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Brasilia, Brazil, 14 - 21 October 1973

Agenda item 5

PRODUCTION OF SELF-FLUXING PELLETS AND THEIR BLAST-FURNACE PERFORMANCE[1]

by

Kasumasa Taguchi
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Corrigendum 1

Page 6, line 18	±50°C should read ±25°C
Page 12, lines 7 & 8	This sentence should read : "The value obtained is 5.5 t/d for Period II and 6.38 t/d for Period III, by 1% increase of pellets proportion of burden."
Page 18, line 4	18 should read 18 t
Page 23	Add extra reference : 5) G. von Struve : Stahl u. Eisen, 91 (1971), No. 17, pp. 971-980.
Illustrations	Figures 6, 7, 8, and 11 should be as shown overleaf.

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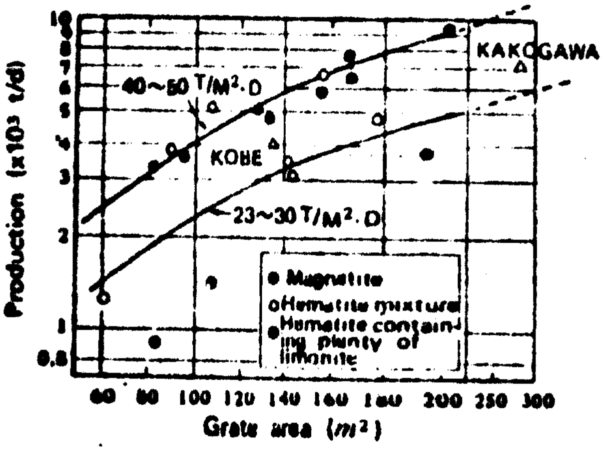

Fig. 6 Relation between effective area of preheating zone and productivity[5)]

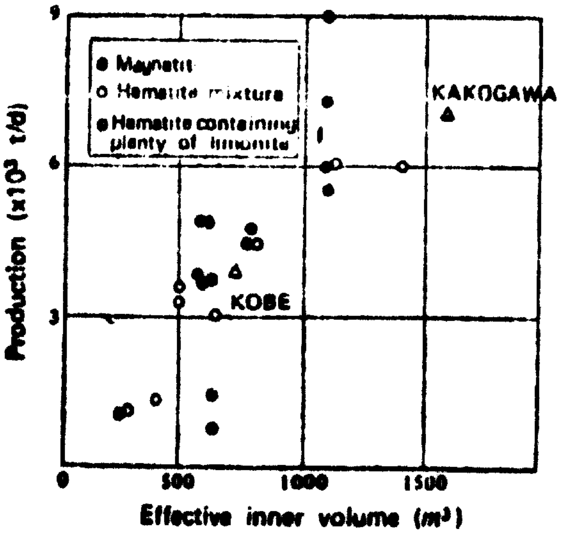

Fig. 7 Relation between effective inner volume of rotary kiln and productivity[5)]

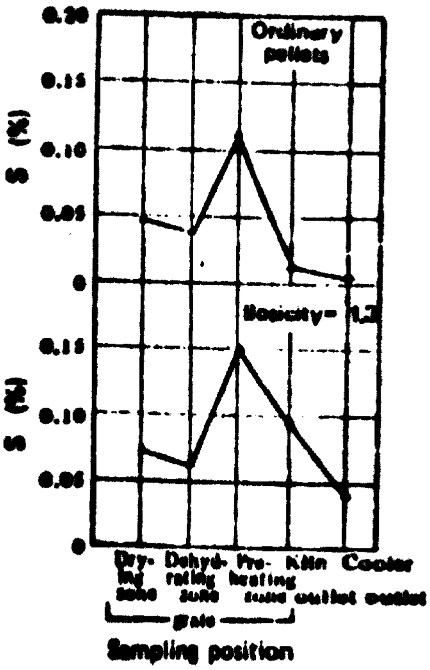

Fig. 8 Behavior of S in pellets in commercial pelletizing process

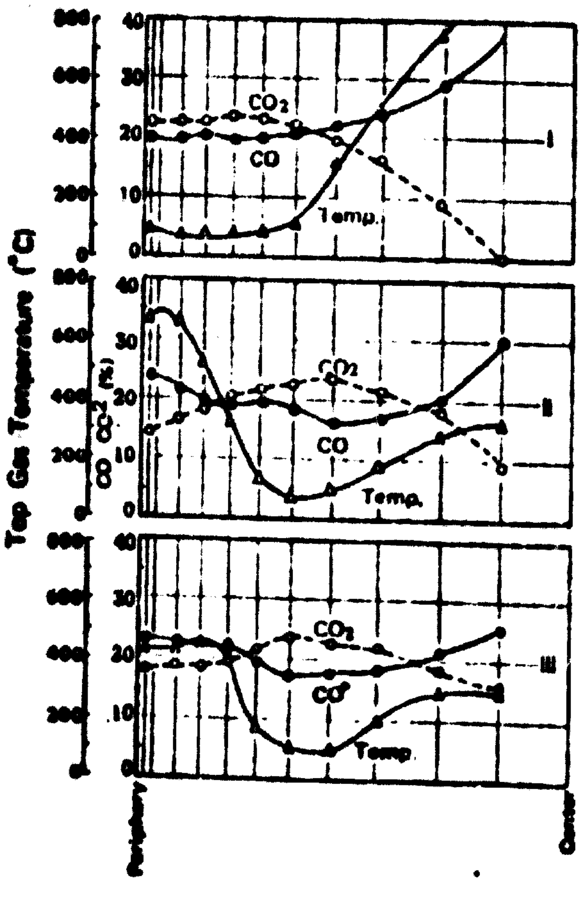

Fig. 11 Typical temperature and gas composition distribution at each period

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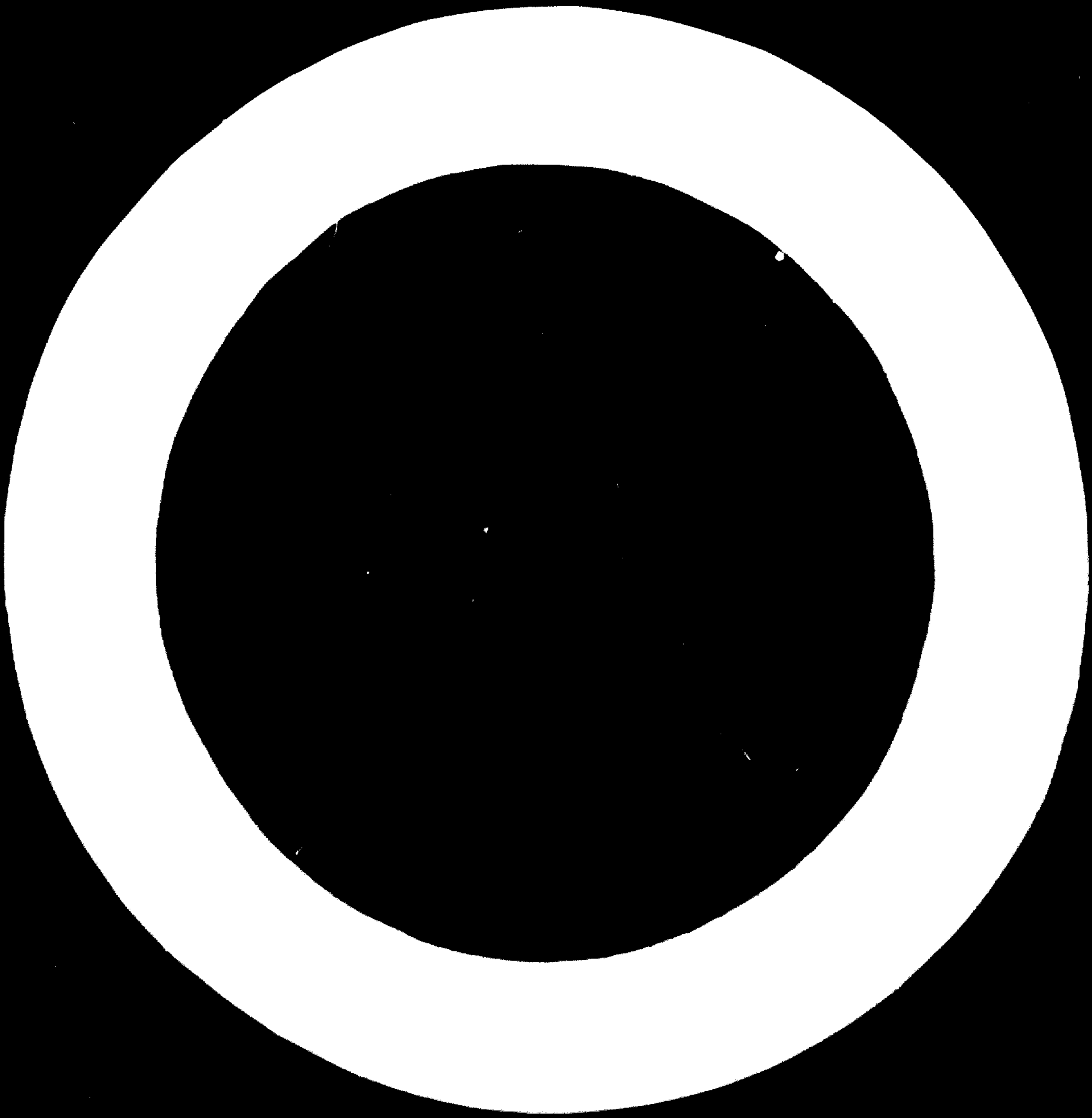

SUMMARY

Kobe Steel Ltd completed its first pelletizing plant at Nadahama Works in September 1966, and began the production of self-fluxed pellets with a lime/silica ratio of 1.3 in April 1967. These pellets are used in No. 3 blast furnace (hearth dia. 9.5 m) at the works. Tests were made of the effects of the basicity, proportion, etc., of the pellets on the blast-furnace operating data. with satisfactory results.

A 2 million t/year pelletizing plant was later started up at Kakogawa Works in July 1970. This plant has been producing self-fluxed pellets since it started, and is supplying the main burden to No. 1 blast furnace (hearth dia. 11.6 m) which started up at the same time.

The proportion of pellets used on No. 3 furnace at Nadahama and No. 1 furnace at Kakogawa has reached a level of about 85%. The two furnaces started smoothly and have produced good results up to the present.

This paper covers the production of self-fluxed pellets, their properties, and their performance in the blast furnace.

1. Production of self-fluxed pellets : Mixed ores from various parts of the world are used, including magnetite concentrates, specular hematites, limonites, and natural hematites. Magnetite concentrate is mixed at the rate of about 40% at Nadahama and 20% at Kakogawa.

The pelletizing plants at both plants are similar, using the grate-kiln system. Grinding is performed in a dry closed-circuit system, comprising a ball mill and two air separators. Green pellets are produced by disk pelletizer.

The grate-kiln system is used for indurating. It consists of three passes - drying, dehydrating, and preheating, which makes possible the treatment of limonite ores. Fuel to the rotary kiln is controlled by the process computer to keep the indurating temperature constant. Temperature control is especially important for producing good-quality self-fluxed pellets.

For product quality, special importance is attached to reduction properties such as softening and reducibility. Laboratory and plant research have been used to improve these properties. As a result, it has been possible to obtain good-quality pellets by controlling such factors as basicity, indurating temperature, particle size of ground material, and pellet size. By measuring porosity, which is closely related to reduction properties, it has become possible to supply pellets that vary little and are constant in quality.

Problems have occurred in the production of self-fluxed pellets from reduction in productivity, kiln adherence (sticking), reduction in desulphurization, etc.

There is reduction in productivity on the grate due to the heat of decomposition of limestone. However, in practice, there was no significant drop as compared with acid pellet production. Self-fluxed pellets have better indurating qualities than ordinary pellets in the rotary kiln.

Kiln adherence increases as basicity rises. However, improvements in practice have caused little, if any, operational problems. Sulphur content also increases with rise in basicity, and so care has to be taken in selecting low-sulphur raw materials.

2. Use of self-fluxed pellets in the blast furnace : Tests on Nadahama No. 3 furnace to determine the effect of the proportion of pellets charged on the furnace operating data showed that as the proportion increased to 54%, 60%, 70%, and 80%, gas permeability and burden reducibility improve, thereby increasing productivity. The rate of increase per 1% of pellets

is 0.17-0.19%. The fuel rate dropped 1.34-1.59 kg/t-p per 1% of pellet addition. The drop in fuel rate was mainly due to the improvement in the reducibility of the burden, increased CO and H_2 utilization rate, and reduced limestone consumption.

A constant proportion of 70% of pellets was used in trials to study the effect of pellet basicity. The fuel rate dropped significantly as a result of increasing the lime/silica ratio gradually to 0.5, 1.0, 1.3, and 1.4. This was due to the fact that the burden reducibility improved in the same way as when the pellet proportion was increased, resulting in a rise in the utilisation of gas. The fuel rate dropped 3.8-4.2 kg/t-p for a basicity of 0.1.

The No. 1 furnace at Kakogawa is large (11.6 m hearth dia., working volume 2843 m^3), and is equipped with moveable throat armour to secure uniform burden distribution. Before self-fluxed pellets were used in this furnace, basic tests of the burden distribution were carried out, using a 1/10 model of the furnace.

On the basis of these test results, various tests were carried out on blast furnace operation, leading to the establishment of conditions for optimum burden distribution. By making the gas distribution at the furnace top uniform, it was possible to improve the productivity and lower the fuel rate.

After the furnace conditions had been stabilized by manipulation of the throat armour in this way, a study was made of the reduction behaviour of self-fluxed pellets with a view to further lowering of the fuel rate. Increase in pellet basicity and control of porosity caused an improvement in the reduction properties of the pellets. The reduction of pellet size improved the reducibility, which in turn led to a marked drop in the fuel rate of the furnace.

It has been found that reduction in pellet size is also effective in preventing holdups in reduction due to the metallic shell formed.

1. Introduction

Studies on the production of self-fluxed pellets have been made over a long period, but there have been no instances in which they been produced industrially and used regularly in blast furnaces.

However, in Kobe Steel Ltd , we aimed at the reduction of fuel rate in the blast furnace and at the improvement of productivity in planning the production of self-fluxed pellets and in clarifying problems concerning the production of self-fluxed pellets . After we have continued our studies on quality improvement, we now have come to the conclusion that we are able to produce self-fluxed pellets far superior in quality to ordinary pellets by choosing suitable indurating conditions.

Thereupon, since starting up the pelletizing plant, constructed in the Nadahama works, in September 1966, we gradually increased the basicity, and in April of the next year, shifted to self-fluxed pellets of 1.4 basicity. These pellets were used in No.3 blast furnace (hearth dia.= 9.5m) in Nadahama works. As a result of tests with a high proportion of self-fluxed pellets and ordinary operations, it was noted that reduction in fuel consumption and productivity improvement had been made possible by the use of self-fluxed pellets at an increased proportion. Thus we were able to attain our initial objectives.1)

This was followed by the commencement of operation of a 2 million-ton/year pelletizing plant at Kakogawa works in July 1970. No.1 blast furnace (hearth dia.=11.5m) of Kakogawa, simultaneously put into operation, used a high proportion of 80 - 85% self-fluxed pellets; this furnace has been in successful operation up to the present.2) This report will cover the production and properties of self-fluxed pellets, and also the operating data of blast furnaces.

2. Production of self-fluxed pellets.

2.1 Raw material.

We are using iron ores imported from various parts of the world after mixing several types.

The proportion is at times varied according to the incoming shipments of the ore. One instance of main burden used at the Kakogawa pelletizing plant is shown in Table 1. The proportion of magnetite concentrate is about 20%.

Table 1. Chemical compositions of main raw materials

Kind of Ore	T.Fe	FeO	SiO_2	CaO	Al_2O_3	MgO	S	L.O.I.
Magnetite concentrate	66.14	26.6	0.43	1.50	0.77	2.86	0.050	0
Hema. with specular hema.	66.69	0.15	2.47	0.07	1.24	0.05	0.005	1.57
Low grade hema. with limo.	59.83	0.23	6.84	0.06	3.98	0.05	0.013	3.58
Hema with limo.	61.32	0.21	2.80	0.03	3.00	0.06	0.014	5.06

Hema. = Hematite, Limo. = limonite, L.O.I. = Loss on Ignition

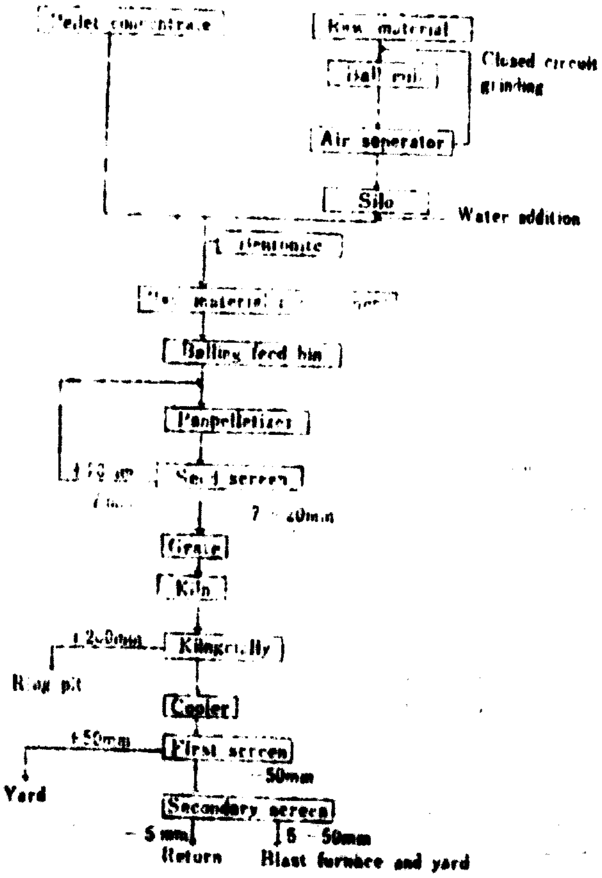

Fig. 1 Flow sheet of pellet plant

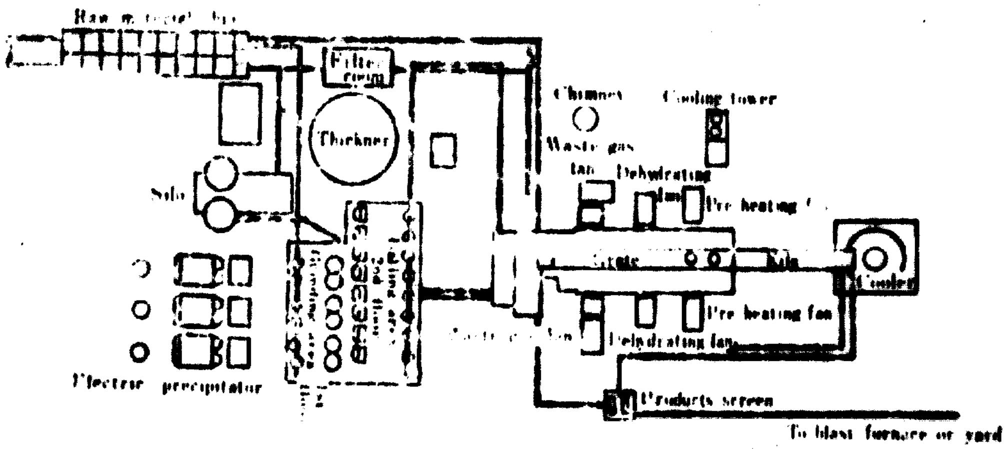

Fig. 2 Pellet plant layout

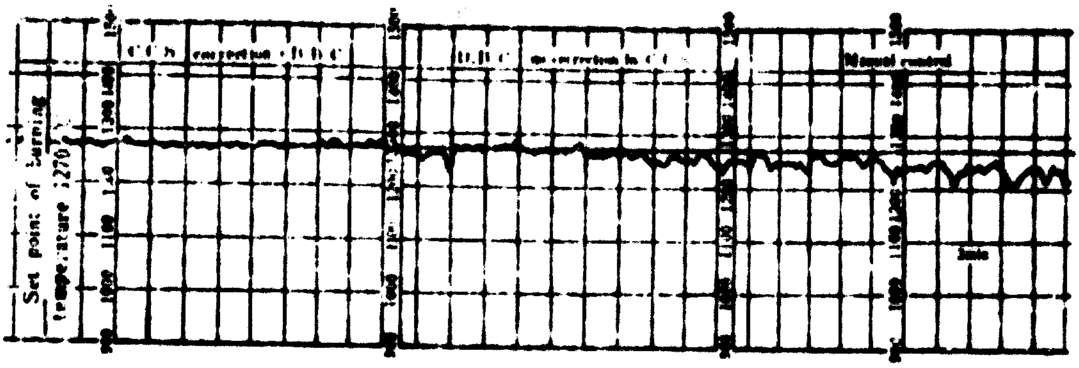

Fig. 3 Record chart of kiln firing temperature

2.2 Equipment

Fig. 1, 2 and Table 2 respectively show the flow sheet, layout, and specifications of main equipment. Grinding is done by the dry grinding closed-circuit system. Limestone is ground in the system together with the ore.

Balling is done in the disc pelletizer; indurating is done by the grate-kiln system.

The grate is divided into three passes, so that it is possible to treat limonite ores containing water of crystallization. Extensive use is made of process computer to save manpower, improve quality, and stabilize it. Especially in the indurating of self-fluxed pellets, it is necessary to have precise control of the indurating temperature in the kiln; thus the use of computer for making this control assures a successful operation.

Fig. 3 is a comparison of the fluctuation in temperatures between the manually controlled and the computerized control of the kiln indurating temperature. It shows that the manual control gives a fluctuation of ±50°C but that the computerized control minimizes it to ±10°C.

Table 2. List of main items of plant

	Name	Number	Specification
Grinding	Ball mill	3	4.9øx7.55m length center drive type 3000kw
	Air separator	6	5.5mø
Balling & burning	Disc pelletizer	8	6.0mø
	Seed screen	8	1.8m widthx5.49m length opening 7mm
	Travelling grate	1	4.7m widthx67m length 3 chambers (dry, dehydrate, preheat)
	Rotary kiln	1	6.6møx46m length
	Annular cooler	1	17møx2.5m width

2.3 Quality of Kakogawa pellets.

Table 3 shows an instance of the qualities of pellets which are produced by Kakogawa pelletizing plant of Kobe Steel Ltd. Table 4, for comparative purposes, gives the specifications in Japan of imported ordinary pellets. When the two tables are compared, it is seen that the self-fluxed pellets of Kakogawa pelletizing plant are superior to ordinary pellets in every respect such as crushing strength, degree of reduction, swelling index.

Table 3. Qualities of Kakogawa pellets (Typical example)

Crushing strength	300 kg/P
Tumbler index	-1mm 3%
Porosity	25 - 27%
Mean size	11.5mm
Degree of contraction (R.Tu.L.*)	30 - 35%
Degree of reduction (R.T.u.L.*)	90 - 95%
Degree of reduction (JIS)	85 - 90%
Swelling index (JIS)	8 - 12%
Strength after reduction (JIS)	65 kg/P
Chemical composition	
T. Fe	60.0%
FeO	0.15%
SiO_2	4.5 %
CaO/SiO_2	1.25
Al_2O_3	2.2 %
MgO	0.4 %
S	0.03%
P	0.04%
Cu	0.01%
TiO_2	0.28%

* Reduction-Test-under-Load
Load: 2.0 kg/cm^2, Temperature: 800 - 1100°C
Reducing gas: CO 30%, N_2 70%
Sample: 50±5mm Thick, Reaction tube: 75mm I.D.

Table 4. Specifications of imported pellet (An example)

Crushing strength (mean value)	250 kg/p min.(6 - 16mm)
Crushing strength (min. value	-80 kg/p 5% max.
Tumbler index	-1mm 4% max.
Size (9 - 16mm)	85% min.
Size (-5mm)	4% max.
Degree of reduction (JIS)	60%
Strength after reduction(JIS)	45 kg/p min. (9 - 16mm)
Swelling index	14% max. (9 - 16mm)
Chemical composition	
T. Fe	64.00% min.
SiO_2	5.00% max.
Al_2O_3	1.50% max.
P	0.05% max.
S	0.01% max.
Cu	0.03% max.

2.4 Pellet quality control.

Our routine quality control items are shown in Table 5.

Sampling is done by an automatic box sampler, installed in the chute of a belt conveyor, which passes the screen product and conveys it to the blast furnace or the ore stock yard.

Of the items shown in Table 5, the utmost importance is attached to the reduction properties, such as softenting property and reducibility.

The reason for this is that a very high level of cold crushing strength is obtained, as is seen in Table 3. This strength is commonly regarded as very important.

Porosity is regarded as important as a means of estimating the reduction properties. Although the reduction property is important, the method for testing it is complicated and the test takes a long time. For this reason, the measuring frequency is actually limited to a considerable extent. So, it is desirable that the estimation be made by the use of some other simpler method of measurement. In this sense, porosity is better than cold crushing strength. It is essentially for this reason that the frequency is as small as once a day, despite the importance attached to the reduction property.

It is clear that this degree of frequency is not enough for making a comparative study in relation to the operating data of blast furnace This, however, is compensated by porosity. But, the relationship between porosity and reduction property is not determined by any one factor, but it varies with other factors, such as basicity. Consequently, it is necessary to grasp at all times the relation between porosity and reduction property. Softening property and reducibility are being measured mainly for this purpose. Fig. 4 and Fig. 5 show relationships between porosity and softening property & reducibility.

Table 5. Frequency of the tests

Item	Frequency	Items	Frequency
Chemical analysis	every 2 hrs	Reducibility (JIS)	every 2 days
Cold crushing strength	every 4 hrs	Reducibility (R.T.u.L.)	every day
Porosity	every 4 hrs	Softening (R.T.u.L.)	every day
Size distribution	every 8 hrs	Swelling (IS)	every day

2.5 Problems concerning the production of self-fluxed pellets.

There were initially doubts about such problems in the production of self-fluxed pellets as the reduction of productivity, the occurrence of adherence on the rotary kiln wall, and the reduction of desulphurisation. However, none of these fears were justified to any large extent.

1) Reduction of productivity

The ground particle size of limestone is finer than that of iron ore, which makes it easy for bursting to occur on the grate. Furthermore, the heat of decomposition of limestone in the preheating zone prolongs the time of preheating. For these reasons, it was feared that productivity might be reduced, but actually the results did not justify them to any significant extent.

That is to say, as shown in Fig.6, the productivity of the Kakogawa and Kobe pelletizing plants is about the same as that of any other plant. Consequently, it is considered that the reduction of productivity of self-fluxed pellets is small.

Also, the productivity in the rotary kiln is not much different from the case of ordinary pellets, as can be seen in Fig.7.

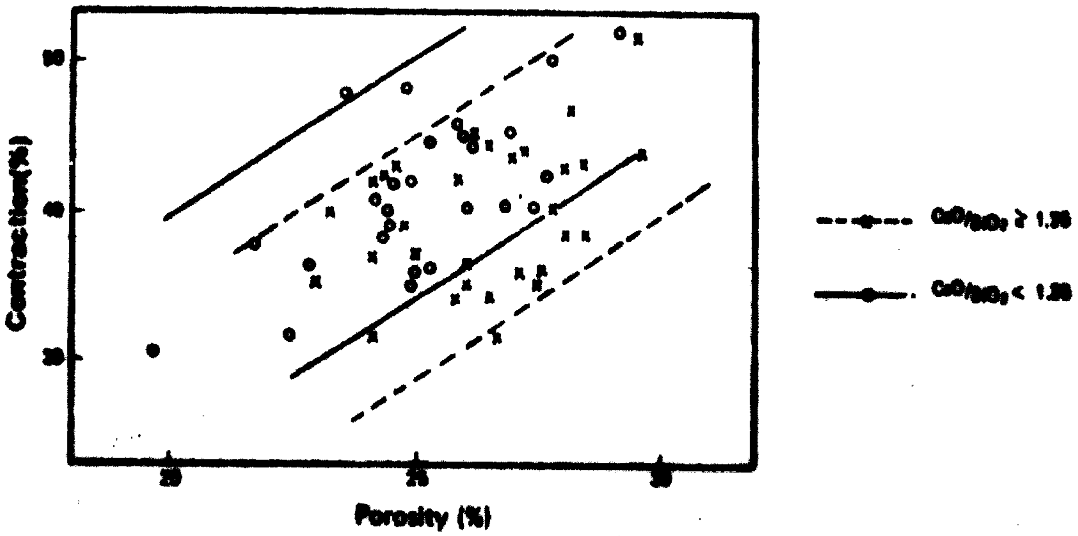

Fig. 4 Relation between porosity and softening (Commercial plant)

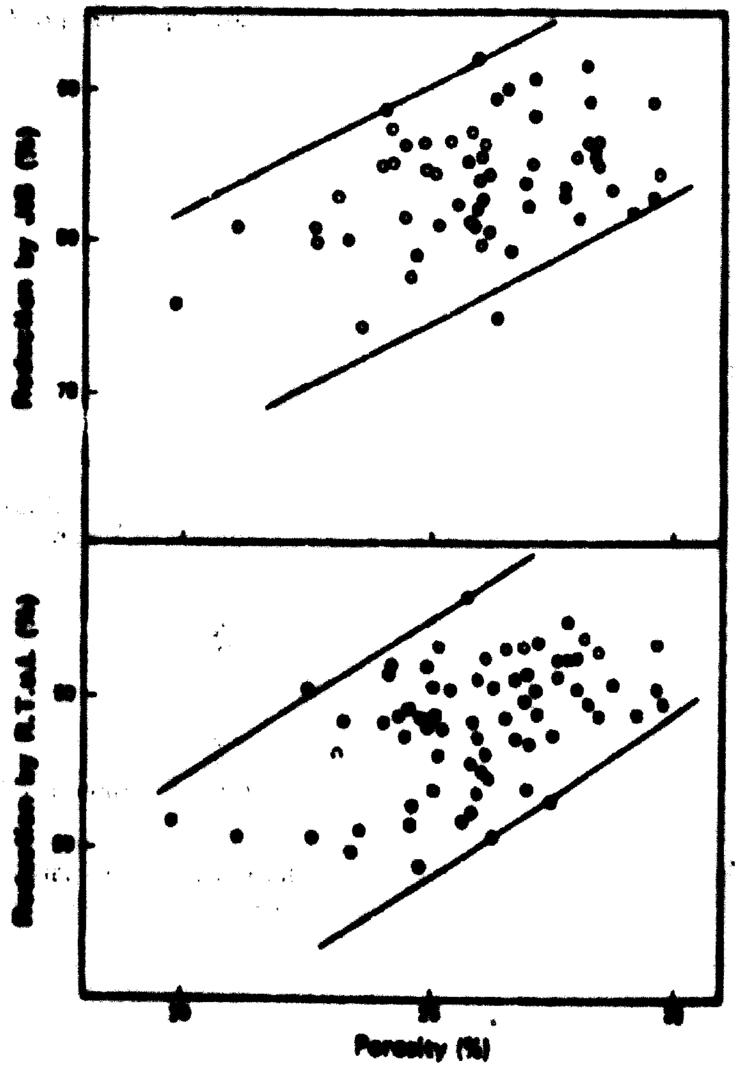

Fig. 5 Relation between porosity and reducibility (Commercial plant, Pellet dia: 10~15mm)

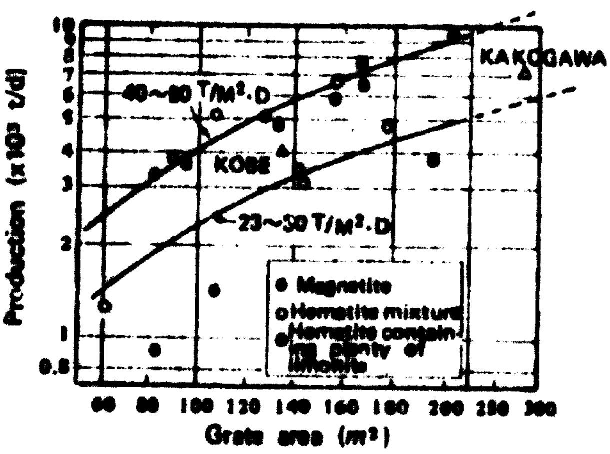

Fig. 6 Relation between effective area of preheating zone and productivity

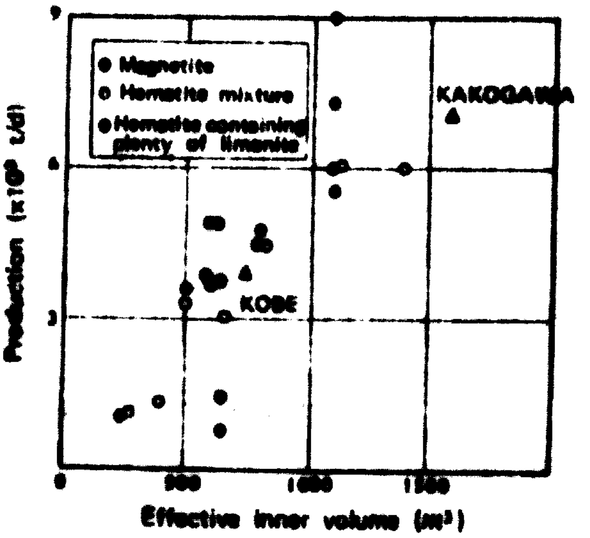

Fig. 7 Relation between effective inner volume of rotary kiln and productivity

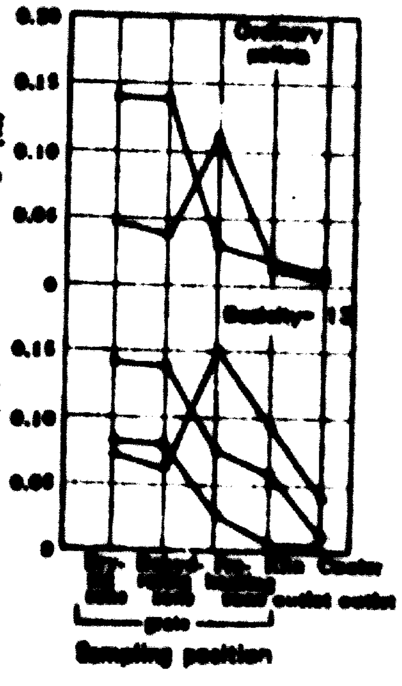

Fig. 8 Behavior of S in pellets in commercial pelletizing process

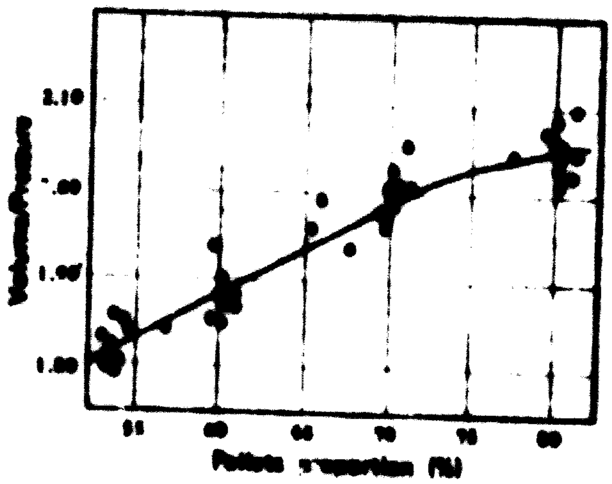

Fig. 9 Relation between pellets proportion and volume/pressure of blast

2) Kiln adherence

Kiln adherence is believed to be caused by factors such as abrasion of preheated pellets, the presence of low-melting point minerals such as calcium-ferrite, and an excessively high indurating temperature.

As the basicity of pellets increased, it was noted that the ocurrence of kiln adherence tended to increase. However, this tendency showed a decrease as the degree of skill in the operation increased. There is hardly any case of operational trouble due to kiln adherence.

3) Desulphurization

As an increase was made in the basicity of pellets, it was noted that the S content of product pellets showed an increase. To look into the cause of this phenomenon, we investigated the behavior of sulphur in pellets during the heating process in comparison with the case of ordinary pellets.

Results are shown in Fig.8. S in pellets decreases more or less in the dehydrating zone, and considerably increases in the preheating zone. Thereafter, for ordinary pellets, the desulphurization in the kiln progresses to the full. In contrast with this, in the case of self-fluxed pellets, the desulphurization is slow and the S content is high. For this reason, desulphurization takes place also in the cooler. After all, the S content of product pellets is higher than that of ordinary pellets.

The increase of sulphur in the preheating zone is due to the absorption of SO_2 in the exhaust gas of rotary kiln that is here introduced. In the case of self-fluxed pellets, the presence of CaO causes SO_2 to be fixed, impeding the desulphurization within the rotary kiln.

As a result of this investigation, it has been found that there is an essential reduction in desulphurization in the production of self-fluxed pellets.

3. Blast furnace performance using self-fluxed pellets

3.1 Performance at Nadahama No.3 blast furnace

Almost all of the self-fluxed pellets produced at Nadahama pelletising plant have been used at Nadahama No.3 blast furnace (hearth dia. = 9.5m), and some investigations1) have been performed.

3.1.1 Effect of pellets proportion of burden

In order to investigate the effect of pellets proportion of burden on blast furnace performance, an experiment was carried out at Nadahama No.3 blast furnace.

In the experiment, pellets proportion of burden wasgradually increased from period I to IV, keeping the other conditions constant as much as possible.

The operating data during the experiment are shown in Table 6. As can be seen from the table, following results were obtained.

1) Permeability in furnace was improved with the increase of pellets proportion. Relation between pellets proportion and permeability is shown in Fig.9. The improvement of permeability is considered to be mainly due to the pellets size distribution, particularly to the low fraction of fine.
2) Production rate was increased with the increase of pellets proportion. In period IV, however, slight decrease of production rate was observed. This is due to the fact that blast volume could not be kept constant because of the drop of blower capacity in summer.

But the increase of production rate with the increase of pellets proportion is clear in the data of corrected production rate which is modified by blast volume. The reason of the increase of productivity is considered to be the high permeability and reducibility of burden.

The increase of production rate in period II and III were calculated with the value of stage I as standard. The value obtained is 5.5 t/d for period II and 6.38 t/d for period III, respectively. These values correspond to the increasing rate of 0.17 - 0.19% for one percent of increase in pellets proportion.

3) Fuel rate was decreased with the increase of pellets proportion. This is mainly due to the high reducibility of self-fluxed pellets. The reducibility of burden in each period is shown in Table 7. In Table 8 and 9, carbon balance and heat balance in test period are shown. From Table 8, it is known that reducing gas efficiencies (Eco, E_{H_2}) are increased with the increase of pellets proportion. The decrease of fuel rate in period II, III and IV were calculated with the value of period I as standard, and the results are shown in Table 10. From the results it is clear that fuel rate decreases at a rate of 1.34 - 1.59 kg/t-p for one percent increase of pellets proportion.

Table 6. Blast furnace operating data with fluxed pellets.

Test period Operating data	I	II	III	IV
Burden composition (%)				
Fluxed pellets	54.1	60.8	70.4	80.5
Algarrobo	22.5	18.5	11.7	0
Selo-Iman	10.8	7.5	4.4	5.1
Kiriburu	10.8	10.8	10.6	0
Goldwarthy	0	0	0	10.5
Hamersley	1.8	1.8	1.8	1.7
Krivoi-Rog	0	0.6	1.1	2.2
Production rate (t/d)	3251	3288	3355	3213
Corrected production rate*	3251	3288	3355	3336
Coke rate (kg/t-p)	470	462	448	439
Oil rate (kg/t-p)	44.0	45.6	45.1	49.9
Ore/coke	3.270	3.288	3.357	3.474
Blast data				
Volume (Nm^3/min)	2940	2940	2940	2840
Pressure (g/cm^2)	1609	1572	1474	1386
Temp. (°C)	1080	1080	1071	1054
Moisture (g/Nm^3)	15.7	17.4	21.2	22.7
Volume/pressure	1.827	1.870	1.995	2.049
Si in pig iron (%)	0.51	0.53	0.49	0.50
S in pig iron (%)	0.046	0.042	0.038	0.040
Slag data				
Volume (kg/t-p)	259	253	243	247
CaO/SiO_2	1.23	1.24	1.24	1.24
Al_2O_3 (%)	13.91	13.98	15.57	14.79

Top gas data				
CO_2 (%)	18.4	19.0	19.6	20.1
CO (%)	23.4	23.4	22.9	22.1
H_2 (%)	3.0	3.1	3.3	3.5
N_2 (%)	55.2	54.5	54.2	54.3
Temp. (°C)	181	176	164	182
Hanging/d	0	0	0	0
Slip/d	7.0	11.0	9.1	3.2
Dust (kg/t-p)	44.6	32.5	34.9	28.1
Charge/d	153	152	149	140

* Corrected by blast volume.

Table 7. Average reducibility* of burdens in various test of period.

Period I	Period II	Period III	Period IV
68.2	69.8	72.0	73.1

* measured by JIS method

Table 8. Carbon balance for test operation (kg/t-pig).

Item / Test period	I	II	III	IV
C in coke	422.6	415.6	402.9	398.1
C in oil	37.9	39.3	38.8	42.9
C in pig iron	44.3	44.0	44.2	43.5
C in dust	14.0	10.2	11.0	8.7
C gasified	402.2	400.7	386.5	383.8
C consumed by dry blast	287.1	279.4	267.0	263.4
C consumed by H_2O in blast	13.6	14.7	17.2	18.2
C required reduction of Si, Mn & P	7.3	7.7	7.3	7.4
C solution loss	94.2	98.9	95.0	94.8
E_{CO} (%)	41.0	42.0	44.4	46.7
E_{H2} (%)	32.7	34.8	36.5	39.1

Table 9. Heat balance for test operations (kcal/t-pig).

Item / The period	I	II	III	IV
(input)				
Combustion of coke	607,743	582,471	554,526	535,815
Combustion of oil	74,461	77,169	76,323	84,445
Heat of indirect reduction	19,348	18,736	17,821	16,245
Heat of dry blast	464,486	419,971	426,429	414,596
Heat of oil	2,310	2,394	2,593	2,507
Heat of moisture in blast	10,957	11,815	13,678	14,243

Total heat in	1,179,305	1,142,556	1,091,370	1,067,851
(output)				
Heat of H_2 reduction	6,883	7,725	9,870	10,942
Heat of Si, Mn, P reduction	49,791	41,502	40,984	41,243
Heat of solution loss	301,440	317,760	304,000	303,360
Heat of calcining of limestone	33,200	27,000	16,200	11,870
Heat of metal	303,240	304,590	304,500	304,010
Heat of slag	108,949	106,700	102,500	104,277
Heat of decomposition of moisture in blast	32,195	34,545	40,420	42,770
Heat of top gas	112,712	107,846	96,969	107,122
Radiation and cooling losses	239,895	194,888	175,927	142,257
Total heat out	1,179,305	1,142,556	1,091,370	1,067,851

Table 10. Relation between pellets proportion and corrected fuel rate.

Item \ Test period	I	II	III	IV
Pellets proportion (%)	54.1	60.8	70.4	80.7
Corrected fuel rate (kg/t-p)	514	505	488	480
Difference from period I (kg/t-p)	0	-9	-26	-34

3.1.2 Effect of pellets basicity

At Nadahama pelletizing plant, the basicity of pellets has gradually been increased since shortly after start-up. The effect of pellets basicity on the blast furnace performance was examined for the following period, keeping the pellets proportion of burden constant at about 70%.

Period I	Ordinary pellets	(Oct. 1966 - Nov. 1966)
Period II	$CaO/SiO_2 = 0.5$	(Nov. 1966 - Dec. 1966)
Period III	$CaO/SiO_2 = 1.0$	(Dec. 1966 - Janu. 1967)
Period IV	$CaO/SiO_2 = 1.3$	(Janu.1967 - Feb. 1967)
Period V	$CaO/SiO_2 = 1.4$	(May 1967 - June 1967)

The results obtained are shown in Table 11. In Table 12 and 13 chemical compositions and physical properties of the pellets used during the test period are shown. From Table 13, it can be seen that the reducibility of pellets improves with the increase of basicity.

From Table 11, it is clarified that coke rate decreases with the increase of pellets basicity. This is due to the improvement of burden reducibility according to the increase of pellets basicity as mentioned above. As the other reason of decrease of coke rate, such factors as decrease of heat loss carried out by top gas and caused by decomposition of limestone are considered.

The relation between basicity of pellets and corrected fuel rate are shown in Table 14. From this table it is clarified that with pellets proportion under 70%, fuel rate decreases at a rate of 3.8 - 4.2 kg/t-p per 0.1 of basicity increase.

Table 11. Blast furnace operating data with regular and fluxed pellets.

Test period	I	II	III	IV	V
Operating data	Ordinary pellets	Fluxed pellets CaO/SiO_2 =0.5	Fluxed pellets CaO/SiO_2 =1.0	Fluxed pellets CaO/SiO_2 =1.3	Fluxed pellets CaO/SiO_2 =1.4
Burden composition					
Pellets (%)	70.0	69.9	69.9	69.9	57.9
Sized ore (%)	30.0	30.1	30.1	30.1	42.1
(kg/t-p)	158	129	77	51.2	59
B.O.H.Slag(kg/t-p)	40	29	48	43	44
Production rate (t/d)	1716	2151	2403	2809	3185
Corrected production rate*	1791	2212	2403	2809	3246
Coke rate (kg/t-p)	587	563	553	519	478
Oil rate (kg/t-p)	0	0	0	0	32.2
Ore/coke	2.591	2.645	2.756	2.932	3.228
Blast data					
Volume (Nm^3/min)	1856	2136	2325	2420	2829
Pressure (g/cm^2)	997	994	1194	1288	1530
Temp. (°C)	891	972	885	1070	1078
Moisture (g/Nm^3)	19.0	17.7	28.1	29.0	27.3
Volume/pressure	1.906	2.152	1.947	1.880	1.849
Si in pig iron (%)	0.57	0.52	0.54	0.49	0.47
S in pig iron (%)	0.060	0.043	0.036	0.043	0.041
Slag data					
Volume (kg/t-p)	294	269	278	265	243
CaO/SiO_2	1.19	1.24	1.23	1.24	1.24
Al_2O_3 (%)	11.38	11.22	11.17	14.31	13.92
Top gas data					
CO_2 (%)	17.7	18.2	18.7	18.9	19.0
CO (%)	25.1	24.9	23.9	23.8	23.9
H_2 (%)	1.8	1.6	2.0	1.8	2.8
N_2 (%)	55.9	55.3	55.4	55.4	54.3
Temp.(°C)	223	222	214	181	176
Hanging/d	0	0	0	0	0
Slip/d	0	0	0.6	3.3	8.8
Dust (kg/t-p)	17.0	13.3	20.3	21.7	37.7
Charge/d	106	122	135	146	152
Shut down (min 1d)	40	28	0	0	24

Table 12. Chemical composition of regular and fluxed pellets.

Type of pellets	T.Fe	FeO	SiO_2	CaO	Al_2O_3	TiO_2	MnO	CaO/SiO_2
Regular pellets	62.30	0.42	5.90	0.88	1.00	0.41	0.25	0.15
Self-fluxed pellets								
CaO/SiO_2: 0.5	61.52	1.77	4.13	2.03	1.02	0.48	0.25	0.49
" 1.0	60.53	1.08	4.20	4.24	0.76	0.45	0.26	1.01
" 1.3	61.06	0.72	3.46	4.50	1.33	0.44	0.24	1.30
" 1.4	61.31	0.44	3.29	4.57	1.54	0.37	0.37	1.39

Table 13. Physical properties of regular and fluxed pellets.

Item Type of pellets	Porosity (%)	Compression strength (kg/pellet)	Tumbler index (+5mm%)	Reducibility (%)	Final pressure drop(R.U.L test (mmAq)
Regular pellets	21.7	425	98.1	58.5	8
Self-fluxed pellets					
CaO/SiO_2: 0.5	23.2	409	96.5	64.6	58
" 1.0	23.9	465	97.9	73.8	91
" 1.3	26.9	414	97.0	77.6	296
" 1.4	26.9	398	96.3	79.0	310

Table 14. Relation between CaO/SiO_2 of pellets and corrected fuel rate.

Test period Item	I	II	III	IV	V
CaO/SiO_2 of pellets	0.15	0.49	1.01	1.30	1.39
Corrected fuel rate (kg/t-p)	549	547	513	506	499
Difference from period I (kg/t-p)	0	-2	-36	-43	-50

3.2 Performance at Kakogawa No.1 blast furnace

Kakogawa No. blast furnace is a large one, with a hearth dia. of 11.5 m and effective inner volume of 2843 m^3. It has equipment for the control of burden distribution, namely moveable throat armour.

At Kakogawa No.1 blast furnace, we have been studied particularly the effect of burden distribution and qualities of self-fluxed pellets on blast furnace performance.

3.2.1 Effect of burden distribution

Before actual operation of armour, we made a detailed experiment[2] at our Central Research Laboratory on the burden distribution using a model shaft with a reduced scale of 1/10 for Kakogawa No.1 blast furnace.

Based on the results of the experiment, we made an investigation[2]), in actual blast furnace performance, on burden distribution using the throat armour for three periods.

Fig. 10 shows operating results for the periods. The pellets proportion of burden during the investigation is about 80% and the properties of the pellets are as shown in Table 3.

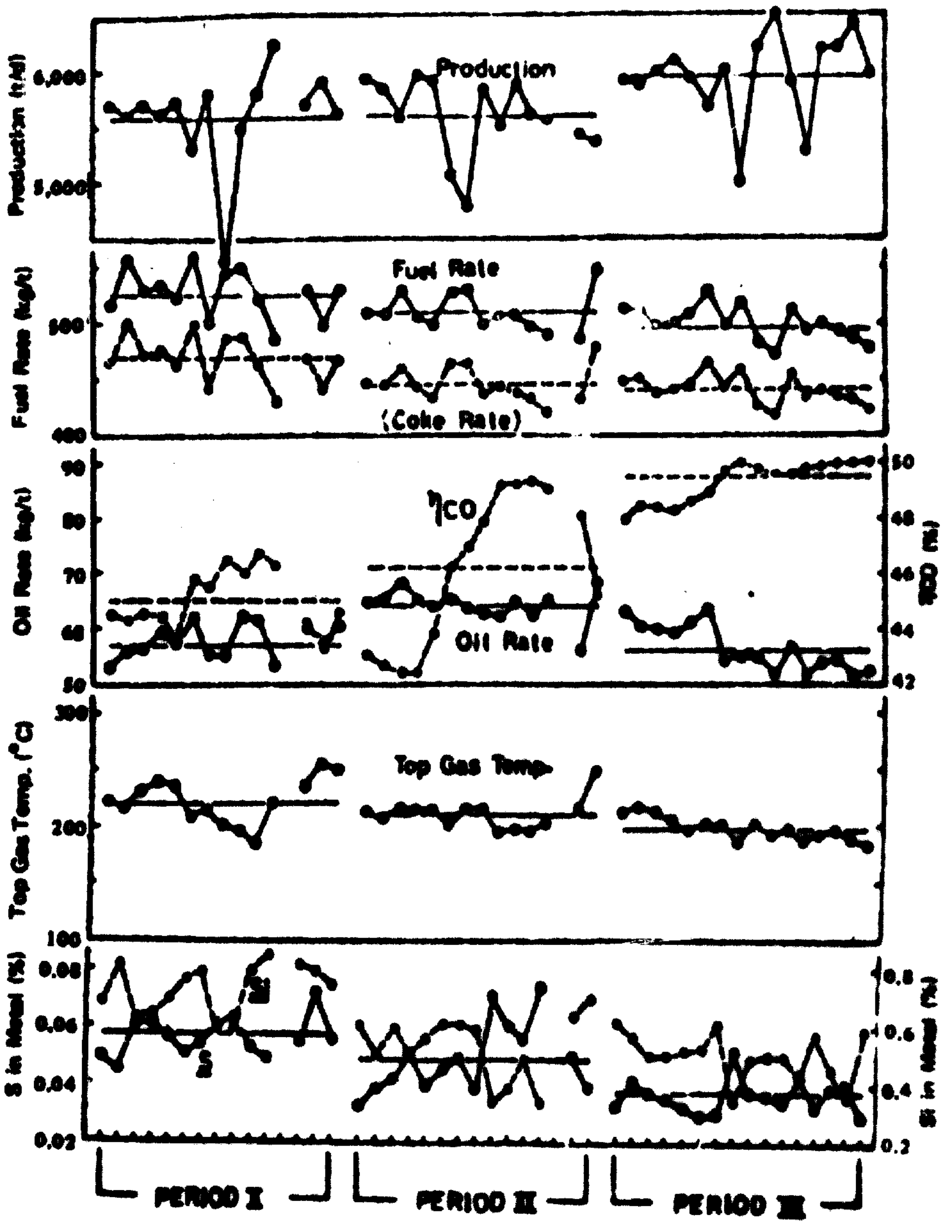

Fig. 10 Operating results at Kakogawa No. 1 blast furnace

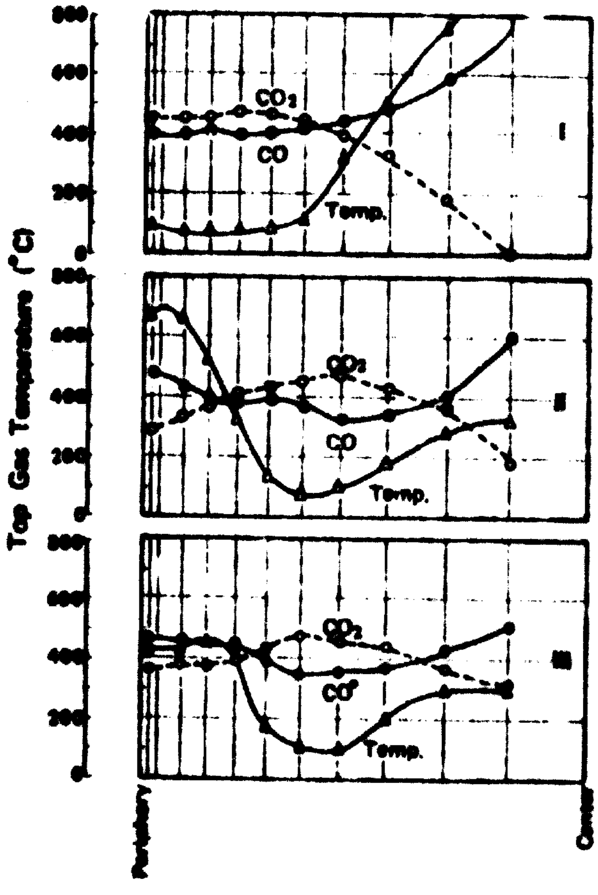

Fig. 11 Typical temperature and gas composition distribution at each period

Prior to the first alternation of throat movable armour setting (Period 1), the furnace was run with charging sequence of C/O and medium setting position of the throat movable armour for coke, setting position at medium for pellets and coke base of 18. Under these conditions, the furnace behavior and the fuel consumption were not satisfactory. High sulphur content of 0.057% (average) and wider fluctuation of this were observed and six tuyeres were damaged per month. Fig. 11-I shows the typical temperature and CO_2 content found for the burden in question over the furnace radius. From the very high temperature and very low CO_2 content in the center of the furnace it was concluded that this was a central operation. The important thing was to improve gas flow by means of the adjustment of the throat movable armour, namely to increase the top gas utilization in order to reduce the fuel consumption. In order to minimize the loss of the high sensible heat of the top gas unutilised in the centre of the furnace two different armour settings for pellet charging were adopted, according to the charging sequence of $C/P_1/C/P_2$ without any particular alternation of throat armour for coke, however, coke base increased slightly compared with period I. (Period II)

During this period for the pellet charging, the armour settiing system consisted of the outer side setting position for the first charging (P_1) and the inner side setting for the second charging (P_2). The temperature and gas composition variations thus obtained can be seen in Fig. 11-II. From this, the temperature decreases and the CO_2 increases at the center of the furnace, this indicate that very intensive gas flow at the center was modified. At the periphery, however, the temperature was relatively high, so that uniform gas flow has not been obtained. Decreases in the top gas temperature and increases in the gas utilisation ($CO\%/CO\%+CO_2\%$) were obtained. As a result, fuel consumption (Coke rate + oil rate) dropped from 527 kg to 510 kg per ton of hot metal and sulphur content and its fluctuation were reduced. As to the damage of the tuyere, the results show a figure of three tuyeres damaged per month.

In an attempt to obtain the further modification of the gas flow, improvements on the two different armour setting for the pellets were carried out with slight increasing of the coke base to 42 t (period III). During this period, armour setting position for the pellets varied according to the probe measurement record. For the coke charging, armour setting was fixed at medium setting position. The temperature differential found betw en over the radius markedly reduced compared with period I. In addition to a considerable increase in the CO_2, which means increase in the top gas utilisation, the sensible heat and temperature of the top gas were also reduced, as shown in Fig. 11-III. On the operating results, fuel consumption improved 36 kg per ton of hot metal, and production rate increased 35 ton per day compared with period I. Sulphur content and its fluctuation were markedly reduced. Only one tuyere was damaged per month. As a result, the furnace was run very smoothly with low fuel consumption.

The distribution of the material was considerably modified, and then almost uniform gas flow was obtained. This uniform gas flow may have contributed to reduction in fuel consumption.

In order to clarify the reason for the reduction of fuel consumption, a two-stage heat balance (reference temperature of 1000°C) was calculated. Table 15 shows a results of the calculation. The total heat input decreased from 879.5×10^3 Kcal per ton of hot metal in period III. The decrease in the combustion heat of coke and sensible heat of blast mainly contributed to the reduction of the total heat input. Decrease in the total heat output was brought by the decrease in the heat of direct reduction. Therefore, reduction of fuel consumption may be brought by decreasing the heat of direct reduction.*

Calculating the operating lines at each period according to Rist's method[4], it was found out that the shaft efficiency is improved from period I to period III, i.e., as gas flow distribution is improved. As the reducibility of the pellets and the oil rate in the blast furnace have been almost constant during these periods, it was concluded that the uniform gas flow contributed considerable improvement of the shaft efficiency, and then the coke rate decreased from period I to period III.

Table 15. Two Stage Heat Balance* at Kakogawa No.1 Blast furnace

Item	Period Unit	I X10^3KCal/THM	II X10^3KCal/THM	III X10^3KCal/THM
Input	Combution Heat of Coke	572.5	553.5	542.1
	Sensible Heat of Blast	101.8	98.2	76.3
	Combustion Heat of Oil	205.2	217.5	202.7
	Total	879.5	869.2	821.1
Output	Heat of Decomposition of H_2O in Blast	31.4	53.5	30.1
	Heat of Direct Reduction of Iron Oxide	381.3	340.7	339.5
	Heat of Reduction & Melting of SiO_2, MnO, P_2O_5	69.9	60.7	57.7
	Sensible Heat of Hot Metal, Sensible Heat of Slag Heat Loss	396.7	414.5	393.8
	Total	879.5	869.2	821.1

* Reference temp.: 1000°C

3.2.2 Effect of pellets quality

So far as the qualities of pellets were concerned, softening property, reducbility, and porosity were studied.

In our study on the reducibility of the self-fluxed pellets, a slowing down of the reduction rate was observed during the high-temperature reduction. Fig. 12 shows the rate of reduction at various temperature. During reduction, a formation of metallic iron shell was observed, and this proved to be the reason for the slowing down of reduction.

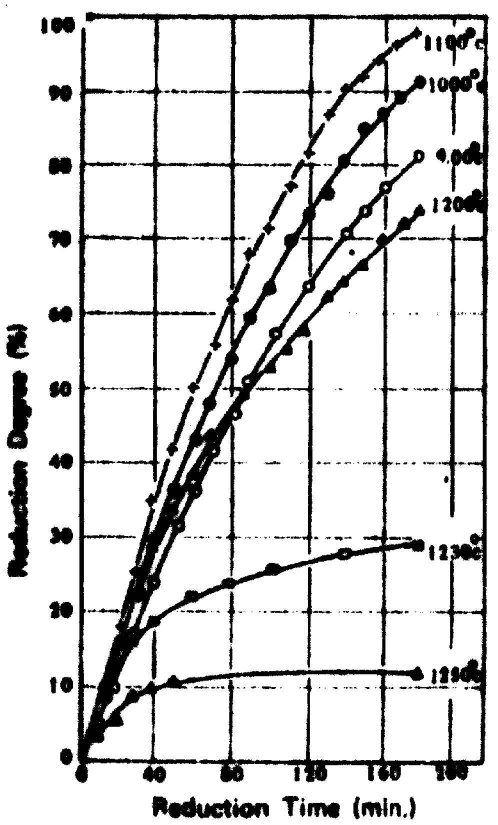

Fig. 12 Rate of reduction at various temperature

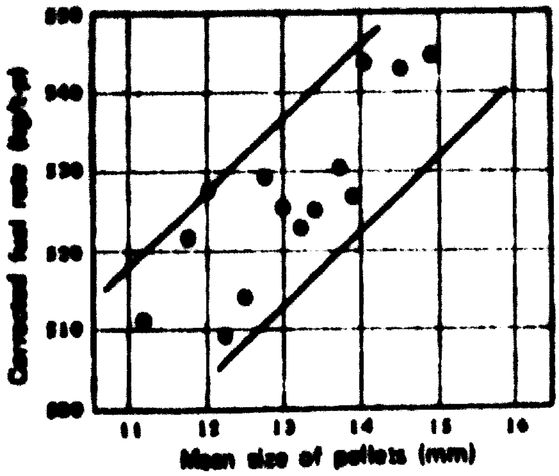

Fig. 13 Relation between size of pellets and corrected fuel rate

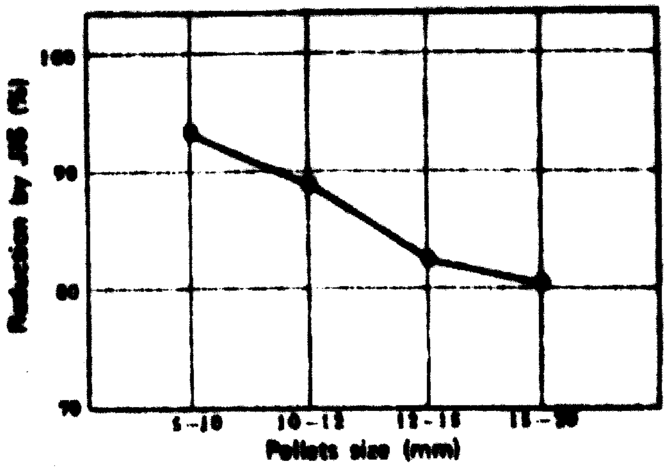

Fig. 14 Relation between pellet size and reducibility

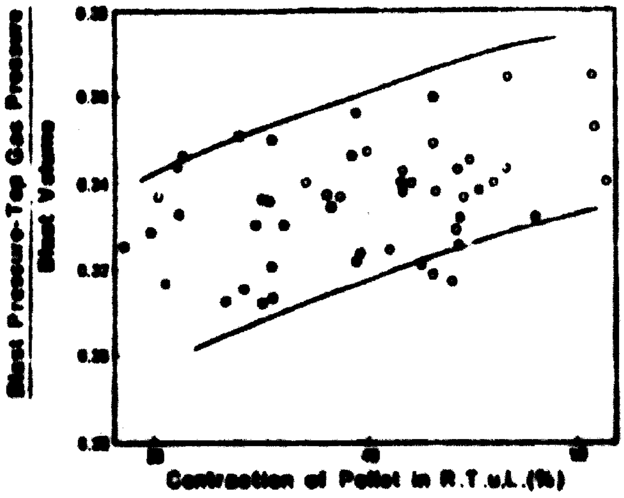

Fig. 15 Relation between softening of pellet and pressure drop in blast furnace

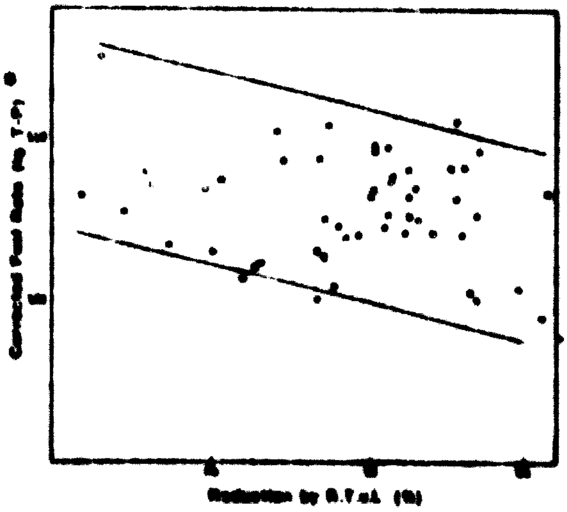

Fig. 16 Relation between reducibility of pellet and corrected fuel rate in blast furnace

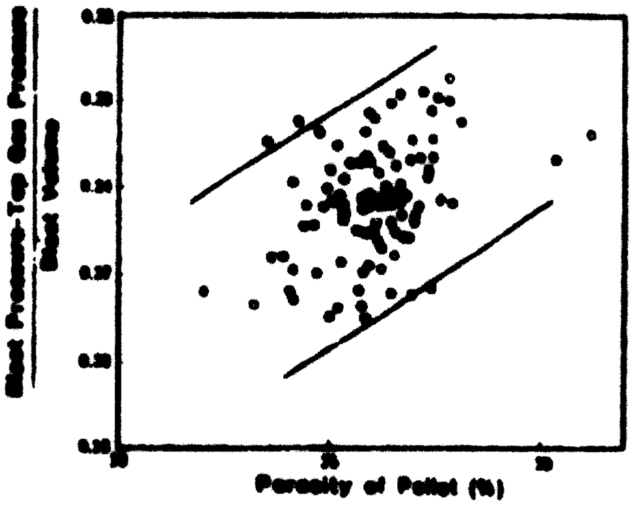

Fig. 17 Relation between porosity of pellet and pressure drop in blast furnace

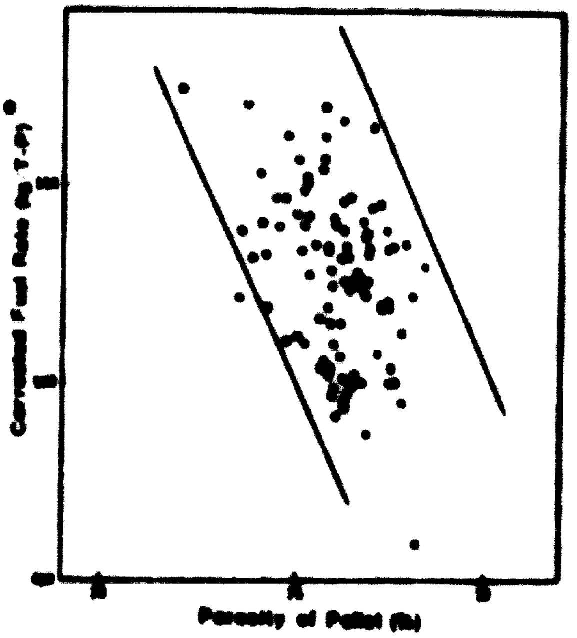

Fig. 18 Relation between porosity and corrected fuel rate in blast furnace

Note:

R.T.u.L.: (Reduction Test under Load)

	Standard	Correcting Rate (kg/t-P)
Slag Volume	[illegible] kg/t-P	[illegible] kg/t-P
Si in Pig Iron	[illegible] %	[illegible] %
Ash in Coke	[illegible] %	[illegible] %
Blast Temperature	[illegible] C	[illegible] C
Moisture in Blast	[illegible] g/Nm³	[illegible] g/Nm³

To avoid the suppression of reduction by metallic iron shell in the blast furnace, it is most efficient to keep the uniform operation. As another means to prevent such defect of pellets, we made the pellets size smaller.

Fig. 13 shows the relation between pellets size and fuel rate in blast furnace. From this figure the effect of pellets size reducing fuel rate is clear. The effect of reducing pellets size is considered to be due to the improvement in reducibility. In Fig. 14, the relation between pellets size and reducibility is shown.

As mentioned before we have performed strict daily quality control at the pelletizing plant. We investigated[5] the effect of pellets quality on the blast furnace performace with the daily quality control data.

The results are shown in Fig. 15 - 18. From these results it is clear that (1) gas pressure drop in the blast furnace decreases with the decrease of contraction (improvement of softening property), (2) fuel rate decreases with the increase of reducibility, (3) porosity has the influence on both gas pressure drop and fuel rate, namely gas pressure drop decreases and fuel rate increases with the decrease of porosity.

Consequently we consider these pellet qualities to be of major significance in blast-furnace performance.

In Table 16, the target of pellets quality control is shown.

Table 16. Target of pellets quality control

Items	Target of control
Cold crushing strength (kg/p)	280
Porosity (%)	24 - 28
Mean size (mm)	11.5 ± 0.5
Degree of reduction* (%)	80
Degree of reduction** (%)	88
Degree of contraction (%)	45
Swelling index	13.0

* JIS, ** Reduction - Test - under - Load

4. Conclusion

It is established by fundamental studies on the production of self-fluxed pellets and the practical operation that in case of self-fluxed pellets control of indurating temperature is important much more than in the case of ordinary pellets.

It is proved from the blast furnace performance that self-fluxed pellets are superior to ordinary pellets as blast furnace material.

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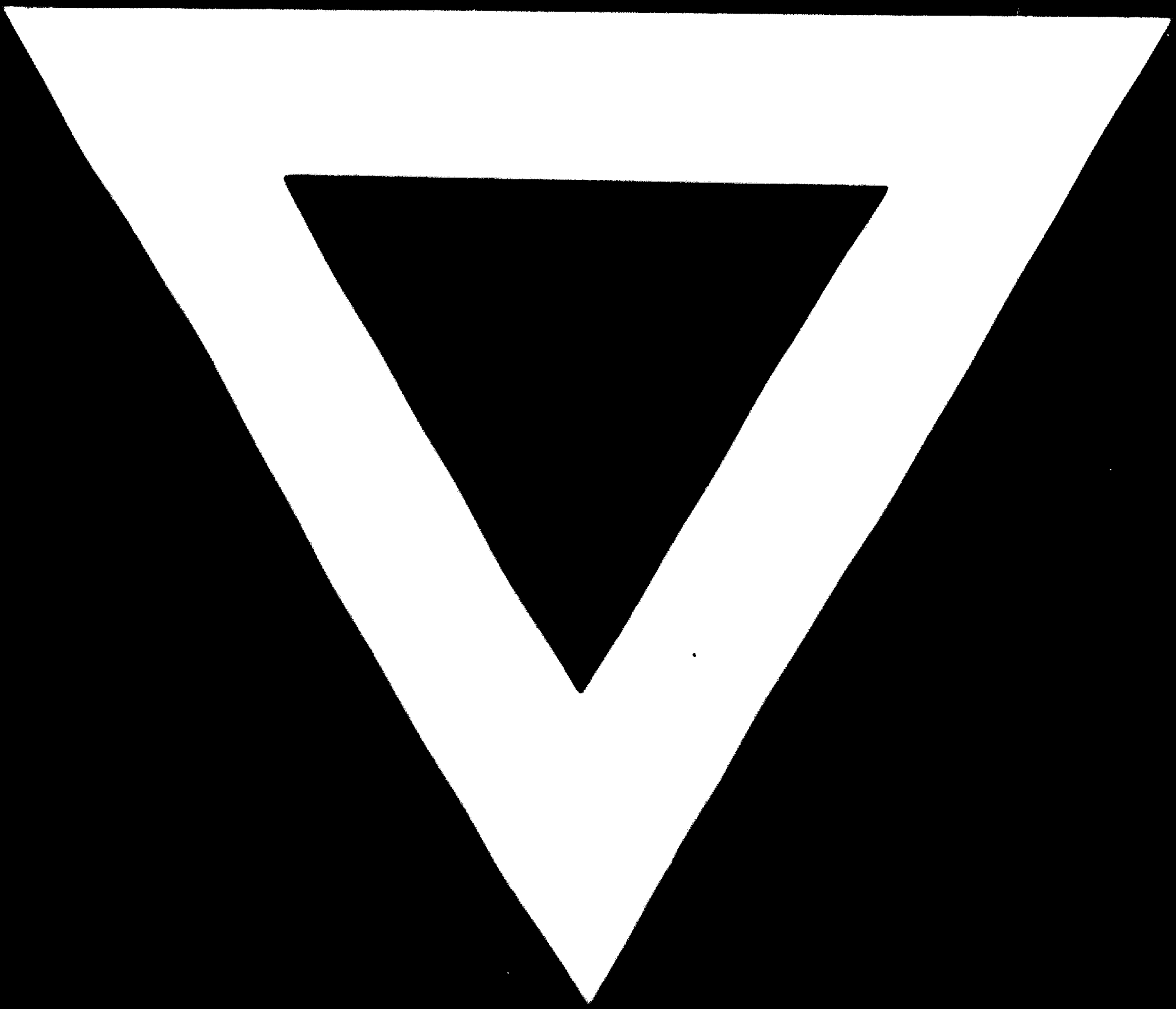

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