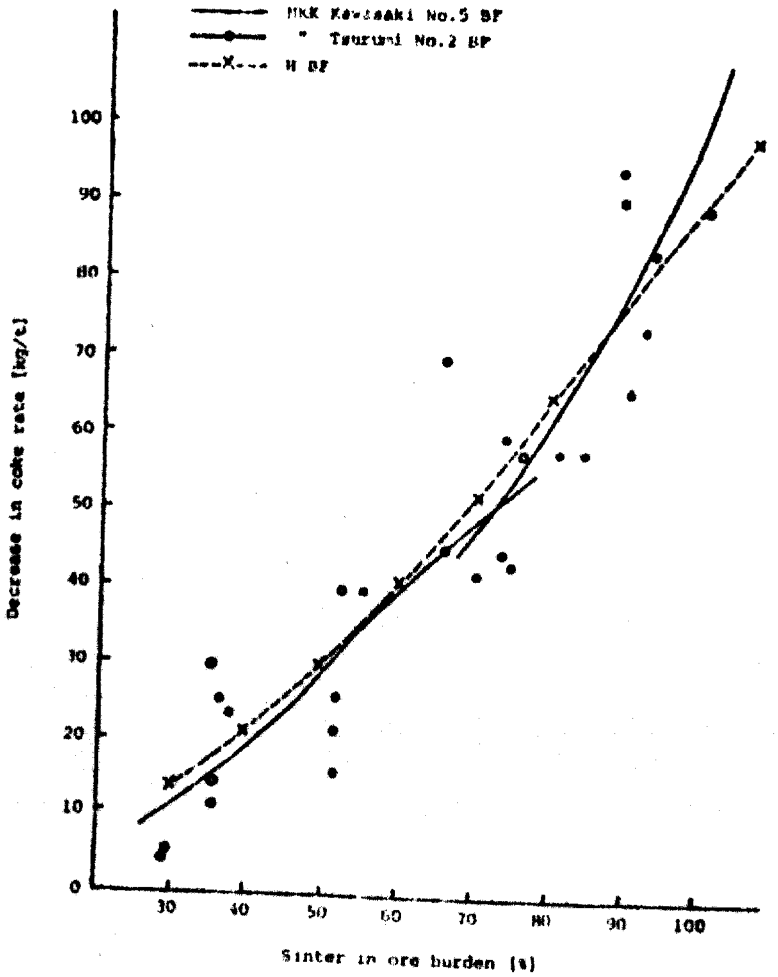


Fig.3 Effect of sinter ratio on the decrease in coke rate

Fig.3 shows the effect of sinter ratio in ore burden on the blast-furnace operation. A 10% increase in sinter ratio corresponds to a reduction of coke rate of about 10kg/t and to a production increase of about 2%. In the case of the Fukuyama Works, where ores are sized to 8 - 25mm, however, the effect of sinter ratio on the coke rate is slight.

With regard to the effect of sinter strength and mixing of fines in the burden on blast furn-

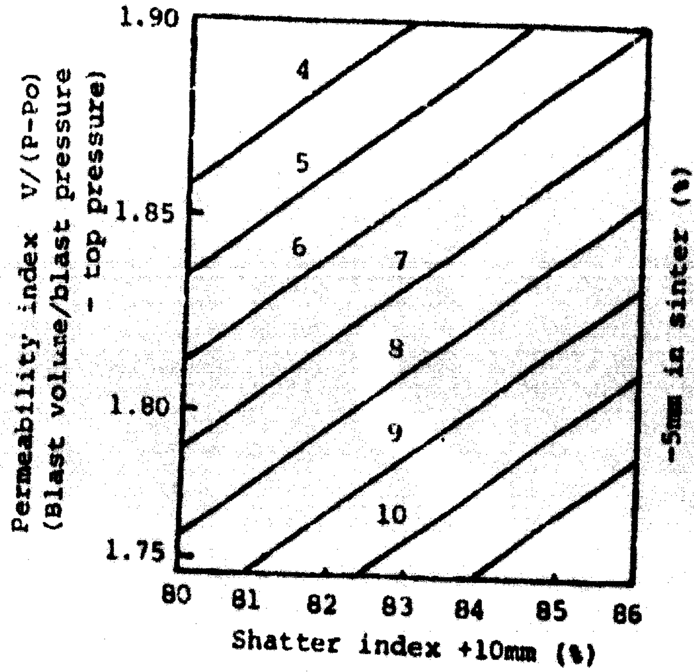


Fig.4 Relation between blast furnace condition and sinter quality

ace permeability, NKK Mizue No.1 BF (1,728m^3, daily production 3,800 tons) operating with a sinter ratio of about 65% gives a relation as shown in Fig.4. Because -5mm fine sinter impairs the permeability, it is necessary to control this fraction to less than 5% by a closer screening applied before charging.

At NKK's Fukuyama BF Plant having furnaces daily producing 10,000 tons, the sinter strength is controlled through measurement of tumbler index based on continuous automatic sampling to feed back results to the operation of the sinter plant.

Improvement of sinter quality is largely contributing to that of operating results of blast furnaces. In producing and using sinter having stable chemical and physical properties, attention is given to the following points:

(1) Many kinds of fine ore of different properties are subjected to bedding to manufacture sinter of a uniform chemistry with a view to minimizing variations in quality of burden raw materials.

(2) Sinter having high cold and hot strengths is produced to ensure a sufficient strength in blast furnace. Appropriate quantities of FeO, CaO, and SiO_2 are mixed and proper sintering is applied so that the produced sinter is not broken into fines during the reducing reaction at temperatures near 500°C.

(3) Sinter is sized to 5 - 50mm. Facilities are provided to ensure that -5mm sinter fines are not charged into the blast furnace. For this purpose, -5mm sinter fine is sieved off before charging into the sinter bin on the BF side, and sinter is screened again on removal from the bin and weighing, in the case of the recent large-capacity blast furnaces.

(4) Special improvements and devices are incorporated into large mass-production sinter plants for smooth and stable operation and easy maintenance.

2.3 Pellets

Since the steel industry of Japan depends upon many iron-ore sources abroad, pelletizing of many kinds of fines was considered to be technically difficult, and the efforts to prepare fine ore have been exclusively directed towards increasing the sinter production capacity. Pellets have, however, become an important subject in the aspect of purchase for the following reasons:

(1) Therefore, as the development of the existing sources of

supply proceeds, rich ores finely broken in flotation are pelletized instead of low-Fe ores containing much impurities such as Cu and S.

(2) In addition to fine ores produced in large quantities in exploiting mines, flue dust and other fines not applicable in sintering can be utilized.

(3) Progress made in the pelletizing technology has made it possible to produce pellets suitable for blast furnace operation in large quantities.

(4) High grade pellets containing little impurities have advantages almost equal to those of self-fluxing sinter.

2.4 Coke

With the trend toward larger blast furnaces, there has been an increasing demand for higher quality of coke, especially higher strength. But this has so far posed no problem because strong coking coals from the United States were blended at a high percentage. Shortage of supply caused a decrease in blending ratio of strong coking coals. Decrease in strength was, however, avoided through the establishment of proper blending practices based on the accurate knowledge of the properties of various coking coals and the improvements in production techniques including dry charging and oiling, applied to raise the charging density and adhesion, thus permitting production of coke having a stable quality and smooth operations even in large-capacity blast furnaces.

The effect of ash in coke on the coke rate is as follows: a 1% decrease in ash in coke leads to a reduction of coke rate of about 15kg/t.

3. Blast furnace operation

3.1 High temperature blast

The blast temperature had been raised from 500 - 700°C so far used to only about 800°C by 1960, partly because of the insufficient preparation of raw materials. Operations have later been carried on at higher blast temperatures for the following reasons:

(1) Intensified raw materials preparation resulted in sized ores containing less fines and this gave a better permeab-

ility through the furnace.

(2) Using a higher percentage of self-fluxing sinter with a higher strength and containing less fine has stabilized the operation.

(3) With the use of oil injection started in 1962, a higher blast temperature was required for keeping an appropriate flame temperature at tuyere. Increase in blast temperature has a remarkable effect on the reduction of coke rate and production increase. With this fact in view, efforts were made to obtain the maximum temperature of blast by the effective use of the existing hot stoves. Expansion of hot stove capacity was attempted in installing a new blast furnace and in relining a blast furnace.

Since the sensible heat of blast accounts for about a third of the heat input to the blast furnace, the increase in blast temperature leads to the reduction of coke rate: as shown in Fig.5, a 100°C increase at a temperature of 800 - 1,100°C permits saving of coke rate by about 20kg/t, and at 1,100 - 1,200°C, about 15kg/t.

A blast temperature of 1,300 °C is now possible through the increase in hot stove capacity, improvement of stove design, development of improved refractory bricks, prevention of leakage at joint portions of bustle pipe and branches, improvement of materials of valves and nozzle, and enrichment of blast-furnace gas by coke-oven gas or oil. Most blast furnaces are now actually operated at about 1,100 - 1,200°C.

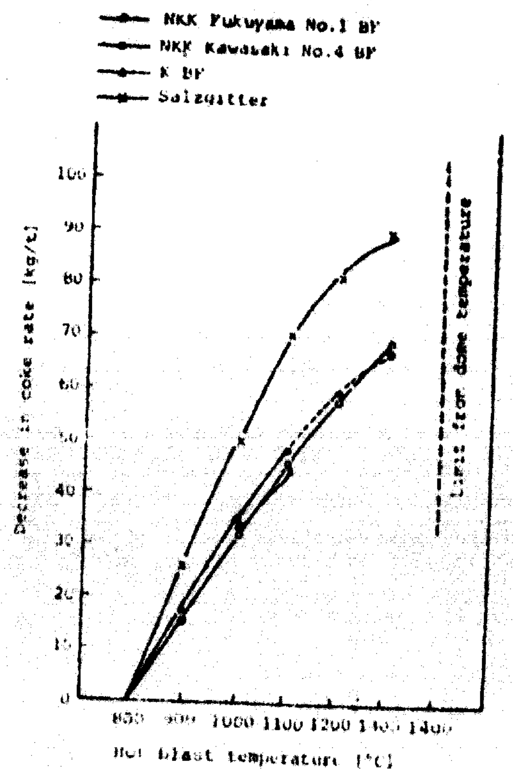


Fig.5 Effect of hot blast temp. on the decrease in coke rate

3.2 Blast modification

Technologies of humidity control, oxygen enrichment and fuel injection have been applied to improve operational conditions.

3.2.1 Humidity control

As a measure to improve blast furnace operating results, the high-temperature blast was experimentally applied to reduce coke rates. However, a simple increase in blast temperature led to disturbance of furnace condition and this limited the application to a certain extent. It has become clear, on the other hand, that the difference in humidity of atmosphere has a considerable effect on the furnace condition.

From 1958, steam was injected into the cold blast main to control the blast humidity. This permitted considerable stabilization of blast-furnace operation, and the humidity controlling operation in combination with high temperature blast and oxygen enrichment has become popular since. The possibility of controlling the flame temperature at tuyere to a certain level by the injection of fuel has, however, almost eliminated the necessity of steam addition, and the temperature of hot metal has since been controlled by fuel injection.

3.2.2 Oxygen enrichment

Oxygen enrichment in blast largely raised the production of blast furnace. In Nippon Kokan's Keihin blast furnace, oxygen enrichment operation was applied for the first time in Japan in 1959 with the use of low-cost excess oxygen from the adjacent plant.

As the enrichment of oxygen raised the flame temperature at the tuyere, leading to an unstable furnace condition, humidity control was simultaneously applied, with the introduction of the theory of constant theoretical flame temperature at tuyere. A 1% enrichment of oxygen brought about a 5% increase in production and a slight decrease in coke rate. This is also the case with the recent operating results at the other iron producers in Japan.

Progress of the basic oxygen steelmaking process has made available oxygen in large quantities, and this enhanced the popularization of oxygen-enriched blast. In many blast furnaces at present, 2 - 3% oxygen are used for heat compensation in injecting more fuel in place of costly coke and for improving the combustion efficiency of injected fuel.

3.2.3 Fuel injection

Fuel injection through the tuyeres is the most important practice next to raw materials preparation in blast furnace operation. It is still being reviewed and researched for more effective application. Heavy oil injection has been studied in Japan since 1959, applied in practice since 1961, and rapidly became widely used in the industry. All the blast furnaces are now operating with oil injection, considerably reducing the iron cost. Fuel injection has the following favorable features:

(1) Reduction of coke rate

(2) Stabilization of blast-furnace operation and production increase

(3) Compensation of shortage in coke oven capacity or saving of coking facilities

(4) Low investment in installing the injection equipment on blast furnace.

For the effective application of fuel injection, attention should be given to the following points:

(1) Heat compensation capable of keeping the flame temperature at tuyere within a certain range

(2) Limit of combustion load for individual tuyeres

(3) Changes in permeability, heat exchange, and reducing reactions caused by varying volume of gas produced per ton of hot metal

(4) Injection method (for example, engineering of atomizing, etc.)

(5) Measures to cope with unexpected blow-off and other troubles.

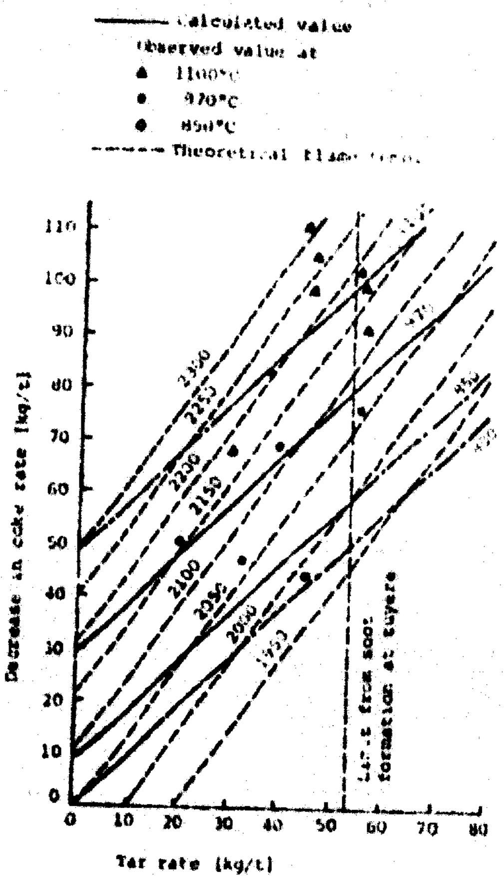


Fig.6 Effect of amount of injected tar on the decrease in coke rate at different hot blast temperatures

Heat compensation and combustion load are the most important problems in injecting fuel. Reduction of coke rate brought by the fuel injection is related to the blast temperature. According to the operating results of Nippon Kokan's Kawasaki No.4 BF, as shown in Fig.6, the limit of oil injection is 30kg/t at a constant humidity, i.e., with a lower limit of 2,000°C and an upper limit of 2,200°C of the theoretical flame temperature and a blast temperature of 800°C under the conditions at that time. With a blast temperature of 1,100°C, even an injection of 110kg/t is possible from the point of view of heat compensation alone.

Limit of the ratio to the amount of oxygen necessary for the perfect combustion of oil, referred to as excess oxygen ratio, is considered to be 1.1 - 1.2, and this would result in a limit of oil injection of 110kg/t and that of tar injection of about 90kg/t. For the injection of oil over this limit, conceivable methods include blast-atomizing combustion, use of oxygen atomizing burner, and injection of specially produced reducing gas through the lower part of shaft.

In recent operations of Nippon Kokan's Fukuyama blast furnaces, in which oil injection of about 80kg/t applied in combination with oxygen enrichment is reducing the coke rate to about 400kg/t, it is necessary to keep the theoretical flame temperature at rather a high level of 2,300 - 2,400°C.

According to the result of experiments in the experimental blast furnace (10t/day) at Nippon Kokan's Technical Research Center, it is possible to reduce the coke rate to 210kg/t by injecting reducing gas made from about 220kg/t of oil.

A problem in economics of oil injection is the replacement ratio between coke and this substitute fuel. The replacement ratio available, ranging between 2 and 0.6, varies considerably with the operating conditions, because:

(1) Use of heavy oil permits high blast temperature, humidity reduction, and oxygen enrichment.

(2) Oil injection increases reducing gas and raises the reducing efficiency in shaft and the CO/CO_2 ratio of the top gas.

(3) Variation in the combustion condition causes soot formation.

Complicated combinations of these factors cause considerable changes in replacement ratio, but an appropriate heat compensation keeps it within the range of about 1.0 - 1.2.

3.3 High top pressure operation

Increase in blast volume for raising blast furnace productivity reduces the passage time of gas through the furnace (i.e., the reaction time) which lowers the utilization ratio of gas, raises the top temperature, and increases the coke rate. Pressure drop in the furnace also increases. The blast volume, increased over a certain limit, results in imbalance of permeability through the furnace and other troubles such as channelling and flooding.

If the high top pressure operation is carried on with a mean furnace pressure (absolute pressure) p times that in an ordinary operation, the furnace gas density is also brought to p times. As the furnace gas speed becomes 1/p even with the same blast volume, the pressure drop in the stack becomes 1/p and the limiting grain size of splashing particles becomes as small as 1/p.

The limit of flooding, in which slag and ore, immediately after being melted in the bosh, are blown upward by gas and are solidified at the upper part at a somewhat lower temperature into scaffolding form, preventing the passage of gas, becomes so large as 1.2-th power of p and this minimizes hangings. This means that high top pressure permits stable operations, even with a larger blast volume.

Application of high top pressure requires installation of a mechanism to keep the furnace top gas-tight and a gas pressure controlling equipment. By the introduction of technology from the U.S., Nippon Kokan's Mizue No.1 blast furnace and some other furnaces started high top pressure operation in Japan in 1962. At this Mizue No.1 BF, having a working volume of 1,704m^3, a top pressure of 0.4kg/cm^2 has been maintained for one campaign of 64 months, thus producing 3,200 tons/day on average throughout the period.

Most of the newly constructed furnaces in Japan are operated with high top pressure, and many of the existing furnaces are being modified to adopt high top pressure operation at the time of relining. As shown in Fig.2, among 67 blast furnaces now in operation, 43 furnaces are based on high top pressure operation. Top pressure has been gradually raised to the present general level of 1.0 - 1.5kg/cm^2: it is even 2.5 kg/cm^2 max. in some very recent large-capacity blast furnaces. As is presented later in this report, Nippon Kokan's Fukuyama No.4 BF is daily producing 10,000 - 10,500 tons with a top pressure of 2.0 - 2.3kg/cm2 (2.5kg/cm^2 max).

According to the results of NKK's Fukuyama and other iron producers in Japan, high top pressure operation has the following effects:

(1) Top pressure and permeability

Fig.7 represents the effect of the top gas pressure (Po, kg/cm^2) on the permeability index (V/P-Po) for Fukuyama Nos.1 to 4 blast furnaces, where V indicates the blast volume (m^3/min) and P, the

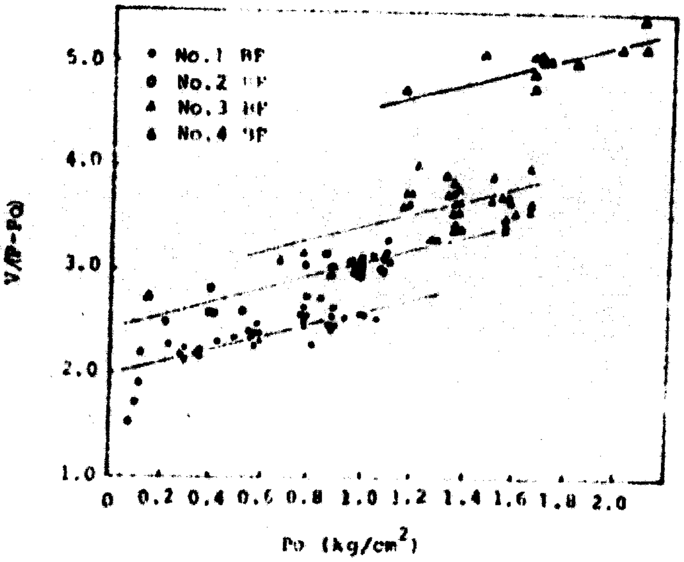


Fig.7 Relation between top pressure and permeability

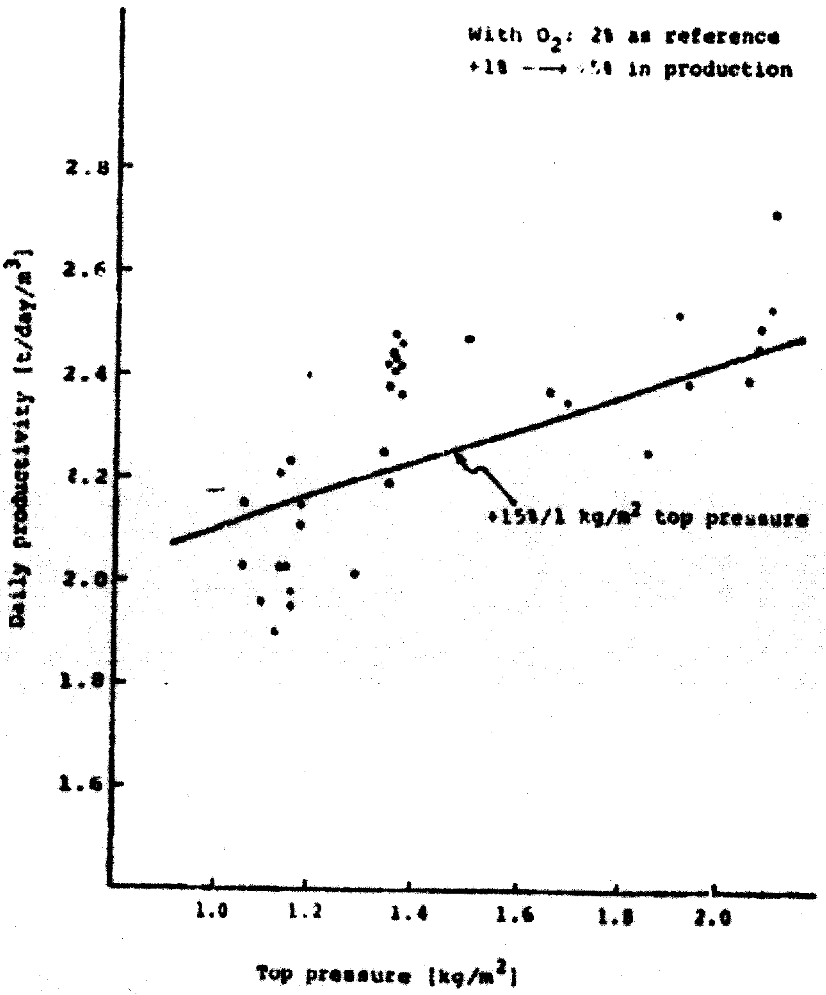


Fig.8 Relation between top pressure and productivity

blast pressure (kg/cm^2)

(2) Effect on production increase

As shown in Fig.8, the increase in top pressure raises the productivity: a 0.1kg/cm^2 increase in top pressure corresponds to an increase of about 1.5% in productivity.

(3) Effect on coke rate

The reducing ability is considered to increase in prop-

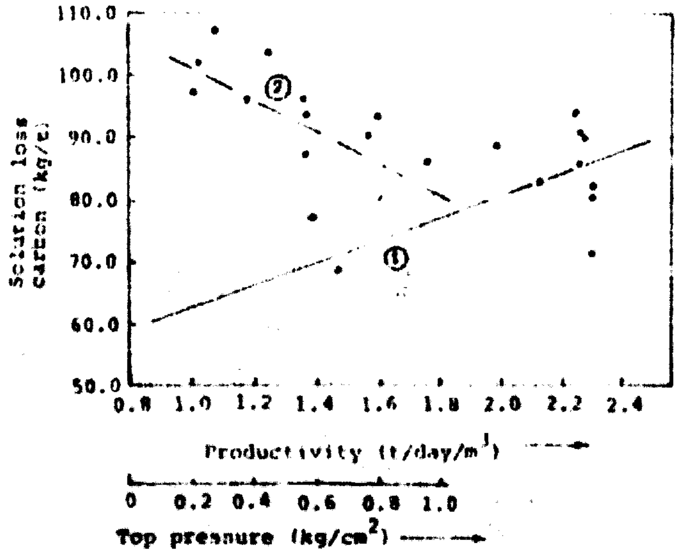


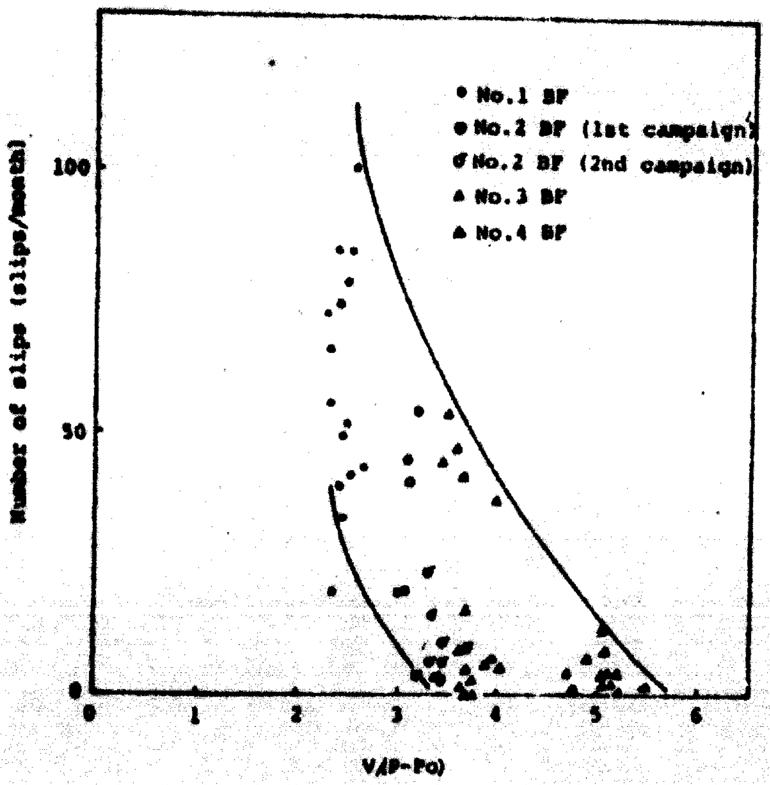
Fig.9

(1) Relation between productivity and solution loss at a top pressure of 0.8kg/cm²

(2) Relation between top pressure and solution loss at a productivity of 2.3t/day /m^3

Fig.10

Relation between permeability and number of slips



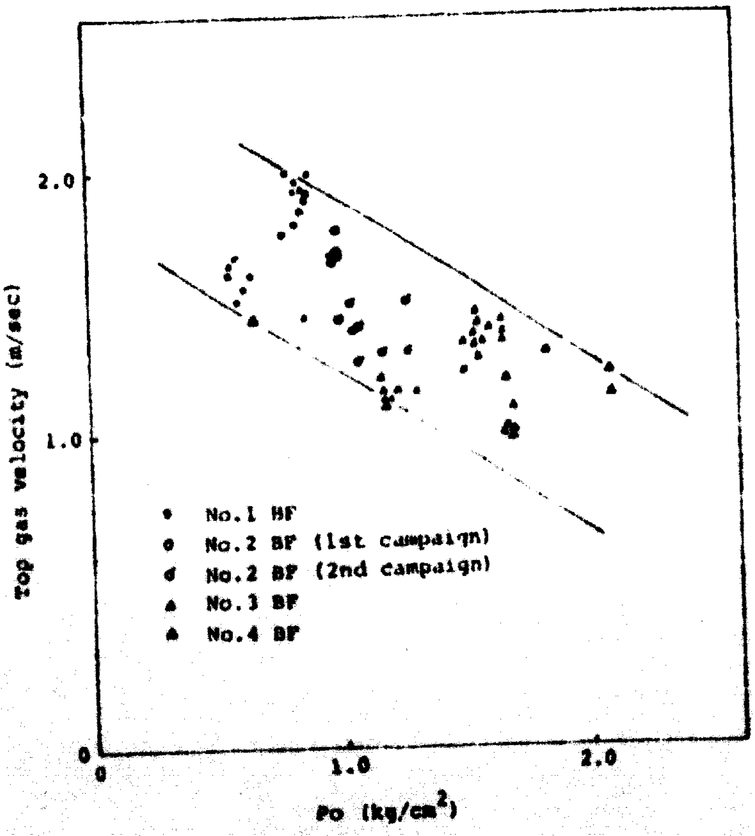
ortion to the increase in reducing gas partial pressure caused by the increase in furnace pressure. As shown in Fig.9-(2), the increase in top pressure reduces solution loss, whereas, as is known from Fig.9-(1), the higher daily productivity results in an increased solution loss, thus slightly reducing the coke rate.

(4) Decrease in dust loss

A higher top pressure leads to a better permeability, and

Fig.11

Relation between top pressure and top gas velocity



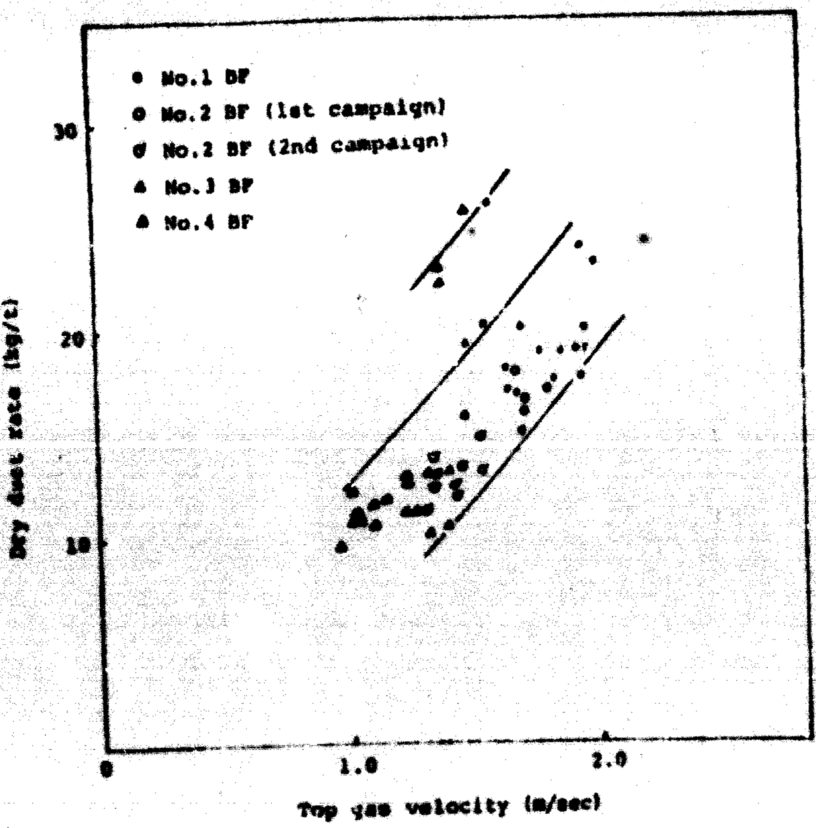


Fig.12

Relation between top gas velocity and dry dust rate

therefore reduces the number of slips as shown in Fig.10. As is clear from Figs.11 and 12, furthermore, higher top pressure slows down the top gas velocity, thus reducing the dust loss. This fact is theoretically supported by the decrease in limiting grain size of particles blowing upwards.

3.4 Raw materials and operating factors affecting production and coke rate

In an operation with an ore size of about 40mm and a blast temperature of about 1,100°C, the effect of raw materials and operating factors on the production and coke rate is approximately expressed by the following formulae:

$$Pr = A \frac{\left\{1+ \frac{5}{100}\cdot O_2 + \frac{15}{100}(TP-TP_o)\right\} V}{Cr_o - \frac{20}{100}(T-T_o) + 10(As-As_o) + \frac{20}{100}(S_V-S_{V_o}) - 1.0(SPR-SPR_o)} \quad \text{..........} \; (1)$$

$$Cr = Cr_o - \frac{20}{100}(T-T_o) + 10(As-As_o) + \frac{20}{100}(S_V-S_{V_o}) - 1.0(SPR-SPR_o) - 1.0(Oil-Oil_o) \quad \text{..........} \; (2)$$

Where,
- Pr: Iron production [T/D]
- A: Constant
- O_2: Ratio of oxygen enrichment $= (T.O_2 \text{ in blast})/(\text{blast vol.}) + (O_2)$
- T.P.: Top pressure [kg/cm^2]
- V: Furnace inner volume [m^3]
- Cr_o: Reference coke rate [kg/THM]
- T: Blast temp. [°C]
- As: Ash in coke [%]
- S_V: Slag volume [kg/THM]
- SPR: Ratio of (sinter + pellet) in ore charge

* Suffix o indicates reference operating condition.

The degree of contribution of these factors to the production and the coke rate are outlined in the following table:

	Contribution to production increase (tons/day)	Contribution to coke rate decrease (kg/THM)
Oxygen enrichment	$\frac{5}{100}\cdot O_2\cdot Pr_o$	
Higher top pressure	$\frac{15}{100}(TP-TP_o)Pr_o$	
Higher blast temp.	$\frac{\frac{20}{100}(T-T_o)}{Cr_o-\frac{20}{100}(T-T_o)}\cdot Pr_o$	$\frac{20}{100}(T-T_o)$

Lower ash in coke	$\frac{10(As_o-As)}{Cr_o-10(As_o-As)}\cdot Pr_o$	$10(As_o-As)$
Smaller slag vol.	$\frac{\frac{20}{100}(SV_o-SV)}{Cr_o-\frac{20}{100}(SV_o-SV)}\cdot Pr_o$	$\frac{20}{100}(SV_o-SV)$
Higher ratio of agglomerates	$\frac{1.0(SPR-SPRo)}{Cr_o-1.0(SPR-SPR_o)}\cdot Pr_o$	$1.0(SPR-SPR_o)$
Larger amount of oil injection		$1.0(Oil-Oil_o)$

4. Problems in the economics of operation of blast-furnace equipment, especially in large-capacity furnaces

4.1 Economics of large-capacity blast furnace

Steelmaking in integrated iron and steel works has been changed from the open-hearth furnace process to the converter process. The high efficiency of the latter process and the expansion of unit capacity of rolling facilities have brought the most economical annual production unit of iron works from the conventional order of five million tons to about ten million tons, and this level was rapidly raised furthermore to even 16 million tons as is observed in Nippon Kokan's Fukuyama Works.

To cope with this trend toward larger facilities and the increasing demand for hot metal from converters, there is a strict requirement for a stable supply of large quantities of low-cost hot metal to be produced in blast furnaces having increased capacities. Along with the blast furnace capacity expansion, the operating practices presented above and incidental improvements in facilities were achieved. Such expansion of blast furnace capacity has the following merits and demerits in operation and construction of facilities.

(1) Economics of operation

Heat balance in NKK's blast furnaces was reviewed as shown in Fig.13. As is evident from this figure, the heat loss from wall decreases in a larger capacity blast furnace, so that the heat consumption per ton of iron therefore slightly decreases. A larger capacity blast furn-

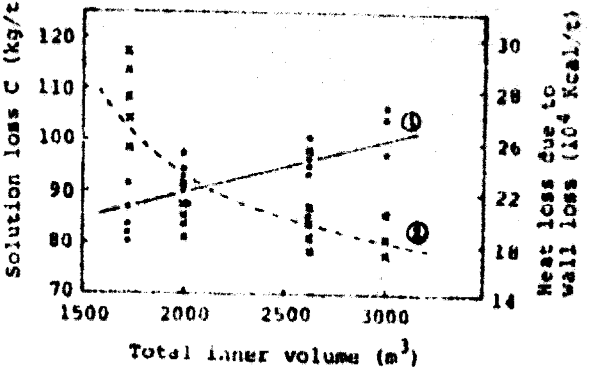


Fig.13 Wall loss and solution loss vs. inner volume

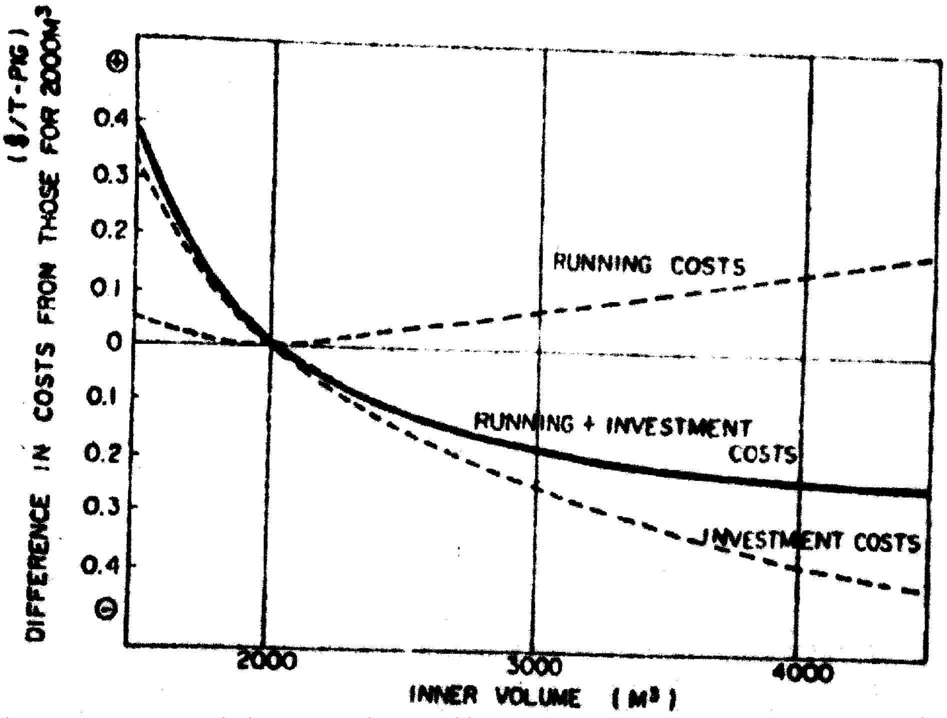


Fig.14 Inner volume of blast furnace and running and investment costs

ace causes increase in solution loss. This is considered attributable to the fact that the furnace height is not so large as to be proportional to the increase in inner volume, thus resulting in a shorter descent time of burden. The labor cost is reduced along with the increase in furnace capacity. However, the operating cost of the blower increases accordingly as high top pressure operation is applied for a stable operation of large-capacity blast furnace. Because the increase in blower operating cost exceeds the decrease in labor cost, the overall operation costs tend to be higher with the increase in furnace capacity, as shown in Fig.14.

(2) Construction cost

The construction cost per ton of iron is inversely proportional to a third power of the inner volume. This results in the decrease in unit depreciation cost, interests and repairing cost, as shown in Fig.14 representing this tendency with an inner volume of 2,000m^3 as reference.

(3) Advantages of large-capacity blast furnace

Comprehensive judgement on factors in operation and facilities indicate that a larger capacity of blast furnace lowers the production cost of hot metal. This advantage, remarkable up to an inner volume of about 2,500m^3, becomes less pronounced over the limit of about 4,000m^3, as is evident from Fig.14.

In deciding the capacity of a blast furnace, it is naturally necessary to consider the production scale of the works, locational conditions, supply of raw materials and capacity balance or energy balance with steelmaking and rolling processes from the point of view of the works as a whole. In addition, close attention should be given to the effect of blast furnace troubles on the subsequent processes and measures to be taken against the production decrease at the next relining.

4.2 Blast furnace capacity and profile

In deciding the size of a blast furnace, the properties of raw materials should be taken into account: in view of the past results in Japan, the following points should be noted.

Along with the increase in blast furnace capacity, the requirements on the burden size and strength have become severer, and improvement and advancement have been from time to time attempted. In designing a large-capacity blast furnace, however, it is necessary to ensure primarily sufficient permeability. For this purpose, the blast furnace capacity was increased by enlarging the hearth diameter and other cross-sectional sizes, not by raising the furnace height too much. Rather, the increase in the pressure drop in the shaft was inhibited by raising the top pressure because of the necessity of compensating the decrease in the ratio of effective cross-sectional area in the lower part of the furnace, and simultaneously, efforts have been made to provide a large difference from the flooding limit at bosh. As shown in Fig.15 representing the relation between the inner volume and furnace height from the stock line to tuyere level, the furnace height is not so high in blast furnaces of 2,000m^3 and larger.

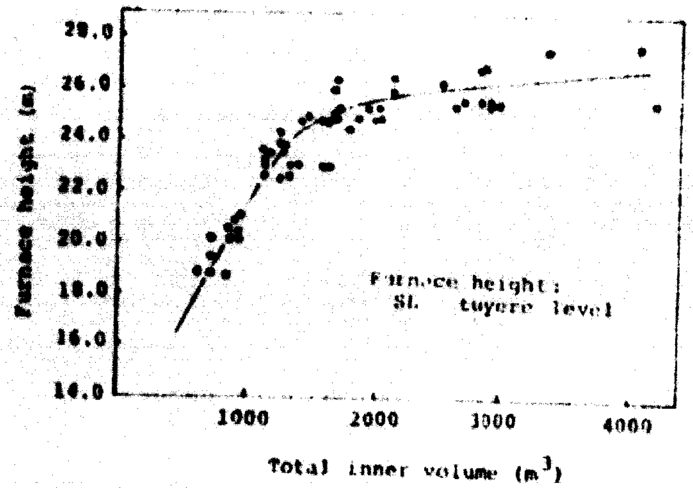


Fig.15 Relation between total inner volume and furnace height

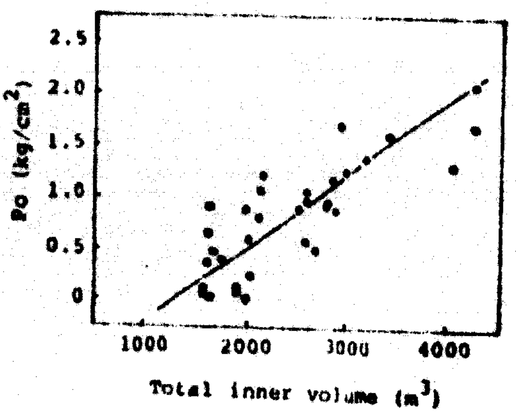


Fig.16 Relation between total inner volume and top pressure

Fig.16 indicates the relation between the inner volume and the top pressure: a larger capacity corresponds to a higher top pressure.

Fig.17 shows the relation between the inner volume and the pressure drop (P-Po) from the tuyere to the furnace top. The pressure drop slightly increases in 2,000 m^3 and larger blast furnaces under the effect of a higher top pressure, and shows a tendency similar to the

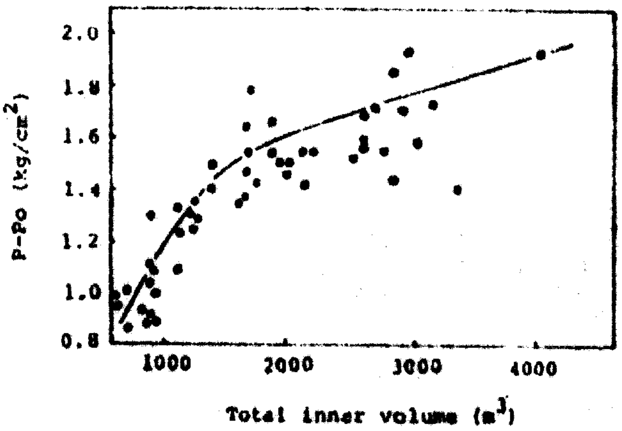


Fig.17 Relation between total inner volume and pressure drop

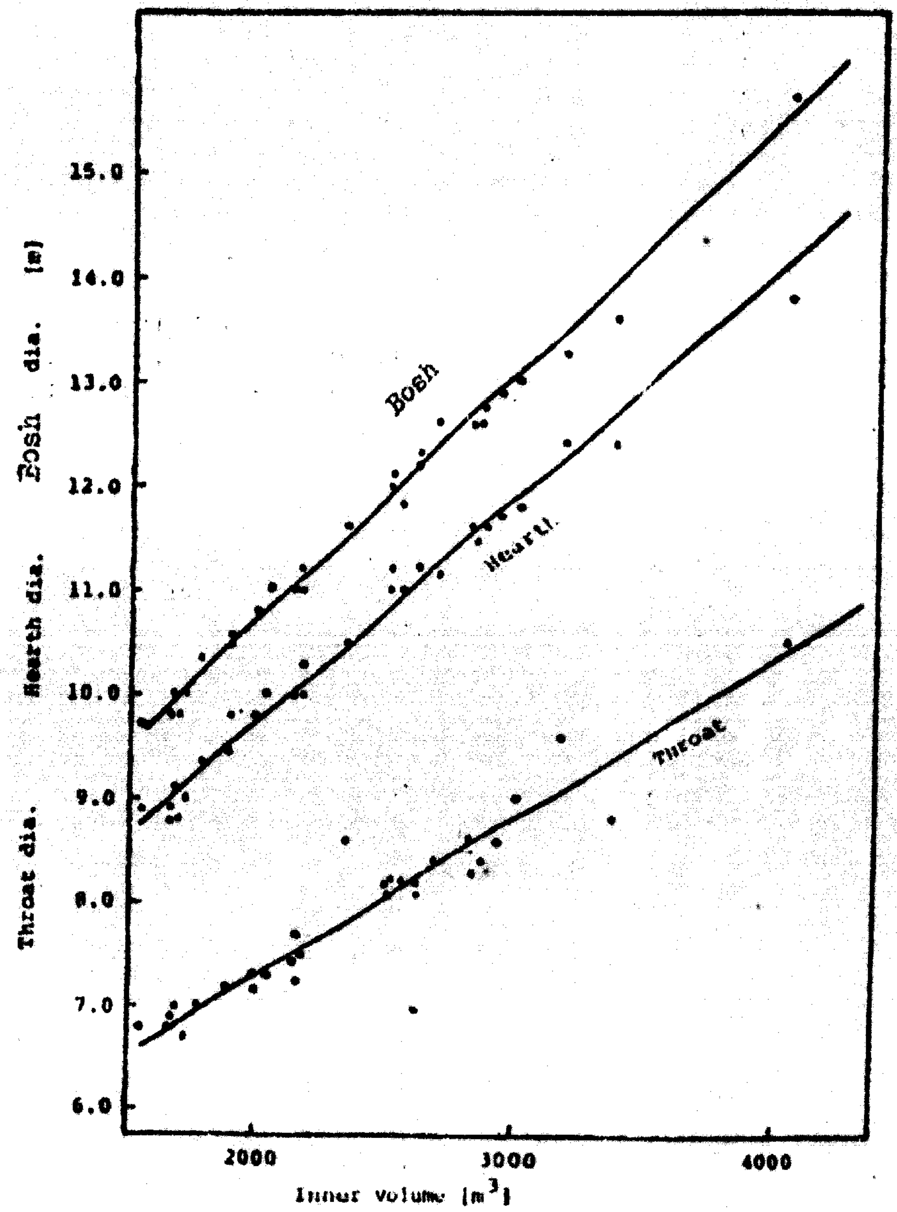


Fig.18

Relation between inner volume and diameter of bosh, hearth, and throat relation with the furnace height given in Fig.15. The relation between the diameter of bosh and throat and the inner volume is represented in Fig. 18. These diameters increase linearly.

For information, profiles of NKK's Mizue No.1 BF (1,728m^3), Fukuyama No.2 BF (2,828m^3) and Fukuyama No.4 BF (4,197m^3) are compared in Fig.19.

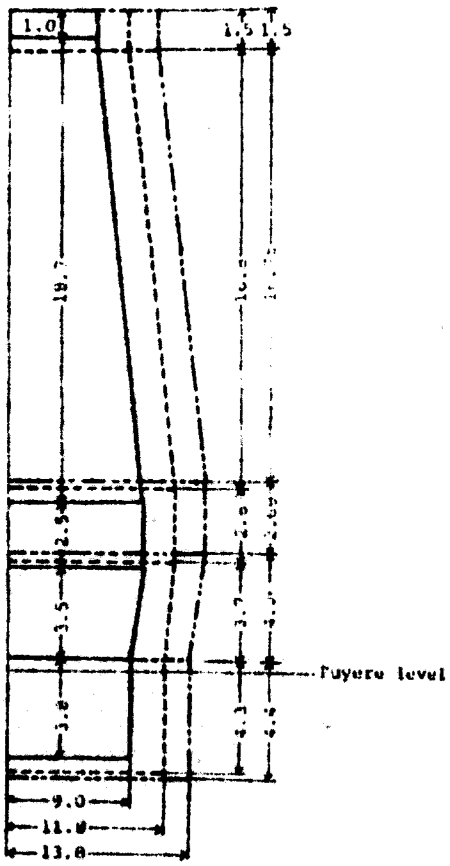


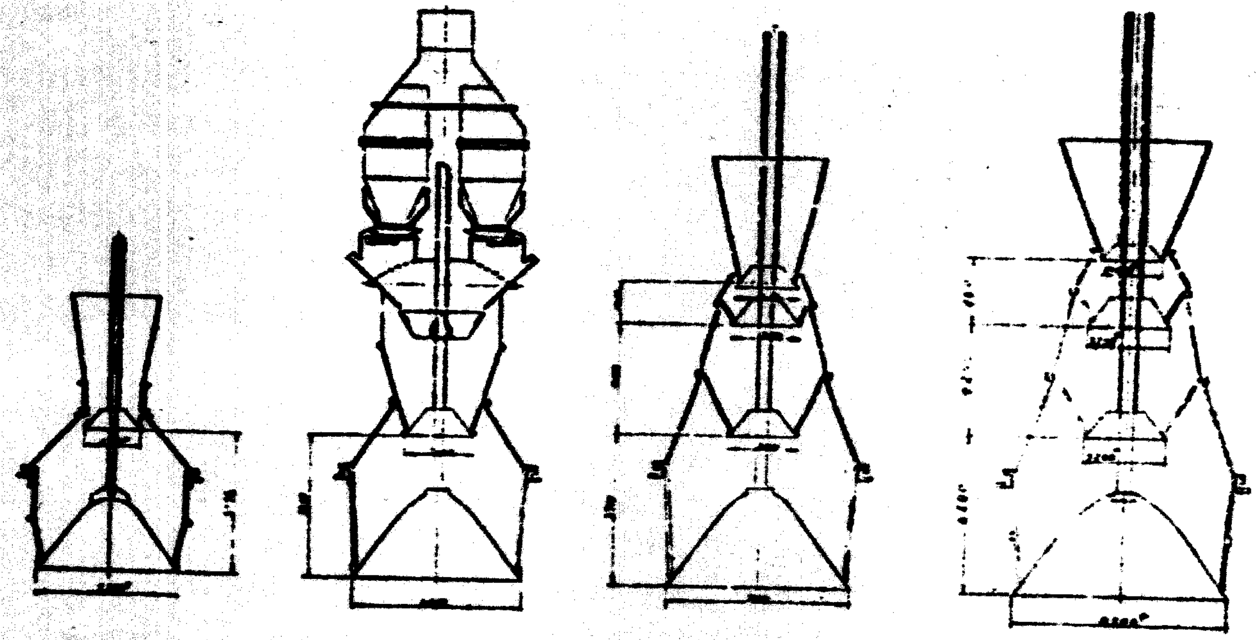
Fig.19 Profile of Fukuyama Nos.2 and 4 BF and Keihin Mizue No.1 BF at NKK

4.3 Charging equipment

In feeding from the raw materials bins, it is desirable to weigh raw materials after passing through a vibrating screen so as to prevent charging of fine ore and coke breeze. Stabilization of the blast furnace heat balance is essential for weighing coke accurately. In recent blast furnaces, coke is automatically charged with fixed bogies so as to feed coke with a constant dry weight through continuous measurement of moisture content.

The object of the top charging equipment is to distribute uniformly the burden raw materials in the furnace, as well as to seal the high pressure top gas. Among various systems for this purpose, there is the 2-bell valve seal type, in which large and small bells give a uniform distribution and a seal valve is used for gas sealing purposes. Since this type still causes non-uniformity in the circumferential direction, the 4-bell type is adopted in NKK's most recent Fukuyama Nos.3 and 4 blast furnaces, in which the middle and small bells ensure gas tightness, and a rotating bell provided above these middle and small bells ensures uniformity of burden in the circumferential direction. In this type, the large bell serves chiefly to keep an appropriate burden distribution in the furnace and is used throughout a campaign without changing, whereas the middle and small bells are changed at intervals of 15 - 20 and 9 - 12 hrs every 3 - 5 million tons of production. These types are in service in NKK's Fukuyama Works as shown in Fig.20.

With regard to the radial distribution in the furnace, measures taken included the proper selection of distance between the wall of throat and the large bell and change of ore-coke charging sequence and coke base in accordance with the



	No.1 BF	No.2 BF	No.3 BF	No.4 BF
Top pressure [kg/cm^2]	1.0	1.5	2.0	2.5
Hearth dia. [m]	9.8	11.2	11.8	13.8
Inner vol. [m^3]	2004	2626	3016	4197

Fig.20 Comparison of charging equipment at Fukuyama

operating conditions of the furnace. In a large capacity furnace, in which it is impossible to control sufficiently the radial distribution, the installation of movable armors is necessary. Among various conventional types of movable armor providing respective merits and demerits, the NKK system, based on horizontally movable armors by oil hydraulic drive, gives a very slight head from the large bell to the stock line, and ensures smooth actuation. It is furthermore characterized by the possibility of repairing and changing from outside safely and easily, and is giving satisfactory results.

In an attempt to achieve two functions of uniform circumferential distribution by the large bell and radial distribution control by movable armor in a single equipment, the bell-less charging equipment was recently developed, in which a rotary chute was provided in place of the large bell and the angle of inclination of this chute was adjustable. The new type has already been applied in practice in a blast furnace in Europe, and its application to larger furnaces will be increasingly studied in the future.

4.4 Casthouse arrangement

Treatment of hot metal and slag in large quantities is an important problem in a large-capacity blast furnace. Practice in this respect has changed from the provision of two tapholes for a casthouse into the installation of two casthouses, each of them with one or two tapholes. In NKK's Fukuyama blast furnaces having three tapholes for a daily production of 10,000 tons, a tapping speed of 8 tons/min is maintained, partly owing to the high blast pressure of 4kg/cm^2, and tapholes tap hot metal for 2 hrs. and then are closed for 4 hrs. The present practice is believed to be sufficient also for repairing the runners in front of the tapholes. Various modifications have been made to the runner arrangement and discharge port to hot metal ladles, and the tilting runner has become widely used.

Among various maintenance operations, particular attention has been paid to runner repairs. In addition to a large crane of about 30 tons, a swinging travelling jib crane of about 50 tons is arranged to facilitate runner changing and also to speed up gun repairs and other shop operations.

Measures are taken to prevent fume from the tapholes, hot metal runner and discharge port to hot metal ladle for the improvement of work environment and prevention of air pollution by fume and dust.

4.5 Maintenance of blast furnace facilities

A large-capacity blast furnace is operated under various severe conditions such as charging of large quantities of raw materials, treatment of much hot metal and slag, and high top pressure. Moreover, the production loss at the time of trouble or relining is also very large. Equipment should therefore have a high reliability.

For this purpose, various improvements have been made to the design of the blast furnace proper, cooling system, charging equipment, hot stoves and gas cleaning equipment. As to the arrangement and construction of these facilities, devices are incorporated so as to permit easy and rapid inspection and repair.

Tuyere with double cooling passages are now employed to raise the velocity of cooling water at the nose and to minimize burn-out so that any failure is not too serious. Various new methods for detecting breakout have been devised. Reduction of time and mechanization in broken tuyere changing operations are being encouraged.

Mesures are also being taken to select bricks, runner materials, and other refractories of a long life in conformity to various requirements.

5. Operating results

Recent operating results of Nippon Kokan's Fukuyama Works are indicated in Table 1, as an example of a large-capacity blast furnace.

Fukuyama No.4 BF, brought into operation in April 1970, had a daily average production of 10,017 tons in November 1970. The slump experienced in Japan in 1970 - 1972 obliged NKK to limit the production, but after the recovery of market condition in the latter half of 1972, the production was again increased.

6. Trends in ironmaking technology

The progress of ironmaking technology during the past fifteen years in Japan and the results achieved in this period have been surveyed. In conclusion, the following measures have been taken in various fields, such as raw materials, operations and facilities, with a view to stabilizing blast-furnace operations from the point of view of technology and economics. Combination of these efforts can produce more remarkable achievements than a simple accumulation of individual effects.

(1) Adequate preparation of raw materials, especially the assurance of supply of high-quality sinter.

(2) Stable supply of high-quality coke.

(3) Fuel injection, which has lowered the coke rate and controlled the furnace heat, thus stabilizing operations.

(4) Installation of superior blast furnaces and ancillary facilities based on the most modern techniques.

(5) Improvement of maintenance practices of equipment and measures against troubles, and reduction of off-blast time.

(6) Application of the most advanced control technology to stabilize operations and minimize troubles.

(7) Improvements in treatment and control of large quantities of hot metal and slag.

In large-scale works directed towards a greater degree of mass-production, the superiority of large-capacity blast furnace has been recognized in technology as well as in economics, supported by these technical innovations. In consequence, even in the existing works, smaller furnaces are being replaced by large-capacity ones, and simultaneously, there is an active move toward satisfying the requirements for mechanization and pollution control.

However, the uncertain supply of good coking coals and the price increase resulting therefrom will be problematic in the future because of the exhaustion of resources. To cope with these future problems, research and development efforts are being made on the utilization of light-coking coals by formed coke process, further reduction of fuel cost by charging of prereduced pellets and injection of heated reducing gas into the lower part of shaft. Tests are being carried out in operating blast furnaces, and great hope is placed on the future progress of these efforts.

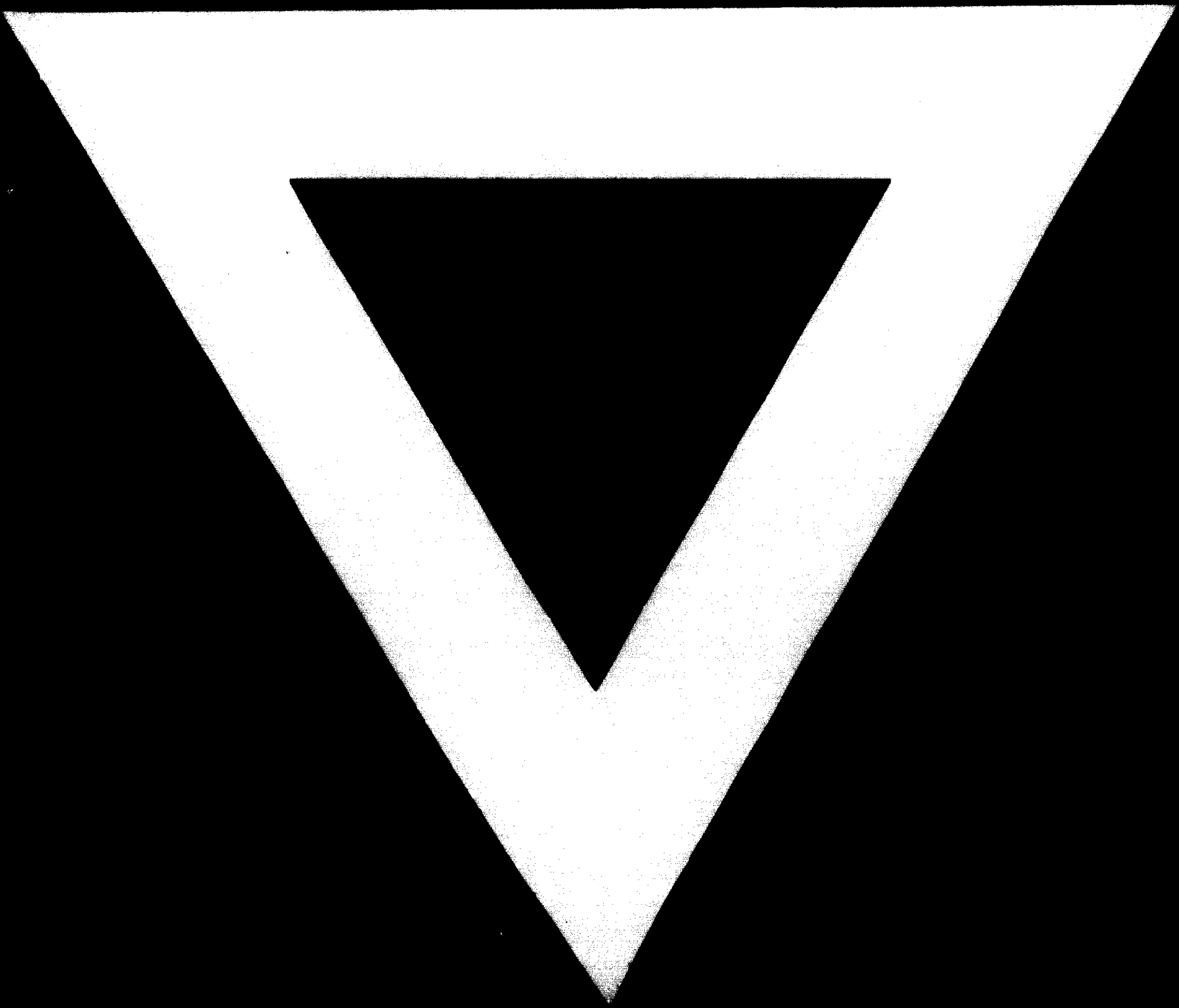
Table 1 Operating results of Fukuyama blast furnaces
(Monthly results during a year following the blowing-in)

	1BF	2BF	3BF	*4BF	**4BF
Blowing-in	Aug.26,'66	Feb.15,'68	Jul.25,'69	Apr.26,'71	
Inner volume, m^3	2,004	2,626	3,016	4,197	
Hearth dia., m	9.8	11.2	11.8	13.8	
Production, t/D	4,639	6,064	6,834	10,017	10,119
Productivity,$t/D/m^3$	2.32	2.31	2.27	2.39	2.41
Coke rate, kg/t	469	469	465	437	403
Oil rate, "	34	26	40	52	64
Fuel rate, "	503	495	505	489	467
Sinter ratio, %	70	64	76	80	73
Slag ratio, kg/t	253	260	274	290	282
Blast vol.,Nm^3/min	4,073	5,309	5,842	7,722	7,240
Blast pressure,kg/cm^2	2.24	2.61	2.93	3.61	3.49
Top pressure,	0.59	0.99	1.36	2.10	2.20
Blast temp., °C	1,112	1,146	1,159	1,200	1,190
Oxygen enrich., %	0	0	0.6	1.4	2.3
Si in pig, %	0.71	0.69	0.66	0.71	0.64
S in pig, "	0.038	0.037	0.038	0.032	0.033
Slag basicity, CaO/SiO_2	1.23	1.17	1.16	1.13	1.18
Ash in coke, %	9.2	9.1	10.6	10.5	9.90
Coke strength,DI^{30}_{15}***	92.4	93.2	91.8	92.0	93.0

* Monthly results during seven months after blowing-in

** Recent results as of December 1972

*** Test method: JIS K2151-1972



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