Recent Trends in Iron and Steel Making in Japan

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IRON AND STEEL PRODUCTION

Iron making

TABLE I shows the results of the blast furnaces in Japan in 1958. The total national output of pig iron in 1957 was 6,500,000 tons. Twenty-seven of the thirty-nine blast furnaces were in operation, and the production per blast furnace was as follows :

	1953	1954	1955	1956	1957
Production per blast furnace (t/d) ...	597	571	654	682	683

TABLE I

Capacity of blast furnace in Japan (As of July, 1958).

Company	Works	Blast Furnace No.	Rated Capacity (t/m)	Operation at the Time of Survey	Date of Blowing-in	Total Output (t/m)
Yawata Iron & Steel Co., Ltd.	Yawata	Higashida				
		No. 1	300	not operating		
		No. 2	300	"		
		No. 3	400	operating	Apr. 1, 1955	594,178
		No. 4	400	"	Mar. 10, 1956	369,318
		No. 5	500	"	June, 27, 1956	397,035
		No. 6	500	"	Dec. 14, 1951	1,234,952
		Kukioka				
		No. 1	700	operating	June, 11, 1955	843,840
		No. 2	700	"	Oct. 5, 1956	506,989
		No. 3	1,000	"	Dec. 5, 1955	1,042,478
		No. 4	1,000	"	Dec. 1, 1952	2,222,699
		Tobata				
		No. 1	400	not operating		
		No. 2	300	"		
Fuji Iron & Steel Co., Ltd.	Muroran	Nakamachi				
		No. 1	700	operating	May 26, 1953	1,379,608
		No. 2	700	"	Oct. 1, 1957	204,304
		No. 3	700	"	May. 30, 1956	551,005
		Wanishi				
		No. 1	350	not operating		
		No. 2	350	"		
		No. 3	225	"		
		No. 4	225	"		
	Kamaishi	Kamaishi				
		No. 8	700	operating	Dec. 1, 1954	1,008,416
		No. 9	350	not operating		
		No. 10	700	operating	Aug. 28, 1952	1,620,120
	Hirohota	Hirohata				
		No. 1	1,000	"	June. 20, 1957	425,041
		No. 2	1,000	"	Aug. 24, 1956	845,741
Japan Steel & Tube Co., Ltd.	Kawasaki	Ūgimachi				
		No. 1	400	not operating		
		No. 2	350	"		
		No. 3	600	operating	Dec. 1, 1951	1,758,081
		Ōshima				
		No. 4	600	"	Aug. 10, 1956	655,449
		No. 5	600	"	Dec. 15, 1952	1,491,492
	Tsurumi					
		No. 1	200	not operating		
		No. 2	300	operating	Dec. 20, 1955	271,651
Kawasaki Steel Corp	Chiba	No. 1	600	operating	June. 17, 1953	1,508,954
		No. 2	1,000	"	Mar. 19, 1958	122,128
Sumitomo Metal Industries Ltd.	Kokura	No. 1	450	operating	Apr. 28, 1956	402,205
		No. 2	650	"	Jan. 21, 1958	99,629
Amagasaki Iron & Steel Co., Ltd.	Amagasaki	No. 1	400	operating	Apr. 1, 1953	816,766
		No. 2	600	"	May. 25, 1957	231,168
Nakayama Steel Works, Ltd.	Osaka	No. 1	450	operating	Jan. 18, 1957	246,744
		No. 2	450	"	Mar. 18, 1953	974,842
Total		39			27	

Whenever new blast furnaces are erected or blast furnaces are relined, the tendency is to enlarge the inner volume of the furnace. Tobata No. 1 Blast Furnace of Yawata Works, which is expected to be blown-in by end of 1959 will be 1,500t/d. Effort is made chiefly towards enlarging furnace capacity by decreasing the thickness of the furnace walls. For example, the inner volume of Higashida No. 4 Blast Furnace has been raised to $537m^3$ from $474m^3$ by reducing the walls of the bosh from 650 mm to 425 mm, and those of the shaft from 710 mm to 575 mm. The use of carbon blocks has also gradually increased. At the Kukioka No. 1 Blast Furnace carbon block is used even for the bosh. Almost all blast furnaces in Japan have started using carbon blocks, thereby preventing damage to the bottom of the furnaces.

Besides enlargement of furnace body, use of carbon blocks and improvement in the quality of fire bricks, the production efficiency of blast furnaces has been remarkably raised by preparation of raw materials, quality control, and better hot stoves. As can be seen from Table II the average coke ratio was of 700 kg per ton of pig iron in 1957. In 1958 this figure further went down to 650 kg and a new record of 525 kg per ton of pig iron has been established at the Kukioka No. 2 blast furnace in November 1958. Such a low coke figure could not even be thought of a few years ago.

In recent years moisture control has been effected by decreasing the moisture in the blast or by adding steam, thereby controlling the moisture in the blast to between 10 to 20 gr. Oxygen enriched blast was experimentally used at the Higashida No. 6 Blast Furnace in 1958.

Steel making

In Japan steel making is at present carried out chiefly by open-hearth furnaces, although L-D converters have been introduced increasingly. Very rapid strides have been made recently in the open-hearth steel production efficiency. To give an example,

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Operation results of blast furnace at Yawata Works.

J.F.Y.	Pig Iron Production t/y		Coke Ratio		Analysis of Pig Iron		Bleeder Gas Analysis		Coke Ash
	Yawata	Japan	Yawata	Japan	Si	S	CO	CO_2	
					%	%	%	%	%
1950	786,531	2,167,053	0.956	0.902	1.22	0.047	29.7	11.1	15.48
1951	1,131,622	3,160,438	0.905	0.912	1.25	0.042	29.3	11.5	14.99
1952	1,198,426	3,336,112	0.886	0.855	1.07	0.035	28.3	12.6	14.61
1953	1,434,670	4,579,625	0.818	0.823	0.98	0.033	28.4	12.8	13.28
1954	1,398,469	4,383,469	0.717	0.727	0.75	0.026	26.8	14.1	12.30
1955	1,657,946	5,260,703	0.704	0.713	0.73	0.027	26.6	14.0	11.84
1956	1,925,235	5,974,674	0.708	0.730	0.73	0.028	26.4	14.1	12.02
1957	2,108,406	6,492,420	0.687	0.702	0.74	0.028	25.0	15.3	11.68

a successful record was established of production of 28t/hr. with fuel of 50×10^4 Kcal/t in 100-ton furnaces. This was chiefly due to the effective and proper use of a large quantity of oxygen, a main characteristic of the open-hearth operation in Japan.

Many improvements have been made in open-hearth furnace practice in the post-war period. To point out some of the changes made, there are the gradual replacing of gas by heavy fuel oil, the popularisation of the automatic control of operations, and the spreading of measurement of the temperature of the steel bath by means of immersion thermo-couples, the enlargement of furnace capacity, the utilisation of oxygen, and the use of basic refractory bricks. Active research is being made particularly on the use of oxygen, which is being more and more used. An experiment performed in 1949 at the Amagasaki Steel Works by eight steel companies under the joint auspices of the Japan Iron and Steel Association and the Japan Iron and Steel Federation can be said to be the origin of the use of oxygen in the open-hearth process. In this test, oxygen proved to have a remarkable effect in melting scrap and in bessemerising. All the steel companies in Japan have since launched into the regular use of oxygen in steel making.

The use of oxygen in the open-hearths of the major steel companies in Japan in 1958 is shown in Table III. It will be observed that oxygen of 10–50m³ per ton of ingot is used, and with the progressive use of oxygen, the fuel consumption required to make a ton of steel has been lowered year by year, thus boosting steel making efficiency.

In Table IV is shown the increase in the amount of oxygen consumption, the consequent decrease in fuel consumption per ton of steel and the improvement in steel making efficiency at Yawata Works. In this table there is a peak of oxygen consumption in 1954, denoting that at that point a large quantity of oxygen was used in making tests on utility of using oxygen. It may be stated that to bring about these results, the switchover from gas to heavy fuel oil, and the efforts made to improve combustion through the study of burners have contributed in no small degree. In

Consumption of oxygen in the open hearth furnace of main steel makers (As of October 1958).

Company and Works		Combustion Aid (m^3/t)	Acceleration of Melting (m^3/t)	Bessemerising (m^3/t)	Total (m^3/t)
Yawata Iron & Steel Co., Ltd.	Y(No.1 Steel A(Plant	3.5	7-8	1.0	11.5-12.5
	W(No.2 "	–	17.0	3.0	20.0
	A(No.3 "	6.0	15.0	4.0	25.0
	T(No.4 " A(	5.0	10.0	3.0	18.0
Fuji Iron & Steel Co., Ltd.	Muroran		7.0	3.0	10.0
	Kamaishi	10.0	15.0	5.0	30.0
	Horohata				
Japan Steel & Tube Corp.	Kawasaki	10.0	4.0	1.0	15.0
	Tsurumi (100t)	2.5	5.0	1.5	9.0
	(60t)	–	4.5	1.5	6.0
Kawasaki Steel Corp.	Fukiai	35.8	3.5	8.0	47.3
	Hyogo	14.0	3.0	5.0	22.0
	Chiba	10.0	28.0	12.0	50.0
Sumitomo Metal Industries Ltd.	Kokura	8-10.0	8-8.5	4-4.5	20.0
			5.0	5.0	10.0
			2.0	3.0	5.0
	Wakayama		4-5.0	3-4.0	7-9
Nakayama Steel Works		10.0	15.0	10.0	35.0
Nihon Kokan Co., Ltd.	Muroran	10.5	2.0	1.5	14.0
Nisso Steel Mfg. Co., Ltd.	Oshima			3.0	3.0
Toshiba Steel Co., Ltd.				3.0	3.0
Aichi Steel Works, Ltd.			9.0	1.0	10.0
Osaka Steel Mfg. Co., Ltd.		16.0	2.5	1.5	20.0
Nichia Steel Works, Ltd.	Amagasaki	3.0	6.0	2.0	11.0
Kobe Steel Works, Ltd.		11-14.0	1.2-1.8	1.2-3.7	14-20.0

TABLE IV

Changes of oxygen and fuel consumption, and steel making efficiency (average of all works).

Year	1951	1952	1953	1954	1955	1956	1957	1958
Oxygen Consumption (m^3/t)		7.4	7.4	14.4	13.0	10.0	10.4	14.4
Steel Making Efficiency (t/h)	9.0	10.25	12.3	13.2	13.1	13.65	14.4	17.5
Fuel Consumption ($\times 10^4$ Kcal/t)	154	131	100	84	81	86	83.5	69.7

other companies, more or less the same kind of development has been going on.

It must, however, be carefully remembered that with increased oxygen consumption in the open hearth furnaces, the ratio of pig iron can be boosted, helping to mitigate the shortage of scrap. In Table V is illustrated the relation between oxygen consumption and the pig ratio.

The increased use of oxygen, however, gives rise to the problem of the lining life. As a counter-measure,

TABLE V

Relation between oxygen consumption and pig iron blending ratio.

Oxygen Consumption (m^3/t)	0	1.0	6.0	6.5	10.0	15.0	19.0	22.5
Pig Iron Blending Ratio (%)	45	52	59	57	62	72	72	73.5

the adoption of basic fire-bricks has been considered, beginning with the front and back walls, and from the uptake to the roof, or to the regenerator. The use of basic fire-bricks has gradually increased and according to a survey in 1958, out of 21 plants, four open-hearth furnace plants are lined overall with nothing but basic fire-bricks and replacement with basic fire-bricks is going on in twelve, and there are five plants with zebra roof.

With the increased use of oxygen, a lot of dust piled at the gitter and the wear and tear on the fire-bricks at the gitter became a problem. These fire-bricks are being replaced by basic bricks. A plan to make the intervals between a checker bricks greater has been considered.

Furnace size in Japan has been enlarged only as far as plant building structure would permit. At present the largest open-hearth furnace in Japan is of 150t/heat, and even larger size of furnaces are now under study. However, they seem to have reached the limit permitted by the plant structure. Therefore, the promotion of steel production efficiency and cost reduction are being effected by the increased use of oxygen.

In short, we are very proud to have reached a record of 50×10^4 Kcal/t in fuel consumption but still futher research and progress will be needed.

II

L-D CONVERTERS IN JAPAN

Steel making in Japan has been carried out chiefly in open hearth furnaces and until quite recently there were no converters in operation except the five 20-ton Thomas converters at Japan Steel and Tube Corp. At Yawata Iron and Steel Works two 15-ton Bessemer converters were operated between 1901–1927. However, they were dismantled mainly due to the worsening raw material situation. As a means of tiding over the scrap shortage brought about as a result of increased production in the post-war period, the subject of constructing converters was taken up again in 1951, and various tests using converters were made. Following the world trend towards increased use of oxygen in the converter process, progress made in oxygen generators, and use of oxygen enriched blast, side and top blows; Yawata constructed a small experimental converter.

In 1952 at Linz, and in the following year at Donawitz, L-D converters were put into use. At Yawata Works melting tests were made, with the 5-ton experimental converter: 260 heats by side-blowing, and 1330 heats by top-blowing between 1954-1956. We were convinced that top-blowing with pure oxygen was more advantageous, and that this process could be used with the refractories produced in Japan, and that it was also suitable for the molten pig iron produced at Yawata. The decision was reached to erect two 50-ton L-D converters, and a license was applied for through Japan Steel and Tube Corp., who are the agents for L-D converter in Japan.

At Japan Steel and Tube Corp. "Oxygen Enrichment of Blast for Thomas Converters" had been under serious study, but when the superiority of top-blown converters was reported, the patent for this process was obtained from the Oesterreichshe Alpine Montan Gesellschaft.

The levelling work at the site of Yawata Works for construction of the 50-ton L-D converters started in May, 1956, and in October the same year, construction commenced. The operation of the 50-ton L-D converters began in September of the following year. At Japan Steel and Tube Corp. two 42-ton converters have also been completed and are in operation. These four L-D converters are now operating in Japan and Table I briefly describes their capacities.

The first modernisation and expansion programme of Japan's Iron and Steel Industry in the post war period has been completed, and the second programme is now steadily being carried out to expand Japan's steel making equipment. In order to cope with the scarcity of scarp iron necessary for steel making, emphasis has been placed on

TABLE I

L-D converters in Japan.

	Capacity & Number	
Name of Companies and Works	Yawata Iron & Steel Co. Ltd. Yawata Works	Japan Steel and Tube Corp. Kawasaki Works
Converter	50t x 2 (Concentric shell)	42t x 2 (Concentric shell)
Mixer	650 x 1 (Gas firing)	600t x 1 (Gas & oil firing) 550t x 2 (Operated with 3 Thomas converters of 20 tons each)
Waste Heat Boiler	60t/h x 2 (Waagner Biro's)	(none)
Steam Converter	70t/h x 1 (Kawasaki Heavy Industry)	(none)
Dust Collector	Waagner Type Wet Dust Collector & Wet Cottrel	Peace Anthony Venturi Scrubber
Oxygen Generator	4,250 Nm^3/h x 1, (Linde) 4,500 Nm^3/h x 1 (Hitachi)	4,250 Nm^3/h x 1 (Linde Frankel) 2,000 Nm^3/h x 1 (Linde Type)

the installation of converters rather than on the increased construction or remodelling of open-hearth furnaces. All converters are of the L-D type adapted to the raw materials situations.

At Yawata Works a huge expansion programme is now under way in the Tobata area, adjacent to Yawata city. A 1,500 t/d blast furnace is expected to be completed this autumn and two 60-ton L-D converters are planned as a steel making facility in Tobata area, and construction work is progressing steadily. L-D converters to be constructed in Japan are shown in Table II. By 1962 the expected aggregate output of steel ingots in Japan will be 20,200,000 tons including steel from electric furnaces, and of this 477,000 tons or roughly 24% will be produced by L-D converters.

In the case of the 50-ton L-D converters at Yawata the experience obtained from the small experimental converter has been utilized, and no serious difficulties have been encountered. By October, 1958, 420,000 tons of steel ingots have been turned out. As is shown in Table III, using 85% molten pig iron and oxgen of 99·6% purity, with 30 min. intervals from tap to tap, production of 42,000 t/m is being made with 31–35 blows with the two converters operating altenately. Production could be raised to 50,000 t/m, the quality of steel is superior, and the life of the refractories has been prolonged. More than 300 heats are possible before replacing the refractories.

The elimination of the red fumes given off during the L-D converter operation is one of our most important problems. The 50-ton converters at Yawata Works are equipped with a waste-heat boiler, and a dust collector made by the Waagner Biro Co. 320 kgs of steam are obtained as

Table II

L-D converters scheduled to be constructed in Japan by 1962.

Name of companies \ Year		1957*	1958*	1959	1960	1961	1962
Yawata Iron & Steel Co., Ltd.	Yawata Works	50tx2					
	Tobata Works			60tx2			
Japan Steel & Tube Corp.	Kawasaki Works		42tx2				
	Mizunoe Works			60tx2			
Fuji Iron & Steel Co., Ltd	Hirohata Works				50tx2		
	Muroran Works						50tx2
Amagasaki Steel Co., Ltd				30tx2			
Nakayama Works, Ltd.					30tx2		
Sumitomo Metal Industries, Ltd.	Kokura Works					35tx2	

(* Already constructed)

Table III

Analysis of pig iron produced by L-D converter of Yawata works.

C %	Si %	Mn %	P %	S %
4.4 - 4.6	0.63 - 0.71	0.90 - 1.05	0.29 - 0.33	0.026 - 0.034

recovered heat per ton of steel. The dust collecting rate is 99·5% and the dust remaining in the waste gas is only 50 mg/mm³.

The notable characteristics of the L-D converter process are that the oxygen in the bath at the time of blowing-up is less than that of the open hearth process, and the quantity of N_2 is also smaller. The actual results achieved by Yawata Works are as shown in Table IV. As for phosphorus, the scrap used being far less in the converter than in the open-hearth furnace, phosphorus is eliminated in the converter in the progress of decarburation. At Yawata works no trouble has been experienced in dephosphorisation, because we can practice the control of the phosphorus content in the pig iron, composition of slag and its amount and of the relation between the deposphorisation and blowing, etc., thanks to the experience gained with the experimental converter.

Table IV

Comparison of chemical composition between L-D converter steel and open hearth steel of Yawata works.

Steel \ Composition	P%	S%	N%	O%
L. D. Steel	0.019	0.020	0.002	0.011
Open Hearth Furnace Steel	0.015	0.023	0.004	0.019

In the L-D converter, sulphur does not come from the fuel as in case of the open hearth furnace. That the amount of oxygen in the bath at the end of refining is small means that a deoxidiser is less needed and the cleanliness of steel is improved. Nitrogen is 0·0016% at the end of refining due to the use of oxygen of high purity, and even in the ladle only 0·002% which is lower than open hearth steel and so much the better for deep drawing sheets. Being not contaminated by scrap, it contains less metallic impurities than open hearth steel. At Yawata, at present 95% of the L-D converter steel is rolled into strips and used for making cold rolled deep drawing and galvanised sheets, etc. Compared with open-hearth steel, L-D converter steel is, as shown in Table V, very excellent, and very popular among automobile makers. The sheets from ingot iron are welcome everywhere for use as enamelling sheets. At Japan Steel and Tube Corporation, boiler tubes, casing tubes,

TABLE V

Comparison of properties of strip steel between L-D steel and open hearth steel of Yawata works (as rolled).

	Thickness of Sheet (mm)	Yield Point Kg/mm²		Tensile Strength Kg/mm²		Elongation %		Erichsen Value (mm)	Number of Coils Tested
		L	C	L	C	L	C		
L.D. Steel	0.6	22.18	23.24	33.87	34.50	43.04	42.69	9.95	256
	0.8	21.93	22.95	34.01	34.68	43.84	43.52	10.36	425
	0.9	21.75	22.72	33.78	34.06	44.04	44.02	10.59	48
	1.0	20.01	21.83	33.21	33.76	44.43	44.40	10.80	576
	1.2	21.92	22.82	33.57	34.26	43.84	43.57	11.14	189
O.H. Steel	0.6	23.99	25.17	35.72	36.31	40.88	40.44	9.73	71
	0.8	22.38	23.35	34.21	34.71	42.87	42.86	10.18	288
	0.9	21.34	22.33	33.87	34.46	43.21	42.57	10.40	58
	1.0	22.22	23.37	34.27	34.91	42.95	42.44	10.35	99
	1.2	21.82	23.18	33.93	34.66	42.64	42.47	10.84	127

plates, and structural steel are being produced by L-D converters and all of them are very satisfactory.

The L-D process is therefore expected to play a vital role in the future of Japanese steel industry.

III
ORE BENEFICIATION IN JAPAN

Iron ore

The changes in the source of supply of the iron ore consumed by the blast furnaces of Yawata Iron and Steel Works in the post-war period are shown in Table I. Until J.F.Y.* 1947 the percentage of domestic ore was high when compared with total ore consumption, but in J.F.Y. 1948 the import of iron ores from the United States, South East Asia, India and other countries began. Including imported ore contained in sintered ore, at present 75% of the total iron ore used in Japan is imported.

TABLE I

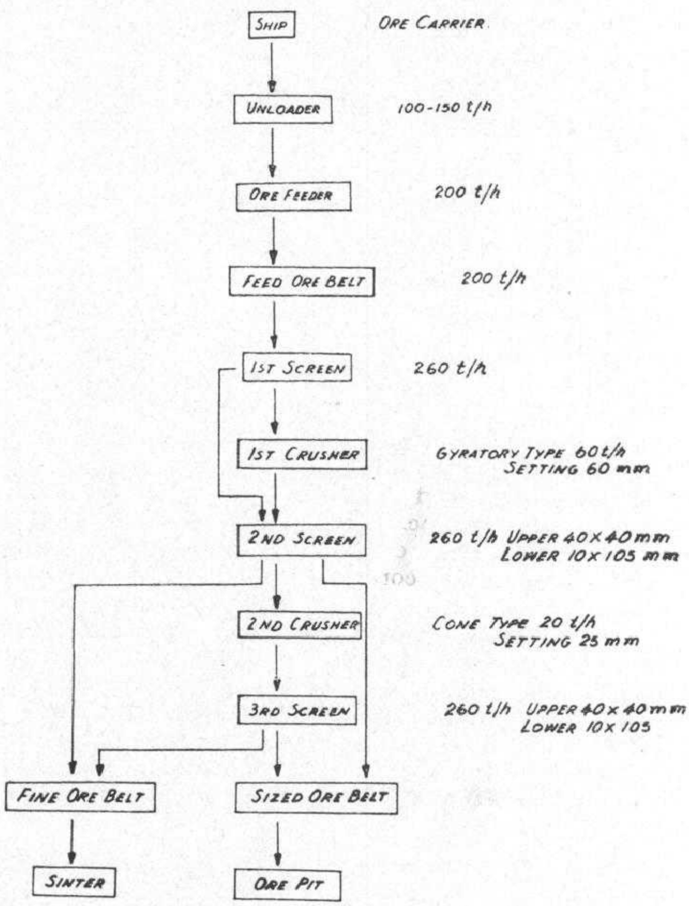
Variation in source of iron ore in blast furnace of Yawata works.

J.F.Y. \ Iron Ore	Sinter	Domestic	U.S.A.	Latin America	South-east Asia	India	Others	Total
	%	%	%	%	%	%	%	%
1950	32.5	14.4	1.3		42.0	5.0	4.8	100
1951	25.2	8.4	17.3		38.6	7.3	3.2	100
1952	28.7	4.7	29.2		28.2	8.5	0.7	100
1953	30.3	3.6	22.6		38.3	4.2	1.0	100
1954	40.9	1.6	12.0		37.3	6.1	2.1	100
1955	40.7	1.9	6.7	0.1	39.3	10.2	1.1	100
1956	35.9	1.0	7.0	2.4	36.3	16.8	0.6	100
1957	42.8	1.0	7.5	1.4	28.5	18.2	0.6	100

* Japanese Fiscal Year, starting from April 1st and ending March 31st of the following year.

To raise the efficiency of the blast furnace, it is important for the charging ores to be of suitable and uniform size without containing fines. Accordingly, magnetite is crushed to below 35 mm and hematite or limonite to below 40 mm. Fine ore below 10 mm is screened out to be used as material for sintering.

The average Fe content was 57·4% in 1957. Iron ore beneficiation at Yawata Works is shown in the flow sheet given below.



Flow sheet of iron ore beneficiation at Yawata works.

At Kawasaki Iron and Steel Corporation the ore-bedding system has been adopted by which a constant quality of ore is secured by the use of 4 bedding piles each 100 m long and 15,000 tons.

Sintered ore

Table II shows the use of sintered ore in Japan. Since the beginning of 1958 the blending ratio of sintered ore has been further increased, reaching 700–800 kg per ton of pig iron.

At Yawata Works there are two Dwight Lloyd type sintering plants with rated capacity of 1,000 t/d each, one Greenawalt type of 1,000 t/d, and one A.I.B. type of 600 t/d producing at present about

TABLE II

Use of sintered ore in Japan.

J.F.Y.	Total Output of Pig Iron (ton)	Consumption of Sintered Ore (ton)	Sintered Ore Used per Ton of Pig Iron (kg/t)
1946	152,462	91,043	597
1947	294,161	153,576	522
1948	850,550	392,339	461
1949	1,494,880	675,820	452
1950	2,167,053	1,136,405	524
1951	3,160,438	1,572,353	498
1952	3,336,112	1,791,607	537
1953	4,579,625	2,435,786	532
1954	4,383,468	3,018,469	689
1955	5,260,703	3,522,698	670
1956	5,974,674	3,693,953	618
1957	6,492,420	4,478,003	690

5,000 tons of sinter per day. The modern type D.L. plant is equipped with forced air-cooling facility. In Table III are shown the blending ratios of raw materials and the quality of the product from the D.L. Sintering Plant at Yawata Works. Thanks to the increased production of sintered ore, the blending ratio of pyrite cinder has been lowered and the ratio of imported fine ore has been sharply increased. All-out efforts have been made to produce sintered ore with high strength and containing few fines: At the Kokura Works of Sumitomo Metal Industries, Ltd. a record for lowest coke consumption (548 kg per ton of pig iron) has been established with 100% sintered ore blended with limestone. Yawata Works has been experimenting on blending limestone with sinter since June, 1958 and a new monthly record of 525 kg of coke was achieved at the Kukioka No. 2 Blast Furnace in November, 1958.

Pelletising process is now being developed in Japan for the purpose of utilising very fine ore. As a result of treating low grade ore, fine ore is becoming more and more pulverised. At present, a 700-ton/d pelletising plant is operating at Kawasaki Iron and Steel Corporation. At the Yawata Works of Yawata Iron and Steel Corporation and at the Kokura Works of Sumitomo Metal Industries, Ltd., similar equipment is being operated on a commercial scale.

Fluxes

With the progress in the preparation of iron ore, grain control of fluxes has become important. Grain size analysis of limestone and open hearth slag is as follows:

	+70 mm	70-50 mm	50-10 mm	—10 mm
Limestone	0·2%	32·8%	67·0%	—
Open hearth slag ...	3·3%	31·4%	62·3%	3·0%

Fluxes are also being sized under 50 mm, so that they will contribute to the uniform distribution of material charged into the blast furnace, and open hearth slag of under 10 mm is being blended as material for sintered ore.

Coal and coke

The quality of coke has been remarkably improved during the post-war period. As is shown in Table IV, besides blending 35–40% American coal as high coking coal, some Saghalien and Australian coal plus about 6% domestic coal are also used.

The various coals are blended precisely by using an automatic weighing machine. They are crushed so that fine coal under 3 mm occupies over 85% of the

TABLE III

Blending ratio of raw materials and quality of product of Dwight Lloyd Sintering Plant at Yawata Works.

J.F.Y.	Blending Ratio %						Quality of Product %			
	Pyrite cinder	Domestic fine	Foreign fine	Scale	Iron sand	Open hearth slag	Total Fe	Cu	Fine under 10 m/m (%)	Shatter index 10m/m (%)
1953	43.4	0.2	37.3	1.5	17.6	-	57.9	0.18	13	79
1954	48.7	4.0	26.9	2.4	16.7	1.3	59.4	0.21	12	77
1955	47.8	4.4	23.1	5.0	15.0	4.7	59.0	0.17	9	79
1956	40.1	3.9	27.5	6.7	15.7	6.1	57.6	0.13	8	81
1957	26.1	2.7	45.1	6.1	13.3	6.7	58.0	0.08	5	83

TABLE IV

Blending ratio of raw coals and coke qualities.
(shown in per cent)

			1950	1951	1952	1953	1954	1955	1956	1957
High Coking Coal	Imported Coal	American (L.V.)							2.65	7.89
		American (M.V.)	17.82	25.89	32.85	34.28	37.26	35.81	31.47	28.95
		Kailan	8.91	0.10		0.79	1.13	3.38	7.10	4.51
		Doi	0.30			0.83	0.47	1.08	0.91	0.48
		Indian	0.65	10.65	9.39	4.93	3.11			
		Others	2.38	0.03	0.06	0.36	0.20	0.58	0.77	0.32
		Total	30.06	36.67	42.30	41.19	42.17	40.85	42.90	42.15
	Domestic Coal	Hokusho	12.18	15.12	8.78	7.42	8.21	7.38	5.98	5.69
	Total		42.24	51.79	51.08	48.61	50.38	48.23	48.88	47.83
Low-Coking Coal %	Imported Coal	American (H.V.)		1.50	1.72	3.87	0.09		0.33	0.31
		Saghalien	0.58							1.25
		Kailan	0.30			1.41	1.52			
		Canadian		2.76	0.42					
		Australian								2.02
		Total	0.88	4.26	2.14	5.28	1.61		0.33	3.56
	Domestic Coal	Chikuho	42.58	33.38	35.36	34.66	39.31	42.27	40.30	37.02
		Nishi-Kyushu	10.35	6.86	9.33	9.89	7.54	6.93	8.72	9.77
		Hokkaido	0.13	0.20	0.19	0.63	1.16	2.57	1.77	1.[illegible]0
		Others	0.56	0.05	0.02					
		Total	54.62	40.49	44.90	45.18	48.01	51.77	50.79	48.59
	Total		55.50	44.75	47.04	50.46	49.62	51.77	51.12	52.17
Other Coals	Coalite		1.75	1.67	0.27					
	Oil Coke			1.72	1.61	0.93				
	Breeze		0.26	0.07						
	Anthracite		0.27							
	Total		2.26	3.46	1.88	0.93				
Grand Total %			100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

	1950	1951	1952	1953	1954	1955	1956	1957
Ash %	15.48	14.99	14.61	13.28	12.30	11.84	12.02	11.68
Drum Index (15m/m) %	90.90	92.02	92.14	91.92	92.71	92.66	92.36	92.52
Average Grain Size m/m			80.4	77.1	78.0	75.7	77.4	75.9

total charge into the coke oven. Coal is carbonised in the oven at 1,200°C flue temperature.

The ash content is 11% and Drum index 92-93%. The average grain size is 75 mm, breeze under 15 mm is screened out and there is almost no breeze over 100 mm.

The Drum index is the percentage of yield of over 15 mm screen coke after 10 kg of sample coke is crushed and abraded in a steel drum of 1,500 mm dia. with blades for 30 revolutions in two minutes.

IV

EXPERIMENTS ON LOW SHAFT FURNACE AT YAWATA IRON AND STEEL CO., LTD.

Low shaft furnace iron manufacturing is roughly classified into two methods according to the fuel employed for the furnace. One uses poor quality fuels such as weak coking coals, semi-coking coal, anthracite, etc. The other is called the DHN method in which weakly coking coal, non-coking coal, lignite, etc., which are regarded as inferior quality raw materials for metallurgical coke, are charged directly into the furnace with other raw materials, iron ore, limestone, etc. made into briquettes.

Using the former method, we changed a 3-ton experimental blast furnace into an experimental low shaft furnace. For one year and nine months from December 1954 to August 1956, we studied whether it efficiently produced pig iron for steel making or for various alloys.

Profile of the experimental low shaft furnace

The design of the experimental low shaft furnace is given in Fig. 1. The index of the height of the furnace to the diameter of the hearth of the experimental furnace was 1·405, equal to the value of Oberhausen's experimental furnace.

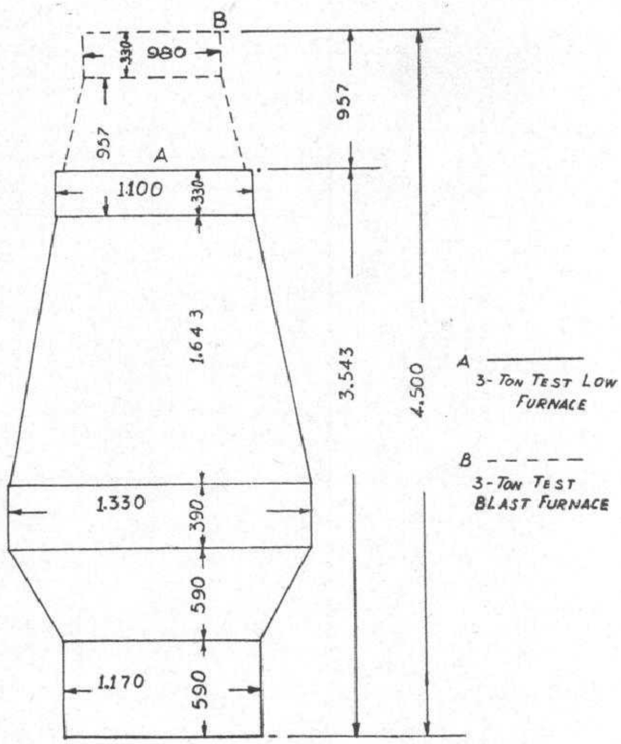


Fig. 1.
Section of test low furnace.

The series of tests comprised five stages. The first test was a preliminary one to clarify the properties of the experimental furnace. Weak coking coal was used from the second test onwards. Although production of pig iron for steel making by the low shaft furnace has not yet shown satisfactory results due to the difficulty of controlling the chemical composition, this question was taken up in the second and fourth tests. The low shaft furnace is fit for manufacturing ferro-alloys and it seems that it has fair possibilities in this respect, however, only ferro-chrome and spiegel were actually produced with the experimental furnace. In the third, fourth and fifth tests, ferro-manganese, spiegel, high silicon pig iron and foundry iron were blown under various conditions, and the manufacturability of these alloys were examined. The results of the tests are summarised in Table I.

Preliminary test

(*i*) *Basic pig iron by air blowing operation* : In order to grasp the operating properties of the experimental low shaft furnace, a preliminary test was carried out comparing the results of the low shaft furnace to those of the 3-ton test blast furnace using metallurgical coke as fuel. First, the air blowing operation was carried out using coke of 10–25 mm in size and iron ore of 5–10 mm. This combination gave the best results in the 3-ton test blast furnace. Iron ore of less than 5 mm was then used. This frequently produced hanging in the 3-ton test blast furnace. In the case of the low shaft furnace, good results were obtained with ore under 5 mm. The results were better than those in the 3-ton blast furnace.

(*ii*) *Foundry pig iron by blowing enriched oxygen* : In order to obtain basic data on ferro-alloys, tests were carried out using O_2 enriched to about 25%. During the air blowing operation, there was no marked difference between the test blast furnace and the experimental low shaft furnace, however, when the oxygen density was enriched to 25%, the coke ratio decreased by about 20% and the production of pig iron increased by 38%.

Production of basic pig iron

(*i*) *Air blowing operation using weak coking coke* : Weak coke (made from Chikuho coal of 10–25 mm and iron ore (from Vancouver) of under 5 mm, which had shown the best results in the low shaft furnace operation using metallurgical coke, were used and compared with the results using metallurgical coke. The Drum test index of the weak

TABLE I

Results of the interim industrialisation test of low furnace iron manufacturing.

Test Items	Test Furnace	Coke Ratio	Si	S	Adequate Size		Volume of Pig Iron (t/D)	Ore used	Coke used	Content of O_2 at Air Blowing (%)	Remarks
					Coke	Ore					
1. Pig iron for steel by air blowing operation	Blast furnace	1.19	1.29	0.066	10-25	5-10	7.014	Ut. ore	Metallurgical coke	air	Coke ratio was descreased by making size of ore-5mm
	Low shaft furnace	1.09	0.82	0.036	"	-5	7.499	"	"	"	
2. Pig iron for steel by enriched oxygen blowing	Low shaft furnace	1.04	1.22	0.032	"	"	8.925	"	"	25.2	Coke ratio could be further decreased
3. Foundry pig iron by enriched oxygen blowing	Blast furnace	1.38	1.51	0.039	"	5-10	5.289	"	"	air	Coke ratio could be decreased. (test blast furnace air blowing)
	Low shaft furnace	1.11	1.57	0.050	"	-5	8.266				
4. Basic Pig iron using weak coking coal and air blowing operation	Low shaft furnace	1.23	1.14	0.37	"	"	6.345	Vencouver ore	"	air	In case of weak coking coal be used, coke ratio increased considerably.
		1.70	1.07	0.042	"	"	5.035	"	Low coking coal	"	
5. Basic pig iron using weak coking coal and enriched oxygen blowing operation	Low shaft furnace	1.46	1.10	0.051	"	"	5.8111	"	Metallurgical coke	25.7	Using-1 mm ore and metallurgical coke, the results which were not inferior to the air blowing operation were obtained
		1.27	1.14	0.065	"	"	6.243	"	Low coking coal	30.1	
		1.21	0.91	0.082	"	-1	6.763	"	"	30	
6. Manufacturing of ferro manganese	Low shaft furnace	1.99	0.64	0.004 Mn 66.3	"	-1.5	4.539	Indian manganese ore Vancouver ore	"	40	Although weak coke coal is used, the results were better than those of the large blast furnace.
	Higashida No.1 B.F.	2.40	0.56	0.009 Mn 67.6	"		103		Metallurgical coke	air	
7. Manufacturing of spiegel	Low shaft furnace	1.65	0.23	0.011	"	-1.5*	5.25	Indian manganese ore Vancouver ore	Low coking coal	31.2	The results are nearly equal to those of the spiegel blowing by the Higashida No.1 Blast Furnace. In this case, adquate sizes are: coke: 10-25 ore: 1.5-5 or 5-10
		1.20	0.85	0.015	"	5-10	7.166	Indian manganese ore Goa ore	"	25.0	
8. Manufacturing of high silicon pig iron	Low shaft furnace	1.56	4.50	0.034	"	-1.5	5.508	Ut. ore	"	30.7	Considerably good results were obtained using 1.5 mm ore and enriched oxygen blowing.
9. Manufacturing of foundry pig iron	Low shaft furnace	1.43	2.18	0.029	"	-1.5	5.946	"	"	30.5	Results cannot be improved much by enriched oxygen blowing. When the content of O_2 be increased, conditions in the furnace become unstable.

* Inadequate size.

coke was about 40–60% and the ash content at about 14% did not differ much from that of metallurgical coke. When the operation results of manufacturing pig iron for steel making are compared using the two kinds of coke, the results when using weak coke were inferior, increasing the coke ratio and decreasing the pig iron produced.

In regard to the temperature inside the furnace, it was high everywhere around the belly, shaft, and top of the furnace. Losses of heat were considered large.

(*ii*) *Enriched oxygen blowing operation using weak coke*: Using the same ore and coke as above, the effect of oxygen density upon the conditions in the furnace was examined when oxygen in the air blowing was increased to 25%–30%. When weak coking coal was used and oxygen density increased to 25–30%, etc., the coke ratio decreased and the volume of pig iron was increased. The gas temperature at the top of the furnace, the indirect reduction ratio, etc. were considerably improved. When the oxygen density was increased in air blowing, however, the FeO content in the slag and the S in the pig iron tended to increase. The temperature at the top of the furnace showed a decreasing trend making a sharp temperature curve.

(*iii*) *Determination of optimum size of ore*: In order to examine the best size of ore when using weak coking coal and with oxygen in air increased to 25%, 30%, etc., tests were carried out arranging ore size at 5–3, 3–1, and under 1 mm. Ore under 1 mm showed the best results in the test. The coke ratio at this time was 1·21.

(*iv*) *Determination of optimum size of weak coke*: Using ore of under 1·5 mm size, the best coke size in the low shaft furnace was examined arranging the size of coke at 5–10, 10–20, 20–30 mm. 10–20 mm coke showed the best results in the test, however, there was no great difference between 10–20 mm and 20–30 mm coke. With 5–10 mm size coke hanging was frequent which hindered smooth operations.

Manufacture of ferro-alloys

Great hope is placed on the manufacture of ferro-alloys with low shaft furnace, but only ferrochrome and spiegel have been actually produced. There has been no case so far of manufacturing ferro-alloys using ordinary quality iron ore and weak coking coal. We, therefore, studied manufacturing conditions for making ferro-manganese, spiegel, foundry iron, and high silicon pig iron with these raw materials.

(*i*) *Ferro-manganese*: Aiming at the manufacture of ferro-manganese containing over 60% Mn, test were carried out using ordinary quality Indian manganese ore, and domestic manganese ore. In the test using Indian manganese ore, when oxygen density in air blowing was increased from 21% (air) to 25%, 32%, and 40%, it was found that operating results such as volume of pig iron, coke ratio, etc. were remarkably improved with the increase of oxygen. The degree of improvement was remarkable between oxygen densities of 20–25%. When the result is compared to that of a large blast furnace, though the test low shaft furnace is much smaller than a large blast furnace, it was proved that the results are more satisfactory than those of the blast furnace. Similar results were found in case of the domestic manganese ore, but as it is inferior in quality to the Indian manganese ore, the results were bad and it seemed that it would not fit for ferro-manganese production.

(*ii*) *Spiegel*: Spiegel which contains 20–25% Mn was manufactured using the same raw materials as in the case of ferro-manganese. In the case of spiegel, operating results were improved remarkably with the increase of oxygen density, and, with an oxygen density of 30%, the coke ratio was equal to that of spiegel manufacturing with a large blast furnace (Higashida No. 1 Blast Furnace).

Next, effects of ore size and quality upon the results were examined keeping the oxygen density in the air at 23–25%. Ore under 1·5 mm was fit for pig iron for steel, and comparatively larger sizes of ore, 10–5 mm, 5–1·5 mm, showed good results in the case of spiegel. The reason is that the specific gravity of the manganese ore is small and flue dust loss increases. When magnetite ore from the Larap mine, hematite ore from Dungun and Goa mines were used, hematite ore showed better results, and ore of high Fe content showed a little better coke ratio and more production of pig iron, but there was no great difference.

(*iii*) *High silicon pig iron*: Using Utsh ore under 1·5 mm and weak coking coal of 10–25 mm, and oxygen density of 25% and 30%, high silicon pig iron was experimentally produced. In this case also the effects of oxygen density were remarkable and the results with oxygen density of 30% were fairly good, not inferior to the results of the large blast furnace (Higashida No. 3 Blast Furnace).

(*iv*) *Foundry pig iron*: Using the same raw materials as in the case of high silicon pig iron, foundry pig iron was manufactured with oxygen density at 25% and 30%. In the case of foundry pig iron, enrichment of oxygen does not give as good effects on the operating results as in the case of ferro-alloys.

From the above experiences, it can be said that low shaft furnace iron making which requires enriched oxygen blowing as a rule, is fit for the manufacture of those kinds of pig iron which require the maintenance of the hearth at a high temperature.

Manufacture of ferro-alloys by blowing with oxygen density of 60%. A cold enriched oxygen of 60% blow was carried out to examine whether smooth operation would be possible for the manufacture of pig iron for alloy, and whether the top gas now contained ingredients fit for ammonium synthesis. In the cases of ferro-manganese and high silicon pig iron making, the results were not inferior to those obtained when using 30% oxygen.

But in the case of the foundry pig iron, the adjustment of the chemical composition of the pig iron was difficult. In every case, slip in the furnace increased a little, but the ratio of top gas (CO-H_2) to N_2 was about 3 : 1 and the gas was fit for ammonium synthesis.

Conclusion

We have changed our 3-ton test blast furnace (effective height : 3·6 m) into an experimental low shaft furnace (effective height : 2·6 m) and carried out experiments on low shaft furnace iron production. The results obtained are as following :

(*i*) Efficient manufacturing of basic pig iron with the experimental low shaft furnace was possible with ore size under 5 mm when weak coking coal is used and the oxygen density is 25–30%. Coke size in this case was 10–25 mm.

(*ii*) For ferro-alloys, test manufacturing of ferro-manganese, spiegel and high silicon pig iron was carried out. All showed the best results with oxygen density of about 30% and results were better than with the large blast furnace.

(*iii*) Aiming at the effective use of top gas, ferro-alloys were manufactured with an oxygen density of 60%. Ferro-manganese and high silicon pig iron showed fairly good results, but it was difficult to adjust the constituants of foundry pig iron. However, in every case, the proportion of CO and H_2 in the top gas was high and considered fit for ammonium synthesis.