SPONGE IRON TECHNOLOGY—EFFORTS AT THE NATIONAL METALLURGICAL LABORATORY

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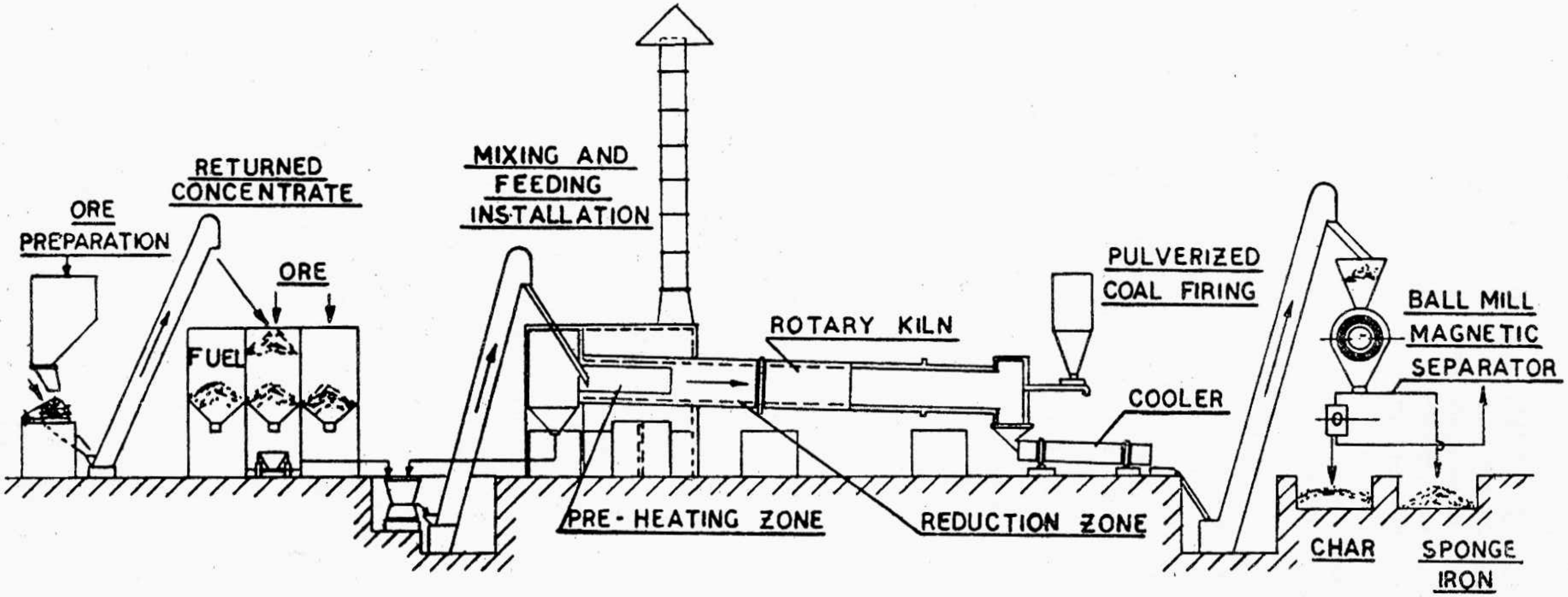
"EVEN if the proposed new steel plant were to be operated efficiently at 100% of the rated capacity, it will incur an annual loss of rupees sixty crores!"

The above conclusion of the feasibility study made out by the consultants for the proposed new steel plant at Vishakhapatnam came as a surprise to many. The findings were, however, anticipated in some knowledgeable quarters in India. The role of the conventional iron and steel production technology which has predominated all over the world since the middle of the last century has all along been severely restricted by certain well known geographical and economic factors. Basically, like many other primary metallurgical industries, the iron and steel industry is a highly capital intensive and has to deal with huge tonnages of comparatively low value raw-materials producing either a medium product or as is happening in case of the Bhilai steel plant — an undervalued product! The economic structure of the steel industry is based on the solid understanding that the raw-materials must be cheaply available at plant site from proximate areas. It is also based on this implicit understanding that the raw materials must fulfil an increasingly strict set of specifications concerning their physical and chemical properties.

Availability of coking quality coal, which is just mediocre at its best, is restricted to Eastern Bihar in India. It would be understandable if the role of the conventional iron and steel technology peters out beyond a distance of few hundred kilometres from the Bihar coal fields.

And yet India is endowed with abundant reserves of good grade iron ore and non-metallurgical coal in several parts of the country. If steel plants were to come up in these parts, obviously the century old conventional approach is neither technically nor economically feasible.

Direct reduction technology based on production of almost completely metallised lumps by in-situ reduction of iron ore without involving fusion, and directly feeding the metallised lumps (sponge iron) into electric arc melting furnaces to make quality steel—is the most obvious answer to such situations anywhere in the world. At several places natural gas and non-metallurgical coals are abundantly available. There has been hectic developmental activity to find alternative route suited to local conditions for production of steel by processes other than the conventional. As a result, an amazing number of processes for direct reduction have been developed—some to commercially successful stage.



A SCHEMATIC FLOW-SHEET OF THE N.M.L. PROCESS

Cost of money

Of all the cost constituents that total up the ultimate price of steel, the least discussed—particularly from Research and Development platforms—is the cost of money. In case of such a capital intensive industry as iron and steel producing a medium priced product such as bulk structural steels, the cost of money may constitute anywhere from one third to one half of the total cost and is the biggest single cost item. The average investment per annual ton of the installed capacity of steel plants that came up in India in the fifties has been well over Rs. 3,000 per annual ton. The monetary over-heads, even if determined on a modest assumption of 15% reach a level of Rs. 450 per ton—a sizeable proportion of the controlled steel price in the country today.

Developing countries like India, can ill-afford such costly technology which puts a severe burden on their available internal resources for growth and development. A study of the year by year project costs in the country clearly points out that the investment costs are continuing to escalate and the cost of money component will continue to erode the profitability of future projects. For such situations as this, the direct reduction processes are well suited because of their low capital requirements per annual ton of steel. Estimates differ from one process to another as also from one location to the other. Our own preliminary estimates for a 300,000 tons per year sponge iron facility based on rotary kiln—solid reductant technique is around Rs. 800 per tonne/year.

Development of coal based sponge iron process at the National Metallurgical Laboratory

In view of the extensive occurrences of non-coking coals and their proximity to important iron ore deposits in India, it was decided that a major thrust in the development of sponge iron technology should be concerned with the utilisation of the non-coking coals as reductant and fuel. From amongst the known approaches, the following two were readily selected:

(1) Rotary kiln method of solid state reduction

(2) Vertical retort furnace using solid reduction.

Rotary kiln process

N.M.L. had a 10.67 m long, 0.76 m I.D. rotary kiln which could be pressed into a preliminary investigation to test whether the know-how for sponge iron production could be developed readily. The kiln is lined with fire brick and is driven by a 3 H.P. variable speed motor. The kiln is mounted on a chassis, inclination of which can be changed. This facility along with control on the revolution between 0.5-2.0 r.p.m. gives enough flexibility in controlling the residence time of the charge in the kiln. Three chromel-alumel thermocouples are evenly spaced along the kiln shell and are connected through strip-rings to a multi-channel temperature recorder which also records the exit gas temperature. A diagramatic sketch of the NML rotary kiln system is shown in Figure 1. The first-ever campaign producing sponge iron on tonnage scale for the first time in the country was successfully concluded on the Dusshera Day in October 1970 when several tonnes of pellets made from Donimalai concentrates were successfully reduced to 95% metallisation. The programme of developing the know-how in rotary kiln was continued thereafter with unabated zeal and have resulted in accumulation of large store-house of information concerning a number of ores, ore fines, coals and other raw-materials and their response to the rotary kiln approach for sponge production.

All was not smooth sailing as was assumed based on the success of the first campaign. Subsequent campaigns went through numerous difficulties and teething troubles in the development of the technology. It was soon learnt that not all ores could be reduced to over 90% metallisation and that their reducibility also controls the productivity of the kiln. It was also learnt by hard experience that whereas some coals gave higher output and metallisation, some others gave much less. By continuous process of study of the physical and chemical characteristics of various raw-materials and their response to the rotary kiln approach, it was possible to lay down parameters for raw-materials for their successful conversion to sponge iron. Since then we have been running this kiln at a production rate of 3 to 4 tons of sponge iron per day continuously except stoppages required for kiln modifications and additions. We have also considerably modified the original kiln which had been designed and obtained for magnetising roast treatment of ores.

Some typical results

Some typical results obtained from some of the campaigns using different types of iron ores and coals from various parts of the country are illustrated in the enclosed Tables I & II. It has been possible to obtain sponge iron from lump ore in size range of —18+6 mm as well as screened and indurated pellets made from iron ore fines on a Disc Pelletiser having a capacity of 2 tons per hour. The size of the pellets was controlled between 6.5 to 12.5 mm. More recently, NML had obtained through the courtesy of Messrs. Tata Iron & Steel Co. Ltd., approximately 130 tons of indurated pellets from their Noamundi Plant. These have been processed and successfully converted into sponge iron with a high degree of metallisation and the metallised pellets have been successfully converted into steel in the 500 KVA steel melting furnace.

Non-coking coals from 3 different sources viz., Wardha Valley, Singareni, and Ballarpur have been tested successfully. A part of the total carbon requirement of the process is being met by recirculating the char which is separated magnetically and returned along with fresh charge to the kiln. The thermal requirements in different campaigns have varied from 3.5 to 3.7 million KCal per ton of sponge iron produced However, it is expected that with a longer kiln this requirement can be appreciably reduced.

Operational results of the rotary kiln

Iron ore lumps :— Iron ore lumps were treated in the rotary kiln with non-metallurgical coal. The charging rate was 300 kg per hour with coal to ore ratio as 1:1. The temperature of the kiln was maintained between 1000-1050 degree C.

High degree of metallisation was achieved. Ring formation was absent. With the recirculation of char, the heat requirements in different campaigns varied from 3.5 to 3.7 million KCal per tonne of sponge iron produced.

Heat-hardened pellets :— The operation of the kiln using heat-hardened pellets was also smooth but there was considerable degradation of pellets, particularly when the size of the pellets was large. The results showed that the degree of metallisation was slightly lower in the case of large sized pellets. The thermal requirements were found to be similar to those required to pre-reduced lumpy ores.

Green pellets :— The degradation of green pellets was low and the ring formation was absent. Higher degree of metallisation was obtained. A higher degree of operational temperature in the range of 1080-1100 degree C could also be maintained in the kiln.

Table I
Chemical analysis of iron ore lumps

Location of ore	Constituent %					
	Fe	SiO_2	Al_2O_3	S	P	CaO+MgO
Dalli-Rajhara	66.4	2.2	2.0	0.01	0.02	0.2
Bailadila	66.5	0.9	2.3	0.015	0.04	trace
Barajamda	63.5	1.7	2.3	0.02	0.03	0.4
Kiriburu	62.8	1.82	4.34	0.04	trace	trace
Surajgarh	66.7	0.8	3.36	0.03	0.03	trace

Table II
Proximate analysis of non-coking coal

Location	Constituent %				Cal. Value KCal/kg	Ash softening °C
	Moisture	VM	FC	Ash		
Ghugus colliery (Maharashtra)	4.5	32.5	42.6	20.4	5520	1190
Singareni colliery (A.P.)	5.2	28.2	44.8	23.8	5385	1280
Ballarpur colliery (Maharashtra)	2.9	31.8	39.4	25.9	5140	1245

Operation of the kiln by throwing coal from the discharge end

In order to utilize the volatiles of the coal, coal throwing device was incorporated to throw 50% of coal from the discharge end. With this set-up it was possible to remove fuel-oil burner and temperature profile inside the kiln could be maintained properly. 50 per cent of coal was charged along with iron ore pellets from the feed end. The operational results of the kiln showed that the reduction of pellets was high.

Summarised operational results are given in Table III.

Present status of the NML's rotary kild process

The know-how developed at the National Metallurgical Laboratory is comparable with any of the similar approaches developed abroad. This has been possible by an intensive programme of continuous investigations with a large variety of raw-materials. Over 100 tons of sponge iron are now awaiting melting trials in a local foundry having a 4 ton and 10 ton electric furnaces. In the ensuing weeks a programme has been planned for inplant melting trials when it will be possible to assess the industrial performance of the sponge iron which has already been successfully converted into steel in the Laboratory's one ton arc furnace.

Encouraged by the persistently good results, the Steel Ministry have given an ad-hoc grant for installing a 100 M3 kiln which will not only give better results due to longer length, but also serve as an ideal demonstration and proving unit.

Vertical retort furnace

The sponge iron production in the vertical retort furnace using solid reductants such as coal, charcoal, coke etc. has its own set of advantages. The vertical retort furnace approach has been commercially tried out in the continent where the Echeverria process seemed to have been gaining momentum. The approach calls for externally fired retort furnace usually 450 mm to 500 mm diameter which is charged continuously at the top with a mixture of iron ore and solid reductant. Gradually the mixture descends down into hotter zone of the charge wherein iron ore is reduced in presence of carbonaceous reductants The reduced metal continues to descend down and is ultimately discharged out of the furnace. A few such prototype units had appeared in Spain a few years ago. The attractive features of this approach are low capital investment for economically viable units making it ideal for small production for meeting local requirements —a situation which is particularly true at many places in India.

At the National Metallurgical Laboratory a vertical retort measuring 0.22 m dia. and 2.44 m long has been set up in a gas fired furnace of 1.15 m height, both the ends of the retort project beyond the top or bottom of the furnace. The retort has arrangements for periodical charging of the raw materials and a screw mechanism at the botton continuously discharges the finished products from underneath into a hermetically sealed, water cooled drum.

Experimental results

Campaigns in this retort have been conducted maintaining a temperature of 950-1000°C over a zone extending 600 mm. Particle size of the raw materials has been restricted to —15+5 mm. As an example, 100 kg of iron ore and 80 kg of coal are mixed together and fed into the retort with retention time of 1 hour 45 minutes. Sponge iron with 85-95% metallisation at a daily output rate of 150 kg was obtained which corresponds to a productivity of about 3.8 tons per M3 of the reactor volume. The productivity of the retort is much more as compared to the productivity of the rotary kiln per unit volume. It is

Table III
Summarised operational results

Type of ore	Type of coal	Type of limestone	Feed rate kg/hr. Ore	Coal	Char	Stone	Operating temp. °C	Product assy % Fe(T)	Fe(M)	% of S	degree metallsation
(A) Iron ore lumps											
Dalli-Rajhara	Singareni	Bhabanathpur	150	115	35	6	1050	88.4	77.8	0.03	88.0
Bailadila	Ghugus	Bhabanathpur	150	115	35	6	1045	87.0	76.4	0.05	88 0
Barajamda	Ghugus	Bhabanathpur	150	115	35	6	1070	90.2	82.8	0.03	91.8
Kiriburu	Singareni	Bhabanathpur	150	115	35	6	1070	86.0	73.1	0.05	85.0
Surajgarh	Ballarpur	Surajgarh	150	115	35	6	1070	89.2	77.9	0.06	87.3
(B) Iron ore heat-hardened pellets											
Donimalai	Ghugus		150	150	—	—	1060	90.3	78.3	0.11	87.1
Bailadila	Ghugus		150	150	—	—	1060	88.2	78.1	0.12	88.6
Noamundi	Singareni		150	115	35	6	1070	90.5	82.3	0.03	90.4
(C) Iron ore green pellets											
Donimalai	Ghugus		150	115	35	—	1050	88.8	75.3	0.12	86.3
Bailadila	Singareni		150	115	35	—	1060	88.4	81.3	0.11	91.9
Kiriburu	Singareni	Bhabanathpur	150	150	—	7	1060	86.4	76.8	0.05	87.9
Surajgarh	Ballarpur	Surajgarh	150	115	35	7	1080	88.4	79.2	0.07	89.6
(D) Operation with coal throwing											
Noamundi (hundred pellets)	Singareni	Bhabanathpur	150	56	19	6*	1060	89.8	82.4	0.04	91.7
Surajgarh (green pellets)	Ballarpur	Bhabanathpur	150	56	19	6*	1070	88.7	81.9	0.03	92.3

*Coal thrown 75 kg/hr.

now proposed to put up a pilot plant unit producing a few tons of sponge iron per day by this technique which is ideally suited to meet the local requirements of small electric furnaces.

A photograph of the present set up is shown in Figure 2.

Use of naphtha for production of sponge iron

It is well--known that the most active reductants for iron oxide are hydrogen and carbon-monoxide. These active gases can be readily obtained by reforming of such petroleum products as natural gas and other lighter hydro-carbons. The process of reforming comprises of partial oxidation of the hydrocarbon to produce a mixture of carbon-monoxide and hydrogen. Such reactions can be exemplified by the following equations:

$$CH_4 + H_2O + \text{heat} \longrightarrow CO3 + H_2$$

$$CH_4 + CO_2 + \text{heat} \longrightarrow 2H_2 + 2CO$$

A number of successful reforming processes have been developed which give a high efficiency of conversion into a mixture of carbon-monoxide and hydrogen. Several sponge iron processes have been developed based on the reformed natural gas (Methane). A few of them have reached successful commercial status such as HyL process, Midrex process, the Purofer process, Armco process and others. In the HyL process, for example, the reformation of natural gas results in a mixture containing about 75% hydrogen and 15% carbon-monoxide. However, there is considerable latitude for proportion of hydrogen and carbon-monoxide for efficient metallisation of the iron ore. A number of successful installations based on these commercially successful processes have come up and are coming up in areas where abundant supplies of cheap natural gas is available. In addition, there are potential areas in North Africa and Middle-East where gas based direct reduction technology could be successfully implemented.

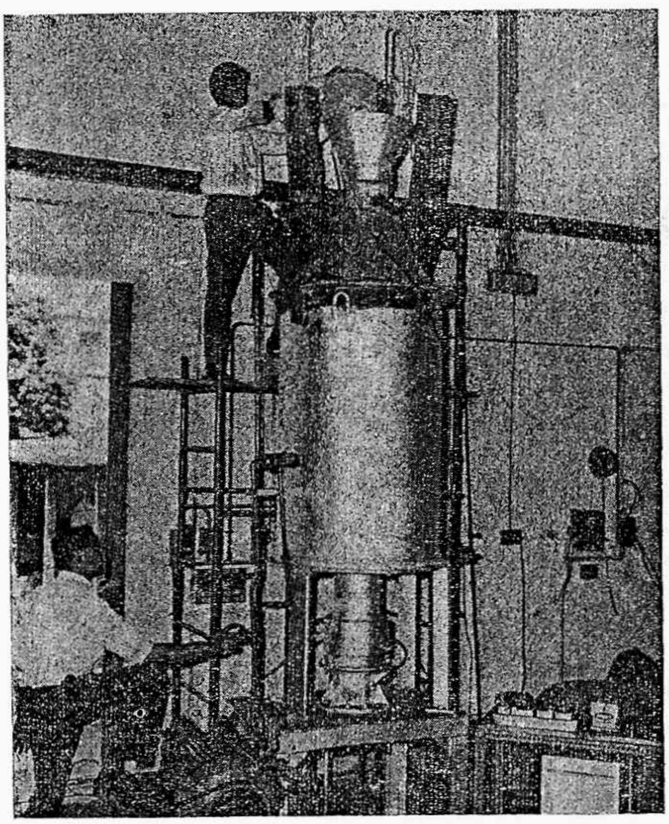


Fig. 2 — Vertical retort furnace set up at N.M.L. for sponge iron production.

In India there is no known source of abundant gas supply yet. Whatever gas is available in Cambay and Assam is not enough to sustain commercial size sponge iron production plant.

However, the National Metallurgical Laboratory has instituted a programme for direct reduction of iron ore to sponge iron using naphtha as a source of hydro-carbon. When the programme was initiated a few years ago, naphtha was available in surplus quantities in the country. Although today whatever is available is being diverted to manufacture of fertilisers and chemicals, the work at the National Metallurgical Laboratory has been further accelerated with well-defined purpose of developing a technology using hydro-carbons for direct reduction. The process originally developed on 100 grams batch scale has been considerably modified and scaled up into a continuously operating vertical reactor producing about 100 kilograms of highly metallised sponge iron per day.

Naphtha comprises of a range of petroleum distillates of a wide range of volatility. Octane ratings are however, far too low for its use in internal combustion engines but its low sulphur content and freedom from ash make it ideal for many industrial applications requiring clean hydro-carbons. The sp. gravity is about 0.67 with a sulphur content of 20-500 ppm. The carbon hydrogen ratio is about 5:1 and the calorific value ranges between 11,100-11,300 KCal/kg.

The novelty of the NML process is that no separate reforming of naphtha is required. Naphtha is vaporised in a vaporising unit and the vapours are injected into a reducing column. A fuel pump is used for the purpose of passing naphtha vapours from the vaporiser to the reactor. A vertical reactor has been designed and used for proving the process on continuous scale in the laboratory; it comprises of a 90 mm internal diameter alloy steel tube which is resistant to high temperature oxidation. The reactor has arrangement for continuous charging of the feed at the top and discharging of the product at the bottom. At present the reactor temperature is maintained by an external electric furnace. The residence time of the ore in the reaction zone can be varied from 30-90 minutes. The capacity of this reactor varies from 75-100 kilograms per day depending upon the reducibility of the ore. Figure 3 shows a view of this reactor.

The ascending reducing gases from the reactor pre-heat the descending iron ore particles converting themselves into carbon-dioxide and water vapour due to the reaction with oxygen in the iron ore. The process has the advantage of a continuous working system as against the batch operation of the HyL process. It also has the advantage of the blast furnace wherein counter-current exchange of heat and oxygen leads to high metallurgical efficiency. A continuously

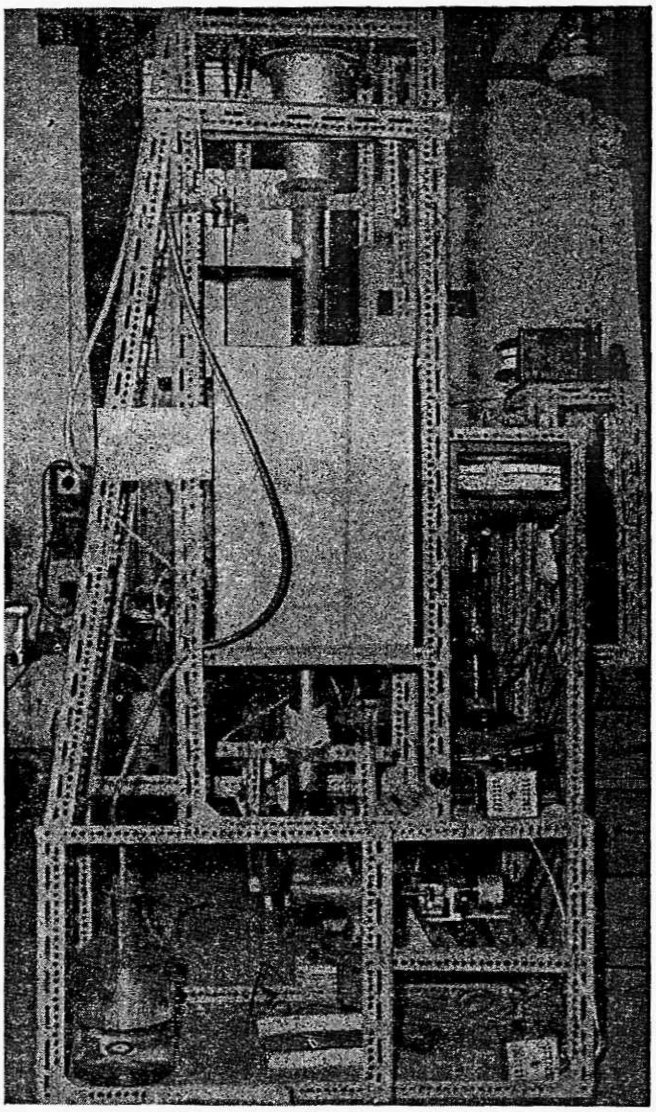


Fig. 3–Naphtha based continuous sponge iron production unit.

operating screw discharging system withdraws the reduced sponge from the bottom of the reactor into a hermetically sealed receiving drum from where it is hermetically withdrawn.

The following Table gives typical analysis of the iron ores reduced by this process:

			I	II
1.	Fe	..	59.8%	62.6%
2.	SiO_2	..	5.9%	1.3%
3.	Al_2O_3	..	3.8%	3.9%
4.	P	..	0.035%	0.09%
5.	S	..	0.17%	trace

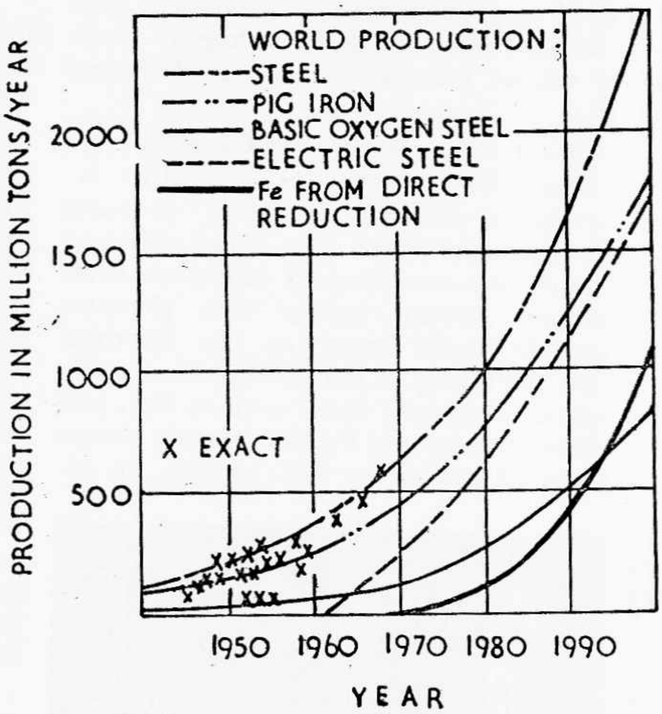


Fig. 4–Estimation of crude steel production by various processes upto the year 2000

With a reaction temperature of 1000°C, the residence time of about 45 minutes, a sponge with 98% metallisation was produced at the rate of 4 kg/hr. using 120 cc of naphtha per kilogram of the sponge.

The process has other advantages. As stated earlier, no separate costly reforming system is involved. The process is also continuous in operation and being counter current in principle has the advantage of efficient heat and oxygen transfer. The naphtha consumption is of the order of 120 litres per ton of sponge iron produced. There is also no deposition of carbon soot as would be naturally expected if hydro-carbons were to be directly used for oxide reduction. The process has also the advantage that it uses the sulphur free reductant resulting in a very low sulphur sponge iron. Further it has no solid contamination such as ash or char which have to be separated in the process using rotary kiln solid reduction techniques. Our present costing indicates that the direct cost of production will not exceed Rs. 150 per ton of sponge inclusive of the present excise duty on naphtha. Also the technology so developed can be exported to Middle-East countries and North African countries where naphtha is abundantly available.

Why continue with naphtha

A question arises whether it is desirable to continue work on naphtha reduction when in India there is no immediate possibility of obtaining abundant quantities of naphtha. However, deep thinking on this problem has convinced us at the National Metallurgical Laboratory, that the work should not only be continued but scaled up further to a pilot plant capable of producing at least 5 to 10 tons of sponge by this process per day. The reasons for such aggressive posture are the following:

Although the country does not have abundant supplies of its own today, there is no guarantee that it will never come across reserves of its own in the near future. For technologies to develop from laboratory stage through the pilot plant and prototype stages will require persistent efforts over a period of a few years. This has been amply proved by the history of the development of such commercially successful processes today as HyL process and the Midrex process whereas even after years of work, the Purofer process and Armco process have yet to establish their commercial credentials. It is, therefore, necessary that if off-the-shelf and proven technology is to be got ready by the time abundant sources of hydro-carbons are located and developed in the Fifth Five Year Plan, the technology to produce sponge iron by using these and similar hydro-carbons should also be synchronously got ready for immediate implementation.

Sponge iron plant at Mangalore

There is nothing to prevent us from importing naphtha from naphtha rich countries in the Middle East and to export sponge iron instead of exporting iron ore which we are doing today. This can be best exemplified by the case of Kudremukh Project which envisages export of iron ore concentrates in slurry form from the port of Mangalore at a price of about U.S. $10-11 per ton. It can be boldly proposed that instead of doing so, a naphtha based sponge iron plant could be set up near Mangalore where the iron ore concentrates could be converted into sponge by importing naphtha from the Middle East. Since such a highly metallised product fetches an international price of about 40 $ per ton, foreign exchange cost involved in importing naphtha from abroad will be more than amply reimbursed.

Future trends in steel production

Geographical and economic conditions in India and many other developing countries clearly point towards a steel strategy other than the conventional. The role of the Direct Reduction Technologies will grow rapidly and India will have ample opportunities to benefit by the current research and development efforts for development of sponge iron. This shortcut is technically feasible and economically attractive. In Southern and Western parts of India it is the only feasible way to set up several centres of modest capacities.

All over the world there is tremendous hope in the future role of direct reduction technology. Several forecasters have predicted an ever increasing percentage of steel arising out of sponge iron melting (Figure 4). It can be safely predicted that in the 5th Five Year Plan period at least 3-5 commercial size operations will spring up at different places in India. This will be a period of bridging the credibility gap. The total tonnage will probably be less than half a million tonnes. But it can be equally confidently predicted that these ventures will pave the way and build up enough boldness to plunge in for million ton plants in the 1980-85 period.

The role of direct reduction technology is not restricted to steel-making only. It has been proved in several inplant trials in the West that use of pre-reduced burden in the blast furnace appreciably lowers the coke-rate and increases the blast furnace productivity. Our present blast furnaces have to put up with high ash coke (25-28% ash) and the coke rate has been as high as 850 kg/ton of pig iron. Pre-reduction is one way out to increase productivity. The National Metallurgical Laboratory has a low-shaft furnace which is proposed to be converted into a baby-blast furnace. One of the objectives of the proposed unit will be to determine the comparative advantages of pre-reduced burden. If the results are convincingly encouraging, one of the commercial blast furnaces could be put on a pre-reduced feed for inplant trials.

Iron and steel industry is a very heavy industry. Its inertia is often frustrating. But when it gets going nothing can stop it. Nothing can stop the important role of sponge iron in the world iron and steel industry. Indian steel industry also will not be lagging behind.

DISCUSSION

Dr. P. E. Mehta (Consulting Engineer, New Delhi)

The question of importing Naphtha is difficult as in an International Seminar on Petroleum Refining in Developing Countries held in New Delhi, the then Minister of Petroleum and Chemicals mentioned that for import of Crude for the refinery programme as envisaged in 1980, our total foreign exchange earnings today will be required for importing crude for the refinery programme.

The question is on what basis suggestion has been made to set up sponge iron plants using imported Naphtha. The possibilities of finding inland oil reserves to use for sponge iron manufacture are now bright from our present knowledge. Even our new fertiliser plants have to be based on other feed-stocks than naphtha.

So I want to find out from Dr. Altekar on what basis they are very optimistic of using Naphtha for sponge iron conversion......?

Prof. V. A. Altekar (Author)

Questions have been raised about the advisability and economics of a process based on Naphtha in light of its position in India. True, we have no known source of naphtha now, but, it does not preclude the possibility of coming by an indigenous source, or of obtaining Naphtha in barter trade.

For technologies to develop from laboratory stage through the pilot plant and proto-type stage, it requires persistent efforts over a number of years. This has been amply proved by the history of the development of such commercially successful processes today as the HyL process and Midrex process whereas even after years of work, the Purofer process and Armco process have yet to establish their commercial credentials. It is, therefore, necessary that if 'off-the-shelf' and proven indigenous technology is to be got ready by the time abundant sources of hydrocarbons are located and developed in the country, the technology to produce sponge iron by using these and similar hydrocarbons should also be synchronously developed for immediate implementation at a later date. Besides, the technology so developed can be exported to Middle East and North African countries where fractions like naphtha are abundantly available.

It is possible to import naphtha from the naphtha-rich countries in the Middle East and export sponge iron instead of exporting iron ore which we are doing today. For example, the Kudremukh Project envisaged the export of iron ore concentrates in slurry form from the port of Mangalore at a price of about US $10-11 per ton. Instead, a naphtha-based sponge iron plant could be set up near Mangalore to exploit the iron ore concentrates importing naphtha from the Middle East. Since such a highly metallised product fetches an international price of about $ 40 per ton, foreign exchange cost involved in importing naphtha will be more than amply reimbursed. The R. & D. plans of NML therefore include this naphtha based process also in addition to the coal based projects reported elsewhere in this volume.

Mr. M. Krishnamurthy, (Bihar Alloy Steels Ltd., Ranchi).

i) Whether Lignite has been used in the direct reduction process.?

ii) How far in your opinion Lignite in India can become a useful material in the direct reduction processes.?

Prof. V. A. Altekar (Author)

i) NML has scheduled studies on use of lignite for sponge iron making in the near future. Low sulphur samples of lignite from existing sources have been asked for.

ii) Lignite can be used as a reductant in the direct reduction processes to a very limited extent. The two important difficulties are the high percentage of moisture and sulphur. The moisture creates difficulty at the charging end of the rotary kiln and may produce adherent ring. The high sulphur content of the lignite would increase the suphur pick up by the sponge iron. To eliminate this, limestone can be charged with ore and coal but due to high percentage of sulphur large quantities of limestone will be necessary. Also, another difficulty may arise depending on the strength of lignite, the poor abradability of lignite, leading to high dust generation and losses.

Mr. S. Dharanipalan (Bhilai Steel Plant, Bhilai).

Prof. Altekar was telling something about iron ore deposits that are dispersed in India. I have a small question and that is regarding the behaviour characteristics of iron ore deposits in South. It had a higher degree of metallisation whereas iron ore from Rajhara has given a lower degree of metallisation. I am interested about Rajhara Deposits. The Rajhara ore did not result in higher metallisation upon direct reduction. Can the author throw some more light on the subject?

Prof. V. A. Altekar (Author)

I referred in my paper about the tests conducted on Donimalai and Rajhara iron ores. From the rotary kiln tests it was found out that Donimalai iron ore pellets have shown better degree of metallization in comparison to Rajhara iron ore lumps. The reasons for such a behaviour can be the various physico-chemical properties of the two ores. It is well known that these properties can vitally change the reducibility and in turn, the percentage metallization.

Mr. S. N. Banerjee (Steel & Allied Products Ltd., Calcutta).

What is the basicity ratio of sponge iron produced and FeO content of the same as these will determine the suitability of its use in the electric furnace smelting?

Prof. V. A. Altekar (Author)

Normally in the rotary kiln, metallization of the order of 92% has been obtained while, in other processes developed at NML it is upto 95%. The FeO content of the sponge, will vary according to the percentage metallization. The basicity of the slag produced will also depend on the nature of the original gangue minerals which vary from one deposit to the other, but which can be controlled by preprocessing such as washing.