The Role of National Metallurgical Laboratory in Ferrous Metallurgical Research and Development in India

Dr. B. R. Nijhawan

THE world production of ingot steel was not more than 60,000 tons in 1850; 500,000 in 1870; it rose to an all-time record of two million tons at the turn of the nineteenth century. Today it has crossed the 300 million tons mark and in tonnage output and value, it surpasses that of all other metals combined. Of the diverse factors that have contributed to such a phenomenal growth of the iron and steel industry, the role of research and development in the metallurgy of iron and steel is supreme.

India has not lagged behind in the general expansionary trends of the iron and steel industry. It has been quoted abroad that "of all the plans for increasing industrial output, the Indian plan for steel must surely rank with the grandest". India's ingot steel production by 1961 is planned for 6 million tons a year. Our Second Five Year Plan envisages a total expenditure of Rs. 559 crores for the establishment of three State steel plants in the public sector (Rs. 439 crores on the plants proper and Rs. 120 crores on ancillaries). Both the private and public sectors are actively contributing in this national endeavour. In the private sector, the Tata Iron and Steel Company have now practically completed their programme for expansion to two million tons ingot steel production per year.

Metallurgical processes

There are many metallurgical processes that have not basically changed in theory or practical application but have undergone dramatic changes in scale and efficiency under the effects of modern scientific and engineering technology. With the stupendous consumption figures of raw materials involved in the iron and steel industry of the world today, technological trends thereof relate to such modifications in the production methods as would suit the changing pattern in the nature and quality of raw materials at our disposal on the one hand and to meet the varied and severe standards of service requirements of the finished product on the other. This process is largely aided by the latest innovations in sister sciences and developments in modern engineering which force its pace differently in different parts of the world. Important technological developments in the metallurgy of iron and steel are taking place such as, in the preparation of raw materials, alternative methods of iron and steel production, developments in continuous casting, electronic instrumentation, up-to-date automation, etc. In the case of raw materials, concentrated attention has been given to ore preparation and agglomeration, developments in sintering techniques, obtaining suitable metallurgical coke from poor coking coals by blending and proper sizing and classification of raw materials.

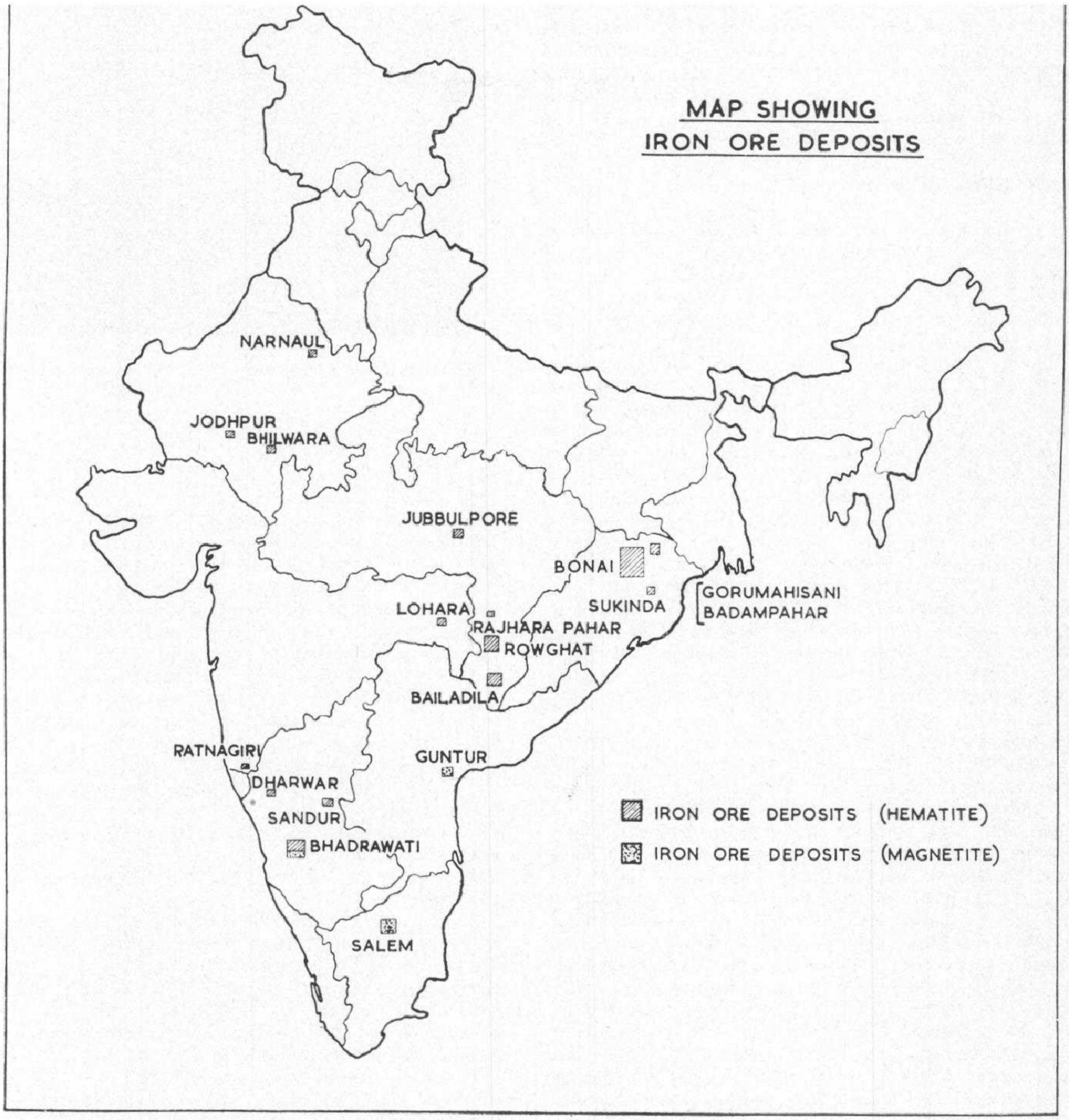
Important developments are taking place in alternative iron production techniques, such as, the smelting of iron in low shaft furnace utilising non-coking coals or/and low grade iron ores. Likewise, important developments have taken place in the steel-making process, such as, the L-D Oxygen Converter process, Cyclo-Steel process in the U.K., oxygen blown Rotary Converter processes—the Kaldo and the Rotor in Sweden and Germany, etc.

Resources of India

Though India's iron ore resources are classic both in quality and reserves, resources of her coking coals are far from satisfactory and thus alternative methods of using non-coking coals for iron production have to be investigated and developed. Although the potential coal reserves of India are estimated at 62,000 million tons, the reserves of known coking coals, have been estimated at only 1,500 million tons. Thus only a small part of the rich iron ore resources of India can be converted into steel on the basis of its own coking coals following conventional production methods. In view of the shortage of metallurgical coking coals, there is a growing realisation that the use of coking coal needs to be substituted by non-coking coals particularly by the railways. The new locomotives are being designed to use lower grades of coal. Electrification of railways should further reduce the demand for superior types of coal. The railways which use annually about 4·7 million tons of coking coal have agreed to change their locomotive boilers to enable them to use non-coking coal in place of coking coal scheduled to be released for metallurgical use as follows:

			Million tons
By 1st April 1957	...	...	1·7
By 1st April 1958	...	...	1·5
By 1st April 1959	...	...	1·5

Dr. B. R. Nijhawan, Ph.D., F.I.M., F.N.I., Director, National Metallurgical Laboratory, Jamshedpur.



With this overall appraisal of the iron and steel industry, the role of technological research and development in any country to day becomes dominant. This is more so in India in the present stage of our development in the context of our successive Five Year Plans. It is in this context that the part played by the National Metallurgical Laboratory in the development of Indian iron and steel technology assumes importance. The efforts at the National Metallurgical Laboratory have followed the old adage that limited objectives be chosen in the present context of our development. With iron and steel industry as in any metallurgical industry, one of the important themes of work would naturally relate to the raw materials involved in its operations. In the case of iron and steel, the raw materials are basically, iron ore, coke, fluxes, ferro-alloys, etc. The accompanying map shows the location of iron ore in India. The investigations into the treatment of iron ore have related to beneficiation of low-grade iron ores, blast furnace flue-dust treatment, sinter production investigation, reducibility studies of iron ores, oxygen steel-making semi-pilot plant studies, etc. Some of the important investigations are outlined below.

Beneficiation of iron ores

Iron ore samples from Bonai, Orissa, were received from the Indian Bureau of Mines at the instance of the Ministry of Steel, Mines and Fuel, Government of India, with a request to investigate its beneficiation to about 65% Fe, in connection with their new trade agreement for export of iron ores to Japan. The sample assayed Fe, 59·6%; SiO_2, 2·23%; Al_2O_3, 4·45% and loss on ignition at 1,000°C, 7·5%. Due to low alumina and silica contents in the sample, washing and gravity methods of beneficiation were not successful. Calcining the sample at 500°C and above, eliminated most of the combined water automatically upgrading the sample to over 64% Fe. Heating the sample gradually to 650°C and soaking it at this temperature for half an hour yielded a calcined product assaying 64·1% Fe. The saving in freight for the calcined, enriched ore, should more than offset the cost of crushing and calcining. Similarly upgrading work on lateritic iron from Rajharapahar, Madhya Pradesh, assaying 34·14% Fe, 19·24% SiO_2, 18·02% Al_2O_3, 1·10% TiO_2 and 0·13% P was undertaken for the Bhilai Steel Project.

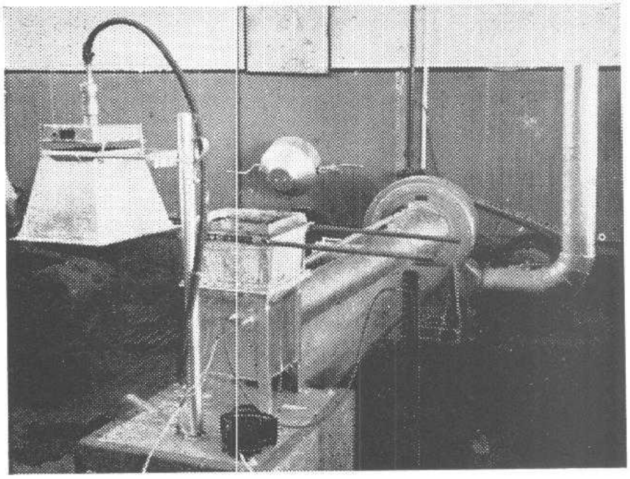
Beneficiation of a magnetite ore assaying 36·5% Fe and 44·2% SiO_2, and containing principally magnetite, quartz, hematite, kyanite and sillimanite was undertaken. Dry magnetic separation of the sample did not produce satisfactory results. Wet magnetic separation at—48 and—65 mesh sizes yielded magnetic concentrates assaying 62·5% Fe, 11·1% SiO_2 and 64·3% Fe, 9·6% SiO_2 with a recovery of about 88% iron in both cases. Dry magnetic separation at—10 mesh followed by wet magnetic separation of the rougher concentrate at —48 mesh produced a final concentrate assaying 61·98% Fe, and 12·1% SiO_2 with a recovery of 86·5% Fe. Tabling the sample at—48 mesh gave a concentrate assaying 65·21% Fe, and 8·8% SiO_2 with an overall recovery of 82·8% Fe, but higher recovery could be obtained at the expense of grade of the concentrate. Tabling at—48 mesh and magnetic separation at—65 mesh can, therefore, yield nearly the same results, because the slime and tailing loss during tabling almost balanced the loss of hematite in the non-magnetic product. Semi-pilot plant trials employing tabling as well as magnetic separation are also undertaken.

A laminated iron ore from Rajharapahar iron ore deposit, Madhya Pradesh, assaying 54·8% Fe, 11·16% SiO_2, 4·46% Al_2O_3, 0·075% P and 4·96% loss on ignition, was received from the Indian Bureau of Mines for beneficiation tests for the Bhilai Steel Plant. Quartz was the predominant gangue with ferruginous clay (altered feldspar and lateritic material) and a little magnetite. Washing and screening of the fines, which contained a large proportion of the alumina and silica in the ore, yielded a concentrate assaying 60·3% Fe with a recovery of 84·1% iron. Tabling the slime obtained by washing produced a table concentrate assaying over 60% Fe and this, when mixed with the above combined concentrate, improved the recovery to 90·1% Fe for about the same grade. Flotation of the slime after classification gave even a slightly higher recovery (91%) for nearly the same grade of concentrate. The scheme of washing followed by flotation of the fines appears to be the best, particularly in view of the large capacity of the plant envisaged.

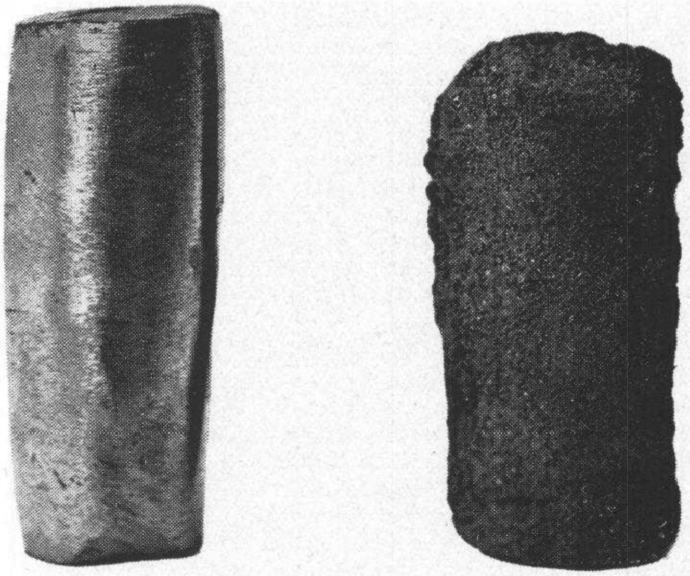
A sample of classifier overflow from the Noamundi iron ore washing plant was received from Messrs Tata Iron and Steel Company Limited for beneficiation tests. As received, the sample assayed 51·42% Fe, 12·80% Al_2O_3 and 8·5% SiO_2. It was desired to produce a—200 mesh product, assaying over 90% Fe_2O_3, for paint manufacture.

Straight tabling of the sample as received, as well as tabling after attrition grinding, yielded concentrates of the specified grade. Attrition grinding released more of the aluminous material and yielded after tabling a concentrate with lower alumina content. Though concentrates of the required grade could be produced by the above methods, they contained 10–12% of plus 200 mesh oversize material which would require further grinding in a ball mill for paint manufacture.

A sample of flue dust from the iron blast furnaces of the Tata Iron and Steel Co. Ltd.,



Sintering plant designed and constructed at National Metallurgical Laboratory.



(A) (B)

Reduced compacts as obtained before (A) and after grinding (B)

Jamshedpur, assayed 39·47% Fe, 14·38% SiO_2, 9·54% Al_2O_3, 3·30%CaO, 0·51% Mn and 0·23%P. It contained lateritic hematite, magnetite, ochre, quartz, calcite and coke dust. Tabling of the sample after classification yielded a composite product assaying 60·63%Fe, 4·62% SiO_2, 6·82%Al_2O_3 and 0·20%P with a recovery of 64·2%Fe in the product. Straight magnetic separation did not produce a satisfactory grade of concentrate.

Laboratory studies

Extensive laboratory studies were made on the sintering of iron ore fines from ore deposits at Rajharapahar, Madhya Pradesh, to feed the Bhilai steel plant. The effects of variables such as composition of sinter mix i.e. contents of coke, moisture, basicity and raw material proportions on the sintering time and on the quality of sinter produced have been studied. Optimum conditions for obtaining a self-fluxing sinter were evaluated at length with a sintering laboratory scale unit designed and fabricated in the Laboratory. Similarly laboratory studies were made on the sintering characteristics of magnetite concentrate obtained after upgrading of low grade Salem magnetite ore. The effects of variables such as basicity, coke and moisture contents in sinter mix on the sintering time and their effects on the quality of sinter produced, were investigated. Research results showed that the optimum amounts of coke and water contents were 7·0 and 9·0 per cent respectively for producing a self-fluxing sinter with a basicity ratio of 0·85.

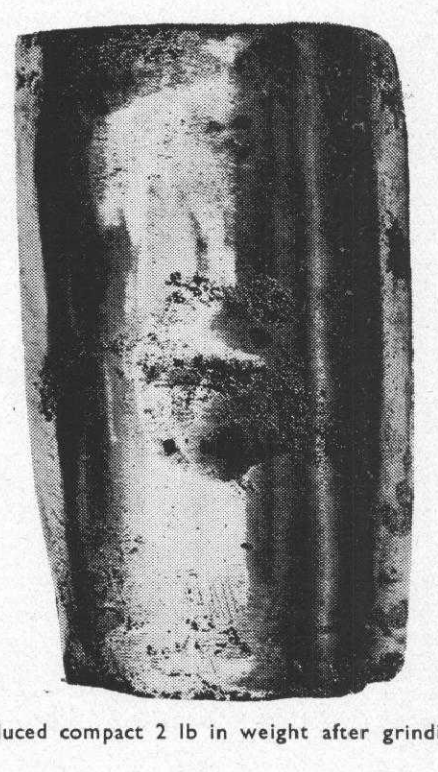
Reducibility of Salem magnetite ore

An investigation was made to assess the reducibility of Salem magnetite iron ore based on hydrogen reduction of lumps and briquettes made thereof. The temperature of reduction varied from 700–1,000° C with different rates of hydrogen flow. Reduction rate was observed to considerably slow down after 70 per cent of reduction was completed. The reduction experiments were also conducted after table concentration of the magnetite ore, these concentrates containing 5–6% silica. Likewise, tests were also undertaken on concentrate containing 13% SiO_2 obtained after wet magnetic separation of the raw ore. These studies showed that reducibility of the ore concentrates compared favourably with that of high grade hematite iron ores used in India at present for iron production.

Direct reduction of iron ore to yield usable steel

A process of producing steel directly from Indian iron ores has been investigated at the National Metallurgical Laboratory with a view to its application on a cottage industry scale.

In the process developed, crushed iron ore, dried and ground preferably finer than—70 mesh, is packed in a paper tube and embedded in solid charcoal in a sealed steel canister. The purpose of the paper tube or mould is to hold the loose fine ore in the desired shape until the charcoal has been packed round it in metal canister. The paper burns off in the subsequent operation leaving a compact mass of the ore. The canister is heated to the reduction temperature and then raised to a sintering temperature of the order of 1,100°C for several hours depending on the carbon content required in the



Reduced compact 2 lb in weight after grinding.

steel. A fairly compact steel bar is obtained after reduction which lends itself readily to hot working. Optimum conditions for obtaining full reduction and the desired density in the compact were determined initially by passing carbon monoxide gas over pellets made from ground iron ore of different mesh sizes The carbon monoxide was obtained from CO_2 by means of a reducing train. Iron ores from different Indian localities were examined. It was observed that each ore possessed different characteristics in respect of shrinkage, subsequent swelling, percentage loss in weight and reducibility.

When the reduction was carried out with charcoal, and coarse and fine mesh iron ore sizes were mixed together, the resultant density of the reduced product was higher than that obtained when only coarse or fine mesh ore size was individually treated ; in the former case, the product showed freedom from surface cracking. Variations in sintering conditions had pronounced effects on the density of the product obtained, for all ores. Reduction at 900°C and subsequent sintering carried out at 1,100°C gave a denser steel product than when the reduction was done at 750°C. High sintering temperatures such as 1,200°C gave low density products. Addition of mill scale to the charge increased the density of the steel, particularly in the case of ores low in iron contents.

The density of the sintered product obtained varied from 4 to 7. The compact could be hot worked by forging or swaging, with increase in density. The resultant material was amenable to heat treatment.

It is believed that the process has useful potential applications on the cottage industry scale in this country for the fabrication of small agricultural and other tools in rural areas where high grade iron ore is available.

Iron ores occur in most of the States of the Indian Union but several of the deposits are not rich enough or large enough to be considered as economically workable at the present day. Relatively rich deposits are to be found in Bihar, Madhya Pradesh, Orissa, Bombay, Mysore and Madras. The ancillary materials required for steel making in the normal way are coking coal, flux and refractories. So far, known coking coal is available only from the Jharia, Raniganj and Bokaro coal fields in Bihar and to a small extent in the Kanhan Valley field in Madhya Pradesh. Ores will have to be crushed and ground for the direct reduction which will cost a considerable amount of outlay for machinery, like, jaw crusher, grinding mill, etc. Fairly extensive deposits of powdery ore occur as pockets and lenses passing into one of the other types. The material crumbles to powder easily. Sieve analysis shows that the bulk of the ore will pass through 10 mesh and as much as 40 to 50 per cent may be as fine as 200 mesh. The powdery ore consists largely of hematite with some quantity of martite. This naturally occurring powdery ore is ideally suited for the process. As regards fuel any carbonaceous material such as coal dust, coke, charcoal, can be used. Electric furnace was used in the laboratory experiments, but for cottage industry a kiln similar to that used for brick making is more suitable. As a matter of fact the industry can be started in conjunction with the brick making industry where the brick kiln will be available and also the labour can be trained easily for making moulds and pots. It may be mentioned here that instead of steel canisters, ceramic pots can be used for holding the paper moulds. These pots can be made out of fireclay. Instead of paper moulds, porous sand moulds can also be used for holding the powdered iron ore.

From the above outline, it will be seen that the process is simple and does not require any expensive equipment. The investigation in the Laboratory was carried out on experimental basis with small paper moulds and as such, it is difficult to give any definite figures on the economics of the process at this stage of the investigation. Further work on direct reduction of Sulaipat ore was also done. The ore has been electro-magnetically treated to reduce the gangue material and extruded in shape of bars with different binding agents. These bars are given varying reduction and sintering treatments to study the density of the reduced product. The reduced product is further forged and rolled. With the treated ore a good crack free product was obtained which could be forged and rolled easily to obtain steel comparing favourably with that of steel manufactured by normal processes.

Investigations were carried out to establish optimum conditions for sintering and semi-stabilisation of dolomite from Chatona Pendidih area for use in steel melting furnaces in Bhilai Steel Plant. The dolomite which was mostly fine grained and of uniform quality was crushed to three different grain sizes and varying percentages of iron ore were thoroughly mixed with each grain size fraction of dolomite and fired to 1,600°C for one hour. Incorporation of 5% iron ore to dolomite crushed to pass 25 mm sieve and firing to 1,600°C for one hour gave a good clinker which did not hydrate for more than a month.

Ferro-alloys

Development work on the production of ferro-alloys based on indigenous raw materials has been undertaken including a process for the thermal beneficiation of indigenous ferruginous chrome ores. Investigation work shows that an ore with Cr : Fe ratio of 1·6/1 is upgraded to a product with Cr : Fe ratio of 3·5/1 consistent with 80–85% chromium recovery. Research work relating to the production of low carbon ferro-chrome by reducing chromite with ferro-silicon and aluminium has been carried out. A process has been worked out for the production of vanadium pentoxide from vanadiferrous magnetites of Singhbhum and Mayurbhanj Districts. The vanadium pentoxide thus produced will be utilised for the production of ferro-vanadium or the oxide used as such as a Catalyst. The role of alumino-thermic reactions in the production of ferro-alloys has been dealt with on the basis of investigations conducted at the National Metallurgical Laboratory. Reference may also be made to other projects on the production of ferro-alloys particularly the smelting of ilmenite sands, vacuum treatment of high carbon ferro-chrome, etc.

L-D Semi-Pilot Plant investigations

A basic lined converter having a capacity of treating 250 lb of molten metal per heat has been designed and fabricated in the National Metallurgical Laboratory to study the possibilities of refining high silicon medium phosphorus Indian pig irons to desired grades of carbon steel by oxygen steel making processes. By adopting a specially timed double slagging technique and adjusting the oxygen flow-rate at 10 cft. per minute per cwt. metal and simultaneously controlling the temperature by addition of limestone/lime and iron ore/mill scale assisted by suitable arrangement of oxygen tip position on the buffer slag zone during the second stage of lancing after removing the siliceous slag in the first stage, following results have been obtained from Indian pig irons with an average composition as follows:

Carbon 3·5–4·0%; Silicon 1·5–2·0%; Phosphorus 0·35–0·4% and Sulphur 0·035–0·04%.

Metal charge
%

	C	Si	P	Mn	S
1.	3·3	1·64	0·35	0·74	0·044
2.	3·08	1·96	0·36	0·78	0·032
3.	3·46	1·82	0·36	0·76	0·037
4.	3·38	1·63	0·38	0·77	0·037
5.	3·7	1·5	0·37	0·78	0·036
6.	3·24	1·88	0·38	0·80	0·035

Blown metal
%

	C	Si	P	Mn	S
1.	0·02	0·04	0·04	Traces	0·028
2.	0·03	0·03	0·05	0·05	0·023
3.	0·02	0·019	0·036	0·09	0·03
4.	0·29	0·03	0·058	0·04	0·02
5.	1·06	0·05	0·066	0·06	0·03
6.	0·025	0·02	0·03	0·08	0·02

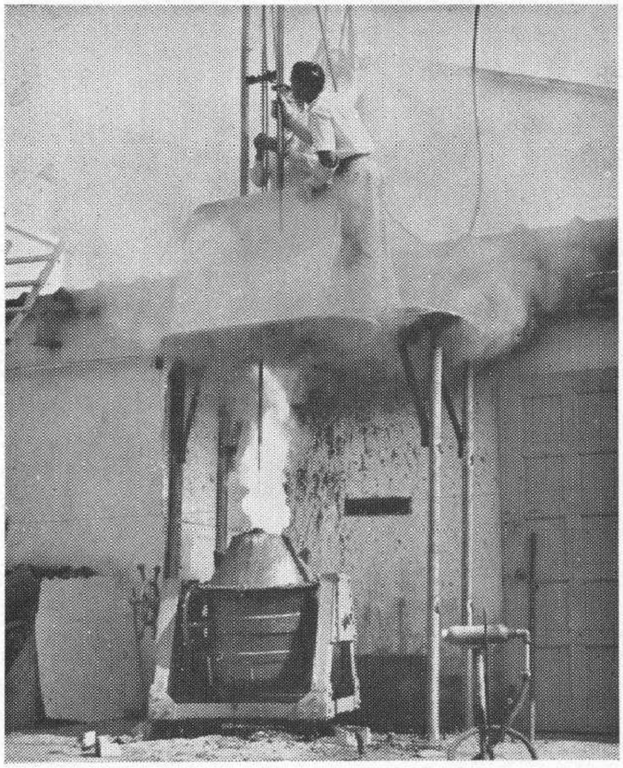
Time of Oxygen lancing—1st stage 4-5 minutes
2nd stage 6-7 minutes
at oxygen pressure 80–150 lb/sq. in.

The average slag composition was as follows:

	CaO	SiO_2	FeO	Fe_2O_3	P_2O_5	MgO	MnO
1st stage slag	33·6	33·5	11·3	3·9	0·58	8·6	7·9
2nd stage slag	25·8	14·1	3·80	4·8	3·0	12·6	2·2

The average physical tests of the steels obtained are given below:

Hardness	...	120–126 BHN
Izod impact test	...	70–72 ft. lb.
Tensile strength	...	Yield point 20-23 tons sq. in.
		Ultimate tensile strength (tons/sq. in.) 24–26
		Elongation % (on 1″ G.I.) 30–33

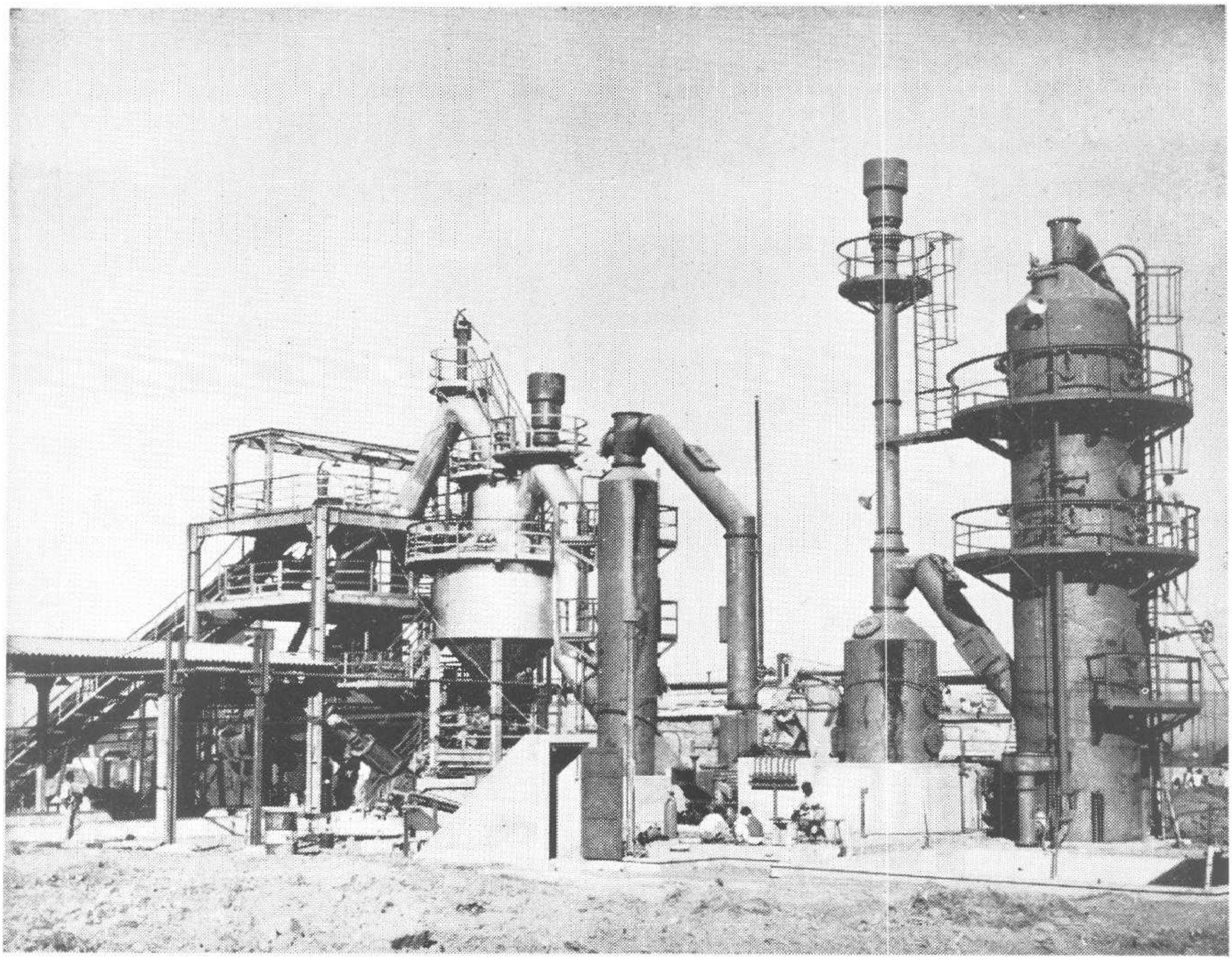


"L-D" Converter—designed and fabricated at the National Metallurgical Laboratory—in operation.

Oxygen consumption was of the order of 1,900–2,000 cft. per ton of steel made. These experiments were done in a small vessel with oxygen injection and the results thereof cannot be directly interpolated on industrial scale. Yet it is felt that they provide sufficient nucleus data for much bigger scale implementation. Fuller details of the work done on L-D process of steel making are given in another paper to be presented before the Symposium. We have currently designed a bigger L-D vessel of over 6 tons capacity for oxygen steel-making investigation in conjunction with Low-Shaft Pilot Plant, work on which is to commence shortly.

Low-Shaft Pilot Plant Furnace Project

Work on Low-Shaft Pilot Plant Project is expected to start shortly. This Pilot Plant has been set up by the National Metallurgical Laboratory in collaboration with Metals Committee of Council of Scientific and Industrial Research at a capital cost of over Rs. 27 lakhs and recurring grant of Rs. 10 lakhs for the Second Five Year Plan.



15 tons per day Low Shaft Furnace Pilot Plant set up by the National Metallurgical Laboratory at Jamshedpur.

As referred to earlier, developments in scientific technology and engineering have brought in its wake important changes in the production of iron and steel. The conventional blast furnace which is sine qua non for economic iron production, requires high grade raw-materials such as hard but porous metallurgical coke and either lumpy iron ore or sintered iron-ore. The reserves of high grade raw-materials are gradually decreasing all over the world and alternative methods of iron-making are being actively investigated. While India has plentiful reserves of rich iron ores, such processes have special significance in India due to poor reserves of coking coal and their occurrences over small geographical region. Among such alternative processes, the low shaft furnace process has got several attractive features. These furnaces are more or less similar to the blast furnace with considerable reduction in its effective height which widens the choice of raw materials and allows the utilisation of furnace gas of high thermal value. Such furnaces are round, oval or rectangular in section. Our Low Shaft Furnace Pilot Plant has a production capacity of 15 tons of pig iron per day and will be able to treat different inferior grades of raw-materials. The object of the comprehensive investigations is to assess the possibilities of making commercial grades of pig iron with raw-materials like soft iron-ores, iron-ore fines, beneficiated magnetite iron-ore with various non-coking high ash coals or carbonised lignite, plentiful supplies of which exists in India but are unsuitable for exploitation in conventional blast furnaces. The results of these extensive investigations will be of great value and enable the establishment of small units for iron and steel production in different parts of India.

The 15 tons per day Low Shaft Furnace Pilot Plant supplied by the Demag-Humboldt Niedeschachtofen, Duisburg, West Germany operates on iron-ore, limestone, non-coking coals briquettes. The daily operation of the plant needs over 100 tons of raw-materials. The plant has provision for crushing the raw-materials which are then elevated by bucket-elevator and stored in five storage bunkers. These are drawn from the bunkers in calculated proportions by a moving trolley with a bin, and dumped in a hopper. The mixed raw materials are lifted by bucket elevator and fed into a vibrating screen and thence into mixers where coal-tar pitch is added. The intimate mixture of ore, coal and limestone passes through dough mixers and then briquetted under pressure in roller briquetting machine about six tons of briquettes will be necessary to produce a ton of pig iron. Weighed amounts of briquettes are charged into the furnace by a system of belt conveyors. The furnace is lined with carbon-blocks up to the hearth level. Blast supplied by turbo-blower will be preheated to about 600°C in a metal tube recuperator. At the start of each individual campaign, the blast will be preheated by oil burners in the recuperator. After furnace gas becomes available, it will be used for pre-heating the blast. The slag from the furnace will be granulated for further use. Molten pig iron will be cast in the form of pigs in the casting house. The raw gas will be thoroughly cleaned by its passage through the dust catcher, primary cooler, drop-catcher and final cooler and a part of it will be utilised for heating the blast in the recuperator whilst the balance be bled at this stage. The recovered tar and dust will be utilised for making briquettes.

The power required for the operation of the plant will be supplied from a 500 kVA transformer which will step down the voltage from 6,600 to 450 volts. The total cooling water requirements for cooling the furnace and for gas cleaning is about 1 million gallons a day. With the installation of water cooling and circulating tanks, make-up water to the tune of 10,000 cft. per day will be needed. Water from the furnace cooling will be utilised for slag granulating and water from the gas cleaning system and from the tuyere cooling will be recirculated after cooling through sprays so as to bring down the make-up water consumption to its minimum. Processed steam will be supplied by coal fired steam boiler which will supply 1 ton of steam per hour, at a pressure of 7 atmospheres with a degree of superheat of about 350° C. It has been provided with filtration and water softening units. Fuller details of this Pilot Plant are given in another paper to be presented in the Symposium.

In conclusion it is stated that during the period following the establishment of this Laboratory, progress in research in many fields of iron and steel metallurgy has been steady and rewarding, placing a high premium on ingenuity, scientific research and development work.

DISCUSSIONS

Dr. A. Lahiri, Director, C.F.R.I., (Jealgora) : Some of the points raised by Dr. Nijhawan are worth thinking about particularly in the context of planning the iron and steel industry in the Third Plan and afterwards. There is a feeling that we are extremely short of coking coal, though we have almost unlimited reserves of iron ore and that our chief bottle-neck in the production of iron and steel might be coking coal. The facts as they stand are, however, not exactly so. Our real problem today is that of a sound organisation rather than having more reserves. Even with the 1,500 million tons which is a figure obtained several years back on very meagre data, we still have a good amount of coal yet. We could produce with it 750 million tons of steel and apart from that I would like to give the background of those data and reserves and put you metallurgists at peace that you need not be worried about the coking coal situation. In the Jharia Coal Fields there is a number of coal seams representing a reserve of nearly 15,000 million tons. A single bore hole going to 3,000 ft. in what is known as the Barren Measures has proved the existence of the whole of Jharia Field below this strip though much of the coal is burnt and of inferior coking quality. In addition to that, we have at the CFRI been working on this problem on pilot plant scale and here in Jamshedpur in the coal blending and coke research laboratory, for the last ten or twelve years. We have found that quite 50% of the coal required for making a good coke for conventional blast furnaces could be obtained from other sources, so that for the next years to come, perhaps for the next 25, 30 or even 50 years, there may not be any actual trouble about resources but at the same time this does not mean that there is not any problem ; the problem is that we have the coking type of coal but not the exact quality required. Metallurgists on their side could also try to ease the situation to some extent. You can afford to do this if you adopt 100% sintering of ore. By this method you can relax your specification for ash and also reduce consumption of coke. For every 1% of ash extra that they could accept in the blast furnace above, say 20 or 22% ash in coke, we shall have 10% more reserves of coking coal, because for every 1% of reduction of ash we have to lose about 10% of the coal which has to be either burnt up or just stored back in the mines. Other aspects of the problem will be discussed in some papers contributed to this Symposium from our Institute. I would like to emphasise again that just because we are short, or we think that we might be short, we should not forget about the fuel economy in the blast furnace. You have also to adopt scientific principles for preparation and blending of coal for coking. This means right technique and equipment. Now the main problem that the Indian iron and steel industry would face with regard to the supply of the most important raw materials after iron ore, is that today a large scale industry is being fed by almost a cottage industry ; this is because coal mining in this country has remained in the hands of very small entrepreneurs, particularly so in the Jharia and neighbouring coal fields. Tatas have been very wise in arranging their own mines or having their coal supplied by big miners, but the public sector plants today are in the ridiculous position of having to beg from door to door, even from collieries producing 100 tons a day to feed a steel plant of the size of one or two million tons a year. This is in short the situation today and apparently it is more on the side of organisation and on the side of conservation in utilisation. The latter aspect lies in the hands of metallurgists and that is in fact the real problem. Otherwise, for the next 20 to 25 years to come I believe there should not be any difficulty in getting the raw materials and we need not even have the fear that in the near future, the development of the iron and steel industry in India will be stumped because of raw materials.

Dr. B. R. Nijhawan (*Author*) : I should thank Dr. Lahiri for his thought provoking remarks. If I may say so, there are two ways of expressing the same thing. We are either brothers in arms or partners in crime but the conclusion arrived at is essentially the same.

As pointed out, it is probable that we may not have to worry about coking coal for the next 25 years or so and we might also discover some more metallurgical coal deposits in the years to come. But at the same time, we know that even countries having good deposits of metallurgical coal devote considerable attention to the subject. We are to go ahead with our integrated iron and steel plants based on conventional processes utilising metallurgical coal but I believe we should also explore other avenues and alternative methods of iron-making to find out ways and means of utilising non-metallurgical coals. Dr. Lahiri has been modest while referring to the research he has conducted in this connection. Good work has been done at the CFRI relating to the optimum utilisation of the existing raw materials by suitable coal blending and experimentation to improve upon the coking properties of the coal normally known as poor or medium coking coals. On this particular subject which is not fundamentally my domain, I am sure Dr. Lahiri will throw more light in the course of this Symposium.

Regarding the subject of economy of fuel for an equal iron output, there are several methods which are being investigated all the world over. The U.S.A and the U.S.S.R. as well as many other countries are examining how fuel consumption can be cut down to yield the maximum output of iron. A special lecture would be required to describe the various methods to improve upon coke consumption such as, high top pressure, use of sinter, control of blast humidity and many other modern developments which go to increase the output of iron in relation to the coke consumed.

Mr. B. S. Sharma, Mysore Iron and Steel Works : I have a clarification to seek from Dr. Nijhawan on the direct iron ore reduction to yield usable steel. He has stated that a compact bar steel is obtained after reduction and lends itself to hot working. He has later mentioned about pellets over which carbon monoxide is passed. I would like to know if hydrogen has also been included in the carbon monoxide and if any kind of work has been done in this laboratory on this matter.

Regarding oxygen steel making it is known that the cost of oxygen rises very steeply as the degree of purity increases. It has been stated that oxygen of 99·7 or even 98·8% purity will be required. I would like to know if, in the case of a small converter of 10 to 12 tons, oxygen purity could be brought down to 96 or 97% to have a cheaper oxygen though it may prolong the blow period. Will it be worthwhile examining the economics of a slightly lower purity of oxygen for a longer period of blow and has any work been done in this direction ?

Dr. B. R. Nijhawan (*Author*) : We have not done any particularly advanced work on hydrogen reduction of iron ore except in so far as it relates to the determination of reducibility studies for the iron ore magnetites. We utilised the coke oven gas because the process as investigated by us will essentially yield carbon monoxide and we wanted to determine the optimum reducibility relationship or optimum conditions for such reduction.

Regarding the subject of L-D steel versus purity of oxygen I must say that we have used only cylinder oxygen gas which is of high purity but on the subject of lesser purity oxygen, I would reserve my comments on this matter till Mr. Gupta of the Indian Oxygen and Acetylene Co. and his British associate from the U.K. tell us more about it.