Iron Smelting with Non-Coking Coals in Low Shaft Furnace*

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In relation to classical reserves of high grade iron ore in India, the reserves of good metallurgical grade of coking coals are extremely limited and that too confined to in the Bengal-Bihar belt. The development of small and medium scale iron and steel plants depends on the exploitation of sub-standard raw materials particularly the fuel unsuitable for conventional smelting in big blast furnaces of a million tonnes integrated iron and steel complex. The Low Shaft Furnace Pilot Plant installed at the National Metallurgical Laboratory, Jamshedpur(India) is designed to operate on sub-standard raw materials and non-metallurgical fuels for iron smelting.

In 5～6 years of extensive and painstaking trials, a great variety of raw materials have been investigated on a comprehensive scale. It has been established that technological, operational and economic considerations preclude the adoption of a single stage process based on the smelting of single component burden of ore-fuel-limestone briquettes. The operational complexities and non-recovery of potential by-products have rendered the direct utilization of non-coking coals for iron smelting as lumpy bedded charge also impractical. The use of low temperature carbonized coke made from non-coking coals has enabled effective furnace operational control and uniformity of pig iron output of consistent composition.

Carbon saturation of pig iron in initial trials was found to be low which depended on the basicity and MgO content of the slag. The effects of changes in the basicity of slag on carbon, silicon of pig iron, sulphur partition and on technical aspects of smelting, flux rate and fuel rate were investigated. The effects of particle size of raw materials and the rate of blowing, on top gas temperature, CO/CO_2 ratio, fuel rate and dust loss were also comprehensively studied. Dolomite additions were found to improve the slag fluidity but somewhat adversely affected sulphur partition.

It has been established that iron smelting in a low shaft blast furnace with low temperature carbonized coke can be successfully adopted in areas where coking coals reserves were limited.

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Introduction

Conventional iron-making in the blast furnace depends on smelting lumpy or agglomerated iron ore burden employing hard metallurgical coke as the reductant and source of heat supply. Apart from direct reduction processes,[1] iron smelting in a Low Shaft Furnace can well be undertaken with substandard fuels, such as non-coking coals[2]~[4] low temperature coke carbonized from non-metallurgical coals, sub-size nut coke,[2][5]~[8] lignite coke,[9]~[12] anthracite etc. In India iron ores deposits are more or less uniformly dispersed. Scanty reserves of high grade metallurgical coking coals localized in Bengal-Bihar region of India, have given rise to intensive research and pilot plant investigations in the Low Shaft Furnace Pilot Plant of the National Metallurgical Laboratory at Jamshedpur, India; results of these investigations based on sub-standard fuels and raw materials including iron ore fines, were outlined in the International Symposium on "Iron and Steel making with Particular Reference to Indian Conditions"[2] held in February, 1963. Further work on the subject since carried out and some of the results thereof have been discussed in this paper.

The investigations were conducted in a Low Shaft Furnace of 1300 mm hearth diameter, effective height of 2·6 m, useful volume of 7·3 m^3 provided with four tuyeres, details of which have been outlined earlier.[2][3] Sections through shaft, hearth and the furnace profile are shown in Fig. 1.

Chemical Analysis of Raw Materials

Chemical composition of iron ores and fluxes collected from the different parts of India are given in Tables 1 and 2. The fusion points of the ore were high. The proximate analyses of coking and non-coking coals, their caking index are given in Table 3. The analysis of coal ash is recorded in Table 4. The proximate analyses of nut-coke and low temperature carbonized coke made from wholly non-coking coals and their ash analyses are given in Tables 5 and 6. The non-coking coals are characterised by high volatile

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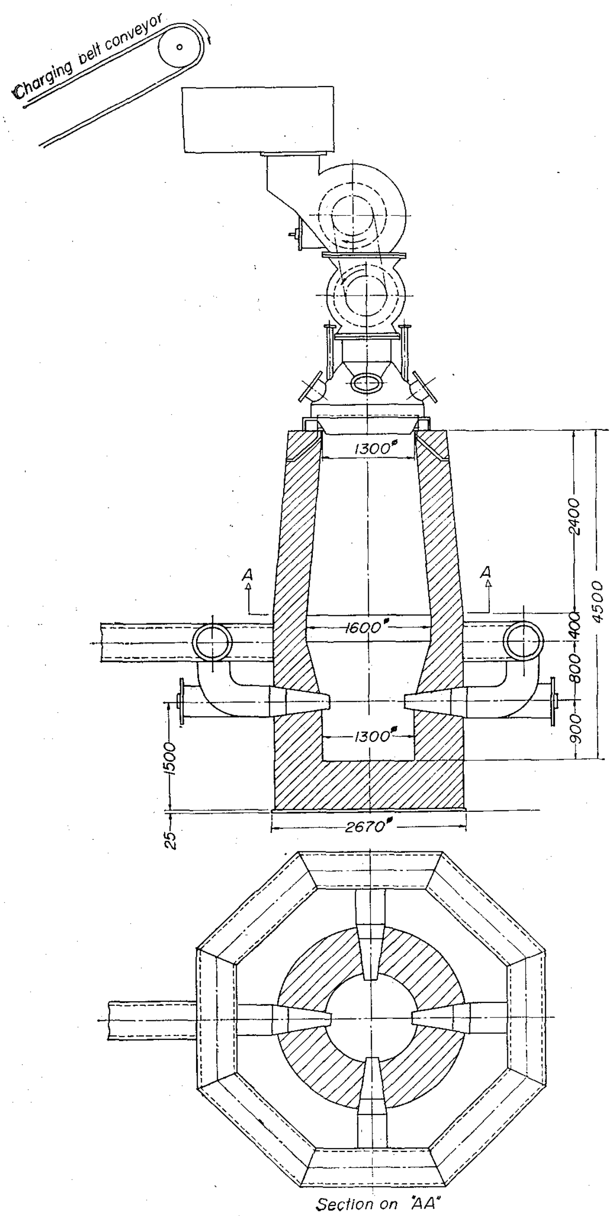

Fig. 1. Section through shaft and hearth of the 15 tonnes/day low shaft furnace.

matter and high ash contents chiefly containing over 50% SiO_2 and 25% Al_2O_3.

Smelting Trials

During the five to six years of extensive trials, iron ores and fluxes from the various states of India having widely different physical and chemical characteristics were smelted with non-coking coals and low-temperature carbonized coke made thereof by non-conventional technique. The effects of the variation of the operational conditions like particle size of iron ore and limestone, the depth of the burden, blast temperature, pressure and volume, basicity degree of the slag and dolomite additions on the smelting characteristics were determined.

The non-coking coals were utilized (i) by briquetting with iron ore fines and limestone, (ii) lumpy form of burden and (iii) after carbonization at low temperature with its conversion to soft coke.

Nut coke $-35+12$ mm sub-standard in size and unsuitable for iron-smelting in conventional pig iron blast furnace was also extensively employed in the Low Shaft Furnace Pilot Plant investigational trials.

In the lumpy form of burden, iron ore fines (70% below 6 mm) was employed directly. The slag basicity CaO/SiO_2 of 1·0 to 1·2 was normally aimed.

Smelting of Self Fluxing Briquettes

The raw materials (0 to 5 mm) are briquetted in roller briquetting machine with the addition of 4% coal-tar pitch and 4% sulphite lye as binders. The briquettes contained 18～25% iron ore, 12～19% limestone and 59～64% non-coking coal. The flow sheet of the briquetting process is shown in Fig. 2. The shape and size of a briquette is shown in Fig. 3. The coking characteristics of coal largely determined stability of the briquettes within the furnace. As the briquettes were subjected to progressively increasing load and higher temperatures during their descend, the room temperature crushing strength of the green briquettes or after their carbonization at various temperatures could not precisely indicate the furnace stability. The variation of the crushing strength, Shatter and abrasion indices with temperature are recorded in Tables 7 to 9.

In general the strength of the briquettes increased on carbonization. But in order to simulate smelting conditions the furnace stability was determined by under load tests at progressively higher temperatures. During smelting of a mixed burden consisting of 50% briquettes and nut coke, the latter improved the permeability of the burden column; the disintegration however, of briquettes into fine particles of dust constituted the most difficult problem for their successful utilization for iron smelting. The operational results with progressive increasing quantities of briquettes in the burden are recorded in Table 10. The fuel consumption and the slag volume decreased with increased amounts of briquettes in the burden. During extensive trials exclusively with self-fluxing

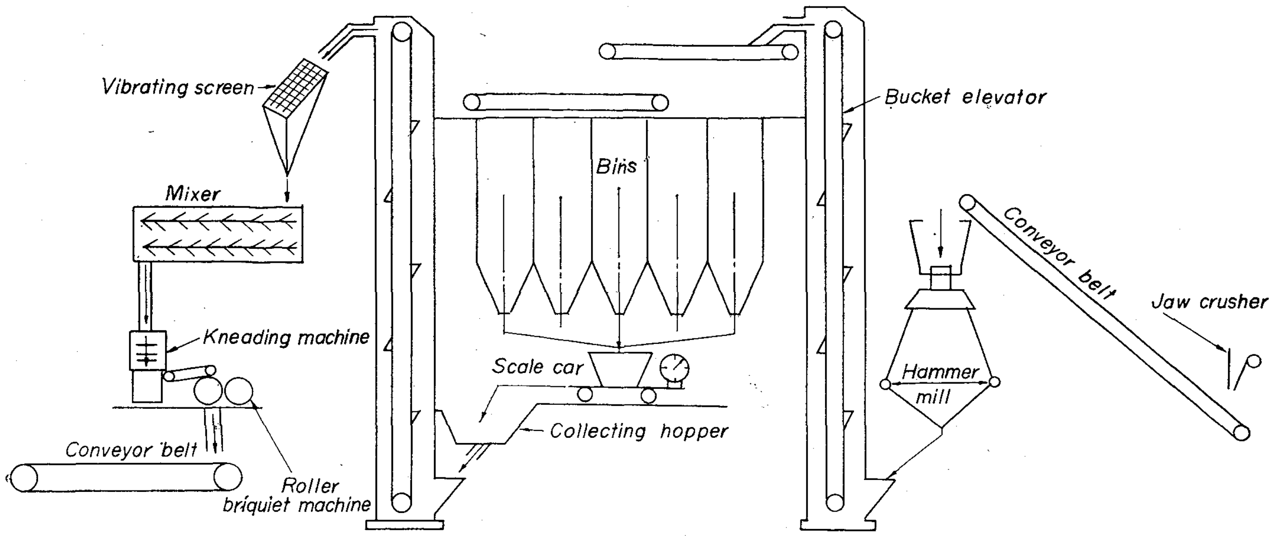

Fig. 2. Flow sheet of briquetting plant.

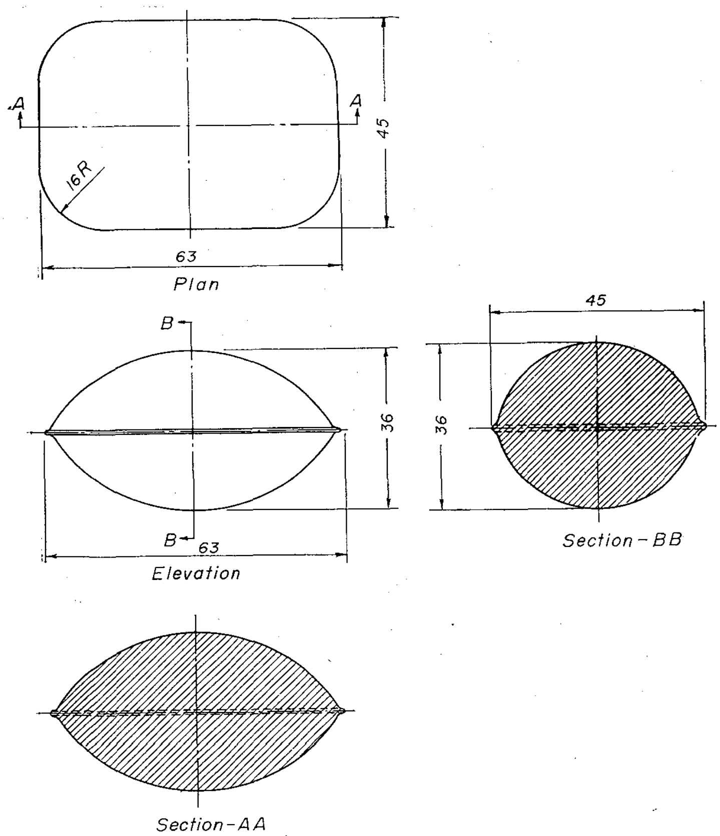

Fig. 3. Size and shape of briquettes.

briquettes, the wind rate was deliverately altered by increasing the effective tuyere diameter from 60 mm, through 75 mm to 100 mm in steps and the results are summarised in Table 11. With the increase in wind volume daily output increased from 7 tonnes through 9 tonnes to 11.2 tonnes, which altered the fixed carbon consumption per unit hearth area per hour from 606 kg, through 846 kg to 1081 kg inclusive of dust loss, which was about 10% of the burden. The top gas CO/CO_2 ratio, fuel rate and slag volume increased at the higher rates of blowing.

Although intimate contact of the fine grained constituents in the briquette was expected to promote reduction and lower the fuel rate, latter was higher compared to a burden consisting of nut coke and optimum sized lumpy iron ore, which was due distinctly to the heat requirements for the carbonization of coal present in the briquettes. The amount and quality of coal-tar recovered during the process of gas cleaning could not be employed as binder for briquetting.

Apart from the impossibility of obtaining briquettes of adequate furnace stability containing besides other constituents non-coking coals exclusively, the technological difficulties of their smelting and the cost of binders precluded the commercial adaptation of the single stage one component burden process,[3)4)] particularly under Indian climatic and monsoon rainy conditions.

Non-coking coals-bedded form of burden:

As coals of reasonably high caking index will form a sintered mass at the higher stack region of the furnace and interfere with the smooth descend of the burden, coals of poor caking index were chosen. The particle size of the iron ores varied from 35% to 95% below −12 mm and for limestones for 80 to 98% below −25 mm. The operational results are summarised in Table 12.

The direct utilization of high volatile (26～40%)

Table 1. Composition of iron ores, %.

No.	Location	Fe	SiO_2	Al_2O_3	S	P	Fusion point °C	Apparent porosity %
1	Barajamda (Orissa)	59·92 ～64·50	3·20 ～6·34	4·10 ～5·20	0·01 ～0·29	0·02	1580	12·30
2	Barbil (Orissa)	57·70 ～61·10	2·20 ～4·11	9·50 ～12·10	0·31	0·04	1475	10·20
3	Barbil (Orissa)	66·0	4·60	3·20	0·02	0·03	1450	14·10
4	Noamundi (Bihar)	63·00	3·50	6·00	0·04 ～0·30	0·13 ～0·22	1450	27·70
5	Warrangal (Andhra Pradesh)	63·64	3·80 ～4·60	2·00 ～5·90	0·30	0·06 ～0·12	1424 ～1500	13·16 ～17·31
6	Chanda (Maharashtra)	64·30	3·10	2·50	Trace	0·03	1530	25·00
7	Mohindergarh (Punjab)	62·60	6·65	2·00	0·03	0·40 ～1·20	1424	7·90
8	Chomu-Samod Morija (Rajasthan)	61·60	9·90	1·20	0·20	0·05	1475	6·05
9	Bolani (Orissa)	57·00	5·00	6·50	0·03	0·05	—	—

Table 2. Analyses of limestone and dolomite, %.

No.	Location	CaO	SiO_2	Al_2O_3	MgO
1	Birmitrapur (Orissa)	44·80	6·96	1·60	3·57
2	Warrangal (Nadhra pradesh)	32·20	0·30	0·56	25·00
3	Salem (Madras)	54·31	0·88	1·23	1·01
4	Rajur (Maharashtra)	47·28	6·68	0·85	3·45
5	Birmitrapur (Orissa)	32·60	3·90	1·60	20·40
6	Jalpaiguri (Assam/W. Bengal)	31·30	0·63	0·40	20·70

high ash (16～24%) non-coking coals of very low coking indices employed in bedded form of burden although some what more successful than briquettes cannot also be adapted on commercial scale owing to poor permeability of the stock, irregular descent of burden to non-uniform furnace operations and wide fluctuations in composition of the pig iron smelted.

Smelting with Low-Temperature Carbonized Coke Made from Non-Coking Coals

In view of technical drawbacks and highly unfavourable economics of iron production under commercial conditions by the direct utilization

Table 3. Proximate analyses, caking index of non-coking and coking coals.

No.	Colliery	Moisture %	V.M. %	F.C. %	Ash %	Caking index B.S.S.
1	Jambad (Raniganj)	3·50	39·94	41·10	20·50	2
2	Samla (Raniganj)	4·50	34·00	47·50	14·00	2
3	Ghusick-Muslia (Raniganj)	4·50	31·10	38·80	25·60	6
4	Jaipuria (Raniganj)	3·20	35·00	41·00	20·50	2
5	Sirka (Bokaro) Raniganj-Karanpura	3·50	30·80	49·52	19·70	2
6	Saunda -do-	3·70	31·00	51·50	9·80	2
7	Khaskenda -do-	6·60	35·90	45·20	12·30	2
8	Real Jambad -do-	4·70	33·60	43·90	17·80	2
9	Bankola (Raniganj)	4·00	32·00	44·56	19·40	2
10	Kargali (Bokaro) (Washed coking coal)	1·20	30·00	56·60	12·20	24
11	New Sitalpur (Disergarh coking coal)	1·50	36·30	49·30	12·90	20
12	Central Satgram (Raniganj)	3·40	36·00	43·00	17·60	7
13	Saltore (Raniganj)	2·50	36·40	48·80	12·30	9
14	Ghughus (Maharashtra)	9·70	34·40	42·80	13·10	2
15	Kamptee Kanhan (Maharashtra)	5·00	34·00	37·80	23·40	2
16	Hindhsthan Lalpeth (Maharashtra)	5·30	32·70	45·80	16·20	2
17	Singareni (Andhra)	7·10	26·10	49·50	17·50	2

Table 4. Analyses of coal ash contents, %.

No.	Origin	SiO_2	Al_2O_3	CaO	MgO	Fe	P	S
1	Jambad	57·85	22·28	—	2·90	6·94	0·59	0·40
2	Samla	62·96	22·82	4·55	1·63	5·09	0·60	1·01
3	Ghusick-Muslia	63·73	21·93	1·09	2·40	5·43	0·15	—
4	Jaipuria	53·28	23·00	5·43	1·63	9·18	0·51	0·39
5	Sirka	54·26	27·26	2·74	1·05	6·57	0·50	0·63
6	Saunda	61·20	31·90	2·70	3·10	2·70	0·46	0·54
7	Khaskenda	49·04	24·93	2·44	1·33	4·37	0·59	0·48
8	Real Jambad	61·50	27·80	2·10	2·20	4·40	0·33	0·31
9	Bankola	56·30	24·46	10·42	0·39	4·59	0·377	—
10	Kargali	46·30	29·70	3·92	3·35	5·88	0·33	—
11	New Sitalpur	54·40	25·30	6·60	2·50	4·10	0·50	—
12	Central Satgram	58·12	25·74	3·07	1·27	6·44	0·61	0·44
13	Saltore	50·00	30·52	6·60	3·12	3·47	0·29	0·53
14	Chughus	57·80	35·00	3·70	2·80	0·59	—	—
15	Kamptee Kanhan	55·00	34·90	2·90	3·20	2·90	0·11	1·30
16	Hindhsthan Lalpeth	42·80	47·00	3·80	2·30	1·80	—	—
17	Singareni	65·60	22·80	1·30	1·40	6·30	0·058	0·21

Table 5. Proximate analyses of carbonized fuels, %.

No.	Nature of fuel	Moisture	V.M.	F.C.	Ash
1	Nut coke	3·00	1·80	75·10	20·10
2	Low temperature carbonised coke (Kolsit-R.R.L.)	2·30	8·90	65·67	21·20
3	-do- (C.F.R.I.)	5·80	4·60	61·60	28·00

of non-coking coal, it is considered that employment of low temperature carbonized coke with prior elimination of volatile matters, moisture and recovery of potential by-products with consequent increase in its fixed carbon content, improved metallurgical reactivity and physical strength will not only improve the iron smelting characteristics but will also distinctly improve the overall economics of iron smelting. Extensive smelting campaigns were conducted with 'kolsit'-a low temperature carbonized coke made exclusively from non-coking coal (Singareni collieries, Andhra Pradesh) in internally heated Lurgi "Spul-gas" carbonization pilot plant at the Regional Laboratory, Hyderabad. Following the utiliza-

Table 6. Ash analyses of carbonized fuels, %.

No.	Origin	SiO_2	Al_2O_3	CaO	MgO	Fe	P_2O_5	S
1	Nut coke	52·10	33·00	3·80	2·10	6·00	1·58	0·51
2	Kolstit (RRL)	62·07	22·72	1·59	2·18	7·60	0·11	0·26
3	L.T. (C.R.R.I.)	56·31	22·00	3·45	2·20	7·61	1·83	0·27

Table 7. Crushing strength of briquettes at different temperatures.

Room temperature 25°C	Temperature °C			
	200	400	600	800
20～25 kg	25 kg	18 kg	36 kg	45·5 kg

Table 8. Screen analysis after Shatter Test of green briquettes carbonized at different temperatures.

Condition of briquette	mm; Fraction %				
	−50 +25	−25 +12	−12 +6	−6+3	−3
Green	75·30	21·70	1·00	0·56	1·50
Carbonised 200°C	14·00	56·00	15·00	6·00	9·00
〃 400°C	22·00	38·80	17·00	11·80	10·40
〃 600°C	33·00	37·80	11·80	7·40	10·00
〃 800°C	40·80	31·80	10·90	9·90	6·60

Table 9. Screen analysis after abrasion test of green and carbonised briquettes.

Condition of briquettes	Abrasion index on +3·18 mm fraction
Green	69·6
Carbonised 200°C	17·0
〃 400°C	15·8
〃 600°C	25·4
〃 800°C	24·0

tion of 'kolsit's semlting trials were conducted with another variety of low temperature carbonized coke made exclusively from non-coking coals of Raniganj field by low temperature carbonization in externally heated ovens at the Central Fuel Research Institute, Dhanbad. The physical properties of these soft cokes were inferior to metallurgical coke.

The smelting operations were conducted with a large varieties of ores of different chemical and physical characteristics and imposed conditions. The particle size of the raw materials is given in Table 13 and the operational data are summarised in Table 14. The smelting with low temperature carbonized coke made from totally non-coking coals and containing 8～10% volatile matter was characterised by smooth descent of the burden which fed adequately prepared burden to the smelt-

Table 10. Operational conditions, analyses of pig iron, slag and gas under progressively increasing briquettes in the burden.

Operational variables	Pct. of briquettes in the burden		
	25	50	75
Hot blast volume Nm^3/hr	2000	2250	2000
Hot blast pressure mmWC	1600	2700	2600
Hot blast temperature °C	575	580	575
Top gas temperature °C	380	375	350
Fuel consumption F. C./tonne	1·80	1·64	1·64
Slag volume/tonne of iron	1·10	0·93	0·93
Flue Dust (% burden weight)	4·0	7·0	10·0
Analysis of pig iron Carbon %	3·10	2·90	3·30
〃 Silicon %	3·50	3·60	2·40
〃 Sulphur %	0·03	0·04	0·08
Analysis of slag CaO%	37·80	38·40	35·80
〃 SiO_2%	33·65	32·20	33·00
〃 FeO%	0·40	0·40	0·50
Analysis of top gas CO%	24·1	25·0	22·7
〃 CO_2%	4·1	4·7	3·6
〃 CH_4%	5·0	5·5	5·9
〃 H_2%	1·2	1·7	2·8
〃 N_2%	62·0	62·0	62·0

Table 11. Operational conditions, analyses of products at different blowing rates.

Operational variables	Tuyers diameter in mm		
	60	75	100
Volume of hot blast Nm^3/hr	2050	2600	2850
Pressure of blast in mmWG	1800～3000	2200～2800	1900～2600
Temperature °C of hot blast	580～600	575～595	595
Temperature °C of top gas	350～400	350～450	350～450
Pig Iron: F.C.%	2·8～4·0	2·4～3·4	2·7～3·3
Si%	2·5～4·5	2·7～5·6	2·8～5·1
Mn%	0·34	0·24	0·2
S %	0·03～0·15	Trace-0·14	0·02～0·10
P %	0·7	0·7	0·6
Slag: CaO%	34～37	35～40	34～11
SiO_2%	30～34	29～34	30～36
FeO%	0·9	0·7	0·5
Al_2O_3%	21～22	22·0	20·7
MgO%	9～10	6·0	7·6
Top gas: CO%	23·4	23·0	21·30
CO_2%	4·7	3·5	3·0
H_2O%	2·0	2·5	1·36
CH_4%	6·8	6·7	10·0
N_2%	61·9	61·8	64·34
CO/CO_2 ratio	5·0	6·6	7·1
Pig iron, tpd.	6·9	8·77	11·2
F.C./tonn of pig iron	2·0	2·2	2·2
Slag volume	1·261	1·34	1·3
Flue dust (% burden weight)	10·0	10·5	11·0

Table 12. Operational characteristics with non-coking coals.

Data on	Saunda coal			Singareni coal		Real Jambad coal	Khaskenda coal		Mahara-stra coal 32% only	Sampla coal
	Ore 1 O.M. chipes	Ore 2 N.V.	Ore 4 Noamundi	Ore S. Lal	Ore Andhra		Ore S. Lal	Ore N.V.	Chanda ore	Barbil
Fuel rate F.C./tonne of pig iron	1·9	2·6	2·1	1·8	2·0	2·8	1·93	2·45	2·5	2·5
Slag volume/tonnes/tonne of pig iron				1·73	1·8		1·3	1·7	2·0	1·9
Blast volume Nm^3/hr	21～2300	23～2600	22～2400	2500～2700	2700～2900	2400～2600	2200～2300	1700～1800	1500～1600	1500～2000
Blast pressure mmWG	21～2500	2100～2300	2100～2300	2100～2350	1900～2100	1800～2000	2000～2100	2200～2350	2300～2500	1800～2000
Hot blast temp. °C	585	580	580	575	580	590	585	590	595	580
Top gas temp. °C	360	420	380	410	330	415	395	420	450	400
Av. analysis of pig iron: C%	2·5	3·2	2·8	3·2	3·25	3·0	3·0	3·0	2·80	3·0
Si%	4·0	4·2	3·7	2·7		3·8	3·6	2·9	3·25	2·5
S%	0·07	0·10	0·08	0·09	0·12	0·02	0·05	0·09	0·07	0·06
Av. analysis of slag: CaO%	41·8	31·5	39·3	40·8	38·6	36·8	35·5	38·7	35·0	38·0
SiO_2%	32·2	35·0	34·5	37·3	35·3	34·5	31·2	35·0	34·0	32·0
Al_2O_3%									0·0	21·0
MgO%									8·5	4·0
FeO%	0·40	0·7	0·6	0·5	0·6	0·9	0·8	0·9	1·4	0·8
Av. gas analysis: CO%	24·0	2·6	2·5	21·7	23·0	24·0	29·4	24·0	24·0	26·0
CO_2%	4·3	3·6	4·2	4·7	4·2	3·8	4·9	3·0	3·8	3·0
CH_4%	7·6	6·2	7·0	8·8	8·1	8·6	7·6	7·4	6·5	8·0
Ratio of CO/CO_2	5·5	7·2	6·0	5·0	5·5	6·3	6·0	8·0	6·3	8·7
Dust loss % raw material	9·0	12·0	10·0	5·0	5·0	11·0	7·0	9·5	14·0	8·0

Table 13. Screen Analysis of raw-materials smelted with low-temperature carbonized coke, %.

Materials	−50 +25	−25 +12	−12 +6	−6+3	−3
	In mm				
Kolsit (a)[a]	32·20	56·30	3·40	0·50	7·60
(b)[b]	36·50	58·90	3·97	0·34	0·29
Iron ore (S. Lal)	6·80	31·60	42·50	10·60	8·50
Iron ore (Andhra)	6·70	55·90	33·80	3·10	0·50
Iron ore (Barbil)	—	2·80	68·60	26·60	2·00
Iron ore (Punjab)[c]	—	9·20	32·00	43·50	15·30
Iron ore (Orissa Mineral-Barbir)	—	2·30	26·10	26·20	45·40
Limestone (BISRA)	2·70	35·20	35·80	14·10	12·20
Limestone (Andhra)	14·10	62·40	10·60	5·20	7·70

Remarks:

a) As received.

b) After screening through-12 mm screen.

c) After crushing and screening.

ing zone and thereby led to uniform furnace operations and uniform analyses of pig iron casts.

A comparison of the fuel rate obtained with the two varieties of low temperature carbonized cokes showed that the fuel rate with L.T.C. (C.F.R.I.) was higher than with Kolsit. Apart from difference in their reactivities, the higher ash content of 28% in the L.T.C. (C.F.R.I.) resulted in higher slag volume, whilst its larger particle size and higher CO/CO_2 ratio of the top gas accounted for the higher fuel rate. The porus spongy structure with large number of fissures parallel to its banded structure, relatively poor resistance to crushing resulted in its higher dust loss.

Smelting with Nut-coke

It has been well established that −35 mm subsize nut coke is highly disadvantageous in big

Table 14. Operational characteristics with low-temperature carbonised coke.

Data on	Fuel	KOLSIT					L. T. C. (C. F. R. I.)			
	Iron ore	Andhra ore	S. Lal ore	Punjab iron one	Barbil	Orissa Mineralu Barbil	Iron ore (Orissa Mineral)	Punjab iron ore	Andhra ore	Orissa Mineral
	Limestone	Andhra limestone	Limestone (Bisra)	Limestone (Bisra)	Limestone (Bisra)	Limestone (Bisra)	Orissa	Orissa	Andhra & Madras	
Fuel rate F. C./t. of pig iron		1·90	1·28	2·20	1·40	0·99	2·32	1·81	2·20	1·58
Slag volume t/tonne of pig iron		1·35	0·75	1·65	1·10	0·69	1·97	1·52	1·60	1·54
Blast volume N mm³/hr		2600∼2800	2400∼2600	2000∼2200	2200∼2600	2100∼2500	1850∼2200	1900∼2100	1950∼2300	2100∼2300
Blast pressure mmWG		1800∼2000	2400∼2600	2100∼2400	2400∼2700	1700∼2100	1850∼2000	2100∼2500	1500∼1900	2000∼2300
Hot blast temperature °C		595	590	590	585	500	585	585	500	485
Top gas temp. °C		385	400	375	375	350	375	370	400	335
Av. analysis of pig iron: C%		3·50	3·25	3·75	3·20	2·90	2·75	3·75	2·75	2·70
Si%		3·75	3·00	2·35	2·80	2·60	3·75	3·27	3·60	4·00
S%		0·06	3·04	0·05	0·02	0·07	0·07	0·11	0·13	0·08
Av. analysis of slag: CaO%		35·00	39·00	43·20	37·00	38·00	35·00	35·30	32·50	35·00
SiO_2%		35·00	33·00	36·00	30·00	35·00	35·00	42·40	37·50	34·50
Al_2O_3%		17·00	18·00	14·70	23·00	18·00	22·00	18·05	19·80	20·00
MgO%		18·00	8·00	5·50	8·50	7·00	5·50	5·00	6·40	6·50
FeO%		0·80	0·90	0·60	1·50	1·50	1·50	0·55	3·60	0·65
Av. gas analysis: CO%		25·00	23·00	23·40	24·00	22·40	24·50	24·00	25·20	25·20
CO_2%		5·00	6·00	3·30	5·50	5·60	3·50	4·20	3·80	4·00
CH_4%		7·00	6·00	7·50	5·00	5·80	5·00	4·50	5·00	5·00
Ratio of CO/CO_2		5·00	4·00	7·00	4·40	4·00	7·00	5·70	6·80	6·40
Dust loss, % R. M.		3·00	6·00	3·00	5·00	6·00	7·00	5·70	8·00	8·00

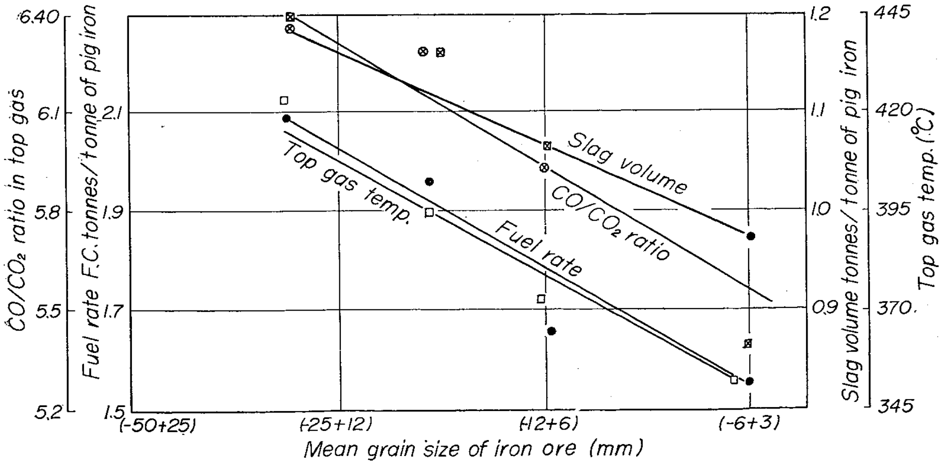

Fig. 4. Particle size of ore, CO/CO_2 ratio, fuel rate and slag-volume.

blast furnace operations.[14] Its use reduces the permeability of the burden column and its addition as fuel leads to false economy in conventional blast furnace operations. The size grading of coke is essential for increasing the productivity. In consideration of these aspects, the utilization of surplus sub-size nut-coke of 12 mm to 35 mm size available from the integrated iron and steel plants in small blast furnace and low shaft furnace operations is highly attractive from more than one angle. The purposes for employing nut-coke in the Low Shaft Furnace Pilot Plant were (i) for ascertaining the smelting characteristics at the initial stages, (ii) as corrective dose for regulating the smelting trial operations (iii) as mixed fuel with either non-coking coals or self-fluxing briquettes and (iv) for smelting of raw materials from the regions possessing no coal deposits. But due to the short stack height of the furnace, adequate heat exchange could not be attained, resulting in high top gas temperature. The effects of matching the fine particle size of the burden constituents on lowering the temperature of top gas vis-a-vis smelting characteristics were comprehensively investigated, and

Table 15. Operational characteristics with nut coke.

Data on		Rajasthan ore / Rajasthan limestone / Andhra limestone	Maharashtra ore / Maharashtra limestone / BISRA dolomite	Punjab ore / BISRA limestone / BISRA dolomite	Bolani ore (96%-3mm) / Madras limestone / —
Fuel rate F. C./tonne		1·60	2·00	1·54	1·48
Slag volume tonne/tonne		1·00	1·00	0·97	1·00
Blast volume Nm^3/hr.		2600～2900	1700～1950	2200～2600	2500～2600
Blast pressure mm WG		1700～2000	1500～2300	2000～2200	1500～1600
Hot blast temperature °C		525	590	585	525
Top gas temp. °C		450	450	345	450
Av. analysis of pig iron:	C%	2·75	2·60	3·20	3·50
	Si%	3·00	3·55	3·70	2·70
	S%	0·065	0·045	0·066	0·07
Av. analysis of slag:	CaO%	37·00	27·00	38·20	42·56
	SiO_2%	28·50	33·00	33·90	31·40
	Al_2O_3%	17·00	24·00	19·90	18·60
	MgO%	8·00	7·00	6·45	6·20
	FeO%	0·90	0·80	0·65	1·10
Av. gas analysis:	CO%	22·00	22·00	26·80	25·00
	CO_2%	3·50	3·50	4·60	4·90
	CH_4%	5·00	5·00	3·00	3·90
Ratio of CO/CO_2		6·00	6·00	5·40	5·10
Dust loss % of R. M.		4·50	9·00	10·00	2·40

Table 16. Consolidated data on operation with Kolsit and fine-grained iron ore showing decrease of fuel rate with progress of smelting.

Fuel rate F. C./tonnes of pig iron		2·00	1·82	1·61	1·49	1·28	1·19	0·99
Slag volume tonnes/tonne of pig iron		1·20	1·16	1·08	0·99	0·88	0·82	0·69
Av. analysis of metal:	C%	3·36	3·40	2·80	2·90	3·60	3·40	2·90
	Si%	1·86	2·64	1·60	2·30	5·14	3·74	2·60
	S%	0·13	0·155	0·10	0·076	0·014	0·067	0·073
	P%	0·40	0·11	0·09	0·097	0·094	0·09	0·063
	Mn%	0·62	0·69	0·77	0·42	0·75	0·15	0·34
Av. analysis of slag:	CaO%	35·10	36·10	38·50	41·80	～	39·70	～
	SiO_2%	36·50	35·90	34·90	32·40	～	33·60	～
	FeO%	2·00	2·50	1·50	1·20	～	2·00	～
	Al_2O_3%	18·00	17·20	16·40	16·00	～	16·70	～
	MgO%	7·50	7·80	7·90	7·90	～	7·70	～
	S%	0·33	0·48	0·49	0·52	～	0·47	～
Av. analysis of gas (by vol.):								
	CO%	24·60	24·10	24·60	N. D.	22·00	22·20	22·40
	CO_2%	5·20	5·20	5·80		5·10	5·40	5·60
	CH_4%	4·80	5·20	5·00		6·30	6·00	5·80
	CO/GO_2%	4·80	4·60		4·20	4·10	4·00	

N. D.＝Not determined.

the results are recorded in Table 15.

Study of Operational Variables

Fuel rate:

The higher CO/CO_2 ratio in top gas indicated that steep temperature gradient, small height of the furnace shaft with consequent faster rate of descent of the burden militated against maximum gaseous indirect reduction in the Low Shaft Furnace COHEUR[8] accounted for 16% higher fuel rate due to higher CO/CO_2 ratio in the top gas of the International Low Shaft Furnace. From the high CO/CO_2 ratio in the top gas of commercial low-shaft furnaces at Calbe, East Germany STRUVE and ERBERT[15] indicated that the mean degree of indirect reduction was 30% in comparison to 55～60% in normal blast furnace, which was partly responsible for high fuel rate. The only means of improving the CO/CO_2 ratio was therefore by proper matching of the particle sizes of the burdening materials. Fig. 4 shows the effects of the mean particle size of the iron ore on the CO/CO_2 ratio, fuel rate, top gas temperature and slag volume. The CO/CO_2 ratio decreased from 6·4 to 5·4, with consequent improvement in indirect reduction and thereby decreased the fuel rate and slag volume significantly. The lower top gas temperature indicated better heat exchange and preparation of the descending burden. The progressive replacement of lumpy limestone (50～75 mm) with fine grained limestone (97% below-6 mm) was studied. While utilization of fine grained iron ore was not instrumental in promoting excessive flue dust lossed due to the coalescence of superficially reduced iron particles, the finer particles of limestone were carried into the flue dust and the basicity of the slag thereby differed appreciably from the calculated values. However, the replacement of lumpy limestone (50 to 75 mm) progressively by 25%, 50%, 75% fine grained limestone (97% below-6 mm) decreased the fuel rate by 10%, 19% and 30%; increased the daily iron output by 29%, 40% and 42% whilst increasing unfavourably the flue dust losses by 8%, 40% and 62% respectively. The decreased permeability and increased flue dust losses, therefore, limited the use of fine grained ore or particularly flux, beyond certain optimum values. The data in Table 16, demonstrated that constancy of the smelting operation over a long period reduced the fuel rate significantly. Fig. 5 shows that the fuel rate itself was significantly influenced by the hot blast temperature and Fig. 6 show that silicon contents of pig iron influenced the fuel rate.

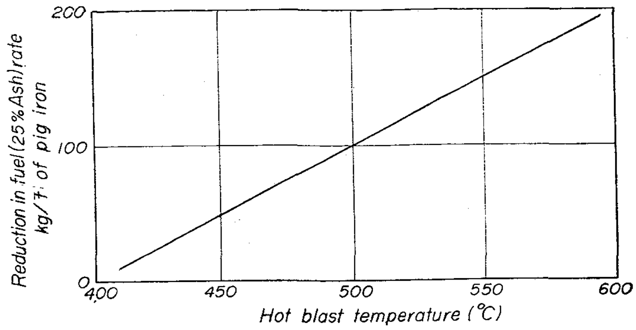

Fig. 5. Effect of hot blast temperature on fuel rate.

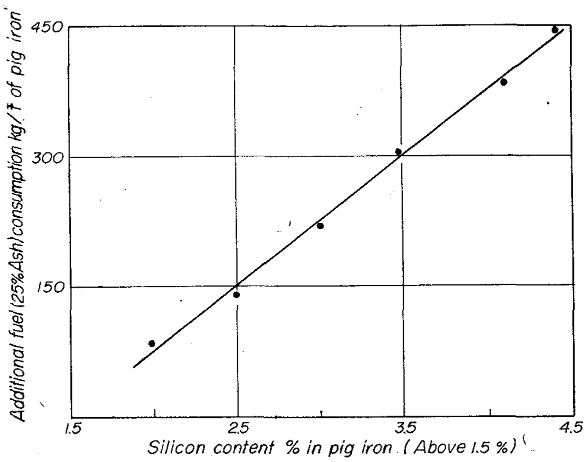

Fig. 6. Influence of silicon contents on fuel rate.

Table 17. Effect of decreasing the basicity degree of slag on smelting characteristics.

Slag basicity degree (CaO/SiO_2)	1·0	1·87	0·70
Slag volume tonnes/tonne of pig iron	1·94	1·81	1·60
Av. analysis of metals:			
C%	3·0	2·75	2·40
Si%	3·4	3·80	3·90
S%	0·08	0·18	0·17
Mn%	0·40	0·38	0·20
P%	0·14	0·11	0·09
Av. analysis of slag:			
CaO%	37·80	32·50	25·20
SiO_2%	38·20	37·50	35·40
FeO%	0·70	3·60	7·60
Al_2O_3%	18·10	19·80	25·42
MgO%	4·40	6·20	6·40
CO/CO_2 ratio in top gas	6·40	6·70	6·80

Smelting under different slag basicities:

The fuel rate in a Low Shaft Furnace is higher than in a conventional big blast furnace primarily due to the limited indirect reduction as indicated

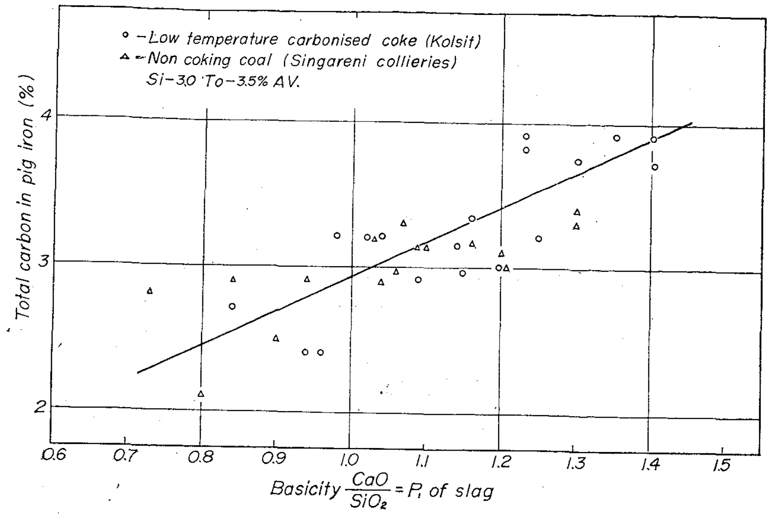

Fig. 7. Basicity ratio and carbon contents.

by the high CO/CO_2 ratio. Strauve[15] conducted investigations in low-shaft furnace with basicity ratios CaO/SiO_2 of 1·12 and 0·69 when the flux rate dropped from 916 to 870 kg and coke rate decreased from 1980 to 1627 kg/tonne of pig iron. With the object of reducing the flux addition, slag volume and consequently the fuel rate, the basicity values of the slag were maintained at 0·70, 0·87 and 1·0 for extensive smelting trials the results are given in Table 17.

Fig. 7 shows that the somewhat poor carbon saturation in the Low Shaft Furnace pig iron further deteriorated under acid smelting. The smelting characteristics were satisfactory up to a CaO/SiO_2 ratio of 0·60, below which the slag became abnormally viscous. The flux and fuel rates substantially decreased on decreasing CaO/SiO_2 ratio, but the partition of sulphur was adversely affected due to poor sulphur capacity of acid slag, which will require ladle desulphurisation of the pig iron for foundry uses or for steel making.

Partition of sulphur between the smelting products:

From the chemical analyses of the raw materials employed for smelting, it is apparent that most of the sulphur input originated from the fuel. The higher fuel rate in the low-shaft furnace will, therefore, increase the sulphur load and a higher degree of desulphurisation will be required to confine the sulphur content of pig iron within the specified limits. Amongst the other factors, the basicity degree of the slag and silicon contents in pig iron chiefly affect the sulphur partition. Fig. 8 illustrates the effect of basicity degree of the sulphur partition when pig iron contained 2·5 to 3·5% Si. The swings towards high sulphur contents in metal were due to the irregularity of smelting operation. A smooth and regular descent of the burden and low FeO contents in the slag assured desulphurization, as illustrated in Fig. 9. The low retention time in low shaft furnace adversely affects sulphur partition. However, the average sulphur contents of 0·07% under a comparatively low lime basicity ratio of 1·10 was due to high silicon content of 2·5 to 3·5% of pig iron and large slag volume of 1·0 tonnes/tonne of pig iron.

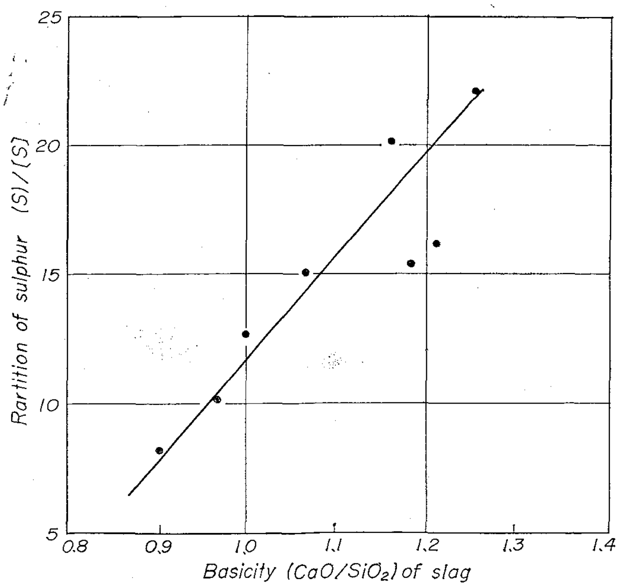

Fig. 8. Basicity of slag and partition of sulphur.

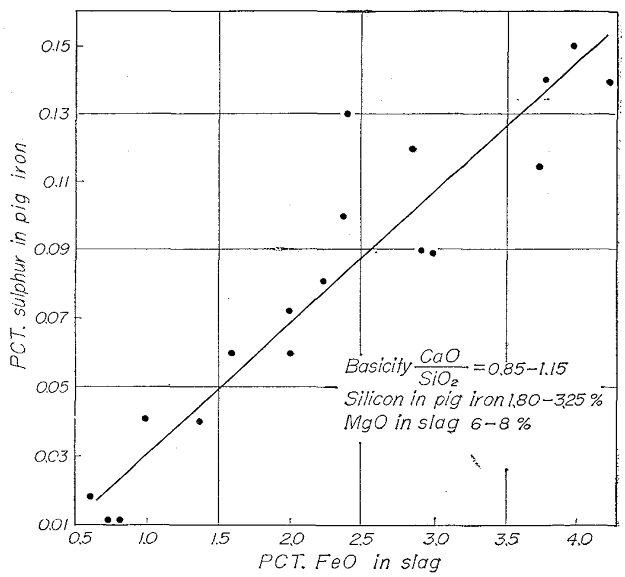

Fig. 9. FeO contents of slag and sulphur in pig iron.

Rate of blowing:

The fuel rate reached a minimum value at an optimum blowing rate. With a burden composed of small lumpy iron ore, blended fluxes of limestone and dolomite and low temperature carbonised coke, effects of increase in blast volume and pressure on the smelting efficiency were examined. On increasing the blast pressure and volume, production of pig iron naturally was increased. The increase in blast volume by 8% and 12% over the base period increased the production substantially without any significant effects on the fuel rates.

Addition of dolomite to the burden:

High alumina in the slag increased its viscosity. In order to improve the fluidity of the slag, the MgO contents were varied from 9∼10%, 13∼15% and 17∼19% in three stages maintaining the lime basicity ratio between 1·15∼1·25. The presence of a minimum of 7∼8% MgO in the slag considerably improved its fluidity and MgO contents up to 15% did not adversely affect the smelting operation. The influence of increasing the MgO content of the slag was equally to improve the carbon saturation in pig iron.

Future Programme of Investigation

In order to study the effect of injection of low shaft furnace top gas of somewhat higher fuel value than the conventional blast furnace gas, a Shaft Furnace 8 m high, 0·51 m hearth diameter was designed and fabricated at the National Metallurgical Laboratory as shown in Photo. 1. The furnace is provided with facilities for injecting gaseous fuels through a set of auxiliary tuyeres placed at the same height as air blast tuyeres but inclined to one another so that the gas stream and air impinge at appropriate points inside the furnace hearth. The four auxiliary tuyeres are placed alternatively to 4 air blast tuyeres. The gas will be injected under pressure and the air blast will be enriched if so desired, with oxygen. In order to recover the sensible heat content from the top gas and eliminate the necessity of expensive blast heating equipment arrangements have been provided for pre-heating the blast at the top of the furnace by means of a recuperator arrangement. An automatic skip hoist feeds the raw materials to the furnace. Suitably located water spray system cools the outer mild steel shell of the furnace excepting the topmost part where the blast heating recuperator has been fitted.

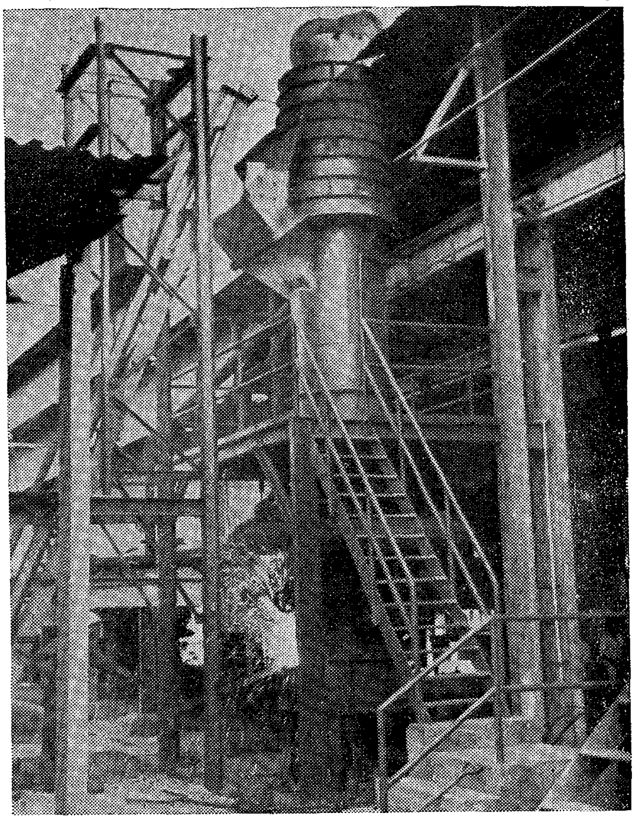

Photo. 1. Shaft furnace with twin tuyeres.

Injection of Light Petroleum Naphtha

References to technical literature show that liquid petroleum naphtha has not so far perhaps been used for direct injection into the hearth of an iron blast furnace. The National Metallurgical Laboratory, Jamshedpur, India will be pioneering a research programme for the injection of liquid petroleum product in its low-shaft furnace pilot plant. The investigation is aimed to utilize surplus naphtha.

Naptha, a cyclic hydrocarbon with a carbon to hydrogen ratio of 5·3 : 1 is obtained during refining of crude oil. The heat value of naphtha is 11,220 Kcal/kg in comparison with 10,227 Kcal/kg for the furnace oil. Naphtha contains only 0·5% sulphur as against 3·0% in furnace oil. Due to its high fluidity, no prior heating is necessary and can be automized readily. But as it is much more volatile and inflamable, the installation of the injection system should have ample safety devices and controls.

The injection system as shown in schematic diagram in Fig. 10 consists of an underground storage tank of 12500 litres capacity provided with fitting arrangement vent hole and indicator. Naphtha in the tank is subjected to a pressure of

1 kg/sq. cm. for its transfer from the underground storage tank to a 225 litres capacity service tank installed above the ground in the naphtha pump room. The service tank has also been provided with a relief valve so that the pressure in excess of 1 kg/sq. cm. can be automatically released. The service tank is adequately equipped with pressure gauge and pressure switches. From the service tank, naphtha flows into two duplex gear feed pumps coupled individually to 1 H.P. motors with1440 r. p. m. which are expected to supply 100 litres of light naphtha per hour at a pressure of 27 kg/sq. cm. The total amount of light naphtha passing through the 18 mm pipe line is determined by the flow indicator. The pumps for the naphtha have been housed in a separate room containing no electrical circuit therein-the pumps are coupled to the electric motors located in a separate room with the shaft properly enclosed in asbestos packings. The entire naphtha pipe line is welded and is laid underground upto the control cubical in the control room, where it is divided into four 6 mm dia. pipes each having a control valve and a pressure indicator to control the rate of flow of naphtha through individual lances placed in the four tuyeres of the Low Shaft Furnace. A three way air purging cock has been provided to facilitate stoppage of naphtha and its purging with compressed air. The lances have been provided with a self closing coupling to prevent possible ignition of naphtha in the supply pipe line at the time of withdrawal of the naphtha lances.

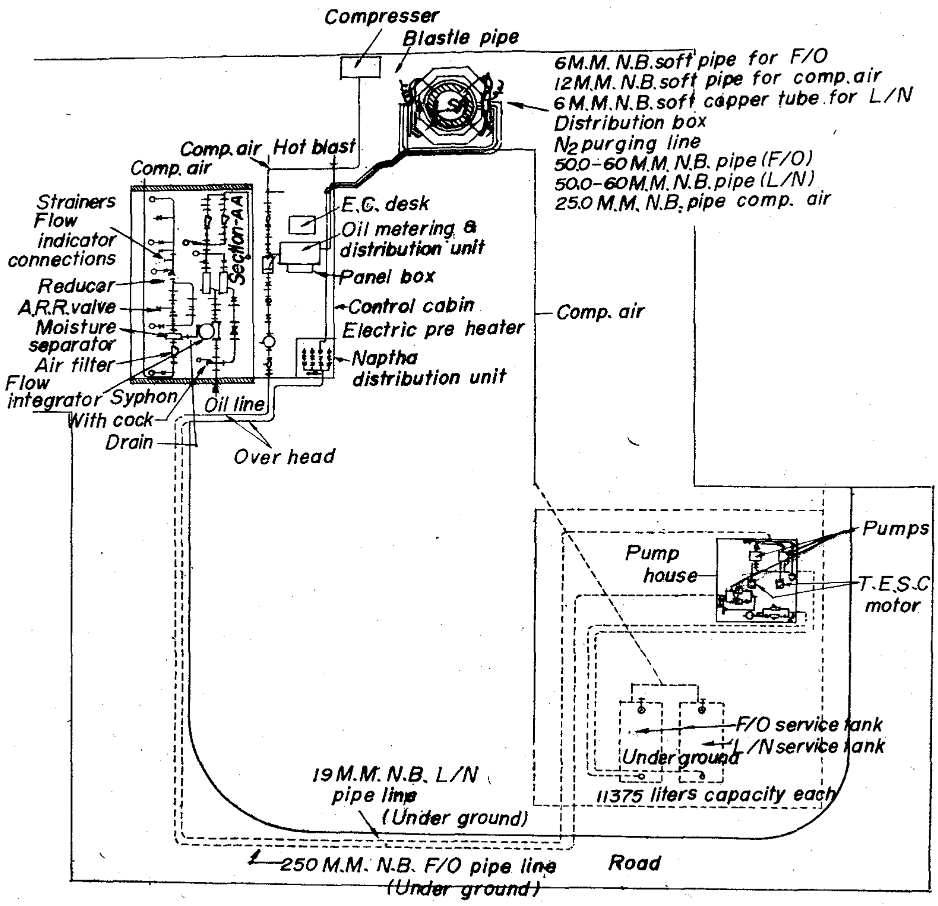

Fig. 10. Schematic layout of fuel oil and light naphtha injection system.

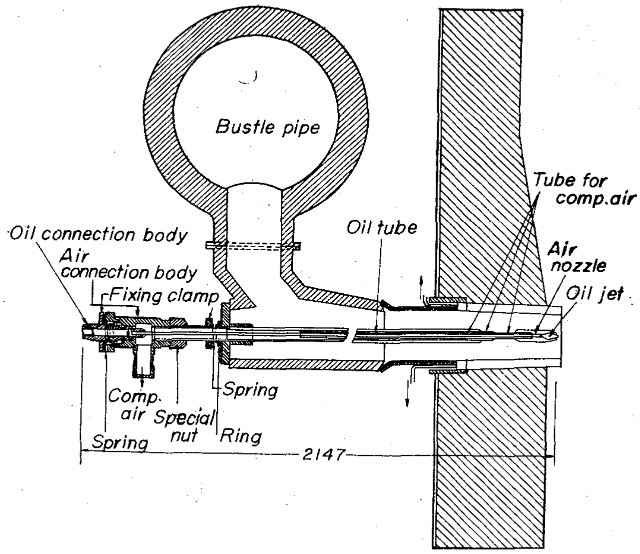

Fig. 11. Naphtha lance assembly in tuyere.

The naphtha injection lances as shown in Fig. 11 are made out of two concentric stainless steel tubes, the inner tube will carry naphtha at a pressure of 18 kg/cm. sq. at the rate of 6～12 litres per hour. The space between the inner tube and ougter tube is for passing compressed air at a pressure of 3 kg/cm. sq. which besides cooling the naphtha lance, will admit the requisite amount of air for the atomisation of naphtha through a suitable designed jet system. The naphtha is kept at high pressure to prevent its vaporisation either in the lance or in the supply line.

The compressed air as cupplied by a compressor operated with a 7·5 H.P. motor having a capacity of 0·6 m^3/min. at a pressure of 13 kg/sq. in. It is provided with a 0·3 m^3 reservoir.

Necessary alarms have been provided in the system to indicate failures due to the stoppage of circulation of naphtha in the lances, burning of the lances, choling of the lances, and failure of the compressed air lines.

Arrangements have been provided for injection of furnace oil with simultaneous enrichment of the blast with oxygen.

Conclusions

On the basis of the extensive investigations it has been concluded that low temperature carbonized coke made from non-coking coals and iron ore fines can be employed for iron smelting in low shaft furnace for the production of desired grades pig iron, at a fuel rate higher than the conventional blast furnace.

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