THE FUTURE OF DIRECT REDUCTION PROCESSES

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NEW production processes find application depending on the demands and opportunities afforded by changing times and conditions. This is also true of direct reduction processes which, after a period of testing and development, are now receiving attention for wider industrial application because the need for it is beginning to be felt. A few direct reduction processes have already been commercially accepted.

The direct reduction processes are being pursued with the objective of producing iron using reductants unsuitable for blast furnaces. The product so obtained could be used either as a melting stock for steelmaking in electric arc furnace or as burden material for iron smelting. In this paper, the authors have used the term 'sponge iron' to identify a highly reduced and metallised product for use as melting stock in steelmaking and the term 'pre-reduced material' for partially reduced ore for processing in iron smelting furnaces.

PRESENT STATUS OF DIRECT REDUCTION PROCESSES

Direct reduction (DR) plants in operation and under construction are listed in Table 1. The plants have been grouped under two major heads, namely those using natural gas and those using coal as reductant. In this table, processes like Wiberg and Hoeganaes have not been included mainly because there has been no further development of these processes in recent years.

PROCESSES USING NATURAL GAS

The HyL, Midrex, Armco and HIB processes use natural gas as reductant.

The HyL process[1] employs fixed bed retorts for batchwise reduction of iron ore using reducing gases obtained by steam reforming of natural gas. This process has been in operation for over the last 15 years in Mexico and is one of the most proven and successful of the existing processes. Though both sized lump iron ore and oxide pellets have been used as feed material, oxide pellets are to be preferred from the point of view of higher productivity and lower natural gas consumption.

The Midrex process[2] also uses reformed natural gas as reductant. Part of the spent gas from the reduction furnace is recirculated through the reforming section. The reaction vessel is a shaft furnace, which like the blast furnace has the inherent advantage of better efficiency. The process has been in commercial operation for the last three years. Generally high grade oxide pellets are used in this process as feed material.

The Armco process[3] also makes use of reformed natural gas for reduction in shaft furnace, and a part of the spent gases is recirculated through the furnace. The first commercial scale plant adopting this process has recently been commissioned at Houston, Texas, USA. The plant has a capacity of 1,000 tons per day.

The HIB process[4] (Hi-iron Briquette process) makes use of fluidised bed reactor for reducing ore fines of minus 10 mesh size with steam reformed natural gas. The commercial scale plant based on this process which has been set up by US Steel is designed to produce a 75 per cent pre-reduced ore, which after briquetting will be used for ironmaking.

PROCESSES USING SOLID REDUCTANTS

Of the various direct reduction processes emloying solid reductants, the rotary kiln process using lignite or coal is of commercial importance. The carbon and volatile matter in the coal furnish the heat as well as the reductant requirements of the process. When low-volatile coals are used, the heat requirements cannot be fully met and therefore gas, oil or pulverised coal has to be additionally used. An excess of carbon is maintained in the charge throughout the length of the kiln in order that reduction could be carried out without sintering in the higher temperature ranges. The early rotary kiln units were primarily installed for the production of pre-reduced material for use in electric smelting furnaces. The first commercial sponge iron plant was commissioned in New Zealand in December 1969.

World capacity

The present world capacity of DR plants is about 5.8 million tons. Of this, the installed capacity of plants which use natural gas and produce sponge iron is 2.2 million tons and the capacity for production of pre-reduced material is 1.0 million tons. The rotary kiln DR plants have a total installed capacity of 0.6 million tons for the production of sponge iron and 2.0 million tons for pre-reduced ore. The growth of world sponge iron capacity and the share of processes using reformed natural gas as well as those which utilise solid reductants in rotary kilns are shown in Fig. 1.

dence in these processes is also reflected by the number of new plants, with a total annual capacity of about 1.8 million tons, which are now under construction. In addition, a number of other plants are under planning, such as the one million ton plant based on HyL process in Iran[5].

Of the different solid reductant processes, the rotary kiln processes such as SL/RN and Krupp are the preferred ones because of the possibility of higher throughputs at lower cost. The application of rotary kiln for ore reduction is not new; it had been used long back in the Krupp-renn process. The large rotary kiln DR units installed recently were initially faced with

TABLE 1

List of Direct Reduction Plants in Operation and under Construction

Product	Process	Country	Place	Reduction unit	Total capacity (metric ton) In operation/ start-up	Total capacity (metric ton) Under construction
Plants using Natural Gas						
Sponge iron	HyL	Mexico	Monterey		105,000	
					220,000	370,000
-do-	Midrex	Brazil	Vera Cruz	Retort	175,000	
		USA	Puebla		245,000	
			Bahia			245,000
		West Germany	Portland		365,000	
		Canada	Georgetown		365,000	
-do-	Armco	USA	Luisiana	Shaft		800,000
Pre-reduced ore	HIB	Venezuela	Hamburg		365,000	
			Contrecoeur			
			Houston	Shaft	320,000	400,000
			Puerto Ordaz	Fluidised bed	1,000,000	
				Total :	3,160,000	1,815,000
Plants using solid reductant						
Sponge iron	SL/RN	New Zealand	Glenbrook	Rotary kiln	150,000	
		Canada	Sudbury	-do-	300,000	
		Brazil	Charqueadas	-do-	60,000	
-do-	Krupp	South Africa	Dunswart	-do-	150,000	
Pre-reduced ore	Elkem	Yugoslavia	Skopje(1)	-do-	1,000,000(2)	
-do-	Witbank	South Africa	Witbank	-do-	800,000	
-do-	SL/RN	South Korea	Inchon(1)	-do-	175,000	
				Total :	2,635,000	

Notes :

(1) The rotary kiln installations at Skopje and Inchon are not operating at present.

(2) Calculated on the basis of 540,000 tons installed hot metal capacity and usage of about 2.5 tons iron ore per ton iron and 30-35 per cent degree of reduction in the rotary kiln.

It will be observed that the capacity of gaseous reductant processes is growing at a faster rate. This is because of the comparatively lower cost of natural gas in the right locations and successful operation of the process and equipment at specified production levels. The growing confi-

a number of operating problems. With increasing experience many of these problems have been solved. It is expected that satisfactory solution to the few remaining problems will also be found in course of time and that these processes will become well established.

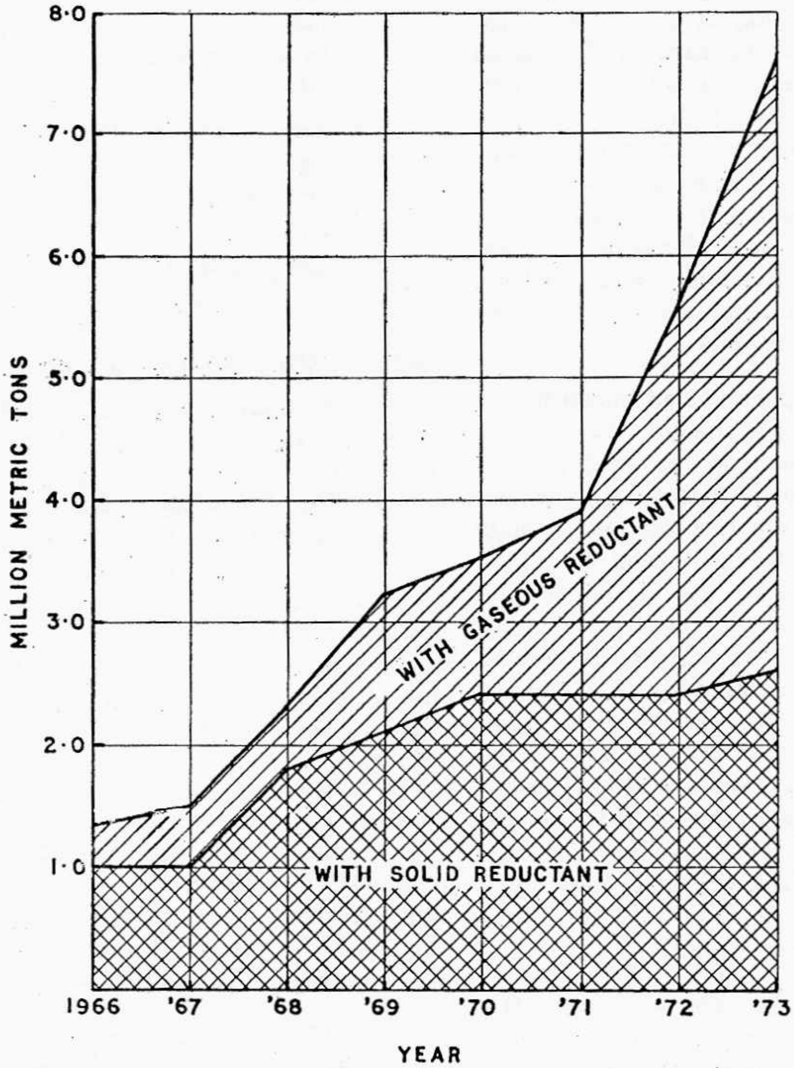

Fig. 1—Growth of world reduced iron ore capacity

USE OF DIRECT REDUCED MATERIAL

Directly reduced ore is utilised either as feed material for iron smelting or as melting stock for steelmaking

The use of pre-reduced material in blast furnaces lowers the coke rate and increases productivity. Tests have been carried out with such materials in many countries including USA[6], USSR[7] and Japan[8]. These tests indicate about 6 per cent reduction in coke rate and about 4 per cent increase in productivity could be achieved for each 10 per cent metallisation of the furnace burden. However, for economic reasons, regular use of prereduced material in blast furnace burden has not established itself. Pre-reduced iron is expensive and the cost increase is not fully offset by the savings effected by the reduction in coke rate and increase in productivity. In this context, the operating results of the first commercial intallation, namely the HIB plant in Venezuela for producing pre-reduced material and its use in blast furnaces will be of interest.

A number of pre-reduction plants were installed during the last decade for utilising pre-reduced material in electric smelting furnaces. These include the Strategic Udy facilities in Venezuela, Yawata process installations in Japan, and the facilities at Skopje, Yugoslavia; Inchon Works, South Korea; and Witbank, South Africa.

Of these, only the plant at Witbank is continuing to operate with hot charging of pre-reduced material in the electric smelting furnace. The main advantages of hot charging are saving in smelting power consumption and higher furnace productivity. The major problems encountered in this process are the formation of kiln accretions, generation of fines and difficulty in maintaining a uniform degree of reduction in the product. Ununiform degree of reduction and fines generation are not conducive to stability of operations in the electric smelting furnace.

While the use of pre-reduced material for iron-smelting is yet to find wide commercial application, use of sponge iron for steel production in electric arc furnaces has been in vogue for a long time. Till about 15 years ago, sponge iron was being produced in small sized units, and its cost was high. Therefore, use of sponge iron was limited to production of special steels for which the low residuals of sponge iron would be an advantage. With the setting up of a number of large size DR units, sponge iron became available at prices competitive to that of steel scrap at specific location and its use has been extended for production of ordinary steels also. Fairly large tonnage of sponge iron have been melted till todate in electric furnaces and there need be no lingering doubts regarding the feasibility of its utilisation as melting stock.

The proportion of sponge iron used in electric furnace charge generally varies between 50 and 70 per cent. Definite advantages in furnace productivity are obtained when, after melting 30 to 50 per cent scrap in the furnace, sponge iron is continuously charged at controlled rates so that its heat requirement for melting equals that generated by the electric arc.

FUTURE ROLE OF DIRECT REDUCTION

The world production of steel is expected to increase from the present level of abont 600 million tons to about 1,00 million tons by 1985. The bulk of this additional capacity would no doubt be through the conventional route employing blast furnace and oxygen converters (top blown as well as bottom blown). Nonetheless, it is expected that DR processes would receive increased attention for the following reasons:

(i) further improvements in direct reduction technology;

(ii) increase in the share of electric furnace steel in total steel production, increasing need of melting stock for the same;

(iii) market as well as regional restrictions limiting the size of steel plants and also lower investment rates for integrated plants based on electric furnace;

(iv) limited availability of coking coal, increase in the cost of coking coal, and availability of other cheaper reductants like natural gas, non-coking coal etc; and

(v) likely shift in the type of energy used and increased use of nuclear energy.

IMPROVEMENTS IN DR TECHNOLOGY

Considerable research and development work is now under way in different countries for widening the scope of application of DR processes. This includes generation of suitable reducing gases from fuels like naphtha, fuel oil and coal for use in DR plants. At present, the generation of reducing gases from these fuels is costlier than reforming natural gas. Efforts are also being made to inject reducing gases directly into the shaft of the blast furnace through auxiliary tuyeres.

Simultaneously, efforts are also being directed towards increasing the unit size of DR plants. The maximum unit size of DR plants is at present 300,000/400,000 tons per year, and the current experience and design trends indicate that this could be doubled in the near future enabling more economic production of DR material.

INCREASE IN EF STEEL CAPACITY

The share of electric furnace steel in total world steel production is expected to increase from about 16 per cent in 1970 to about 25 per cent in 1985[9]. This growth in capacity would require steadily increasing tonnages of melting stock which in turn could create a greater demand for sponge iron.

SIZE OF STEEL PLANTS

Currently, large integrated steel plants of 10 to 15 million ton capacities are being built in advanced countries. Such large scale operations enable production of steel at low cost. Blast furnaces capable of producing over 3 million tons of iron per year from a single furnace are already in operation. The output from two such large blast furnaces could sustain the production of 7-6 million tons of steel melting shop with three 300-ton oxygen converters (two operating).

The installation of such large capacity plants presupposes the existence of a large market for steel. On the other hand, there are areas and regions in the world which need to produce their own steel but having a limited market which cannot sustain such large scale operations. Also these very large integrated plants generally concentrate on the production of wide strips, plates etc. in high tonnage capacity rolling mills. The capacity of even a modern high speed rolling mill for rods, bars and light merchant products, on the other hand, is only around 500,000 tons/year. While obviously a multi-million ton integrated steel plant cannot be based exclusively on the production of light merchant products, an annual capacity of 50,000 to 500,000 tons of wire rods and light merchant products would be just right for mini steel plants

Where the market is limited and the demand is only for light merchant products, as is the case with many developing countries, installation of mini-steel plants has certain advantages. The mini = steel plants based on melting of scrap/sponge iron in electric furnaces could be constructed with smaller investments per annual ton of capacity, which again is an important consideration in developing countries where investment capital is scarce. In the developing countries scrap generation is generally low, and, therefore, production of sponge iron which could be integrated with mini steel plants holds a promising future for such locations.

Coking coal supply

With the rapid changeover to oxygen steelmaking and the correspondingly accelerating demand for hot metal, the demand for good quality coking coal has been increasing at a rate, which has rapidly outpaced the supply, and the development of new resources. The result has been sustained escalation in the price of coking coals. With the expected increase in world steel capacity, the rising demand for coking coals and the rising price trend may be expected to continue. In this context, efforts directed towards reducing coke consumption in the blast furnace have greater relevance than ever before. Use of pre-reduced material is a promising step in this direction.

Coking coal resources are inadequate or entirely lacking in many countries producing steel or about to undertake steel production. Countries which are not well placed to import their coking coal requirements would tend to depend more and more on DR processes based on the use of other fuels more readily available to them. This development will be further enhanced by the specific market conditions where the local and regional demands can sustain only small scale operations.

Energy situation

The iron and steel industry of the future will also be influenced by the overall energy situation. The major primary sources of energy are either the fossil fuels such as coal, oil and natural gas or nuclear energy. Currently, almost the entire world energy requirement is being met by fossil fuels and the share of nuclear energy is negligible.

The estimated world reserves of fossil fuels, their consumption rates in the recent past and the life of these reserves are presented in Table 2.

TABLE 2

World Reserves of Fossil Fuels

	Coal and lignite	Crude oil	Natural gas
a Unit of measure (UM)	10^9 tons	10^9 barrels	10^{12} Cu M
b. World reserves, (UM)	7400 coal[10] and 2, 290 lignite & brown coal	524[12]	450[12]
c. World consumption (UM)	2.9[11] (in 1970)	14 (in 1968)	0.83. (in 1968)
d. Life of reserves, yrs b/c	1650	35	50

Note : The reserve figures for coal includes all categories of reserves—measured, indicated and inferred. The figures for oil and gas are proved reserves The life of coal reserves has been calculated on the basis of 50% recovery of total reserves.

The proved world reserves of uranium are placed at 645,000 tons at an extraction cost less than $ 10 per lb U_3O_8 and 1,225,000 tons at an extraction cost less than $ 15 per lb U_3O_8. These reserves at 2,000 Gcal/kg heat value would last for 36 and 70 years respectively at the present rates of consumption of all kinds of energy.[13]

Of the total world energy consumption of 49.4×10^9 Gcal in 1970, about 35 per cent was from coal, 47 per cent from oil and 18 per cent from gas[13]. The share of oil and gas together has been 65 per cent of the total. It is expected that with increasing rates of consumption of oil and gas, the proved reserves would last only for another 30 years. Therefore, within the next two or three decades the world might have to depend for its energy resources mostly on coal and nuclear energy, the latter source remaining almost unutilised till now.

The price of coal is very much dependent on extraction and transportation costs, and on the market demand and supply conditions. The extraction cost is expected to show an upward trend because of heavy dependence on manpower and the rising cost of labour. Dwindling oil and gas resources in future would also tend to favour a rising trend in the price of coal.

On the other hand, the cost of nuclear energy will be affected only marginally by any increase in the cost of uranium, due to its very high heat content. The cost of nuclear electric power will also be affected only marginally. It may therefore be expected that electrical energy from nuclear power plants would become more and more competitive with thermal power leading to increased use of electricity for steel production in electric arc furnace.

INDIAN SITUATION

The present steel consumption in India is around 6 million tons. To provide the minimum basic needs of the growing population the economy may well need about 100 million tons of ingot steel per annum by 2000 AD. Even at this production level, the per capita steel consumption in India by the end of the century will be cnly a little over 100 kg which is the current level of steel consumption of developing countries like Argentina, Chile, Mexico and Iran, and much below the 600 kg per capita consumption of several advanced countries. The future development of the iron and steel industry in India has necessarily to keep in view the raw materials base and the opportunities afforded by the new technologies.

RAW MATERIALS

With a total estimated iron ore reserves of 23,000[14] million tons, India has a large iron ore base for the development of steel industry. On the other hand, the known reserves of good coking coal are low. The coking coal is high in ash and requires beneficiation. The total coking coal reserves in terms of washed and usable coal by the metallurgical industry has been estimated at 3,600 million tons. Further, the occurrence of coking coal is confined to the Bengal-Bihar coalfields located in eastern India.

ENERGY RESOURCES

As the coking coal situation is difficult, the possibility of utilising other forms of energy is of interest. The reserves of the various energy sources in India are given in Table 3.

The proved reserves of uranium U O_8 has been placed at 30,000 tons with possible additional reserves of 27,000 tons.[15]

TABLE 3

Energy Reserves of India

Region	Total coal reserves	Total lignite reserves	Total oil reserves	Total natural gas reserves
	10^6 tons	10^6 tons	10^6 tons	10^6 cu m
Southern	5,514.60	2,032.00	–	–
Western	23,099.40	11.10	140.00	63,600
Northern		20.30		
Eastern	79,799.76	—		
North Eastern	690.10	—		
Total	109,103.36	2,063.30	140.00	63.600

Source : Exhibit No. 1-Power Atlas of India, Central Water and Power Commission of India–1970.

It will be observed that coal is the primary source of energy supply followed by nuclear energy. At the current consumption rates, the life of the crude oil reserves in India is only for seven years. Therefore, from the long term point of view the country would have to depend more and more on coal and nuclear energy

USE OF DIRECT REDUCED MATERIAL

The major integrated steel plants in India are based on blast furnaces for iron production. The coke rates in these furnaces are high, varying from 800 to 950 kg per ton. This high coke rate is mainly caused by the high ash content of the coke, which generally ranges between 23 and 25 per cent and partly due to the high alumina content of Indian ores. The productivity of the Indian blast furnace is less than 50 per cent compared to the best practices obtaining in countries like Japan and USSR. The quality of the coking coals available and their washing characteristics indicate that no significant reduction in the ash content of Indian coke would be possible in future. In the circumstances, to improve the blast furnace performance an all-out effort is needed to reduce the coke rate. The measures for reducing coke rate are well known and these could include the newcomer in the field, namely, utilisation of pre-reduced material.

The average power consumption in the electric iron smelting units in India ranges between 2400 and 2700 kWh per ton, depending on the type of ore used and the quality of iron produced. In this field also, significant saving in power consumption is possible by using pre-reduced material.

However, the use of pre-reduced material for iron smelting has to wait till an economic solution to the production of consistent quality material at reasonable costs is found.

NEED FOR SPONGE IRON

Presently, the demand for steel in India is greater than the production. Steel shortage has caused a servere setback in the development of the engineering industries. In order to quickly augment steel production, a number of small scale units based on scrap melting in arc furnaces have been set up and many more are being planned. The capacity of the individual units range from 30,000 to 100,000 tons per year. Lower investment per ton of annual capacity and shorter construction and gestation periods than large integrated steel plants, availability of indigenously manufactured equipment etc. have attracted entrepreneurs to set up small steelmaking units. Electric arc furnace steel production has increased from 0.51 million tons in 1968-69 to 1.1 million tons in 1971-72.[16] But arc furnace capacity installed is over 2 million tons[16] and production has been only about 50 per cent of installed capacity because of scrap and power shortages. The market price of purchased scrap has risen in the last three years to nearly 2½ times the 1968-69 prices. Because of scarcity of steel scrap and high prices, no new arc furnace steelmaking units are being licensed. Under these circumstances, the future outlook for sponge iron is bright provided it could be produced at reasonable costs comparable to that of scrap.

ECONOMICS OF SPONGE IRON PRODUCTION

The selection of a suitable direct reduction process would depend on specific local conditions, mainly the availability, type and cost of high grade ore and reductant. India has adequate reserves of non-coking coal and high grade ore distributed in different regions of the country, and therefore, solid reductant DR processes such as SL/RN and Krupp would be of major interest. Production of sponge iron by gaseous reduction processes such as HyL, Midrex, Armco and Purofer may be considered for plant locations in Assam and Gujarat when natural gas is available though not in large quantities. Further, import of natural gas from Middle East countries, Bangladesh and Indonesia for use in direct reduction can not also be ruled out.

SPONGE IRON TESTS

The need for and also the possibility of producing sponge iron at prices comparable to that of steel scrap has been realised for quite some time and some preliminary work has already been done. As early as 1963, tests on sponge iron production from high grade concentrates obtained from Kanjamalai ore deposits of Salem were conducted at the laboratories of Lurgi Chemic in West Germany. The reductants used were raw Neyveli lignite and char. Again, in 1970; tests were conducted at the laboratories of Lurgi Chemic in West Germany with lump ore from Hospet and Singareni coal. The National Metallurgical Laboratory, Jamshedpur has already taken in hand both laboratory and pilot plant testing of Indian raw materials for direct reduction in rotary kilns. These test results indicate that some of the local raw materials are suitable for production of sponge iron.

Sizeable tonnage of sponge iron produced in one of the pilot plant tests was subjected to industrial scale melting trials in a 10-ton arc furnace in the Electric Furnace shop at Adityapur of Tata Iron and Steel Company. These tests were conducted for the first time in the country adopting continuous charging of sponge iron. The results of this melting test confirm that sponge iron upto at least sixty per cent of the total charge is a desirable substitute for steel scrap and can be melted with advantage by continuous charging.

The development of a DR process well suited for Indian raw materials will pave the way for the setting up of a number of small DR electric arc furnace integrated steel plants located in different regions of the country to meet the local steel demand for light merchant products. Such small plants could contribute significantly to future steel capacity increase although bulk of the increase will come from large integrated steel plants with blast furnaces and oxygen converters.

RESEARCH AND DEVELOPMENT

The development work now being undertaken at the NML on a suitable rotary kiln reduction technology should pave the way for the successful production of sponge iron under Indian conditions. However, the possibility of gasification of non-coking coals and utilisation of this gas for direct reduction cannot be ignored. R & D efforts need to be initiated in this direction also. The reducing gases generated by this method could also be considered for injection into the blast furnace, for cutting down coke consumption and increasing furnace productivity.

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DISCUSSION

Mr. H. D. Nandy (National Iron & Steel Ltd., Howrah). There are quite a number of Arc Furnace Owners manufacturing steel to the tune of 20/30 thousand tonnes a year. They, on their part, cannot individually set up a sponge iron unit with economic viability, so there is no possibility of setting up an economically viable sponge iron unit which can cater sponge iron pellets to these furnace owners in order to compensate the short fall of melting scrap in the market.

Dr. M. N. Dastur (Author) Yes, it is possible to set up an economically viable sponge iron unit which can cater sponge iron pellets to owners of small furnaces in order to compensate for the shortfall of melting scrap in the market. An economic single unit may be of 100,00 tons to 300,000 tons per year capacity. Though many of the operating problems faced in the initial rotary kiln plants have been solved, as this process is sensitive to the characteristics of raw materials, it would be worth while to set up a rotary kiln sponge iron plant of say 100,000 tons per year capacity. Once we have ironed out the problems in this unit and have developed the know-how on the use of Indian raw materials for sponge iron, we can go ahead with the setting up of higher capacity central sponge iron plants which can cater to the needs of many small arc furnace units in a region.

Mr. K. R. Narayan (Tata Iron & Steel Co. Ltd., Jamshedpur): Quite some time back we were told that the low shaft furnace has got immene possibility. Now we have come to the stage of sponge iron. Would Dr. Dastur tell us which of the two processes is more viable for steel making.

Dr. M. N. Dastur (Author): The low shaft furnace and the sponge iron are two different animals - the former produces hot metal and the latter sponge iron. It is difficult to have a direct comparison. However, this much could be said - low shaft furnaces are not being constructed, whereas several sponge iron plants are in operation and more are under construction. In fact, sponge iron is an excellent substitute for melting scrap.