(1) Recovered gas

Process	Gas composition						Calorific value (kcal/Nm^3)	Amount generated (Nm^3/t-coal)
	H_2	CH_4	CO	CO_2	C_mH_n	N_2		
Formed coke	58.5	20.5	8.9	1.5	1.0	9.6	3672	364
Conventional coke	57.2	29.0	5.8	1.2	4.6	2.2	4800	300

(2) Tar

Process	Specific gravity (15/4°C)	T.I. (%,wt)	Elemental analysis (%,d)					fa
			C	H	N	S	O	
Formed coke	1.135	0.64	89.4	6.5	1.8	0.5	1.8	0.80
Conventional coke	1.170	5.40	90.8	5.0	0.8	0.5	2.9	0.92

Table 2. Properties of recovered gas and tar.

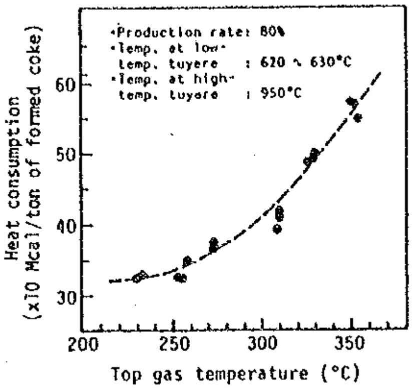

Figure 11. Relation between top gas temperature and heat consumption.

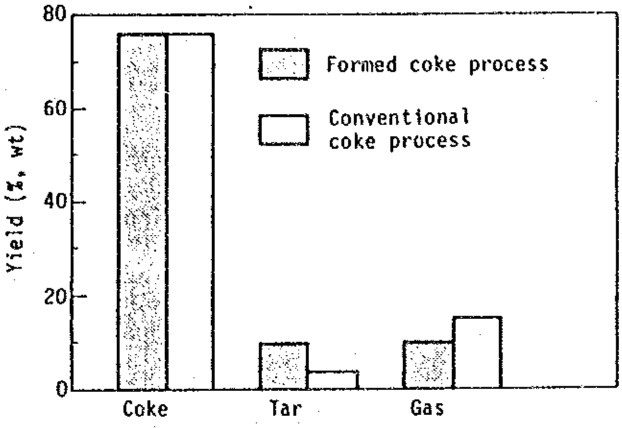

Figure 10. Comparison of fomed coke process with conventional coke process in product yield.

The actual heat consumption in the carbonizing process of the pilot plant is shown in relation to the top gas temperature in **Figure 11**. The heat consumed for carbonization markedly decreased with decreasing top gas temperature and was about 400 Mcal per ton of briquettes when the top gas temperature was about 300°C. Most of this heat is lost in the form of sensible heat of top gas as shown in Figure 12. To recover and utilize the sensible heat of the top gas, a technique was developed for cooling the top gas with the tar generated in the carbonizing process.

Blast-Furnace Test of Formed Coke

Production of Blast-Furnace Test Samples. The target properties of formed coke were established as shown below, on condition that the strength and ash content should be equivalent to those of coke made by the conventional chamber oven process.

$$DI^{150}_{15} = 83 \pm 0.5$$
$$CSR = 57 \pm 2$$
$$Ash < 12\%$$

Formed coke samples were produced over a long period of 15 months, as mentioned earlier. The formed coke produced for the test purpose was stockpiled under cover at a coke yard to prevent moisture increase and fluctuation due to rainfall.

Results of Blast-Furnace Test. The formed coke was tested in Tobata No. 4 blast furnace (inner volume of 4.250 m^3) at Yawata Works, mainly to use it in a large blast furnace for a long period. The test was run from August 1986 to January 1987 as shown in **Figure 13**. The formed coke was continuously used in 20% of the coke charge (30% in some portions) for 74 days. The test performance verified that the formed coke can be used in an actual blast furnace in the same way as coke made by the chamber oven process. Investigation of coke samples taken from the tuyeres indicated that the formed coke is not different from the conventional coke in particle size change in the blast furnace as shown in **Figure 14**. It was also clarified from the observation of the tuyere coke samples that the formed coke retains the original shape down to the tuyere level.

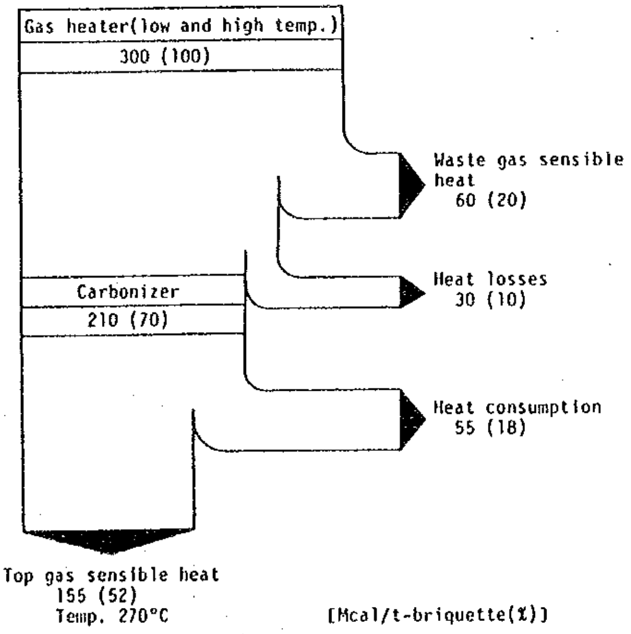

Figure 12. Heat balance in the carbonizing process of the pilot plant.

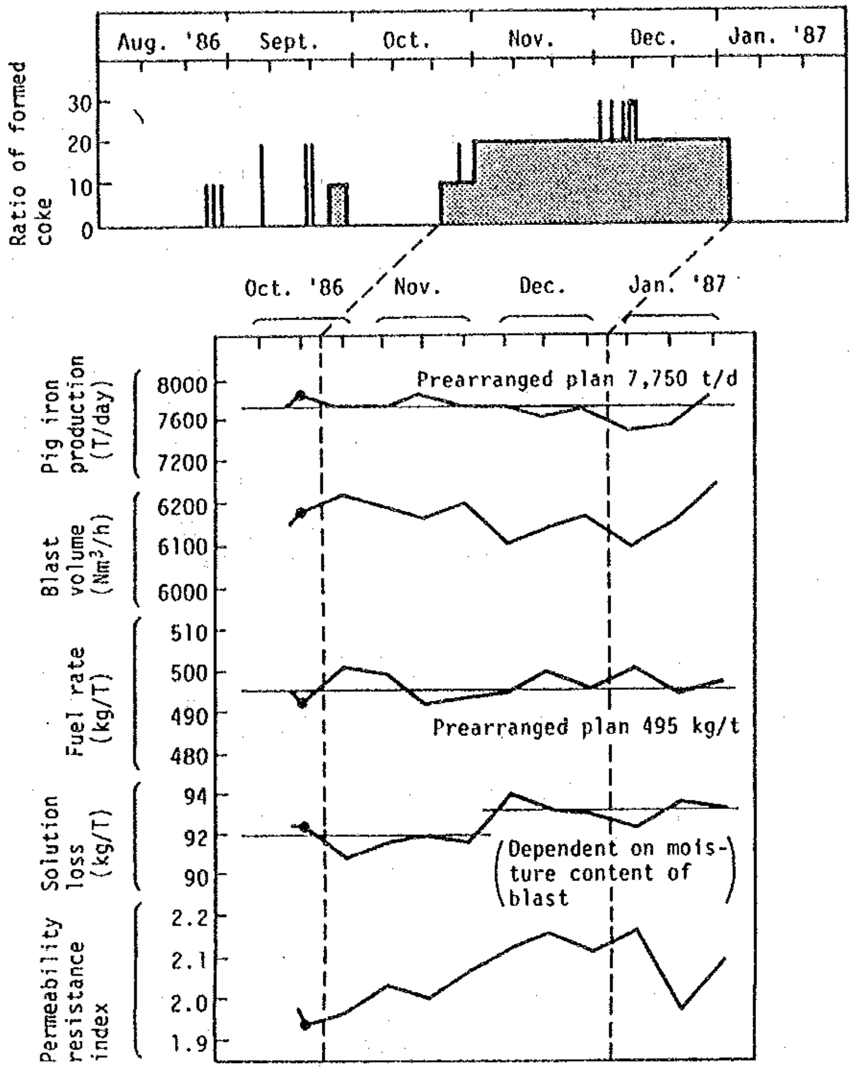

Figure 13. Schedule for testing of formed coke in blast furnace and transitions of operating conditions.

6. Economics of Formed Coke Process

Preconditions for Evaluation of Economics. The feasibility study of the new formed coke process was conducted on a 3,000-t/d commercial plant. The briquetting process of the commercial plant is basically the same as that of the pilot plant. The top gas sensible heat recovery method was adopted in the carbonizing process as shown in **Figure 15.** To avoid technical problems associated with scale-up, the length of the carbonizer was made three times as large as that of the carbonizer of the pilot plant, as described previously. The construction of the carbonizing equipment is schematically illustrated in **Figure 16.** The layout of the 3,000-t/d commercial plant is shown in **Figure 17.**

Economics of the Commercial Plant. The equipment cost and production cost of the formed coke process are compared with those of the conventional chamber oven process in **Figure 18.** It was found that the equipment cost of the formed coke process can be 15% lower than that of the conventional process. The production cost of formed coke depends on the properties of coal used and the price difference between coking coal and noncoking coal. Based on the present price difference (100 for coking coal against 77 for noncoking coal), the production cost of the formed coke process is about 15% lower than that of the chamber oven process.

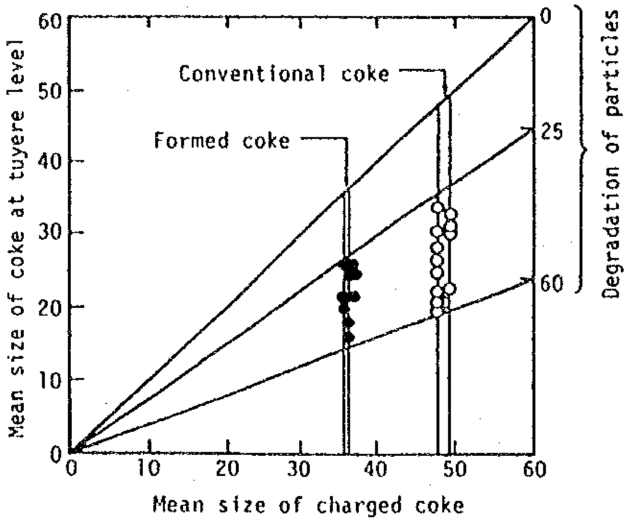

Figure 14. Degradation of particles at blast furnace tuyere.

7. Conclusions

A new formed coke process was established after the test operation of a 200-t/d pilot plant. The formed coke process can use large quantities of noncoking coal as main raw material and can drastically solve the problem of coal resources in the manufacture of blast furnace coke. It can also resolve the problems of the conventional chamber oven process, such as environmental control, automation and labor saving. The new formed coke process can be immediately designed, constructed and operated as a commercial plant, because there are no problems associated with the scale-up of the carbonizer.

Summary

A new formed coke process was developed for the main purposes of using large quantities of noncoking coal and assuring continuous carbonization in the manufacture of blast

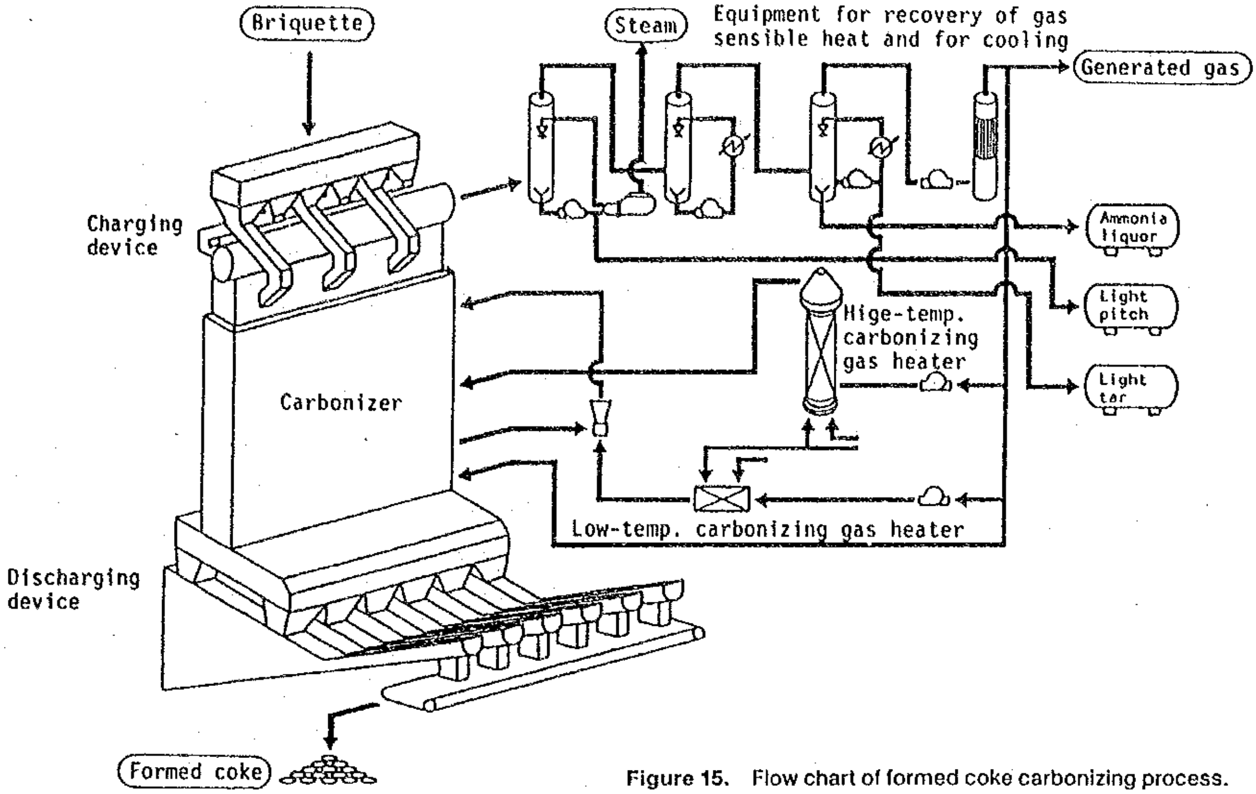

Figure 15. Flow chart of formed coke carbonizing process.

Figure 16. See page 48.

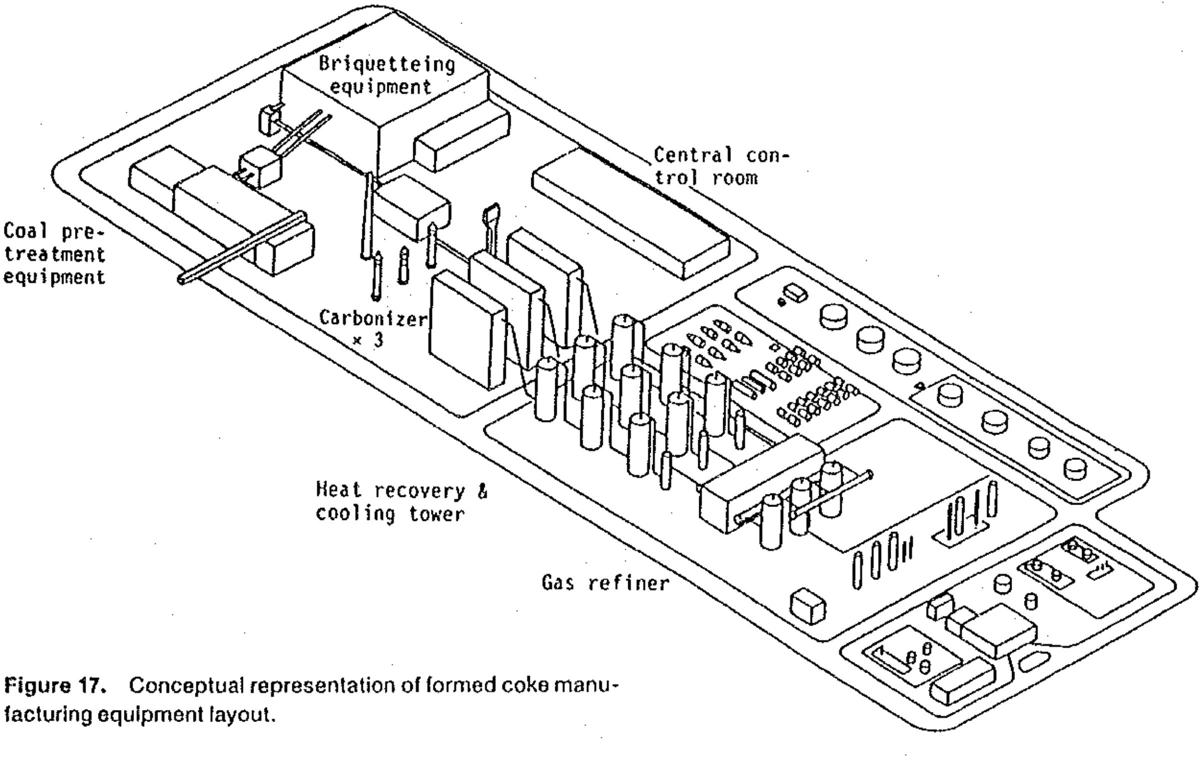

Figure 17. Conceptual representation of formed coke manufacturing equipment layout.

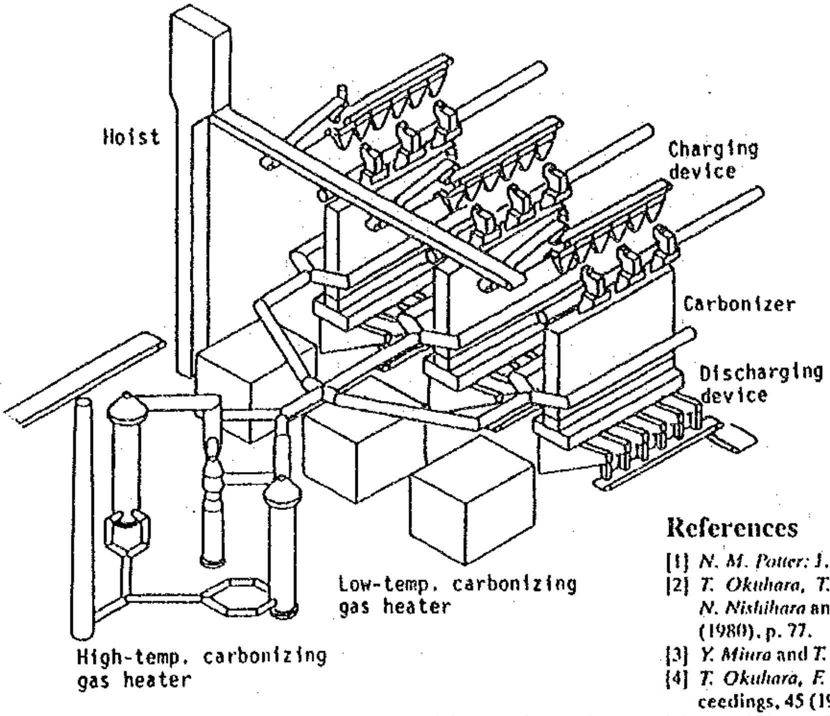

Figure 16. Conceptual diagram of carbonizing equipment.

furnace coke. The formed coke process continuously carbonizes cold briquettes in a shaft furnace of original design. A pilot plant capable of producing 200 tons of formed coke per day was constructed. After three years of test operation and production of 93.000 tons of formed coke, commercial production techniques were established for the formed coke process.

The formed coke process can use noncoking coal in the range of 65 to 100% of the coal blend and produce blast furnace coke of the same quality as produced by the conventional chamber oven process. The carbonizing equipment is all automated and is easy to shut down and restart.

The formed coke produced from the pilot plant was tested in a large blast furnace with an inner volume of 4.250 m^3. After the formed coke was tested with a blending ratio of 20% in the coke charge for a continuous period of 74 days, it was verified that the formed coke can be used in the same way as coke made by the conventional process.

A feasibility study was conducted on a 3.000-t/d commercial plant and the economics of the formed coke process were evaluated. It was found that the formed coke process can reduce both the equipment cost and production cost by 15% as compared with the chamber oven process. The formed coke process can be immediately designed, constructed and operated as a commercial plant, because it involves no technical problems with the scale-up of the carbonizer.

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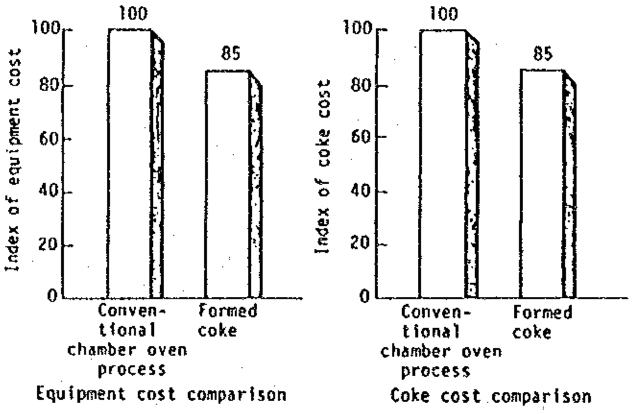

Figure 18. Economical specification of the formed coke process.

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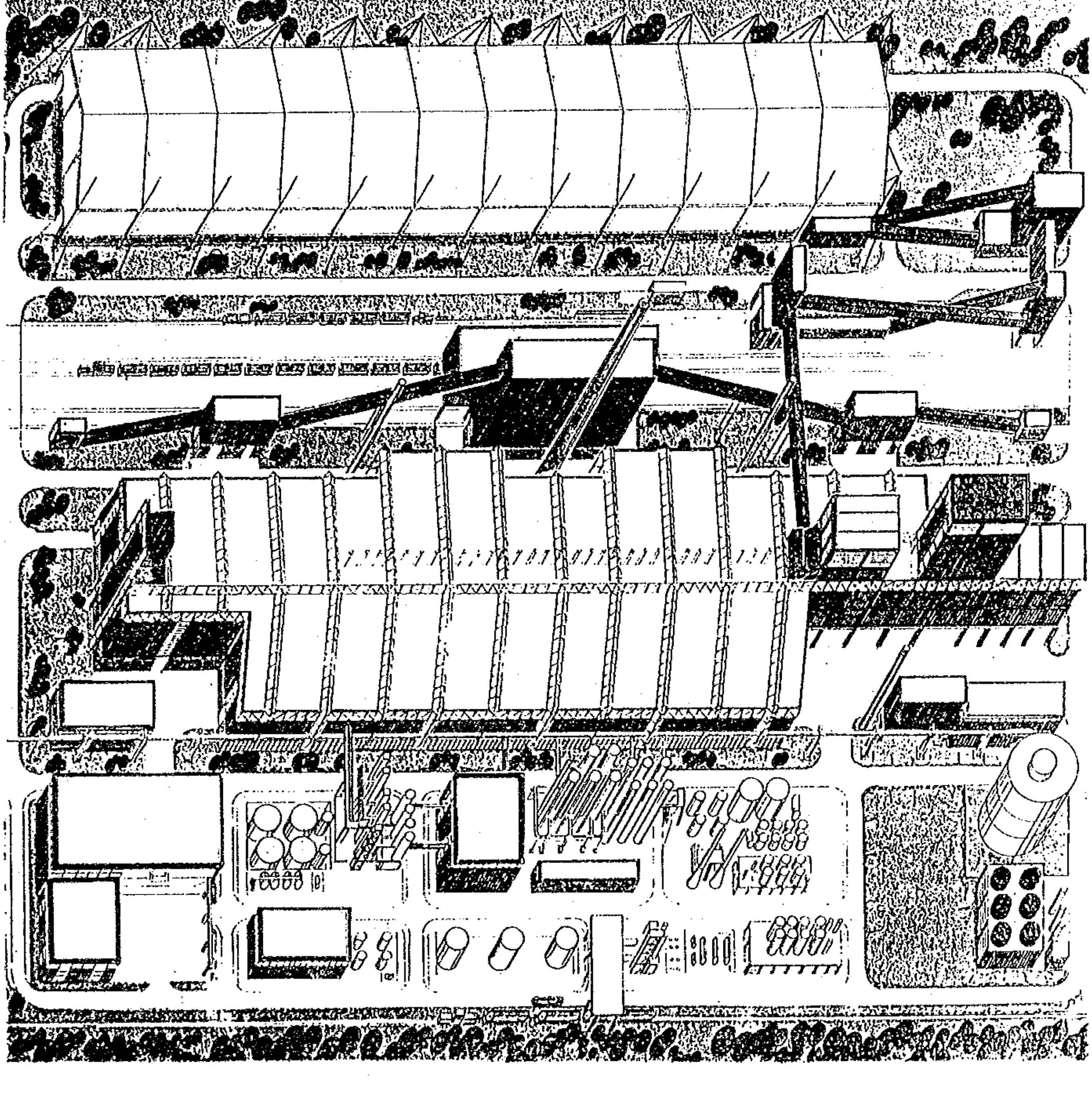

Information 3

S.Kubo, et al.,
"Result of the Test with Formed Coke at Tobata No.4 Blust Furnace",
1990 Ironmaking Conference Processing p405–p412

RESULT OF THE TEST OPERATION WITH FORMED COKE AT TOBATA No.4 BLAST FURNACE

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INTRODUCTION

Research and development have been pursued using a formed coke pilot plant with a production capacity of 200 t/day to develop methods of manufacturing formed coke for blast furnaces. In the final stage of the research, a test was conducted on the use of formed coke in a blast furnace using the Tobata No.4 BF (inner volume: 4,250 m^3) where approximately 61,000 tons of formed coke were used from August 1986 to January 1987. This test, which was primarily intended for the long-period stable use of formed coke in a blast furnace, was conducted charging 20 to 30 % formed coke into the peripheral zone of the blast furnace. During the test period, the behaviour of formed coke in the furnace was investigated by sampling using various samplers.

Also, as an additional test for investigating the behaviour of formed coke in the central zone of the furnace, formed coke was charged into the central zone of the same Tobata No.4 BF just before its blow-out in December 1988, and the coke in the furnace was scraped out after the completion of cooling. A comparative study was made of the properties of the formed coke with those of conventional coke.
The results of these tests are reported below.

FORMED COKE PLANT OPERATIONAL RESULTS

The first test operation of the formed coke plant was started in June 1984, and nine test operations were conducted over a total period of about 580 days, with the last one ending in December 1986. Table I shows the transition of the quality of formed coke produced during the test operation period. Approximately 61,000 tons of formed coke for trial use in a blast furnace were produced during the period from the beginning of the fifth operation in May 1985 to the end of the eighth operation in July 1986 and the coke was used in the Tobata No.4 BF after being stored.

Table II shows the properties of the formed coke and conventional coke trial-used in the furnace. Since a large amount of steam coal is used in producing formed coke, formed coke has a high reactivity with the CO_2 gas. Furthermore, the surface of particles is smooth, the repose angle is low compared with conventional coke, and the porosity is low. The formed coke used in this test has somewhat small particle sizes.

RESULTS OF THE TEST USE OF FORMED COKE IN THE BLAST FURNACE

The formed coke was tested in the Tobata No.4 BF. In this test, the coke behaviour in the furnace was analyzed using a rigid vertical probe, belly sampler and tuyere sampler. In using formed coke, long-period stable use at a blending ratio of 20 % was aimed at, and as shown in Fig. 1, the formed coke was charged into the peripheral zone of the furnace with burden distribution controlled. The movable armor notch used in the test was used with a 5-batch charging based on $CN_5CF_0CN_4O_4O_4$.
(CN: Conventional coke, CF: Formed coke)

Fig. 2 shows the results of the formed coke charging test at the Tobata No.4 BF and the transition of the test operation. A systematic short-period search test was started in August 1986 to study the effect of formed coke charging on burden distribution and gas flow distribution. After this test, another continuous charging test was conducted for 74 days from October 22, 1986 to January 3, 1987.

Because the blast volume was kept almost constant at 6,100 to 6,200 Nm^3/min, the production was almost constant at 7,500 t/day.

The carbon solution began to increase in December. This is because during the test period, daily heat adjustments were made according to the amount of pulverized coal injected, blast temperature and blast moisture to keep a stable furnace condition, with the result that the flame temperature Tf rose from 2,140° to 2,220°C.

The K-value indicating the gas flow resistance increased gradually after the use of the formed coke, showing an increase of about 10 % maximum and of about 4 % on average.
This was due to the small particle sizes of the formed coke and the increase in the gas flow resistance was almost as calculated. The worsening of burden descent was not observed in this period.

During this period, the furnace operation became stable proving that the long-period continuous use of formed coke is possible.

BEHAVIOUR OF FORMED COKE IN THE FURNACE

Investigation was conducted using the rigid vertical probe, belly sampler and tuyere sampler in order to visualize the coke properties in the furnace.

Fig. 3 shows the sensors installed in the Tobata No.4 BF, including those newly developed for this test.

The radial formed coke distribution was measured using a mechanical profile meter at the furnace top, a belly probe and core probe. From the results of the measurement with the profile meter shown in Fig. 4, it is evident that formed coke accumulates in the peripheral zone of the furnace. As shown in Fig. 5, the belly probe samples the burden at three points between the wall and the centre using a pipe of 48 mm in inside diameter inserted by a hydraulic driving device. Most of the formed coke is present near the peripheral zone of the furnace. As shown in Fig. 6, illustrating the core probe, a pipe of about 200 mm in outside diameter is driven to the furnace centre using an air motor and a pneumatic hammer, and coke is sampled. The inside of the pipe is separated into 9 chambers by partitions and nine openings 300 mm x 90 mm are made in the top surface of the pipe at intervals of 300 mm in the longitudinal direction. A cover with holes of similar size is fitted over the pipe. By shifting this cover 300 mm, sampling can be carried out by coke falling into the pipe. The greatest advantage of this sampling method is that the coke sampling position is clear and that the deformation of coke during sampling can be held to a minimum. Results of the sampling reveal that a little more than 20 % of the formed coke is present near the periphery of the furnace and that about 10 % of the formed coke is distributed in the zone between the furnace centre and the middle of the radius of the furnace.

A rigid vertical probe containing coke was inserted in the furnace to investigate the changes of the coke properties in the direction of furnace height. The rigid vertical probe is a water-cooled pipe 100 mm in outside diameter. The tip of the probe can be inserted to 21 m below the stockline (the bottom end of the belly) through one of the insertion holes for sounding devices. As is apparent from Fig. 7, the tip of the probe is provided with a moving sample basket. Sample coke is put in this basket, which descends in the furnace together with the burden. When the basket has reached a predetermined position, it is immediately pulled up and the sample is recovered. Two samples of conventional coke and two samples of formed coke were placed in the same basket for comparison.

Fig. 8 shows the investigation results. The estimation results show that although the conventional coke and formed coke are almost the same in strength entire part from the furnace top to the belly, at the tuyere level the conventional coke shows a general decrease and large variation in strength. The K_2O content of the formed coke increases with increasing descending depth, but in the high-temperature part no difference is observed between the conventional coke and formed coke.

Since the formed coke is made with a high non-coking coal ratio, the JIS reactivity is higher than that of conventional coke before charging. However, the JIS reactivity approaches the same level with the increase in descending depth. The JIS reactivity of coke generally increases with increasing K_2O content, as shown in Fig. 9. This tendency is particularly strong in the case of the conventional coke. As it descends in the furnace, the conventional coke absorbs alkalis and its reactivity is accelerated. In relatively low-temperature zones it becomes almost the same in reactivity as the formed coke at the belly level. This is the probable reason why conventional coke and formed coke show nearly the same strength.

This reason may be explained as follows: Since formed coke has a high non-coking coal ratio as a raw material, the JIS reactivity that indicates the reactivity characteristic of the matrix shows higher values than conventional coke before charging. As shown in Figs. 8 and 9, however, formed coke shows only small increases in the JIS reactivity even after descending in the furnace. In the case of conventional coke, the JIS reactivity increases with increasing descending depth in the furnace, becoming close to the values of the formed coke at the belly level. In other words, conventional coke that has lower reactivity in the matrix than formed coke absorbs alkalis in relatively low-temperature zones during the descent, and its reactivity is accelerated partly due to a higher porosity than in formed coke, with the result that the reactivity and weight loss of conventional coke are almost the same as those of the formed coke at the belly level. It is thought that this results in almost the same strength of both cokes.

Next, the way of reaction of coke with gases is considered.

To compare the reaction in all of the coke with that in the core part, the porosities before and after a Roga test were measured and microporosities under 150 µm of coke pulverized from 840 to 1,680 µm were also measured. Fig. 10 shows the relation between the porosity and the coke temperature. Incidentally, the coke temperature was determined from the graphitization rate. As shown in the graph, the porosity after the Roga test decreases in both the formed coke and the conventional coke, suggesting that the reaction in the surface layer begins at temperatures above 1,000°C. As is apparent from the bottom graph, the microporosity of conventional coke increases by about 10 % at 1,000°C, whereas there is no change in the formed coke. The middle graph shows that the porosity of both cokes before and after the Roga test is almost constant at 1,000°C. From the above, it can be judged that since the reactivity of the matrix of conventional coke is low and the amount of alkalis absorbed is small, the gases in the furnace infiltrate into the interior of the coke, thereby increasing the microporosity, whereas in the case of formed coke, the reaction begins on the surface due to the high reactivity of the matrix and the microporosity is kept constant.

Fig. 11 shows the transition of the direct reduction rate at 1,000°C (corresponding to the bottom of the thermal reserve zone) which was calculated from gas compositions measured with the flexible vertical probe.

Reduction rate and Direct reduction rate are calculated as follows.

Assuming that all oxygen in the ore is reduced and measured at the top of the furnace.

$$\text{Reduction rate} = 1 - \frac{\text{Reduced oxygen at measuring point}}{\text{Reduced oxygen at top}}$$

where reduced oxygen is calculated from N_2 balance

$$\text{Direct reduction rate} = \frac{\begin{pmatrix}\text{Direct}\\ \text{reduced}\\ \text{oxygen at}\\ \text{top}\end{pmatrix} - \begin{pmatrix}\text{Direct}\\ \text{reduced}\\ \text{oxygen at}\\ \text{measuring}\\ \text{point}\end{pmatrix}}{\text{Reduced oxygen at top}}$$

Throughout the test period, direct reduction scarcely occurred at 1,000°C. This suggests that direct reduction scarcely occurs at 1,000°C in the lumpy zone (at temperatures of 1,000°C or less) although the formed coke provides high reactivity.

Fig. 12 shows the changes in the mean size of the conventional coke and formed coke obtained by the core probe on November 6 and December 15 of 1986. The mean size of the both kinds of coke shows decreases in the range from 25 to 65 % and there is no special difference between them. It is evident from this fact also that formed coke does not undergo selective reaction or wear.

Fig. 13 shows typical examples of changes in the fine coke ratio, mean size and coke strength in the radial direction at the tuyere level. After the removal of the slag mixed in the coke breeze, the breeze arising from the formed coke and that from the conventional coke were separated by liquid a hydrometer. Although the fine coke ratio tended to increase toward the furnace centre with both cokes, there was no difference between the formed coke and the conventional coke. The radial change in the mean size tended to decrease toward the furnace centre. It seems that there is no clear tendency in the radial change in strength.

Fig. 14 shows the results of measurement of gas composition using a raceway probe inserted into the raceway during operation. As shown in this figure, the oxygen content of both cokes is nearly zero at a distance of 1.0 m from the tuyere nose. This fact suggests that the combustibility of the formed coke at the raceway is the same as that of conventional coke.

FORMED COKE CENTRAL CHARGING TEST

For the purpose of investigating the behaviour of formed coke in the central zone of the furnace, formed coke was charged into the central zone of the Tobata No.4 BF immediately before blowout in December 1988, and the properties of the coke scraped out of the furnace after cooling were studied by comparison with those of conventional coke.

For the method of formed coke charging, 5 tons of formed coke was charged into the central zone for each charge of 30.5 tons by the movable armor five days before the blowout, and a total of 420 tons at a ratio of 50 % was charged two days before the blowout.

After the blowout, nitrogen cooling was performed. After cooling, the coke was first scraped out from all the tuyeres (approximately 410 tons) and then the coke in the central zone was scraped out from the bottom. For the method of sample preparation for the total furnace contents of approximately 1,100 tons, the portion scraped out from the central zone was subjected to sampling, as shown in Fig. 15. After removing the cohered matter and slag, approximately 170 tons of coke was screened for the total sample. For about each 20 tons of the 45 mm to 15 mm size, both formed coke and conventional coke were sampled simultaneously (Sample A). About 6 tons were sampled and reduced as a partial sample (Sample B). The two kinds of samples thus prepared were subjected to property investigation by chemical analysis and other means.

In taking the samples, the formed coke remained nearly in the original form, although some was lost in the +15 mm range, and was in a state permitting easy recognition from conventional coke.

Tables III and IV show the analytical results for both samples of the coke's chemical composition. In Sample A, the mean values of five samples taken at different positions were adopted for both formed coke and conventional coke, and the sample size was 25 mm to 30 mm. In Sample B, the values are the analytical results of the 50 - 15 mm size range of the reduced sample which was divided into four size ranges for both formed coke and conventional coke. The analytical results show that regarding the properties of the formed coke in the central zone, no conspicuous increase in ash content of the coke was noticed, suggesting that deterioration did not progress greatly as compared with conventional coke.

SUMMARY

The behaviour of the formed coke and conventional coke in the furnace was examined based on the results of the investigation of the properties of coke samples taken from the furnace using the rigid vertical probe, belly probe and core probe. As a result, the following results were obtained:

(1) When the three-batch coke charging pattern is adopted, the formed coke segregates near the periphery of the furnace and descends in this condition in the furnace.

(2) Conventional coke absorbs alkalis during the descent in the furnace and its reactivity increases, resulting in an increase in the coke weight loss. On the other hand, formed coke has essentially high reactivity and is less susceptible to the influence of alkalis. As a result, both cokes show the same coke weight loss at the belly level.

(3) Conventional coke and formed coke provide the same coke strength in all zones from the furnace top to the belly. At the tuyere level, however, the formed coke keeps its strength, whereas the conventional coke shows a decrease in strength on the whole and a large fluctuation.

(4) The reason for this seems to be that the gases in the furnace infiltrate the interior of the conventional coke due to the low reactivity of the matrix, resulting in an increase in the porosity, whereas in the case of the formed coke, the reaction occurs on the surface due to the high reactivity of the matrix and the porosity is kept constant.

(5) The results of the formed coke central charging test conducted as an additional test also showed less progress of deterioration compared with conventional coke.

CONCLUSION

The results of a series of formed coke charging tests at the Tobata No.4 BF showed that the properties of formed coke in the furnace were comparable to those of conventional coke. It was further confirmed that in the lower part of the furnace formed coke showed rather better strength.

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Table I Transition of formed coke quality

	1st	2nd	3rd	4th	5th	6th	7th	8th	9th
Steam Coal Ratio (%)	74.2	74.5	70.0	74.2	66.0	65.0	70.9	73.9	89.2
Coal Mean Size (mm)		0.78	0.69	0.54	0.55	0.42	0.46	0.44	
Coke DI$^{150}_{15}$ (%)	81.1	82.9	81.9	83.0	84.0	84.3	83.9	84.3	81.6
CSR (%)	51.1	55.2	55.3	51.6	56.4	56.6	56.7	56.2	44.5
CRI (%)	39.0	36.1	33.6	39.6	36.4	37.0	35.8	36.3	40.9
Mean Size (mm)	39.4	40.2	41.8	39.6	38.5	38.0	38.3	37.0	39.4
−25mm (%)	7.5	7.4	6.5	6.5	7.3	6.6	5.8	7.9	6.0
Porosity (%)	38.1	37.8	39.6	37.9	38.2	38.3	38.9	35.0	32.8
					← Trial Use in a Blast Furnace →				

Table III Composition of coke (sample : A)

Conventional Coke (%)			Formed Coke (%)		
Ash	V.M.	F.C.	Ash	V.M.	F.C.
30.3	0.6	69.1	15.9	0.6	83.5

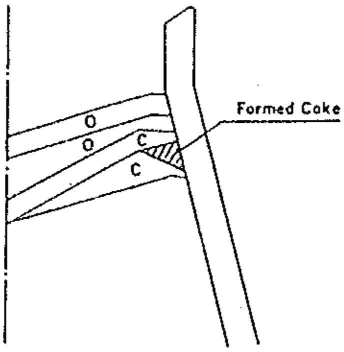

Fig. 1 Burden distribution profile

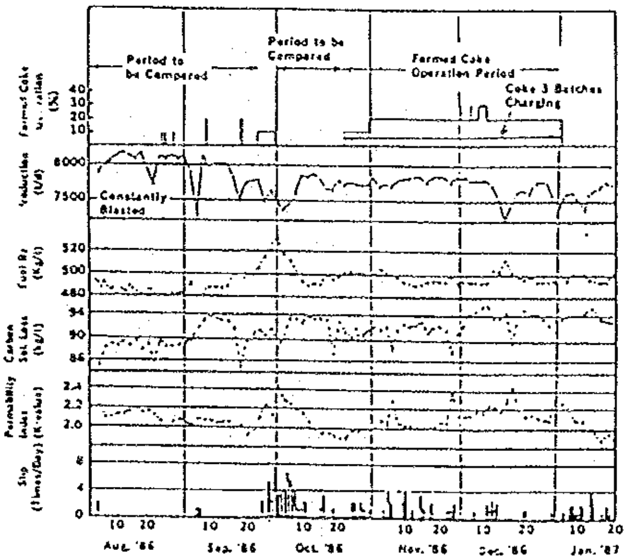

Fig. 2 Operation result of the Tobata No. 4 BF (Aug. '86 - Jan. '87)

Table II Comparison of coke properties

		Conventional Coke	Formed Coke
Ash	(%)	11.5	11.7
Volatile Matter	(%)	0.38	1.30
Fixed Carbon	(%)	88.2	87.0
Mean Size	(mm)	49.0	36.4
Void	(%)	50	44
Porosity	(%)	50	38
Bulk Density	(t/m³)	0.50	0.65
Repose Angle	(deg)	42	38
CRI	(%)	29.2	36.6
CSR	(%)	57.8	55.9

CRI : Coke Reactivity Index
CSR : Coke Strength After Reaction

Table IV Composition of coke (sample : B)

Grain Size	Conventional Coke (%)			Formed Coke (%)		
	Ash	V.M.	F.C.	Ash	V.M.	F.C.
50~35 mm	28.3	0.7	71.0	13.1	0.6	82.8
35~25 mm	28.1	0.6	71.2	24.4	0.6	75.0
25~20 mm	31.7	0.6	67.7	17.9	0.6	81.5
20~15 mm	33.2	0.7	66.1	29.1	0.7	70.2
Average	30.3	0.7	69.0	21.1	0.6	78.3

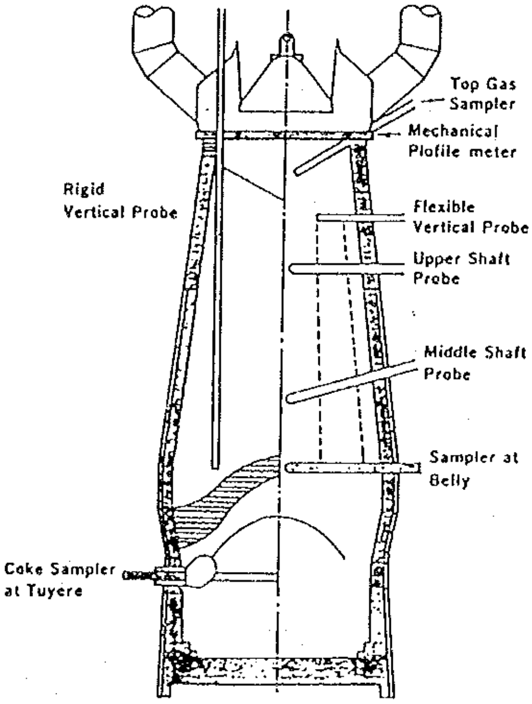

Fig. 3 Arrangement of sensors at Tobata No.4 BF

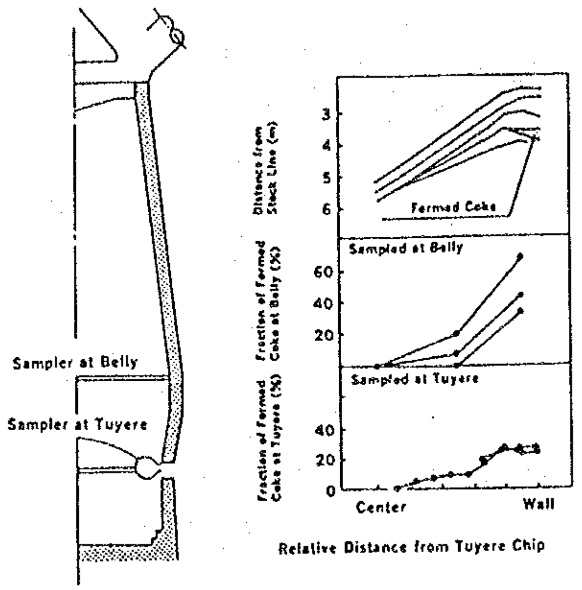

Fig. 4 Change of formed coke distribution along furnace height

(Specification)

Measuring Position	Centre Intermediate (4.0 m Apart from Centre) Periphery (6.6 m Apart from Centra) (Correspond to Flexible Vertical Probe respectively)
Sampler	48 mm Inside Diameter Steel Pipe
Sampling	at Scheduled Shutdown

(Sampling Procedure)

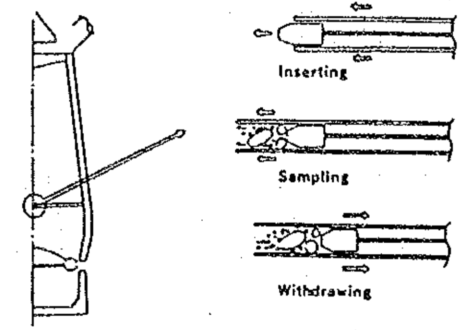

Fig. 5 Outline of belly probe

(Specification)

Sampler Drive Unit	
Driving Force	10 tons
Driving Rate	4 m/min
Utility	Air (5 kg/cm²)
Sampler Hammering	
Hammering Force	150 kg-m
Hammering Freq.	400 times/min
Utility	Air (5 kg/cm²)
Sampler Pipe	
Diameter	STPT 200 A Sch80
Number of Sample	9
Type	Drop-in Type

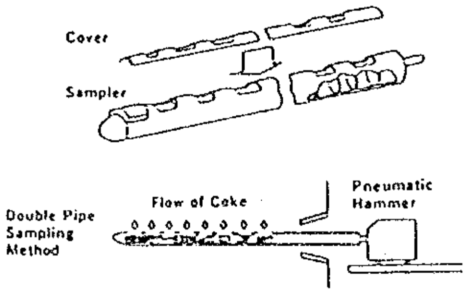

Fig. 6 Outline of core probe

(Specification)

Measuring Position	750 mm from Throat Wall 21 m from Stock Line (Bottom of Belly)
Measurement	Temperature and Gas-Content (CO and CO_2)
Measuring Time	During Operating
Probe	ϕ100 mm Steel Pipe, 30 m long with Sampler Basket

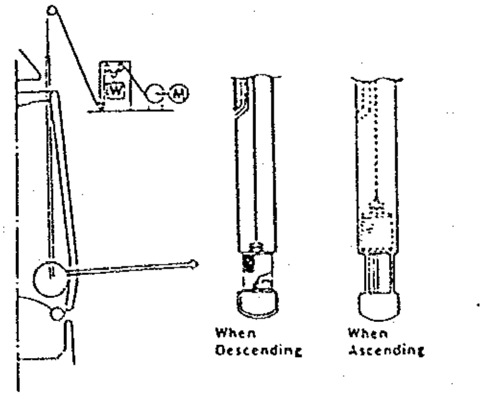

Fig. 7 Rigid vertical probe for recovery of reacted coke in BF

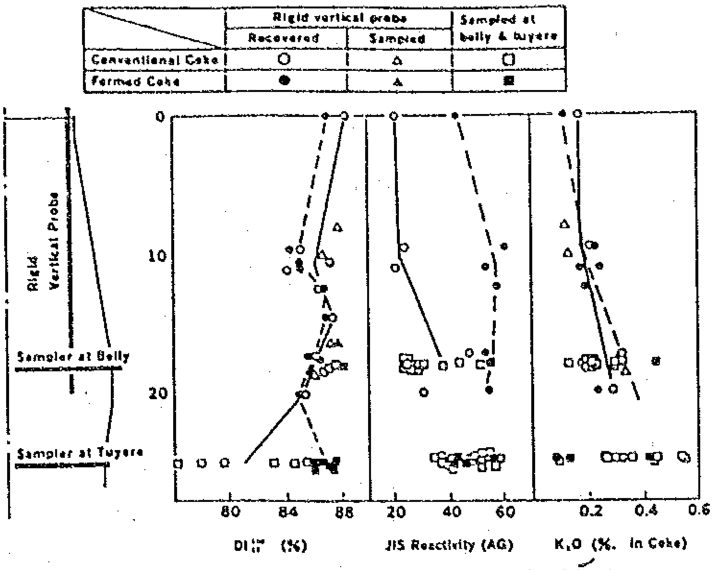

Fig. 8 Behaviour of coke properties in the blast furnace

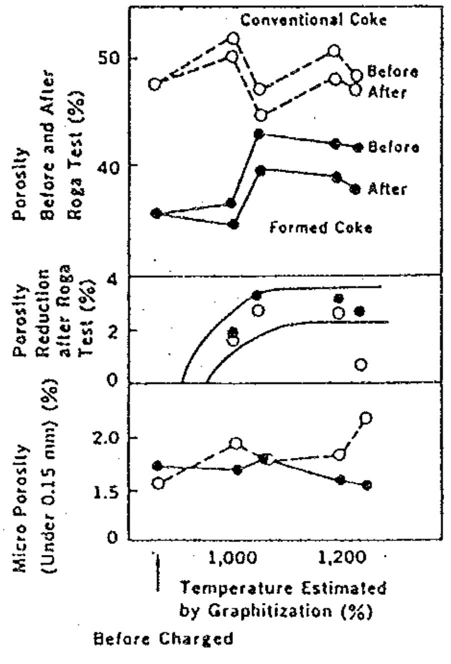

Fig. 10 Porosity of cokes

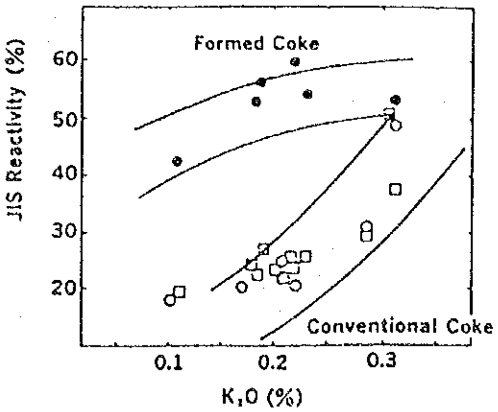

Fig. 9 Influence of K₂O on JIS reactivity

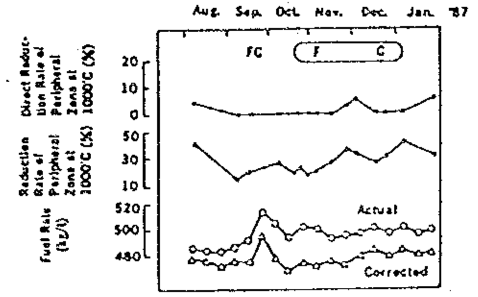

Fig. 11 Influence of formed coke on reduction

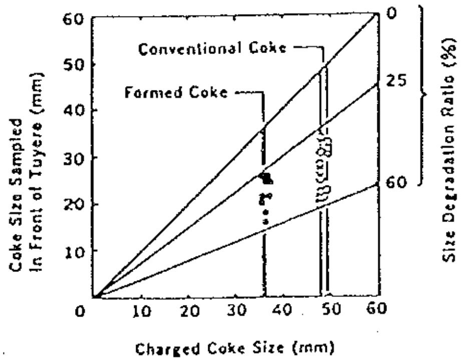

Fig. 12 Coke size degradation in BF

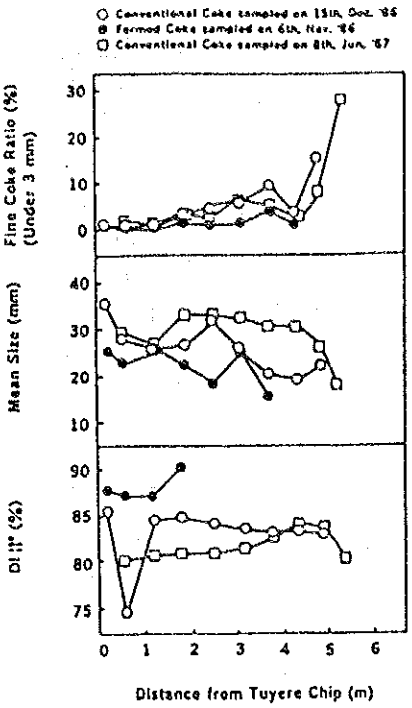

Fig. 13 Properties of coke sampled in front of tuyere tip

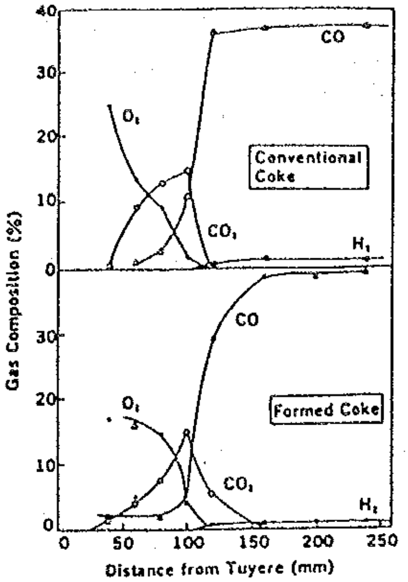

Fig. 14 Distribution of gas composition at the raceway

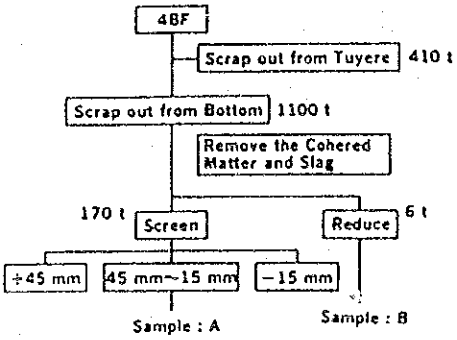

Fig. 15 Method of coke sampling

Information 4

I. Komaki, et al.,
"Development of Advanced Formcoke Process",
The First International Congress
of Science and Technology of Ironmaking, 1994

The First International Congress of Science and Technology of Ironmaking, 1994, Sendai, ISIJ

DEVELOPMENT OF ADVANCED FORMCOKE PROCESS

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Synopsis: Nippon Steel has succeeded in developing a formcoke process that enables production of improved formed coke having gas permeability comparable to that of metallugical coke obtained from conventional coke ovens. The carbonization technology established in the new formcoke process provides formed coke less susceptible to breakage and requires less energy, compared with the former technology.

Experiments using blast-furnace models were carried out. The result was that it would be possible to use the improved formed coke in the blast furnace in amounts up to 50% of the coke blend.

Keywords : Formed coke, Gas permeability, X-ray CT, Fissure, Carbonization, Energy consumption, Blast furnace, Distribution control, Dead-man

1. Introduction

Most of the coke ovens presently in operation in Japan would be replaced at the beginning of the 21st century.

A revolutionary shift from the conventional coke-oven process to a shaft-oven process is earnestly desired in that the continuous process enables carbonization in a closed system, an advantage making the coking process cleaner and easier to comply with environmental regulations.

Many variations of the formcoke process were developed around the world during the 1960s and 1970s. The latest variation was the Japan Iron & Steel Federation Process developed in the 1980s (Fig. 1). As already reported, the JISF process has undergone three-year operation tests in a 200-tpd pilot plant and large blast furnace test at a 30% of formed coke ratio [1][2].

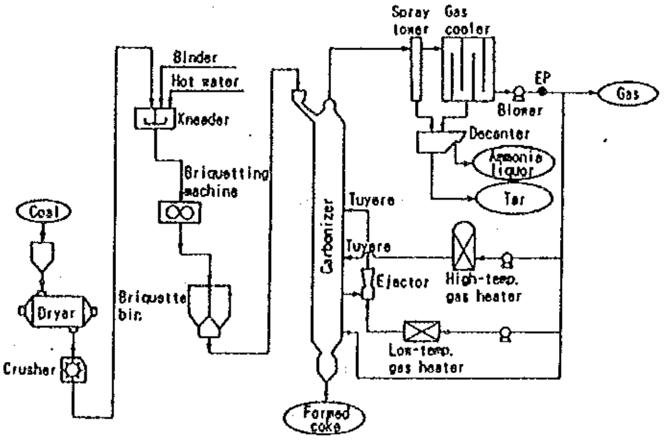

Fig. 1 Process flow of JISF 200 t/d pilot plant

There are two problems to be solved before the commercial operation.

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1) The formed coke produced by the JISF process has a resistance to gas passage nearly twice that of conventional coke.
2) The JISF process consumes more energy than the conventional coke-oven process.

This study is to report on the development of an improved variant of the JISF process and the results of studies made to find ways for using the formed coke of large amounts in the blast furnace.

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2. Requirements for improved physical properties

2.1 Gas permeability

Gas permeability was determined by introducing air at 0.5 to 1.2 m per sec. through a sample-packed bed and measuring the pressure drop caused thereby. The pressure drop thus measured was translated into the pressure drop under normal conditions in the blast furnace using Ergun's equation.

Fig. 2 provides the measured gas permeability of pillow type formed coke and conventional oven coke. The resistance of the formed coke to gas passage per meter of coke-layer thickness stands at 1.1 kPa/m, 1.8 times that of conventional coke - a result in good agreement with the value previously reported. In addition, the as-formed coke of 43 mm has a 0.5 kPa/m of resistance to gas passage as against 0.3 kPa/m for conventional coke of 55 mm.

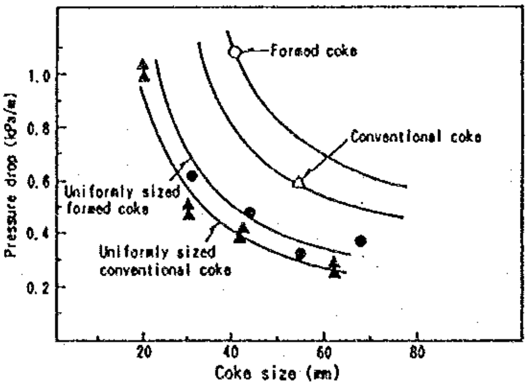

Fig. 2 Gas permeability of coke

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2.2 Shape

The aim of improvement of the shape of formed coke in this study was to achieve gas permeability in the as-formed state equal to that of conventional coke.

As understood from Fig. 2, the aim can be met by increasing the size of formed coke to around 70 mm. This size increase, however, will increase the weight of coke to 300 g per piece and may cause degradation during transport. It should also be noted that the bulk density of formed coke should be reduced to maintain a suitable thickness of the coke layer in the blast furnace.

From these considerations, an approach was adopted to improve the gas permeability - by reshaping the formed coke. The preconditions set in this reshaping were that the target shape can be attainable with double roll presses, that the formed coke produced be of a size comparable to conventional coke, namely, around 55 mm in diameter, and that the reshaping be by no means a cause of noticeable increase in thermal stresses exerted as the briquette is carbonized.

Fig. 3 compares the reshaped formed coke with former formed coke. The new shape coke has grooves in its surfaces and its void fraction is as low as 49%, a level almost comparable to that of conventional coke. Table 1 presents the measured gas permeability of the samples of different shapes tested. The new shape formed coke has gas permeability very close to that of the conventional coke.

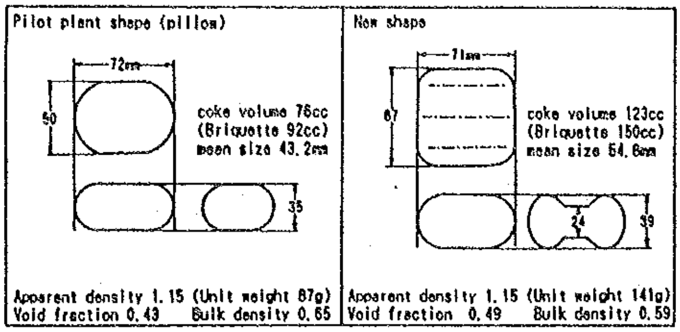

Fig. 3 Shape of formed coke

Table 1 Permeability measurement results (Experiment of 600ϕ permeation pressure drop)

	Conventional coke	Formed coke		
		Pillow-type	Pillow-type (Large size)	New shape
Coke size (mm)	55	43	55	55
Pressure drop (kPa/m)	0.300	0.480	0.390	0.295

(BRQ vol. 180cc)

3. Formed coke manufacturing process

3.1 Prevention of internal fissures during carbonization

Several studies have been reported on the mechanism of internal fissure formation due to the thermal stresses [3]. A new coal carbonization technology was required that would prevent fissures in large formed coke.

First of all, former formed coke was tested for the probability of internal fissuring. The formed coke was subjected an X-ray CT scanning and the result was that almost 80% of the formed coke produced by the previous process has internal fissures.

As a preliminary experiment, briquettes made in hydraulic presses were carbonized in an X-ray CT carbonizer and the formation of internal fissures was observed [4]. In all cases, the internal fissures observed originate at the center of briquette in the semi-coke temperature range, from 600° to 750°C, and propagate to the surface. The results of a series of these experiments have revealed that it is possible to suppress the formation of internal fissures with use of proper heating-up pattern, while achieving a carbonization rate 1.2 times that with the pilot plant.

Fig. 4 presents the result of a heating-up test for the reshaped, formed coke. Despite the reshaped coke being 150 cc in briquette volume or 1.6 times that of former pillow type formed coke, the heating-up rate is close to that for the small pillow type formed coke, rather than to that for the large pillow type one, an advantage that favors reduced thermal stresses.

The pattern of heating in a shaft oven is dependent on the temperature of the heating gases blown through tuyeres and the oven top temperature. The temperature of high temperature tuyere gas is a determinant of the final coke temperature and needs to be decided in relation to the quality of the coke. From the quality of the coke, that temperature was set constant at 900°C.

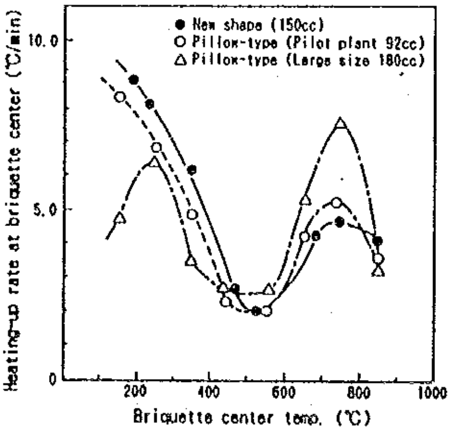

Fig. 4 Heating-up rate of formed coke

Then, a simulation model for heat transfer in a shaft oven was used to estimate the heating-up pattern at varied temperatures of low temperature tuyeres and oven-top temperature. The patterns of heating-up thus estimated are shown in Figs. 5 and 6. These results indicate

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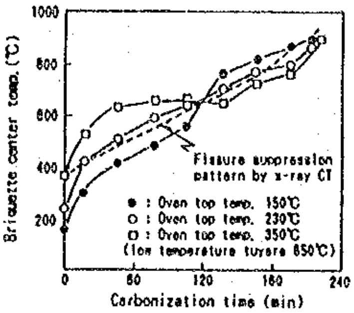

Fig. 5 Comparison of heating pattern in case of change of oven top temperature

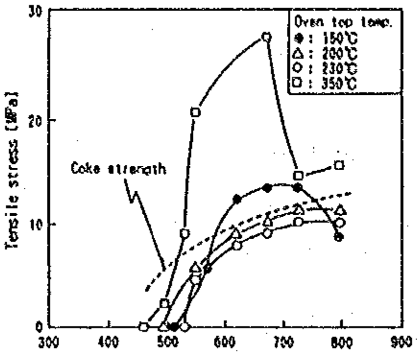

Fig. 6 Changes internal stress of formed coke every heating pattern

that it is possible to heat up the formed coke in the shaft oven in a pattern similar to the heating-up pattern that was found effective in the preliminary X-ray CT experiments in reducing internal fissures, assuming the thermal stresses at the center of briquette can be kept under the tensile strength of the semi-coke. Thus it has been confirmed possible to avoid any rapid temperature rise at the center of briquette if heated at 650°C to 675°C at the low temperature tuyeres and at 200°C to 270°C at the oven top.

A direct heating furnace was used to undergo a carbonization experiment. The test results are, as seen in Table 2, in good agreement with those of the estimation made using a simulation model: virtually no internal fissures under heating conditions of 650°C to 660°C at the low temperatures tuyeres and 200°C to 230°C at the oven top.

Table 2 Ratio of unfissured formed coke every heating pattern (Productivity 122%)

(%)

Low-temp. tuyere / Oven top	625℃	650℃	660℃	675℃	700℃
150℃	0 (42.8)	20 (22.0)	30 (22.0)	0 (12.1)	0 (15.3)
200℃	0 (30.0)	80 (8.7)	100 (8.2)	0 (8.0)	0 (25.1)
230℃	0 (22.4)	80 (4.8)	80 (4.4)	0 (6.1)	0 (15.5)
270℃	10 (24.2)	10 (3.6)	10 (3.6)	0 (6.0)	0 (16.2)
350℃	10 (24.1)	10 (9.3)	20 (8.9)	0 (9.0)	0 (16.7)

Note : The parenthesized numerals denote the maximum heating rate at the briquette center (℃/min.)

The formed coke obtained has cold strength and hot strength fairly comparable to those previously attained with the pilot plant.

3.2 Reduced energy requirement

The best way to cut energy consumption in the formcoke process is to reduce the oven-top temperature and thereby keep to a minimum the quantity of sensible heat that might otherwise be carried away from the shaft oven. The gas temperature at the oven top ranges from 200°C to 230°C in the improved formcoke process, levels far lower than in the pilot test, i.e., from 350°C to 270°C. Fig. 7 shows the energy balance of the process, an energy saving of around 35% can be expected in terms of calorific value.

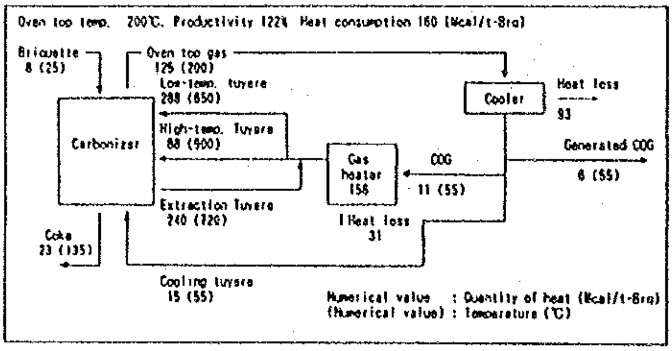

Fig. 7 Heat balance in new process

4. Prerequisites for increased use in blast furnace

Numerous tests were carried out during the 1970s for the practical use of formed coke in blast furnaces. In most cases, an increase in pressure drop of

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gases passing through the furnace was reported. In addition, the increase of gas flow close to the wall was also reported as an irregularity encountered.

These phenomena are attributable to the characteristics of the formed coke made in those days, namely, high resistance to gas passage and low repose angle, which caused the formed coke to roll toward the center of the furnace.

Then, the reshaped, formed coke was subjected to model tests with the aim of achieving a 50% of formed coke ratio in a commercial blast furnace.

4.1 Filling properties

A 1/3 scale model of a blast furnace was used for the experiment to determine the filling properties of the formed coke in the furnace.

Fig. 8 indicates the angle of inclination measured on each specimen using a profile meter. The angle of inclination of the pillow type formed coke is 37.4 deg. without blast, 2.3 deg. lower than the 39.7 deg. of conventional coke. The reshaped, formed coke, by contrast, has an angle of inclination equal to that of conventional coke -39.6 deg. This agreement was verified also in the blast conditions.

Another factor that affects the distribution of coke in the blast furnace is the stability of deposits. The degree to which the coke layer is forced to collapse when overlaid with iron ores was measured using an electrode type thickness gauge. At 50% and 100% of reshaped, formed coke ratios, the degree of collapse is nearly equal to that for conventional coke.

From the results of the above experiments it has been ascertained that even formed coke having *a smoothly-curved surface can have filling properties* almost comparable to conventional coke, if it is properly shaped.

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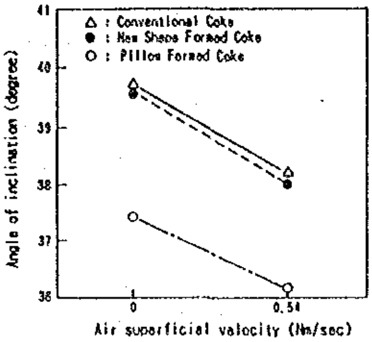

Fig. 8 Relation between angle of inclination and air superficial velocity

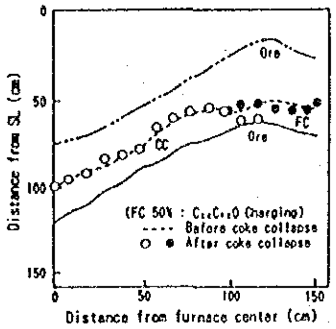

Fig. 9 Experimental results of 50% peripheral charging of formed coke (1/3 model)

4.2 Distribution control

The next experiment was to find the best pattern of burdening. Peripheral charging, a practice to prevent formed coke from being deposited in the center of the furnace, was used in the 1/3 scale model. As obvious from Fig. 9, there occurred no outflow of formed coke from the peripheral terrace even at 50% formed coke ratio. From this it may be concluded that the formed coke may be used in the blast furnace in amounts up to 50% of the coke blend from the viewpoint of burden distribution.

The ore to coke ratio was also measured in the experiment. High O/C regions were present from the intermediate to the wall. To reduce these peaks by properly burdening, various patterns of coke charging were estimated by the index of gas flow distribution calculated by the burden distribution model, and the results are shown in Table 3. Hence it is believed possible to bring the gas flow distribution close to that of conventional coke by properly adjusting the pattern of formed coke charging.

Table 3 Gas flow distribution index

(%)

Charging mode		Center	Inter-mediate	Periph-eral	Devia-tion
(1) CC I 0 I 0 I	Conventional coke charging	38.3	30.0	31.7	-
(2) CC I FC I 0 I	Peripheral charging-1 (1/3 model)	41.1	29.5	29.4	4.56
(3) FC I CC I 0 I	Peripheral charging-2	39.8	28.2	32.0	3.6
(4) CC I FC I CC I 0 I	Peripheral charging-3	40.0	27.0	32.9	5.9
(5) FC I CC I 0 I	Center charging	40.1	28.5	31.4	3.8

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4.3 Phenomena observed in the lower part of furnace

The phenomena that take place in the lower part of the blast furnace with formed coke having a low repose angle have not been fully explained as yet. A 1/20 scale, three-dimensional semi-circular model was used to make clear these.

For the quasi-formed coke, the repose angle was set at as low as 26.6 deg. to make those phenomena clearer. As a result, it could be ascertained that the use of the formed coke of a low repose angle and low void fraction tends to reduce the dead-man and to expand the pseudo-stagnant layer.

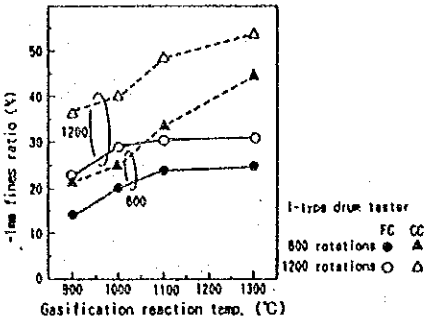

Fig. 10 Coke degradation after CO_2 reaction

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In addition, the increasing metal ratio in the dead-man reduces the liquid permeability if a formed coke of low void fraction is used.

Finally, the formed coke was tested for the degradation after reaction with carbon dioxide gas, and the test results are shown in Fig. 10. The formed coke outperforms conventional coke in resistance to degradation after reaction.

All these findings suggest that formed coke can be used in the blast furnace without impediments in much larger amounts per charge than previously if its gas permeability, repose angle and void fraction are improved to the levels of conventional coke.

5. Conclusion

An advanced formed coke of improved gas permeability and depositability could be obtained by reshaping.

A new process has thus been developed that can produce such advanced formed coke, with internal fissures and energy requirements far lower than the formed coke previously obtained.

All findings of basic studies suggest that the formed coke of improved shape can be used in the blast furnace in much larger amount than the formed coke previously proposed.

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6. References

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