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Moscow, USSR, 19 September – 9 October 1968

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APPLICATION OF LOW-SHAFT FURNACE FOR IRON MAKING WITH SUB-STANDARD RAW-MATERIALS [1]

by

A.B. Chatterjea and B.R. Nijhawan,
India

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[1] The views and opinions expressed in this paper are those of the authors and do not necessarily reflect the views of the secretariat of UNIDO. The document is presented as submitted by the author, without re-editing.

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APPLICATION OF LOW SHAFT FURNACE FOR IRON-MAKING WITH SUB-STANDARD RAW MATERIALS[1]

by

Dr. A. B. Chatterjea, B. R. Nijhawan,
India

SUMMARY

In comparison with the rich deposits of high grade iron ores spread in different parts of India, proved reserves of high grade metallurgical coking coals are not only limited but are also located in a narrow Bengal-Bihar belt. However, the proved reserves in India of non-coking and semi-coking coals are abundant. Such an inbalance leads to the inevitable necessity of iron smelting with non-metallurgical coals and lignites in regions where the latter and high grade iron ores abound. The establishment of small and medium iron production plants in the country is based on the use of sub-standard raw materials, such as iron ore fines and fuels unsuitable for iron smelting in the conventional large-sized iron blast furnace. The low shaft small blast furnace pilot plant project was started at the National Metallurgical Laboratory of India about a decade back during which extensive pilot plant scale trials have been conducted on sub-standard raw materials including the extensive use of low-temperature carbonized coke made from non-coking coals.

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* This is a summary of a paper issued under the same title as ID/WG.14/22.

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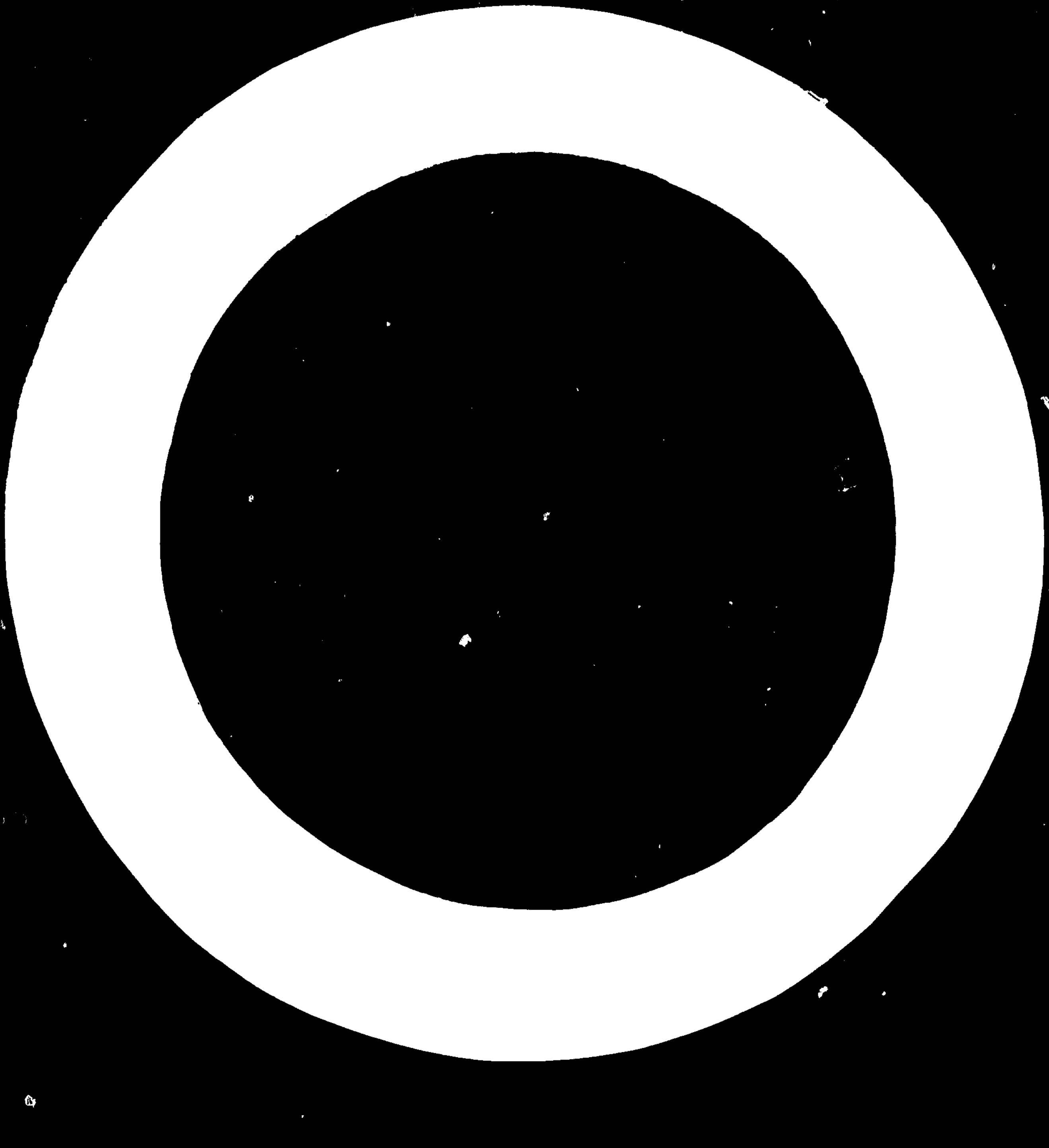


The low shaft small blast furnace pilot plant of the National Metallurgical Laboratory has an attached briquetting plant, hot blast and gas cleaning units along with liquid fuels (oil or naphtha) injection system, the integrated operations of which have yielded valuable results. The low shaft small blast furnace with a capacity of 15 tons per day of iron production has a hearth diameter of 1300 mm and effective height of 2.6 m and total volume of 7.3 m^3.

A review is presented in this paper of typical operational results including effects of different iron ores including high titania iron ores, dolomitic flux, particle size analyses of the raw materials, slag basicity factors on the analyses of slag and metal vis-a-vis iron production, fuel rates and slag volumes. The physical and metallurgical characteristics of the raw materials employed were substandard. The reducibility of the iron ores, dissociation characteristics of fluxes and the reactivity of the fuels employed were significantly different in the various trials conducted. Apart from the changes in the chemical and physical characteristics of the raw materials, changes in the operational conditions were additionally imposed for comprehensively studying the smelting parameters. The particle size classification of the iron ore, flux and the fuel covered wide ranges. Iron ore fines (52%, -12 + 3 mm, 48% -3 mm) were successfully smelted.

The utilization of non-coking coals for iron smelting was attempted in three different ways, viz. i) by making a single component burden of self-fluxing briquettes containing fine particles of iron ore, limestone and the non-coking coal; ii) employment of lumpy row non-coking coal in bedded form of burdening, and iii) prior carbonization of the non-coking coal at low temperature producing char or soft coke of inferior physical strength.

The technological difficulties of making strong briquettes sufficiently stable to withstand the temperature and loading conditions in the furnace and the unfavourable economics due to the additional cost of binders employed for briquetting made the process commercially unattractive. The employment of non-coking coals of very low caking index in bedded form of burden led to serious operational difficulties and wide swings in the chemistry of the pig iron produced and cannot be adapted for iron smelting in a low shaft furnace. Besides, the non-recovery of potential by-products from the coal was economically disadvantageous. Low temperature carbonization of non-coking coal affords utilization of by-products, while elimination of moisture and major amount of volatile matter yields a better fuel for iron smelting. The physical strength of low temperature carbonized coke is significantly inferior to the blast furnace coke. The reactivity towards carbon dioxide or oxygen is higher and accelerates the "solution loss" reaction affecting the fuel rate adversely. The use of low-temperature carbonized coke for iron smelting was characterized by smooth descent of the burden, regularity of the operation with the production of desired grade of pig iron. Fine grained ores can be smelted directly in industrial low shaft furnaces of appropriate design for optimum indirect reduction and transference of heat.

The generation of the dust and the fuel rate depended on the physical and chemical characteristics of the low-temperature carbonized coke, the latter was related to the chemical analysis and the nature of the coal. It was observed that all non-coking coals would not yield "Char" suitable for iron smelting in low shaft furnaces.

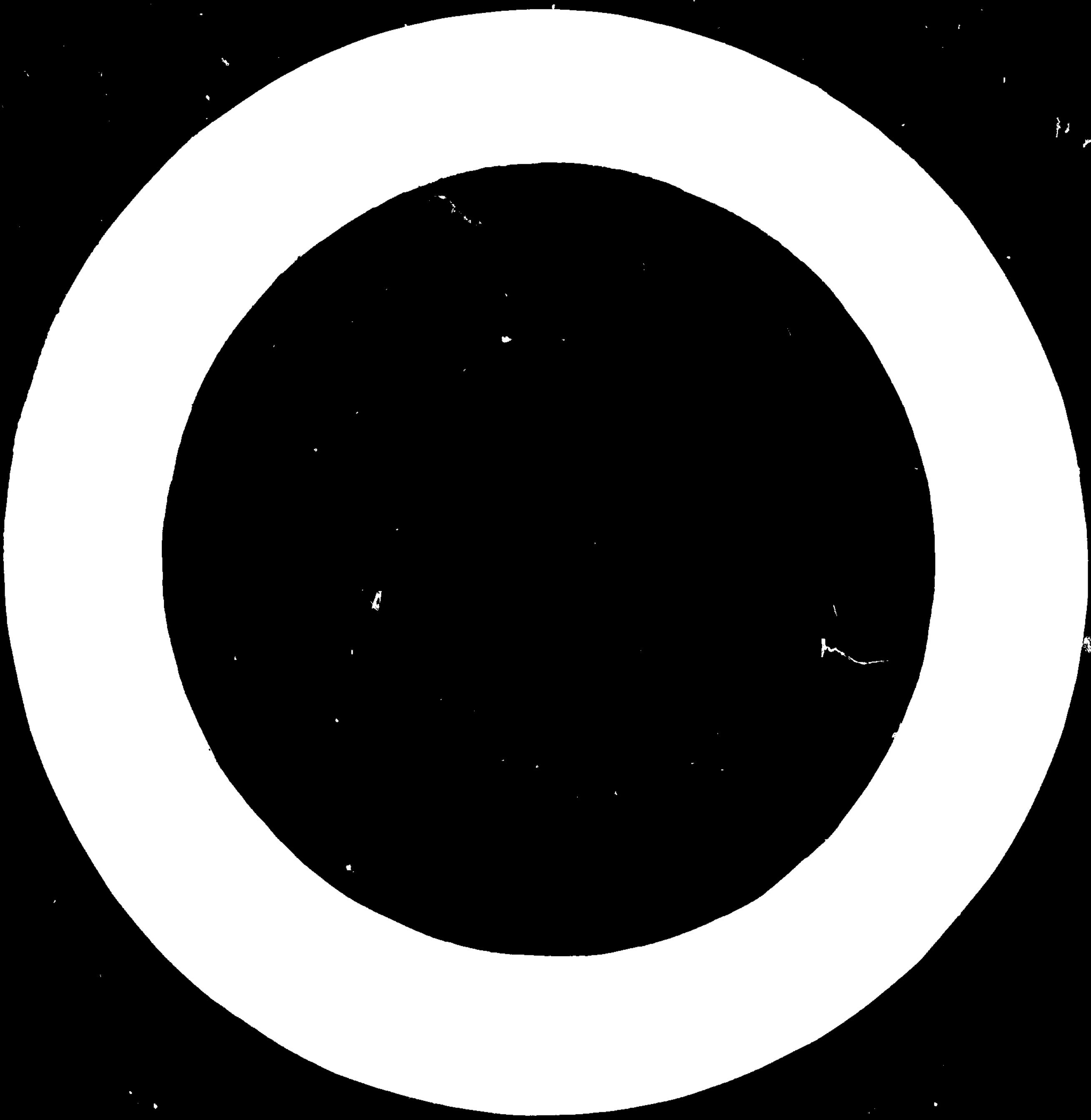
The employment of high sulphur coke was limited by the partition of sulphur under the operational conditions. The utilization of high titania (15% TiO_2) ore depended on the viscosity of slag, which was related to its basicity degree.

Summarizing the effects of variation of the operational conditions, it was concluded that the inherent characteristics of the low shaft furnace led to high top gas temperature, high CO/CO_2 ratio indicating poor indirect reduction and poor exchange of heat both of which contribute towards high fuel rate. The top gas temperature depended on the nature of the fuel and particle size of the raw materials. The CO/CO_2 ratio and top gas temperature were lowered by the decrease in particle size of iron ore with consequent lowering of the fuel rate. Due to the limitation of the gaseous indirect reduction, the effect of the reducibility of the ores on the fuel rate was marginal. The normally low carbon saturation of pig iron was improved by raising the basicity degree of the slag or by the presence of MgO in it. The presence of 8 - 10% MgO in the high alumina slag assured adequate fluidity. The acid smelting lowered the fuel rate but adversely affected desulphurization and carbon saturation. The fuel rate (25% ash in fuel) decreased by 50 kg/ton of pig iron with 50% rise in blast temperature between 400 - 600°C. Increase in silicon by 2% necessitated 300 kg/ton of fuel additionally.

From the extensive trials, it emerged that ore fines can be smelted with non-metallurgical fuels of poor physical characteristics and the process is technically and economically acceptable despite the slightly higher cost of production in low shaft furnaces.

Depending on the limited market demand and non-availability of suitable grades of raw materials for iron smelting in the highly capital intensive classical blast furnace, the low shaft furnace technique of smelting iron can be adapted in developing countries and regions possessing scanty resources of metallurgical grades of coking coals in relation to non-coking coals.

General economies of iron production in a low shaft small blast furnace have been comprehensively discussed particularly under Indian conditions of marketing foundry grades of iron, based on which recommendations have been made for the establishment of small iron production plants on a regional basis in India.



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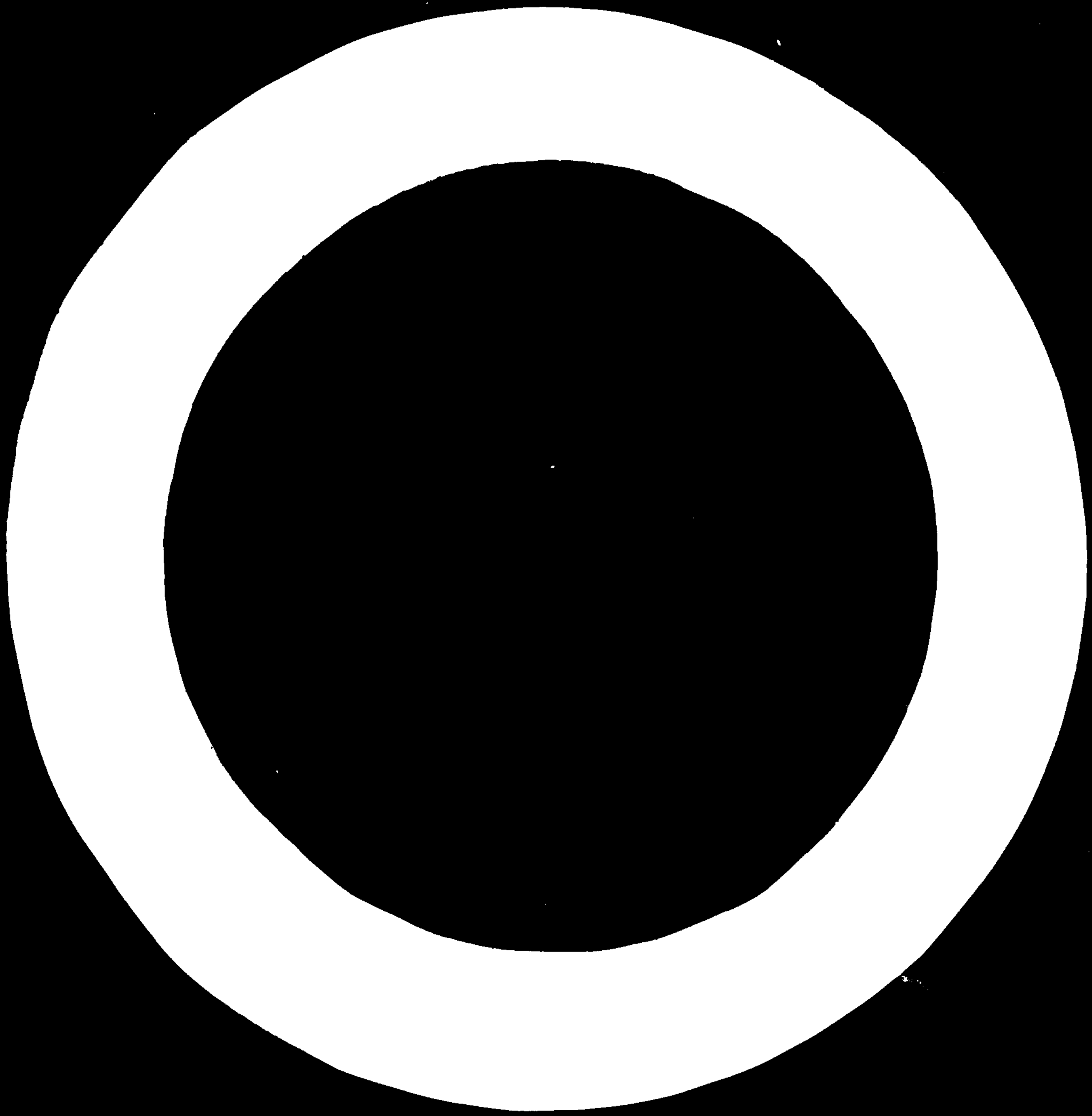

APPLICATION OF LOW-SHAFT FURNACE FOR IRON MAKING WITH SUB-STANDARD RAW-MATERIALS

by

***A.B.Chatterjea and **B.R.Nijhawan**

ABSTRACT

In relation to classical reserves of high grade iron ore regionally dispersed in India, reserves of good metallurgical grade of coking coals are extremely limited and that also confined to a narrow Bengal-Bihar belt. However, resources of non-coking coals are abundant in India. The establishment of small and medium scale iron and steel production plants is based on the use of substandard raw-materials, such as ore fines and fuels unsuitable for smelting in the conventional large sized iron blast furnaces. The Low Shaft Furnace Pilot Plant at the National Metallurgical Laboratory, Jamshedpur (India) has now been in operation for almost a decade to develop suitable techniques for iron production using sub-standard raw-meterials such as friable iron ores, iron ore fines and non-metallurgical coals including low-temperature carbonized coke made therefrom.

A great variety of raw-materials have been smelted on a comprehensive scale. The physical and chemical characteristics of these ingredients were relatively inferior and unsuitable for smelting in blast furnace. The reducibility of the iron ores, dissociation characteristics of limestones and reactivity of the fuels employed for smelting were significantly different. It has been established during the National Metallurgical Laboratory trials

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that non-coking coals used directly for iron smelting in a single component burden comprising of ore-fuel-limestone briquettes is totally impractical adjudged on technical feasibility or production economics. The operational complexities and non-recovery of potential by-products prevented the direct utilization of lumpy non-coking coals as bedded charge. Iron smelting with low temperature carbonized coke (L.T.C.) made from non-coking coals gave good operational results in terms of uniformity of composition, consistent output and optimum coke rates. The particle size classification of the iron ore, limestone and the fuel covered wide ranges. Iron ore fines (52% -12+3 mm, 48% -3mm) were successfully utilized.

Deliberate changes in the furnace operation were made to study their effects on fuel rate, slag rate, productivity, carbon saturation and desulphurization etc. Operational economics and integrated capital costs have been outlined.

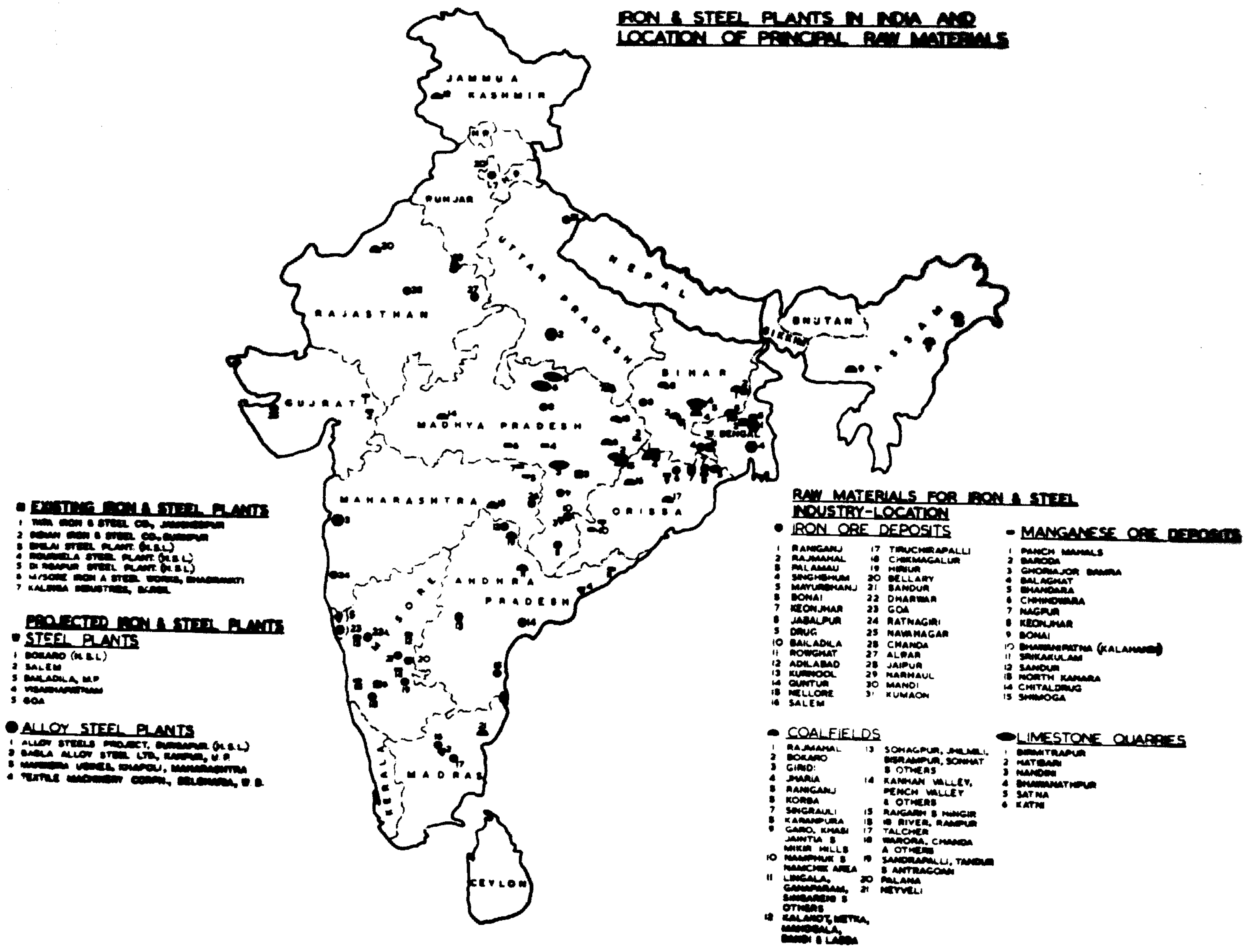
It has been shown that iron smelting in a low-shaft small blast furnace with iron ore fines and low-temperature carbonized coke can be successfully adopted in developing countries where raw-materials conditions so warranted.

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. In India, iron ore deposits (21,000 million tonnes) are more or less uniformly dispersed and abundantly available. Scanty reserves (1500 million tonnes) of metallurgical coking coals are localised in Bengal-Bihar belt, while non-coking coals (103,000 million tonnes) and lignite are abundantly available and more or less evenly distributed. The occurrences of these raw-materials in India areshown in Fig.1. The disposition of these essential raw-materials focussed the necessity of conducting intensive research and pilot plant investigations on iron making with non-coking coals in the Low Shaft Furnace Pilot Plant of National Metallurgical Laboratory, Jamshedpur, India. A large number of reduction processes[1] have been developed for iron smelting without metallurgical coke. Amongst these the low-shaft furnace closely resembles the blast furnace[2]. The conventional big iron blast furnace is absolutely dependant upon the use of coke

Figure 1

Occurrence of Raw-materials in India



of high physical strength as it is subjected to compressive stresses and friction at high temperature. The shaft height of the low-shaft furnace is adjusted to suit the inferior physical characteristics of raw-materials employed. The aspect of low-shaft furnace smelting with non-coking coals,[3-13] low temperature carbonized coke made from non-metallurgical fuels [3,4,6,7], sub-size nut coke [3,4,14-17,23], lignite coke [17-21] have been reported. Amongst these, the low-shaft furnace plant at Calbe in East Germany is successfully operating with low grade iron ore and chiefly with lignite coke briquettes [18-22] in the fuel burden.

The reported investigations were intermittantly conducted in a low-shaft furnace during a period of 8 - 9 years. The furnace has a hearth diameter of 1300 mm, effective height of 2,6m, useful volume of 7,3 m^3, provided with four tuyeres (45 - 100 mm dia). The low-shaft furnace pilot plant has facilities for pre-heating the air blast by burning clean furnace gas in a metallic tube recouperator and wet gas cleaning. The burden is transported to a weighing hopper and is charged in the furnace by a belt conveyor. The details of the plant equipment have been reported.[3,4] The sections through the shaft, hearth and the profile of the furnace are shown in Fig.2.

CHEMICAL AND PHYSICAL CHARACTERISTICS
OF RAW-MATERIALS EMPLOYED

Chemical analyses of iron ores and fluxes collected from the different parts of India and their particle size are given in Tables I and II. The different varieties of low temperature carbonized coke differ significantly in their physical characteristics, but none possessed the high impact strength and resistance to abrasion characteristic of a good blast furnace coke. Reducibility characteristics of the ores were determined with hydrogen[24] and the results are summarised in Fig.3. The fusion point of the ores is high and the porosity of some ores is low. The dissociation behaviour of the limestone is shown in Fig.4. Due to the limited time for smelting in the low-shaft furnace stack, reducibility of the ore and dissociation characteristics of the limestone are relatively more important than for the conventional blast furnace. The proximate analyses of coking and non-coking coals, their caking index are given in

Figure 2

Section through shaft and hearth of the 15 tonnes/day Low Shaft Furnace

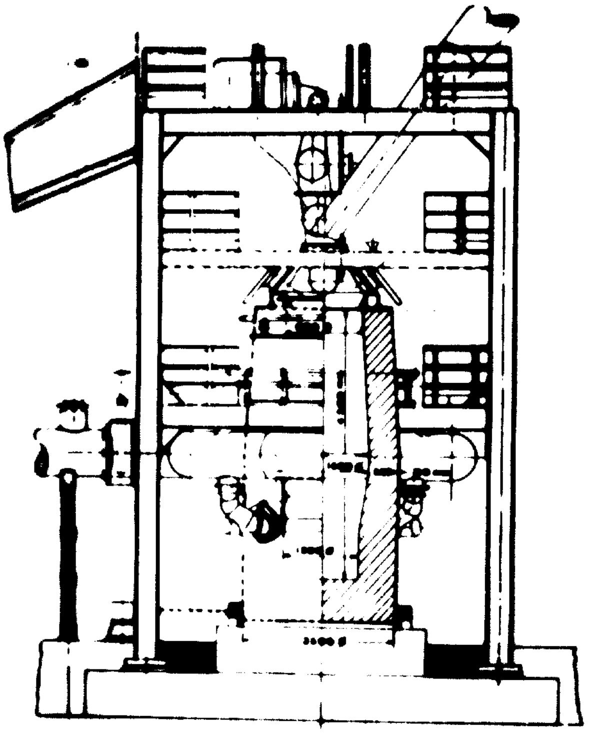


Figure 3

Reducibility Characteristics of the iron ores

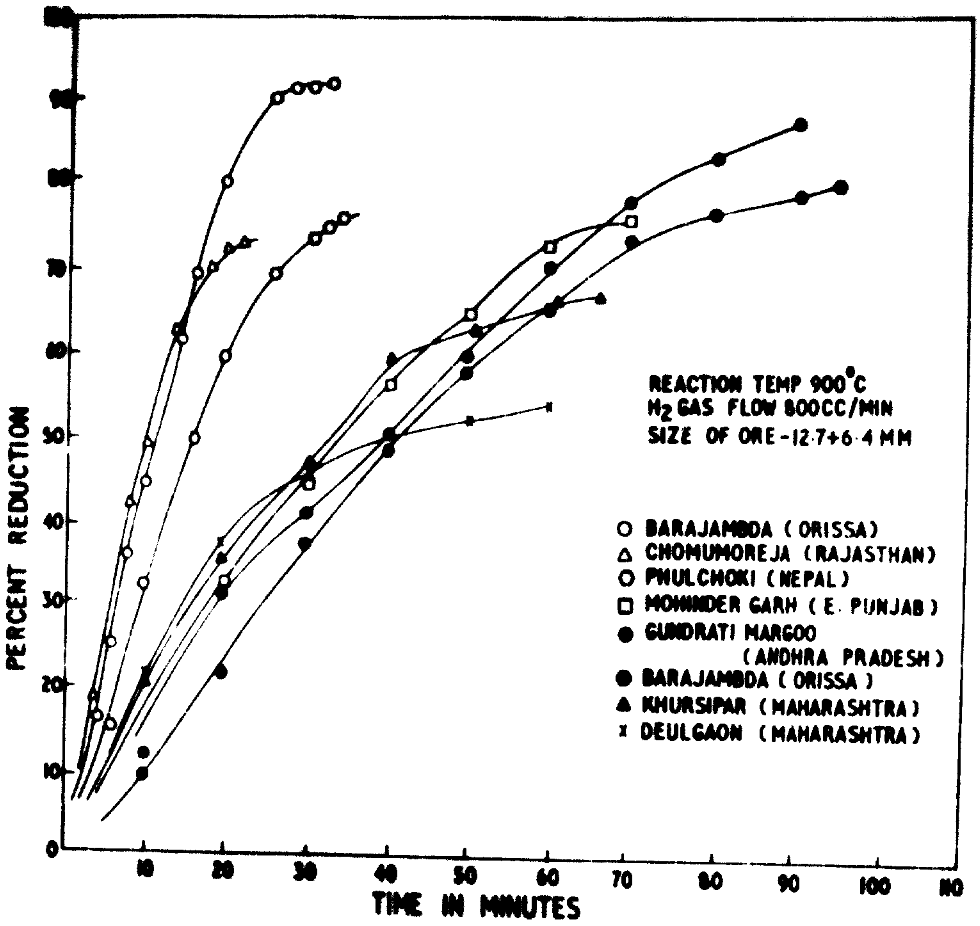


Figure 4

Dissociation Characteristics of limestone

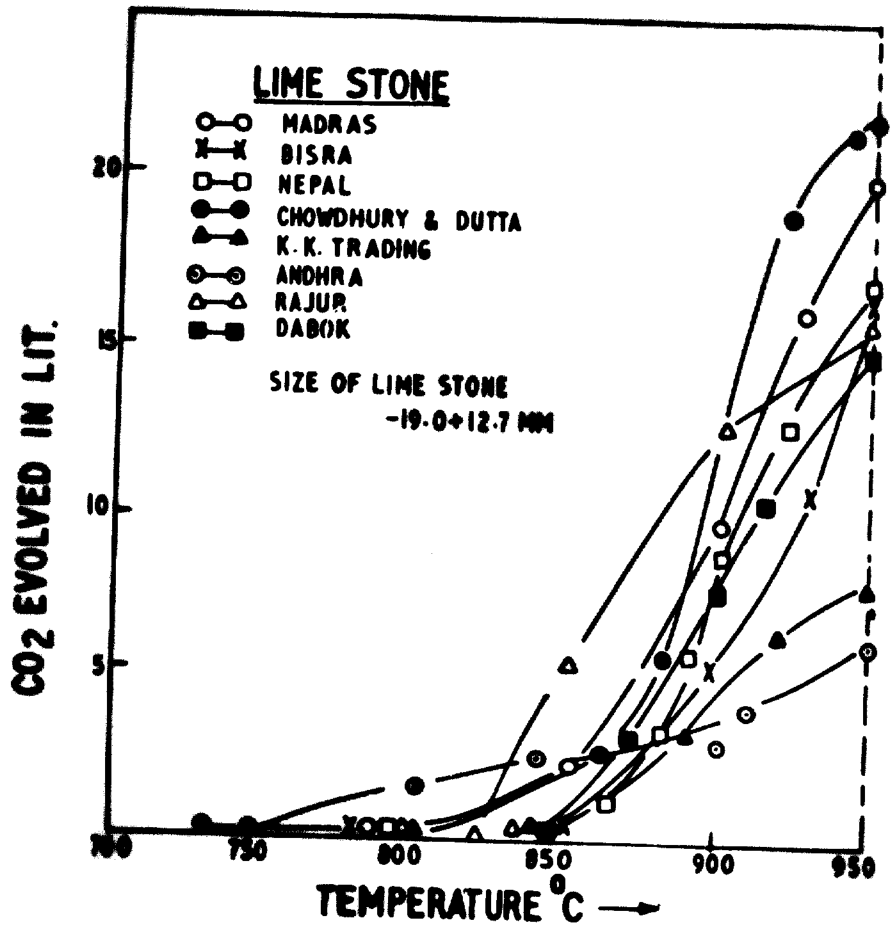


Table I

Chemical analyses of iron ores, %

No.	Location	Fe	SiO_2	Al_2O_3	S	P	Fusion Point, °C	Apparent Porosity, %	Average particle size, mm
1.	Barajamda (Orissa)	59.92- 64.50	3.20- 6.34	4.10- 5.20	0.01- 0.29	0.02	1580	12.30	52% -12+3 45% -3
2.	Barbil (Orissa)	57.70- 61.10	2.20- 4.11	9.50- 12.10	0.31	0.04	1475	10.20	43% -12+6 20% -6
3.	Barbil (Orissa)	64.14	3.28	4.57	0.01	0.02	1450	14.10	43% -12+6 53% -6
4.	Noamundi (Bihar)	63.00	3.50	6.00	0.04- 0.30	0.13- 0.22	1450	27.70	64% -25+12 24% -12
5.	Warrangal (Andhra Pradesh)	63.64	3.80- 4.60	2.00- 5.90	0.03	0.06- 0.12	1424- 1500	13.16- 17.31	60% -25+12 40% -12
6.	Chanda (Maharashtra)	64.30	3.10	2.50	Tr.	0.03	1530	25.00	90% -30+6
7.	Mohindergarh (Punjab)	62.60	6.65	2.00	0.03	0.40- 1.20	1424	7.90	75% -12+3 15% -3
8.	Chomu-Samod Morija (Rajasthan)	61.60	9.90	1.20	0.20	0.05	1475	6.05	90% -30+6
9.	Bolani (Orissa)	57.00	5.00	6.50	0.03	0.05	-	-	96% -3
10.	Deulgaon (Maharashtra)	64.40	3.72	2.00	0.089	Tr.	0.10 (TiO_2)	4.31	60% -25+12 20% -12
11.	Khursipar (Maharashtra)	54.44	1.04	5.12	0.096	0.027	14.50 (TiO_2)	2.86	57% -25+12 23% -12
12.	Phul Choki (Godvari, Nepal)	60.00	9.00	2.80	0.038	0.01- 0.05	-	-	72% -25+12 12% -12+6

Table III. The analyses of coal ash are recorded in Table IV. The particle size, proximate analyses of nut-coke and low temperature carbonized coke (made from wholly non-coking Indian coals), their ash analyses etc. are given in Tables V and VI respectively; these fuels have high ash contents which analysed over 50% SiO_2 and 25% Al_2O_3.

TABLE II - Analyses of limestone and dolomite, %

	Location	CaO	SiO_2	Al_2O_3	MgO	Particle size, mm
1.	Birmitrapur (Orissa)	44,80	6,96	1,60	3,57	35%-25+12 b) -12
2.	Warrangal (Andhra Pradesh)	32,20	0,30	0,56	25,00	62%-25+12 b) -12
3.	Salem (Madras)	54,31	0,88	1,23	1,01	90%-75+12 b) -12
4.	Rajur (Maharashtra)	47,28	6,68	0,85	3,45	75%-25+12 20%-12
5.	Dabok (Rajasthan)	54,80	1,24	1,22	2,00	50%-50+12 50%-12
6.	Birmitrapur (Orissa)	32,60	3,90	1,60	20,40	36%-25+12 b) -12
7.	Jalpaiguri (Assam/West Bengal)	31,30	0,63	0,40	20,70	87%-25+12 b) -12

b = balance

TABLE III - Proximate analyses, caking index of non-coking and coking coals

Sl. 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.	Kargil (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.	Hindusthan Lalpeth (Maharashtra)	5,30	32,70	45,80	16,20	2
17.	Singareni (Andhra)	7,10	26,10	49,50	17,50	2

TABLE IV - Analyses of coal ash contents, %

No.	Origin	SiO_2	Al_2O_3	CaO	MgO	Fe	P	S
							(in coal)	
1.	Jambad	57,85	22,28	-	2,90	6,94	0,59	0,40
2.	Samla	62,96	22,82	4,56	1,63	5,09	0,60	1,01
3.	Ghusick-Musila	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	0,93	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	0,90	-
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.	Ghughus	57,80	35,00	3,70	2,80	0,59	-	-
15.	Kamptee	55,00	34,90	2,90	3,20	2,90	0,11	1,30
16.	Hindusthan 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 V

Proximate analyses of carbonized fuels, %

No.	Nature of fuel	Moisture	V.M.	F.C.	Ash	Particle size, mm	Reactivity	
							Towards CO$_2$	CRB l/min.STP
1.	Nut coke	3.00	1.80	75.10	20.10	64% -25+12 27% -12	63.23	-
2.	Pearl coke	1.10	4.35	71.35	23.20	42% -25+12 60% -12	51.90	0.85 - 1.27
3.	Low temperature carbonised coke (Kolsit- R.R.L.), Singareni Colliery.	2.30	8.90	65.67	21.20	34% -50+25 58% -25+12	-	-
4.	Low temperature carbonised coke (C.F.R.I.), Raniganj area.	5.80	4.60	61.60	28.00	50% -50+25 50% -25	85.10	0.310
5.	" (C.F.R.I.) Wardha Valley Coals.	8.50	4.10	61.50	25.90	48% -50+25 38% -25	71 - 98	0.438
6.	" (R.R.L.) Wardha Valley Coals.	0.75	13.09	54.42	31.74	48% -50+25 32% -25	92.10	0.324
7.	" (C.F.R.I.) (Talcher coals)	5.40	8.60	69.10	16.90	-ditto-	-	-
8.	Coke (20% Assam coal in blend)	1.06	2.04	77.46	19.44	71% -50+25 21% -25+12	-	-
9.	Naturally burnt coke (Digwadih 15 seam)	1.0	14.00	69.80	15.20	-50+15	-	-

TABLE VI - Ash analysis of carbonized fuels,%

	Fuel	SiO_2	Al_2O_3	CaO	MgO	Fe	P	S
							(Coke)	
1.	Nut coke	52,10	33,00	3,80	2,10	6,00	0,43	0,51
2.	Pearl coke	55,28	25,10	4,85	2,50	7,80	0,40	0,35
3.	Kolsit(RRL)	62,07	22,72	1,59	2,18	7,60	0,11	0,26
4.	L.T.C.(CFRI)	56,31	22,00	3,45	2,20	7,61	0,50	0,27
5.	L.T.C.(CFRI)	53,80	28,00	5,68	1,88	4,60	0,14-0,21	0,23
6.	L.T.C.(R.R.L) Wardha Valley	50,10	31,02	9.47	Tr.	6,20	0,14	0,36
7.	L.T.C.(CFRI) Talcher	65,36	26,60	3,26	Tr.	4,46	0,30	0,30
8.	Coke(Assam)	50,88	27,60	4,76	0,80	10,08	0,28	1,20
9.	N.B.C. (Digwadih)	52,80	34,20	3,40	4,70	4,10	0,135	0,50

SMELTING TRIALS

The investigations were sub-divided into several campaigns which were conducted under widely different physical and chemical characteristics of raw-materials. Additionally various alterations of operational conditions like particle size classification, charging sequence, depth of the burden, hot blast temperature, blast rate, basicity degree of the slag, dolomite addition, analyses of pig iron, oxygen enrichment, injection of fuel oil or light petroleum napththa with or without the enrichment of the blast with oxygen on the smelting characteristics were evaluated. The results given are based on the attainment of reasonably steady state of smelting. Normally the burden was calculated to result in basicity degree $\frac{CaO}{SiO_2}$ of 1,2 to 1,3.

The non-coking coals were utilised (i) by briquetting with iron ore fines and limestone making a single component burden, (ii) lumpy form of burden and (iii) after carbonization at low temperatures to yield char or soft coke.

Nut coke (-35 + 12 mm) and pearl coke (-25 + 6 mm) that are unsuitable for iron smelting in conventional iron blast furnace, were also extensively employed in the low-shaft furnace, particularly for studying the variations in physical characteristics of raw-materials and operational conditions in relation to smelting efficiency.

Based on the extensive trials, voluminous data have been collected. For the sake of brevity, only the salient points will be described.

Smelting of Briquettes containing Ore-Flux and Coal

One mode of utilization of non-coking coals for iron making depends upon the smelting single component briquette burden comprising iron ore fines, limestone and non-coking coal fines. These ingredients are crushed and screened to 0-5 mm in size mixed in proper proportions and briquetted in roller briquetting machine with the addition of 4% molten coal-tar pitch and 4% sulphite lye as binders. The carbonization and smelting of briquettes consisting of ore-flux and coal in 12 t.p.d. experimental furnace was considered as successful.[8-13] Based on it smelting trials exclusively with briquettes in a commercial furnace of rectangular cross section (2 x 4m) and 5.5m effective height were unsatisfactory[9] due to disintegration of the briquettes in the furnace. In view of large resources of non-coking coals in India, the suitability of the process was thoroughly investigated at the National Metallurgical Laboratory.[3,4,5,7]

The briquettes contained 18-25% iron ore, 12-19% limestone and 59-64% coal. Noamundi iron ore fines (Table I, IV) were always used, while non-coking coals from Central Satgram (Table III,12), Saltore (Table III,13). Bankola (Table III, 9), Sirka (Table III,4) and Maharashtra (Table III,14) were employed; an addition of 25-40% coking coal (Table III,10) was indispensable for developing adequate high temperature strength. Maharashtra coals (Table IV, 14,15,16) did not yield satisfactory briquettes even with 50% addition of coking coal. The caking characteristics of coal largely determined high temperature under load stability of the briquettes within the furnace. During the smelting, the permeability of the burden column was not affected in a mixed burden consisting of briquettes and nut coke. However, the disintegration of the briquettes with heavy dust formation constituted the major difficulty in the utilization of briquettes exclusively. Considering that the wind velocity may possibly influence the operational conditions, during smelting exclusively with self-fluxing briquettes, the wind rate was altered by increasing the effective tuyere diameter from 60 mm, through 75 mm to 100 mm in steps with consequent increase in the daily output from 7 tonnes through 9 tonnes to 11.2 tonnes and alteration in the fixed carbon consumption per unit hearth area per hour from 605 kg, through 846 kg to 1081 kg inclusive of the flue dust loss, which was about 10% of the burden. However, the top gas CO/CO_2 ratio, fuel rate and slag volume increased at the higher rates or blowing. Although intimate contact of the fine grained ore particles with the reductant in the briquette was expected to promote reduction and lower the fuel rate, the latter was in effect, higher compared to a burden consisting of nut coke and optimum sized lumpy iron ore; the higher fuel rate was distinctly due to the heat requirements for the carbonization of coal present in the briquettes in the upper region of the furnace. 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 strength and furnace stability containing besides other constituents non-coking coals exclusively, the operational difficulties encountered during their smelting and the high cost of binders adversely affected the production economics; these factors precluded the commercial adaptation of the single stage one component burden process. In subsequent trials, the utilization of non-coking coals was, therefore, attempted in different ways, and the process of single component burden was abandoned.

Non-coking Coals - Lumpy Bedded Burden

Attempts were made for the direct utilization of lumpy (50 to 100 mm) high volatile (26-40%), high ash (16-24%) non-coking coals of very low coking indices, such as Saunda (Table III, 6), Singareni (Table III, 17), Real Jambad (Table III, 8), Khaskenda (Table III, 7), Maharashtra (Table III, 14, 15, 16), and Samla (Table III,2) introduced in bedded form of burden. The particle size of the iron ores varied from 35% to 95% below 12 mm and for limestone 80 to 90% below 25 mm. Details of the raw-materials and operational results are summarised in Table VII. It was found that totally non-coking coals of very low caking index, non-friable in nature and which did not form a sintered mass on carbonization could be employed, but the process cannot be adapted on commercial scale owing to poor permeability of the stack, highly irregular descent of burden leading to erratic furnace operations and wide fluctuations in composition of the pig iron smelted. The potential by-product values of coal cannot be recovered and credited for calculating the cost of production of pig iron. As such, this process of lumpy non-coking coal charge for iron smelting was considered to be impracticable.

Smelting with Naturally Burnt Coke

The porosity of the naturally burnt coke was low and the alumina contents in its ash was high. During smelting with medium size ore (Table I, 2) and limestone (Table II, 1) the combustion of the coke in the tuyere zone appeared to develop inadequate temperature and the smelting was extremely irregular causing frequent tendencies for chilling of the hearth. It was considered that lack of porosity, sluggish combustion and high alumina contents in its ash did not enable its use for iron smelting.

Smelting with Low-temperature Carbonized Coke Made From Non-coking Coals

As direct utilization of raw non-coking coals was technically and economically impracticable, it was considered that low-temperature carbonization of non-coking coals to yield low-temperature carbonized coke or "char" with partial removal of volatile matter, increase in the fixed carbon content and recovery of potential by-products yielding slightly improved physical characteristics, will be suitable for iron smelting in suitably designed low-shaft furnace. The smelting technique will closely resemble the blast furnace process and will be distinctly economical than the processes based on the direct utilization of raw-non-coking coals.

Extensive smelting campaigns[3,4,6] were conducted with 'kolsit' (Table V,3)- a low temperature carbonized coke made exclusively from non-coking coal (Singareni Collieries, Andhra Pradesh, (Table III, 17) in internally heated Lurgi " Spulgas" carbonization pilot plant at the Regional Research Laboratory, Hyderabad. Following the successful utilization of 'Kolsit', smelting trials were conducted with low-temperature carbonized cokes (Table V, 4) made exclusively from a large varieties of non-coking coals of Raniganj field by carbonization in externally heated ovens at the Central Fuel Research Institute, Dhanbad.

Table VII

Operational Characteristics with Non-coking coals

Data on		Saunda Coal		Singareni coal		Real Jambad coal	Khaskenda coal		Maharashtra coal	Samla Coal
	Ore 1 B.M. chips	Ore 2 N.V.	Ore 4 Noamundi	Ore S.Lal	Ore Andhra	N.V. Ore	Ore S.Lal	Ore N.V.	32% only Chanda ore	Barbil
Fuel rate F.C./tonne of P.I.	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	1.80	-	1.30	1.70	2.0	1.9
Blast Volume m^3/hr.	2100-2300	2300-2600	2200-2400	2500-2700	2700-2900	2400-2600	2200-2300	1700-2800	1500-1600	1500-2000
Hot blast Temp. °C	585	580	580	575	580	590	585	-	595	580
Top Gas Temp. °C	360	420	380	410	330	-	-	-	450	400
Av. Analysis of pig iron %										
Si 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	0.1	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	38.00
SiO$_2$	32.2	35.0	34.5	37.3	35.3	34.5	31.2	35.0	34.0	32.00
Al$_2$O$_3$	-	-	-	-	-	-	-	-	20.0	21.00
MgO	-	-	-	-	-	-	-	-	8.5	4.0
FeO	0.40	0.70	0.60	0.50	0.60	0.9	0.8	0.9	1.4	0.8
Av. Gas analysis %										
CC	24.00	2.60	2.50	21.70	23.00	24.0	29.4	24.0	24.0	26.0
CO$_2$	4.30	3.60	4.20	4.7	4.2	3.8	4.9	3.0	3.8	3.0
CH$_4$	7.6	6.20	7.00	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-materials	19.0	12.0	10.0	5.0	5.0	11.0	7.0	9.5	14.0	8.0

Low temperature carbonized coke made from Talcher (atC.F.R.I.) and Maharashtra non-coking coals (at C.F.R.I. and R.R.L.) were also employed. The physical properties of these soft cokes were significantly inferior to those of metallurgical coke; reactivity of the former towards oxygen and carbon dioxide was higher (Table V) in comparison with the latter. The high reactivity towards CO_2 will promote "solution loss" reaction in the furnace stack and lower the efficiency of carbon utilization.

Smelting operations were conducted on ores of different chemical and physical characteristics under different operational conditions. The results are given in Table VIII. The smelting trials with L.T.C.(R.R.L.), L.T.C. (C.F.R.I.) and L.T.C. made from Talcher coal were characterised by smooth descent of the burden which fed adequately prepared burden to the smelting zone and thereby led to uniform furnace operations and consistent analyses of pig iron produced. Due to the poor physical strength, the low-temperature carbonized cokes made from Wardha Valley coals were not suitable for iron smelting. It was considered that poor physical strength and high susceptibility to degradation of some of the low-temperature carbonized cokes (such as Wardha Valley coals) were serious deterrants to their employment in industrial low-shaft furnace, but by and large such product can be utilized for iron smelting.

Smelting with Nut-coke

It is well known that exclusive use of -35mm sub-size nut-coke is highly detrimental to the working of the normal sized conventional blast furnace. 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 in view of its lower price structure as also from technical stand point. The objectives of using nut-coke in the Low Shaft Furnace Pilot Plant were (i) for ascertaining the smelting characteristics of hitherto unknown raw-materials in the initial stages, (ii) as corrective dose for regulating the smelting operations, (III) as mixed fuel with either non-coking coals or self-fluxing briquettes, (iv) for smelting of raw-materials from the regions possessing no coal resources[23] and (v) for studying the effect of operational variables on smelting efficiency. The short stack height of the N.M.L. low shaft furnace does not enable adequate exchange of heat between the descending burden and ascending stream of gas and

Table VIII

Operational Characteristics with Low-temperature Carbonized Cokes

Data on												
Fuel	Kolsit (R.R.L.)						LTC(CFRI) Talcher	L.T.C.(C.F.R.I.)			LTC(Wardha Valley Coals /LTC(RBL)	LTC(CFRI)
Iron ore	Andhra	ore	S. Lal ore	Punjab iron ore	Barbil	Orissa Mineral Barbil	Barajamda (60% -12 +6 mm)	Mohindergarh	Andhra ore	Orissa Mineral	Deulgaon ore	Duelgaon ore
Lime-stone	Andhra	Bisra	Bisra	Bisra	Bisra	Bisra	Salem (Madras)	Orissa	(Andhra/Madras	Bisra	Rajur	Rajur
Fuel rate F.C./t of pig iron	1.90	1.20	1.28	2.20	1.40	0.99	2.00	1.81	2.20	1.85	1.75	1.90
Slag Volume t/t of pig iron.	1.35	0.84	0.75	1.45	1.10	0.69	1.10	1.52	1.60	1.45	1.60	1.47
Blast Volume Nm^3/hr.	2600-2800	2500-2700	2400-2600	2000-2200	2200-2600	2100-2500	2475	1900-2100	1950-2300	2100-2300	-	-
Blast pressure mmWC	1800-2000	2000-2100	2400-2600	2100-2400	2400-2700	1700-2100	1450	2100-2500	1500-1900	2000-2300	-	-
Hot blast temp. °C	595	590	590	590	585	500	500	585	500	485	480	530
Top Gas Temp. °C	385	375	400	375	375	350	360	370	400	335	450	460
Av. Analysis of pig iron % C	3.5	3.2	3.25	3.7	3.2	2.9	2.9	3.75	2.75	2.70	2.54	2.7
Si	3.75	3.5	3.00	2.35	2.8	2.6	2.75	3.27	3.60	4.00	3.70	3.5
S	0.06	0.04	0.04	0.05	0.02	0.07	0.08	0.11	0.13	0.08	0.09	0.08
Av. Analysis of Slag%												
CaO	35.00	38.40	39.00	43.20	37.00	38.00	37.60	35.30	32.50	35.00	36.80	34.10
SiO_2	35.00	32.00	33.00	36.00	30.00	35.00	33.80	42.40	37.50	34.50	35.13	35.50
Al_2O_3	17.00	17.95	18.00	14.70	23.00	18.00	19.60	18.05	19.80	20.00	24.00	26.20
MgO	18.00	8.20	8.00	5.50	8.50	7.00	6.80	5.00	6.40	6.50	8.00	7.40
FeO	0.80	3.20	0.90	0.60	1.50	1.50	1.00	0.55	3.60	0.65	0.80	0.70
Av. Gas Analysis %												
CO	25.00	24.00	23.00	23.40	24.00	22.40	24.30	24.00	25.20	25.20	25.47	24.50
CO_2	5.00	4.50	6.00	3.30	5.50	5.60	3.50	4.20	3.80	4.00	3.65	3.70
CH_4	7.00	3.40	6.00	7.50	5.00	5.80	4.70	4.50	5.00	5.00	3.72	4.20
Ratio of CO/CO_2	5.00	5.30	4.00	7.00	4.40	4.00	7.00	5.70	6.80	6.40	6.20	6.60
Dust loss %R.M.	3.00	4.50	6.00	3.00	5.00	6.00	6.00	5.70	9.00	10.00	4.20	4.50

results in high top gas temperature. The effects of matching the particle size of the furnace burden constituents, mainly of the ore on the lowering the temperature of top gas vis-a-vis smelting characteristics were comprehensively investigated. Pearl coke (60% below 12 mm) was successfully employed. The results of these trials are summarised in Table IX. It is considered that foundry and special premium grades of pig iron can be economically produced in small blast furnaces or low-shaft furnaces employing surplus nut coke and pearl coke as fuel, thereby relieving the large blast furnaces in an integrated iron and steel plant for the production of basic iron meant for steel making.

Smelting with High Sulphur Coke

The tertiary coal of Assam contains 8% ash and 3 to 4% sulphur and possesses fairly good caking properties. The suitability of the coke containing 20% Assam coal in the blend was assessed by smelting with iron ore fines (Table I,3) in the range of 47% -12mm +6mm balance -6mm and limestone (Table II, 2,3). The fuel burden consisting exclusively of low-temperature carbonized coke (61,5% F.C., 4,1% V.M., 8,5% H_2O, 25,9% ash and 0,23% S) was progressively replaced with 25%, 70% and 100% Assam coke (Table V,8). At the basicity degree $\frac{CaO}{SiO_2}$ of about 1,1, the sulphur contents in pig iron increased to 0,07%, 0,083% and 0,13% in the three stages of smelting with Assam coke at an average partition coefficient $\frac{(S)s}{(S)m}$ of 18. The exclusive utilization of Assam coke will necessitate better partition ratio by increasing the basicity degree of the slag.

Smelting of Titaniferrous Ore

Iron ores containing high amount of TiO_2 are not normally used for iron smelting in blast furnace. The smelting of titaniferrous ore deserves consideration for a) for producing a slag containing high TiO_2 for further processing, (b) for making special grade of pig iron containing small amounts of titanium, and (c) the need to make iron in the context of non-availability of titania free ore. High fuel consumption during smelting and formation of a highly viscous slag are chief objections against high titania ore. In the N.M.L. trial, the maximum permissible amount of high titania ore in the ore burden was investigated. On the attainment of steady state of smelting with Deulgaon ore (Table I,10), Rajur limestone (Table II,4), and nut coke, 25% ore

Table IX

Operational Characteristics with Nut Coke and Pearl 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	Orissa ore Rajasthan limestone	Deulgaon ore Rajur limestone	Deulgaon ore 50% Khursipar ore 50% Rajur limestone	Deulgaon ore Pearl coke Rajur limestone
Fuel rate F.C./tonne		1.60	1.6	1.54	1.48	1.35	1.20	1.30	1.50
Slag volume/tonne/tonne		1.00	1.00	0.97	1.00	0.91	0.86	1.00	0.93
Blast volume Nm^3/hr.		2600-2900	17-1950	22-2600	25-2700	24-2600	2350	2300	1950
Blast pressure mmWG		1700-2000	15-2300	20-2200	15-1600	17-1900	2000	2400	1700
Hot blast temperature °C		525	590	585	525	450	500	500	500
Top Gas Temp. °C		450	450	345	450	380	475	480	420
Av. analysis of pig iron %									
	C	2.75	2.60	3.20	3.50	2.75	2.60	3.24	2.80
	Si	3.00	3.55	3.70	2.70	3.75	3.50	3.64	3.20
	S	0.065	0.045	0.066	0.07	0.07	0.06	0.024	0.07
Av. Analysis of Slag, %									
	CaO	37.00	27.00	38.20	42.56	35.37	36.50	31.00	38.30
	SiO$_2$	28.50	33.00	33.90	31.40	32.36	30.30	34.50	35.30
	Al$_2$O$_3$	17.00	24.00	19.90	18.60	18.23	18.70	19.80	20.70
	MgO	8.00	7.00	6.45	6.20	4.50	6.70	6.50	4.30
	FeO	0.90	0.80	0.65	1.10	1.20	0.90	1.50	0.60
Av. Gas Analysis, %	CO	22.00	22.00	26.80	25.00	26.27	25.20	25.60	25.60
	CO$_2$	3.50	3.50	4.60	4.90	4.20	4.20	4.10	4.50
	CH$_4$	5.00	5.00	3.00	3.90	4.00	3.60	3.80	3.50
Ratio of CO/CO$_2$		6.00	6.00	5.40	5.10	6.20	6.00	6.20	5.70
Dust loss % of R.M.		4.50	9.00	10.00	2.40	3.30	2.00	4.70	3.00

in the ore burden was replaced with equivalent weight of high titania (15% TiO_2) ore (Table I,11), in the initial stage and 50% in the next stage; such partial replacement with titaniferrous ore resulting in 5% TiO_2 in the slag in the initial stage did not specifically contribute to any irregularity in smelting operations. In the next stage, the TiO_2 contents of the slag was about 10%. The slag was viscous. In the presence of TiO_2 in the slag, the viscosity was observed to depend upon the basicity degree and TiO_2 decreased the viscosity of acid slag. The carbon rate increased from 1,2 tonnes in the base period to 1,24 with 25% high titania ore and to 1,30 with 50% of high titania ore. The carbon saturation improved from 2,6% to 3,44% at 0,54% titanium content in the pig iron. Despite the acidic nature of the slag, the presence of titanium in pig iron contributed to the absence of iron oxide in the slag and its low oxygen potential favoured desulphurisation leading to low sulphur in the pig iron.

Smelting trial was conducted with low temperature carbonized coke (C.F.R.I.) (Table V,5) with identical observations. It was concluded that smelting of high titania ore was commercially unattractive.

STUDY OF OPERATIONAL VARIABLES

Particle size of Iron Ore and Flux on Top Gas Temperature, CO/CO_2 ratio and Fuel Rate

The effective height of commercial low-shaft furnace is about 4 - 5 m. Whilst this restricted height enables the ulitization of raw-materials of inferior strength for smelting, it obviously reduces the passage time and smelting period of the burden in furnace. The particle size of the ore and flux has to be properly adjusted to ensure optimum transfer of heat, thereby keeping the top gas temperature within reasonable limits.[26] The steep temperature gradient and limited gas-solid contact do not afford optimum indirect reduction as evidenced by the high CO/CO_2 ratio. Coheur[17] accounted for 16% higher fuel rate due to higher CO/CO_2 ratio in the top gas of the International Low Shaft Furnace. From an average CO/CO_2 ratio of 6 in the top gas of commercial low shaft furnace at Calbe, East Germany, Struve and Evbert[20] mentioned that the optimum degree of indirect reduction was 30% in comparison with 55 - 60% in a conventional blast furnace, which was partly reflected in

Figure 5

Effect of the particle size of the ore on CO/CO2 ratio, Fuel rate, Top-gas temperature and slag volume

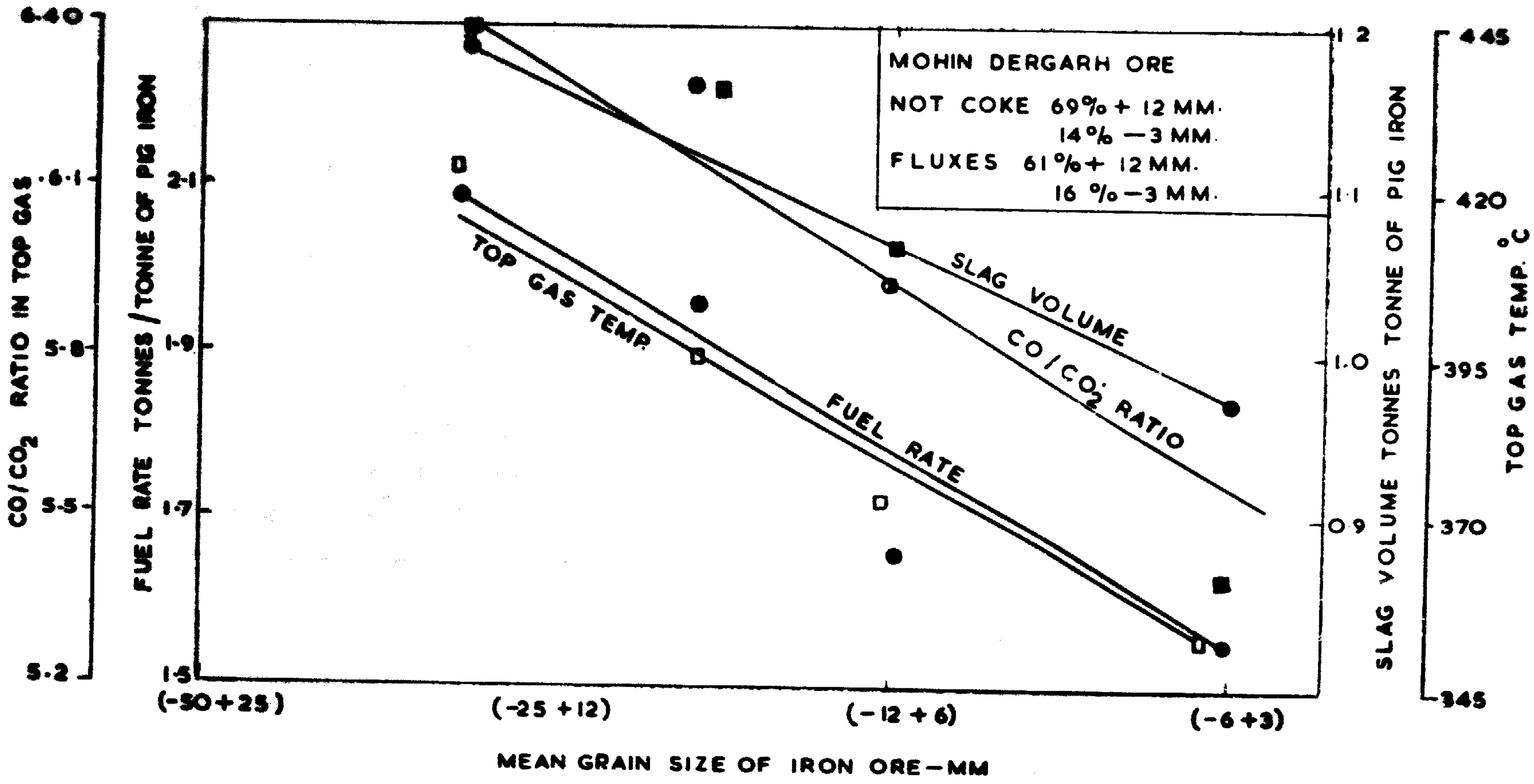
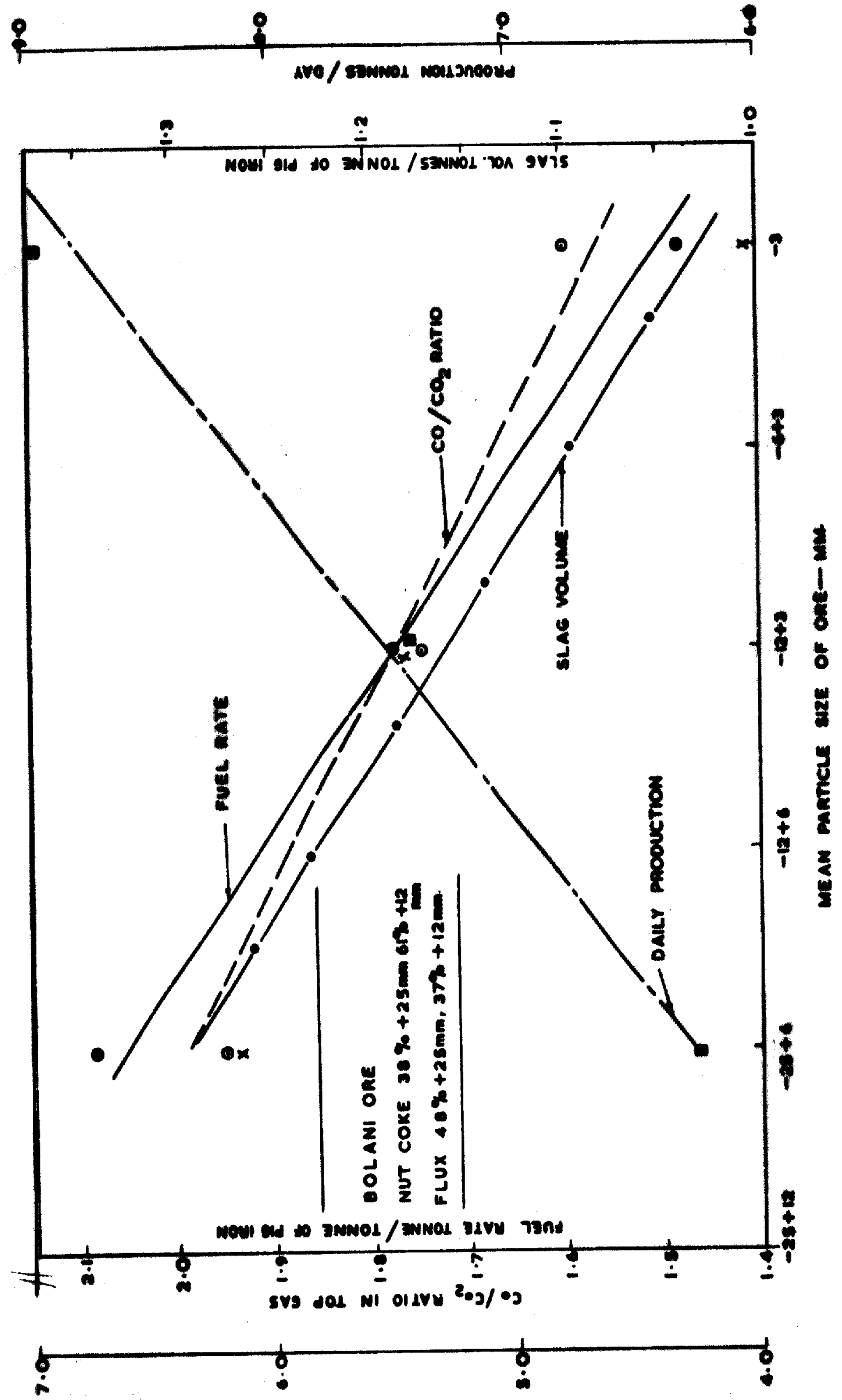


Figure 6

Influence of size of ore on CO/CO2 ratio, Fuel rate, Top-gas temperature and slag volume



high fuel rate. Ludemann and Struve[22] mentioned that at times indirect reduction was as low as 26% in Calbe furnace. In view of higher throughput time, the only possibility to improve the indirect reduction was by reduction of the particle size of the raw-materials. Due to the limited scope of employing fuels of different particle size ranges, the effects of variation in the particle size of the ores and limestone on the smelting parameter were investigated. Two different varieties of crushed iron ore were used and either nut coke or low temperature carbonized coke was employed as fuel. As the size of the fuel cannot be reduced to below 12 mm, optimum voids in the burden depended on the particle size of the other components of the burden. The effects of the mean particle size of the ore (Table 1,7) on the CO/CO_2 ratio, fuel rate, top gas temperature and slag volume employing nut coke as the fuel are shown in Fig.5, while with another ore (Table I,9), the effect of the particle size of the ore on fuel rate, CO/CO_2 ratio, slag volume and daily production is shown in Fig.6. These trials clearly demonstrated the improvement in smelting efficiency by adjustment of particle size of the ore.

The progressive replacement of lumpy limestone (-75+25mm) by fine grained limestone (97% below, -6 mm) appreciably lowered the fuel rate and increased the daily production whilst unfavourably increasing the flue dust losses. It was observed that coalescence of the superficially reduced iron ore particles limited the flue dust losses, but fine particles of limestone were carried away by the gas stream. The utilization of the iron ore fines also depended upon the characteristics of the fuel employed for smelting, as for example exceedingly fine grained ore was incompatible with the low temperature carbonized coke, but the smelting was satisfactory with nut coke. For restricting the top gas temperature within reasonable limits, the enrichment of the blast with oxygen was not necessary[3,4,14-17] and the top temperature was controlled by using iron ore fines in the ore blend.

Smelting under almost identical operational conditions and employment of identical raw-materials with the exception of fuel, indicated that the fuel rate largely depended on its physical properties and chemical analysis and reactivity.

Figure 7

Effect of Hot Blast Temperature on Fuel Rate

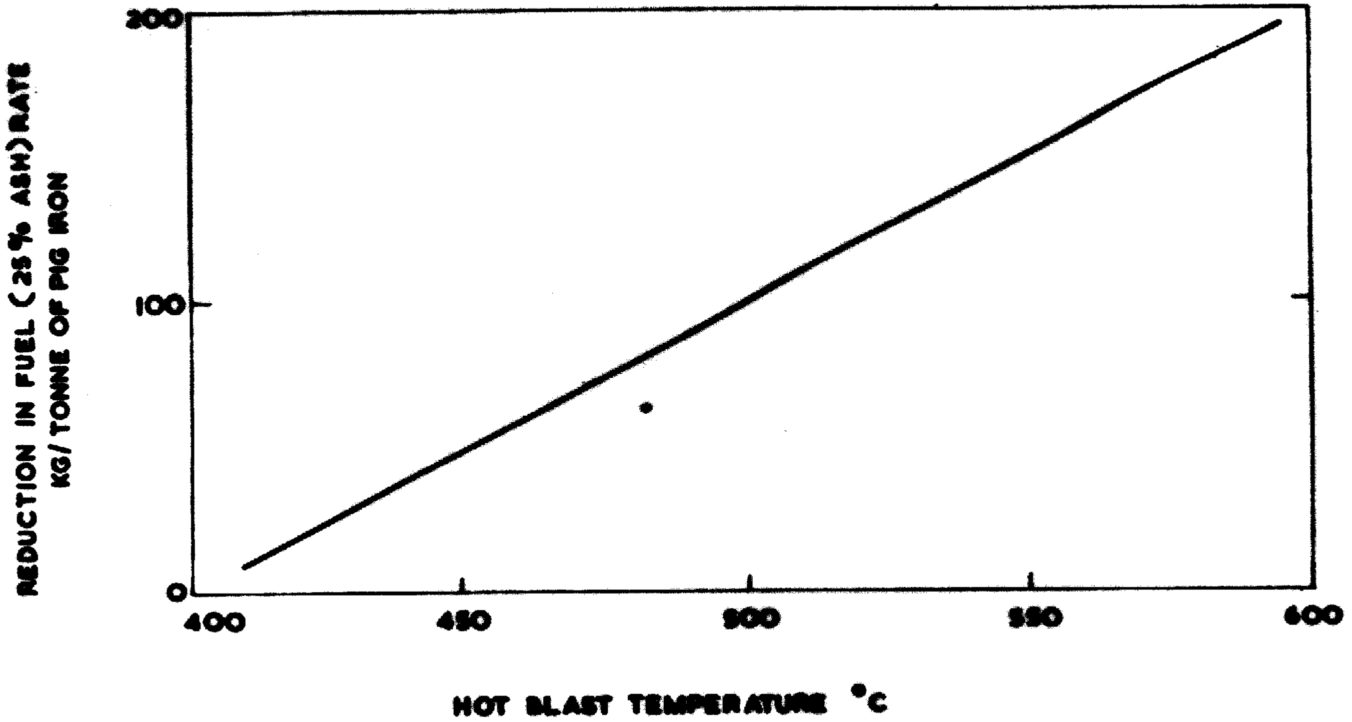
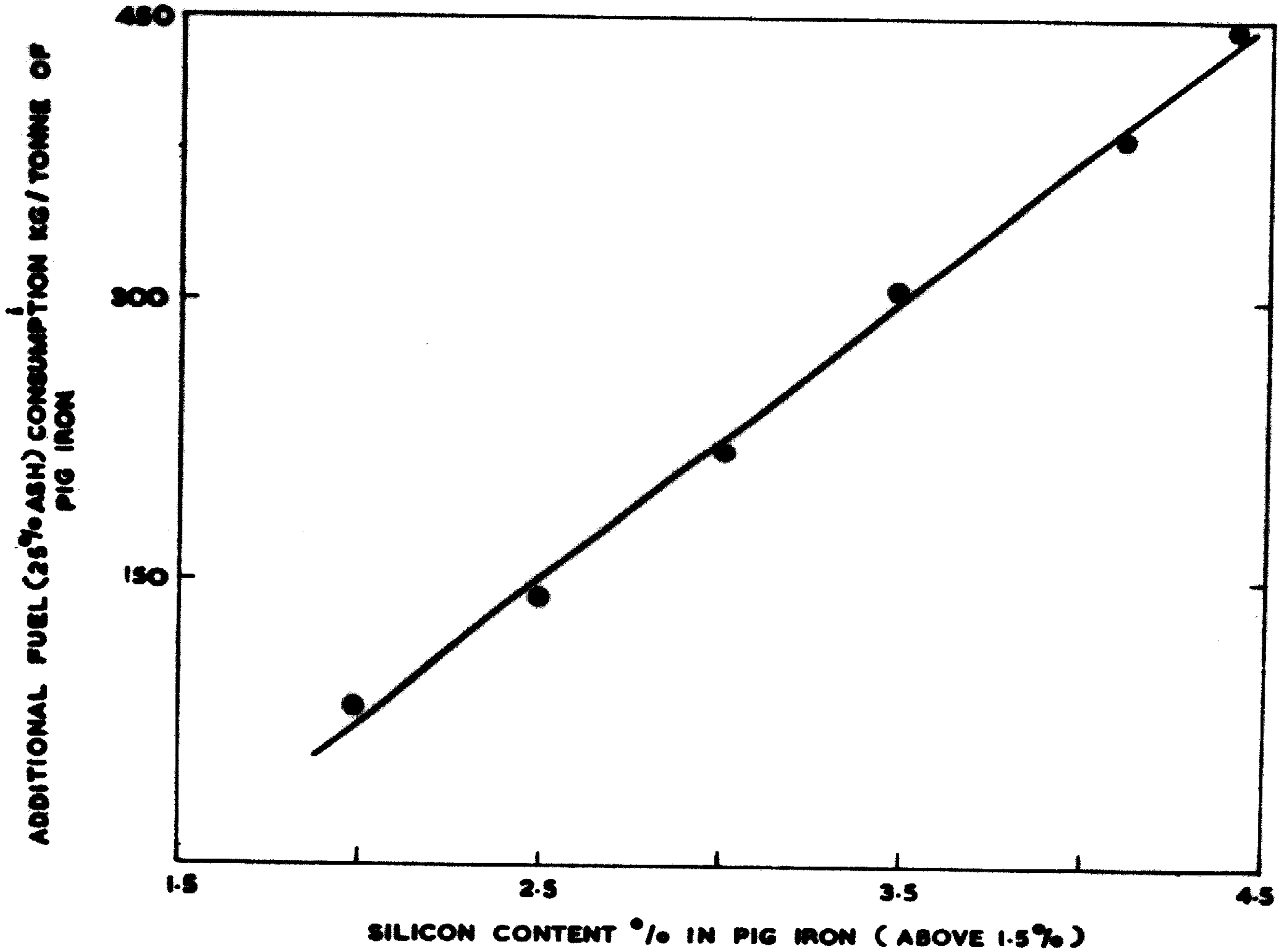


Figure 8

Influence of Silicon Contents on Fuel Rate



Hot Blast Temperature and Silicon Contents in Pig Iron

The benefit of high hot blast temperature on lowering the fuel rate is well known. Fig. 7 shows that a variation of hot blast temperature between 400 to 600°C at 50°C intervals demonstrated that the fuel rate (25% ash in fuel) decreased by 200 kg/tonne on raising the temperature from 400 - 600°C. Fig. 8 shows that an increase in silicon content from 1,5% to 3,5% necessitated 300 kg/tonne of additional fuel (25% ash). These factors also account for the high fuel rate observed in some campaigns.

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 by the high CO/CO_2 ratio and high top gas temperature. Decrease in slag volume by lowering its basicity degree can lower the fuel rate[22]. With the object of reducing the slag volume and consequently the fuel rate, the basicity values of the slag were maintained at different levels and were increased by 0,2 from 0,6 to 1,4 with appropriate flux additions. In three different trials, nut coke (Table V,1), low temperature carbonised fuel (C.F.R.I.) (Table V,4), and Kolsit (Table V,3) were employed as fuel without variation of other operational conditions. The somewhat poor carbon saturation in the low shaft furnace pig iron further deteriorated under acid smelting. The smelting characteristics were satisfactory upto a CaO/SiO_2 ratio of 0,60, below which the slag became abnormally viscous. The flux and fuel rates substantially decreased with decreasing CaO/SiO_2 ratio and the production increased, but the partition of sulphur and carbon contents in pig iron was adversely affected.

Carbon Saturation

Regardless of the chemistry and particle size of the fuel employed for smelting, the carbon saturation of the iron produced in low shaft furnace was lower in comparison to pig iron made in blast furnace. In the International Low-shaft Furnace at Liege, the difficiency in carbon saturation was partly avoided and the carbon content was raised by restricting the particle size of the fuel to below 25 mm in size or by the addition of coke breeze to the charge. Coheur[17] reported distinct improvement in carbon contents on decreasing the mean particle size of the coke. In the smelting of self-fluxing briquettes at the National Metallurgical Laboratory, the particle size of fuel was 0 - 5 mm, but despite its exceedingly small size, the carbon saturation was poor. The average carbon content of foundry grade pig iron produced in a battery of commercial low shaft furnaces at Calbe, East Germany[22] is 3,45%. It is, therefore, to be considered that the short stack height with steep temperature gradient, poor indirect reduction and predominant direct reduction of iron ore in the lower bosh and hearth regions afford limited scope for carburization of iron. The carbon saturation also depends on the basicity degree of slag and silicon contents of pig iron. Paschke and Hahnel[27] noticed the decrease in carbon contents from 3,70% to 2,80% on decreasing the CaO/SiO_2 basicity degree of the slag from 1,59 to 0,36. The carbon saturation decreased by 0,07% on lowering the basicity degree by 0,1. During smelting of foundry grade pig iron in low-shaft furnace with change in lime basicity degree CaO/SiO_2 from 1,2 to 0,69, Struve[28] noticed that carbon saturation decreased by about 0,2% due to the lowering of the basicity degree by 0,1. These two examples indicate that carbon saturation in low shaft furnace largely depends upon the basicity degree of the slag. Based on the extensive data with variation in the chemistry and the particle size of the fuels and ores employed for smelting, it was observed that the carbon content of pig iron was largely dependant upon the basicity degree CaO/SiO_2 of the slag, as shown in Fig.9, higher basicity degree facilitated due to carburization of the iron. The addition of dolomite to the burden resulting in 7 - 10% MgO in the slag in the basicity range $CaO/SiO_2 = P_1$ of 1,0 - 1,4 was found to increase carbon content of pig iron. The exclusive employment of a dolomitic limestone (32% CaO, 25% MgO) resulting in a slag composition of 32% CaO, 29% SiO_2, 16% Al_2O_3 and 22% MgO was associated with optimum carbon saturation of 3,5%. Additionally the CO/CO_2 ratio was lowered to 4 - 5 and the slag became exceedingly fluid; the saturation of carbon was attributed to all these associated factors.

Addition of dolomite to the burden

High alumina in the slag increases its viscosity. In order to improve the fluidity of the slag, the MgO contents in the slag were varied from 9 - 10%, 13 - 15% and 17 - 19% in three stages maintaining the lime basicity ratio between 1,15 - 1,25 by the dolomite addition. The presence of a minimum of 7 - 8% MgO in the slag considerably improved its fluidity and MgO contents upto 15% did not adversely affect the smelting operation. The influence of increasing

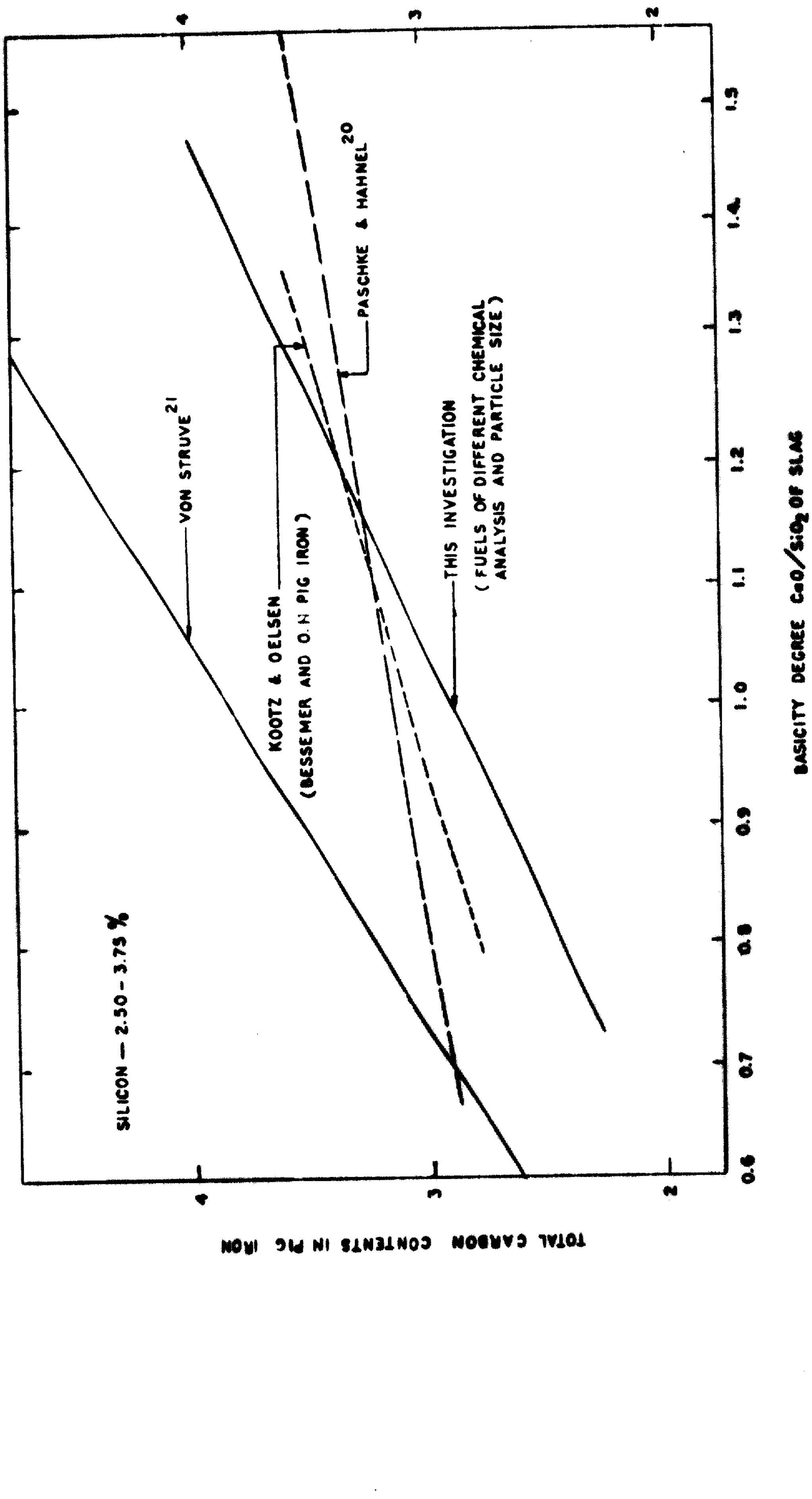


Figure 9

Dependence of Carbon Saturation of Pig Iron on the Basicity Degree of the Slag the MgO content of the slag was found to improve carbon saturation in pig iron.

Partition of Sulphur between Metal and Slag

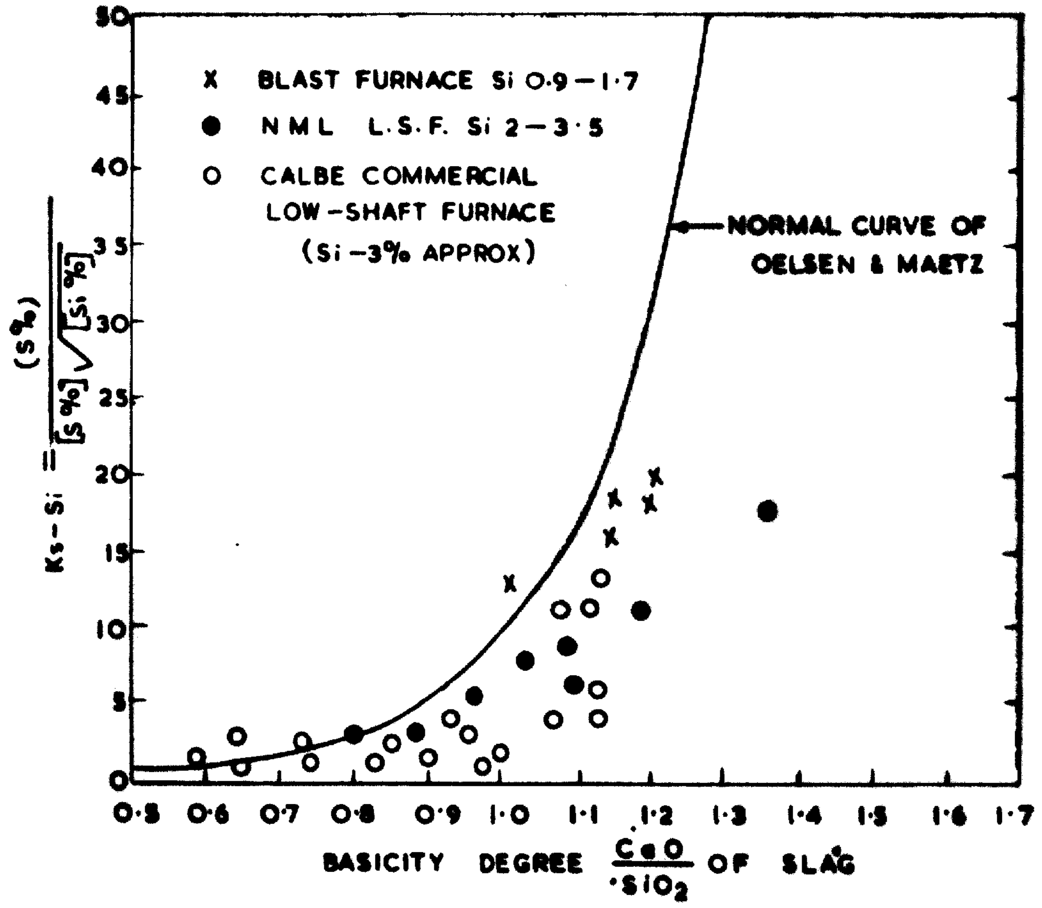
The sulphur content of pig iron should conform to the desired specifications. In the absence of external desulphurization treatment, the sulphur input from the raw-materials should be partitioned between the slag and the metal, so that the slag holds major amount of it. The desulphurization in the blast furnace depends on the basicity degree of the slag, silicon contents of the metal, temperature of the metal and slag, FeO contents of the slag and its volume. Due to relatively higher fuel rate, the sulphur input in the low shaft furnace is higher and the slag volume is also higher. By and large, the higher silicon content should favour desulphurization. Despite these factors, the sulphur partition index $\frac{(S)s}{(S)m}$ was found to be lower in the low shaft furnace. It is considered that the thermal conditions, poor indirect reduction and lower retention time in low shaft furnace adversely affect sulphur partition as shown in Fig.10.

It was observed that the technological aspects of iron smelting in a low-shaft furnace are not exactly identical to the blast furnace smelting, the difference is contributed by the operational conditions of faster descent of the burden to the smelting zone and the temperature gradient.

The extensive developmental investigations with raw-materials differing widely in their physical and chemical characteristics have evolved a cohesive pattern of their utilization in industrial scale for the economic benefit of the developing countries.

Figure 10

Basicity Degree of Slag and Partition of Sulphur in Laboratory Tests, Blast Furnace and Low-Shaft Furnace



INDUSTRIAL TEST WITH LOW-TEMPERATURE CARBONIZED COKE MADE FROM TALCHER COAL

An industrial low-shaft blast furnace with a hearth diameter of 2,5 m, both diameter of 3,0 m, effective height of 10,20 m provided with 6 tuyeres of 120 mm dia. is in commercial operation with nut coke (-35 + 15 mm), iron ore (-25mm + 10 mm) containing 60-61% Fe, limestone (+25 mm -50%, -25mm balance) containing 50% CaO for the production of foundry grade pig iron (2,5 - 3,5% Si) with a hot blast volume of 17,000 Nm^3/h at a temperature of 800 - 860°C. It produces 90 - 100 tonnes pig iron/day with a coke rate of 1250 kg/tonne of pig iron, associated with top gas CO/CO_2 ratio of 4 and slag volume of 750 kg/tonne of pig iron. It was employed for conducting industrial scale trials to determine the technical feasibility and commercial acceptability for the utilization of low temperature carbonized coke made from washed Talcher non-coking coal in continuous vertical retorts at the Central Fuel Research Institute. The coke was screened to remove -12 mm fraction and particle size composed of 45% + 25 mm balance +10 mm. The basicity degree $\frac{CaO+MgO}{SiO_2}$ was 1,14 to 1,37. The chemical analyses of raw-materials employed, physical characteristics of the fuel and the operational data are summarised in Table X.

No operational difficulties were experienced. A maximum coke consumption of 1,35 t/tonne was observed. As the phosphorus content in pig iron was 0,112 - 0,160%, it can be used for making malleable iron and special iron castings. Despite the short duration of the test and the height of the shaft of the furnace, it was considered that the employment of low-temperature carbonized coke made from Talcher coal can be considered for iron smelting in a suitably designed low-shaft furnace.

Based on the tests conducted at the low-shaft furnace pilot plant of the National Metallurgical Laboratory (Table VIII) and in an industrial furnace, an industrial complex at Talcher for the production of coke, pig iron, and fertilizer has been proposed.[29]

TABLE X - Industrial Trials with Talcher Coke

Chemical Analyses of Raw-materials, %

1. Iron Ore

Fe	SiO_2	Al_2O_3	S
61,0	2,5	7,0	0,06

2. Limestone

CaO	MgO	SiO_2	Al_2O_3
47,0	0,9	11,0	1,0

3. (i) Low Temperature Carbonized Coke (Talcher) %

F.C.	Moisture	Ash	V.M.	S	P
69,1	5,4	16,9	8,6	0,30	0,085

3. (ii) Low Temperature Carbonized Coke Ash %

SiO_2	Al_2O_3	CaO	Fe
65,36	26,60	3,26	4,46

4. Physical Properties of Low Temperature Carbonized Coke

Bulk density (dry basis)	-	540 - 600 kg/m^3
Micum Index (-40 + 20 mm)	-	68 - 79

5. Analysis of Pig Iron %

C	Si	S	P
3,70-4,02	2,44-4,88	0,012-0,065	0,112-0,116

6. Analysis of Slag %

SiO_2	Al_2O_3	FeO	CaO	MgO	S
28 - 33	26 - 29	0,3 - 0,6	33 - 38	4 - 5	0,7 - 0,9

ECONOMICS OF IRON PRODUCTION IN THE INDUSTRIAL LOW-SHAFT BLAST FURNACE

It is considered that pig iron produced in blast furnaces of highly capital intensive integrated iron and steel plant should be converted into steel, while foundry and special grades of pig iron be produced either in low-shaft furnace or medium shaft blast furnaces. The chief technical requirements of the blast furnace for its dependance on strong metallurgical coke and lumpy or agglomerated ferrous burden are well known. Iron ore fines can be agglomerated but problem remains for the medium ore sizes viz + 3/8" or so which are too coarse for sintering but are unsuitable for direct charging in blast furnace. The low-shaft furnace can smelt such ores satisfactorily with inferior grade of fuel. The chief objection raised against the small units, is perhaps the adverse economics of iron production in small scale. Admittedly the fuel rate in the low shaft furnace will be slightly higher than in the blast furnace; but the costs of the inferior grades of raw-materials smelted in the former will be reasonably lower than the regular large blast furnace raw-materials, and are expected to balance the relatively higher cost of production.

The coefficient of heat utilization in the low-shaft furnace of the National Metallurgical Laboratory as reckoned by the top gas temperature and its CO/CO_2 ratio was unsatisfactory due to the restricted shaft height of the furnace. For iron smelting with either low temperature carbonized coke or sub-size coke, the effective height of the furnace can be appropriately increased. The temperature of the hot blast can also be raised. The increase in furnace size, higher hot blast temperature, consistency of smelting operations with uniformity of raw-materials will appreciably reduce the fuel consumption. In fact the trials conducted in a 100 tonnes per day industrial low-shaft blast furnace with small lumpy iron ore (-25 to +5mm), limestone (-40 + 20 mm), the fuel rate with low temperature carbonized coke amounted to 1350 kg/tonne, while with screened nut coke employing -25 + 12 mm fraction exclusively, the coke rate (dry) was 1000 kg/tonne for producing pig iron containing 4.0% Si, even when the alumina content of the slag was abnormally high at 30%. It is, therefore, reasonable to conclude that for industrial scale operation in a furnace of 100 - 150 tonnes daily output, the consumption of low-temperature carbonized coke will be about 1300 - 1400 kg per ton or iron, whilst with graded (-25 + 12 mm) coke size, the fuel rate could be brought down to less

than 1000 kg per ton or iron.
For improving the over all economics of iron production, the surplus top gas, slag, flue dust should be properly utilized. Besides, the availability of regional raw-materials and other ancilliary facilities such as water, electric power in the vicinity of the iron works will largely determine the ultimate economics of the iron smelting in low-shaft blast furnace. The initial capital investment for an iron smelting unit without high degree of mechanization or automatic controlling devices, which may be somewhat unsophisticated in comparison with a large, modern blast furnace, will be lower per annual tonnes. The capital cost will largely depend on the provision of facilities for the carbonization of the fuel, associated with the by-products recovery plant. It is considered that surplus nut coke available from the integrated steel plants can usefully be employed for iron smelting in small furnaces.[30,31] The commercial success of its utilization has been proved and the firm has installed two more 120 tonnes per day furnaces and facilities for generating 12 M.W. of power from surplus top gas. For a 100,000 tonnes annual output two 150 tonnes/day low-shaft blast furnaces can be installed as shown in tentative layout of the plant in Fig.11.

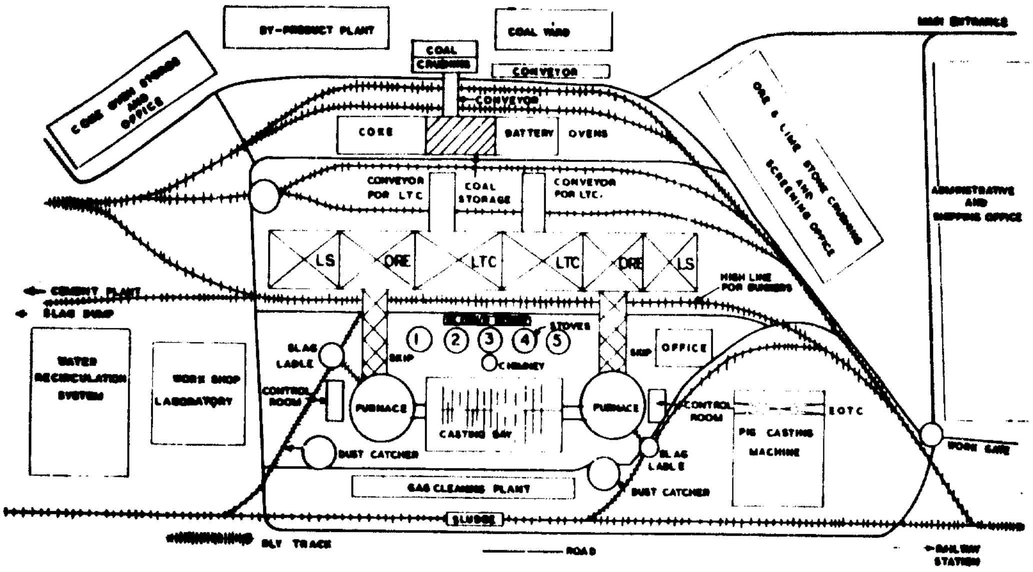
The consumption of raw-materials and approximate production cost estimates for annual production of 100,000 tonnes of pig iron are given in Table XI.

Based on exhaustive studies, calculations, quotations and enquiries from different overseas and internal suppliers, the tentative capital cost structure is given in Table XII.

It is further emphasised that on the face of non-availability of satisfactory grade of raw-materials for blast furnace iron smelting, the slightly increased cost of production of pig iron in a low-shaft furnace through the utilization of regional raw-materials can be attractive in developing countries.

Figure 11

Layout of 100,000 tonnes per annum Pig Iron Plant



LAYOUT OF 100.000 TONNES PER ANNUM PIG IRON PLANT.

TABLE XI - initial production cost estimates per tonne of pig iron based on an annual output of 100,000 tonnes of pig iron.

Description	Required per tonne of pig iron	Cost per tonne of pig iron inclusive of freight, etc.	Total cost per tonne of pig iron
1. **Materials**			
(Suitably screened and sized)			
i) Iron ore	1,50	Rs. 18,00	Rs. 27,00
ii) Limestone	0,75	Rs. 16,00	Rs. 12,00
iii) Low Temperature Carbonized coke tonnes	1,3-1,4 Production cost calculation have been made on the higher coke rate of 1,4 tonnes per tonne of pig iron.	Rs. 100,00	Rs. 140,00
Total Materials Cost			Rs. 179,00
2. Power requirement:			
i) Power expenses including the chief power consuming factor i.e. air blast blowers and other auxiliaries.			Rs. 18,50
3. Utility services, shop requirements and common work expenses such as steam, water etc.			Rs. 5,00
4. i) Depreciation and interest on capital (at 10% of capital)			Rs, 47,00
ii) Wages, overheads, etc.			Rs. 15,00
5. Provision for refractory relining			Rs. 5,00
Gross production cost of one tonne of pig iron			Rs. 269,50

(Carried over)

Table XI (Continued)

(Brought forward)

1	2	3	4
Gross production cost of one tonne of pig iron.			Rs. 269,50
6. <u>Credits</u>			
i) Low Shaft Furnace gas available to other shops having a calorific value of 1250-1350 kcal/nm^3 at Rs. 8,50 for 10^6 Kcal.			Rs. 28,00
ii) Slag and flue dust			Rs. 1,50
Gross credit/tonne of pig iron			Rs. 29,50
NET COST OF PRODUCTION/TONNE OF PIG IRON			Rs. 240,00

TABLE XII - Estimated Capital Cost Equipment for 100,000 tonnes pig iron plant. (excluding customs duty, insurance, ocean and rail transport charges, port handling charges, etc.)

Sl.No.	Equipment	Foreign exchange stated in equivalent rupees	Rupees
		Rs.	Rs.
1.	Low Shaft Blast Furnaces, gas cleaning plant, pig casting machine including erection.	8,312,500	15,900,000
2.	Soil investigation	-	125,000
3.	Foundations, Civil Engineering and Building Works for (1)	758,100	7,620,000
4.	Electric Blowing Plant including Erection and Civil Works.	3,165,400	1,460,000
5.	Works services, plant water services including erection and civil works, rail track, roads, office, fire fighting equipment, locomotives and vehicles.	452,200	4,880,000
6.	Maintenance, Workshops and Equipment including erection and civil works.	1,197,000	1,300,000
7.	Engineering services	1,662,500	200,000
	Total	15,547,700	31,485,000
	Grand total (including foreign exchange and rupee expenditure)	Rs. 47,032,700	

or 4,7 crores of rupees

SUMMARY AND CONCLUSIONS

The imbalance between the well dispersed classical deposits of iron ore and the relatively small localised occurence of coking coal, the extensive deposits of non-coking coals and lignite, stimulated comprehensive investigations on the production of pig iron with non-metallurgical fuels in a low-shaft furnace pilot plant. It has facilities for briquetting, generation of hot blast and gas cleaning. The 12-15 tonnes/day furnace has a hearth diameter of 1300 mm and effective height of 2,6 m and total volume of 7,3 m^3.

A large varieties of raw-materials were smelted during the extensive trials to develop an appropriate technique of iron smelting with inferior raw-materials particularly fuel. Apart from the changes in chemical and physical characteristics of raw-materials employed, alteration in operational conditions were additionally imposed for comprehensive assessment of the smelting parameters.

The utilization of non-coking coals for iron smelting was attempted in three different ways, viz. i) by making a single component burden of self-fluxing briquettes containing fine particles of iron ore, limestone and the non-coking coal; ii) employment of lumpy raw non-coking coal in bedded form of burdening, and iii) prior carbonization of the non-coking coal at low temperature producing char or soft coke of inferior physical strength.

The technological difficulties of making strong briquettes sufficiently stable to withstand the temperature and loading conditions in the furnace and the unfavourable economics due to the additional cost of binders employed for briquetting made the process commercially unattractive. The employment of non-coking coals of very low caking index in bedded form of burden led to serious operational difficulties and wide swings in the chemistry of the pig iron produced and cannot be adapted for iron smelting in a low-shaft furnace. Besides the non-recovery of potential by-products from the coal was economically disadvantageous. Low temperature carbonization of non-coking coal affords full recovery and utilization of by-products, while elimination of moisture and major amount of volatile matter yields a better fuel for iron smelting. The physical strength of low temperature carbonized coke is significantly inferior to the blast furnace coke. The reactivity towards carbon dioxide or oxygen is higher and accelerates the "solution loss" reaction affecting the fuel rate adversely.

The use of low-temperature carbonized coke for iron smelting was characterised by smooth descent of the burden, regularity of the operation with the production of desired grade of pig iron. Fine grained ores can be smelted directly in industrial low-shaft furnace of appropriate design for optimum indirect reduction and transference of heat.

The generation of the dust and the fuel rate depended on the physical and chemical characteristics of the low-temperature carbonized coke, the latter was related to the chemical analysis and the nature of the coal. It was observed that all non-coking coals would not yield 'Char' suitable for iron-smelting in low-shaft furnace.

The employment of high sulphur coke was limited by the partition of sulphur under the operational conditions. The utilization of high titania (15% TiO_2) ore depended on the viscosity of slag, which was related to its basicity degree.

Summarising the effects of variation of the operational conditions, it was concluded that the inherent characteristics of the low-shaft furnace led to high top gas temperature, high CO/CO_2 ratio indicating poor indirect reduction and poor exchange of heat both of which contribute towards high fuel rate. The top gas temperature depended on the nature of the fuel and particle size of the raw-materials. The CO/CO_2 ratio and top gas temperature were lowered by the decrease in particle size of iron ore with consequent lowering of the fuel rate. Due to the limitation of the gaseous indirect reduction, the effect of the reducibility of the ores on the fuel rate was marginal. The normally low carbon saturation of pig iron was improved by raising the basicity degree of the slag or by the presence of MgO in it. The presence of 8 - 10% MgO in the high alumina slag assured adequate fluidity. The acid smelting lowered the fuel rate but adversely affected desulphurization and carbon saturation. The fuel rate (25% ash in fuel) decreased by 50 kg/tonne of pig iron with 50% rise in blast temperature between 400 - 600°C. Increase in silicon by 2% necessitated 300 kg/tonne of fuel additionally.

From the extensive trials, it emerged that ore fines can be smelted with non-metallurgical fuels of poor physical characteristics and the process is technically and economically acceptable despite the slightly higher cost of production in low-shaft furnace.

Depending on the limited market demand and non-availability of suitable grade of raw-materials for iron smelting in the highly capital intensive classical blast furnace, the low-shaft furnace technique of smelting iron can be adapted in developing countries and regions possessing scanty resources of metallurgical grades of coking coals in relation to non-coking coals.

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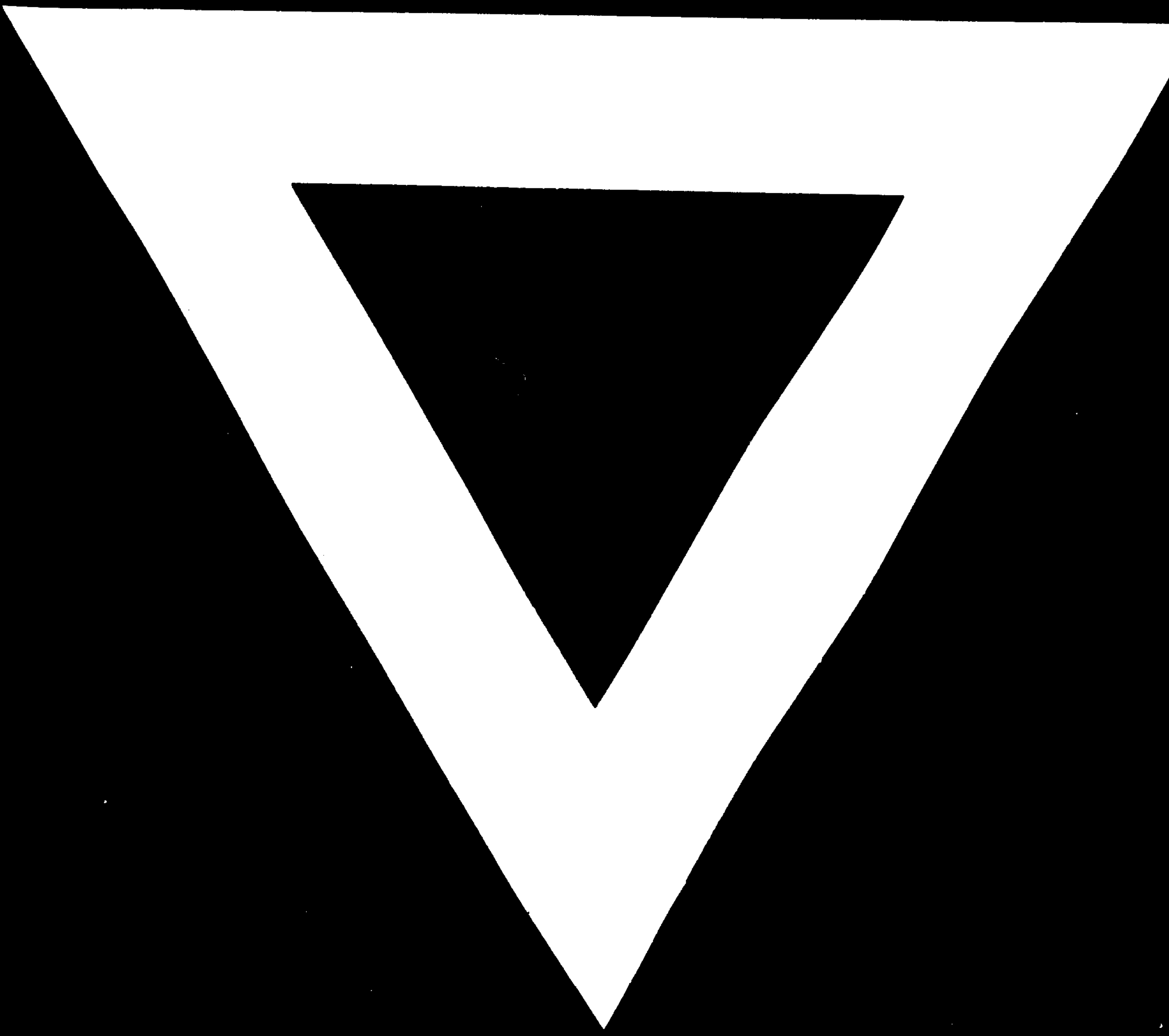

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