OPERATIONAL ASPECTS OF SPONGE IRON PRODUCTION IN A ROTARY KILN

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ABSTRACT

ON the background of the imbalance in the occurrences of vast deposits of high grade iron ore with that of coking coal, and simultaneous availability of enormous quantity of evenly distributed non-coking coals, extensive trials to ascertain the possibilities of their exploitation were conducted in an experimental rotary kiln of 10.67 m. length with 0.76 internal diameter. Several iron ores, or green and heat-hardened pellets and varieties of non-coking coals were employed. The proportion of iron-coking coal in the charge was in excess of the stoichiometric requirement. A temperature profile of 950—1025°C in the reaction zone was maintained by the combustion of fuel oil from an axially located burner and partial combustion of coal volatiles, or exclusively by the combustion of coal volatiles, by throwing coal inside the kiln. In the two ways of meeting the thermal requirements, the alteration in the temperature profile was marginal. The retention time was 90 to 110 minutes. The degree of metallization varied between 87 to 92%, and no operational difficulties were experienced even with green pellets. Agglomeration or ring formation was avoided by proper adjustment of operational parameters. The microscope examination revealed total absence of wustite and completion of conversion to metallic iron. The heat requirements of 4.6—5.25 million kilo-calories/ton of sponge iron could be lowered to 3.5—3.7 kilo-calories/ton of sponge iron with partial recirculation of char. The trials yielded adequate data for designing a commercial prototype, or for industrial production of sponge iron.

Introduction

The direct reduction processes, developed for converting iron ore directly into metallic iron without melting the ingredients arose keen interest throughout the world due to the non-availability of coking coal or as the coke price is gradually rising and the coking coal reserves are dwindling at a fast rate, on which the smelting of iron ore in the blast furnace inescapably depends. Due to these factors and also the limited market demand in certain areas, the conventional ironmaking process cannot be adopted in all countries and with the object of bypassing the traditional blast furnace, large number of non-conventional techniques have been developed to suit the raw material available in the vicinity of the plant. The product of direct reduction processes known as sponge iron is used mainly as high quality melting stock for steelmaking.

A continuous process which can produce an end product of consistent quality involving minimum unit operations using simple, dependable equipment, has a chance of becoming a widely used process in the steel industry. In this context, a rotary kiln may be selected as the most promising type of equipment as it is comparatively inexpensive to build, reliable to operate

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FLOWSHEET OF A COMMERCIAL KRUPP SPONGE IRON PLANT FOR PROCESSING OF ORE FINES OR CONCENTRATES

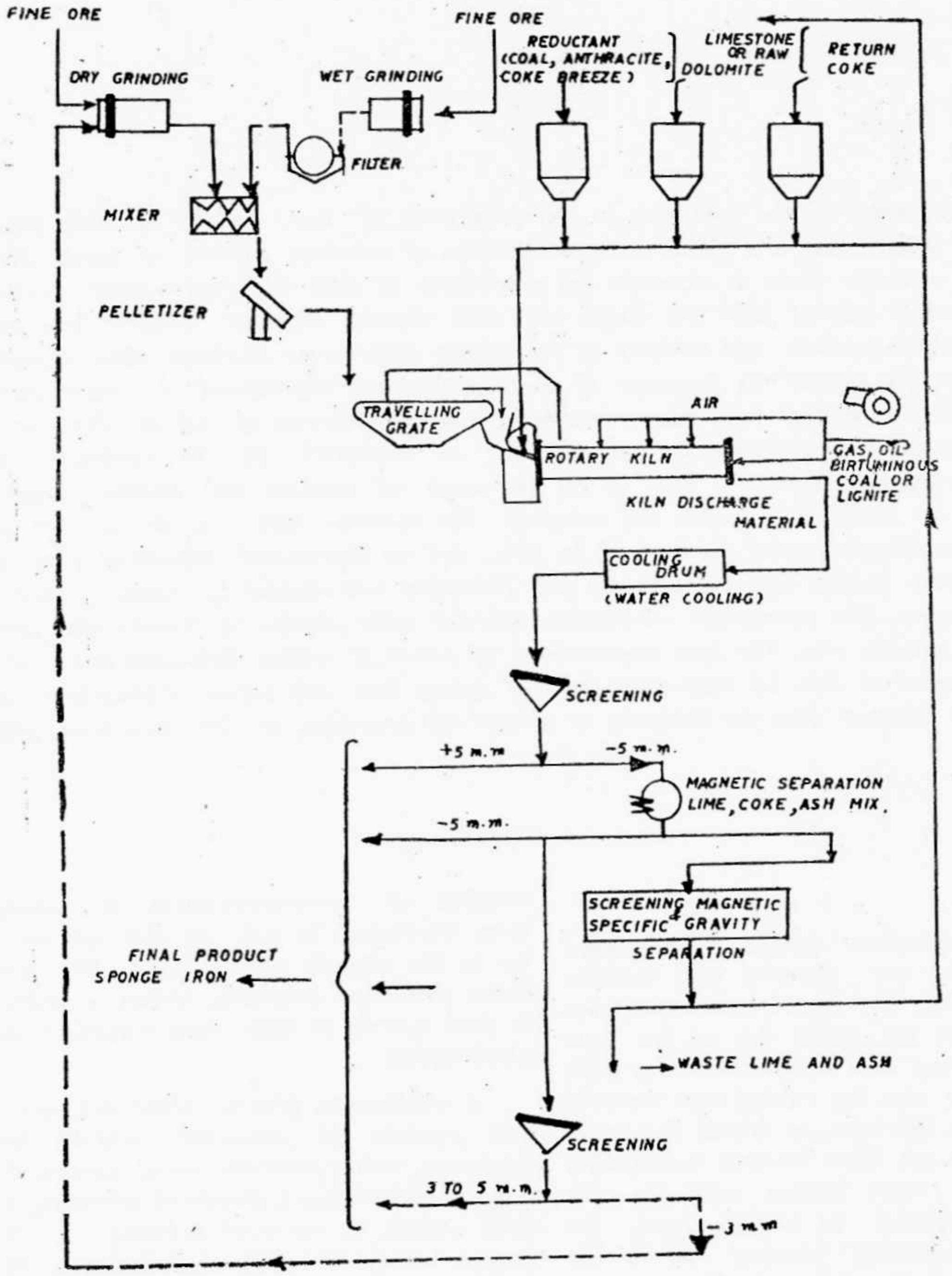


Figure 1

and suited to continuous processing.

In India, the production of steel from sponge iron is specific and immediately necessary because of the following reasons:

a) The coking coal deposits in India are exceedingly limited and located in a small geographic region. The reserves of good grade coking coal are located in Jharia and which do not need any washing, is estimated to be 1600 million tonnes. After washing and blending, about 3,000 million tonnes may be used for iron-smelting. With the present rate of consumption, the reserves will last for 70 to 80 years. This clearly indicates the necessity of lowering the consumption of coking coal in ironmaking. Apart from the limited reserves of non-coking coal in India, the blast furnace operation is confronted with the high ash content in coking coal, which increases the coke rate. Adaptation of means to reduce the coke rate in the blast furnace, such as by the utilization of pre-reduced material will be advantageous.

b) There is no natural gas reserve in India and as such the direct reduction processes employing the solid reductants, are of significance for the commercial production of sponge iron.

c) There are vast reserves of high grade iron ores in different localities of India where there is no occurrence of metallurgical coal. Steel production from these ores must therefore take some alternative route other than conventional blast furnace methods.

d) The overall economics of such processes using Indian raw materials for production of sponge iron and finally steel therefrom, must be comparable with the conventional steelmaking processes already in operation.

Keeping these in view, series of experiments were conducted in the National Metallurgical Laboratory using a rotary kiln of 10.46 m long with 0.76 m internal diameter having a production capacity of 3—4 tonnes of sponge iron per day. The details of pilot plant experiments using various types of ore lumps, heat hardened and green pellets with non-metallurgical coals as solid reductant are presented.

ROTARY KILN—SOLID REDUCTANT PROCESSES

1. Krupp Sponge Iron Process

The Krupp Sponge iron process uses a rotary kiln for the reduction of high grade lump ores or pellets (Fig. 1). The feed is introduced together with reducing and de-sulphurizing agents (limestone or raw dolomite) into an inclined rotary kiln, heated counter current to the flow of hot gas and reduced to form sponge iron. Depending on its content of volatile matter, the coal is partly blown into the kiln from the discharge end and /or partly fed together with the ore into the kiln. The product discharged from the kiln consists of a mixture of sponge iron, surplus fuel, desulphurizers and ash and is subsequently cooled in a rotary cooler.

Separation of the sponge iron from the surplus fuel, deslphurising agent and ash is accomplished by a combination of screening, magnetic separation, and if necessary, gravity separation. The kiln is fired from the discharge end with a deficiency of air. It is fitted over its whole length with tuyers extending through the shell which permits air to be blown into the kiln for burning the carbon monoxide evolved during reduction and the volatiles available from the coal. This makes it possible to maintain a uniform temperature profile of 950°—1050° C over three fourth of the kiln.

The kiln can be preceded by a travelling grate or shaft type pre-heater for preheating the feed in order to improve its fuel economy. When processing lump ore or burnt pellets, it is, in the final analysis, the price of fuel that determines whether a grate or a preheater is used. Compared with the travelling grate, the shaft type pre-heater requires less initial maintenance costs, particularly since it has practically no moving parts.

2. The SL–RN Process

In the course of extensive development work by both SL and RN groups, it appeared that the process variants in both the systems pre-

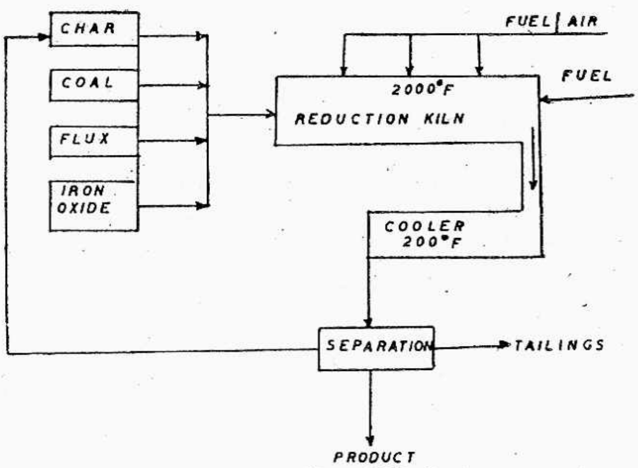


Fig. 2 The SL/RN Stelco Lurgi/Republic steel, National Lead Process is characterized by two kilns one for metallization and one for cooling this is rotating Kiln process which uses a solid reductant.

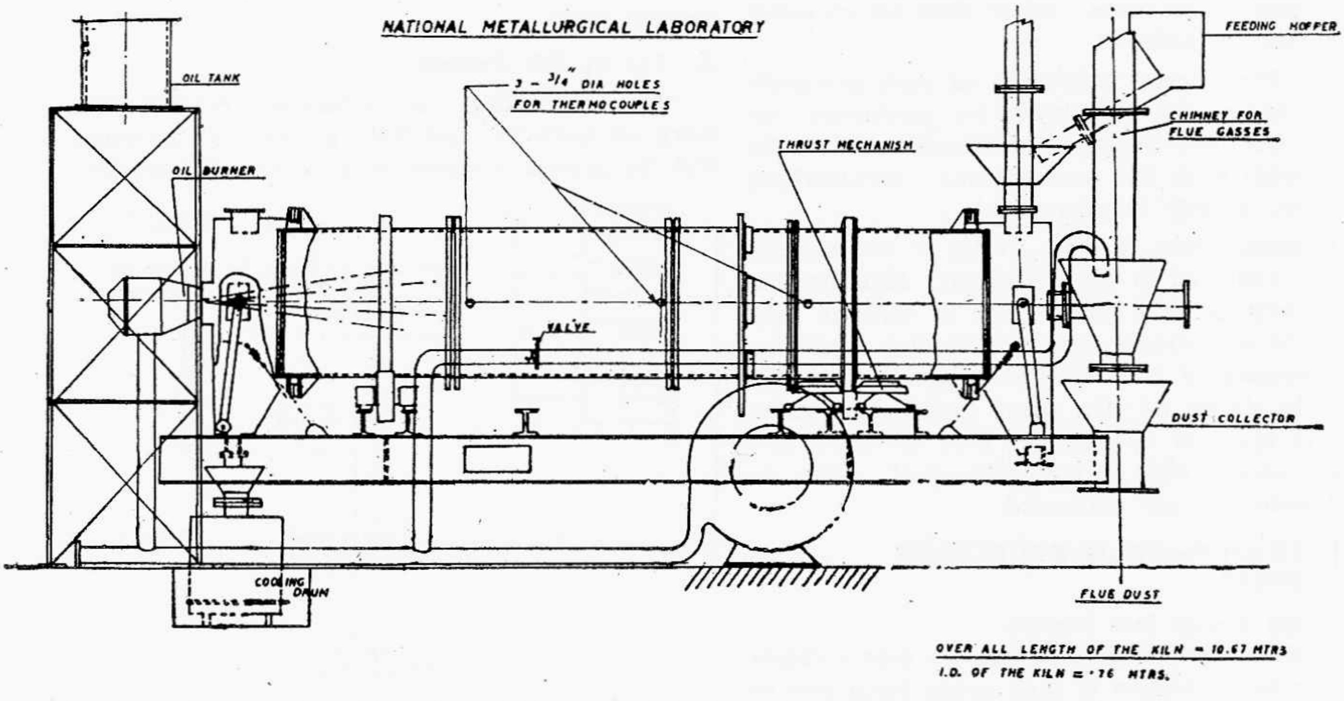
sented advantages under certain conditions. To most efficiently utilise experiences of both groups for industrial purposes, the groups decided on an amalgamation which, in 1964, led to SL-RN process,

For the development of the process upto the present state, three pilot plants have been erected and operated and several commercial plants are already in operation or are in the state of erection. The SL-RN process also uses rotary kiln for reducing iron ore. The plant, as shown in Fig. 2, essentially consists of raw material handling and preparation systems, rotary kiln with heating arrangements for reduction of iron oxide, kiln for cooling the reduced material and the facilities for separating sponge iron from char by screening and magnetic separation. The kiln is slightly inclined and is heated by an axial burner located centrally at the discharge end and several shell burners properly distributed along the length of the kiln. The axial burner at the discharge end can be employed for firing pulverised coal, oil or both or natural gas as fuel. Secondary air is supplied through air nozzles to the burners mounted on the shell. With shell burners and admission of requisite quantity of secondary air through the air nozzles, it is possible to maintain a constant temperature of about 1100°C over 60 per cent of the kiln length. The materials gradually move through the hot kiln in a direction opposite to the flow of gas. It has been claimed that iron ore occurring in different mineralogical forms, has been successfully treated with solid fuels like anthracite, bituminous high volatile coals and lignite and sponge iron containing 96.7 per cent total iron, 94.1 per cent metallic iron and a degree of metallization of 97.3 per cent has been achieved.

Rotary Kiln Reduction Process at NML

The rotary kiln at NML (Fig. 3) consists of a steel shell of 900 mm diameter and 10700 mm in length. The kiln is provided with spring loaded stationary inlet and outlet segments with proper air tight seals to prevent infiltration of air or gas leakage between the stationary heads and the rotary kiln. These stationary portions enable discharge of the kiln material and feeding of the raw material into the kiln.

The kiln is lined with high alumina fire clay bricks leaving an internal diameter of 760 mm, the thickness of the lining is 70 mm. The embankment at the feed end made of 90 mm fire clay brick has decreased the spilage of the feed material and a semi-circular cone made of 5 mm m.s. sheet is fitted at the feed end to prevent the spillage to a minimum quantity. A dust catcher is also provided to collect dust from the exhaust gases. Two retaining rings, made also of fire clay



SKETCH OF ROTARY KILN FOR SPONGE IRON PRODUCTION

Figure 3

brick, one at the discharge end and the other at the middle of the kiln have increased the bed depth and retention time of the charge inside the kiln. The inclination of the kiln can be varied from horizontal position to about 10 percent. The rotation of the kiln at a constant speed can be varied from 1/2 r.p.m. to 2 r.p.m. through a variable speed motor and reduction gear assembly.

Charging and heating arrangements :

The raw materials like iron ore, pellets, coal and limestone are conveyed to storage bins by bucket elevators. Magnetic vibratory feeders are used for charging iron ore/pellets, coal and/or limestone to a conveyor belt. The charging rate can be adjusted over wide limits by controlling the vibratory feeders. The materials from the conveyor belt are charged into the rotary kiln through a chute.

The kiln is provided with an oil burner located at the axis of the kiln at the discharge end Four thermo-couples are fitted in the kiln at various distances from the burner end for continuous recording of temperature inside the kiln. By proper adjustment of the oil burner as well as controlled amount of secondary air the desired temperature profile in the kiln can be maintained.

Recently coal throwing system is incorporated which can replace the oil firing arrangement. It is possible to throw high volatile coal of 12 mm size upto the half the length of the kiln. The proper temperature profile in the kiln can be maintained by throwing desired quantity of coal burning the volatiles of the coal to provide necessary heat and reduction temperature. Typical temperature profiles for both oil firing and coal injection systems are shown in Fig. 4.

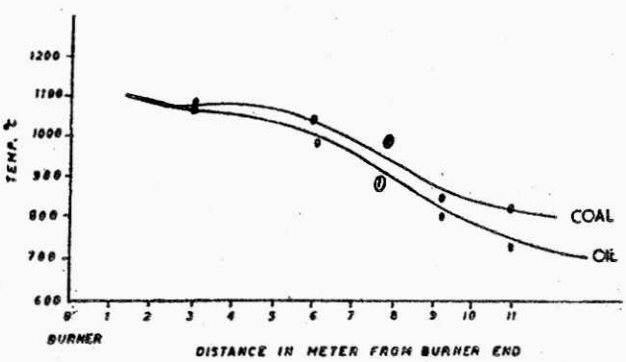


Fig. 4

Discharge of sponge iron

Due to the slope and rotation of the kiln, the charge gravitate from the charging to the discharging end. The retention time can be altered by altering the speed of rotation and the slope of the kiln. The materials are discharged through a chute to a water cooled collecting drum. The collecting drum is kept inside a cooling jacket in which cold water is continuously passed to cool the reduced material. The drum is removed when it is filled up and further cooled in a tank of running water to prevent the reoxidation of sponge iron. As this arrangement needs constant attention and is intermittent, arragements are being made to provide a rotary cooler which will be mounted below the main kiln.

Physical and chemical characteristics of raw materials employed.

1. Iron Ore :

The iron ore used in the campaigns were from Dalli-Rajhara mines of M.P. Bailadila mines of M.P., Barajamda mines of Orissa, Kiriburu mines of Orissa, and Surajgarh mines of Maharashtra.

It was intended to study the prereduction characteristics of lumpy iron ores as well as of pellets, both in the green and indurated states. For employing sizegraded lumpy iron ores, they were crushed and screened to —19 +6mm size. The chemical and screen analyses of ores are recorded in Tables I and II respectively.

Iron ore pellets :

Green pellets: For pelletization, the ore was ground to 80 per cent —325 mesh and pelletized in a disc pelletizer in the conventional way with the addition of 0.5 to 1.0 per cent bentonite. For studying the behaviour of green pellets in the production of sponge iron, iron ore from Donimalai mines, Mysore. Bailadila mines, M.P., Kiriburu Mines, Orissa and Surajgarh mines, Maharashtra were used. The chemical and screen analyses of green pellets are recorded in Tables III and IV respectively and the physical properties of green pellets are given in Table V.

Indurated pellets: Pellets made from Donimalai, Bailadila and Kiriburu iron ores were heat-hardened in a pot grate furnace designed and fabricated in the National Metallurgical

Laboratory. Pellets from Noamundi iron ore were supplied by M/s. Tata Iron & Steel Co. Ltd., in the indurated condition from their Noammundi Pelletizing Plant. The chemical and screen analyses of indurated pellets are recorded in Table VI and VII respectively. The physical properties of the indurated pellets are recorded in Table VIII.

Non-coking coals

Non-coking coals of Maharashtra and Andhra Pradesh were used as reductants. The Maharashtra coal belongs to meta and ortholignitious variety. The high moisture and volatile matter make the coal unsuitable for metallurgical purposes, except for steam generation.

Being of a non-coking variety, it is not used for blending purposes in metallurgical coals. These coals were crushed and screened to —18 mm +6 mm size. Proximate analyses of coals used are given in Tables IX and the sieve analysis in Table X. *Limestone*: The limestones used in different campaigns are received from Bhavanathpur, Orissa and Surajgarh, Maharashtra. The limestone was crushed to 3 mm size. The chemical and sieve analyses of the same are recorded in Table XI and XII respectively.

OPERATION OF KILN AND EXPERIMENTAL RESULTS

Behaviour of Iron Ore lumps

Iron ore lumps as recorded in Table 1 were reduced in the rotary kiln along with non-metallurgical coals. The iron ore lumps and coal were charged at the rate of 300 Kg/hr. Light diesel oil was used as burner fuel. The temperature profile was maintained between 1000-1050°C. Excess amount of coal abvove the stoichiometric quantity was charged for enhancing the rate of reduction, and to attain high degree of metallization. The revolution of the kiln was kept at the minimum i.e. 1/2 r.p.m. The operation results are recorded in Table XIII.

Behaviour of indurated pellets

The next series of tests were conducted with indurated pellets as described in Table VI. During the operation, the pellets degraded considerably but the degree of degradation varied with the nature of the charged pellets. The degree of metallization was dependant on the size of pellets. The operational results are recorded in Table XIV.

Behaviour of green pellets

Pre-reduction of green pellets was associated with two major advantages. Green pellets, being more porous, can withstand the internal stresses developed during reduction and phase transformation and therefore did not suffer serious degradation in reducing atmosphere. The heat-hardening cycle can be avoided if green pellets were directly charged for pre-reduction and thereby the operational cost can be minimised to a considerable extent. The pellets may however, get crumbled at the feed end of the kiln due to the mechanical and thermal shocks if the compression strength of pellets were low. As the physical strength decreases with time, experiments were conducted in the rotary kiln by feeding the pellets directly from the disc pelletizer. With a feed of proper fineness with high specific surface area and using 1% bentonite as binder, it was possible to make pellets having 3 to 4 Kg. compression strength. The size of pellets was controlled between 6 to 12.5 mm. There was practically no degradation of these pellets during sponge iron-making in the rotary kiln. The operational results of these campaigns are recorded in Table XV.

Exclusive utilization of coal

In order to meet the thermal requirement exclusively by the utilization of the volatiles of the coal, a suitable mechanism was evolved to throw —12.5 mm coal upto the half of the length of kiln from the discharge end. The furnace was however, initially heated upto 1050°C by oil burner and which was removed and the fuel-throwing system was introduced into the kiln. 50 per cent of the coal of +6—19 mm size was fed in the conventional manner along with the indurated pellets from the feed end and the balance 50 per cent consisting of —12.5 mm size was thrown from the discharge end. The temperature profile, as shown in Fig. 4, could be continuously maintained by burning coal exclusively. The results of the operation are recorded in Table XVI.

DISCUSSION OF RESULTS

Lumpy ore: Pre-reduction studies conducted with different lumpy ores along with non-coking coals indicated that pre-reduction to a high degree of metallization could be achieved in a rotary kiln. The temperature profiles, in all the campaigns conducted, were kept sufficiently below the ash fusion temperature of the reductants and no agglomeration or ring formation was experienced during the continuous operation of the kiln. The fuel oil consumption per tonne of sponge iron produced from different lumps varied from 60 to 70 Kg. In the absence of limestone in the charge, the sulphur pick up by the sponge iron was high, but it could be reduced by using 4 per cent limestone in the feed.

The heat requirement, calculated for different campaigns varied from 4.6 to 5.25 million kilo calories per tonne of sponge produced but with the recirculation of char obtained after magnetic separation of the rotary discharge and subsequent screening, this could be lowered to 3.5 to 3.7 million kilo calories.

Indurated pellets: It was observed that the heat hardened pellets degraded during their passage through the kiln. The degradation increased with increase in the size of the pellets. Although substantial amount of fine was generated due to the degradation, no ring formation was observed during these campaigns. Recirculation of a certain quantity of char after removal of the fines by the screening did not show any deterimental effect on the degree of metallization. The oil consumption rate was similar to the previcus campaigns and no appreciable differences was noticed for the thermal requirement of the kiln.

MINERALOGICAL STUDIES

Microscopic examination of the reduced pellets revealed that in most cases the magnetite-wustite phase was totally absent indicating complete reduction of iron oxide into metallic iron phase. The reduced phase was homogenous and was in advanced state. Further, complete recrystallisation followed by considerable grain growth of the metallic iron phase which had reduction process from the earlier iron oxide, stage by stage, was observed (Fig. 5). The metallic iron grain had enlarged bonded and sintered together due to the grain growth with the simultaneous break up and the thinning of the intergranular bond of slag phase as well as iron oxide phasc (Fig. 6). At places graphic intergrowth of slag bond (dark grey) iron oxides phase and metallic iron phase was noticed indicating the conversion and replacement of the former by the latter (Fig. 7) during process of reduction.

Green pellets: It was observed with green pellets that the degradation of pellets and subsequent dust formation inside the kiln was low and accretion on the wall was absent. The degree of metallization was also high, a higher operating temperature upto 1080-1100°C could be maintained in the constant temperature zone of the kiln without any fusion of the discharge product. The thermal input, without million kilo calories per tonne of sponge iron but with recirculation of thermal input, without recirculation of char, varied from 4.80 to 5.20 million kilo-calories per

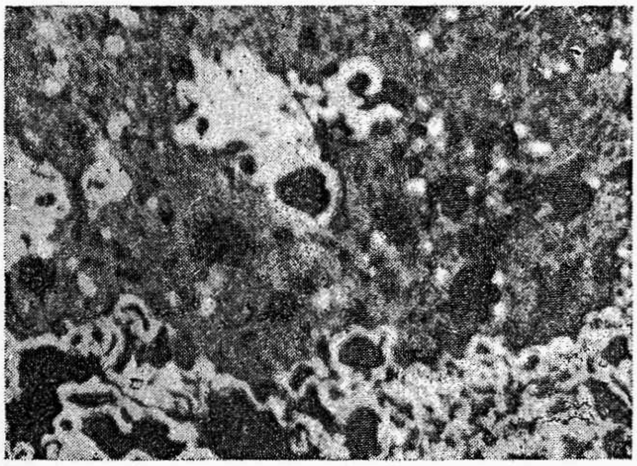


Fig 5 Showing core of the pellet in the metallic iron grains (white) and their advancement of grain growth with magnetite-wustite phase (light grey) in a slag bond(dark grey). Dark areas are pits. Reflected illumination X 100

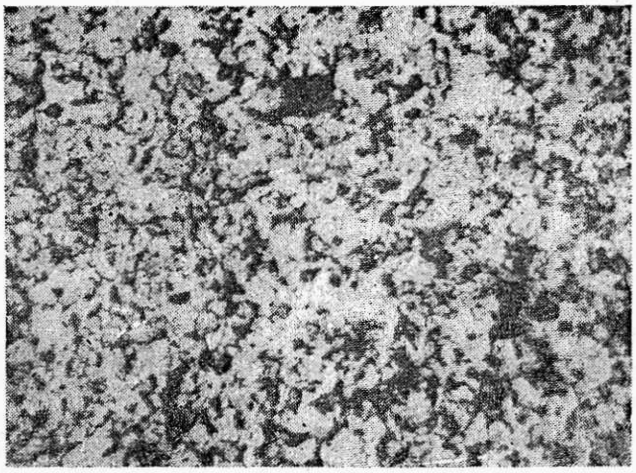


Fig 6 Showing advanced stage reduction consisting of metallic iron phase (white) grains growing and coming very close to each other with magnetite–wustite phase (light grey) and slag bond (dark grey). Dark areas are pits. Reflected illumination X 200

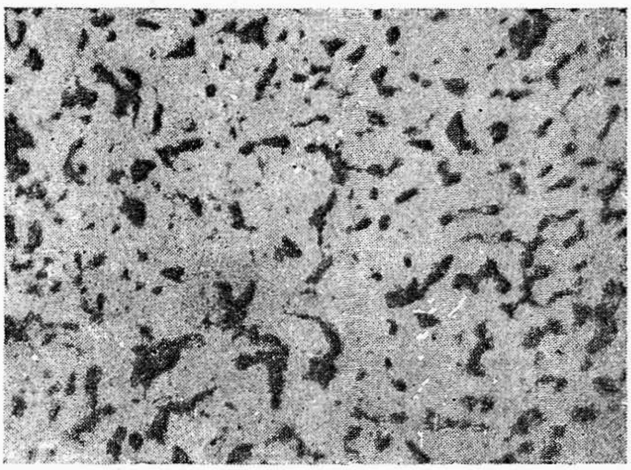


Fig. 7 Showing highly advanced stage of reduction with metallic iron phase (white) together with very faint outlines of thinned magnetite-wustite phase (light grey) and slag bond (dark grey). Reflected illuminiation X 400

tonne of sponge iron but with recirculation of char, it was reduced to 3.5 to 3.82 million kilo-calories per tonne of sponge iron.

The throwing of coal from the discharge end led to the following advantages over oil firing system:

a) The oil consumption, a major item in the cost calculation, could be entirely eliminated without disturbing the temperature profile of the kiln.

b) The temperature profile, as seen in Fig. 4, was slightly flatter than that obtained during oil firing, indicating that the constant temperature zone could be extended to a large length of the kiln. The temperature in the discharge end was low ensuring the better utilisation of heat input and it also prevented agglomeration of the kiln product. The microscopic examination of the product indicated almost complete metallization with minor amounts of magnetite-wustite phase, as shown in Fig. 8.

c) The thermal input in the kiln was lowered to 3.00 to 3.30 million kilo-calories per tonne sponge produced: evidently due to the improved thermal efficiency of the kiln.

Conclusion

Experimental operations of rotary kiln using different iron ore lumps, indurated and green pellets and non-metallurgical coals indicated that with proper control of operational parameters, furnace atmosphere and temperature profile, a degree of metallization higher than 90 per cent can be achieved. High grade iron ore can be fed directly into the kiln in proper sides. Green pellets did not suffer any degradation during reduction as was the case with indurated pellets. Coal throwing from the discharge and upto 50 per cent of the total coal charged showed encouraging results. The fuel oil input for maintaining the kiln temperature could be entirely curtailed saving thereby major operational cost of production.

The rotary kiln process using solid reductant proved promising. Accretion phenomenon was insignificant during the entire range of experiments. No pyrophorocity was observed during the storage period of the sponge products.

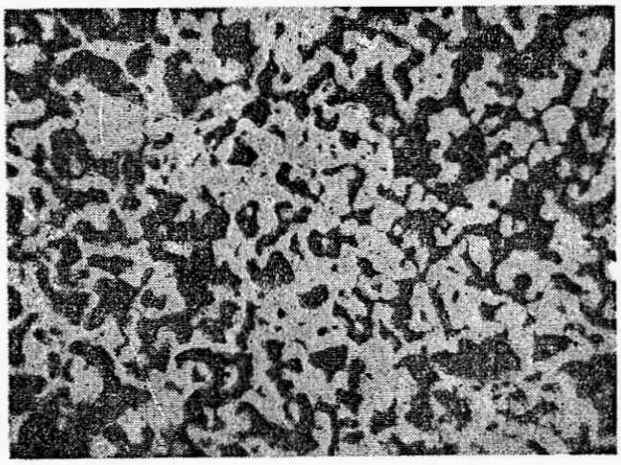


Fig. 8 Showing graphic intergrowth of metallic iron phase (white) and slag bond (dark grey) and iron oxide phase (light grey). Reflected illumination X 200

Photomicrograph of sponge iron pellets (Coal Injuction process) of Noamundi Iron Ore

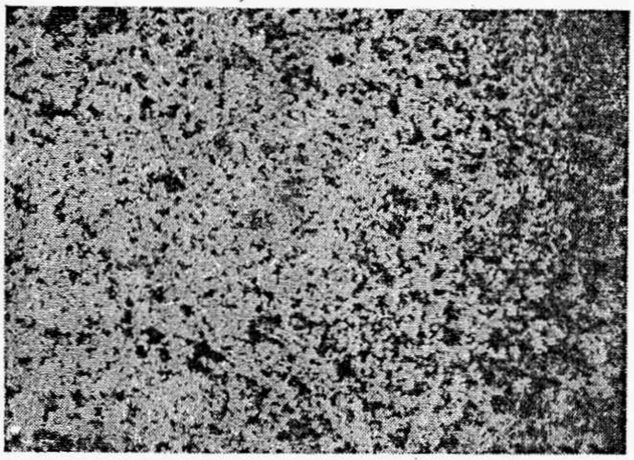


Fig. 9 Showing highly advanced stage of reduction with metallic iron phase grains (white) and slag bond (dark grey) with very faint lines of magnetite-wustite (light grey). Reflected illumination X 100.

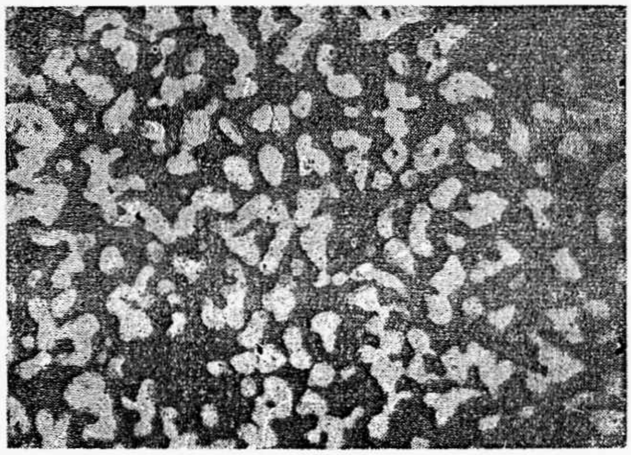


Fig. 10 Showing grain growth of metallic iron phase (white) in a slag matrix (light and dark grey). Dark areas are pits. Reflected illumination X 200.

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Discussion

Mr. S. K. Basu (Guest, Keen Williams Ltd., Calcutta). What is the suitability of your sponge iron with 75-80% Metallic iron for electric arc furnace melting?

Dr. A. B. Chatterjea (Author) The degree of metallisation of sponge iron produced experimentally varied from about 85 to 92-3%. In a subsequent paper by R. D. Gupta et.al. the processing of such sponge iron for steel making has been thoroughly discussed. It may, however, be briefly mentioned at this stage that difficulties were not experienced in the conversion of sponge iron with a degree of metallisation varying between 85-92% for conversion to steel. The effect of degree of metallisation on steelmaking parameters is well known and the question has been raised by several speakers. The techno-economic aspects of degree of metallisation on sponge iron making and its conversion to steel in electric furnace have been exhaustively dealt with.

Mr. S.N. Banerjee (Steel & Allied Products Ltd., Calcutta). FeO content and basicity of sponge iron play important part in Electric Furnace smelting. It is my knowledge that with FeO content between .6/1.2% and basicity nearing one is suitable for such smelting. I like to know what is the result achieved in your experiment and how your product suits for Electric Furnace Smelting?

Dr. A. B. Chatterjea (Author). The question regarding the basicity of sponge iron is not quite clear. The sponge iron inevitably contains a certain amount of silica and alumina as well as FeO depending on the chemistry of ore/pellets used for making sponge iron and the degree of metallisation. However, as it does contain any CaO in it, the question of basicity of sponge iron does not arise. The correct basicity degree of slag during steelmaking can be achieved by the addition of fluxes.

Mr. G. C. Bhattacharjee (Globe Steel, Ballabgarh). (1) What will be the Wt. of the charge (iron ore and its approx. iron content), (2) What will be the consumption of non-coking coal? (amount of ash in the coal), (3) What will be the time required for conversion of iron ore in rotary kiln into sponge iron, (1 ton), (4) What will be the range of metallisation in the sponge iron, (5) What will be the approximate pricing of per ton of sponge iron made in Rotary kiln?

Dr. A. B. Chatterjea (Author) The weight of the individual components such as iron ore, non-coking coal and limestone comprising the charge has been indicated in the paper. It has also been mentioned that in order to promote the rate of reduction, the weight of the non-coking coal was in excess of the Stoichiometric ratio. The exact consumption of non-coking coal, will, however, depend on the circulation of return char and the amount of fines generated from a particular non-coking coal during reduction in the kiln.

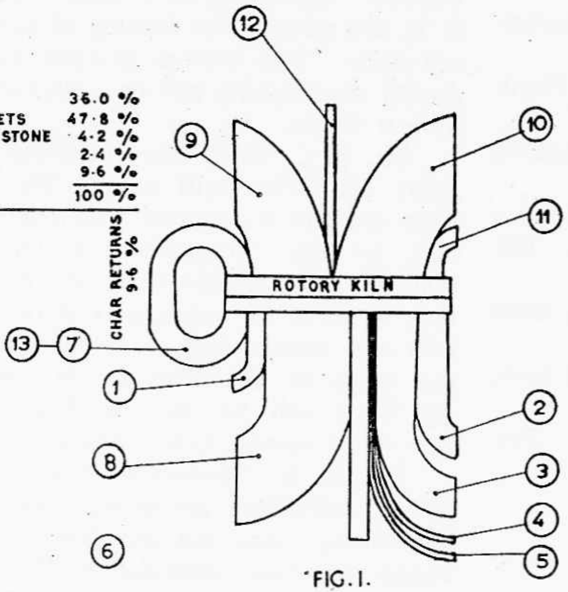
The direct reduction in a rotary kiln is a continuous process and the time required for the conversion of requisite amount of iron ore to one ton of sponge iron would depend on the dimension of the rotary kiln. In so far as the experimental kiln at the NML is concerned, the daily output of sponge iron amounted to 3-4 tons/day.

Regarding the degree of metallization, enough has been said in reply to questions put by various other speakers and reference may please be made to these answers.

In so far as the cost for the production of sponge iron is concerned, independent calculations have been made by a firm of Consulting Engineers as well as by the speaker and it is considered that depending on the cost of raw materials, and the location of the plant, the cost of production of one ton of sponge iron will vary from Rs. 325 to Rs. 370/-

MATERIAL BALANCE CHART

9	COAL	36.0 %
10	PELLETS	47·8 %
11	LIME STONE	4·2 %
12	OIL	2·4 %
13	CHAR	9·6 %
		100 %



DISCHARGE

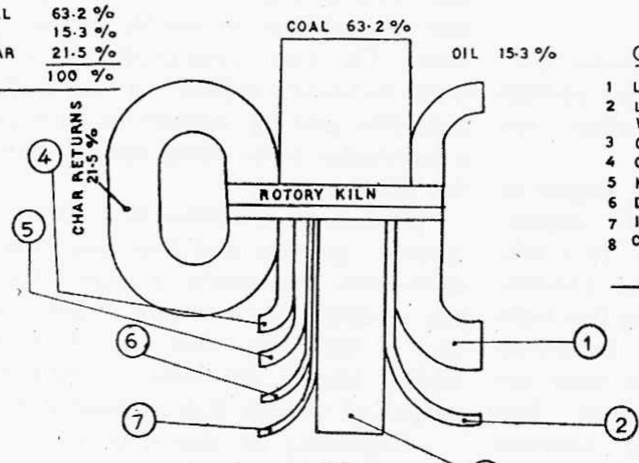
1.	COAL ASH	6.2 %
2	C IN WASTE GAS	15·7 %
3	O_2 REMOVED FROM ORE	16·5 %
4	IGNITION LOSS	1·8 %
5	WATER	2·5 %
6	FINES	5·9 %
7	RETURN	9·6 %
8	SPONGE	41·8 %
		100 %

FIG. 1.

INPUT CHART

COAL	63·2 %
OIL	15·3 %
CHAR	21·5 %
	100 %

HEAT BALANCE CHART



OUT PUT

1	LOSS IN WASTE GAS	20·5 %
2	LOSS THROUGH KILN WALL	7.6 %
3	O_2 REDUCTION	35·3 %
4	COAL LOSS	7·4 %
5	KILN DISCHARGE	5·8 %
6	DRYING	0·9 %
7	IGNITION LOSS	1.0 %
8	CHAR	21.5 %
		100 %

FIG. 2.

Table I

Chemical analyses of lumpy iron ores employed

No.	Iron ores.	Fe	SiO_2	Al_2O_3	S	P	CaO+MgO
		Constituent %					
1.	Dalli-Rajhara	66.4	2.2	2.0	0.01	0.02	0.2
2.	Bailadila	66.5	0.9	2.3	0.015	0.04	trace
3.	Barajamda.	65.5	1.7	2.3	0.02	0.03	0.4
4.	Kiriburu	62.8	1.82	4.34	0.04	trace	trace
5.	Surajgarh.	66.7	0.8	3.36	0.03	0.03	trace

Table II. Particle size classification of lumpy iron ore.

	Ore	Size analysis %			
		-6 mm	+6-12 mm	+12-18 mm	+18-25 mm
1.	Dalli-Rajhara	6.5	53.5	37.4	2.6
2.	Bailadila	9.7	65.5	21.6	3.2
3.	Barajamda	3.1	71.8	24.3	0.8
4.	Kiriburu	11.3	58.0	28.4	4.3
5.	Surajgarh	4.3	54.1	38.9	2.7

Table III. Chemical analyses of green pellets employed

	Iron Ore pellets.	Fe	SiO_2	Al_2O_3	S	P	CaO+MgO
		Constituents %					
1.	Donimalai	65.9	1.71	2.35	0.07	trace	0.3
2.	Bailadila	65.6	1.63	2.80	0.013	0.04	0.13
3.	Kiriburu	61.2	2.05	4.58	0.04	0.01	0.10
4.	Surajgarh	64.7	2.1	4.3	0.07	0.04	0.6

Table IV. Sieve analyses of green pellets.

	Iron ore pellets	Size analysis %			
		-6 mm	+6-9 mm	+9-12 mm	+12-15 mm
1.	Donimalai	7.2	26.1	52.7	14.0
2.	Bailadila	0.9	12.2	74.3	12.6
3.	Kiriburu	12.6	12.7	64.3	10.4
4.	Surajgarh	7.7	32.7	43.8	15.8

Table V. Physical properties of green pellets.

	Donimalai	Bailadila	Kiriburu	Surajgarh
Moisture %	12.5	11.8	12.0	10.9
No. of drops required to rapture from 500 mm height.	10-12.5	9-11	12-14	10-12
Green comp. strength kg/pellt.	2-2.5	2.3 - 2.4	3.0 - 3.5	2.7 - 3.0
Dry compression strength after 24 hours of storage.	4.0-4.5	3.5-3.7	4.5-5.0	3.5-3.9

Table VI. Chemical analyses of indurated pellets employed.

	Indurated Pellets.	Fe.	SiO_2	Al_2O_3	S	P	CaO+MgO
		Constituents %					
1.	Donimalai	66.4	1.67	2.38	0.08	trace	0.2
2.	Bailadila	66.8	1.7	2.78	0.05	0.05	0.23
3.	Kiriburu	63.4	2.7	5.0	0.03	0.03	0.12
4.	Noamundi	66.3	1.2	2.0	0.03	0.13	2.50

Table VII. Screen analysis of indurated pellets.

	Indurated pellets	Size analysis				
		-6 mm	+6-9 mm	+9-12 mm	+12-18 mm	+18-25 mm
1.	Donimalai	8.5	34.2	50.4	6.9	-
2.	Bailadila	7.4	13.7	72.1	6.8	-
3.	Kiriburu	11.2	7.4	65.8	15.6	-
4.	Noamundi	4.0	2.4	22.6	31.4	39.6

Table VIII. Physical properties of indurated pellets.

	Donimalai	Bailadila	Kiriburu	Noamundi
Compression strength Kg/pellet.	220	239	216	237
Tumbling index %-6.5mm	87.2	90.8	84.8	89.4
Abrasion index %-28 mesh	6.2	3.7	7.2	4.6
Microporosity %	29.8	26.9	33.4	31.2
Reducibility rate for 90% reduction in mts.	105	110	102	105
Swelling index gm/gms.	3.4	3.5	3.2	4.1

Table IX. Proximate analyses of the non-coking coals.

Location.	Moisture	VM	F.C.	Ash	Cal.value Kcal/Kg.	Ash softing temp. °C.
	Constitrent %					
1. Ghuges Colliery, Maharashtra.	4.5	32.5	42.6	20.4	5520	1190
2. Singereni colliery, Andhra Pradesh.	6.2	28.2	44.8	23.8	5385	1280
3. Ballarpur Colliery, Maharashtra	2.9	31.8	39.4	25.9	5140	1245

Table X. Screen analysis of non-coking coals.

	Location.	-6mm	+6-12mm	+12-18mm	+18 mm
		Sieve analysis %			
1.	Ghuges colliery, Maharashtra.	5.8	47.4	38.2	8.6
2.	Singereni colliery Maharashtra.	9.1	50.1	34.3	6.5
3.	Ballarpur Colliery Maharashtra.	12.9	31.0	50.6	5.5

Table XI. Chemical analyses of limestone employed.

Location.	CaO	MgO	Al_2O_3	SiO_2	Fe_2O_3	CO_2	P	SO_3
	Constituents %							
1. Surajgarh, Maharashtra	45.96	1.83	5.6	5.68	1.60	38.2	0.03	0.35
2. Bhabanathpur Orissa.	44.92	5.10	2.84	5.76	0.96	39.26	0.037	0.42

Table XII. Sieve analysis of Limestone.

Location	+6mesh	+8mesh	+10mesh	+14mesh	+20mesh	+28mesh	+35mesh	-35mesh
	Sieve analysis %							
Surajgarh	4.3	10.7	11.3	19.8	18.4	8.1	7.5	19.9
Bhabanathpur	3.8	12.3	13.4	18.7	21.8	10.1	6.2	13.9

Table No. 13: Results of Sponge Iron production from Iron ore lumps.

Campaign No.	Type of raw material charged: Ore	Coal	Limestone	Feed rate Kg/hr.: Ore	Coal	Char	Limestone	Fuel oil Kg/tonne of sponge iron	Operating Temp °C	Product assay %: Fe (T)	Fe (M)	S	P	% Metallization	% Iron recovery in sponge	Physical properties of sponge iron: Comp. strength	Abrasion index -28 mesh
1.	Dolli-Rajhara M.P.	Singareni A.P.	—	150	150	—	—	62.%	1040	88.7	78.1	0.09	0.04	88.2	95.9	127.3	7.5
2.	Do	Do	Bhavanathpur orissa	150	115	35	6	71.2	1050	88.4	77.8	0.03	0.07	88.0	93.2	136.1	6.0
3.	Bailadila M.P.	Ghughus Maharastra	—	150	150	—	-	70.6	1060	86.4	76.9	0.11	0.07	89.0	92.3	124.8	4.3
4.	Do	-Do-	Bhavanathpur orrisa	150	115	35	6	75.0	1045	87.0	76.4	0.05	0.07	88.0	95.3	126.1	4.5
5.	Barajamda Orissa	-Do-	—	150	150	—	-	69.4	1060	86.2	77.1	0.12	0.09	91.2	95.1	142.6	0.7
6.	Do	Do	Bhavanathpur orissa	150	115	35	6	69.8	1070	90.2	82.8	0.03	0.08	91.8	97.2	143.1	0.8
7.	Kiriburu Orissa	Singareni A.P.	—	150	150	—	-	56.0	1070	84.2	72.8	0.12	0.04	87.6	95.9	151.2	0.4
8.	-Do-	-Do-	Bhuvanathpur orissa	150	169	35	6	57.8	1070	86.0	73.1	0.05	0.04	85.0	96.0	144.2	0.6
9.	Surajgarh Maharastra	Ballarpur Maharastra	—	150	150	—	-	58.4	1070	89.6	77.9	0.11	0.06	87.0	94.7	127.8	6.4
10.	-Do-	-Do-	Surajgarh Maharastra	150	115	35	6	56.0	1072	89.2	77.9	0.06	0.07	87.3	95.8	130.1	6.2

Table 14 : Results of Sponge Iron Production from indenated pellets

Com-paign No.	Type of raw material charged: Pellets	Coal	Lime stone	Feed rate Kg/hr.: Pellets	Coal	Char	Lime-stone	Fuel oil Kg/tonne of sponge	Operating temp °C	Product assay: Fe(7)	Fe(M)	S	P	% Degree of metalli-zation	% Degree of degra-dation	% Iron recovery in sponge	Physical properties: Com. strength Kg.	Abrasion index -28 mesh
1.	Domi-malaii Mysore	Ghugus Maharastra	-	150	150	-	-	72.0	1060	90.3	78.3	0011	0.02	87.1	9.8	92.8	143.5	1.2
2.	Baila-dila M.P.	Ghugus Maharastra	-	150	150	-	-	68.3	1060	88.2	78.1	0.21	0.97	88.6	6.2	94.5	156.4	0.8
3.	Kiri-buru Orissa	Singa-reni A.P.	-	150	150	-	-	66.8	1060	86.1	75.2	0.14	0.04	87.9	6.0	90.3	138.7	1.8
4.	Noamundi Bihar (-25+12.5-mm-93.6%)	Singe-reni A.P.	-	150	150	-	-	71.3	1060	88.5	77.1	0.13	0.18	87.8	37.8	83.0	129.2	2.4
5.	Noamundi (-15+12.5-mm-21.2%)	Singa-reni A.P.	-	150	150	-	-	66.4	1060	88.2	79.3	0.12	0.15	90.0	12.2	91.1	152.6	0.9
6.	Noamundi (-15+12.5-mm-21.2%)	Singa-reni A.P.	-	150	115	35	-	72.6	1080	90.7	82.4	0.11	0.14	90.3	9.8	89.2	154.1	0.8
7.	Noamundi (-15+12.5-mm-21.2%)	Singa-reni A.P.	Bhaba-nathpur Orissa	150	115	35	6	71.8	1070	90.5	82.3	0.03	0.08	90.4	9.5	90.3	148.2	1.2

Table No. 15: Results of Sponge Iron production with green pellets

Compaign No.	Type of raw material charged: pellets	Coal	Limestone	Feed Rate Kg/hr.: Pellets	Coal	Char	Limestone	Fuel oil Kg/tonne of sponge iron	Operating Temp. °C	Product assay %: Fe(T)	Fe(M)	S	P	% Degree of: Metallization	Degradation	% Iron recovery in sponge	Physical properties: Comp. strength	Abrasion index -28mesh
1.	Donimalai Mysore	Ghugus Maharastra	--	150	150	—	—	79.2	1050	88.4	79.3	0.11	0.03	89.8	4.7	95.2	156.2	0.7
2.	-Do-	-Do-	--	150	115	35	--	83.2	1050	88.8	78.3	0.12	0.03	86.3	3.8	92.9	148.0	0.9
3.	Bailadila M.P.	Singareni A.P.	---	150	150	—	--	69.9	1070	88.1	78.4	0.14	0.04	89.0	3.5	95.6	147.9	1.1
4.	-Do-	-Do-	—	150	115	35	—	69.0	1060	88.4	81.3	0.11	0.03	91.9	3.5	91.9	148.2	12
5.	Kiriburu Orissa	Singareni A.P.	Bhavanathpur orissa	150	150	—	7	66.8	1060	86.4	76.8	0.05	0.06	87.9	4.7	96.51	142.1	1.5
6.	Surajgarh Maharastra	Ballarpur Maharastra	—	150	150	—	—	67.7	10701	90.9	82.7	0.12	0.11	91.2	5.0	96.5	153.8	0.8
7.	-Do-	-Do-	Surajgarh Maharastra	150	115	35	7	64.6	1080	88.4	79.2	0.04	0.07	89.6	4.8	96.1	151.2	0.9

Table No. 16 : Results of Sponge Iron production by coal throwing

Campaign No.	Type of raw material charged			Feed rate Kg/hr.				Fuel oil Kg/tonne of sponge iron	Opening Temp °C	Product assay %				%Metallization	% Iron recovery in sponge	Physical properties	
	Pellets	Coal	Limestone	Pellets	Coal	Char	Limestone			Fe(T)	Fe(M)	S	P			Comp. strength	Abrasion index -28mesh
1.	Noamundi Bihar	Singereni, A.P.	--	150	75	--	-	75	1070	90.3	82.9	0.11	0.12	91.8	93.3	157.2	0.6
2.	-Do-	-Do-	Bhavanathpur. Orissa	150	55	10	6	75	1060	89.8	82.4	0.04	0.08	91.7	92.7	149.0	0.9
3.	-Do-	-Do-	-Do-	150	--	50	6	100	1075	87.4	76.3	0.03	0.09	87.3	94.6	152.8	1.0
4.	Surajgarh Maharastra (Green)	Ballarpur Maharastra	-Do-	150	75	--	6	75	1070	89.6	82.7	0.03	0.07	92.3	95.7	143.4	2.3
5.	-Do-	-Do	-Do	150	56	19	6	75	1070	88.7	81.9	0.03	0.06	92.3	95.0	145.1	2.3