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DEVELOPMENTS IN COKING TECHNOLOGY[1]

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SUMMARY

In general, good coking coal is expensive, whilst non-coking coal is cheap. This is dependent upon the geological distribution of the coal deposits and the supply conditions in the coal market.

On the other hand, the demand for coking coal that is higher in quality as well as lower in price continues to increase because of the rapid growth of the world iron and steel industry.

In order to resolve this contradiction between price and quality of coking coals, a considerable amount of research and development effort has been made in the field of coke production.

The present paper gives practical examples of the research and development carried out in this field in Japan, including the selection of coking coals, pre-treatment of coal charges, increase in the size of coke ovens, the use of formed coke, and new caking materials.

1. INTRODUCTION

Coking technology covers a very wide field; however, this paper will deal only with coke for blast-furnace use.

At first, it is essential for the coke of blast furnace to be heavy-duty against impact, abrasion and high temperature and to be strong enough to keep its shape while it comes down from the top to the bottom of the furnace. Secondly, the content of impurities such as ash, sulphur, and phosphorus should be fairly low. In order to meet the two conditions mentioned above, it is necessary to use a coking coal of excellent quality as the raw material for the coke. For this reason, research and development in coking technology are based on requirements by the operators of blast furnaces.

The blast furnace operators are given an important task to reduce the cost of iron for supplying iron products in the market at a lower price.

The price of the coke forms a large part of the iron cost.

Therefore, blast furnace operators always are looking for inexpensive coke of good quality.

In general, a coking coal of high quality is expensive, and one of low quality is economical. To produce a cheaper coke, the quality of the coke must be lower. On the other hand, to make the coke of good quality, the price of coke increases.

In order to solve this contradiction, a great deal of effort has been done for research and development in the field of coke production.

2. IRON PRODUCTION IN JAPAN

The total production of iron was less than 10 million tons until 1959, but the huge demand for iron and steel after then increased the production to over 70 million tons in 1971.
In the same time, blast furnaces increased in size, and there was remarkable progress bringing high productivity and lower coke ratio, with improvements in the quality of burden, the realization of high temperature blast, high top pressure operation, fuel injection and oxygen enrichment of the blast. These developments are shown in Fig. 1 and 2.

3. CONSUMPTION OF COKING COAL IN JAPAN

In Japan, before 1945, the coke for blast furnace use was made from the blend of Chinese and domestic coking coal, but its quality was not high enough.
After World War II, the improvement of coke quality became essential for the increase in the production of iron and steel.
To gain this end, the import of the US hard coking coal of high quality was started in 1948. As a result, the ash content of coke was greatly reduced, reaching about 10 % in 1958, with the decreased ash content of also the domestic soft coking coal. At the same time, the strength of coke was improved,close to the present level.

With the further increase in the production of iron and steel, coking coals from Australia and Canada were also imported.
In 1971, the consumption of coking coal for iron production amounted to 55 million tons, and the sources of these coals are as follows:-
US---34%, Australia---29%, Canada---12%, USSR---4%, Poland---2%, Domestics ---19%.
The progress of the growth is shown in Fig. 3.

4. DEVELOPMENTS OF COKING TECHNOLOGY IN JAPAN

The development of coking technology in Japan has been influenced by the consumption tendency of coking coal.

During the restoration period of the Japanese economy after War II, it was necessary to bring up and expand at a high pace the coal industry and the iron and steel industry.

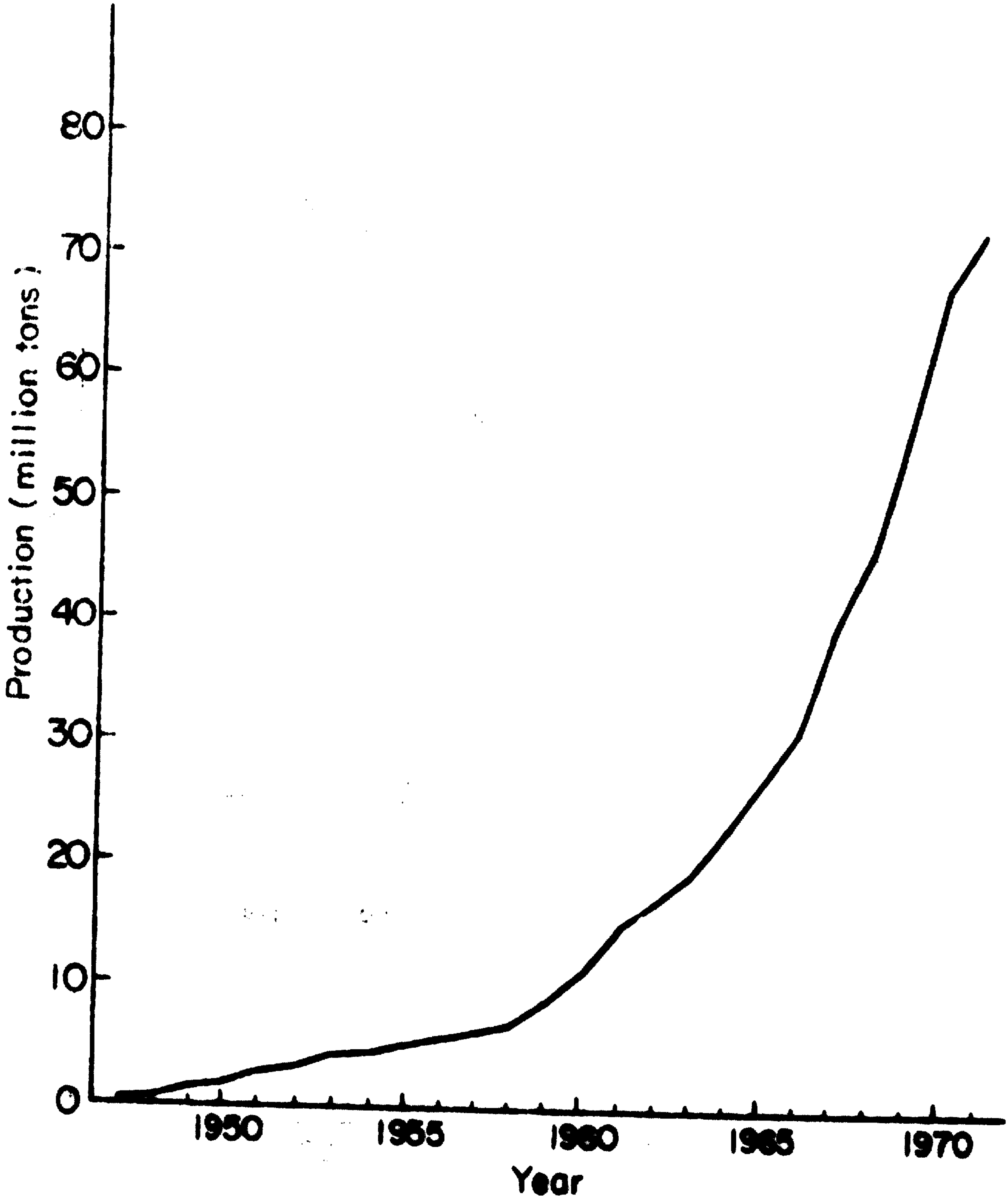


Fig. 1 - Development of iron production in Japan

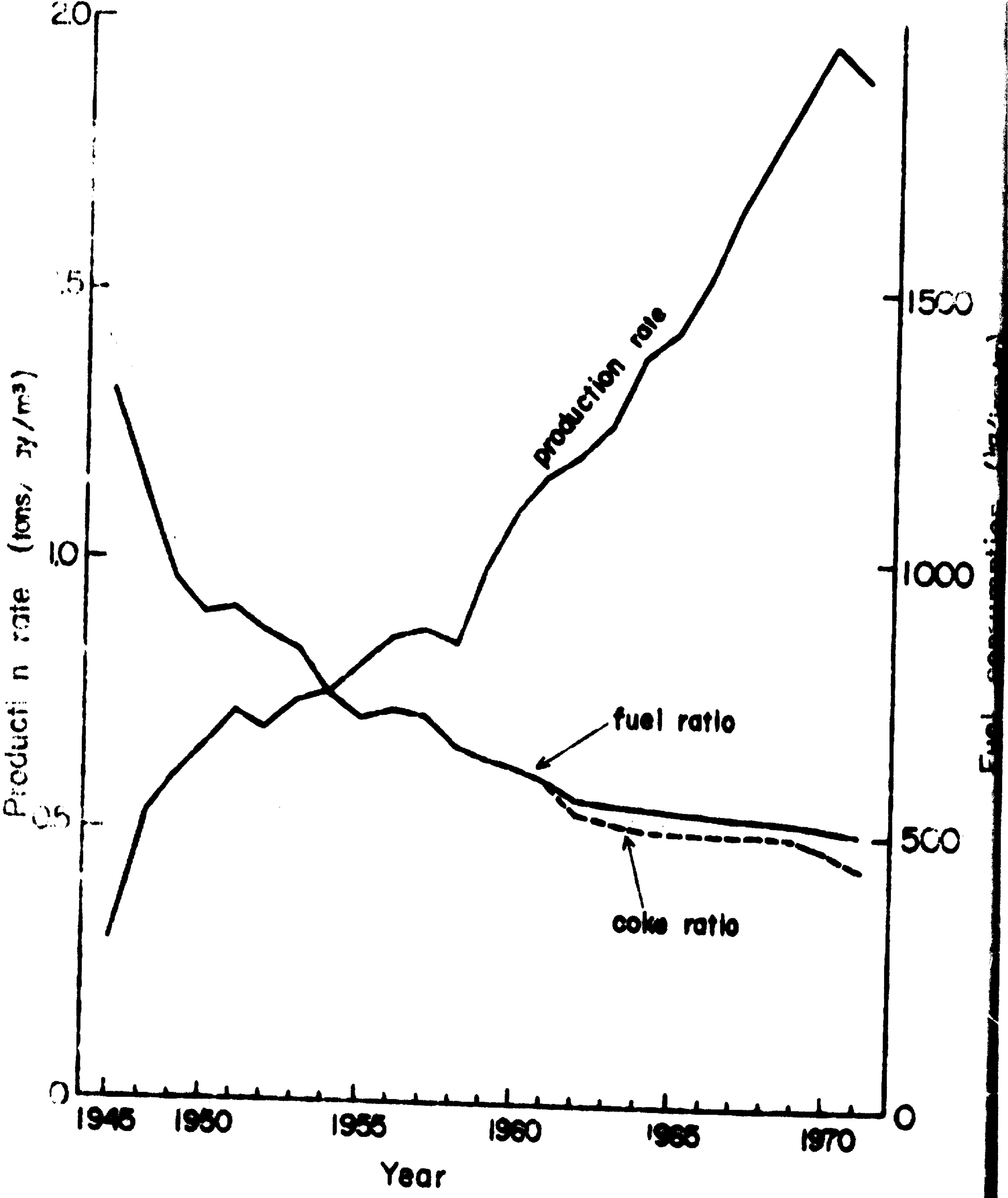


Fig. 2 - Development of blast-furnace production rates and fuel consumptions in Japan

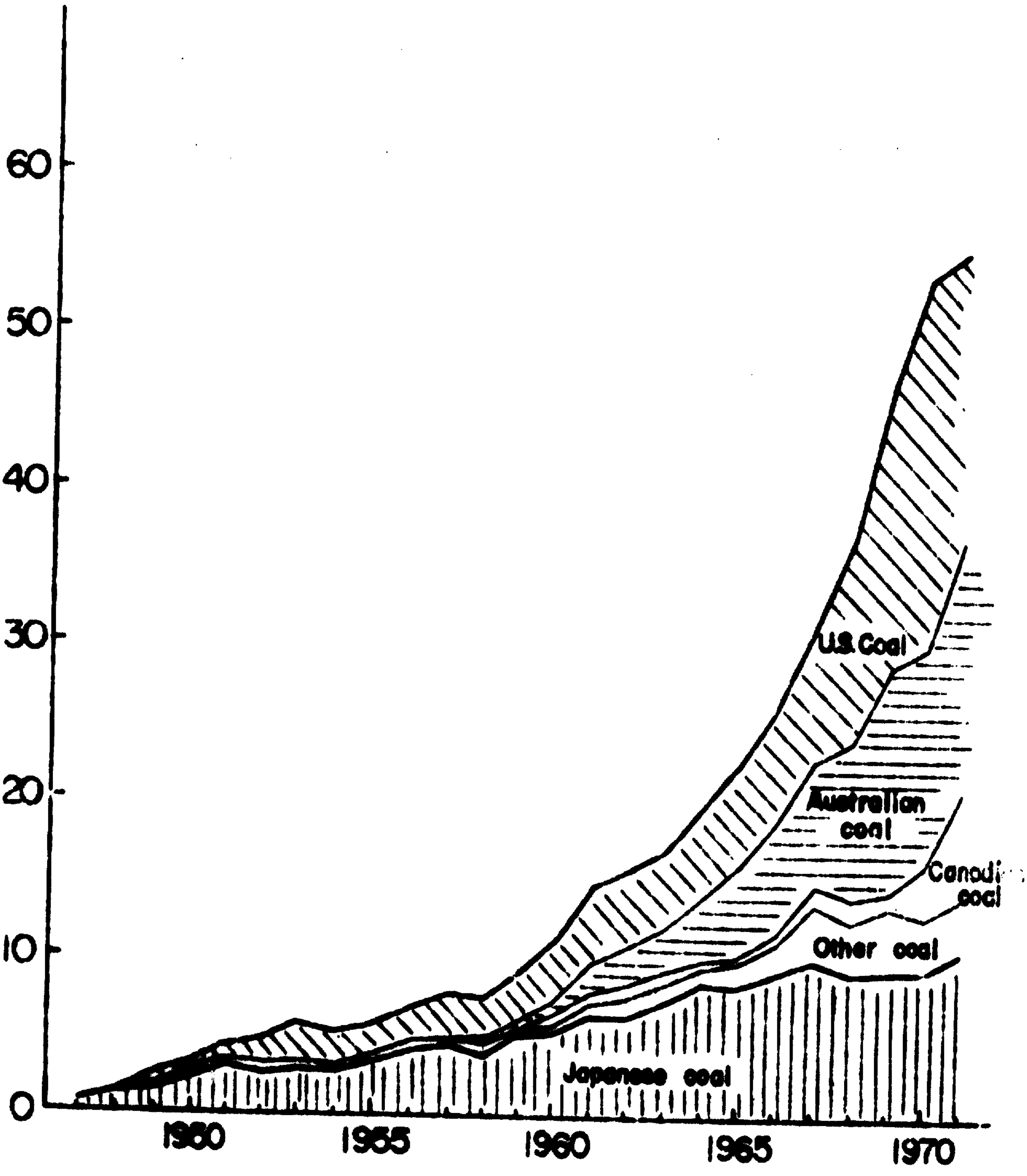


Fig. 3 - Development of coking coal consumption in Japan

The iron and steel industry was obliged by government policy to use domestic coal.

However, the production of hard coking coal in Japan had been very little and the deposit of this coal was almost exhausted. Most of the coal produced was soft coking coal of high volatile content.

As the result of many kinds of research, it was concluded that the most suitable coal to cover the poor strength of the domestic coking coal was U.S. hard coking coal of low to medium volatile content.

After 1957, Australian and Canadian coking coals were imported to reduce the cost of coke. However, these coals contain much more inert materials than the US and the domestic coals, and such inert materials exist mainly in coarse particles of the coal.
When such coals are used for coal blending in coke oven, the strength of coke naturally falls. The fall of coke strength could be compensated by making some suitable treatment before the coal is charged into coke oven. The methods for the pre-treatment include further crushing, selective crushing, dry charging, briquette charging of coal blend.
They were adopted into Japanese coke-plant practice, with good results.

On the other hand, coke ovens became larger as blast furnaces increased in size. Until 1960, most of the Japanese coke ovens had been 4 meters high with the charging quantity of about 15 tons per oven.
In 1965, a 6 meters high coke-oven battery was constracted for the first time and new ovens after then were almost more than 5 meters high.
With the enlarged coke ovens, the charging quantity of coal per oven was increased to about 35 tons.

Along with the enlargement of coke ovens, carbonization time was greatly shortened. The carbonization time was usually 4 hours per 100 mm of oven width, but nowadays it has shortened further to 3.5 hours.

It seems that for conventional coke ovens the limit of development has been reached with the improvement in pre-treatment technology of coal charge, the enlargement of coke ovens and the increase in productivity of coke ovens.

So long as the conventional coking method is employed, coking coal, especially hard coking coal of good quality is absolutely necessary.
However, hard coking coal of good quality is deposited in some limited

areas on the earth, and the resources of it are tending to become exhausted. Therefore, we are compelled to develop new technology in the field of coke production. Non-coking coal is more abundantly deposited than hard coking coal. The experimental use of non-coking as a part of coal blend for production of metallurgical coke has been carried out by many countries all over the world. In the conventional coking method, even if the use of non-coking coal is possible by the adjustment of coking properties in the blend, the ratio of non-coking coal is said to be about 5% at maximum.

Other than the conventional coking method, formed coking method is regarded as the most promising. This method permits the use of non-coking coal more than 80%. This method has not yet been applied commercially on an industrial scale, but it is expected to be realized economically in several years.

Recently in Japan, strong caking materials from petroleum, with similar properties to hard coking coals of good quality, are being tested for the production of coke.
This method will be commercialized on an industrial scale in a few years after the present development stage.

5. SELECTION OF COKING COAL

There are various methods of classifying coals. The classification method of ASTM(1), for example, is shown in Table 1.

The coking coal is classified into three types, i.e. low-volatile bituminous coal, medium-volatile bituminous coal, and high-volatile bituminous coal. It is also usually classified into hard coking coal and soft coking coal in accordance with the strength of produced coke.

In order to decide what kind of coking coal is used as a coal charge for coke ovens, it is necessary to know the caking characteristics of each kind of coal.
The most important factor is the strength of coke, when it is carbonized. The relations between the caking characteristics of coal and the coke strength are represented in terms of coking properties.
The coking properties of coal depend on the content of volatile materials and the fluidity.

Table 1. Classification of coals by rank (ASTM)

Class	Group	Fixed Carbon, per cent (Dry, Mineral-Matter-Free Basis)	Volatile Matter, per cent (Dry, Mineral-Matter-Free Basis)	Calorific Value, Btu per lb (Moist, Mineral Matter-Free Basis)	Agglomerating Character
I. Anthracite	1. Meta-anthracite	>98	<2	---	Nonagglomerating
	2. Anthracite	92----98	2-----8	---	
	3. Semianthracite	86----92	8----14	---	
II. Bituminous	1. Low-volatile bituminous coal	78----86	14----22	---	Commonly agglomerating
	2. Medium-volatile bituminous coal	69----78	22----31	---	
	3. High-volatile A bituminous coal	<69	>31	>14,000	
	4. High-volatile B bituminous coal	----	----	13,000-14,000	
	5. High-volatile C bituminous coal	----	----	11,500-13,000 10,500-11,500	
III. Subbituminous	1. Subbituminous A coal	----	----	10,500-11,500	Nonagglomerating
	2. Subbituminous B coal	----	----	9,500-10,500	
	3. Subbituminous C coal	----	----	8,300- 9,500	
IV. Lignite	1. Lignite A	----	----	6,300- 8,300	
	2. Lignite B	----	----	<6,300	

In general, a coal containing less inert materials has high fluidity under the same degree of coalification. The fluidity of high-volatile bituminous coal is higher than that of low-volatile bituminous coal, as seen in Fig. 4. The coke made from high-volatile coking coal is weak in strength because of many fissures (Fig. 5).
The use of low-volatile coking coal in coke ovens cause their walls to break because of the strong expansion pressure of the coal.

Therefore, it is necessary to mix at a suitable ratio, as a regular practice, high-volatile coking coal with low-volatile coking coal in order to produce high-strength coke of good quality.
The blending ratio is dependent on experience in most cases.
In Japan, for example, the following has been understood as a rule in blending coals for the produce of coke. Namely, when the coking properties are represented by the two indices of volatile matter and fluidity, coal blends within the range shown as "charging coal" in Fig. 6 are most suitable.

In recent years, however, there have been attempts in many countries to show the coking properties by means of coal petrography.
Shappiro's(2) research is one of the most conspicuous attempts and is nearly a completed blending rule as far as the coals of US origin are concerned.

In case of Japan, coals from many countries are used at various mixing ratios, so that Shappiro's blending rule can not be applied without some modification. Y. Okuyama says(3) " Various coking coal can be stratified by two parameters -- Reflectance of Vitrinites and Gieseler maximum fluidity of coal --. This stratifing system is useful to pre-evaluation of coking coals, especially in the case of large quantity of sample cannot be obtained."

It is important first of all to know the coking properties of coals available, if you want to produce coke for blast furnaces in your country. Secondly, you should determine a target value of the strength of coke. It will naturally determine kinds of coal and contents of coal blending accordingly.

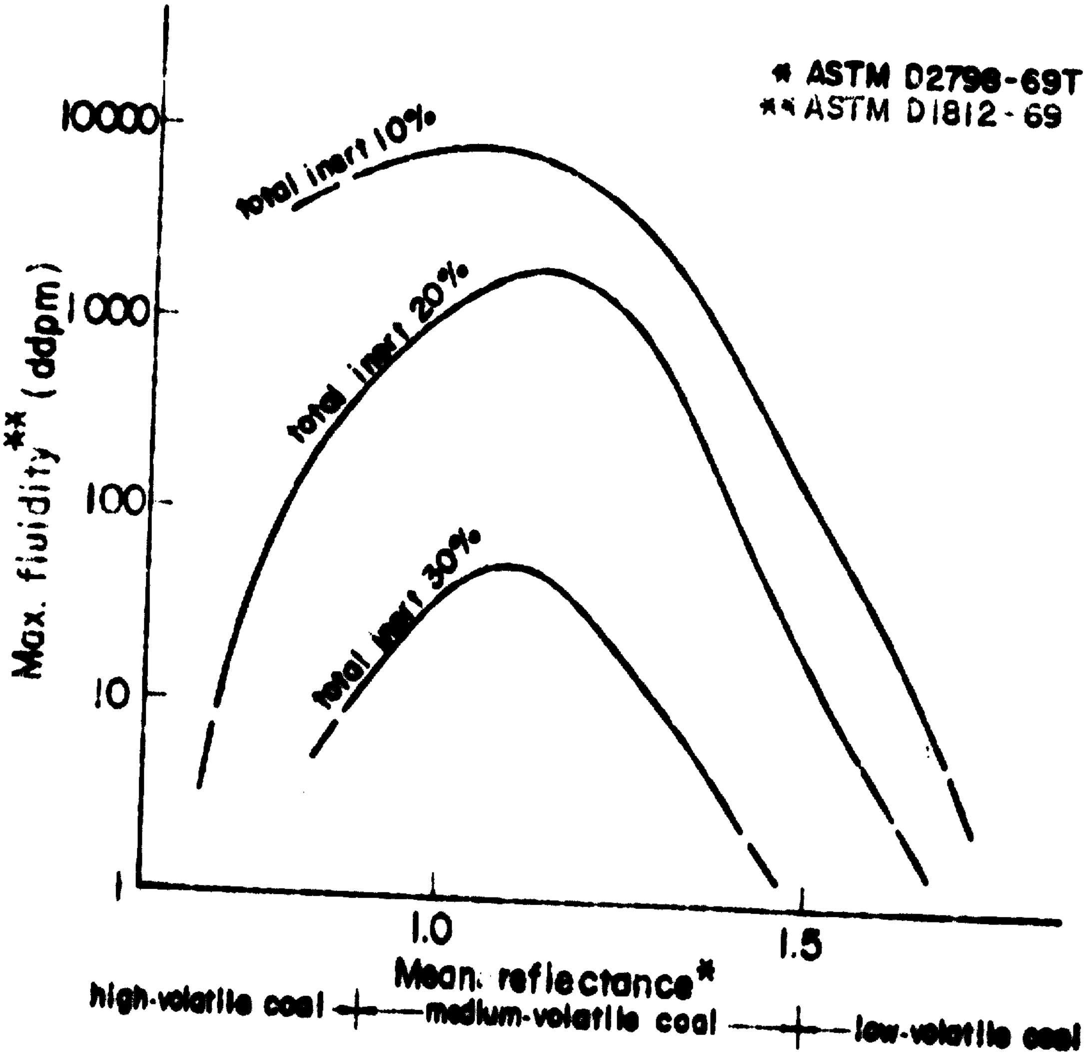


Fig. 4 - Relationship between maximum fluidity and ranking of coals

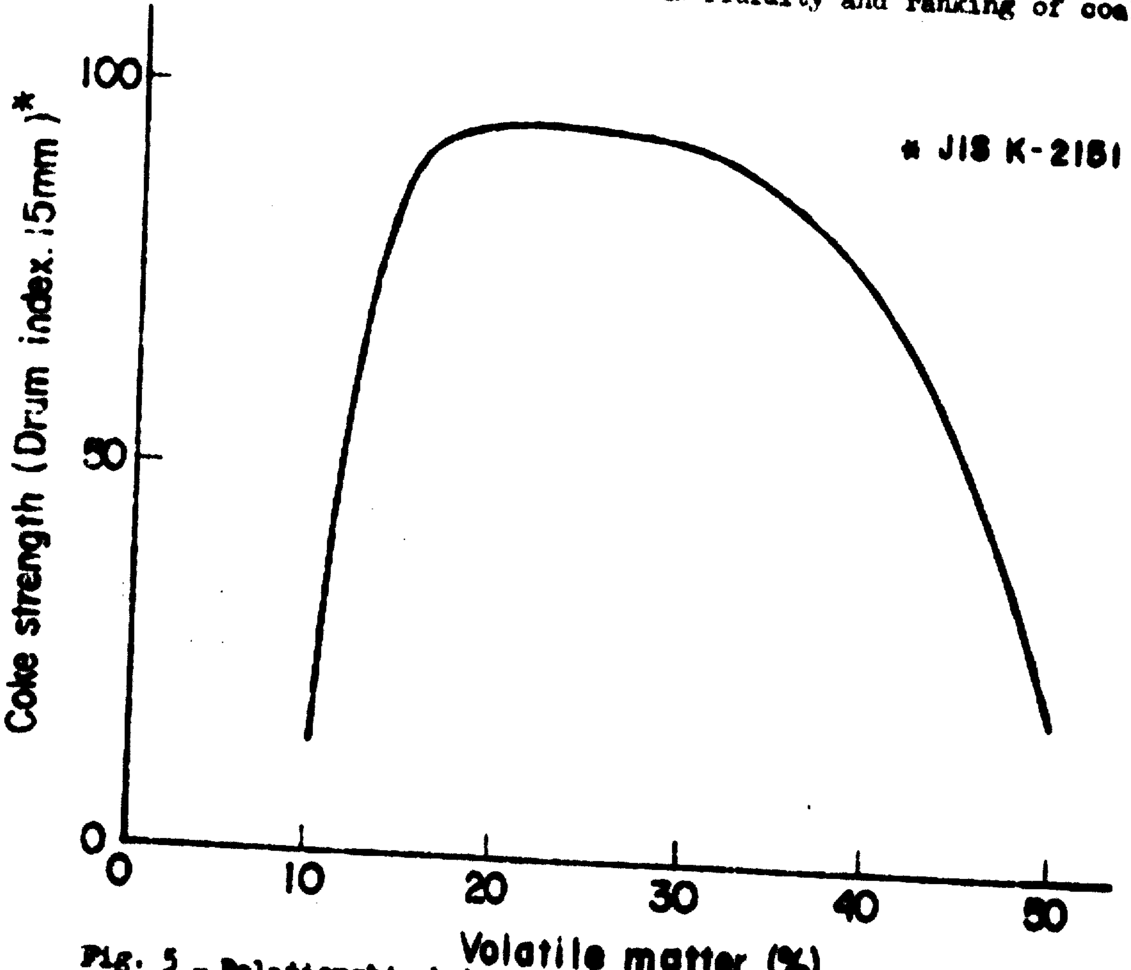


Fig. 5 - Relationship between volatile matter in coal and coke strength

In case there are some limitations on them, you should try to improve the strength of coke by the use of pre-treatments of coal blends.

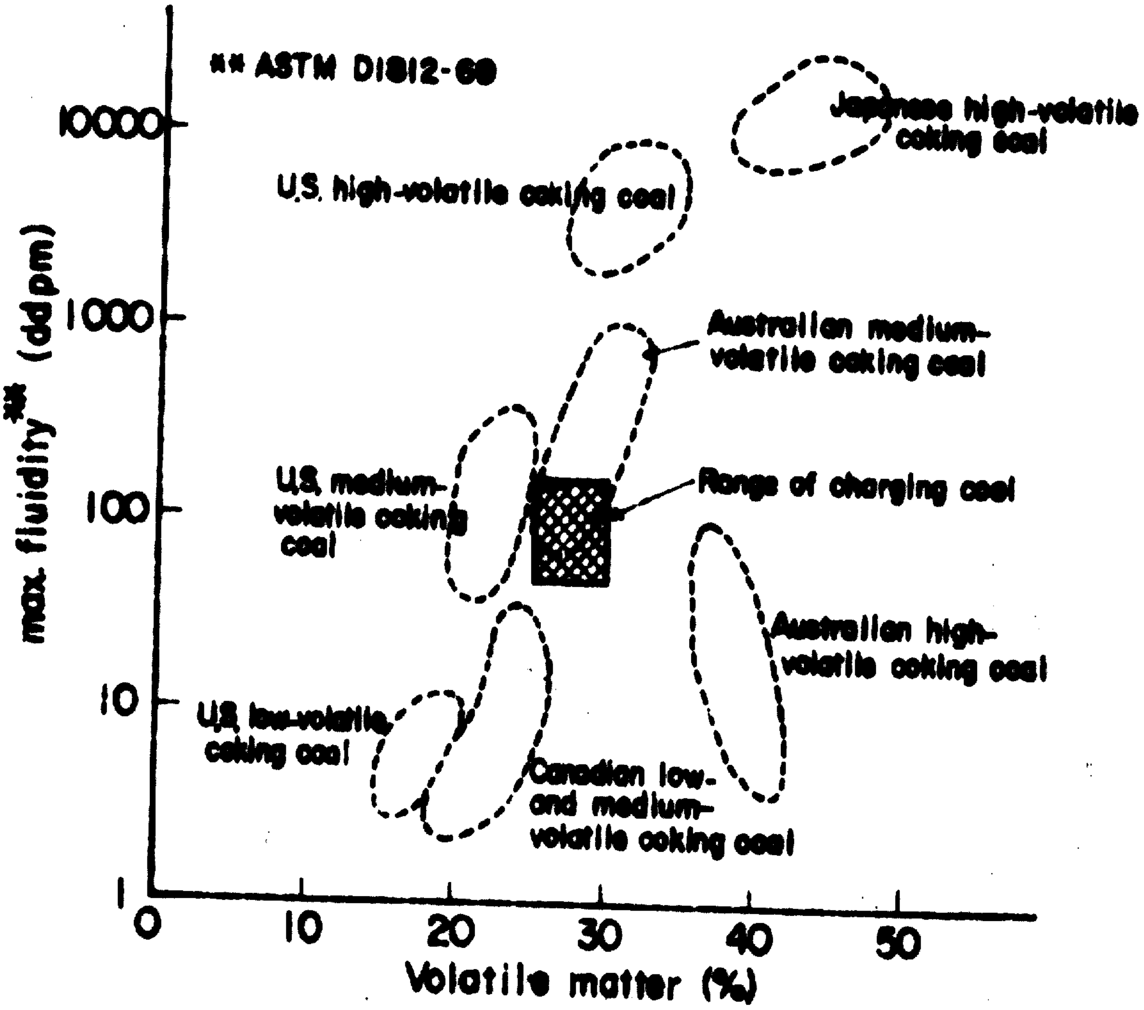


Fig. 6 - Rules for coke blending

6. PRE-TREATMENTS OF COAL BLEND

6-1. Selective Crushing of Coals

Regarding rules for the composition of industrial coal blends, D. W. Van Krevelen(4) says as follows:

" The inerts present in a blend must be substances that do not contract in the region of resolidification so that the mean contraction rate of the blend decreases. On the other hand, at higher temperature they should contract in preferably the same way as the other coals. If they do not, it is recommendable to grind them very finely."

Coal is usually ground to a specific particle size before charging. The particle size of coal charge is related to the strength of produced coke as shown in Fig. 7.

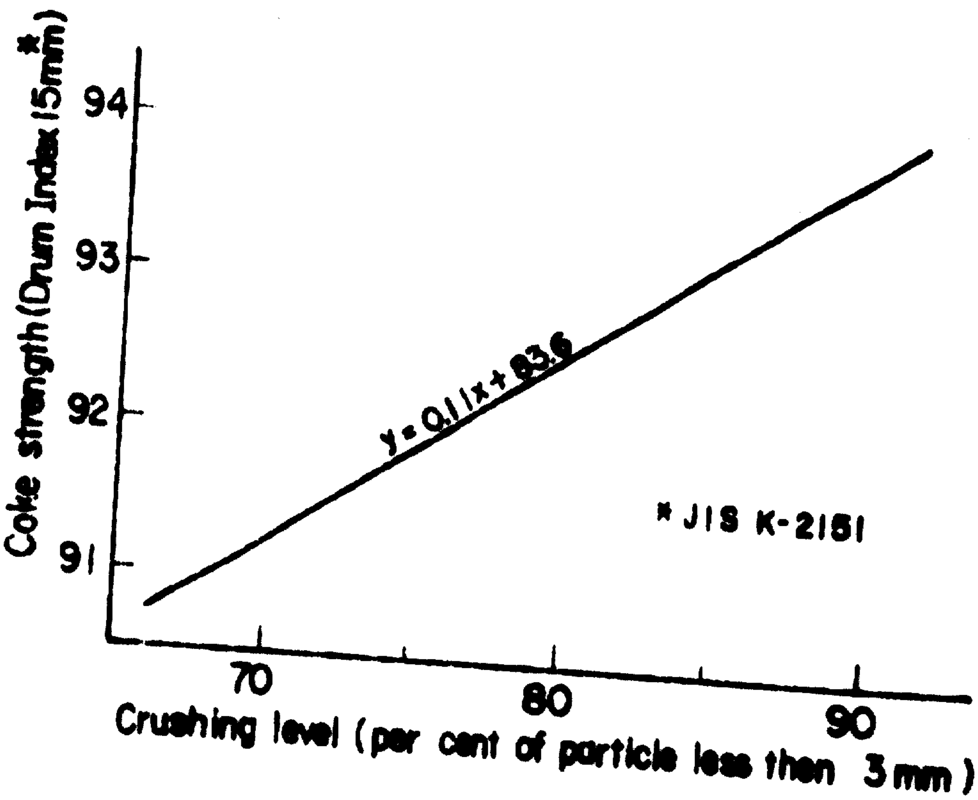


Fig. 7 - Relationship between crushing level of coal and coke strength A

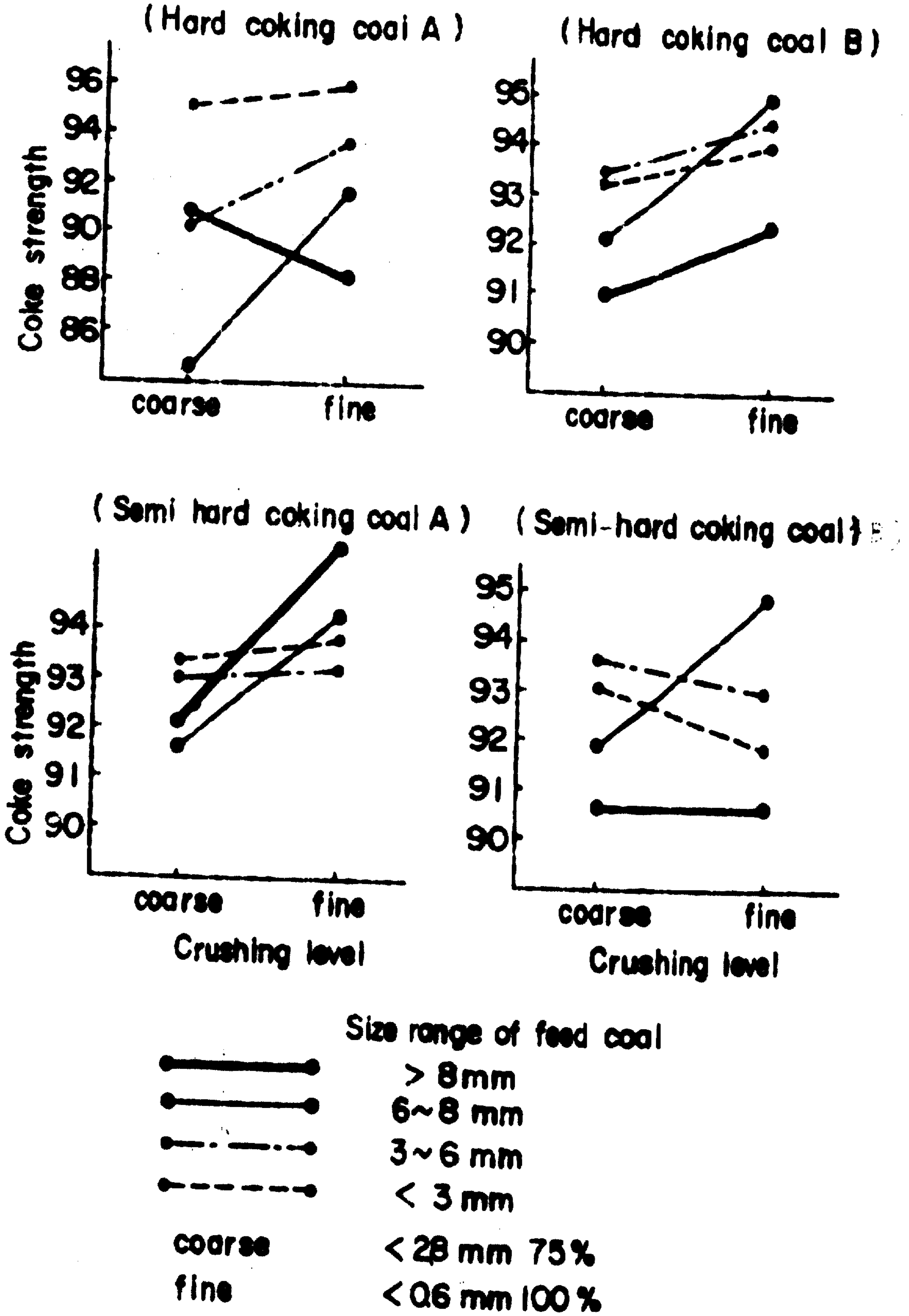


Fig. 8 – Relationships between crushing level of coal and coke strength

Coking properties sometimes vary depending upon their particle sizes even if they are produced from the same deposit. This is illustrated in Fig. 8. In some cases, finer particles increase the coke strength, and on the other hand, there are some coals whose strength does not increase, even with fine particles.

Such a phenomenon is understood as follows:-
The coals in which inert materials are concentrated are usually hard and difficult to grind, and then they may cause cracking and spoil the coke strength.
On the other hand, coals with less inert materials are easily ground, so that the structure of coke from these coals becomes homogeneous and the coke strength is improved. Therefore, it is necessary to grind finely coals containing much inert materials and to scatter the particles uniformly into the coke structure.

From the viewpoint mentioned above, several kinds of improvement were carried out on the crushing method of coals in Japan where coking coals of high inert material contents have been increasingly used. For example, an effective crushing method is being used by the Kashima works of Sumitomo Metal Industries, Ltd. which installed a screening equipment and a coal dryer in the crushing process of coke plant. Fig. 9 shows the flow diagram of the coal preparation plant at Kashima.

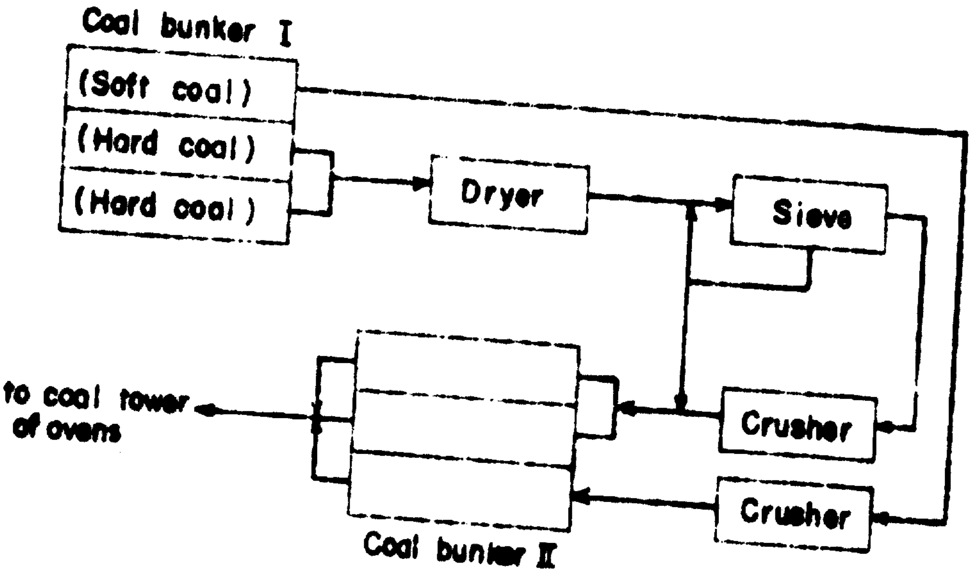


Fig. 9 - Flow diagram of coal preparation plant at Kashima

6-2. Dry Charging

It is commonly known that the decrease of moisture content in coal charge increases the bulk density of coal charge, and it results in improvments in coke strength.

In 1965, a large scale experiment was carried out on bulk density of coal charge by The Iron and Steel Institute of Japan, and Fig. 10 shows the results(5).

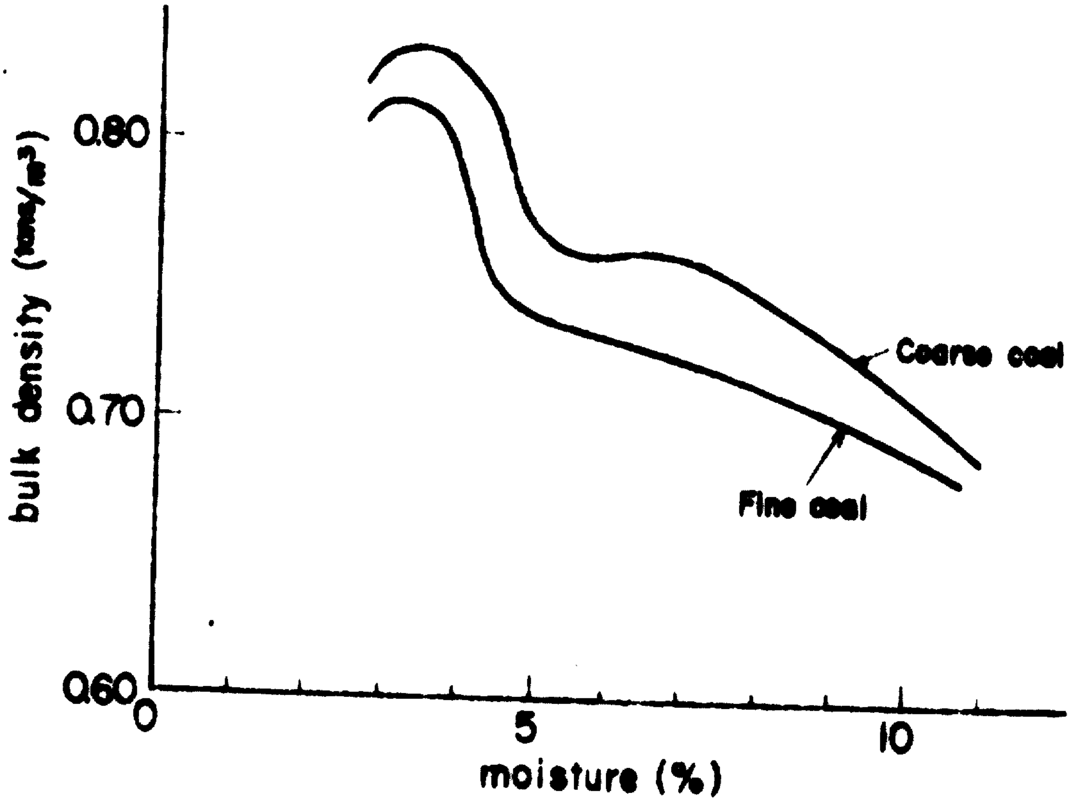


Fig. 10 - Relationship between moisture content in coal and bulk density

In 1968, a coal dryer of 300 tons per hour was constructed in the coke plant at the Fukuyama works of Nippon Kokan K.K. and coal drying started from December of that year.

From the results(6), the decrease of moisture content from 8 % to 4.5 % of the coal charge could increase the quantity of coal charge into coke ovens by 7 %, shorten the carbonization time by 3 %,and raise the productivity of coke ovens by 10 %. Good results were obtained also in improvement of coke strength and uniformity of coke size.

6-3. Briquette Charging

Briquette charging is one method for improving coke strength.

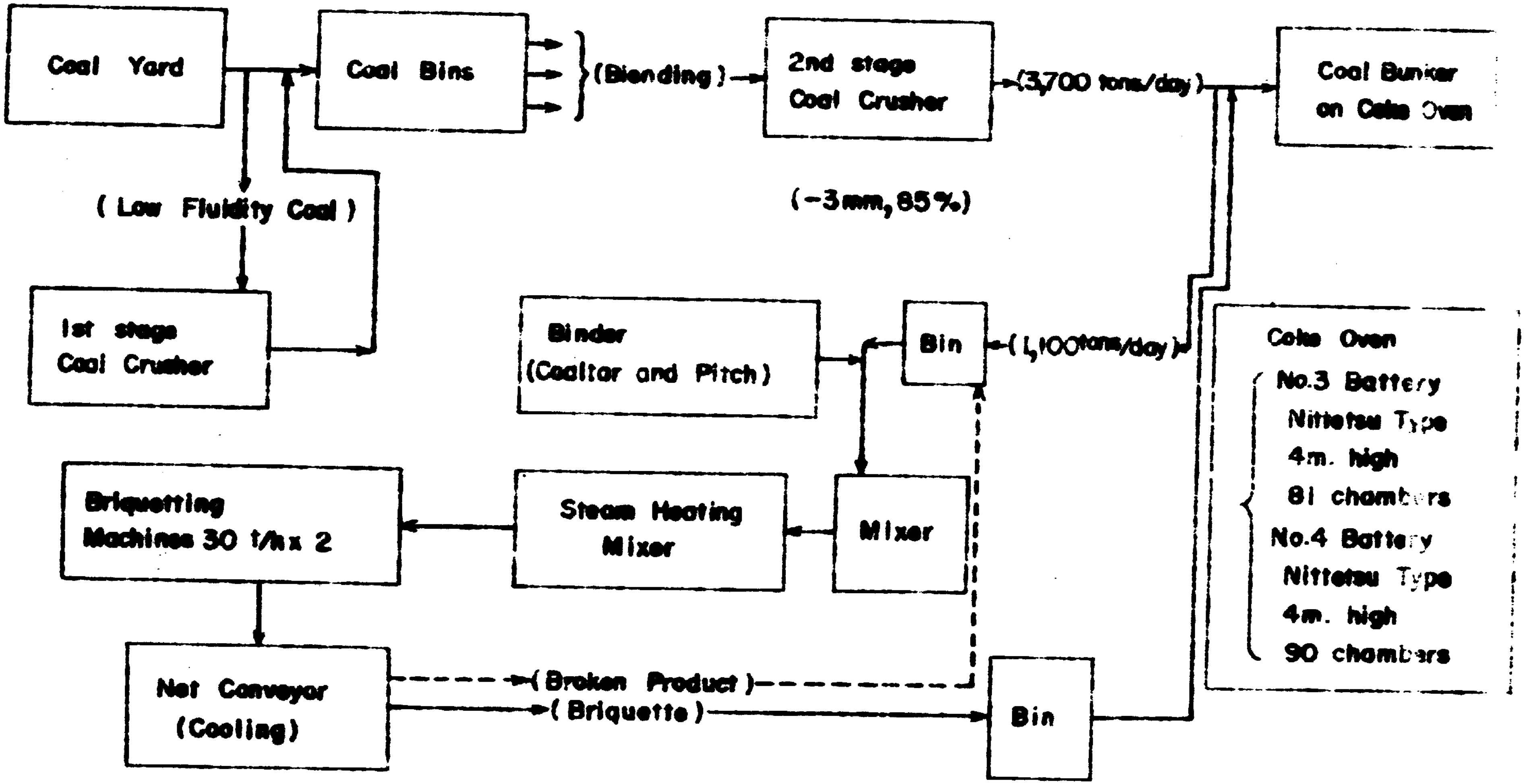
Two methods are used for briquette charging. One is to charge the total quantity of coal charge in the shape of briquettes into coke ovens without using a binder. This method has been carried out for many years at the Volklingen works of Roehlingsche Eisen und Stahlwerke GmbH, West Germany.

In Japan, an industrial-scale experiment of this method was carried out for two years from 1965 by The Iron and Steel Institute of Japan(7). As the results, it was found that the quantity of coal charge has increase by 15 % and the hard coking coal in the coal charge can be reduced by 12-15 %.

In this method, however, coal briquettes are easily broken during charging into coke ovens and there are many problem in putting it to practical use in a large scale coke plant. For this reason it could not be adopted in Japan.

In another method, a part of coal charge is made into briquettes using a binder, and then the coal briquettes are charged into coke ovens after mixing them with the remaining coal charge.

This method has already been operating on a commercial scale at the Tobata works of Nippon Steel Corporation since 1971, and the effect of briquetting 30 % of coal charge has been reported as follows(8):-
Coke strength increase by 1 to 4 %, dependent on type of coal.
If the coke strength is fixed, about 10 % of the coking coal can be replaced by non-coking coal. The bulk density of the coal charge is increased by approximately 8 %. Fig. 11 shows the block flow diagram of this coke plant.



(Size 44mm x 44mm x 26mm)

Fig. 11 - Flow diagram of the coal briquette charge system at the Tobata Works

7. ENLARGEMENT OF COKE OVENS

In Japan, blast furnace have been getting larger and larger in volume, and today there is one large furnace with exceeds 4000 cubic meters, for which about 5,000 tons per day of coke are needed.

The production capacity of coke oven is determined by the number of ovens, carbonization time and the inner volume of oven chamber.

Since there is a lower limit to the carbonizing time, it is necessary to increase the number of oven or the inner volume of oven chambers so that the coke output can be raised. The former requires larger area and more workers although it is easy technically.
Therefore, the latter has been adopted in many cases in Japan.
Fig. 12 indicates a typical relation between coke requirements and oven numbers.

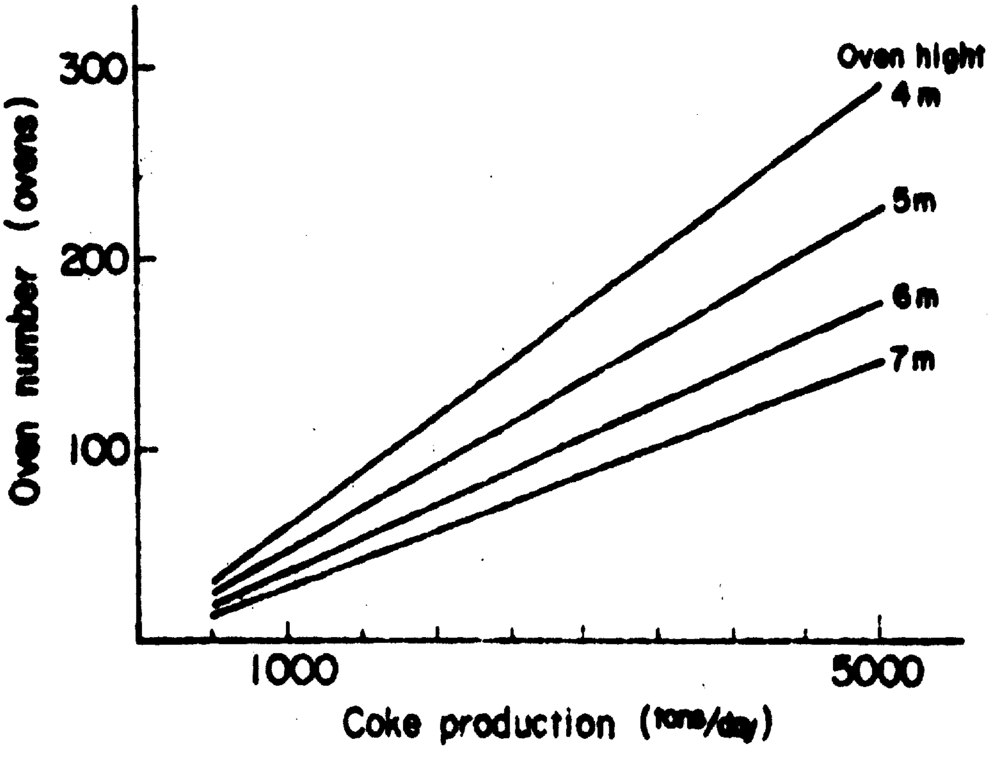


Fig. 12 - Relationship between coke requirements and number of ovens

There were many technical problems in the enlargement of coke ovens in order to make adequate equipment of uniform combustion system. However, they were completely solved by the improvement based on long experience, and then the 7.125 meters high ovens were installed at the Kashima works in 1971. Table 2 shows the operating data of these ovens.

Table 2. Operation data of the Kashima No.1 coke plant

Number of ovens		108
Oven height (meters)		7.125
Oven length (meters)		16.50
Oven width (meters)		0.46
Effective inner volume (cubic meters)		47.70
Coal charge (tons per oven)		35.30
Carbonization time (hours)		17.1
Mean flue temperature (°C)		1,362
Heat consumption (k.cal.per kg.)		686
Coal analysis:	total moist (%)	8.7
	ash (%)	8.0
	volatile matter (%)	29.0
	total surphur (%)	0.54
	grain size (% of -3mm)	77.5
Screen analysis of coke:	+ 100 mm (%)	4
	100 - 75 (%)	21
	75 - 50 (%)	39
	50 - 25 (%)	29
	- 25 (%)	7
Coke strength in JIS method:	+ 50 mm (%)	25.4
	+ 25 mm (%)	85.6
	+ 15 mm (%)	92.4
Productivity (tons per oven per day)		37.1

Table 3. Formed coke processes in the world

Process	State	Plant capacity	Main equipments
AUSCOKE (Broken Hill Proprietary Ltd.)	Australia	100 tons/day	Briquetting machine Fluidized sand bed coker, Shaft oven
B.B.F. (Bergbauforschung)	W.-Germany	120 tons/day	Low-temperature carbonizer, Hot-briquetting machine Sand coker
C.C.C. (Consolidation Coal Co.)	U.S.A.	10 tons/day	Pre-heater, Low-temperature coker, Rotary kiln, Shaft oven
F.M.C. (Food Machinery Corp.)	U.S.A.	250 tons/day	Catalyzer, Carbonizer Calciner, Briquetting machine, Curing oven, Shaft coker
H.B.N.P.C. (Houilleres du Bassin du Nord et du Pas-de-Calis)	France	150 tons/day	Briquetting machine, Shaft oven
I.N.I.E.X. (National Institute of Extractive Industries)	Belgium	120 tons/day	Briquetting machine Fluidized sand bed coker, Shaft oven
UKHIN (Ukrainian Coking Institute Sapozhikov)	U.S.S.R.	300 tons/day	Pre-heater, Chain's bearing mould Chamber oven
National Institute for Pollution and Resources)	Japan	2 tons/day	Pre-heater, Hot briquetting machine Shaft coker
Coal Research Institute of Japan	Japan	50 tons/day	Pre-heater, Hot briquetting machine Annular kiln
Nippon Steel Corporation	Japan	un-known	un-known
DKS (Sumitomo Metal Industries, Keihan Rentan Kogyo, Didier Kellogg)	Japan	130 tons/day	Briquetting machine Shaft oven

8. FORMED COKE

8-1. Production process

Much research has been carried out on formed coke in many countries over a long period. The principal processes for the purpose of producing formed coke for the blast furnace are shown in Table 3. They are roughly classified as briquetting and carbonizing.

There are two methods for briquetting of coals, i.e. briquetting with a binder such as pitch at a temperature (more or less 100°C) - the cold briquette method, and briquetting without a binder at a high temperature (350-450°C) to melt coking coals blended - the hot briquette method.

There are also two methods in the carbonization of coal briquettes, direct heating with gas or sand at a high temperature and indirect heating through firebricks, as in the conventional carbonization.

The advantages and disadvantages of these processes are shown in Table 4.

Table 4. Evaluation of production processes of formed coke

	Coal briquetting		Carbonizing	
	Cold	Hot	Direct	Indirect
Advantages	Production process is simple.	No binder required.	Short carbonization time. Fewer workers. No air pollution.	Engineering of the conventional coke ovens is applicable. High calory of emitted gas.
Disadvantages	Binders are expensive.	Needs equipment to withstand high temperature.	High maintenance cost. Low calory of emitted gas.	Long carbonization time.

8-2. Coking mechanism

It is a well-known fact that the mechanical effect of "briquetting" increases the caking power of coals and improves coking properties. According to our research, the briquetting effect of coals may be outlined as follows:-

(1) Briquetting not only makes the distance between coal particles shorter, but also makes the particles more powdery, increasing the surface area of reactive materials in the coals. Such reactive materials give coatings on inert materials in the coals and make easier the mutual melting reaction with binders such as pitch. Consequently coke strength increases.

(2) Briquetting pressure is desired tc be as high as possible to make the reactive materials work effectively for coking action.

(3) The suitable particle size of raw coal dependsupon its coking properties, but fine particles are preferable to get higher coke strength.

(4) Volatile matter content and contraction characteristics of the coals affect coke strength.

(5) If there are too many reactive materials in raw coals, the formed coke fuses together.

8-3. Raw materials

Before adopting a formed coke method, it should be checked whether there is any difficulty to obtain the raw coals.
As aforementioned, it is necessary to select suitable coals, as in the conventional coking process. However, there is a wider range for selection than the conventional one because much more non-coking coal can be used. The resources of non-coking coals are abundant, and a large quantity of petroleum coke can also be used.

When a suitable coal is found, the caking characteristics should be examined first of all. At the next stage, experimental production of formed coke should be carried out using individual coals or coal blendsmixed at various ratios. By examining the quality of the produced coke,it might be found that there is a certain relation between them. A basic pattern of coal blend is determined according to the result. Since the basic blending ratio of coals is fixed, a coal briquetting method and a carbonizing method of coal briquettes are determined at the third stage.

As for the briquetting method, we would recommend cold briquetting which permits easy operation of the equipment.

With regard to the coking method, there are many processes, as already mentioned, but these processes have not yet been commercialised. However, we think that the indirect carbonizing method has in engineering of facilities.

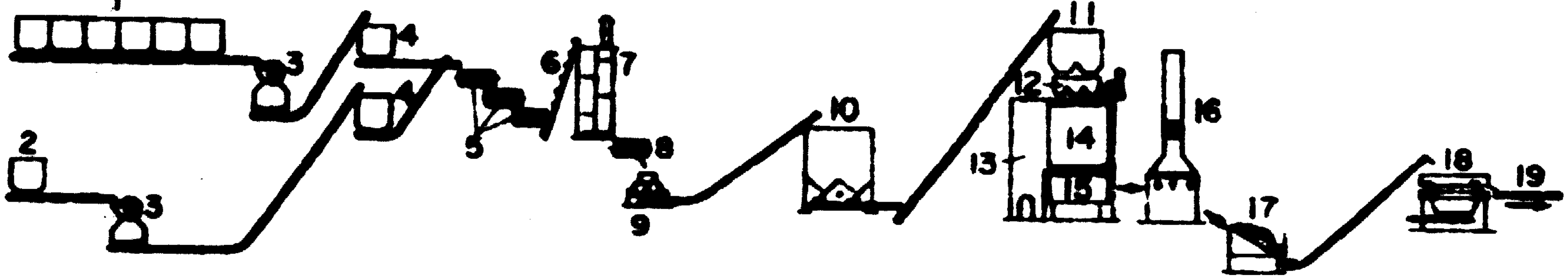
8-4. Use of formed coke into blast furnace in Japan

About 14,000 tons of formed coke was used on trial at the Kokura works of Sumitomo Metal Industries, Ltd. from December, 1971 to April, 1972. The blast furnace used for this experiment has a inner volume of 1,350 cubic meters and produces normally 3,000 tons per day of iron. The formed coke made for this experiment was produced by a medium scale equipment at the Osaka Coke plant of Keihan Rentan Kogyo Co., Ltd. The production process of this plant is shown in Fig.13. The quality of this formed coke is superior to the conventional coke as shown in Table 5. The operation data of the blast furnace during the experiment is shown in Table 6.

Table 5. Quality of formed coke and conventional coke

	Formed coke	Conventional coke
Proximate and ultimate analysis:		
Total moisture (%)	0.6 - 2.8	2.0 - 4.0
Ash (%)	9.5 - 10.5	10.0 - 11.0
Volatile matter (%)	0.5 - 1.3	0.7 - 1.0
Fixed carbon (%)	90.0 - 88.2	89.3 - 88.0
Mechanical strength:		
JIS's Drum Index +15 mm (%)	94.0 - 96.0	91.8 - 92.5
ASTM's Hardness + 6 mm (%)	69.0 - 75.0	66.2 - 69.5
Tumbler Index at 1,000°C +6 mm (%)	77.0 - 80.0	66.0 - 70.0
Crushing strength (kg per piece)	660	620
Screen analysis: + 50 mm (%)	0	60.0 - 65.0
50-25 m (%)	90.0 - 97.0	30.0 - 35.0
25-15 mm (%)	1.0 - 4.0	3.0 - 4.0
- 15 mm (%)	1.0 - 5.0	3.0 - 6.0
average (mm)	47×47×30	70
Porosity (%)	32.7	48.7
Relative density	1.13	1.00
Reactivity by CO_2 gas (%,weight)	7.0 - 8.0	6.0 - 7.0

Fig. 13 - The DKS formed coke process



1. 1st. Constant feeder
2. Binder bin
3. Crusher
4. Constant feeder
5. Mixer
6. Bucket conveyer
7. Kneader
8. Screw feeder
9. Briquette machine
10. Ground storage bin
11. Coal briquette bunker
12. Charging car
13. Recuperator
14. Over Chamber
15. Quenching car
16. Quenching tower
17. Coke wharf
18. Coke Sieve
19. to Coke yard

Table 6. Operation data of the blast furnace using formed coke

Operating period		Normal base	30% Formed Coke	50% Formed Coke
Output of pig iron (tons/day)		2,827	2,947	2,878
Blast volume (Nm³/min.)		2,300	2,400	2,300
Enriched oxygen volume (Nm³/min.)		20	20	25
Blast temperature (°C)		1,146	1,150	1,150
Blast pressure (kg/cm²)		1.93	2.18	2.07
Top pressure (kg/cm²)		0.90	1.00	0.90
Permiability index (P/V)		0.445	0.488	0.501
Ore to coke rate		3.61	3.62	3.80
Sinter content of burden (%)		92.8	93.3	93.7
Number of charges per day		134	140	133
Coke ratio (kg/iron ton)		437	437	424
Heavy oil consumption (kg/iron ton)		62	57	63
Total fuel ratio (kg/iron ton)		499	494	487
Total fuel ratio after correction (kg/iron ton)		499	492	495
Dust in blast furnace gas (kg/iron ton)		8,7	7.6	8.8
Number of slip (times/day)		0.5	0.6	0.0
Condition index of blast furnace		1,521	1.540	1.374
Content in iron (%)	C	4.47	4.55	4.46
	Si	0,69	0,68	0,61
	S	0,039	0,034	0,032
Content in blast furnace gas (%)	CO	22,1	21,6	21.4
	CO_2	21.0	22,9	21.7
	H	3.2	3.2	3.3
	CO/CO_2	1,05	0,94	0.99

Throughout the experiment, the use of the formed coke caused no trouble in the operation of the blast furnace. However, with the increase in the quantity of formed coke, there was a small rise in blast pressure. This was caused by the fact that the size of the formed coke was smaller than of the conventional one.

8-5. Economy

The possibility of commercial use of formed coke process depends upon its production cost. If there is no large difference in the production cost between conventional coke and formed coke, it may be suitable for practical use.

W. Peters(10) says, " Thorough examination of the costs of formed coke production in large units leads to the conclusion that distinct advantages are above all offered

when: (1) low-volatile coals are available or
(2) cheap high-volatile coals are available or
(3) volatile matter to the extent of 6 % can be permitted in the coke."

L. Soubrier(11) says " Capital investment for formed coke plant is 10 % more economical than that for the conventional coke plant, but the formed coke process will be more expensive in operation cost. ... Finally, we must take into account the advantage for furnace operation of using a sized and dry coke, and the elimination of air pollution."

According to our calculation, the capital investment of the DKS formed coke process may be 10 to 20 % more economical than that for the conventional coke ovens, when the coke production amounts to 30,000 tons per month or more. Furthermore, the operation cost of this process is nearly the same or a little lower than that of the conventional process.

In any case, whenever a new coke plant is installed in the future, it should be decided to adopt the conventional method or a new process only after studying the future energy situation of the country concerned.

9. NEW CAKING COMPOUNDS

In Japan, new researches are being carried out to produce caking materials from various petroleum oils, in order to cope with the shortage in resources of good coking coals, and there are at present two methods.

One is the research of production of the synthetic coking coal carried out by the National Research Institute for Pollution and Resources(12). The characteristics of synthetic coking coal are shown in Table 7 and Fig. 14.

Table 7. Characteristics of Synthetic coking coal and a hard coking coal

	Synthetic coking coal	Itmann coal (U.S.)
Ash (%) ---------------	0	6.2
Volatile matter (%) ---	12.6	18.0
Fixed carbon (%) ------	87.4	82.0
Crusible Swelling Number	8-1/2	8
Coke strength, +15 mm -	94.3	92.5

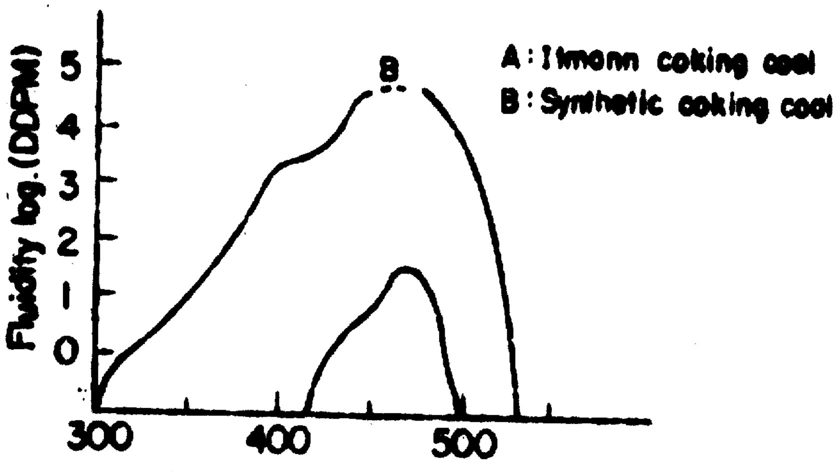


Fig. 14 - Fluidity of synthetic coking coal as a function of temperature

The other is the research of production of Improved coal(13) which is carried out jointly by Sumitomo Metal Industries, Ltd. and Kureha Chemical Industries, Co.

This is a method taking advantage of the characteristics of the pitch which is obtained as the result of cracking of oils at a high temperature.

This pitch has the characteristics shown in Table 8, and has the right properties to improve the coking properties of coals, when it is blended into non-coking coals, as shown in Table 9.

Table 8. Characteristics of pitches from oil and coal pitch

	Pitch-A	Pitch-B	coal pitch
Feed stock of pitch --------	Crude oil	Asphalts	Coal tar
Ash (%) ------------------	0.1	0.1	0.1
Volatile matter (%) --------	34	40	50
Fixed carbon (%) -----------	65	59	49
Crucible Swelling Number ---	n.d.	n.d.	n.d.
Flow point (°C) ------------	210	200	75
Hydrogen / Carbon ----------	0.79	0.85	0.62
Benzen Insolubles (%) ------	63	48	16
Quinoline Insolubles (%) ---	30	20	4

Table 9. Blending effects of Pitch to various kind of coals

Blending ratio of Pitch (%)	0	5	10	20	30
Semi-hard coking coal (A)--	92.0	92.9	93.0	93.2	93.6
Semi-hard coking coal (B)--	91.7	92.6	92.8	93.2	93.2
Soft coking coal (A)-------	75.4	77.0	81.5	84.2	87.7
Soft coking coal (B)-------	88.4	92.6	93.6	95.4	94.9
Poor coking coal ----------	36.0	77.1	91.5	93.8	----
Anthracite (A) ------------	X	X	X	57.7	88.2
Anthracite (B) ------------	X	X	15.5	86.8	93.2
Semi-anthracite------------	X	36.0	40.2	92.3	92.7

Note: (1). Figures show a index of the coke strength measured by JIS method (Drum index, + 15 mm.).

(2). The index of coke strength for blast furnace is necessary more than 91.5.

(3). " X " mark shows that the coal blend was not coking.

Table 10 shows the coking properties of the Improved coal which is obtained from the mixture of and non-coking coal. It looks much like those of the low-volatile coking coal.

Table 10. Coking properties of Improved coal

Blend No.	1	2
Used coals:		
Low-volatile coking coal (%)	25.0	0
Medium-volatile coking coal (%)	55.0	55.0
High-volatile coking coal (%)	20.0	20.0
Improved coal (%)	0	25.0
Analysis of coal blend:		
Volatile matter (%)	26.9	26.6
Crusible Swelling Number	4	3
Coke strength:		
Drum index, + 15 mm (%)	93.1	93.8

This Pitch is scheduled to be produced from asphalt (vacuum residue) on an industrial scale from 1975 in Japan.

These attempt to produce new caking materials from petroleum oils are a useful way of relieving the expected shortage in hard coking coal of good quality in the future.

10. Conclusion

Coking coal reserves are one of the most important factors in predicting the future of coking technology. The total reserves of coking coal over the world are reported to be 928 billion tons(14). On the assumption that the world consumption of coking coal amounts to 590 million tons per year, the reserves cover demand for about 160 years.

However, in the last few years, it is said that the reserve of low-volatile coking coal has been scarce. This is because low-volatile coking coal is only to be found in a few areas in the world. Although official reports have been made about the reserves of each kind of coking coal all over the globe, the reserves of low-volatile hard coking coal are believed to be extremely scarce as compared with the total reserves of coals.

On the other hand, iron and steel production all over the world is expected to reach 790 million tons in 1975 and 994 million tons in 1980. The anticipated coking coal requirement for various purposes, including steel production, is 1,000 million tons in 1980.

Under these conditions of demand and supply for coking coal, developments in coking technology in new fields are needed. Above all, the development of formed coke process and new caking materials are significant.

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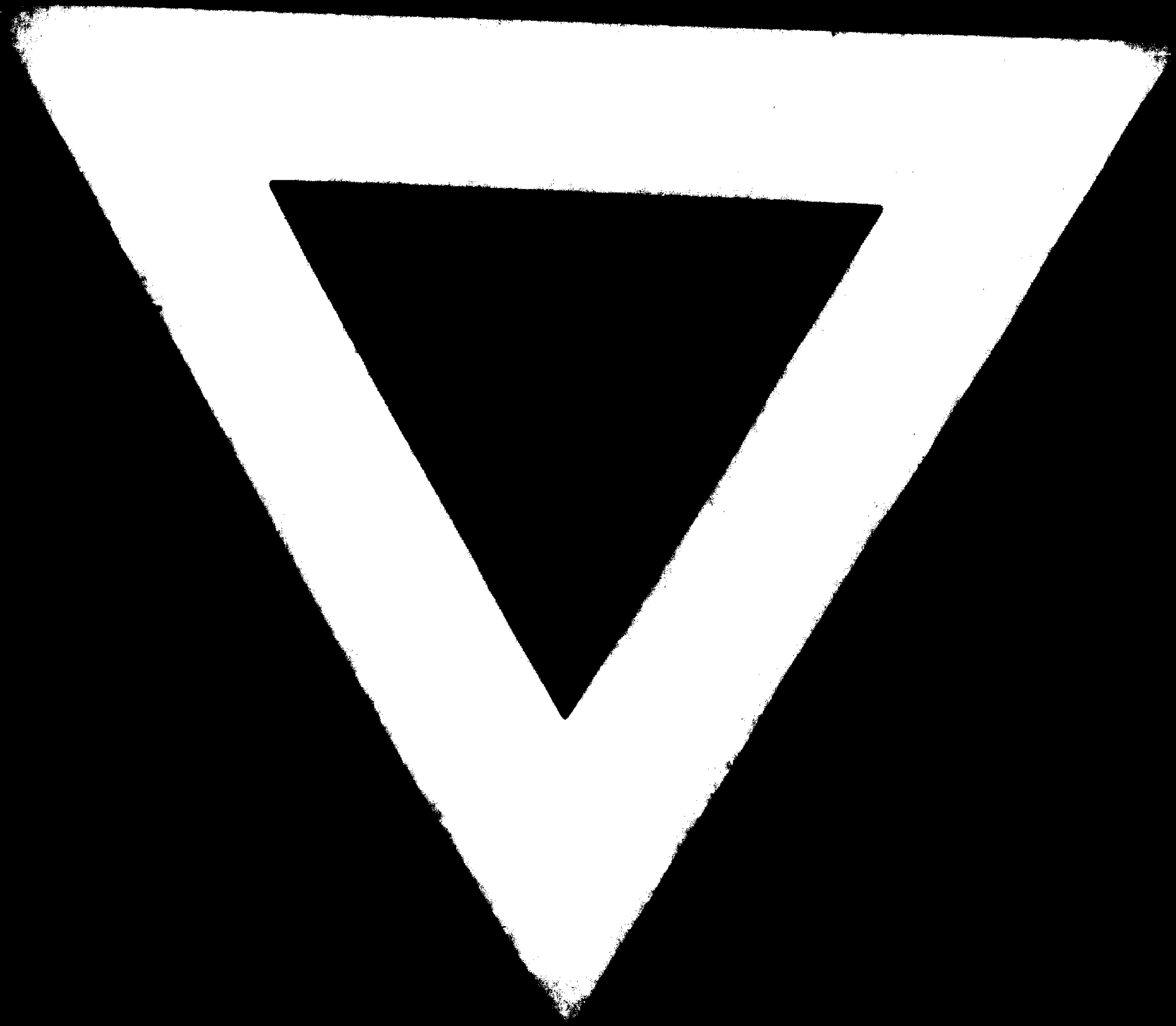

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