Operation of a Blast Furnace with Self-Fluxing Sinter*

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I. Operation and Results

This paper describes the experiments on the blast furnace operation by use of lime-sinter at Kukioka No. 2 blast furnace of Yawata Iron & Steel Company from June 1958 to March 1959.

By 100% self-fluxing sinter burden, a high iron productivity over 0.044 ton per day per cubic ft. of inner volume and the lowest coke rate of 1036 lbs. per ton iron were obtained.

This presentation will discuss the effects of the lime-sinter burden on the operation of the blast furnace.

Kukioka No. 2 blast furnace has 31,060 cubic ft. of inner volume (defined by the Iron & Steel Institute of Japan as the volume from the stock-line to the bottom) and 23 ft. of hearth diameter. The sinter ratio in burdens was increased gradually from June 1958 and 100% sinter burden was used from Nov. 1958 to March 1959. During this period the limestone content in the sinter-mix was changed to 0, 5 and 10 per cent respectively. A-sinter is the sinter of 10 per cent limestone in sinter-mix, B-sinter is of 5 per cent limestone and C-sinter is of no limestone. The schedule of operation, characteristics of the lime sinter, raw materials and operating results are shown in Table I-IV.

Table I. The schedule of the experimental operation

Year	1958							1959		
Month	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.
Limestone in sinter-mix per cent	5	10	10	10	10	10	10	5	5	0
Sinter ratio in burdens per cent	40	40	60	80	80	100	100	100	100	100

Table II. The quality of sinter

Year	1958							1959		
Month	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.
Fe content	56.64	54.33	54.18	55.05	54.60	55.8	55.3	57.0	57.4	58.3
Sulphur content	0.03	0.06	0.11	0.07	0.08	0.03	0.04	0.03	0.03	0.03
CaO/SiO ₂ ratio	0.68	1.42	1.27	1.21	1.22	1.41	1.36	0.85	0.82	0.50
Degree of oxidation	92.98	93.29	92.31	92.59	93.53	93.55	94.21	93.27	94.08	93.10
Shatter test (index per cent +15 mm)	73	72	78	78	79	77	81	84	82	82

Table III. Raw materials used

(Unit: lbs per ton iron)

Year	1958							1959		
Month	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.
Iron ore	Sintered ore	1292	1324	1966	2708	2654	3138	3320	3208	3164
	Korean ore	322	352	382	356	322	0	0	0	0
	Dungun washed	444	448	436	0	0	0	0	0	0
	Dungun	218	216	208	226	Srimeadan 260	0	0	0	0
	Goa	812	818	170	0	0	0	0	0	0
	Others	68	68	66	64	60	0	0	0	0
	Total	3156	3230	3230	3352	3296	3138	3320	3208	3164
Open hearth furnace slag	228	230	220	160	116	110	116	142	116	88
Limestone	238	278	238	152	188	0	2	244	238	382
Metallics	0	0	0	0	0	94	0	0	0	0
Coke	1290	1300	1256	1248	1186	1036	1096	1142	1126	1182

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Table IV. Operation results

Year	1958								1959	
Month	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.
Iron production ton per day	924	938	1018	991	1003	1103	1382	1131	1365	1212
Coke rate lbs. per ton iron	1290	1300	1256	1248	1186	1036	1096	1142	1126	1182
Limestone in sinter-mix per cent	5	10	10	10	10	10	10	5	5	0
Sinter ratio in burdens per cent	40	40	60	80	80	100	100	100	100	100
Ore/coke ratio	2.446	2.482	2.573	2.686	2.779	3.029	3.028	2.809	2.864	2.675
Smelt/coke ratio	2.930	2.872	2.938	2.935	3.035	3.226	3.136	3.147	3.177	3.072
Slag volume lbs. per ton iron	880	884	964	954	930	734	824	894	870	982
Ore rate lbs. per ton iron	3.156	3.230	3.230	3.352	3.296	3.138	3.320	3.208	3.226	3.164
Blast volume cubic ft. per min.	39340	41070	40580	39270	36560	36370	49790	44210	49090	47430
Blast pressure lbs. per square in.	13.22	14.43	13.33	12.66	11.49	9.74	12.47	10.34	14.06	13.34
Blast temperature °F	1517	1506	1535	1463	1517	1616	1483	1596	1630	1567
Top gas temperature °F	390	415	405	420	388	405	433	400	415	420
Top gas CO/CO ₂ ratio	1.53	1.60	1.63	1.65	1.49	1.37	1.42	1.48	1.48	1.54
Times of hanging per 10 days	0.7	0	0	0	0	0	0	0	1.3	0.7
Dust rate lbs. per ton	32	60	54	58	44	30	30	38	28	34
Total input of sulphur lbs. p. ton iron	10.06	10.22	9.82	10.22	10.32	7.54	8.14	7.88	7.84	7.88
Iron quality Si per cent	0.58	0.60	0.60	0.64	0.61	0.68	0.65	0.62	0.59	0.58
" S per cent	0.022	0.022	0.022	0.026	0.024	0.031	0.034	0.023	0.022	0.018
CaO/SiO ₂ of slag	1.37	1.32	1.28	1.19	1.21	1.19	1.16	1.20	1.21	1.21

II. Discussion

Iron Production

In December 1958 with 100 per cent A-sinter burden and February 1959 with 100 per cent B-sinter, the authors tried experimental operations to research the maximum iron production without irregular conditions such as slippings and hangings, and obtained 1300 ton iron per day and 0.044 ton iron per day per cubic ft. of inner volume. In December 1958 using A-sinter, the iron production reached 1300 tons per day smoothly without any trouble but more iron production was impossible due to the limitation of the iron casting practice. On the other hand, in February 1959 using B-sinter, the blast pressure was raised abnormally as the blast volume was increased, and finally some hangings were caused and the iron production was restricted.

The iron production is increased by increase of the blast volume. If the permeability of the stock column is low, the blast pressure rises steeply as the blast volume is increased and finally irregular descending of charge is caused.

On the pressure drop in the blast furnace W.O. Philbrook gives the following equation:

$$\Delta P = f \times G^2 / \rho \cdot g \times 6(1 - \varepsilon) \cdot L / D \cdot \phi \cdot \varepsilon^3 \quad \dots \dots \dots (1)$$

where ΔP : pressure drop kg/m²
 f : friction factor m/sec.
 G : superficial mass velocity

Fig. 1 Change of iron production during experimental operations

ρ : density of gas kg/m²/sec.
 g : acceleration of gravity kg/m³
9.8 m/sec.²
 D : mean size of burdens m.
 L : height of stock column m.
 ϕ : sphericity factor
 ε : free volume coefficient

The equation (1) is modified as follows:

$$f \cdot (1 - \varepsilon) / \varepsilon^3 = \Delta P \cdot \rho \cdot g \cdot D \cdot \phi / 6 G^2 \cdot L \dots\dots\dots (2)$$

The factor ε is unknown, so the authors define

$$f \cdot (1 - \varepsilon) / \varepsilon^3 (= F)$$

as a modified friction factor. Each term in equation (2) is calculated as follows:

ΔP : blast pressure—top pressure

G : (blast volume)/(mean section area of furnace)

L : the height from the stock-line to the tuyere level

ϕ : 1 (assumed)

This modified friction factor F indicates the permeability of the stock column and is affected by the characteristics of each furnace and the absence of burdens.

Fig. 2 shows the change of F during the experimental operations. F decreased when increasing the sinter ratio in burdens and reached minimum at 100 per cent sinter burden. The reason for this improvement is considered to be that the gas-flow resistance of the solid burdens at the upper stack is decreased by the uniformity of the distribution of 100 per cent sinter burden and the primary slag reaction is performed in the sintering process. When the ordinary iron ore burden is used, sticky and high basicity slag is formed at the melting zone. Thus more blast volume and iron production are possible when using 100 per cent A-sinter.

Fig. 2 Change of "F" during experimental operations

Technical Research Institute of Yawata Iron Works investigated this point with an experimental blast furnace by use of A-sinter of 100 per cent, 50 per cent and no sinter in burdens respectively. On each burden, the viscosity, melting temperature and basicity of slag and silicon content in sponge iron were measured at levels of the lower stack, belly and bosh. The viscosity of the primary slag of 100 per cent sinter burden is low at each level. But with a low-sinter burden it is increased steeply at the belly.

The slag basicity changes little in the furnace and SiO_2 in the slag is reduced only a little until the bosh zone. Consequently, the use of high blast temperature is possible by use of 100 per cent A-sinter.

Coke Rates

(1) Comparison of each operation

The coke rates in each month are as shown in Fig. 3 and correlated to sinter ratios in Fig. 4. As shown in Fig. 3, the coke rate of A-sinter is the lowest. The coke rate is decreased with a curved line as the sinter ratio in burdens is increased. Consequently, the coke rate is reduced

Fig. 3 Change of coke rate

Fig. 4 Relation between coke rate and the sinter ratio

Fig. 5 Change of heat balance during experimental operations (Unit: B.T.U. per ton iron)

remarkably by the use of over 60 per cent sinter burden.

(2) Discussion on heat balances

The heat balances of each month are as shown in Fig. 5.

The total heat required per ton iron in November 1958 (sinter ratio=100 per cent) is about 1,080,000 B.T.U. less than in July 1958 (sinter ratio =40 per cent). In November the heat of combustion of carbon was decreased and the sensible heat of the blast was decreased due to decreasing of the blast volume per ton in spite of the use of high blast temperature.

The output of heat will be discussed as follows:

(a) Solution loss:

Table V shows the carbon balance of each month. Although the heat consumption by solution loss changed little, the top gas volume per ton iron and CO/CO₂ ratio in top gas were decreased remarkably in November (100 per cent A-sinter) as shown in Fig. 6. This means a high reducibility of the lime sinter burden.

(b) The heat for calcining of limestone:

During November and December using 100 per cent A-sinter, no limestone was added to burdens and about 288,000 B.T.U. per ton iron was saved.

(c) The sensible heat of the molten slag:

The slag volume was decreased remarkably during use of 100 per cent sinter burden, especially in November 1958. This low slag volume was caused by decrease of the rates of open hearth furnace slag, limestone and coke. The high sinter burden allowed the low basicity operation due to decrease of the input of sulphur, not due to high desulphurization. The saving in heat consumption by low slag volume was considerable.

(d) The heat consumed by the decomposition of moisture in blast:

From June to October 1958 the blast was humidified to 15.6 grains per cubic ft. and not humidified after November because the authors found the moisture did not contribute much to the high sinter operation of the blast furnace. Consequently, about 180,000 B.T.U. per ton iron were reduced after November.

(e) Others:

The moisture in the high-sinter burden is so little that the heat carried out by it was reduced. The radiation loss was decreased after November because of high iron production.

Fig. 6 Top gas volume, CO/CO₂ in top gas and solution loss

Table V. Carbon balance of each month										(Unit: lbs per ton iron)
Year		1958						1959		
Month		Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Jan.	Feb. Mar.
Total carbon gasified in furnace		1036.8	1045.8	1006.2	1002.4	946.8	926.0	870.2	908.4	894.0 935.0
Carbon gasified at tuyeres	Consumed by oxygen	786.4	798.0	753.4	758.6	720.4	623.0	660.8	699.2	668.2 714.8
	Consumed by moisture	60.2	61.2	57.8	58.2	55.2	11.4	12.6	11.0	12.4 11.6
Carbon gasified above tuyeres	By direct reduction	20.6	20.8	21.6	22.2	21.4	22.2	22.6	22.4	21.2 21.4
	By solution loss	165.6	165.8	173.4	163.4	149.8	169.4	174.2	175.8	192.2 187.2