APPLICATION OF SOLID REDUCTANT PROCESSES FOR DIRECT REDUCTION IN INDIA

S. DAS GUPTA
J. C. AGRAWAL
AND
B. ROY
M. N. Dastur & Co (P) Ltd.
Consulting Engineers, Calcutta.

Efforts to develop commercially acceptable direct reduction processes during the last two decades are possibly a revival of efforts made in this direction some two centuries ago. In 1792, Samuel Lucas obtained a patent for converting iron ore to metal using charcoal as reductant. (1) Adrien Chenot also took a patent some time in the middle of the last century to produce sponge iron utilising iron ore concentrates and charcoal in a retort. (2) There are many other names and attempts associated with the early development, of direct reduction which are only of historic interest today.

These early processes of solid state reduction did not have any significant impact on the iron and steel industry, mainly because of the developments in the blast furnace process. The blast furnace process itself passed through three distinct periods in the use of solid fuel, namely the charcoal period, the anthracite period and the beehive coke period, before advancing into the present by-product coke period. The technological and engineering developments have today made possible the design and operation of giant size blast furnaces, capable of producing 10,000 tons and more per day from a single unit.

Some of the major reasons for the renewed interest in the direct reduction processes during recent years are the dependence of the blast furnace on the exclusive use of metallurgical coke, the non-availability of suitable quality coking coal and availability of other reductants in many countries, increasing costs of coking coal, the growing problems of residual elements in steel scrap together with the vagaries of the scrap market which have encouraged the search for a substitute melting stock, economic necessity of installing large capacity plants based on blast furnaces, and the requirement of installing small capacity plants to suit the specific requirements of market and resources.

In this century, the first industrial unit employing direct reduction with solid reductant was installed in 1911 at Hoeganaes, Sweden. (3) Soon after Hoeganaes, another process entered the steel industry, namely the Wiberg process in which the gas produced from coke is utilised as reductant.

In 1958, the Echeverria process came into prominence, and a plant of a capacity of 10,000 tons per year was installed at Legazpia, Spain. (4) However, for economic reasons, this process could not survive and was abandoned some time in 1965.

In more recent times, direct reduction of iron ore in rotary kilns has been gaining ground and between 1966 and till this date seven industrial scale plants have been installed in various parts of the world. These include the facilities at Skopje, Yugoslavia, installed in 1966, (5) followed by the installations at Witbank, South Africa in 1968, (6) at Inchon Iron Works, Seoul, South Korea (7) and at Glenbrook, New Zealand (8) in 1969 and at Falcon-bridge, Canada in 1970.(9) The plant at Dunswart, South Africa, (10) is expected to go into operation by the time this paper is presented and another at Charqueadas, Brazil(11) is also scheduled to commence operations shortly.

It is also reported that a plant based on the Nuevo Proceso, which is a development of Echeverria process, has gone into trial production at Siderurgica Monfalcone (SIMO), Italy, some time last year.(12)

In addition, there are some other processes which are still in the stage of experimentation. A continuous process to produce sponge iron briquettes is under development. (13) Another process is based on pre-reduced sinter produced in sinter strand using high proportion of coke breeze in the mix, and this has been used in blast furnace. (14) Production of metallised pellets in strand machines is also being attempted.

The product obtained from the direct reduction processes needs further processing and is utilised as a feed material for one of the conventional ironmaking or steelmaking processes. In order to identify the usage of the product as well as the degree of reduction achieved from the direct reduction (DR) process, the authors have used the term "pre-reduced material" to indicate direct reduced iron ore/pellets which are partially reduced and which would be utilised for iron smelting. Similarly, the term "sponge iron" used in this paper identifies a highly metallised and reduced material utilised as a melting stock for steelmaking.

Iron and Steel in India

The bulk of the steel produced in the country today is based on the use of blast furnace hot metal. Only in one of the integrated steel plants is hot metal produced in electric smelting furnaces. This plant is of a comparatively small capacity and is located at a considerable distance from the coking coal deposits.

One of the major problems encountered at our large integrated steel plants is in blast furnace operation which is characterised by the high coke rate and low productivity. Efforts to reduce the coke rate and to improve the productivity are in progress, utilizing better prepared raw materials and adopting better operating techniques. In the field of electric smelting also, measures have been introduced to reduce electric power consumption by using better quality ore and better prepared raw materials.

From the present indications in iron and steel industry, the following technological trends are discernible:

i) new large integrated steel plants adopting blast furnace process would come to be located at much longer distances from the coking coal deposits compared to the existing plants;

ii) electric smelting may be adopted in the case of small capacity plants and the cost of electric power at these locations may be higher than those obtaining at the existing electric smelting plants; and

iii) the current rising trend of electric steelmaking capacity in the country would continue.

The new large integrated steel plants would be confronted with the same problems of coke quality(15) as are being faced by the existing units, and perhaps to a greater extent. The cost of coke in the country has shown a rising trend during the past eight years (Fig. 1) and this would be more significant at plants located further away from the coking coal deposits. The possibilities of reducing the coke rate are, therefore, of even greater importance for the new plants.

The rising cost of power in India, as in any other country, has been a matter of great concern for plants utilizing the electric smelting process. This has further emphasised the need for measures which reduce power consumption.

With the installation of new arc furnace capacity, the scrap supply position has been erratic and the prices have been spiralling. To counteract this situation, it would be in the interest of the arc furnace steel industry to develop alternative sources of melting stock.

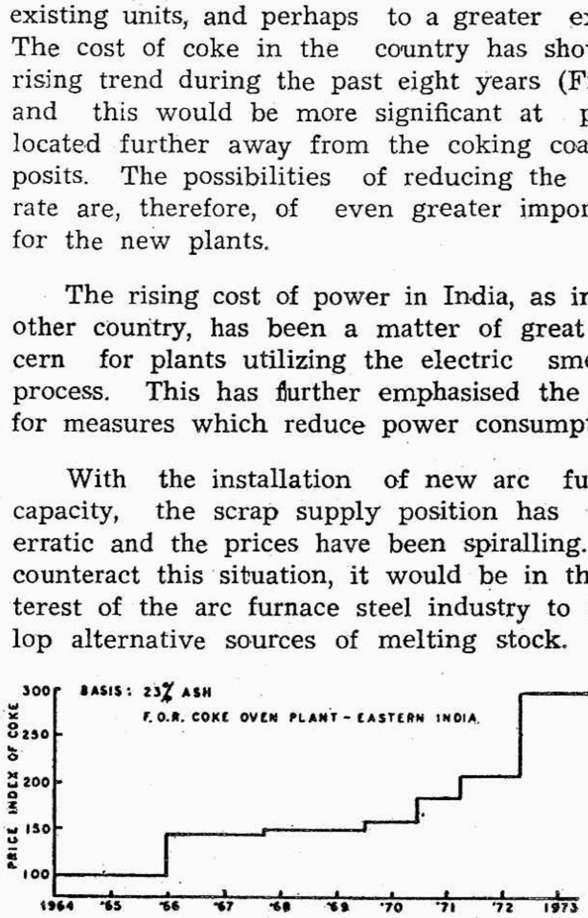

FIG. 1. PRICE TREND OF COKE IN INDIA

Use of pre-reduced material for electric

The use of DR products may be of help in resolving some of the problems mentioned above. Pre-reduced material offers considerable scope for the reduction of coke rate and improvement in productivity in the case of blast furnace operations, and reduction in power consumption in electric smelting furnace and higher productivity. Sponge iron is now established as an alternative to scrap as metallic charge for electric furnace steelmaking. The possibility of the application of the DR processes in India, however, needs to be carefully analysed in the context of the available raw materials, specially the reductant, and of the experience gained elsewhere in the world.

Available reductant

The total coal reserves of India have been estimated at about 109,000 million tons and that of lignite at about 2,000 million tons.(16) Of the total coal reserves, only about 12,000 million tons are of prime and medium coking quality.(17) The oil reserves are estimated at about 140,000 million tons and that of natural gas at 63,6000

It is apparent that the largest reserves of reductant are in the form of non-coking coal and the DR processes should, therefore, be based on the use of this material.

DR processes using solid reductant

The DR processes using solid reductant could broadly be classified into two groups, namely batch processes using retorts/saggers as the reaction chamber, and continuous processes using rotary kilns.

Batch processes

The batch processes (Table 1) which include Hoeganaes, Echeverria and Nuevo Proceso, utilise low volatile reductants like anthracite, coke breeze etc. Additional fuel is required for heating purposes. In these processes, high grade ore concentrate or ore/pellets can be employed for the production of iron powder or sponge iron. These processes are, however, characterised by small scale of operation, and have not found wide commercial application, for economic reasons. As a result, the production of sponge iron by these processes may be suitable only under very special conditions.

TABLE 1 — BATCH PROCESSES OF DIRECT REDUCTION USING SOLID REDUCTANT

PROCESS	Hoeganaes	Echeverria	Nuevo Proceso
PLANT & LOCATION	Hoeganaes, Sweden Oxelosund, Sweden Riverton, USA	Patricio Echeverria S. A. Legazpia, Spain	Siderurgica Monfalcone (SIMO) Italy
PLANT CAPACITY, T/YR	130,000 (total)	20,000	30,000
REACTION CHAMBER	Silicon carbide saggers	40 Nos of alloy steel retorts	8 Nos of silicon carbide lined vessels
RAW MATERIALS:			
Iron ore — quality	High grade concentrate	Lumpy hematite ore Fe — 54-60% SiO_2 — 8.12%	N. A.
— size range	—30 mesh	10 — 50mm	N. A.
Reductant	Coke breeze	Anthracite coal VM — 8.2% Ash — 27.3% F. C. — 62.5% S — 1.1%	Low grade coal
Fuel	Producer gas	Producer gas	Propane
START UP	1911	1958 (closed since 1965)	1972

Attempts to produce sponge iron by a similar process have been made by Guest Keen Williams, at their Shalimar Works (19), near Calcutta. Details of their operation are not available.

Rotary kiln processes

The application of the rotary kiln in the mineral processing industry is not new. It has been widely used for magnetising roasting of iron ore, for reducing zinc bearing ores in the Waelz process, for reducing low grade silicious ores in the Krupp-Renn process, and for pre-treatment of raw materials in the ferro-alloy industry such as ferro-nickel, ferro-chrome and ferro-manganese. In the field of iron ore reduction, this process is being utilised for production of pre-reduced material as well as sponge iron.

Pre-reduction : Electric smelting of pre-reduced ore has been carried out on a commercial scale at a number of plants (Table 2). Pre-reduced material could be either hot or cold charged to the smelting furnace. In the hot charging process the entire amount of carbon and flux required for the iron making process is fed into the rotary kiln. The rotary kiln is fired with the smelting furnace gas as well as with additional fuel like pulverised coal or fuel oil, if required. The volatile matter contained in the reducing material is also utilised to supply a part of the heat for the reduction process. The maximum temperature attained in the kiln depends on the raw material characteristics. While adopting the hot charging technique, therefore, the degree of reduction of the ore burden would be governed by the reducibility of the ore, reactivity of the reductant, and the operating temperature of the kiln. Saving in power consumption during smelting is effected due to the pre-reduction of the ore, calcination of the fluxed material and the sensible heat contained in the charge.

In the cold charging technique, iron ore and reductant (excluding the flux required for smelting) are charged into the rotary kiln. The reductant used in the rotary kiln need not necessarily be the same as that used for the smelting process. Smelting furnace is fed with fresh reductant in the required quantity. The product obtained from the rotary kiln is cooled, screened and magnetically separated to remove fines and non-magnetic fraction. A main advantage of the pre-reduction for cold charging is that the Fe:C ratio of the kiln charge is independent of that required for smelting. Therefore, depending on the ore and reductant characteristics the degree of reduction could be varied by adjusting Fe:C ratio in the kiln feed. The saving in power consumption in this process is brought about only by the degree of reduction of the ore and is, therefore, less compared to the hot charging technique.

The Yawata (or Sasagawa) process of pre-reduction-cold charging-electric smelting for titaniferrous iron sands was pratised at Ohmama plant of Tohoku Denka Kogyo Co and at Ariake Iron & Steel Co. Ltd., Japan.(20) (21) This process utilised beneficiated iron sand in 50 to 200 mesh size as the major raw material. Natural coke was used as reducing agent. Pre-reduction was limited to 60 per cent. The power requirement was brought down to 1,700 to 1,800 kWh/ton by adopting the pre-reduction cold charging technique as against 2,500 to 2,600 required for conventional smelting. This process was adopted in conjunction with 14,100 kVA smelting furnace to produce about 150 tons hot metal per day. However, for economic reasons, this process has been discontinued.

The Strategic-Udy process of pre-reduction-electric smelting was tried at Orinoco Steel Plant in Venezuela. (22) The process utilised a rotary kiln and a 33 mVA arc smelting furnace for production of 400 tons of hot metal per day. The smelting furnace (without pre-reduction) was originally producing about 200 tons per day. The rotary kiln was charged with ore fines along with limestone and coal. However, after prolonged attempts this process was given up, mainly because of the problems encountered in the rotary kiln due to the use of fine size of the raw material and the difficulties in controlling the smelting furnace operation. A major problem of the smelting furnace was due to the operations with open bath which adversely affected the roof life.

At Skopje, Yugoslavia, Elkem process of reduction for low grade iron ores with lignite and coke was attempted, utilizing the hot charging technique for electric smelting. (23) Pre-reduction in the range of 19 to 35 per cent could be attained. As compared to the power requirement of about 3,500 kWh/ton when adopting conventional smelting, the use of pre-reduced material required 1,800 to 2,500 kWh/ton depending on the degree of pre-reduction. At this plant also, the use of pre-reduced material has been discontinued.

At the Inchon Works, South Korea, SL/RN pre-reduction followed by cold charging electric smelting has been tried. It is reported that during the short period of operation it was possible to reduce the power consumption by 40 per cent when using pre-reduced (70%) material as compared to conventional electric smelting. (24) This plant is shut down since March 1971.

At the Highveld Steel Works, Witbank, South Africa, pre-reduction-hot charging electric smelting is being adopted for processing vanadiferrous/titaniferrous iron ore using bituminous coal as reductant. The process was developed by Highveld themselves. This is the only plant which till today is continuing operation on this process flow sheet. At this plant, the degree of pre-reduction is about 35 per cent and the power consumption is of the order of 1,500 kWh/ton.(25)

At major problem of pre-reduction-electric smelting process has been the variations in the degree of pre-reduction of the charge material. This varying degree of oxygen in the charge results in fluctuating slag characteristics as well as the electrical conditions of the smelting furnace.

From the foregoing, it would be noted that attempts have been made to utilise a wide variety of iron ore and reductant in this process. Selection of a suitable reductant as well as the physical characteristics of the ore material are extremely important for adopting pre-reduced hot charging technique. The operations at Skopje indicate that the exclusive use of lignite has been extremely difficult in controlling the rotary kiln operation as well as the electric smelting operation. Similarly, the use of small size coke at Skopje was not found suitable to bring about any pre-reduction. The electric smelting operation was also hampered as a result of bad electrical characteristics of the charge material, when using either lignite or coke. Finally, Skopje attempted to utilise a mixture of lignite (80%) and small size coke (20%) in the rotary kiln. However, the decrepitation of lignite in the rotary kiln resulting in a large amount of fine char in the smelting furnace charge created problems of slag blow, explosion and burning of cables and cooling pipes.

At the Inchon Works, South Korea, where cold charging was adopted, similar problems were encountered and the variation in the carbon balance in the smelting furnace charge as well as varying electrode penetration adversely affected the hot metal composition.

From the engineering view point, the problems associated with the rotary kilns mainly relate to the refractory life of the kiln and the life of the air tubes. It is interesting to note that these problems have been encountered at all plants though the designs of the kilns are quite different. At Witbank the kilns are of co-current types compared to the counter-current types at other plants. At Skopje the feeding of lignite is through scoop feeders located along the length of the kiln. At the Inchon Works it is the conventional SL/RN type kiln.

For pre-heating/pre-reduction and hot charging, shaft furnaces have also been used. The shaft furnaces were tried at Mo-i-Rana, Norway and also at a small plant in Portugal. (26) At both these plants this practice has now been discontinued, for economic reasons.

Sponge iron : The commercial installations of rotary kiln plants producing sponge iron are given in Table 3. There are four plants in operation/start-up/under construction, and of these, three are integrated with arc furnace steelmaking facilities. The only plant which sells its product is Falconbridge, Canada, which produces a nickel bearing sponge.

The iron ore to be used for production of sponge iron should be of high grade containing preferably 65 to 67% Fe like those proposed to be used at Dunswart and Piratini. Under specific local conditions and in certain geographic areas, low grade ores have been used, as in New Zealand. The use of poorer grade ores results in high gangue content in the sponge iron which adversely affects in turn the economics of steel production. The ore to be used in the rotary kiln could be in the form of either sized ores or pellets, or in very special cases, in the form of concentrates. The desirable size of the ore is 5 to 15/20 mm, but this has to be determined on the basis of the reducibility tests. Pellets to be used in the rotary kiln process should have a strength of 30 kg per pellet. (27) It is, however, preferable to use partially or fully hardened pellets.

The reductant used serves both as reducing agent as well as a fuel for supplying the process heat. The reactivity of the reductant, chemical composition and the ash fusion temperature are important considerations. The volatile matter content of coal is utilised in meeting the heat requirement of the process. However, the exclusive use of the high volatile coal is not necessarily of advantage as has been the experience in New Zealand. The use of low ash coals is preferable, as the char obtained from the kiln discharge has to be re-cycled. The higher ash content reduces the effective utilisation of the kiln, increases heat requirement of the process and also increases the tendency of accretion. In this connection, the experience to be gained at the Brazilian plant using 35% ash coal would be of specific interest. (28)

TABLE 2 – ELECTRIC SMELTING PLANTS WITH ROTARY KILNS FOR PRE-REDUCTION

PRE-REDUCTION PROCESS	Yawata (Sasagawa)		Strategic–Udy	Elkem	Highveld	SL/RN
Plant & Location	Tohoku Denka Kogyo Co. Ohmama plant Japan	Ariake Iron & Steel Co. Japan	Orinoco Steel Plant Matanzas Venezuela	Rudnici-i-Zelezarnica Skopje Yugoslavia	Highveld Steel and Vanadium Corporation Witbank, S. Africa	Inchon Iron & Steel Co. Seoul, South Korea
Plant & Capacity, Tons/Year :						
Hot metal	60,000	40,000	120,000	540,000	480,000	175,000
Production Equipment :						
Rotary kiln – Nos	One	One	One	Five	Five	One
– Size	3.5 m Ø x 56 m	3.5 m Ø x 75 m	3.35 m Ø x 107 m	4.15 m Ø x 95 m	4 m Ø x 60 m	4 m Ø x 60 m with preheating grate
Smelting furnace – Nos	One	One	One	Three & Two	Four	One
– Capacity	14.1 mVA	14 mVA	33 mVA	32 mVA 43 mVA	33 mVA	28 mVA
Raw Materials :						
Iron ore – Quality	Beneficiated iron sand Fe – 57% TiO_2 – 11%	Beneficiated iron sand Fe – 57% TiO_2 – 12%	Fines or concentrate Fe – 50–59%	Lump ore Fe – 40–42% SiO_2 – 16–17% Al_2O_3 – 8–9%	Lump ore Fe – 55% V_2O_5 – 1 6% TiO_2 – 13 %	Lump ore and pellet Fe – 49–56%
–Size range	50–200 mesh	N.A.	–10 mm	10 – 40 mm	N.A.	8–20 mm
Reductant – Quality	Natural coke F C. – 67% VM – 4.5–5,5%	Natural coke F.C. – 71% VM – 5% Ash – 21%	Low grade coal F.C. – 40% VM – 44% Ash – 15%	Dry lignite & Coke F.C. –35% Ash10% VM – 45% Ash – 20%	Bituminous coal F C – 55% VM – 32% Ash – 12%	Anthracite F.C. – 62% VM – 5% Ash – 33%
–Size range	–	–15 mm	Fines	20–60 mm	–	Fines
Product & Usage	60% pre-reduction cold charged	Pre-reduced, cold charged	Pre-reduced, hot charged	Upto 35% reduction hot charged	35% pre-reduction hot charge	70% pre-reduction, cold charged
Start Up	1957*	1961*	1963*	1966*	1968	1969*

NOTE : * Pre-reduction is not practised now.

TABLE 3
SPONGE IRON PLANTS WITH ROTARY KILNS

PROCESS	SL/RN	SL/RN	KRUPP	SL/RN
PLANT AND LOCATION	New Zealand Steel Ltd, Glenbrook, New Zealand	Falconbridge Nickel Mines Ltd Sudbury, Canada	Dunswart Iron & Steel Works, Benoni, South Africa	Acos Finos Piratini S. A., Charqueadas, Brazil
CAPACITY, T/YR-SPONGE	150,000	300,000	15 ,000	65,000
PRODUCTION EQUIPMENT :				
Rotary kiln – Nos	One	One	One	One
– Size	4 m Ø x 75 m	5 m Ø x 50 m, with pre-heating grate	4.6 m Ø x 74 m	3.6 m Ø x 50 m
RAW MATERIALS:				
Iron ore–quality	Iron sand green pellets/concentrate Fe – 61% SiO_2 – 1.1% Al_2O_3 – 2.8% TiO_2 – 8.3%	Pyrrhotite pellets Fe – 65-67% Ni – 0.5–1%	Lump ore Fe – 65-67%	Itabira lump ore Fe – 67%
– size range	4 – 8 mm	10 – 12 mm	5 – 25 mm	5 – 30 mm
Reductant – quality	Brown coal (dry) F. C. – 52% VM – 43.3% Ash – 4.7 %	Bituminous coal F. C. – 55% VM – 39% Ash – 37%	Anthracite F. C. – 79% Ash – 11-12% Duff coal F. C. – 57% VM – 26.5% Ash – 16.5%	Bituminous coal F. C. – 38.5% VM – 26 5% Ash – 35%
– size range	– 10 mm	N. A.	N. A.	1 – 25 mm
START UP	1970	1971	Early 1973	Mid 1973

TABLE 4 — EFFECT OF USING PRE-REDUCED MATERIAL ON PRODUCTION & COKE RATE IN BLAST FURNACES

Plant	Materials used	Quantity used	Result	
			Increase in prodn %	Decrease in coke rate %
Experimental blast furnace, Bruceton, USA	98.7% Fe, 98% metallised iron powder	397 kg iron powder per ton hot metal	24.0	19.0
Republic Steel Gadsden, USA	71.0% Fe, 84% metallised briquettes	14% in burden	9.0	11.3
Steel Company of Canada	88.7% Fe, 90.6% metallised pre-reduced pellets	30% pre-reduced pellets in burden	23.0	20.0
Higashida Plant Yawata Steel, Japan	69% Fe, 58% metallised sponge iron	40% sponge iron in burden	18.4	18.4
Nizhnii Tagil Combine, USSR	66-67% Fe, 43-46% metallized pellets	50% metallized pellets in burden	7.6	16.0

Technologically, a serious problem associated with the rotary kiln process is projecting the behaviour of raw materials from the pilot plant to the commercial scale. As a result, the predicted throughput rates are not being readily achieved in commercial installations. Measurement of temperature in the rotary kiln is difficult. Thermocouples introduced in the kiln wall neither indicate the material temperature nor the gas temperature. Quite a few of the problems associated with the operations of the rotary kiln, namely failure of air tubes, formation of accretions and premature failure of refractories, result from this difficulty.

Application of DR process in India

The possibility of adopting DR processes in India has attracted considerable interest. The National Metallurgical Laboratory, Jamshedpur has carried out test work on a variety of raw materials to study their suitability to produce sponge iron. Tests on the production of sponge iron with Indian raw materials have also been conducted by Lurgi in West Germany. Some other tests have also been conducted by the Indian Iron and Steel Co. and Guest Keen Williams.

Pre-reduced material for blast furnaces

While considering the use of pre-reduced material in blast furnaces, it must be recognised that the upper part of blast furnace shaft possibly presents the most efficient direct reduction system. As such, the use of pre-reduced material in blast furnace can be considered, only if the reduction could be carried out more economically outside the furnace (which in turn should bring about an overall saving in the cost of producing iron), or if increased production is to be obtained from a specific installation.

A number of investigations on the injection of iron powder through the tuyeres as well as charging of metallised low grade and high grade sized material in blast furnaces have been carried out in the USA, USSR, Japan etc. Some of the tests results are given in Table 4. (29) to (33) All these confirm that use of pre-reduced material will no doubt reduce the coke rate and increase productivity. However, the use of pre-reduced burden material in blast furnaces is not a commercially established practice till today.

The industrial application of this process still awaits production of pre-reduced material at acceptable costs. The economics has to be evaluated for each location, as it is related to coke and ore prices at site. The first commercial plant for producing pre-reduced material (using gaseous reductant) has been installed in Venezuela and the results of its operations are now awaited with interest.

An attempt has been made to estimate (Table 5) the ceiling price that could be paid for pre-reduced ore under Indian conditions at two different costs of coke — Rs. 210 and Rs. 250 per ton. From Table 5 it will be noted that an extra price of about Rs. 83 to Rs. 95 per ton Fe in pre-reduced product over the price of one ton

TABLE 5–MAXIMUM PERMISSIBLE COST OF 1 TON IRON PRE-REDUCED ORE

Basis : Overall metallisation 25.5% 65% Fe sized ore at Rs. 86 per ton Fe

	Without pre-reduction		With pre-reduction	
COKE COST, RS/TON ..	210	250	210	250
HOT METAL COST, RS/TON :				
Cost of :				
Sized ore ..	30	30	—	—
Pre-reduced ore ..	—	—	30 + $0.365C_1$	30 + $0.365C_2$
Other materials ..	95	95	99	99
Coke ..	161	191	136	162
Operating costs ..	45	45	43	43
Fixed charges ..	38	38	34	34
Total ..	369	399	342 + $0.365C_1$	368 + $0.365C_2$
PERMISSIBLE COST OF 1 TON OF IRON IN PRE-REDUCED ORE, RS ..	—	—	169	181

Fe contained in ore may be acceptable. However this may not be achievable at the prevailing prices of reductant and on the current scale of commercial operation of solid reductant processes.

On the basis of tests conducted in the USSR on sinter strands to produce metallised sinter, a preliminary estimate has been made, to see if such a practice would be of interest to India. It is observed that the increased cost permissible per ton of sinter would be about Rs. 44 to Rs. 47 under the conditions assumed in Table 5 and this may also be difficult to achieve.

Use of pre-reduced material for electric smelting

The electric smelting furnace has a very low shaft and also the volume of gases evolving from the hearth is much lower compared to the blast furnace. It is, therefore, logical that pre-heating of the burden before it is charged into the electric smelting furnace are far more important than in the case of blast furnace. The realisation of this importance is reflected by the number of installations at various places in the world which have attempted to adopt pre-heating/pre-reduction/electric smelting process.

A theoretical assessment of the application of pre-reduction/electric smelting technique has been made for a hypothetical location in India. At this location, based on the use of high grade sized iron ore and small size coke, the cost of production of hot metal when adopting conventional practice would be about Rs. 480 per ton assuming the cost of electric power at 5 paise per kWh, the cost of sized ore at Rs. 62 per ton Fe and the cost of small size coke blend at Rs. 236 per ton. Assuming the use of a 18% ash non-coking coal for pre-reduction, which would yield a char in the rotary kiln suitable for use in electric smelting, in the proportion of 4:1 with small size coke, an extra price of about Rs. 205 per ton Fe could be paid when using hot pre-reduced (50%) charge to obtain the same price of hot metal. In the case of adopting cold charging, the extra cost would be Rs. 160 per ton of Fe. This analysis indicates that economically the hot charging technique would be advantageous under Indian conditions. It needs to be emphasised, however, that the adoption of this technology for commercial scale operation would have to wait till such time satisfactory solutions to the problems related with the control of the process are obtained.

Sponge Iron

While the pre-reduction-smelting process has found industrial acceptance under isolated local conditions, commercial operations and large scale tests have left no doubts about the suitability of sponge iron as melting stock for electric arc furnaces. Production of sponge iron from locally available raw materials has, therefore, gained considerable interest in India during the last five years. Tests have been carried out by Lurgi, West Germany, with iron ores from the Mysore State and reductants from Tamil Nadu and Andhra Pradesh.

As a first step, five different samples of high grade iron ore and three different samples of reductant were sent to Lurgi for conducting bench scale tests. However, two types of ore were rejected because of their relatively high phosphorus contents, and another due to high decrepitation. Only two types were used for pilot plant test. The three different types of reductant tested in the bench scale were raw lignite, lignite char and sub-bituminous coal. The sub-bituminous coal (Singareni) was selected for pilot plant tests on techno-economic considerations.

Raw materials used for pilot plant tests were as follows:

	Iron ore	
	Type 1	Type 2
Fe %	68.4	64.1
SiO_2%	0.74	4.28
P %	0.011	0.043
Size mm	6.20	6.15

	Coal	
	As recd.	Dry
Moist. %	10.3	—
Ash	24.4	27.2
F. C.	43.1	48.1
V. M.	22.2	24.7
Net cal. val. Kcal/kg		5,206

Pilot plant tests were conducted over a period of 10 days during which 67 tons of sponge iron were produced. Of the total sponge iron produced, only 12 tons were of less than 90 per cent metallisation, 34 tons with 90 to 97 per cent metallisation, and 20 tons of +97 per cent metallisation. The sulphur content of the sponge iron was generally below 0.02 per cent. The carbon content of the +6 mm sponge varied between 0.06 and 0.30 per cent.

It was observed that to obtain the desired maximum temperature it was necessary to supply a part of the heat requirement of the kiln either by firing natural gas or pulverised coal. Attempts to use a coal with high volatile content created problems of accretion because of higher temperature in the kiln. The high ash content in the residual char did not permit full utilisation of the char obtained from the kiln discharge.

The tests indicated the possibility of producing sponge iron with high degree of metallisation when using the selected ores and Singareni coal. It also indicated that additional fuel may have to be utilised in the form of pulverised coal to improve throughput rate. It stands to reason that a higher throughput rate may be achieved if a part of Singareni coal could be replaced by a coal with higher volatile matter content.

A decision with regard to the capacity of the plant should also take into account the investment and operating costs involved. The specific investment costs of sponge iron plants with capacities ranging from 60,000 tons to 300,000 tons/year are shown in Fig. 2. For a 60,000 tons/year capacity plant, the investment rate would be of the order of Rs. 900 per annual ton, and that for a 300,000 tons/year capacity plant about Rs. 550 per annual ton. These estimates are on the basis of using a single rotary kiln unit utilizing sized iron ore. The costs relate to the sponge iron production facilities including raw materials handling and yard utilities. Facilities for the preparation of raw materials and off site facilities are excluded from the estimate, as also cost of land, site preparation and interest during construction.

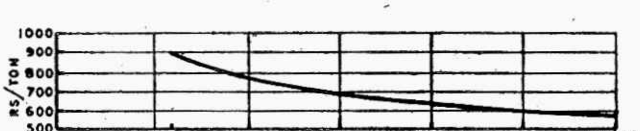

FIG. 2. INVESTMENT COSTS OF SPONGE IRON PLANT

The cost of production of sponge iron in a rotary kiln plant has been calculated for a hypothetical location, where the delivered costs of suitably sized high grade (67% Fe) iron ore is Rs. 65 per ton and coal (22% ash) is Rs. 71 per ton. The cost of sponge iron including the fixed charges is shown in Fig. 3. When operating at rated capacity, the cost of sponge iron would range between Rs. 315 and Rs. 375 per ton, depending on the plant capacity. The effect of operation of the plant at varying levels of capacity utilization has been indicated in Fig. 3.

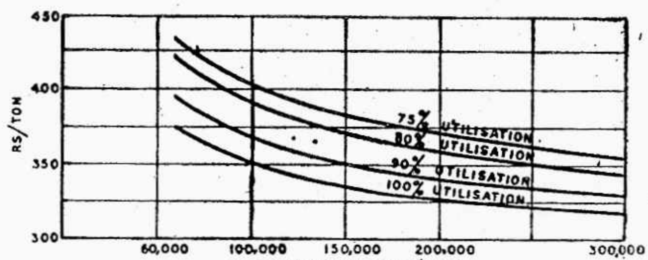

FIG. 3. PRODUCTION COSTS OF SPONGE IRON AT VARYING LEVELS OF CAPACITY UTILISATION

Detailed information regarding the investment as well as operations of batch type processes for production of sponge iron is not available. A rough estimate indicates that the cost of producing sponge iron in such plants with an annual capacity of about 20,000 tons per annum world be around Rs. 425 per ton. These estimates are based on the assumption that suitably sized high grade ore would be available at Rs. 65 per ton, low volatile reductants such as stoker coke at Rs. 165 per ton and gas coal at about Rs. 71 per ton as delivered to the site.

The commercial experience on rotary kiln DR plants till this date indicates that the behaviour of the materials in actual commercial plants is somewhat different from those in pilot plants, and some adjustments may have to be made during initial operations. Further, as the characteristics of the raw materials significantly affect the direct reduction process careful planning would have to be made for ensuring consistency in the quality of raw materials used.

Considerable efforts are being made to overcome the problems associated with the rotary kiln process, and one could expect that solutions to these problems would be found in the near future. On the engineering side, India could benefit substantially from the experience of the rotary kiln operations elsewhere. The size of the rotary kiln should be suitably selected, depending on the reducibility of the ore and the characteristics of the reductants. It would be desirable to provide a flexible arrangement for feeding the reductant both from the discharge end and the feed end. Similarly, the material for the air tubes and refractories should be carefully selected.

The effective use of sponge iron produced from local raw materials in steelmaking is discussed in a separate paper. (34) The economics of sponge iron production is attractive and the authors consider that it might be worthwhile to make a start with a small industrial unit in the capacity range of 60,000 to 10,000 tons per year.

References

(1) Baraclough, K. C.—"Alternative routes to steel: a survey of the position around the time of the Bessemer and Siemens inventions," Proc. Alternative routes to steel, The Iron and Steel Institute, London, 5-6 May 1971.

(2) Grateau, E.—"Memoire sur la fabrication de l'acier fondu par le Procede Chenot," Revue Universelle, 1859, 6, I-62.

(3) Kaup, Von Karl—'Einige probleme der rohstoffnersorgung," Stahl und Eisen, 1971, 91, No. 25.

(4) Jeffries, C. F.—"Echeverria ore reduction process," Steel Times, January 29, 1965.

(5) Andersen, H.C. et al—"Electric smelting with pre-reduced material," Proc. Alternative routes to steel, The Iron and Steel Institute, London, 5-6 May 1971.

(6) Langton, G. "A steel works with a major by-product" International Iron Steel Institute, 6th Annual Meeting and Conference, 8-11 October 1972.

(7) Janke, W. and Garbe, H.—'Sponge iron production by the SL/RN process and further treatment to obtain steel", Metallgesellschaft, A.G., Review of activities, No. 12, 1969.

(8) Jessop, A. F. et al — "Steelmaking with New Zealand iron sands", Proc. Alternative routes to steel, The Iron and Steel Institute, London, 5-6 May 1971.

(9) Pfeifer, H. C. and Scherer, S. G. — "Direct reduction of iron ore by SL/RN process", Contribution to the XXVII ABM Annual Congress, Sao Paulo, July 1972.

(10) Meyer, G. et al — "The Krupp Sponge Iron Process — its products and applications", Seminar on direct reduction of iron ore: technical and economic aspects, Bucharest, September 1972.

(11) Pfeifer, H.C. and Scherer, S.G. — op cit.

(12) Metal Bulletin Monthly, London, Issue No. 13, 1972.

(13) Savelov, N. I. et al — "Research on processes of direct reduction of iron from ores", Seminar on direct reduction of iron ore: technical and economic aspects, Bucharest September 1972.

(14) Steel in USSR, May 1972.

(15) Dastur, M. N., Das Gupta, S. and Parthasarathy, C. R. — "Blast furnace productivity and costs", Trans. I.I.M., June 1968.

(16) Central Water and Power Commission of India — Power Atlas of India, Exhibit No. 1, 1970.

(17) Lahiri, A. — "A study of the problem of coking coal in India — VI", Journal of Mines, Metals & Fuels, January 1972.

(18) Central Water and Power Commission of India — op cit.

(19) Biswas, A. N. and Mukherjee, M. — "Use of directly reduced iron ore in electric furnace steelmaking", Indian Institute of Metals, 26th Annual Meeting, December 1972.

(20) Sasagawa, K. et al — "Manufacture of electric pig iron from iron sand by means of semi-reduced sponge iron".

(21) Ariake Iron & Steel Co. Ltd — "Iron sand smelting method in Japan from semi-reduced sponge iron", October 1963.

(22) Maurice, H. and Udy, M. C. — "The Strategic-Udy installation", journal of Metals September 1973.

(23) Andersen, H. C. — "Present status of Elkem pre-treatment process and hot feed to electric smelting furnaces", Symposium on direct reduction of iron ore: technical and economic aspects, Bucharest, September 1972.

(24) Koenig, H. — "Results of and remarks on the use of directly reduced material in conventional electric reduction furnaces", Symposium on direct reduction of iron ore: technical and economic aspects, Bucharest, September 1972.

(25) Andersen, H. C. — op cit.

(26) Ibid.

(27) Serbent, H. and Janke, W. — "SL/RN Process — Production of sponge iron using solid reductant", Symposium on direct reduction of iron ore: technical and economic aspects, Bucharest, September 1972.

(28) Pfeifer, H.C. and Scherer, S.G. — op cit.

(29) Woolf, P. L. — "Blast furnace operation with pre-reduced burdens", Journal of Metals, February 1966.

(30) Astier, J. et al — "Part I: The use of pre-reduced materials in the blast furnace", Ironmaking to-morrow, Publication 102, The Iron & Steel Institute, London, 1966.

(31) Peart, J. A. and Pearce, F. J. — "The operation of a commercial blast furnace with a pre-reduced burden", Journal of Metals, December 1965.

(32) Takeda, K, — "Ironmaking techniques to-day and to-morrow", Paper presented at VII ILAFA Congress, Montevideo, October 1967.

(33) Mikhalevich, A. G. et al — "Blast furnace operation with the use of metallized pellets in the burden", Steel In USSR, Vol.1, May 1971.

(34) Ratnam, T. V. S. et al — "Use of sponge iron in steelmaking," Paper presented at the symposium on science and technology of sponge iron and its conversion to steel, Jamshedpur, February 1973.