DEVELOPMENT OF FORMED COKE PROCESS

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1. Introduction

The conventional process for making blast-furnace coke requires coking coal as the principal raw material. The proportion of non-coking coal that can be blended with coking coal is not more than 20%, even when pretreatment techniques, such as briquetted coal blending and preheated coal charging, are employed. On the other hand, it is estimated that as much as 70 to 80% of world hard coal reserves are non-coking coals, which are generally less costly than coking coals. Thus, using larger proportions of non-coking coal for making blast-furnace coke is extremely important from the viewpoint of utilizing the more abundant and cheaper coal resource and cutting coke production costs.

The carbonizing equipment employed for the conventional coke making process consists primarily of a number of batch-type coke oven chambers. This equipment by nature causes air pollution and poor working environment, the prevention of which calls for huge investment. Besides, the equipment hardly allows for basic improvements. Hence, appreciable savings of labor which would otherwise be attainable through automation or mechanization are difficult to achieve. This accounts for the high ratio of labor cost to the total coke production cost. Further, coke oven operations are so ionflexible that they cannot be easily adjusted to the fluctuations of demand for coke.

The formed coke process is considered the most promising solution to the above-mentioned problems involved in the making of blast-furnace coke. In order to put a newly devised formed coke process to practical use, it was decided to carry out a research and development project using a pilot plant. This research and development project was undertaken jointly by Kawasaki Steel corporation, Kobe Steel, Ltd., Nippon Steel corporation and Nippon Kokan K.K. under the sponsorship of the Japan Iron and Steel Federation. Nippon Steel Corporation is chiefly responsible for tests on the pilot plant installed at its Yawata Works.

This paper describes the newly developed formed coke process and the results of tests carried out using a pilot plant.

2. History of Research and Development

It is well known that a variety of formed coke processes have long been studied and developed by several countries$^{1),2)}$. Although some of these processes have been developed to such an extent that coke produced by a pilot plant has been tested in blast furnaces, none has yet been put to practical use. As shown in Fig.1, Japan has a history of research on formed coke processes dating back to the early 10950s$^{3)}$. The briquetting and carbonizing processes have been studied extensively. With some processes, formed coke obtained has been tested in blast furnaces$^{3),4)}$.

(Fig. 1)

The newly developed formed coke process currently being developed is based on an original process of Nippon Steel. In this process, cold briquettes are continuously carbonized in a shaft furnace using a gas as the heating medium. Although the idea of using a shaft furnace for continuous carbonization is not new (as shown in Fig.2, it is adopted for the majority of the present formed coke processes), the new process has several innovative features as described later.

(Fig. 2)

This formed coke process has been developed based on the results of research and development carried on by Nippon Steel since the early 1970s$^{5)}$. The joint research on this process sponsored by the Japan Iron and Steel Federation was started in 1978. In the first year of joint research, study was conducted to evaluate the process. At the same time, it was decided to promote the development of this process using a pilot plant. The aforementioned four steelmakers shared in experiments necessary for engineering a pilot plant, investigations of non-coking coal resources and sample tests, research on new briquette binders and new process for producing char from highly volatile non-coking coal, etc. Thus, preparations for the development of the formed coke process using a pilot plant were carried out.

The pilot plant construction work was started in May 1981 and completed in December 1983. A series of formed coke production tests using this pilot plant carried out for three years, from 1984 to 1986. Formed coke produced by the pilot plant was tested in a blast furnace in the second half of 1986. The time schedule for this research and development project is shown in Fig. 3.

(Fig. 3)

3. Description of the process

3.1 Principle of Carbonizing Process

Briquettes are produced by the ordinary cold briquetting process using coal tar pitch as the binder. This process has been already established on an industrial scale. the ultimate goal of the research and development project was the simplest process in which cold briquettes are charged directly into a shaft furnace so that they can be carbonized continuously. In order to realize such a process, it is an essential that the problems which are considered to occur by the carbonizing behaviour of cold briquettes are solved (see Fig.4). Among others, the collapsing and sticking of briquettes due to the softening of the binder in the early stage of carbonization, and the swelling of briquettes and the bonding of coal particles due to the subsequent softening of coal are extremely important items to be controlled.

(Fig. 4)

Eventually, it was found that these problems could be solved by controlling the heating rate of briquette during carbonization. Namely, properly controlling the heating rate of briquette according to the change in briquette temperature as shown in Fig.5 is the key to solving the abovementioned problems. Fig.5 indicates that in the early stage of carbonization the briquettes should be heated as rapidly as possible and thereafter, the heating rate should gradually decreased while keeping an appropriate range. The reason why rapid heating in the early stage of carbonization can prevent briquettes from collapsing or sticking is that a semi-coke layer is rapidly formed on the briquette surface (see Fig.6).

(Fig. 5)

(Fig. 6)

In order to ensure the heating pattern of briquette shown in Fig.5 during carbonization in a shaft furnace, it is necessary to devise a special heating method. To this end, a method was worked out in which low-temperature heating gas and high-temperature heating gas are supplied separately. As shown in Fig.7, this method can not only ensure the optimum heating pattern of briquette, but also heat the briquettes to 1,000°C in 250 minutes. Thus, the first feature of the new carbonizing process is that briquettes in the shaft furnace are carbonized by two-stage heating.

(Fig. 7)

3.2 Carbonizing System

The profile of the carbonizer (shaft furnace) is shown in Fig.8. The shaft furnace is capable of continuous low-temperature carbonizing, high-temperature carbonizing and cooling. This is the second feature of the process. Briquettes charged into the top of the shaft furnace are continuously discharged from the bottom of the furnace as quenched formed coke. This unique construction of the shaft furnace helps to ensure uniform descent of burden in the furnace and eliminates the need of high-temperature coke handling and gas sealing in the high-temperature zone. The shaft furnace has a rectangular cross section so tha the heating gases can be injected from both sides. This makes possible uniform heating of the burden in the shaft furnace.

(Fig. 8)

The third feature of the process lies in the heating gas circulation system, the concept of which is shown in Fig.9. The gas which was used to cool the high-temperature formed coke at the furnace bottom is drawn out of the furnace, then used again a part of the low-temperature heating gas. In addition, gases generated during carbonization of briquettes are cooled to remove the tar and preheated indirectly so that they can be used as the heating gas. The same gases are also used to quench formed coke at the furnace bottom. As a result, combustion waste gas and inert gas are prevented from mixing in the circulating gases for heating and cooling. In this formed coke process, therefore, high-calorie gases can be recovered and the amount of gas to be refined can be kept at a minimum.

(Fig. 9)

3.3 Coals for this process

This formed coke process permits using particular brand of coal, but it aims at using a mixture of coals of different properties with a view to increasing the varieties of coal that can be used for coke making. With this process, the range of coking property of blended coal that can maintain the strength level required of blast-furnace coke can be extended significantly as compared with the conventional coke making process. Namely, as shown in Fig.10, the process offers more allowances for volatile matter and Caking Index(6) which are used to evaluate blended coal that can be used for coke making. Thus, it appreciably expands the scope of coal resources that can be used for blast-furnace coke. In this process, the blending ratio of non-coking coal (Caking Index smaller than 80) is roughly 60 to 80% and that of coking coal is 40 to 20%, though the figures very according to the properties of individual brands of coal used.

(Fig.10)

4. Description of the Pilot Plant

4.1 Purpose and Capacity of Pilot Plant

The purpose of tests using the pilot plant is to establish equipment and operating technologies and to evaluate the quality of formed coke in the blast furnace, in order to develop the process to the commercial stage. therefore the pilot plant has to provide the equipment with all the appropriate functions, such as coal preparation, briquetting, carbonization and circulation of gases. In the process, the carbonizing process having a number of innovative features mentioned above is especially important.

In order to ensure the optimum heating pattern of briquette in the shaft furnace, it is necessary to make clear the burden descent and heating gas flow characteristics. These characteristics in a full-scale shaft furnace to carbonize briquettes on a commercial basis are difficult to predict accurately by a reduced-scale shaft furnace. Therefore, in this pilot plant, the dimensions of shaft furnace which determine the two characteristics are the same as those of a full-scale shaft furnace, so as to ease the problem which would otherwise require careful consideration when scaling up the shaft furnace. Namely, the shaft furnace of the pilot plant has the same width and height as a full-scale shaft furnace. Only the length of the shaft furnace is somewhat shorter. Taking into consideration the scale of the shaft furnace and the amount of formed coke samples needed for testing in a blast furnace, the capacity of the pilot plant was set at 200 tons of formed coke a day.

4.2 Pilot plant process Flow

The process flow of the pilot plant is shown in Fig.11, and the layout of the pilot plant in Fig.12. All the facilities are installed at the same place in the coke plant of Yawata Works. Hence, the supply of raw materials and utilities needed by the pilot plant and the treatment of products obtained from the pilot plant depend entirely on the functions of the Yawata coke plant.

(Fig. 11)

(Fig. 12)

Coals blended and crushed by the coke plant facilities are carried on belt conveyors into the wet coal surge hopper of the pilot plant. The blended coal is dried, crushed and briquetted. The binder needed for briquetting is also supplied from the coke plant through a pipeline. Briquettes are once stored in bins, from which they are transported to the carbonizer. Coal power and broken briquette occurring in the briquetting process and during transportation of briquettes are returned to the kneader in the briquetting process, where they are briquetted again. All these processes are controlled automatically.

Formed coke discharged continuously from the shaft furnace is transported by truck to the stockyard. Gases discharged from the top of the shaft furnace are cooled to remove the tar and mostly recirculated. The reminder is recovered and piped to the Yawata coke plant, where it is mixed with gases generated there and fed into the gas refining process. Also, all tar and ammonia liquor produced in the pilot plant are treated at the Yawata coke plant, together with tar and ammonia liquor produced there. All the utilities required by the pilot plant, such as electricity, fuel gases, steam, nitrogen gas and water, are supplied from the Yawata coke plant.

Thus, the pilot plant integrates all the necessary processes, from the preperation of coals to the cooling of process gases. In addition, the plant is so designed that the results obtained can be directly fed back to commercial production equipment.

4.3 Features of Carbonizing Equipment of the Pilot Plant

A view of the pilot plant is shown in Fig.13, and specifications of the main plant facilities are shown in Table 1. Of the plant facilities, the carbonizing equipment is especially unique. The carbonizer (shaft furnace) is shown in Fig.14. Its dimensions are given in Table 2. As shown, the effective dimensions of the shaft furnace are 0.9 to 1.25m in width, 14.36m in height, and 6.45m in length. This shaft furnace has four charging devices and four discharging devices along its length. The charging of briquettes into the shaft furnace and the discharging of formed coke therefrom are effected automatically.

(Fig. 13)

(Fig. 14)

Table 1

Table 2

Five tuyeres are installed on each side across the furnace width for injecting the heating gases into the furnace and for extracting the waste gas therefrom. At each side of the furnace, an ejector is provided to extract the gas used for cooling formed coke. The low-temperature heating gas is preheated by a recuperator, and the high-temperature heating gas is preheated by hot stoves. Since hydrocarbons contained in the circulating gas, such as CH_4, C_2H_4, and C_2H_6, cause carbon deposit on the inside of the hot stoves as they are thermally decomposed, the gas circulating system burns the carbon deposit away by air during the switching of the hot stoves.

The operations of the briquetting and carbonizing facilities of the pilot plant are controlled fully automatically from the central control room, hence no operator is required at the machine side.

5. Results of Pilot Plant Test Operations

5.1 Operation of Pilot Plant

The pilot plant was put in a hot-run test toward the end of June 1984, following adjustments of the equipment, drying of the carbonizing furnace and training of operators, which had lasted for about six months after the plant was completed. For two years and six months to December 1986, the hot-run test was carried out in nine steps. In this period, the pilot plant was operated for a total of 579 days, producing 93,000 tons of formed coke, of which 61,000 tons were set aside for testing in a blast furnace.

Based on the results of the first three steps of testing (end of June - end of December 1984), the operating procedures were optimized and improvements were made on some plant facilities. As a result, in the fourth step of hot-run test conducted for one month from the end of March 1985, the plant could be continuously operated for 30 days without any trouble. Since technology to ensure stable plant operation was established, the production of formed coke for stockpiling for testing in a blast furnace was started in May 1985 (fifth step). From that time until July 1986 (end of eighth step), the hot-run test was continued with the primary purpose of producing formed coke samples to be tested in a blast furnace. In the ninth, and final step, the pilot plant was operated under widely varied operating and coal blending conditions.

5.2 Establishment of Equipment and Operating Technology

In putting this formed coke process to practical use, it is critically important that the newly developed carbonizing equipment functions as designed. Table 3 shows the results of pilot plant operation in the fifth to eighth steps, in which formed coke samples for testing in a blast furnace were stockpiled. The shortest period of continuous operation of the pilot plant was 70 days, and the longest period 110 days. In each of the test periods, total plant shutdown due to trouble was less than 1%. Thus, the pilot plant was operated quite stably. As a result, the production of formed coke per day exceeded the target in each test step. During the four steps of the hot-run test, the production of formed coke was increased gradually. In the eighth step, the average daily production of formed coke in 110 days of continuous operation was 197 tons, almost reaching the designed capacity of 200 tons per day. In the seventh step, as shown in Fig.15, the pilot plant was operated at its designed capacity (200 t/d) for 61 consecutive days, producing satisfactory results both in terms of output and quality of formed coke. In the ninth step, it output from the carbonizing equipment exceeded 300 tons per day. Thus, it was made clear that by adjusting the operating conditions properly, it is possible to obtain operation results better than initially planned. Judging from these test results, the formed coke process featuring newly developed carbonizing equipment has become ready commercial operation.

(Fig. 15)

Table 3

All the automated systems, including the briquette charging device, formed coke discharging device, and heating gas circulating system, as well as the sealing system, functioned as expected. this indicates that the formed coke process should also be effective in saving labor and improving working conditions drastically. In shutting down the carbonizing equipment during the hot-run test, all the related devices, except the hot stoves, were cooled down to ambient temperature. No trouble occurred with the equipment or subsequent operation. the time required to shut down the carbonizing equipment and to restart the equipment was four days each, proving that the technology involved in the process can respond to production control with flexibility. the equipment and operational characteristics thus confirmed suggest that the formed coke process should be able to solve basic problems inherent in the conventional coke-oven process as initially expected.

5.3 Coal Blending conditions and Coke Quality

As shown in Table IV, various types of non-coking coal, with volatile matter ranging from 19.2% (d) to 44.5% (d), were used for tests in the pilot plant. Each type of non-coking coal was blended with small proportions of coking coal and binder to be used as the raw material for formed coke. Table V shows coal blending conditions and formed coke quality obtained by the pilot plant. When the blending ratio of non-coking coal was in the range 65 to 100%, the strength of formed coke was comparable to that of blastfurnace coke. Thus, it was confirmed that in the new formed coke process, non-coking coal can be used as the principal raw material, and that blast-furnace coke can be produced without using any coking coal. It was also confirmed that the new formed coke process offers more allowances for blended coal properties: volatile matter may range from 23 to 35 (%, d), and caking index from 50 to 70.

Table 4

Table 5

It was found that formed coke strength and blended coal caking index have the relationship shown in Fig.16. With the new formed coke process, when the content of volatile matter and caking index of coal are known, it is possible to estimate the coal blending ratio and the strength of coke formed from the blended coal. Fig.17 shows the relationship between the temperature of gas injected into high temperature tuyeres and the quality of formed coke. As the gas temperature decreases, the content of volatile matter of formed coke increases, while the strength of coke is little affected. From Fig.17, it is evident that the final formed coke carbonization temperature may be lowered to 850 to 900°C.

(Fig. 16)

(Fig. 17)

5.4 Mass and Heat Balance in Carbonizing Process

Fig.18 shows the yields of coke, tar and gases produced in the carbonizing process of the pilot plant in comparison with those in the conventional cokemaking process. Though there is very little difference in coke yield between the two processes, the new formed coke process offers a tar yield twice that of the conventional process. Conversely, the gas yield of the new formed coke process is correspondingly lower. Table 6 compares tar and gas properties between the two processes. the calorific value of gas recovered from the new formed coke process was about 3,700 Kcal/Nm^3, an exceptionally high figure among existing formed coke processes, though it is lower than the calorific value of gas recovered from the conventional cokemaking process. Tar produced in the new formed coke process is soft and shows a small degree of condensation, since it is not subjected to secondary thermal decomposition under high temperatures as is tar in the conventional process.

(Fig. 18)

Table 6

Fig.19 shows heat consumption in the carbonizer of the pilot plant in relation to the top gas temperature. The quantity of heat consumed for carbonization markedly decreases as the top gas temperature is lowered. When the top gas temperature was lowered the near 300°C, the heat consumption became about 400 Mcal/t-briquette, or about two-thirds the heat consumption in the conventional process. As shown in Fig.20, most of the heat consumed in the carbonizer is lost in the form of sensible heat of gas discharged from the top of the carbonizer. In order to utilize this top gas sensible heat, a new method was developed to cool the top gas by tar produced in the carbonizing process as shown in Fig.21. By 40% of the top gas sensible heat (Fig.22).

(Fig. 19)

(Fig. 20)

(Fig. 21)

(Fig. 22)

6.1 Testing of Formed Coke in Blast Furnace

The target properties of formed coke samples for testing in a blast furnace were set as shown below, taking into consideration the properties of coke made by the conventional process and used in the testing blast furnace.

DI_{15}^{150} 83.5 ± 0.5, CSR 57 ± 2, Ash 12%

As mentioned earlier, 61,000 tons of formed coke samples were produced in 15 months from May 1985 until July 1986. All these samples had been stockpiled outdoors until they were subjected to testing in the blast furnace. The formed coke in the stockyard was covered with vinylon sheet as shown in Fig.23 to prevent its moisture content from fluctuating due to rainfall, etc.

(Fig. 23)

6.2 Results of Testing in Blast Furnace

The testing of formed coke produced by the pilot plant was conducted in the Yawata No.4 blast furnace (inner volume: 4,250m^3), chiefly to evaluate the possibility of using formed coke in a large blast furnace on a long-term basis. The tests were started in August 1986 and ended in January 1987. As shown in Fig.24, the blast furnace was continuously operated for 74 consecutive days using formed coke at a blending ratio of 20% (30% for several days). During this period, the blast furnace operational characteristic (fuel rate, burden descending, etc.) remained the same as when only coke made by the conventional process was used, except that the permeability resistance slightly increased due to smaller grain size of formed coke.

(Fig. 24)

An examination of coke samples collected from the tuyeres revealed that the change in grain size of formed coke in the blast furnace was the same as that of coke prepared by the conventional process, as shown in Fig.25. It was also revealed that the formed coke retained its original shape until it reached the tuyere, as shown in Fig.26.

(Fig. 25)

(Fig. 26)

The above-mentioned test results prove that formed coke produced by the new formed coke process can be substituted for coke prepared by the conventional process.

7. Feasibility Study of Commercial Production Equipment

7.1 Suppositions for Feasibility Study

The feasibility study of the new formed coke process was conducted assuming equipment having a coke production capacity of 3,000 t/d. As already mentioned, in order to preclude technical problems involved in scalling up the pilot plant, it was assumed that commercial production equipment had a shaft furnace having the same width and height as the pilot plant, only the shaft furnace length being about three times that of the pilot plant.

Since the new formed coke process permits a much wider variety of coals to be used for making coke, shaft furnace operating conditions, production rate, product yields, etc. are influenced by the properties of coal used as the raw material. This in turn influences economy of the process. In this light, the following three cases, each using material coal of different properties, were considered:

Case I: Blended coal of low volatility and high caking property;
production of formed coke of high CSR

Case II: Blended coal of low volatility and low caking property;
high production rate; low top-gas temperature

Case III: Blended coal of high volatility and high caking property;
low coke yield; high by-product yields

For the purpose of comparison, the conventional cokemaking process was considered. The briquette blend coking process was also partly included in the comparison.

7.2 Results of Feasibility Study

Fig.27 shows the results of comparison of equipment cost. Case I is nearly the same as the conventional coking process, while Case II is less costly by 15%. Case III is costlier than the conventional coking process, but less costly than the briquette blend coking process. compared with the conventional coking process, the cost of the shaft furnace of the new formed coke, but gas cooling equipment is costlier.

(Fig. 27)

Fig.28 shows the results of cost comparison of blast-furnace coke based on the current price difference between coking coal and non-coking coal (the latter is about 23% cheaper than the former). In each of the three cases, the new formed coke process is more advantageous than the conventional coking process in terms of cost of blast-furnace coke. Case II, in particular, is about 15% less costly than the conventional process. The briquette blend coking process is less advantageous than the conventional process. The economic advantage of the new formed coke process over the conventional coking process depends on the price difference between coking coal and non-coking coal and on the blending ratio of non-coking coal. Fig.29 shows the results of evaluation of economic advantage of the new formed coke process over the conventional process with special reference to the two factors. Assuming the blending ratio of non-coking coal as 70%, the new formed coke process becomes more economical than the conventional process when the price difference between coking coal and non-coking coal is 11% or more in Case I and 20% or more in Case III. In case II, the new formed coke process always has economic advantage over the conventional process even when there is no price difference between coking coal and non-coking coal.

(Fig. 28)

As mentioned above, the economy of the new formed coke process varies according to the properties of material coal used. Nevertheless, it can reasonably by expected that the new formed coke process will have advantage over the conventional cokemaking process in terms of both equipment cost and coke cost.

8. Conclusion

With a view to developing a new formed coke process which should be able to solve various problems involved in conventional cokemaking processes, a pilot plant capable of producing 200 tons of formed coke a day was constructed. Using this plant, equipment and operating technologies relating to the production of formed coke, as well as technology for use of formed coke in a blast furnace, could be established. Also, a feasibility study of commercial production equipment indicated the possibility that the new formed coke process would have economic advantage over the conventional coke making processes. Since the new formed coke process involves no technical problems in scaling up the shaft furnace for development of commercial production equipment, it can readily be put to practical use on a commercial basis. It is hoped that the new formed coke process will contribute much to the progress of the world's iron and steel industries as an innovative technology which effectively meets the needs for savings of resources, environmental protection, savings of labor, building of systems, etc. in manufcturing blast-furnace coke.

(Fig. 29)

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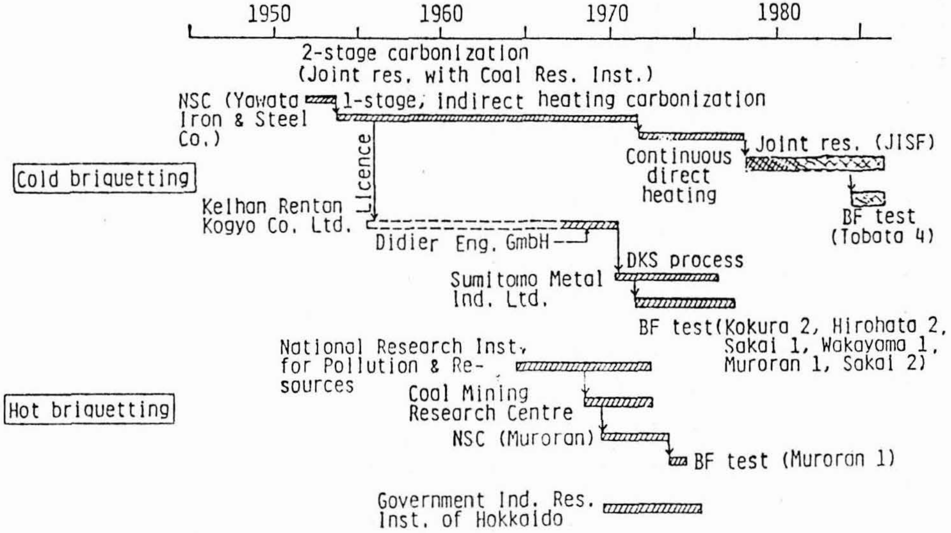


Note: In addition to above research, other unpublished researches have been carried out by member companies since 1960's.

Fig.1 Progress of R. & D. for the formed coke processes in Japan.

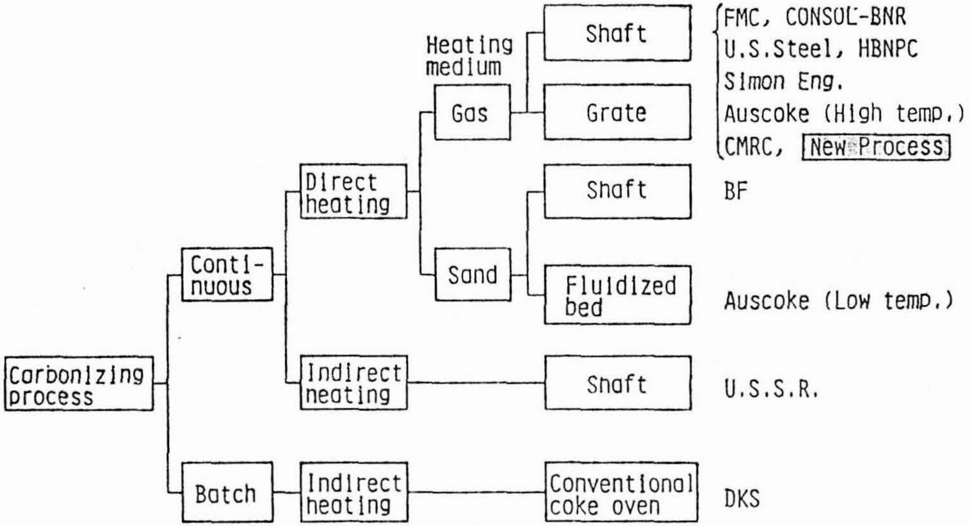


Fig.2 Classification of processes by carbonizing method and position of the New Process.

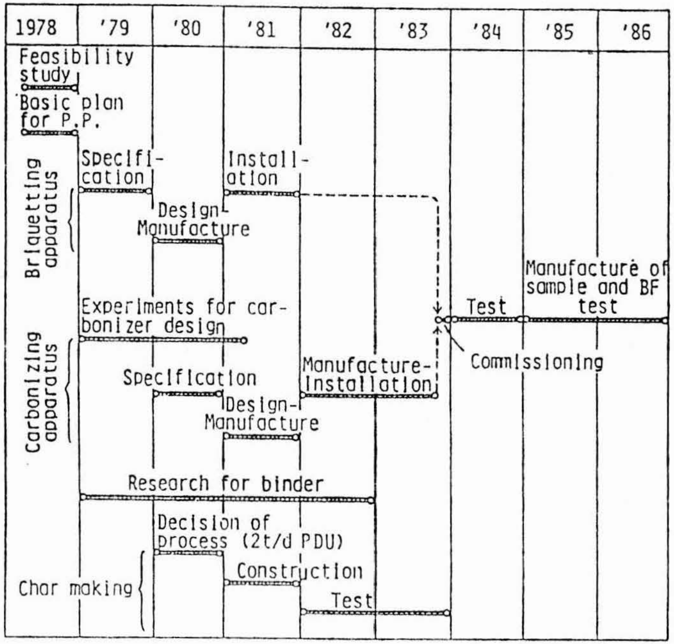


Fig.3 Time schedule for R. & D.

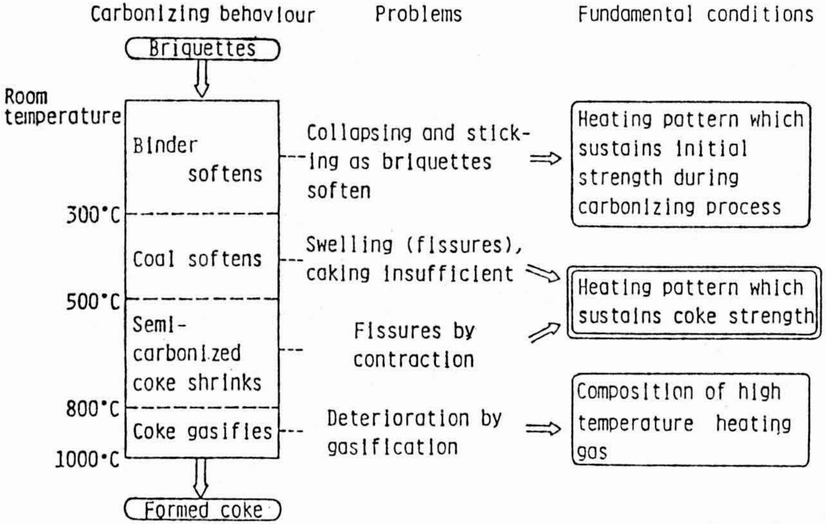


Fig.4 Carbonizing behaviour of cold briquettes and fundamental conditions of carbonization.

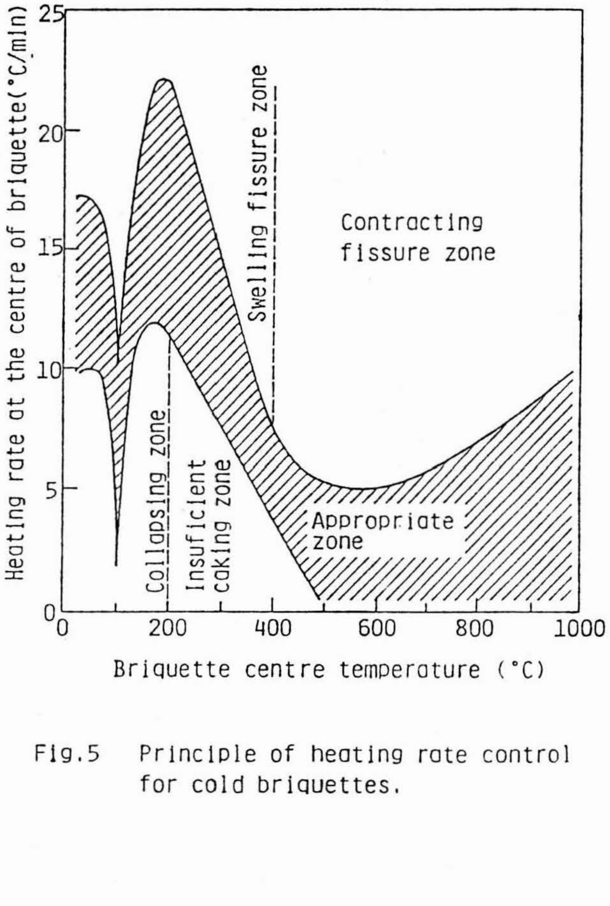


Fig.5 Principle of heating rate control for cold briquettes.

Temperature (°C)	Centre	100	200	300	400
	Surface	350	430	470	530

Fig.6 Section of briquettes heated rapidly in the initial stage.

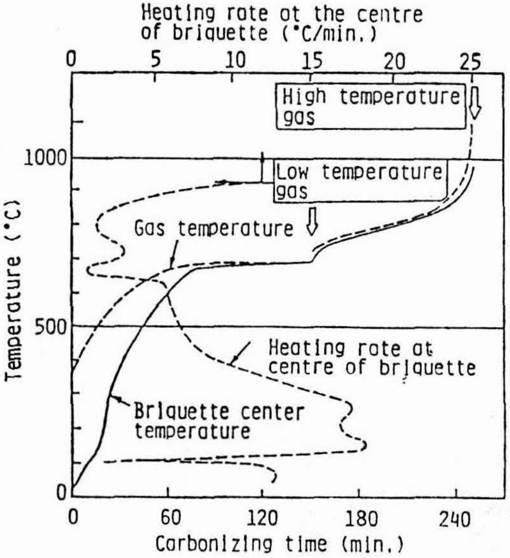


Fig.7 Heating pattern for two-stage heating.

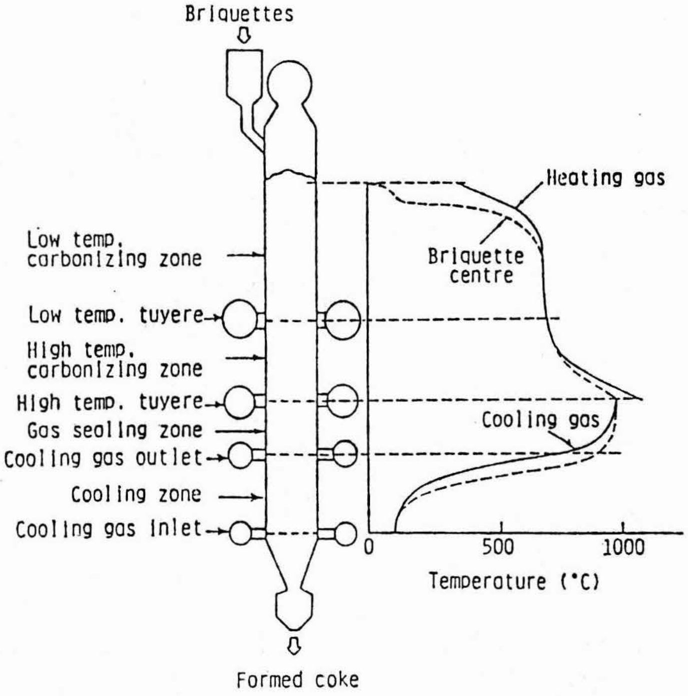


Fig.8 Profile of a carbonizer

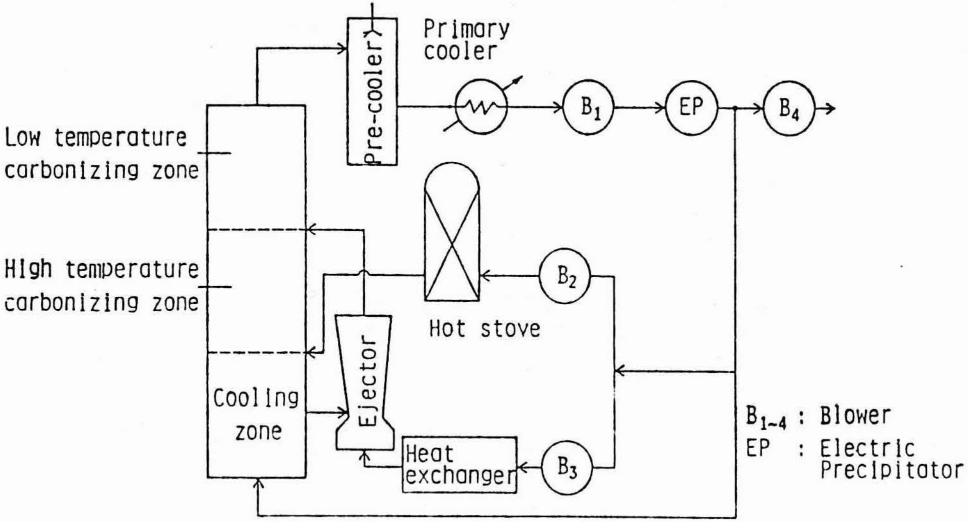
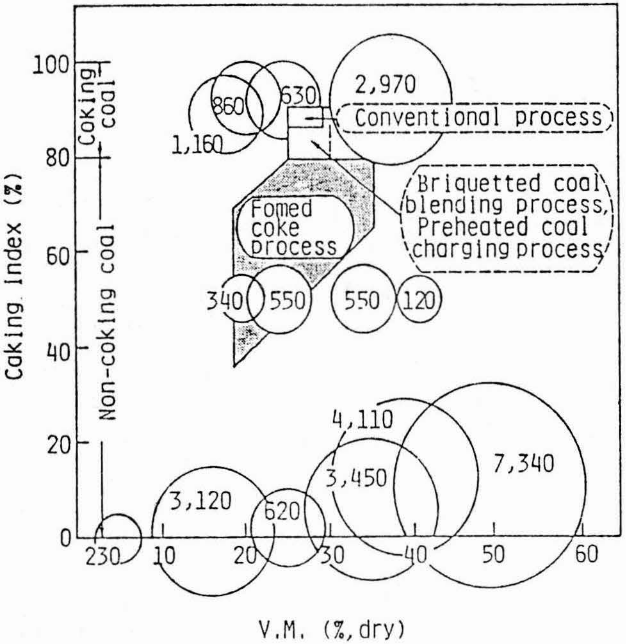


Fig.9 Principle of gas circulation flow.



The figures in circles indicate the theoretical reserves which may be supplied to Japan totaling 2,500 million tons.

Fig.10 Correlations between coal blending conditions and coal resource.

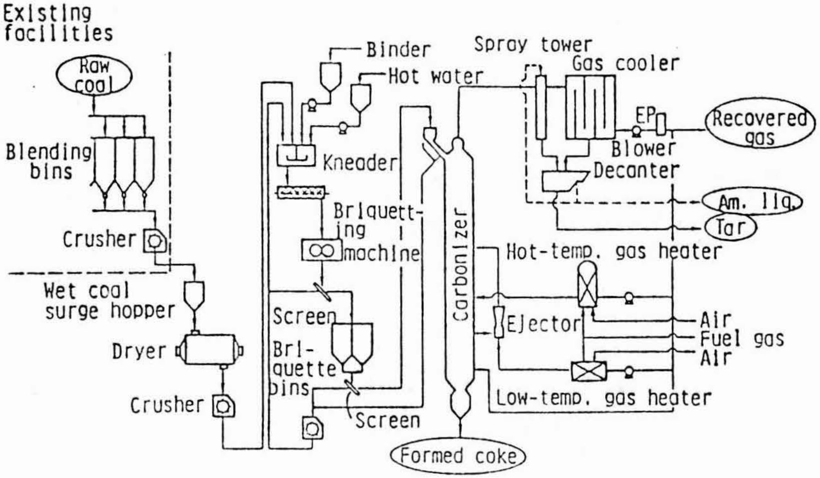


Fig.11 Process flow of the pilot plant.

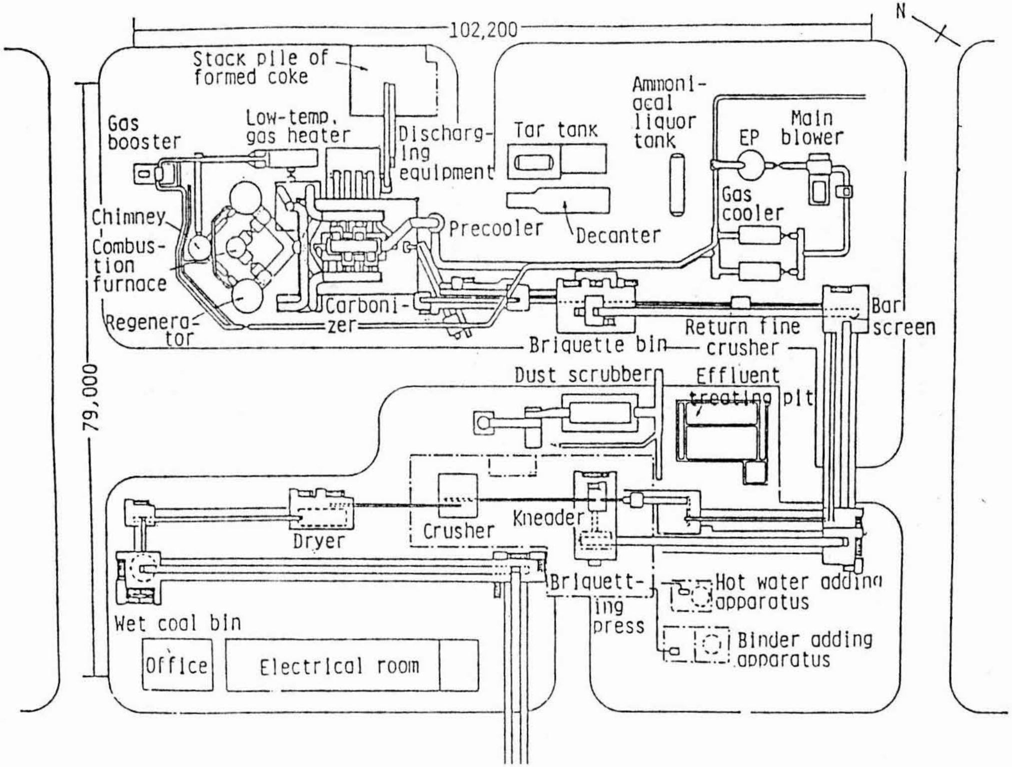


Fig.12 Layout of pilot plant facilities.

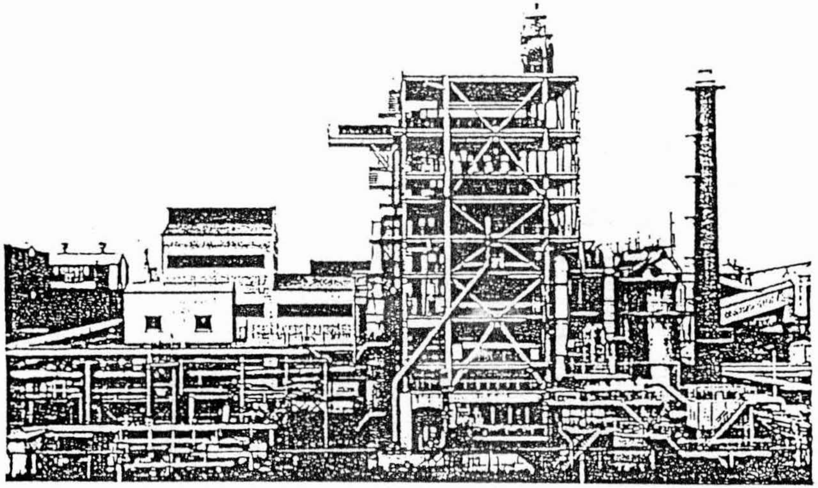


Fig.13 View of the 200t/d pilot plant.

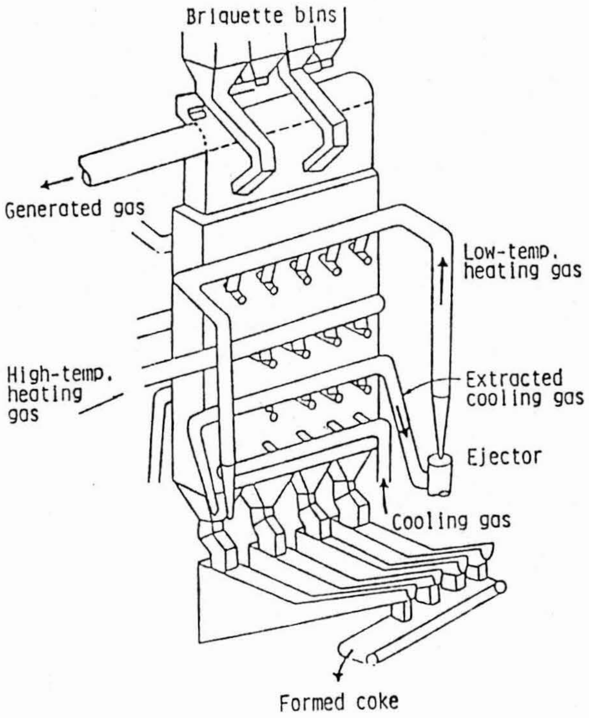
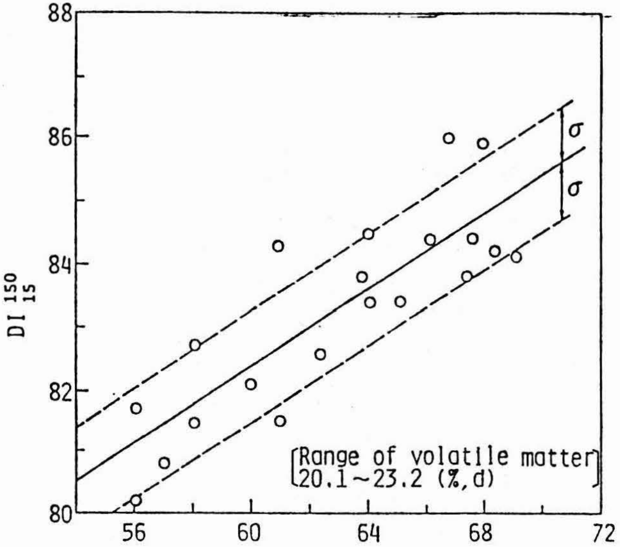


Fig.14 Shematic illustration of carbonizing furnace equipment.



Caking Index of blended coal

Fig.16 Relation between Caking Index of blended coal and coke strength DI^{150}_{15}

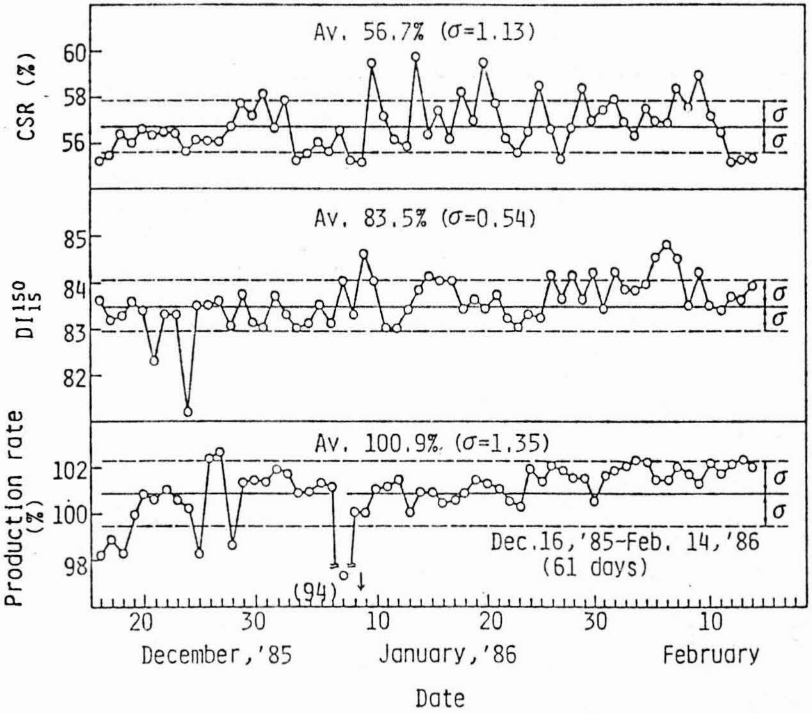


Fig.15 Operating results at 100% production rate.

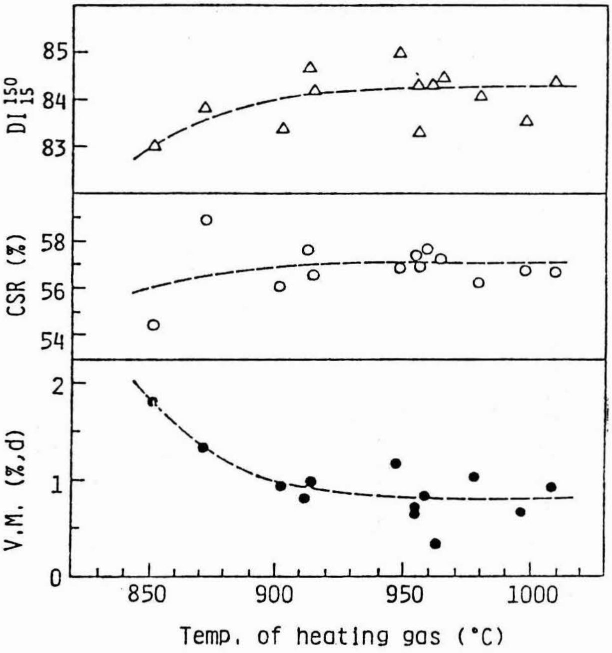


Fig.17 Relation between the heating gas temperature at high temperature tuyere and coke qualities.

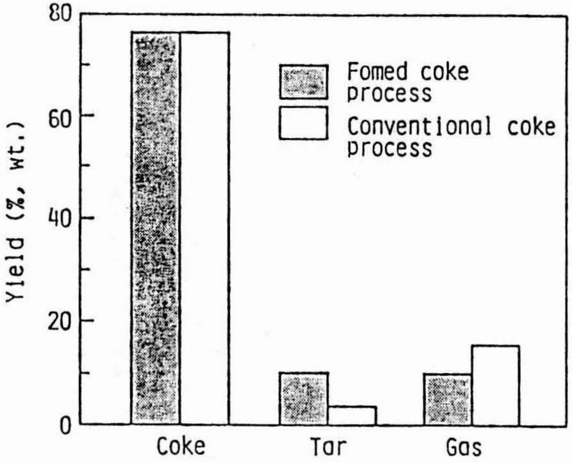


Fig.18 Comparison of fomed coke process with conventional coke process in product yield.

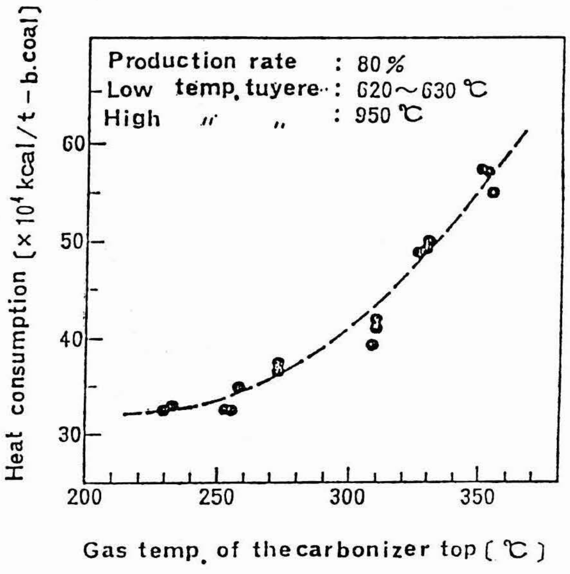


Fig.19 Relation between gas temperature at the carbonizer top and heat consumption

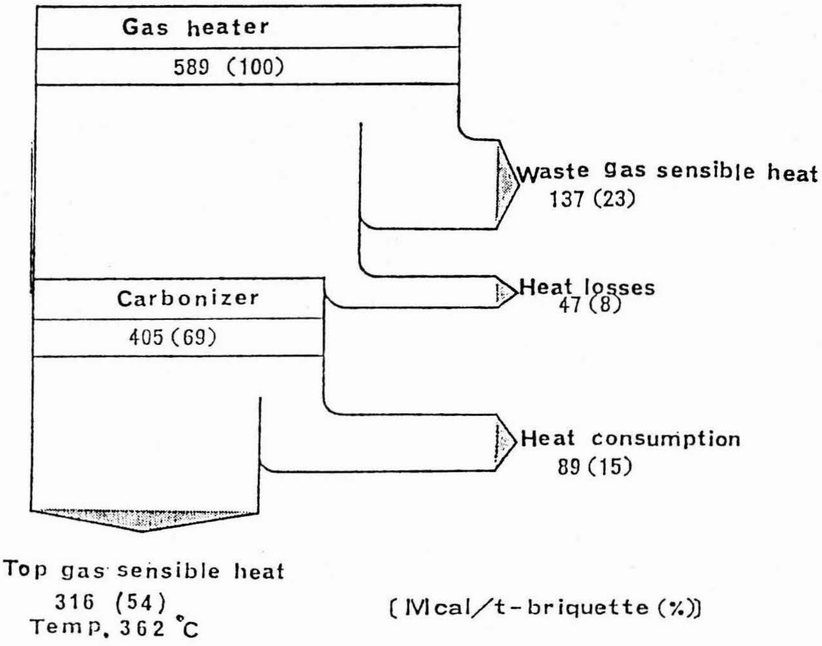


Fig.20 Typical example of heat balance of the pilot plant

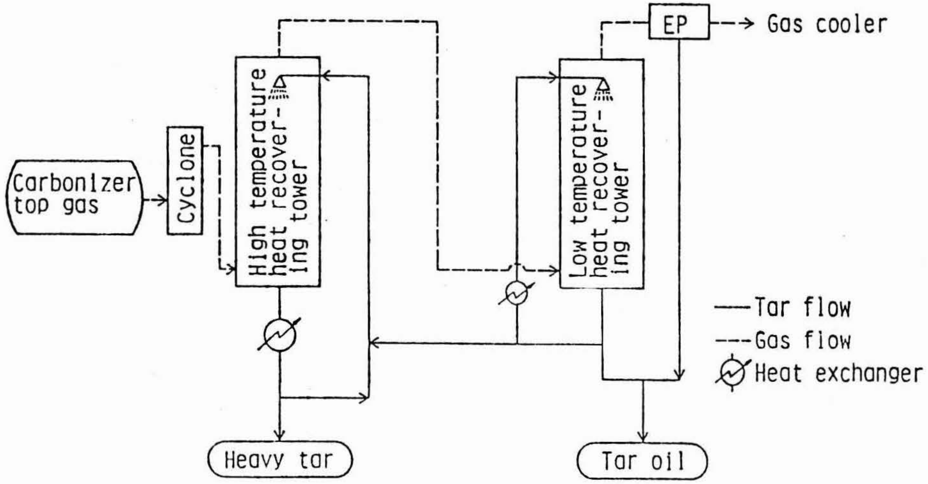


Fig.21 Conceptual sketch of the sensible heat recovering process for carbonizer top gas

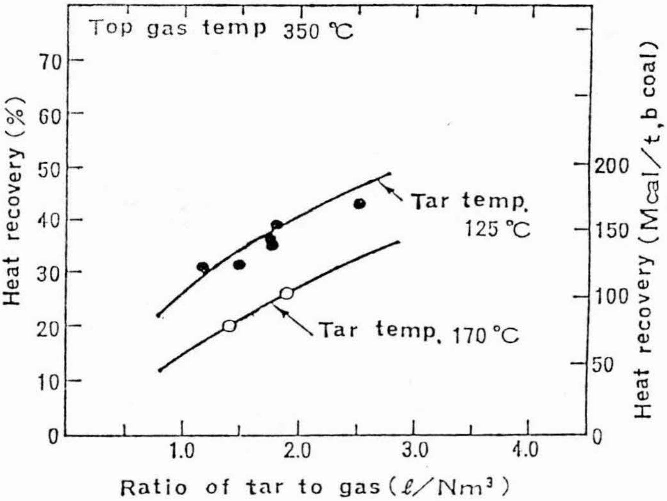


Fig.22 Sensible heat recovery from top gas by tar spray

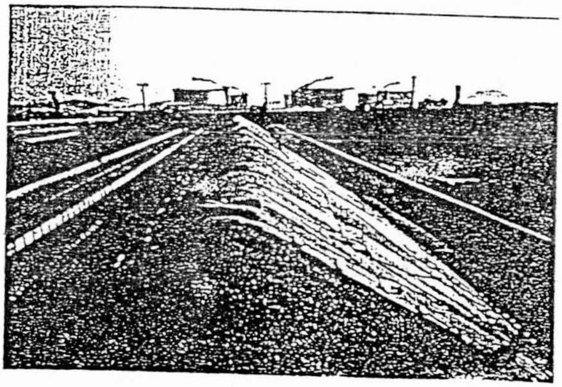


Fig.23 Formed coke stock pile for the blast furnace test

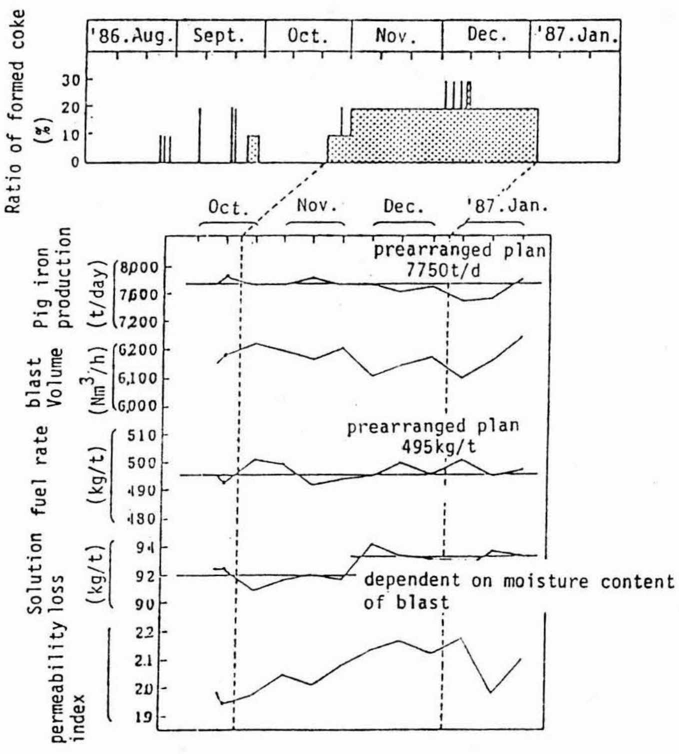


Fig.24 Transition of blast furnace operating conditions using formed coke

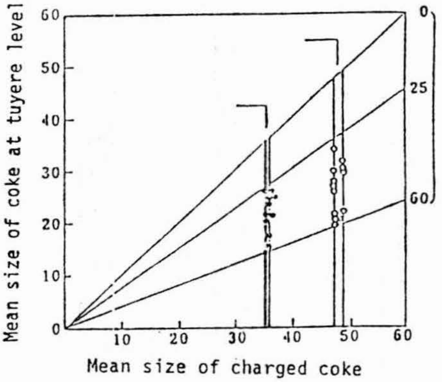


Fig.25 Degradation of particles at blast furnace tuyere

Fig.26 Formed coke sampled from tuyere of Tobata
No.4 blast furnace

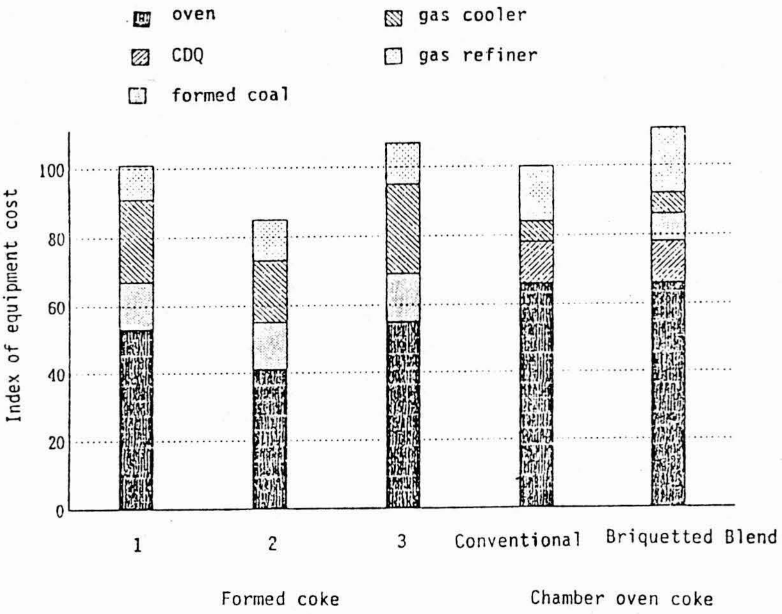


Fig.27 Cost comparison of 3000t/d equipment

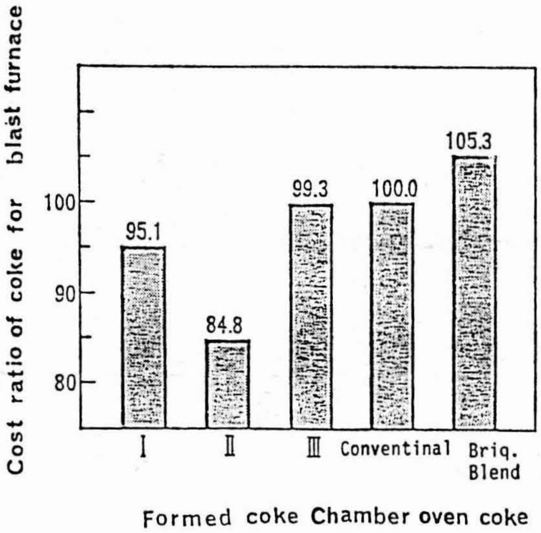


Fig.28 Cost of coke for blast furnace

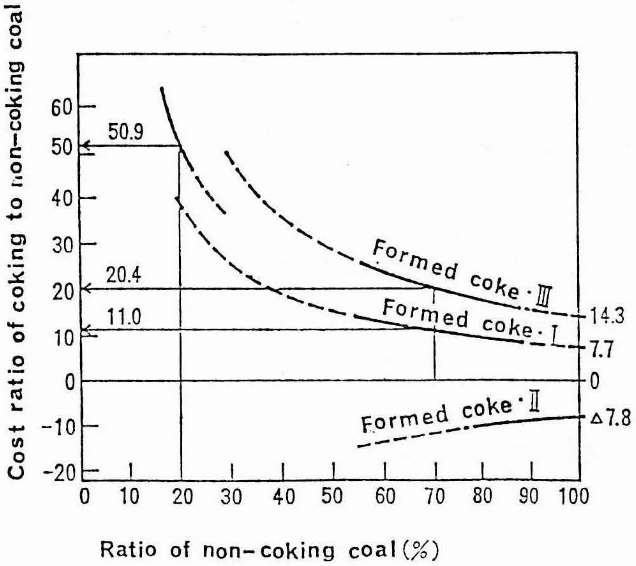


Fig.29 Turning point of commercial profit by price and ratio of non coking coke

Table 1 Main specifications of pilot facilities

No.	Equipment		Number	Capacity	Note
1	Briquetting process	Blending bin	10	200t	Existing facilities
2		2nd crusher	1	150t/h-wet	
3		Wet coal bin	1	50t	
4		Dryer	1	14t/h-dry	
5		Crusher	1	14t/h-dry	
6		Kneader	1	1.5t/batch	
7		Briquetting press	1	18t/h-wet	
8		Briquette bin	1	100t	
9		Returned fine crusher	1	2t/h	
10	Carbonizing process	Carbonizer	1	200t/d	
11		Charging equipment	4	max. : 200kg/batch/unit	
12		Discharging equipment	4	max. : 5t/hr/unit	
13		Precooler	1	30 150 Nm^3/h	
14		Gas cooler	2	15 100 Nm^3/h	
15		Ejector	2	11 200 Nm^3/h-wet	
16		High temp. gas heater	2	5 800 Nm^3/h-wet	
17		Low temp. gas heater	1	13 000 Nm^3/h-wet	
18		Main blower	1	30 150 Nm^3/h	
19		Electric precipitator	1	30 150 Nm^3/h	

Table 2 Dimensions of carbonizer (200t/d)

	Low temp. carbnizing zone		High temp. carbnizing zone	Gas sealing zone	Cooling zone
	Tapered part	Straight part			
Volume (m^3)	13.9	26.6	24.2	23.8	25.0
Hight (m)	2.0	3.3	3.0	2.95	3.11
Width (m)	0.9～1.25	1.25	1.25	1.25	1.25
Length (m)	6.45	6.45	6.45	6.45	6.45
Traveling time (min.)*	50	100	100	105	110

* Production rate 100%

Table 3 Results of pilot plant operation

	5th operation	6th operation	7th operation	8th operation	Total
Days	95 1985.5/12 -8/14	70 1985.9/3 -11/12	90 1985.12/1 -'86.2/28	110 1986.4/3 -7/21	365
Production(t)	15,590	12,900	17,150	21,660	67,300
$\frac{\text{Production}}{\text{Day}}$(t/d)	164 (163)	184 (170)	191 (189)	197 (186)	184 (178)

( )Prearranged plan

Table 4 Properties and blending ratio of coals tested in pilot plant

Coals		Properties						Range of blending ratio (%)
		Ash (%, d)	V.M. (%, d)	T.S (%)	Caking Index	Roga Index	FSI	
Non-coking coals	A	11.5	19.8	0.32	63.5	21.8	1 1/2	0~50
	B*	10.0	19.2	0.53	68.1	20.6	1 1/2	0~17
	C*	11.3	22.6	0.40	48.0	14.0	1	0~29
	D	9.9	26.7	0.38	79.3	48.3	4	0~20
	E	7.4	32.8	0.60	76.9	28.9	1 1/2	0~40
	F	10.2	32.7	0.60	58.6	6.5	1	0~15
	G	10.1	41.2	0.48	21.3	1.6	0	0~10
	H	7.3	44.5	0.71	40.8	18.0	1	0~50
Fine coke	I	11.7	0.4	0.56	0	0	—	0~7
	J**	0.3	10.8	0.67	14.8	0	—	0~10
Coking coals	K	9.7	19.0	0.58	86.5	58.6	8 1/2	0~11
	L	9.7	21.0	0.36	82.6	54.5	6 1/2	0~30
	M	9.4	20.6	0.60	89.0	74.8	9	0~35
Binder	N***	0.1	75.7	0.55	79.8	44.9	—	7~8

* Weathered coal, ** Petroleum coke

*** Coal tar pitch [S.P. 35 ℃]

Table 5 Blending condition and coke quality

			1	2	3	4	5
Blending condition	Ratio (% ,d)	non slightly caking coal	65	68	78	100	75
		caking coal	35	32	22	0	25
		binder	8.0	7.4	7.4	7.4	7.0
	Caking properties	VM(%,d)	26.7	25.8	25.0	24.8	34.4
		C.I.	69.9	65.7	56.5	52.4	68.4
Quality of formed coke	Perticles(%)	+50(mm)	9.2	6.4	3.1	1.9	4.1
		50-25(mm)	83.8	87.0	90.4	93.9	83.3
		-25(mm)	8.0	6.6	6.1	4.5	12.6
	Strength	DI^{150}_{15}	84.1	83.9	84.4	86.3	81.2
		CSR	56.7	56.8	55.8	56.1	47.5
		porosity(%)	38.5	40.1	34.0	29.6	42.4

Table 6 Properties of gas and tar

(1) Recoverd gas

Process	Composition (%, vol)						Calorific value (Kcal/Nm^3)	Gas volume $\left(\frac{Nm^3}{t,\ coal}\right)$
	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℃)	Toluene Insoluble (%, wt)	Ultimate 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