IRON ORE PRE-REDUCTION

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Abstract

World current prereduction capacity of about 5 million tons is expected to rise to over 60 million tons by end of the decade. The paper briefly reviews the major prereduction processes and outlines uses of products. Attempt is made to define the broad parameters of iron ores used for prereduction. Adoption of prereduction by solid reductant process seems to hold our promise for Indian conditions. Application of prereduction as a means of producing steel directly or as an ancilliary process for stretching capacity of existing and future blast furnaces. Possibility of establishing a number of small centers for providing raw materials for foundries and rerolling mills. Recommends experimental industrial application of prereduction during 5th plan period towards gaining experience for wider applications for increasing iron and steel capacity in the 6th and subsequent plans.

General Growth

SEARCH for production of iron by means other than the expensive blast furnace complex requiring increasingly expensive coal/coke consumption has been in progress for a very long time. Though the principle of direct reduction was worked upon about a 100 years ago the commercial application of this principle has been established only very recently. Term direct reduction or prereduction envisages operations by which oxygen from iron ore in the solid state is removed— at temperatures below 2200°F—without going through the smelting stage. Reduction is achieved either reducing gases or through a solid reductant (non-coking coal).

At the end of 1972 total world capacity for production is estimated at about 5 million tons p.m. a highly accelerated growth rate during the current decade is anticipated 5 years ago, Miller and Lorig predicted the world capacity of prereduction in 1980 at about 30 million tons but in 1971 Miller's new estimates indicated 1980 capacity at about 62 million tons and for 1975 at about 10 million tons. Compared to these the total crude steel figures for 1975 and 1980 are 730/760 million tons and over 900 million tons respectively of which electric steel may be 106 and 180 million tons respectively.

Figure I shows the anticipated trend of prereduction capacities and Table I shows comparison of total crude steel, electric furnace steel and prereduction anticipated capacities.

TABLE I

(Figures in Million Metric Tons)

Years	Total Crude	Tons	B.F. %	Prereduction
1970	590	81	13.8	3
1972	620	87	14.	5
1975	735	106	14.4	10
1980	915	183	20.0	62

Processes

Several prereduction methods have been considered in the past but the folowing are amongst the better known in the industry:—viz. HYL., Midrex, ARMCO., US. Steel Nu-Iron (fluidised bed) and the SL/RN. The first 4 are gaseous reductions while the 5th one is a solid carbon reductant process.

TABLE II

WORLD PRE-REDUCTION COUNTRY-WISE CAPACITY

No.	Country	Company and Location		Process	Capacity (tons/annum)	Year
1		Hojalata Y Lamina S.A.	Monterrey	HYL	115,000	1957
2		- Do -	Monterrey	HYL	240,000	1960
3		- Do -	Puebla	HYL	270,000	1969
4		- Do -	Monterrey	HYL	400,000	1973
5	Mexico	Tubos de Acero de Mexico S.A.	Vera Crus	HYL	190,000	1967
					1,215,000	
6		Oregon Steel Co.	Portland	Midrex	400,000	1969
7	U.S.A.	George Town Steel	Georgetown	Midrex	400,000	1971
8		Midland Ross	Batonrouge	Midrex	800,000	1973
9		Armco Steel	Texas	Armco	350,000	1972
					1,950,000	
10	Canada	Falconbridge Nickel Minea Ltd.	Sudbury (Ontario)	SL/RN	300,000	1972
11		Sidbec	Contrecour (Quebec)	Midrex	440,000	1972
					770,000	
12	South-America	U.S. Steel Corp	Ciudad Guayana Venezuela	NU-Iron	1,000,000	1973
13		Acos Firos Piratini S.A.	Brazil	SL/RN	65,000	1972
		Usiba	Brasil	HYL	270,000	1972
					1,415,000	
14	Europe	Korf Industrie Handel GmbH	Hamburg W.Germany	Midrex	400,000	1971
15		Skopje	Yougoslavia	SL/RN		
16	South-Korea	Inchon Iron Words	Inchon	SL/RN	250,000	1972
17	New-Zealand	New Sealand Steel Co.	New Zealand	SL/RN	165,000	1969
18	Japan		Osaka	Midrex	800,000	
19	Iran		Bandar Abas			Under Planning
20	Australia		Hamersley		Probably over 1 million	"Process" Under Reconsideration.
21	S. Africa	Witbank		SL/RN (Early Version)	1,000,000	1967

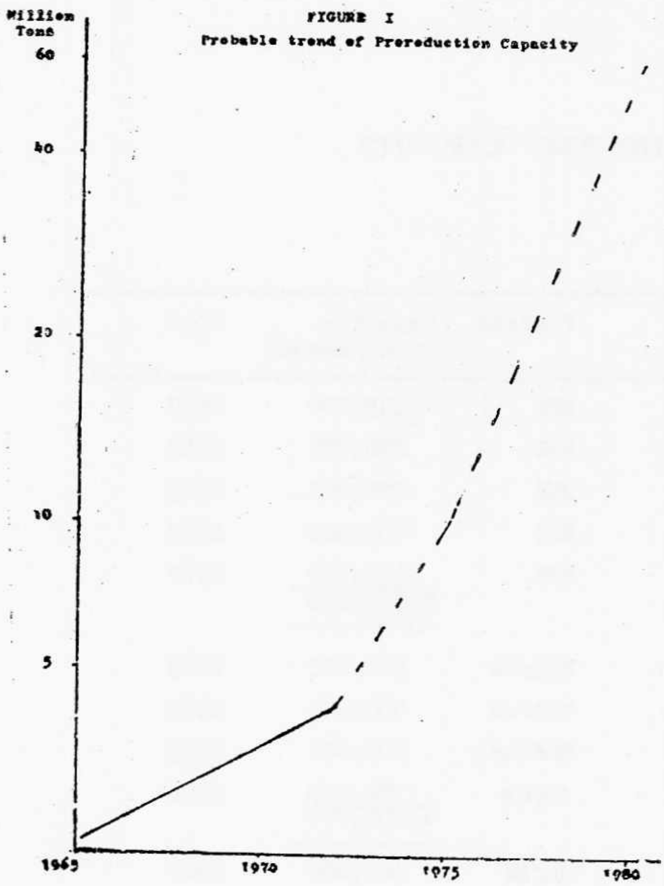


FIGURE I
Probable trend of Prereduction Capacity

HYL process — this is perhaps the 1st to establish itself successfully in industry. The first HYL plant established at Monterry — Mexico in mid-fifties has since produced serveral million tons of prereduced material. Further additions made at Peublo and Vera Cruz. Basically a static bed batch process in which reduction is achieved in vertical retorts. Ore and reformed natural gas (74% H_2—13% CO) enter the reactor at higher end. Reduction time about 12 hrs. Reduction temperature between 870-1050°C. Lump ore or pellets mainly in the size range 1/4" to 1/2" are fed in batches at top of retort. The earliest installations fed on approximately 60 per cent Fe ore gave products at about 82 per cent metallization or 88 per cent reduction. The newer plant at Peublo has better results, Oxide pellets at 65-66 per cent Fe and a gangue ranging from 4-8 per cent; P-0.02 to 0.04 per cent S—0.02 to 0.04 per cent and carrying almost equal proportions of hematite and magnetite and magnetite give about 91 per cent metallization. Practically all plants run near rated capacities.

Although the Midrex process is also a gaseous reduction process much the same as HYL, it is a continuous charge system. It seems to have attracted much attention in the U.S.A. and elsewhere in a short span of time. Reduction is achieved in a vertical furnace on iron oxide pellets by a counter current of hot reformed natural gas. It is reported to produce 92-95 per cent metallization from 65-66 per cent Fe oxide pellets. Energy requirements at the established Portland Plant is in the region of 3.5 million Kcals/ton product which is considered favourable. Earlier established plants are slowly increasing capacity towards the rated level, but still have to approach it.

The ARMCO batch process is somewhat similar to the Midrex process is that it is a gaseous countercurrent reduction but the main difference is in its gas reforming method. It is expected to reduce a 63 per cent Fe oxide pellets to a 95 per cent metallization product. Not much is known about the process as the first 1000 ton/day plant is expected to start production this year (1973).

Orinoco 'Fluidized bed' Nu Iron or High-Iron Briquette (HIB) gaseous reduction is perhaps the only known successful industrial application of iron ore fines below 10 mesh. It too is a counter current reduction achieved in a tall multistage reactor. The first and perhaps the only known plant (1 million t.p.y.) is expected to go on stream early 1973 at Ciudad Guyana-Venezuela although planned for operations in mid 1971. The process consists of 4 basic stages.

(i) Ore preparation:—Fine ore from mines is dried, crushed and screened to 10 mesh size.

(ii) Gas reformation is achieved by mixing natural gas with superheated steam in presence of a nickel catalytic agent at 1500°F. Gas then cooled to remove excess water vapour.

(iii) Actual reduction achieved in tall reactors —dry preheated ore (600°F) pneumatically injected into top of reactors.

(iv) Prereduced material under inert nitrogenous atmosphere is pressed into small briquettes of about 5.5 to 5.7 density at high temperature of about 2700°F. With 58 per cent Fe natural ore and dried iron content of over Fe 63 per cent a prereduced product of 86 per cent total Fe with 75 per cent of its oxygen removed is obtained. Briquettes are planned specially for use in blast furnaces. The main advantage of the briquettes would be uniformity of size and quality enabling use as scrap substitute to enrich burden.

SL/RN—solid reductant process. Iron ores — natural lumps (up to 20 m.m.) or pellets (18-15m.m.) are directly reduced at about 1100°C in a slightly inclined rotary shaft kiln in presence of coal. The special kiln is provided with a series ot burners throughout the full length of the kiln. Limestone/dolomite is used as a sulphur-binder to prevent excess sulphur from coal finding its way into the metallized product.

Kiln product is cooled in special cooler and separated by magnets and screens. The ability to use a wide range of solid carbon reductants is the main inherent advantage of the process. It is well suited to production of low sulphur direct-reduced pellets or sponge of 93-95 per cent metallization. Oxide pellets at 68 per cent Fe give a product at 95 per cent total Fe with about 95 per cent metallization; Sulphur is about 0.03 per cent to 0.01 per cent. In heat energy requirements at about 3.5 million K cal/M.T. product is comparable to the better amongst the gaseous reduction processes. Power consumption is of the order of 55 Kwh/M.T. product.

From the point of view of industrial operations SL/RN is newer than the well established HYL. Start-up difficulties are encountered but these are more in the nature of insufficient engineering and operational problems than process problems. Engineering problems of such nature are normally encountered on nearly all industries particularly where the processes involved are comparatively new. Problems were also found by the HYL gaseous reduction processes, which needed as much as 30 months of experience after start-ups to arrive at satisfactory engineering solutions. Whilst some of the gaseous reduction processes have had time the solid reductant process should be able to hold its own. A year or so from now should see most of the 'problems' removed enabling industry to welcome not only the solid reductant process but prereduction as a whole on a more readily acceptable basis than hitherto.

Use of prereduced material

Broadly depending on the degree of metallization, gangue content etc. the main uses are:—

i) Electric steel making furnace — charged with scrap. Recent studies indicate a mixed charge of prereduced pellets and scrap in approximately 60:40 ratio is more easily processed than a charge wholly of either. As indicated in forecasts given above about 20 per cent of world crude steel — i.e. over 180 million tons — are expected to be electric furnace steel by end of decade. In view of economics, as currently predictable, a very fast growth of use of prereduced ore in electric steel making is strongly indicated. Thus a large percentage of 62 million tons of world prereduced ores will be used directly in electric steel making by 1980.

ii) Basic Oxygen Furnace. With a much lower degree of metallization, down to 75 per cent or 70 per cent. and less stringent specifications for gangue, use in oxygen converters is possible. Although technically any coolant—iron ore with 0% metallzation—can be used the use of prereduced ores will depend on economic evaluation of the numerous factors involved.

iii) Blast Furnace. Number of tests have been made, on commercial and non-commercial scale, using prereduced iron ores in the blast furnace. Although at one time great emphasis was placed on the use of such ores in blast furnaces interested in European and American continents now seems to be largely away from this direction. Nevertheless serious research on this aspect is currently receiving attention in Japan. Japan's interest may be attributed to its unique position in the world as a steel producer very largely dependnt on long distance ocean transport of iron ore and increasingly expensive coking coal. Experiments in Japan have indicated

FIGURE II

Reduction - Metallization

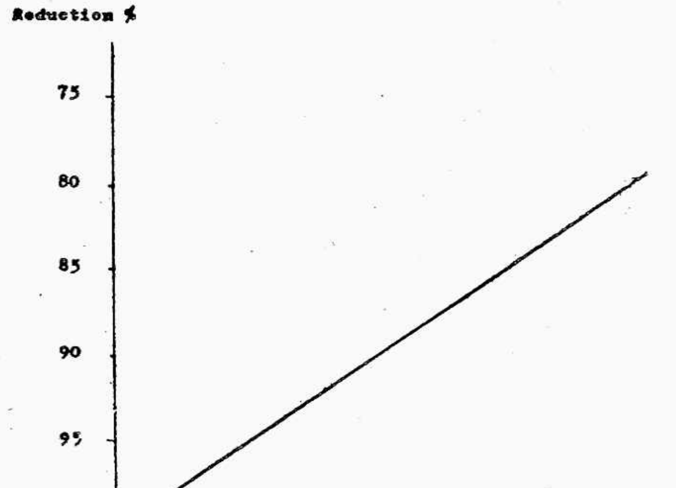
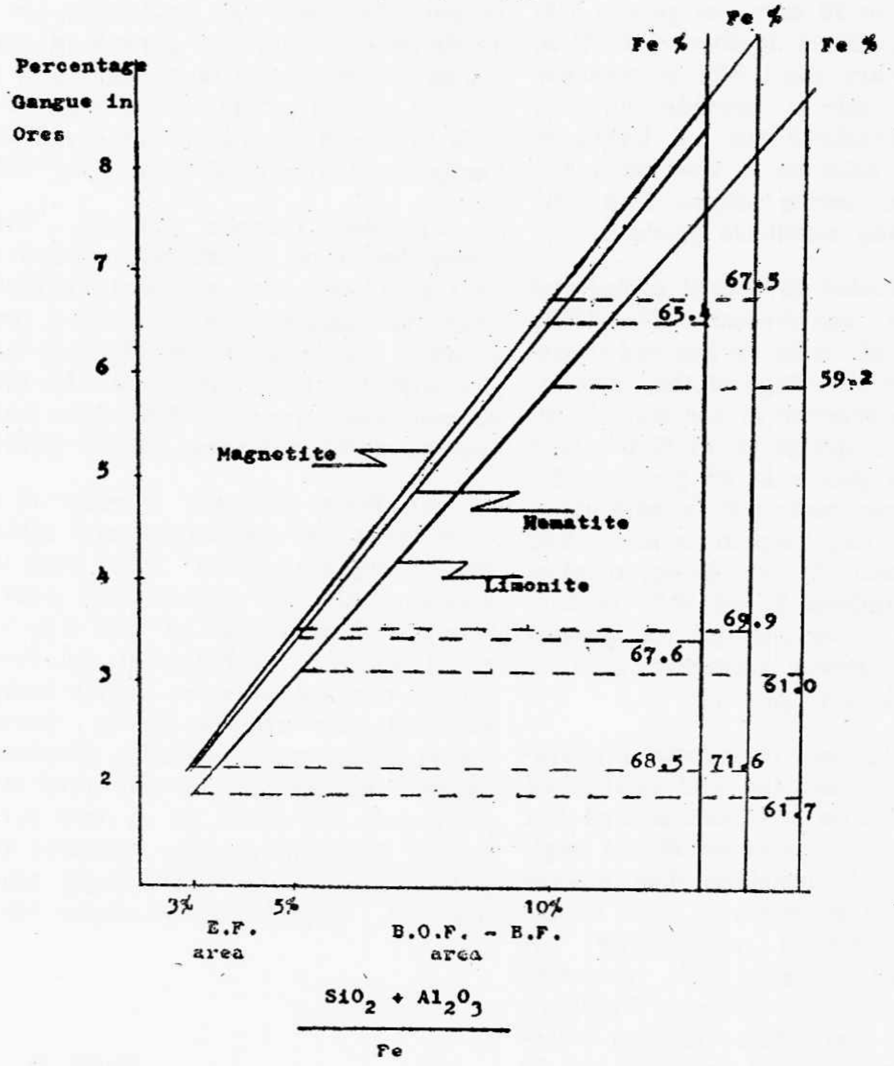


FIGURE III



that a 10 per cent increase in burden metallization decreases coke rate by about 6 per cent.

Studies by U.S. Bureau of Mines in experimental blast furnace indicate that with an 80 per cent reduced burden instead of normal pellets burden lowered coke rate by 53 per cent and increased production rate by 75 per cent. The main question of the use of prereduced ores is of economics; balancing of cost of prereduction against reduction of coal/coke cost and increased pig production. With the current difficulties in supply and production of coking coals and its increasing cost as experienced in India perhaps the use of a supplementary process — use of prereduced ore in B.F. — which decrease the pressure on coking coal/coke is worthy of a systematic study. Added advantage would be increased production at blast furnace.

Specifications of ore and prereduced product

Specifications of iron ore used for prereduction would be guided by the end use of the product (E.F. or B.O.F. or B.F.) and also to some extent on the process used for prereduction. The prereduction industry is still very young and no clear cut specifications for ores to be used have been established. A fairly wide range of iron ores have been used in the commercial and non-commercial plants in the past. On the basis of available data, metallurgical and other considerations and attempt is made below to define the broad parameters of ores for optimum operating conditions under economic environment currently understood.

Broad range of ores to be used in:—

a) Electric Furnace

Electric arc steel furnace is basically not a reduction but a melting furnace. Some reduction is achieved at cost of increased electrical energy and increased use of carbon electrodes. Slag derived from gangue

$$SiO_2 + Al_2O_3$$

in ore will need extra electric energy for slag off. Very low P and S are required to meet steel quality.

Thus desirable:—

Degree of metallization over 90 per cent or reduction over 93 per cent. Residual oxygen less than 0.03 ton/ton steel. Low Fe slag with basicity of under 5% Al_2O_3 + SiO_2/Fe gives gangue in ore at 3.4 to 3.5 per cent (for hematite and magnetite ores respectively). Ores under 3.5 per cent SiO_2 + Al_2O_3 and generally under 3 per cent would appear preferable. To achieve this end superconcentrates with under 2 per cent SiO_2 being experimented upon in U.S.A. To match above conditions Fe in Hematite ores at 67.6 per cent and at 70 per cent in Magnetites and about 61 per cent in limonites.

b) B.O.F.

Metallization down to 75 per cent or even 70 per cent. Oxygen up to 0.07 ton/ton steel.

$\frac{Al_2O_3 + SiO_2}{Fe}$ ratio below 10 percent which works out to SiO_2 + Al_2O_3 in:—

a) Hematite at 6.5% : Fe 65.4%

b) Magnetite at 6.75% : Fe 67.75%

and c) Limonite at 5.7% : Fe 59.2%

c) Blast Furnace

Broadly similar to that used in B.O.F. but lower metallisation 70 — 50% and larger gangue contents are tolerated. Optimum degree of metallization basically a question of balancing economies and will thus have to be worked out separately for individual conditions.

While the above is an attempt at generally defining parameters of ores for optimization of production economies it must be noted that these vary with conditions of economy and availability of resources from country to country. Ores (oxide and prereduced) of less rigid specifications have been successfully used in the past. For instance HYL prereduced ores at 85 per cent metallization and over 6.5 per cent SiO_2 have been used in electric steel furnaces, in a ratio of 60:40 with scrap, for years.

Application under Indian conditions

It is obvious that in view of shortage of natural gas, in most cases, the solid reductant process should hold out promise of greater interest than the gaseous reductant methods. The present problems facing individual plants using the former process need not be cause for pessimism as these do not appear unsurmountable.

Mainly three broad fields of application of prereduction appear possible and to that extent one sees a strong potential, subject to solid reductant process successfully ironing out 'Bugs'.

i) Application to existing and future integrated steel plants as an ancillary (complimentary) process for increasing production of hot metal/ingot steel. High along volumes and high coke rates arising out of fundamentally high ash in Indian coal/coke are contributory factors to low blast furnace productivity; below 1.5 ton/m^3 furnace volume. Introduction of prereduced burden, in blast furnace, with a suitable degree of metallization can substantially decrease coke rate and increase blast furnace production. Viewed like a sinter/pellet plant as a means of making a high prepared burden (prereduced Burden) and using more readily available and less expensive reductant (non-coking coal) capacities of existing blast furnaces stand to be stretched' If technology/economies permit, use of prereduced ore directly in B.O.F. is indicated. Second condition would permit some increase in steel

d) Size specifications

Sized ore or natural pellets (12 m.m — 25 m.m.) Pellets 12 m.m.	static bed. shaft furnace or Rotary Kiln (solid reductant).
Fines Below 10 mesh	Fluidised bed process.

capacity in integrated steel works without going through major investments in blast furnace/coke over complex stage. One would think a solid reductant process judiciously used with above objectives would well demand serious considerations and techno-economic evaluation studies to explore new avenues.

ii) Establishment of new small centres for small scale steel production — mini steel plants — and foundries. Prereduced ore to be used as supplement to or in lieu of scrap in electric furnaces. Centres established near ports viz. Vishakapaatnam, Goa, Madras. Mangalore can have added advantage of using alternative processes based on LNG from Persian Gulf area if justified. Gases from nearby refineries offer another possibility.

iii) Manufacture of prereduced ore/pellet for export. Kudremukh iron ores have already been well studied for export. If the present proposals of collaborations in the area are not found acceptable a modified proposal based on manufacture of prereduced product from Kudremukh ores would be well worth a pragmatic look. Over 500 million tons of fully explored and studied ores so close to the port call for a bold futuristic approach instead of remaining unused over years.

Summary and Conclusions

In spite of numerous difficulties faced, there is no doubt prereduction has come to stay. It is however, not likely, in the foreseeable future, to replace the well established large scale blast furnace method of pig iron manufacture. Used as a method of taking a highly prepared (prereduced) burden for blast furnace or as method of manufacture of sponge for direct use in steel making furnaces prereduction is likely to have noticeable consequences on the future economics of iron and steel making. It probably is likely to aid expansion of world iron and steel capacity. Once the solid reductant method of prereduction is able to remove the present 'bugs' it is likely to find wide application in this country. One, however, need not wait for all these bugs to be removed. If positive steps are straight away taken the prereduction method can be introduced during the 5th or 6th Plan Periods to help increase and probably at a lower cost than otherwise the country's iron and probably at a lower it be too optimistic to think in terms of possibility of establishing one or two small/medium sized prereduction plants for the existing or proposed integrated steel works during the 5th plan, not so much from the point of view of immediate production/economic gains as the 6th and subsequent Plans.