Some problems of iron- and steelmaking in the Hindustan Steel plants

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SYNOPSIS

This paper surveys the basic raw materials and operational data pertaining to three iron and steel plants of Hindustan Steel Ltd. Particular difficulties and specific problems associated with Indian raw materials for iron- and steelmaking are discussed along with metallurgical processing techniques introduced or projected as remedial measures. These measures relate to beneficiation and upgrading of some of the raw materials, and projected developments have been outlined in relation to economics of operation and productivity factors. Reference is made to results obtained with the use of unbeneficiated iron ore fines for self-fluxing sinter-making at one of the plants of Hindustan Steel.

Some results of systematic investigations of Indian raw materials carried out at the National Metallurgical Laboratory for Hindustan Steel are referred to with a view to promote better understanding of the problems of iron- and steelmaking with indigenous raw materials under Indian climatic conditions. SR78D

INTRODUCTION

THE CREDIT for pioneering the growth of a fully integrated and well-planned iron and steel industry in India undoubtedly goes to the house of Tata, which started from a humble beginning and grew to a mighty iron and steel complex. The Government of India has further, under the tempo of five year plans, fully realized the importance of well-knit heavy iron and steel bases to feed the chain reaction growth of secondary and processing engineering industries, in turn forming the backbone of consumer industries catering to the requirements of diverse products essential in times both of war and peace. Even though the iron and steel industry is highly capital intensive, it cannot be left to the vagaries of international trade agreements and barter arrangements to meet iron and steel requirements for almost unlimited applications in industry. This then has underlined the dynamic planning and growth of the iron and steel industry under the impact of our successive five year plans both in the private and public sectors behind the rather well-known difficulties, often foreseen and at times readily unaccountable, through which a developing country, striving for self-sufficiency in iron and steel, has inevitably to pass. It must, however, be conceded that the rise of such a developing industrial economy, despite acute shortage of trained specialists and funds, both indigenous and foreign, represents 'growing on one's own legs' and is not an industrial superstructure with an alien base, unlikely to withstand the stresses of peace and strains of war. This then again underlines the basis upon which the growth of Hindustan Steel has taken place with its three heavily integrated iron and steel complexes and its ultimate aim of attaining self-sustaining economy in its own fields to assist the country to what the economists term as the 'take-off' stage. It is to be admitted that this mighty growth has not been without its tale of sweat and toil and yet there could be little doubt about the ultimate objectives of attaining self-sufficiency in iron and steel, provided the problems of establishment, growth and maintenance of the iron and steel industry at its peak operational efficiency are squarely faced and not lost sight of in the maize of endless discussions. In this review, an attempt is made to outline some of the problems and data on iron- and steelmaking in the plants of Hindustan Steel Ltd.

HINDUSTAN STEEL LTD

Hindustan Steel Ltd at present have three steel plants, one situated at Rourkela, one at Durgapur, and one at Bhilai. The initial capacity of each plant is a million tons of ingot steel annually. The Rourkela plant is planned to be expanded to 1·8 m. tons, Durgapur to 1·6 m. tons, and Bhilai to 2·5 m. tons ingot steel annually by the end of the third five year plan. The new plant at Bokaro, planned for establishment by 1966 will be initially designed for 1 m. tons ingot steel annual capacity and capable of further expansion. The Rourkela plant produces all flat products, i.e. strips, sheets, and plates. It also produces cold rolled sheet, tinplate, galvanized sheet, and pipes from 8in to 20in dia. Durgapur plant produces light structurals, light rails, merchant bars, billets, sleepers, fishplates, and wheels, tyres and axles for the railways. The Bhilai plant produces heavy rails, heavy structurals, merchant bars and billets. The new Bokaro plant will be designed to be a flat products plant, producing plate, strip and sheet. Hindustan Steel are also concerned with an alloy, tool, special and stainless steels plant, with an initial annual capacity of 80 000 tons of ingots, which can be expanded to 160 000 tons and finally to 300 000 tons annual capacity. The location of the iron and steel plants against raw materials centres of supply, etc., is shown in Fig. 1.

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RAW MATERIALS

The problems of an iron and steel plant inevitably revolve around its basic raw materials, production techniques, skill of operational personnel, ability to keep the plant units in efficient trim and mechanical maintenance and, last but not least, flexibility to adjust the applications of latest developments and innovations to Indian conditions. These problems should be studied rationally so that an objectivity of outlook prevails instead of the tendencies to explain away what indeed might have been or should be.

The basic raw materials for an iron and steel industry are iron ore, fuel, the fluxes, steel scrap, etc. Whilst it may not be possible to examine each of these raw materials in this paper, references have been confined to Indian iron ores and limestones used as flux for iron- and steelmaking.

IRON ORES

Despite somewhat opposing views, it has now been established that Indian iron ores may not be classified as some of the classic rich iron ores of the world in a strictly metallurgical sense. The metallurgical characteristics of a classic rich iron ore will depend basically on the nature and characteristics of the ingredients constituting its

TABLE I Iron ore requirements for iron and steel plants, 1965–66

	(Million tons per year)		
Steel plants	Steel production	Foundry grade of pig iron	Total ore requirements
Rourkela	1·8	—	3·5
Durgapur	1·6	0·3	3
Bhilai	2·5	0·3	4 to 4·5
Bokaro	1·0	0·35	2 to 3
TISCO	2·0 }	0·3 over	3·5
IISCO	1·0 }		2·0
Small iron production plants including Mysore iron & steel plant (Bhadravati)	—	0·25	0·4
	9·9 Say : 10·0	1·5	18 to 20

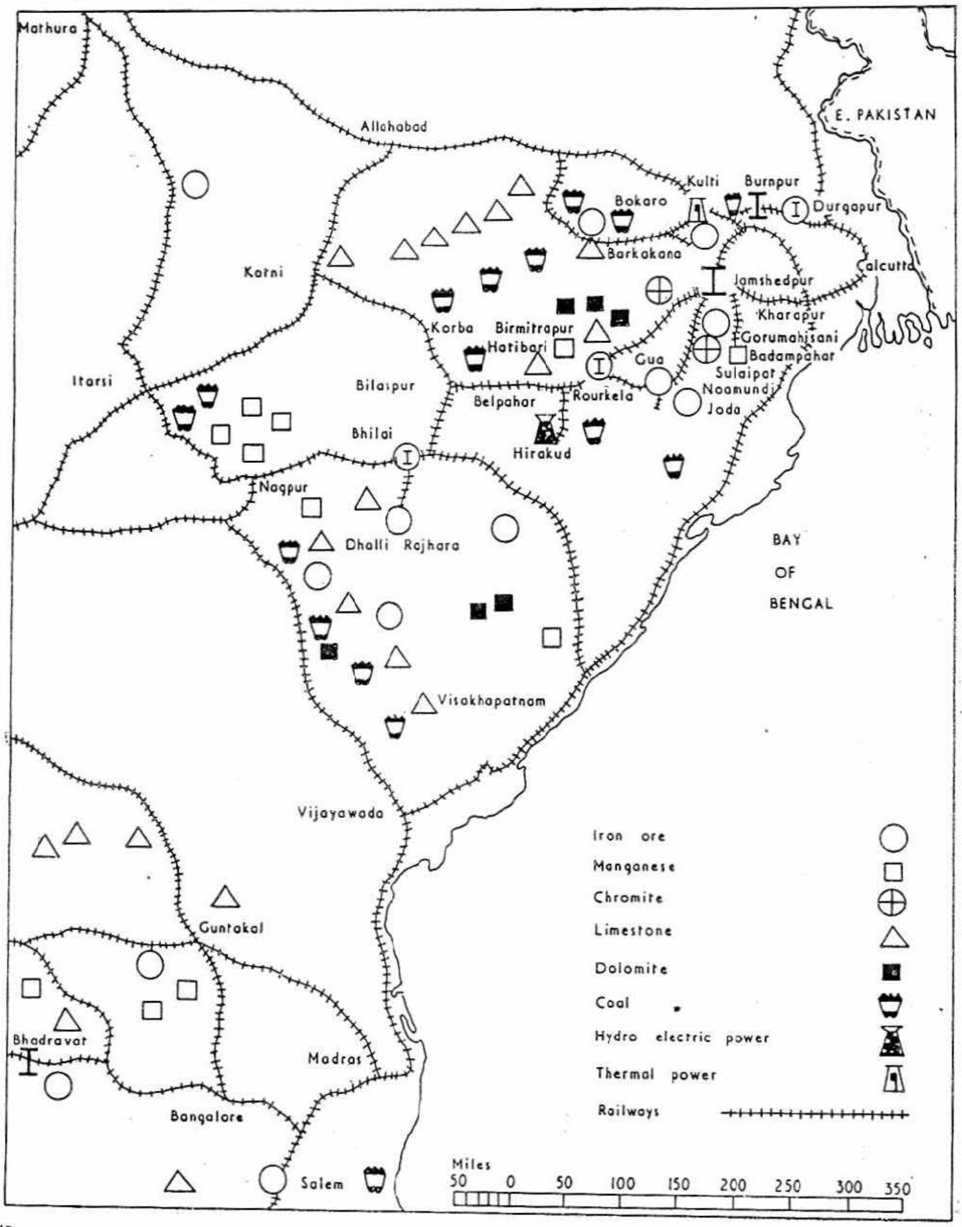
gangue and the latter's physical mode of distribution and structural association with metallic values of the ore and the gangue's selective presence in different ore size fractions. The gangue content of some of the Indian iron ores resides in the finer ore fractions such as in −½in which, under the heavily mechanized iron ore mining conditions now introduced in India, can constitute between ⅓ and ½ of the total iron ore thus mechanically extracted. The full impact of the problem with which India will be faced, relating to the release, storage and use of the masses of iron ore fines that will be mined during our successive five year plans, will increase so much that it will defy scientific solution unless adequate attention is focussed on this important subject and effective steps are introduced to utilize such iron ore fines.

The production of iron ore in the country is being rapidly stepped up. In 1960 about 10·6 m. tonnes of iron ore were mined. The production of iron ore during 1965–6 may be expected to rise to 32 m. tonnes. On this basis, the quantity of iron ore fines that will be released during 1965–6 will be of the order of 10–12 m. tonnes representing broadly about 60 m. rupees (about £4½ m.) in value. The problem cannot be balanced strictly in terms of financial aspects only but basically refers to wasteful discarding of our national assets and non-utilization of iron ore fines for recovery of their metallic values.

The annual iron ore requirements for iron and steel plants in operation today are given in Table I for the period 1965–6.

Further projected developments in these fields are given in Table II.

The above classification is based on expected annual output of 18–20 m. tons of iron ore for domestic consumption and 12 m. tons for exoprt. It will, therefore, be



1 *Location of iron and steel plants and raw materials centres of supply*
(I) *Hindustan steel plants*
I *Other steel plants*

TABLE II Future developments of iron ore

Year	Steel capacity installed	Iron ore requirements for home use	Home consumption Approximate installed capacity at large mines (million tons per year)						Required for export	For export Kiriburu and Bastar/Raipur
			Rourkela (Barsua)	Durgapur (Bolani)	Bhilai (Rajhara)	Tisco (Various captive mines)	IISCO (Gua)	Bokaro*		
1960–61	6·00	9 to 10	2·00	1·00	2·00	3·10	2·00		3·40	
1965–66	10·00	19·00 to 20·00	3·5	3·00	4·50	3·50	2·00	Up to 3·00 (from Kiriburu about 1·5 m. tons fines)	12·00	12 million tons between Kiriburu and Bastar/Raipur

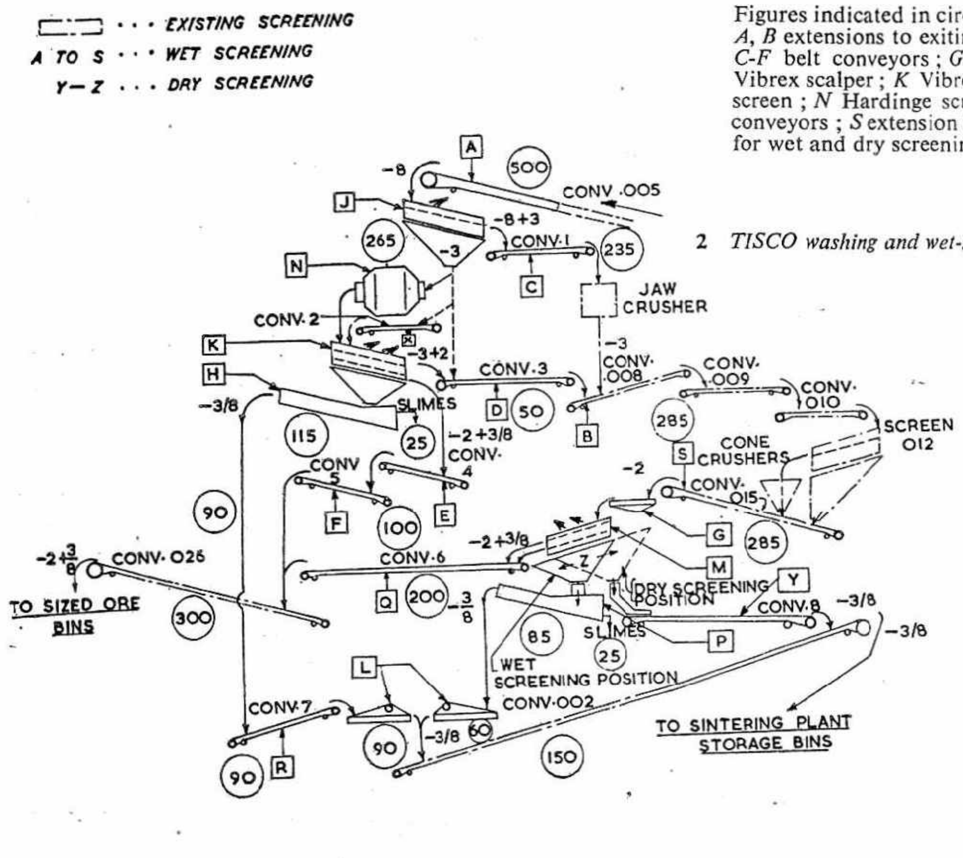
* Largely Kiriburu and new mines Taldih, Megha-thaburu and Sasangdah

realized that the subject of utilization of iron ore fines has to be rationally and comprehensively examined for the utilization of what will, one day, constitute perhaps the biggest national waste of assets and which no other country is likely to permit, in view of the availability today of advanced technology for their utilization.

INDIAN IRON ORE FINES

Utilization of iron ore fines is complicated by Indian weather conditions. The subject was quite simple when hand mining and selective mining yielded lump size iron ore material from which the fines were discarded *in situ*. However, with the introduction of heavily mechanized mining, separation of the ore fines from the lumps by manual methods cannot be attempted or successfully accomplished. It is thus obvious that all the iron ore fines mined would be sent to the ore handling and screening plant along with the lumpy material, which can cause severe complications. It has been the experience of the steel plants that under Indian weather conditions, the screening and handling system becomes completely blinded and choked due to the muddy conditions caused by the action of tropical rain on the admixture of iron ore fines with the lumpy material. It is in this context that the entire subject would perhaps have assumed somewhat less significance, had it not caused serious difficulties and dislocations in ore handling and blinding of the ore screens under monsoon conditions.

In the absence of suitable ore handling, screening, and beneficiation methods to prevent the blinding of the screens, such as through wet screening, and scrubbing the iron ore followed by dewatering classifier treatment (the slime containing at times up to 25–40% insolubles), a modern ore handling and screening plant, involving capital



Figures indicated in circles are tons/h
A, *B* extensions to exiting conveyors
C-F belt conveyors ; *G* vibrating feeder ; *H* Dorr classifier ; *J* Vibrex scalper ; *K* Vibrex screen ; *L* Eliptex screen ; *M* Vibrex screen ; *N* Hardinge scrubber ; *P* Dorr classifier ; *Q,R,X,Y* belt conveyors ; *S* extension to existing conveyor ; *Z* travelling hopper for wet and dry screening

2 *TISCO washing and wet-screening plant*

TABLE III Bolani iron ores (Durgapur steel plant)

	Crushing, dry screening and utilization of fines	Crushing, dry screening and rejection of —½in	Crushing, washing, wet screening and dewatering of fines (—⅜in)	Crushing, washing, wet screening and concentration of only —⅜in fines by jigging or cyclone heavy media separation	Crushing, washing, wet screening and concentration of both lumps (—2in plus ⅜in) and fines (—⅜in) by HMS/jigging
Analysis of final beneficiated iron ore Fe%	56·5	59·75	59·86	61·63	63·36
SiO_2%	5·2	2·29	2·55	1·81	1·49
Al_2O_3%	6·4	5·33	5·17	4·18	3·05
Yield, tons/d	14 000	9 128	12 460	10 220	8 400
Capital cost of ore treatment plant, crores* rupees	2·50	2·50	3·36	4·50	5·40
Cost of treatment/ton beneficiated ore, rupees					
(a) Capital cost	0·894	1·372	1·348	2·20	3·22
(b) Operating cost	0·180	0·276	0·236	0·40	0·60
(c) Cost of raw ore as mined	5·00	7·668	5·618	6·85	8·33
Total cost/ton prepared ore	6·074	9·316	7·202	9·45	12·15
Tons ore required/ton pig iron	1·706	1·614	1·611	1·563	1·522
Total cost ore required/ton pig iron, rupees	10·36	15·03	11·60	14·77	18·49
Difference in alumina, %	...	1·07	1·23	2·22	3·35
Expected production cost/ton saving of pig iron in blast-furnace iron smelting owing to decrease in alumina by beneficiation, rupees	...	4·28	4·92	8·88	13·40

* 1 crore=10 m.

outlay of several million rupees, can be easily brought to a stand-still. As such, the establishment and operation of a sinter production plant, which naturally consumes these iron ore fines, is seriously hindered, if not altogether blocked. It is thus of paramount importance that all avenues should be explored : (*a*) to separate the fines from the lumpy iron ore materials both in fair and rainy weather and (*b*) to utilize the iron ore fines thus separated to the maximum national advantage for home smelting. Comprehensive investigations[1–3] have been undertaken at the National Metallurgical Laboratory on pilot plant investigations of Bolani iron ores for Durgapur, Barsua iron ores for Rourkela, and Kiriburu iron ores for the National Mineral Development Corporation (Appendixes I–IX). There are also investigations on Rajhara iron ores for Bhilai steel plants. Further investigations will cover iron ores from Taldih, Sasungdah captive iron ore mines of Hindustan Steel Ltd. Detailed investigations were also completed for different iron ores used by the Tata iron and steelworks which have formed, to some extent, the basis of their ore beneficiation programme.[4]

It is most gratifying to note that the Tata Iron and Steel Company Ltd has recently commissioned its wet screening plant for iron ores, set up at a capital cost of 8·7 m. rupees, to be used later in the blast-furnace for increasing production of pig iron. Deterioration in the quality of iron ore set in after introduction of mechanized mining in Noamundi and Joda mines which, between them, supply 2·35 m. tons of ore out of an estimated total annual requirement of 3·4 m. tons for production of 2 m. tons of steel ingots. TISCO washing and wet screening plant (Fig. 2) is the first of its kind in India and will crush and wet-screen 500 tons of ore/h.[5] The installation of this plant will pave the way for similar beneficiation and wet screening plants at the Rourkela, Durgapur, and Bhilai mines. The wet screening operation starts when the ore is brought from the tippler by means of a conveyor belt and fed into a screen which has facilities for wet screening. This screen separates them into two sizes : those above and those below 3in. Since the former are not sized ore, these go to the jaw crusher for further crushing, while the latter are conveyed down to a scrubber for thorough scrubbing and washing treatment so that adherent clayey materials are removed. Thus washed and cleaned, the materials travel down to a doubledeck screen with openings of 2in and ⅜in. Here ores come in three sizes : those over 2in, those between 2in and ⅜in, and those below ⅜in. Since the ore above two inches is still not of the required size, it is fed into a secondary crusher. Material between 2in and ⅜in, constituting the sized ore, is sent to bins as blast-furnace feed. The ore below ⅜in, before agglomeration, is treated in classifiers to effect a separation at 100 mesh. High alumina and silica ore fines below 100 mesh are rejected, while those above are retained for sinter. Tatas also have a long range project for ore treatment for establishment at the Noamundi mine.

Perhaps the most important method of utilization of iron ore fines is the use of sinter, including self-fluxing sinter. The use of sinter (self- or non-fluxing) in iron smelting is no longer of merely academic interest nor does it present any novel features. Iron production plants are in operation all over the world with as much as 100% sinter charge with considerable increase in iron productivity and production potential. These sintering techniques utilize almost the entire iron ore fines released during mechanized mining and offer an acceptable solution in two ways : one being the effective utilization of the iron ore fines, which otherwise will present serious stacking and storage problems, and the other, increasing the metal iron production by extracting the metallic values of these ore fines through the medium of the sinter. Obviously if 40 units of iron ore fines of 100 units of mechanized mined iron ore are to be discarded, cost of the mining operation will be high. Therefore on the basis of mining cost alone those 40 units of iron ore fines must be used by all possible techniques acceptable under Indian weather conditions and operational facilities.

Even where ores of good quality are available, as in the USSR, sintering helps to ensure ores of uniform quality and yield a self-fluxing burden to the blast-furnaces. In

TABLE IV Barsua iron ores (Rourkela steel plant)

	Crushing, dry screening and utilization of fines		Crushing, drying and rejection of $-\frac{1}{2}$in		Crushing, washing, wet screening and dewatering of fines $-\frac{3}{8}$in		Crushing, washing, wet screening and concentration of only $-\frac{3}{8}$in fines by jigging or cyclone heavy media separation		Crushing, washing, wet screening and concentration of both lumps (—1in plus $\frac{3}{8}$in) and fines ($-\frac{3}{8}$in) by HMS/jigging	
Analysis of final beneficiated iron ore	Fe% SiO_2% Al_2O_3%	52·47 4·89 11·05	Fe% SiO_2% Al_2O_3%	56·18 3·37 9·35	Fe% SiO_2% Al_2O_3%	55·42 3·18 9·52	Fe% SiO_2% Al_2O_3%	58·52 2·53 7·34	Fe% SiO_2% Al_2O_3%	62·16 1·72 4·67
Yield tons/d	14 000		7 798		12 012		9 352		7 965	
Capital cost of ore treatment plant, 10^7 rupees	2·50		2·50		3·36		4·50		5·40	
Cost of treatment/ton beneficiated ore, rupees										
(a) Capital cost	0·894		1·6034		1·40		2·406		3·388	
(b) Operating cost	0·180		0·180		0·226		0·400		0·600	
(c) Cost of raw ore as mined	5·00		8·976		5·828		7·485		8·788	
Total cost/ton prepared ore, rupees	6·074		10·7594		7·464		10·291		12·776	
Tons ore required/ton pig iron	1·838		1·716		1·74		1·647		1·551	
Total cost of ore required/ton pig iron, rupees	11·162		18·47		12·98		16·93		19·81	
Difference in alumina %	...		1·70		1·53		3·71		6·38	
Expected production cost/ton saving of pig iron in blast-furnace iron smelting owing to decrease in alumina by beneficiation, rupees	...		6·80		6·12		14·84		25·52	

the case of lumpy iron ores being fed into the blast-furnaces in India during the rainy season, a considerable amount of fines adheres to the ore lumps. If these fines are removed from the lumpy material by simple treatment such as washing and scrubbing and wet screening, the lumpy ore materials would present maximum burden permeability to the blast-furnaçe, yielding increased productivity.

The investigations undertaken by the National Metallurgical Laboratory have undoubtedly aroused the interest of the Indian iron and steel industry in not only fully appreciating the desirability but also the scientific necessity of adopting optimum beneficiation techniques in the context of Indian weather conditions coupled with the nature and quality of Indian iron ores being exploited. It may also be mentioned that the interest of the Parliamentary Estimates Committee was equally well aroused in the potentialities of beneficiation techniques *vis-a-vis* utilization of iron ore fines, as also turning the latter into useful mineral assets by agglomerating them into acceptable metallurgical grades of blast-furnace sinter. Though early doubts in some quarters on the inescapability of introducing optimum beneficiation techniques have been dispelled, important issues relating to economics and degree of beneficiation required have been raised at certain levels. These points will be explained in relation to economics of iron production, based on the adoption of requisite beneficiation techniques, taking into account the latter's capital and operational cost figures in relation to lowered costs of iron production, despite some inevitable metallic loss during beneficiation cycles.

ECONOMIC EVALUATION OF BENEFICIATION OF IRON ORES OF THE HINDUSTAN STEEL AND NATIONAL MINERAL DEVELOPMENT CORPORATION

The overall economics of beneficiation of iron ores have to be evaluated taking into consideration both the increased cost due to beneficiation and the ultimate reduced cost of production of pig iron in the blast-furnace by way of lower coke rate, slag volume and higher production, with the use of beneficiated ore.

It is very difficult to estimate precisely the actual reduction in coke rate, slag volume and increased production, unless operational figures are available for the practice employed in an iron and steel works. However, for convenience of calculation, certain assumptions are made which may be considered sufficiently realistic to indicate general trends. The assumptions made for these calculations are :

(i) The cost of raw ore as mined is taken at 5·00 rupees per ton. Transport charges for ore are not included in this
(ii) Beneficiation plant is assumed to operate with a capacity of 14 000 tons of run-of-mine ore per day
(iii) Capital cost of the plant does not include cost of mining equipment and township, but includes cost of machinery, erection, building, water, and power supply to the plant
(iv) For every 1% reduction in the alumina content of the ore achieved by beneficiation, the coke rate and flux rate would decrease by 85 lb and 135 lb respectively per ton of pig iron made. The increase in production of pig iron would be about 2·5%. Due to these factors, the overall saving per ton of pig iron produced would be 4·00 rupees after allowing for depreciation, etc.

The calculations made on the above basis are tabulated in the case of different iron ores. The flow sheets of beneficiation treatment are also included. In some countries, iron ore enrichment has been shown to decrease specific coke consumption by 2% to 3% and to increase blast-furnace productivity by 2–4% for every additional 1% of iron in the ore concentrate. The increased benefits to be obtained by the use of beneficiated ore, in the form of expected saving in production cost of pig iron, are given in Tables III–V.

Even in ancient iron production methods in Indian villages, the villagers used to break down the ore size,

TABLE V Kiriburu iron ores (National Mineral Development Corporation)

	Crushing, dry screening and utilization of fines			Crushing, dry screening and rejection of ½in size fines			Crushing, washing, wet screening, dewatering of fines (−⅜ in)			Crushing, washing, wet screening, concentration of only fines (−⅜in)			Crushing, washing, wet screening, concentration of both lumps and fines (−⅜in)		
	Fe	SiO_2 %	Al_2O_3	Fe	SiO_2 %	Al_2O_3	Fe	SiO_2 %	Al_2O_3	Fe	SiO_2 %	Al_2O_3	Fe	SiO_2 %	Al_2O_3
Analysis of final beneficiated iron ore	60·96	2·4	4·5	62·45	1·39	4·10	62·90	1·57	4·01	63·78	1·19	3·67	65·13	1·0	2·90
Yield, tons/d	14 000 (100%)			10 010 (71·5%)			12 880 (92%)			11·910 (85·1%)			10 330 (73·8%)		
Capital cost of ore treatment plant, 10^7 rupees	2·5			2·50			3·36			4·50			5·40		
Cost of treatment/ton beneficiated ore, rupees															
(a) Capital cost	0·894			1·249			1·304			1·889			2·614		
(b) Operating cost	0·180			0·252			0·256			0·424			0·677		
(c) Cost of raw ore as mined	5·000			6·993			5·436			5·876			6·775		
Total cost/ton prepared ore, rupees	6·074			8·494			6·996			8·189			10·066		
Tons ore required/ton pig iron	1·581			1·544			1·532			1·512			1·480		
Total cost ore required/ton pig iron, rupees	9·607			13·11			10·73			12·38			14·89		
Difference in alumina, %	...			0·4			0·49			0·83			1·60		
Expected production cost/ton saving of pig iron in blast-furnace iron smelting owing to decrease in alumina by beneficiation, rupees	...			2·0			2·45			4·15			8·00		

wash it with water to eliminate some gangue before charging it in their Adivasi clay furnace for iron production on cottage scale without employing any flux.

Coke

Another problem which faces not only the Hindustan Steel plants but also the entire steel industry in India is the shortage of good coking coal. There are various ways by which this shortage could be overcome. The first problem, the high ash in the coking coal, is being solved by setting up washing plants. One plant is installed at Kargali and one is working in Dugda and is to be extended for increased tonnage of washed coal. There are other washing plants coming into operation very shortly at Bhojudih and Patherdih. It has been known for a long time that a certain percentage of weakly coking coals or even non-coking coals can be mixed with the coking coal to overcome the shortage. For this, selective crushing of the weakly and non-coking coals is necessary. The SOVACO process for achieving this is well known and it is felt that all the new installations being put up should have arrangements for selective crushing of weakly and non-coking coals so that the consumption of good coking coal can be reduced. It is also known that the production of coke in the coke ovens can be increased by 7–10% by mixing in oil before the coal is charged in the coke ovens. This step not only increases the coke production from the same battery, but also enriches the gas which is very useful in a steel plant. The Tata iron and steel works have already introduced this practice in their coke ovens while Hindustan Steel are carefully considering its application. Another way of reducing coke consumption is by oil injection through the blast-furnace tuyeres. In some countries where natural gas is available, this gas is injected into the blast-furnace to save coke. In countries where the ash in coal is low, powdered coal is injected in the blast-furnace. Since there is no natural gas available at present in India, oil injection may be the solution. Hindustan Steel are seriously considering low sulphur oil injection in their existing blast-furnaces. All the new blast-furnaces, to be installed during expansion of the present plants or when new steel plants are set up, will have arrangements to inject oil through the tuyeres installed from the beginning. Economy in coke consumption has to be considered in the context of our very ambitious programme of increasing the steel output. The second plan (1960–1) annual target was 6 m. tons of ingot steel, third plan (1965–6) target is 10 m. tons, fourth plan (1970–1) target is 18 m., fifth plan (1975–6) target is 28 m., and the sixth plan (1980–1) target is 45 m. tons of ingot steel. For any advanced country, the above targets should be considered as highly ambitious, and to achieve these targets of steel output, we must be prepared to use all technical developments as far as possible to counteract the shortage of coking coal. It is in the interest of the country that steel plants must go ahead in introducing ways and means of reducing consumption of coking coal in the steel industry. To make good metallurgical coke, it is necessary to have a proper mixture of high-, medium-, and low-volatile coals in the proper proportion. The railways should do their utmost to move these coals to the steel plants, as good metallurgical coke cannot be made by the use of only high-, medium-, or low-volatile coal alone.

Sintering of iron ores

The fast increasing scope of ironmaking technology presents a fascinating yet complex spectrum. Investigations on this vastly complex yet highly important subject have related to prepared and sized burdens, use of self-fluxing sinters made out of suitably treated and beneficiated iron ore fines, and the incorporation in the metallurgy of iron of basic thermodynamic data calculated to convert the technique of ironmaking essentially into optimum slagmaking. In ironmaking, the basic criterion is that it is not merely the high iron content of the ore which determines the suitability of an iron ore but it is also the nature and characteristics of impurity contents of the ore that in the ultimate analysis establish the ore quality and its metallurgical characteristics. Impurity contents of Indian iron ores are of such a nature and quantity that suitable beneficiation treatment of the ore is considered indispensable. Whilst specific economic advantages arising out of the use of beneficiated lump ore and fines have been indicated earlier, the real advantages of beneficiation would lie in increasing iron productivity of a blast-furnace and making its operation more economical and trouble-free.

Of all the processes employed for the agglomeration of iron ore fines, sintering has the largest commercial application. A good sinter can be a perfect agglomerate if it is of uniform composition, is porous, and easily reducible. The production of a good sinter depends upon three main factors : (*a*) coke or fuel content of the charge which controls the sintering temperature in the bed, (*b*) time and mode of ignition which have a marked influence on the overall fuel economy as well as quality of the sinter, and (*c*) moisture content of the charge which controls the permeability and airflow through the bed and thereby the rate of sintering.

Coke breeze is the usual fuel used for sintering. Sinter quality gradually improves with increased fuel content up to an optimum figure beyond which no improvement results. Below the critical value a soft product with much unsintered material results, while excess of fuel increases the sintering temperature thereby melting the charge to give a fused sinter.

Moisture content is important in obtaining proper bed permeability. Too much water fills up the voids in the bed and results in incomplete sintering. With too little water, the porous nature of the bed cannot be maintained under vacuum as compacting takes place. Optimum moisture content is essential for uniform sintering.

Additions other than coke and water are often made for controlling special properties of the sinter. Limestone is added for producing a self-fluxing sinter. Sometimes dolomite is also added to increase the MgO content of the sinter to make the slag of optimum analyses. Other important factors affecting sinter quality are the grade and proportion of raw materials, their sizing, method of mixing and laying of the bed.

Results of sintering tests carried out with the $-\frac{3}{8}$in size material obtained after washing and beneficiation of -2in size Bolani iron ore as well as the $-\frac{3}{8}$in fraction obtained after dry screening the unwashed -2in ore were evaluated at the National Metallurgical Laboratory.[1-3]

Sintering characteristics in each case of (*a*) $-\frac{3}{8}$in classifier sand obtained after washing of -2in size ore, (*b*) a combined heavy media and jig concentrate obtained from the $-\frac{3}{8}$in classifier sand and (*c*) $-\frac{3}{8}$in dry screened product produced from -2in ore, were studied.

It was observed that optimum water content, necessary for obtaining high sintering rates, was found to be 7, 7, and 8% respectively. The coke content was found to be 3 and 4% for making fluxing and non-fluxing sinters respectively for all the three types of ore fines.

It was noted that self-fluxing sinters had invariably higher degrees of oxidation than those of non-fluxing sinters. Good sinters were produced when dolomite was added with limestone to increase the MgO contents of sinter.

Silica and alumina contents were obviously higher in the sinters produced from $-\frac{3}{8}$in dry screened ore fines than those sinters made from the other two types of ore fines.

Barsua iron ores

Sintering characteristics of the $-\frac{3}{8}$in classifier sand obtained after washing of -1in ore and a combined heavy media and jig concentrate obtained from the same sand were determined.

It was observed that the optimum water content necessary was 7% for obtaining good self-fluxing as well as non-fluxing sinters. The coke content necessary was 4%.

Self-fluxing sinters had a higher degree of oxidation than that of the non-fluxing variety. It was interesting to note that self-fluxing sinters were invariably stronger than the non-fluxing ones. Sinter strength increased with increase in basicity ratio up to a certain limit. Good sinters were also produced when dolomite was added with limestone, for increasing the MgO content in the sinter. The $-\frac{3}{8}$in washed material being of a poor grade, the sinter produced from it was obviously high in silica and alumina contents and possessed poor strength. The total insolubles in the sinter produced from the beneficiated $-\frac{3}{8}$in washed product were appreciably lower.

Kiriburu iron ores

Sintering characteristics of -3in classifier sand obtained after washing of -3in ore were studied. Optimum water content was 7% for obtaining good fluxing and non-fluxing sinters and the coke content was found to be 3 to 3·5% for the former and 4% for the latter.

Good quality sinter with a basicity ratio up to 2·0 could be produced by suitable additions of limestone. Dolomite could also be added to increase MgO content of sinter without any deleterious effect on sinter quality. Self-fluxing sinters had a higher degree of oxidation than those of the non-fluxing type. A separate paper emanating from the National Metallurgical Laboratory gives full details of the sintering research studies on those iron ore fines.

However, it is fully emphasized that sinter plant operating with unbeneficiated iron ore fines will not yield the performance expected of it. This is distinctly apart from the position that even should it be possible to handle and screen natural iron ore fines under Indian tropical conditions, the sinter produced from natural untreated iron ore fines will be of hardly any value metallurgically in terms of increased iron productivity, lowered coke and flux rates, apart from ensuring smooth and hanging-free furnace operations. It is not merely necessary to produce sinter at any cost and of any grade, but in order to obtain from its use full iron output potential, it should be of a good metallurgical grade with distinct well established benefits arising out of its application. It should also be borne in mind that it is necessary to incorporate return fines in the sinter mix, which following necessary additions of high-ash coke breeze will make the acid contents (alumina and silica combined) abnormally high in cyclic sinter feeds. Such successive incorporation of return sinter fines in the sinter feed made up of unbeneficiated ore fines will continuously build up the acid contents of the sinter feed to an alarming extent which in cyclic operations will render the resulting sinter of little strength and metallurgical value to be hardly acceptable. These undesirable factors exercise cumulative deteriorating effects when the sinter plant goes into continuous production yielding weak, friable, poorly reducible sinters made out of unbeneficiated iron ore fines.

At Bhilai the use of sinter has been based on the use of natural iron ore fines for several reasons, the main object being to utilize the fines produced at the iron ore mines, which were going to waste and were substantially adding to the cost of mining lump ore. It is also to be stated that Bhilai is seriously considering setting up an ore washing and beneficiation plant both for its present production and future expansion programme on the basis of research investigations underway on the subject at the National Metallurgical Laboratory. With the introduction of sinter the price of iron ore has dropped somewhat. There has not, however, been any appreciable increase in iron production with the use of sinter made out of unbeneficiated iron ore fines in relation to iron production

TABLE VI Density of Indian iron ores

No	Place	Density, g/cm³
1	Bolani	4·38
2	Joda	5·82
3	Noamundi II	5·20
4	Badampahar	3·67
5	Gorumahsani	4·76
6	Noamundi I	4·33

with good quality iron ore that is available. All the same, the present rate of production is about 5% higher than the rated capacity of the blast-furnaces, though this is not all attributed to the use of sinter. The full value of the use of sinter will only be known when all other factors have been completely standardized and the blast-furnaces can run without any hindrance which is not the case at present. With the use of sinter from unbeneficiated fines, the coke rate has not been much reduced due to the fact that Bhilai has been using low grade unbeneficiated iron ore fines containing about 54% Fe giving an ultimate sinter with about 43% Fe. With effective beneficiation of the iron ore fines, the coke rate is expected to drop considerably. As stated above, Bhilai sinter plant is using low grade iron ore fines and, as such, the gangue contents of the ore fines are contributing to increased slag volumes. The performance of the Bhilai blast-furnaces has been slightly better than without sinter in regard to tonnages, and coke rate. The sinter plant is working on its full rated capacity during the dry season. Slight modifications had to be made according to the local conditions for sinter cooling. The sinter plant itself is of a very modern design and construction. Improvements in respect of quality of the fines are contemplated so that the resulting sinter will have a high Fe content with a much lower gangue content so that blast-furnaces can be operated with increasing percentages of the sinter in the burden. This will entail the beneficiation of fines to increase the

TABLE VII Rourkela steel plant : statement of the existing units and additional proposed (All figures in metric measure)

Plant units	One million ton plant Details	Capacity	As per project report for expansion
Coke oven	3 batteries of 70 ovens each	1 045 000 tons of run of oven coke giving 880 000 tons of blast-furnace coke Maximum capacity 1 048 000 tons BF coke	One battery of 80 ovens
By-product plant	Crude tar, napthalene, anthracene, pitch, creosote, benzol, benzene, toluene, xylene, solvent naptha	70 000 nm³/h of coke oven gas can be handled and treated	One additional stream to handle 35 000 nm³/h
Blast-furnaces	3 furnaces of 1 000 tons/d each	900 000 tons of basic iron and 30 000 tons of foundry iron for works use	One additional 1 500–1 800 tons/d to give total of 1 575 000 tons of basic iron plus foundry iron for works use
Sinter plant			Plans for one sinter plant of 5 000 tons of sinter/d capacity are already in hand : no provisions in the expansions
Pig casting machine	One machine	100 tons/h capacity	Plans for additional machine of 1 600 t/day capacity in hand
Steelmelting shop	Three 40 ton LD converters Four stationary basic OH furnaces	750 000 tons of ingot +250 000 tons of ingots	2 additional LD converters each of 60 tons capacity
Soaking pits	2 soaking pits (14 holes)		4 more soaking pits (8 holes)
Slabbing mill	2-high, high lift reversing slabbing mill	To roll 1 million tons of ingots	To roll 1·8 m. tonnes of ingots (inherent capacity of mill)
Plate mill	3·1 m 4-high universal plate mill	170 000 tons of wide heavy plates	Will produce 280 000 tons of finished plates
Hot strip mill	1 700 mm wide strip mill two 4-high roughing stands six 4-high continuous finishing stands	To roll 300 000 HRS for sale and pipe plant 30 000 narrow heavy plates for sale 256 000 strips for cold rolling	Will roll 1·14 m. tonnes of slabs with additional finishing facilities
Pickling plant	1 unit	To pickle 256 000 tons of HRS	1 additional unit to pickle in all 730 000 tons of coils
Cold rolling		170 000 tons of auto body sheet 54 000 tons sheets for hot dip tinning	A new 1 420 mm 5 stand tandem cold rolling mill of 600 000 tons/a inherent capacity
Hot dip tinning	1 unit	50 000 tons of HD tin plates	
Continuous galvanizing lines			160 000 tons/a
Electrolytic tinning line			100 000 tons/a
Electrical sheet mill			50 000 tons/a
Pipe plant	1 unit (electrical resistance welded pipes)	10 to 15 000 tons/month	
Auxiliary shops	Machine shop, welding loco wagon repair, tinsmithy grey iron foundry	Ingot moulds 25 000 tons Bottom plates 3 000 ,, Other castings 6 000 ,, 34 000 ,,	Ingot moulds bottom plates and other castings (64 000 tons/a) after expansion of steel and non-ferrous foundry—yielding roughly 5 000 tons of castings
Power plant	3 turbo generators of 25 MW plus 3 MW back pressure turbo generators	Total installed capacity 78 MW Additional power to be obtained from Hirakud	2 additional 25 MW sets
Lime and dolomite kiln	3 lime shaft kilns gas fired 2 dolomite shaft kilns	80 tons/d each kiln 40 tons/d each kiln	One 100 ton rotary kiln for dolomite
Oxygen plant	3 units	100 tons/d each	One unit of 200 to 250 tons capacity plus provision for expansion later
Fertilizer plant		580 000 tons of calcium ammonium nitrate	

Fe content to about 60% giving a sinter content of well above 50% Fe.

The great advantage Bhilai has received from the use of sinter is the utilization of almost all their waste products of the blast-furnaces and the calcining plants such as the use of fines arising out of crushing of dolomite etc. Also all the millscale, blast-furnace flue dust etc., the disposal of which was a problem, are being utilized to give a self-fluxing sinter, thereby minimizing the requirement of flux in the blast-furnaces. The present economics of the use of sinter would be based on the utilization of the iron ore fines, coke breeze, dolomite fines, lime fines, blast-furnace flue dust, and millscale which were going to waste before the introduction of sinter.

Reducibility studies

Reduction of iron ore in a blast-furnace is governed by the size of the ore and the inherent reducibility. In burden preparation using different ores, it is necessary that the material be graded so that the rate of reduction of the different samples is similar. For ores with poor reducibility, smaller sizes are desired while more easily reduced ores can be used in larger sizes. The reducibility tests carried out at the National Metallurgical Laboratory for iron ores of Hindustan Steel Limited can by no means substitute an index of service smelting behaviour of the ores but do, in general, serve as a useful guide, particularly for relative assessment of reducibility of different ores and sinters. In this paper, results of reducibility studies on Bolani iron ore only will be reported as being of typical interest.

Bolani iron ores along with other Indian iron ores used in the blast-furnace have equally good reducibility. During heating, moisture is expelled in the region of 500°C and the reduction is completed with minute cracks and without disintegration. These cracks provide the path of least resistance for the passage of reducing gases and gaseous reaction product. The density of Bolani ore is compared in Table VI with that of other Indian ores.

The reducibility of Bolani ore compared with others is similar to that of soft ores of Noamundi I, Badampahar, and Gorumahsani. The Bolani iron ore may be classed with the more easily reducible ores. It has been observed that the product obtained after washing and heavy media separation has the *maximum* reducibility. Beneficiation not only serves to secure the removal of silica and alumina but also affects distinct improvements in the reducibility. Ore fractions of −2in plus $\frac{3}{8}$in should preferably be charged in blast-furnaces as sized burden.

Reducibility characteristics[6] of Bolani iron ores after their prior beneficiation were studied with hydrogen as a reducing agent at 800°C and at 5·3 l/min flow rate.

TABLE VIII Bhilai steel plant : statement of the existing units and additional proposed (All figures in metric measure)

Plant units	One million ton plant Details	Capacity	As per project report and after expansion
Coke ovens	3 batteries of 65 ovens each	1 286 000 tons of run of oven coke (including 1 145 000 tons of BF Coke)	3 more batteries each of 65 ovens. 2 290 000 tons of BF coke/a
Blast-furnaces	3 blast-furnaces	1 033 m³ volume 1 135 tons/d, 1 110 000 tons of pig iron including 321 000 tons for sale	3 additional of 1 719 m³ volume 1 750 tons/d 2 361 000 tons including 327 000 tons for sale
Sintering plant	2 machines	1 000 000 tons fluxed sinter	1 additional machine 870 000 tons additional sinter (to be installed in separate building)
Steel melting shop	Six 250 ton stationary basic OH furnaces	1 million tons of ingots	(All existing and future furnaces to be all basic). Five 500 ton stationary 4 new OH furnaces plus one existing 250 ton furnace to be converted to 500 ton furnace
Soaking pits	5 soaking pits (i.e. 10 holes)		10 additional soaking pits (i.e. 20 additional holes)
Blooming mill	1 150 mm 2-high reversing	To roll 1 million ingot tons, into 852 000 tons of blooms	To roll 2·5 million ingot tons into 2 142 000 tons of blooms
Continuous billet 10 stand mill		427 000 tons of billets including 150 000 tons for sale	2 more stands. To produce 1 263 000 tons of billets including 315 000 tons for sale
Rail and structural mill	950 mm 2-high roughing stand plus 3 800 mm finishing stands	365 000 tons of rails and structurals (including 100 000 heavy rails ; 265 000 tons of heavy structurals consisting of beams, channels, rounds, angles, crossing sleepers and sleeper bars)	750 000 tons (500 000 tons rail and 250 000 tons structurals)
Merchant mill	350 mm 12 stand	255 000 tons rounds, squares, flats, beams, angles and light rails	500 000 tons of merchant products
Wire rod mill			400 000 tons/a of 5·3 mm to 10 mm dia. rods
Auxiliary shops	Loco shed, machine shop, structural shop, forge shop, electrical repair shop, building services, foundry	Ingot moulds and accessories, iron castings, non-ferrous, steel castings tons/a 25 000 4 000 300 5 500	Total output of castings after expansion will be 80 950 tons/a Ingot moulds and accessories 62 500 Iron castings 5 500 Non-ferrous 450 Steel castings 12 500 Additions to other shops
Kilns for lime dolomite	One rotary kiln for dolomite Two shaft kilns for lime	Total refractory materials output of 68 900 tons/a	To be increased to 178 000 tons/a
Power plant	Two turbo generator sets	12 MW each	One more 12 MW set
Oxygen plant	Two units	5 000 m³/h each	Additional equipment to meet increased demand
Saleable steel		770 tons/a	

Reducibility tests were done on the crushed, washed and heavy media separated products at −3 plus ⅜in, −2 plus ⅜in and −1½ plus ⅜in size fractions as well as on −0·263 plus 0·185in sinters produced from −⅜in samples. It was observed that the rate of reduction decreases as the ore size increases and no marked difference in reducibility was observed in the different fractions below −2in plus ⅜in. The products obtained after heavy media separation were more readily reducible than those from washing alone and this was attributed to the elimination of lateritic gangue. Based on the reducibility tests, it is recommended that the ore crushed to −2in plus ⅜in washed and beneficiated by heavy media separation would be a suitable feed for the blast-furnace. The reducibility studies on the sinter indicated that the self-fluxing sinter with the basicity of 1·3 possessed the highest reducibility.

LIMESTONE

Limestone is the most important flux used in iron- and steelmaking. When the steel output was small, limestone with less than 5% insolubles could be obtained. With the heavy demands of the expanding iron and steel industry both in the public and private sectors on limestone, the quality of the latter has deteriorated rapidly with insolubles therein averaging 12–13% causing heavy deficiencies in the fluxing power of the limestone, particularly for steelmaking. A student of metallurgy is given the metaphor that 'steelmaking is indeed slagmaking'. This metaphor is turning the Indian steelmaking furnace into one for 'slagmaking' with the poor quality of available limestones today. The National Metallurgical Laboratory has during the last few years undertaken a series of investigations for beneficiation and briquetting of limestone for steelmaking. Earlier investigations were undertaken for Hindustan Steel Ltd on beneficiation of limestone from Purnapani, Sundergarh District (Orissa), and four reports were issued by the National Metallurgical Laboratory in this connexion. Comprehensive identical inves-

TABLE IX Durgapur steel plant : technical data

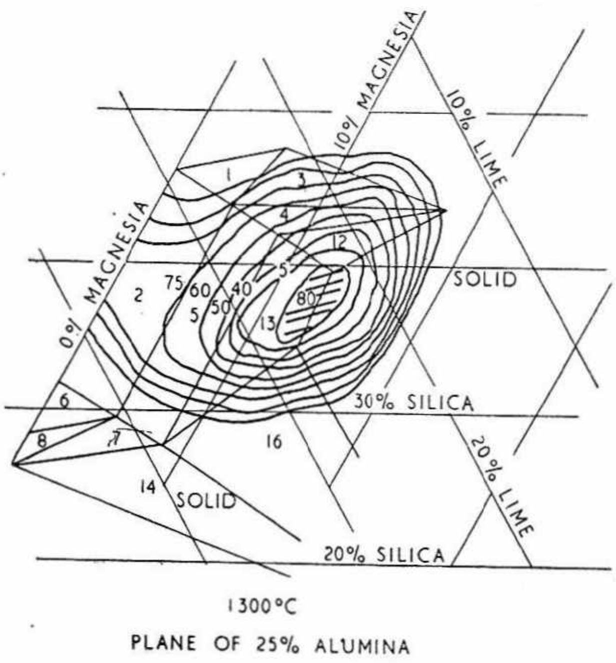
To produce 1 m. tons	After expansion
Coke ovens	
2 rotary tipplers for 4-wheeler opens only 1 end-rock tippler for 4-wheeler closed wagons	1 additional tippler for handling 1 box or two 4-wheeler open wagons at a time
Coal supply	
Jharia coal for washing at DSP washery Barakar coal Dishergarh	-do-
Coke oven batteries	
3 batteries of 78 ovens each=234 ovens	1 more battery of 78 ovens
Coal washery	
Dreboy dense medium separators for 3in–½in coals ACCO feldspar jig washer for ½in to 0in coals Capacity : 360 t/h	Additional feldspar box and surge bunkers to ensure 360 t/h capacity of washery being achieved
Raw material handling	
2 rotary tipplers for iron ore in 4-wheeler open wagons 1 rotary tippler for limestone, dolomite, manganese ore, etc. in 4-wheeler open wagons	2 additional rotary tipplers—one for iron ore lumps and one for iron ores fines. Each tippler will be capable of handling 1 box or two 4-wheeler open wagons at a time
Blast-furnaces	
3 blast-furnaces each of 1 250 t/d capacity	Additional blast-furnaces : 1 500 t/d capacity with beneficiated ore, sinter burden and improved operational techniques
Pig casting M/C	
2 M/cs each 120 t/h capacity	No addition
Steelmaking shop	
2 800 ton mixers 2 desiliconizing stations 2 200 ton OH furnaces with silica roof 1 100 ton open hearth furnace with silica roof	Additional mixer of 1 200 ton capacity Additional desiliconizing station Additional 200 ton open hearth furnace All the 9 open hearth furnaces will be fitted with basic roofs and oxygen lancing facilities to increase their production capacity by 20% (to produce 1·6 million ingot t/a)
Soaking pits	
10 pits bottom-fired with coke oven gas 42in 2-high reversing mill with twin 3 000 hp motors 12in sq blooms normal size	6 additional pits No changes
Blooming mill shear	
1 200 tons capacity	No changes
Intermediate mill	
32in 2-high reversing mill 4 500 hp motor normal bloom size 7in sq	No changes
Secondary hot bloom shear	
700 tons capacity	No changes
Billet mill	
4 roughing stands 4 finishing stands	Practically no changes
Products and capacity	
2in to 5in billets and sleeper bars and slabs required for merchant mill	Sleeper bar production may de transferred to medium section mill Skelp bar for skelp mill
12 000 t/wk of 6 days and 2 shifts/d	18 000 t/wk

(continued opposite)

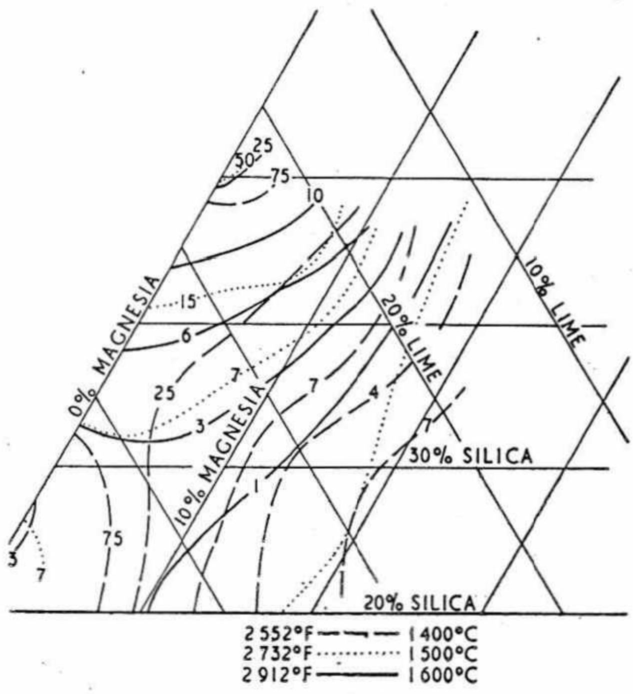
tigations have also been undertaken for the Tata iron and steel works. For limestone to be used as metallurgical flux in steelmaking, maximum availability of base CaO is necessary and, for that purpose, silica content of the limestone should be low, so that its CaO base is not used up in fluxing its own silica, at the expense of the acids arising out of the oxidation of metalloids in a steelmaking bath, such as silica and P_2O_5 which have, of necessity, to be fluxed into the slag. If the percentage of silica in the limestone rises beyond certain minimum values, the steelmaking furnace will be chiefly employed on 'slagmaking' rather than steelmaking. As such, the percentage of silica in limestone for use in open-hearth steelmaking should contain very low silica content, preferably of the order of 1–2%, even though the OH grade limestone is specified to contain not more than 6% acid insolubles which will correspond to about 7·5% total insolubles. The quality of the Indian limestones used in steelmaking *vis-a-vis* their silica contents is deteriorating and the insolubles in limestone for steelmaking are now averaging between 12 and 15%. With these poor grades of limestone, production in the steel plants can be most adversely affected apart from the consequential handicaps and operational difficulties arising, such as poor heat exchange between the furnace gases and the steel bath, causing damage to the furnace roof; extraordinarily high consumption of the limestone itself, in order to meet flux needs of the acids resulting from the oxidation of metalloids; and danger of reversion of phosphorus from slag to metal during end of steel refining period, due to lack of available stabilizing base in the slag; and the dangers of off-heats, etc. The lime slag cover itself is a good heat insulator over the molten metal bath and with increase in its thickness, the inadequacy of maximum heat exchange so necessary in OH steelmaking, will become apparent, as also the resulting possibilities of damage to the OH furnace roof arising out of the upwards heat deflection. All these factors will lead to lower steel output figures and higher production costs, heavy maintenance expenses and overall inefficiency in metallurgical steel refining operations; the cumulative effects of these factors can be far more adverse than is fully realized. Limestone used for calcination to yield burnt lime is specified to contain a total of 10% acid insolubles corresponding to 12% insolubles. The burnt lime is also used in the OH steelmaking to meet inevitable deficiencies of the base CaO during refining stages. If, however, through the adaptation of suitable limestone beneficiation techniques, silica contents of the limestone can be reduced to about 2%, adequate CaO bases should be available to the OH melt and as such, the addition of

TABLE IX (Cont.) **Durgapur steel plant : technical data**

To produce 1 m. tons	After expansion
24-section mill	
2 reheating furnaces 40 t/h each	No expansion practically Sleeper bars may be rolled
1 26in 2 high rougher 2 24in 3 high inter 1 24in 2 high finishing	Some additional finishing equipment will be added
Products and capacity	
IS joints 100×75 to 200×100 mm	Additional products Sleeper bars and 60 lb rails
IS channels 150×75 to 125×65 mm	200 000 tons of rails and sections plus 12 800 tons/a of fish plates as in 1 million ton
Light rails 20, 24 and 30 lb/yd Rounds 70, 75, 80 and 100 mm dia. Bearing plates and fish plates for 50, 60, 75 and 90 lb rails	
Sleeper plant	
Broad gauge and metre gauge sleepers—60 000 t/a on 2 shift basis	75 000 t/a on 3 shift basis
Fish plate finishing plant	
11 000 t/a	No changes
Merchant mill	
2 reheating furnaces 40 t/h each 7 roughing stands 2 intermediate stands 6 looping stands and edgers, skew tables and repeaters	No changes
Products and capacity	
Rods $\frac{1}{2}$in to $2\frac{5}{8}$in dia. Squares $\frac{1}{2}$in to $2\frac{1}{2}$in Flats 4in to 6in wide and down to $\frac{1}{4}$in thickness Angles $1\frac{1}{4}$in×$1\frac{1}{4}$in to 4in ×3in horn cheek sections 240 000 t/a	No changes
Wheel and axle plant	
45 000 wheel sets/a for broad gauge and medium gauge goods and coaching stock with plain and roller bearings	Capacity will be 75 000 wheel sets/a
Skelp mill	
......	250 000 t/a max. size of skelp $9\frac{1}{4}$in width
Power plant	
4 boilers each of 150 000 lb steam/h 500 lb/in² at 775°F 3 turbo alternators of 5 MW each 4 turbo blowers each 90 000 ft³/min at 22 16/in² capacity Fuels : for two boilers gaseous fuel only and for other two gaseous as well as solid fuel can be used	Under study
Oxygen plant	
2 units each capable of 50 tons of oxygen/d with 99·5% purity	One 100 ton unit will be added
Refractories	
2 gas fired, vertical shaft kilns, of 75 t/d for lime burning 1 gas fired rotary kiln of 100 t/d for dolomite burning	Second rotary kiln of 100 t/d capacity



3 *Slag analysis at a slag melting temperature of 1 300°C*



4 *Slag analysis at a slag smelting temperature of between 1 400° and 1 600°C*

burnt lime during steel refining may not be necessary, which will naturally mean considerable saving in the flux costs, considering that burnt lime costs approximately three times the cost of limestone.

The severity of the problem will be realized when the annual steel production in India, now projected at 10·2 m. tons, attains its target figures at the end of the third five year plan ; the contrast will become sharper with increasing deterioration in the quality of metallurgical grades of limestone and lack of its adequate indigenous resources. It would therefore be appreciated that beneficiation of limestone for steelmaking will become a crucial metallurgical necessity, if not an absolute economic necessity. It has been argued that any industrial application of beneficiation techniques must be based on accruing economic advantages. As such the beneficiation costs have to be adjudged in the ultimate analysis against the greatly lowered consumption of the limestone flux, intensification of metallurgical reactions and expected acceleration in steelmaking cycles following on increased reactivity of the upgraded limestone concentrate, reduced possibilities of off-grade steel heats and less damage to the furnace roof etc. It will be difficult to evaluate straightaway the improved economics resulting from the use of beneficiated limestone at this stage, even though there are clear indications thereto. It has been shown in these investigations that the upgraded limestone can be adequately briquetted without involving expensive binders, and the briquettes possess adequate strength for withstanding furnace loads and for providing the necessary lime boil in OH steelmaking. Beneficiated limestone can also be advantageously used in other forms of oxygen and pneumatic methods of steelmaking. For LD oxygen steelmaking, beneficiated and briquetted limestone can serve the purpose equally well, particularly when extraordinarily high strength will not be required in this process.

The use of beneficiated limestone in ironmaking in the blast-furnace has not been taken up in the present series of investigations at the National Metallurgical Laboratory, even though increasingly high ash contents of Indian coke will require in turn additional quantities of the limestone flux. The limestone briquettes required for the blast-furnace will have to be of much greater strength unless the upgraded limestone which is in the form of fines is directly used for making self-fluxing sinter. The reductions in silica content of the beneficiated limestone for use in iron production will have to be balanced against the high alumina contents of Indian blast-furnace slags requiring certain minimum silica values therein.

BLAST-FURNACE SLAG COMPOSITION

The difficulties met in the case of Indian blast-furnace slags, following the high alumina content *vis-a-vis* requirements of fluidity consistent with adequate desulphurizing power, make the subject of ironmaking in the case of unbeneficiated burden highly complex. It has been our observation that requisite additions of MgO in the flux charge, low viscosity and fluid slag can be obtained despite its high alumina content resulting also from very high-ash Indian metallurgical coke. Such low viscosity fluid slags may contain up to 10% MgO. As such, dolomite is added to the blast-furnace aiming at the following typical slag compositions :

Slag constituents, %	For OH basic iron	For foundry grade pig iron
silica	31·5	32
alumina	22	22
lime	34	37
magnesia	9	6·2
ferrous oxide	1·0	0·3
calcium sulphide	1·5	1·5
manganese monoxide	1·0	1·0

With the above slag composition, it is possible to produce basic pig iron containing about 1%Si, up to 1%Mn, below 0·05%S and 0·3%P whilst the requisite foundry grade pig iron containing up to 3%Si can be made.

In this connexion, Figs. 3 and 4 (courtesy John Miles and Partners Ltd, UK) show that at a slag melting temperature of 1 300°C (Fig. 3), the lowest poise is 30 and in the centre of this 30 poise area the equivalent slag analysis, %, is :

Alumina	25
CaO	25
SiO_2	36
MgO	15

Figure 4 shows similar viscosity curves but varying from 1 400° to 1 600°C. This is an enlargement of Fig. 3, but shows a similarity of viscosities to those shown in Fig. 3. Our experience with low-shaft furnace pilot smelting operations at the National Metallurgical Laboratory has confirmed the above observations that with MgO 8–10%, CaO/silica ratio 1·2, low-silicon basic pig iron could be made whilst the slag analysis showed alumina content ranging between 20–25%. A separate paper on iron smelting in low-shaft furnace pilot plant of the National Metallurgical Laboratory is given in section 3.

Summing up, it would not be scientifically plausible or acceptable that research and development studies covering such a wide spectrum are complete in all their phases. However, even after making such a provision, the results of the present investigations clearly indicate that while the pure economist may keep sounding notes of caution in respect of ore beneficiation costs, the plant operators and production metallurgists can equally well claim that without the introduction of optimum beneficiation cycles there may hardly be adequate production figures available to evaluate any economics at all.

TABLE X Average analysis of major raw materials (1961–62)

Items	Particulars	Average 1961–62
Iron ore	SiO_2	4·49
	Al_2O_3	2·83
	Fe	62·37
	P	–
Limestone	SiO_2	11·71
	Al_2O_3	1·44
	Fe_2O_3	2·20
	CaO	44·14
	MgO	2·88
	Loss on ignition	37·40
Quartzite	SiO_2	94·96
	Al_2O_3	1·36
	Fe_2O_3	2·10
	CaO	–
	MgO	–
Manganese ore	Mn	31·33
	P	0·23
	SiO_2	26·67
	Al_2O_3	3·70
	Fe	9·10
	CaO	3·74
	MgO	1·36

It is sincerely hoped that the series of investigations on Indian iron ores which the National Metallurgical Laboratory has systematically undertaken for the Hindustan Steel plants, will not only promote effective understanding of difficult problems but will also lead to

TABLE XI Hindustan Steel Ltd, Bhilai steel works : Production and consumption data of sintering plant (1961–62)

Particulars	Unit	April 1961	May 1961	June 1961	July 1961	August 1961	Sept. 1961	Oct. 1961	Nov. 1961	Dec. 1961	Jan. 1962	Feb. 1962	March 1962	Total 1961–62
Production of sinter														
Machine 1	tonnes	Nil	Nil	Nil	3 050	11 894	9 790	Nil	17 694	26 248	Nil	Nil	Nil	68 676
Machine 2	tonnes	Nil	Nil	Nil	Nil	Nil	Nil	14 878	Nil	Nil	32 305	26 573	36 989	110 745
Consumption of materials														
Iron ore fines	tonnes	Nil	Nil	Nil	4 296	7 260	5 875	12 660	12 200	13 980	21 800	14 435	15 994	108 500
Flue dust	,,	Nil	Nil	Nil	1 050	1 840	790	1 385	2 110	2 090	3 090	2 035	2 295	16 685
Mill scale	,,	Nil	Nil	Nil	480	1 070.	1 128	948	1 308	2 130	2 729	2 566	2 554	14 913
Raw dolomite	,,	Nil	Nil	Nil	20	60	200	550	1 050	1 015	695	1 720	2 604	7 914
Burnt dolomite	,,	Nil	Nil	Nil	180*	255*	215	665	501	176	206	614*	591	3 403
Coke breeze	,,	Nil	Nil	Nil	1 000	1 050	1 983	3 170	3 525	4 440	5 105	4 040	4 178	28 091
Limestone	,,	Nil	Nil	Nil	Nil	Nil	Nil	Nil	2 135	3 860	7 270	3 000	5 089	21 354
Sinter returns	,,	Nil	Nil	Nil	3 380	2 568	2 514	3 825	2 550	2 054	5 912	1 561	7 528	31 892
Consumption of services														
Blast furnace gas	10^3m^3	Nil	Nil	Nil	647	1 116	1 060	1 244	1 340	1 348	1 565	1 337	1 264	10 921
Coke oven gas	10^3m^3	Nil	Nil	Nil	104	181	154	177	184	206	217	181	170	1 575
Total heat	10^5kcal	Nil	Nil	Nil	1 048	1 836	1 659	1 960	2 082	2 158	2 402	2 045	1 917	17 117
Electricity														
Sintering building	kWh	Nil	Nil	Nil	*	623 720	460 800	634 742	383 618	494 993	517 710	500 748	751 172	4 367 503
Mixing bins	kWh	Nil	Nil	Nil	†	108 000	152 000	147 827	165 756	103 039	337 755	201 000	138 827	1 354 204
Water	m^3	Nil	Nil	Nil	50 000	75 200	84 000	104 150	123 858	180 516	229 369	186 011	258 909	1 292 013
Compressed air	10^3m^3	Nil	Nil	Nil	†	608·6	630·6	649·4	633·0	651·0	654·8	592·2	658·0	5 077·6
Oxygen in cylinders	m^3	Nil	Nil	Nil	†	150·8	20·8	306·8	Nil	353·6	353·6	Nil	Nil	1 185·6
Steam	tonnes	Nil	Nil	Nil	†	100	40	119	120	130	131	106	1 113	1 859

* Mixture of lime and dolomite
† Data not available

AVERAGE ANALYSIS OF SINTER, %

Commissioning dates	Particulars	April 1961	May 1961	June 1961	July 1961	August 1961	Sept. 1961	Oct. 1961	Nov. 1961	Dec. 1961	Jan. 1962	Feb. 1962	March 1962	Average 1961–62
Machine 1 3.7.1961	Fe	Nil	Nil	Nil	55·3	54·7	53·4	53·7	47·4	48·6	49·0	47·9	42·7	50·3
	FeO	Nil	Nil	Nil	22·5	19·9	22·8	20·1	14·6	13·4	14·4	14·0	11·0	17·0
	SiO_2	Nil	Nil	Nil	8·2	.7·8	9·1	8·7	9·3	8·5	8·4	8·6	9·7	8·7
	Al_2O_3	Nil	Nil	Nil	7·9	8·5	8·8	8·7	10·8	8·8	8·2	8·9	8·4	8·8
Machine 2 3.9.1961	CaO	Nil	Nil	Nil	5·7	5·5	6·7	6·4	11·4	12·6	12·5	11·9	18·6	10·1
	MgO	Nil	Nil	Nil	1·3	1·6	1·7	1·5	1·9	1·8	1·6	2·3	2·8	1·8
	Av. Basicity	Nil	Nil	Nil	0·43	0·43	0·47	0·46	0·67	0·83	0·85	0·81	1·21	0·68

industrial implementation of beneficiation and sintering techniques in the Indian iron and steel industry.

It is now proposed to outline some data of the iron and steel plant installations of Hindustan Steel Ltd while presenting some typical operational data for the Bhilai steel plant of Hindustan Steel Ltd. In the case of the Rourkela steel plant, one chief difficulty met with has

TABLE XII Specific consumption of materials and services per tonne of pig iron produced and operational data of blast-furnaces

Particulars	Unit	Average 1961–62
Specific consumption per tonne of pig iron		
Ores		
Iron ore	kg	1 443
Manganese ore	kg	49
Sinter and scrap		
Sinter	kg	170
Scrap	kg	0·26
Fluxes and ladle addition		
Limestone	kg	589
Quartzite	kg	32
Coke	kg	959
Miscellaneous		
Sand	kg	5·2
Services		
Coke oven gas	m^3	8·2
Blast-furnace gas	m^3	924
Total heat of gases	10^3k Cal	922
Air blast	10^3m^3	4·16
Compressed air	m^3	5·50
Steam	kg	116·7
Water	m^3	50
Electricity		
Per tonne of production at blast furnace	kWh	9·56
Per tonne of production at PCM	kWh	1·44
Operational data		
Furnace 1 Average blast temp.	°C	833
Furnace 2 ,,	°C	828
Furnace 3 ,,	°C	825
Furnace 1 Average top pressure	Atm	0·30
Furnace 2 ,,	Atm	0·28
Furnace 3 ,,	Atm	0·35
Average dust content in cleaned BF gas	Mg/nm^3	6·4
Flue dust collected per tonne of pig iron	kg	25
Rate of coke burning per useful volume of furnace	kg/m^3	848
Coefficient of utilization of useful volume, overall	m^3/tonne	1·08
Slag output per tonne of pig iron	kg	761

TABLE XIII Production of subsidiary products in blast-furnaces

Particulars	Total 1961–62
Slag, t	
Furnace 1	251 346
Furnace 2	259 010
Furnace 3	250 868
Total	761 224
Flue dust, t	
Furnace 1	9 268
Furnace 2	8 931
Furnace 3	6 797
Total	24 996
Coke breeze seperation, t	
Furnace 1	8 577
Furnace 2	8 654
Furnace 3	8 325
Total	25 556
Nut-coke (for refractory), t	2 613
Runner and scrap (splashing), t	13 746
Blast-furnace gas make, 10^3 m^3	3 042 168
Number of charges	
Furnace 1	59 421
Furnace 2	61 165
Furnace 3	58 077
Total	178 663

TABLE XIV Consumption of materials in blast-furnace shop (1961–62)

Iron ore, t	Lime-stone, t	Manga-nese ore, t	Quart-zite, t	Sinter, t	Scrap, t	Scale, t
1 443 324	583 685	48 649	32 376	170 584	2 568	245

Coke (wet), t	Coke (powder), t	Sand, t	Plastic clay, t	Soft medium pitch, drums @	Lime at pig casting machine, t
958 806	2 190	5 222	1 273	1 199	1 729

@ 2 cwt/drum

TABLE XV Consumption of services in blast-furnaces (1961–62)

Coke oven gas 10^3m^3	BF gas 10^3m^3	Water (10^3m^3) Furnaces	PCN	Total	Steam at 8 atm, t	Air blast 10^3m^3
8 184	924 360	40 346	9 869	50 215	116 713	4 158 603

Compressed air 10^3m^3	Electricity (kWh) Furnaces	PCM	Gas clean-ing plant	Total	Oxygen through pipe lines, m^3
5 475	9 555 918	577 060	968 239	11 101 217	24 219

TABLE XVI Specific consumption of materials and services per tonne of ingot steel

Particulars		Average of 1961–62
Pig iron, kg		
Hot metal	kg	744·1
Cold pig	,,	4·7
Total pig iron	,,	748·8
Scrap, kg		
Purchased scrap	,,	44
Local scrap	,,	220
Total scrap	,,	264
Oxides, kg		
Iron ore	,,	166
Scale	,,	4·6
Fluxes, kg		
Lime	,,	10·6
Limestone	,,	78·5
Fluorspar	,,	0·28
Bauxite	,,	0·73
Fettling materials, kg		
Raw dolomite	,,	40·5
Burnt dolomite	,,	25·9
Magnesite	,,	6·2
Finishing and alloy materials, kg		
Ferromanganese, kg		16·2
Ferrosilicon, kg		0·92
Aluminium, kg		43
Services		
Electricity, kWh		12·81
De-aerated water (for evaporation and cooling system), m^3		0·41
Water, m^3		15·60
Compressed air, m^3		60·30
Oxygen, m^3		23·50
Steam, kg		1·27
Fuels		
B F gas, m^3		316
CO gas, m^3		207
Liquid fuel, kg		8·93
Total heat, 10^3 kcal		1 298

Note: Consumption of compressed air, steam allocated in steel melting shop as per project report distribution. Water consumption based on percentage distribution supplied by water supply division.

TABLE XVII Operating characteristics of steel melting shop (1961–62)

	Period h—min
Fettling	00–38
Charging	02–05
Heating	01–25
Pouring	00–44
Melting	04–00
Refining	03–34
Total	12–26
Total no. of heats tapped	3 160
Average production	
(a) per furnace day,	490·3
(b) per calender day,	2 160·9
Average weight of a heat, t	249·6
Average production/furnace day/m² of bottom, t	6·38
Useful output of steel, t	87·61
No. of ingot moulds consumed	1 846
No. of base plates consumed	1 116
Life of ingot moulds	
(a) Kulti, 5 t heat	59·9
(b) Bhilai, 7 t heat	45·4
(c) Burnpur, 7 t heat	15·9
(d) Russian, 7 t heat	56·7

related to dead burning of dolomite for LD converters (Tables VII–XXI).

TABLE XVIII Consumption of materials in steel melting shop, tonnes

Particulars	Total 1961–62
Pig iron	
Hot metal	586 881
Cold pig	3 709
Total	590 590
Scrap	
Purchased	34 815·6
Local	174 040·4
Total	208 856·0
Oxides	
Iron ore	131 015
Scale	3 607·9
Fluxes	
Lime	8 342·0
Limestone	61 880
Fluorspar	218·6
Bauxite	574·4
Fettling materials	
Raw dolomite	31 935
Burnt dolomite	20 481
Magnesite	4 929
Alloy materials	
Ferromanganese	12 759
Ferrosilicon	725·30
Aluminium billets	27·591
Aluminium notched bars	6·268
Copper	6·228

ROURKELA STEEL PLANT

The most important requirement for the LD operation is to use good calcined dolomite for refractory lining of the converters. In other countries, where low ash coal is available, shaft kilns for calcining dolomite for LD converters may have worked satisfactorily. In India the ash in coal is very high, and therefore, the dolomite cannot be calcined to produce good quality dolomite with the coke available.

Therefore, coke oven gas has been tried in the vertical shaft kilns but Hindustan Steel Ltd is faced with a serious problem of getting good calcined dolomite in sufficient quantities for the lining of the LD converters made in the shaft kilns. It is well-known that rotary kilns fired with gas have worked most successfully in India, and therefore, to solve the problem of getting good calcined dolomite for the lining of the LD converters, a rotary kiln has been ordered for Rourkela in order to dispense with the use of vertical shaft kiln.

Another aspect on which the National Metallurgical Laboratory has undertaken some work for Hindustan Steel Ltd relates to the use of blast-furnace slag for coal mine stowing. The blast-furnace slag, after granulation and suitable sizing was, as a result of these investigations and actual stowing trials, observed to be a good substitute for sand for coal mine stowing purposes. Further work in this connexion is in progress.

CONCLUSIONS

In conclusion, the authors consider it necessary to refer to some points which must be carefully studied for the iron and steel industry in India and its projected growth during the five year plans.

For every ton of finished steel, between 5–6 tons of raw materials are required and have to be transported, so that for the establishment of 10 m. tons ingot steel annual capacity it will be necessary to transport 50–60 m. tons of raw materials each year from different parts to the steelmaking centres, at the end of the third five year plan. One of the serious problems of feeding the iron and steel industry is the transport system. Unless the railway system is adequately expanded and rationally operated, the shortage of raw materials' transport will always present a formidable bottleneck in the execution of production plans and physical attainment of production targets.

The availability of requisite power to operate the iron and steel plant is also lagging far behind the power targets planned and physically required.

The end-product mix projected for the increased output of steel, needs reorientation from targets of sectional capacity to flat products in order to feed consumer engineering industries which will require additional cold-rolled strip capacity to a greater measure than has been projected. Likewise, with the improvement in the standards of living, greater stress will have to be given to the supply of basic finished steel products as the starting point to feed the secondary engineering industries. The expansion and advancement of the secondary industries and those which consume steel end-products will have to be projected and concurrently expanded on a parallel basis along with the iron and steel industry expansion programme.

With the expansion of the iron and steel industry, the training of personnel i.e. managerial, operational and supervisory, should be concurrently examined. A major iron and steel plant is a complex structure, requiring specialized training in specific fields to operate the plant at maximum efficiency whilst ensuring adequate maintenance. It is well-known that lack of these operational production efficiency and maintenance breakdowns can

TABLE XIX Consumption of services in steel melting shop (1961–62)

Blast-furnace gas, 10³m³	Coke oven gas, 10³m³	Liquid fuel, l.	Electricity, kWh	De-aerated water for evaporation cooling system, t	Technical water, t	Compressed air, 10³m³	Oxygen, m³	Steam, t
249 522	163 566	5 969 171	10 107 627	319 550	12 293 184	47 562	18 513 497	999

TABLE XX Average analysis of coke oven gas

Particulars	Average 1961–62
Carbon dioxide, %	3·5
Higher hydrocarbon, %	2·8
Oxygen, %	0·3
Carbon monoxide, %	8·8
Hydrogen, %	58·5
Methane, %	24·3
Nitrogen, %	1·8
Calorific value, kcal/m³	4 340
Density, kg/m³	0·4746

seriously impair the production targets in hand. Trained personnel are required to man the steel industry in order to attain the production targets on the basis of projected plans.

The emphasis on manpower requirements, organization and scheduling and progressing of the main targets, pattern of additional capacity, and development of design organization, are all interlinked factors which have to be coordinated to attain the required expansion as hitherto projected or that further planned during third and fourth five year plans.

It is also stated that actual end-products and pattern of demand has to be suitably reorientated and projected on a realistic basis to ensure that concurrent parallel development of the engineering industries goes hand in hand with the iron and steel expansion plan—these factors require careful planning and execution to prevent any serious unbalancing of production, demand and supply.

The authors have no doubt that, subject to consideration and action required as outlined above, the iron and steel industry in India will continue its dynamic growth

TABLE XXI Average analysis of blast-furnace gas

Particulars	Average 1961–62
Carbon dioxide, %	15·4
Oxygen, %	0·2
Carbon monoxide, %	27·2
Nitrogen, %	52·8
Density, kg/m³	1·3102
Hydrogen, %	4·4
Calorific value, kcal/m³	940

on the lines planned to attain self-sufficiency and to put the country on the iron and steel map of the world.

ACKNOWLEDGMENTS

The authors wish to thank the general manager of the Bhilai steel plant for supplying the exhaustive data on plant operations etc. The authors also wish to thank different investigators at the National Metallurgical Laboratory, references to whose work and investigations reports have been made in the text of this paper.

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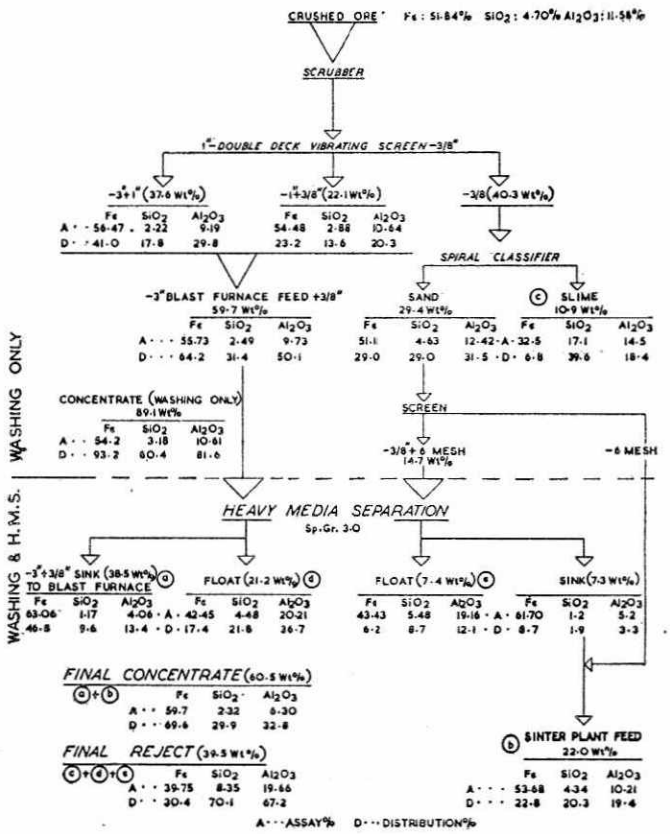
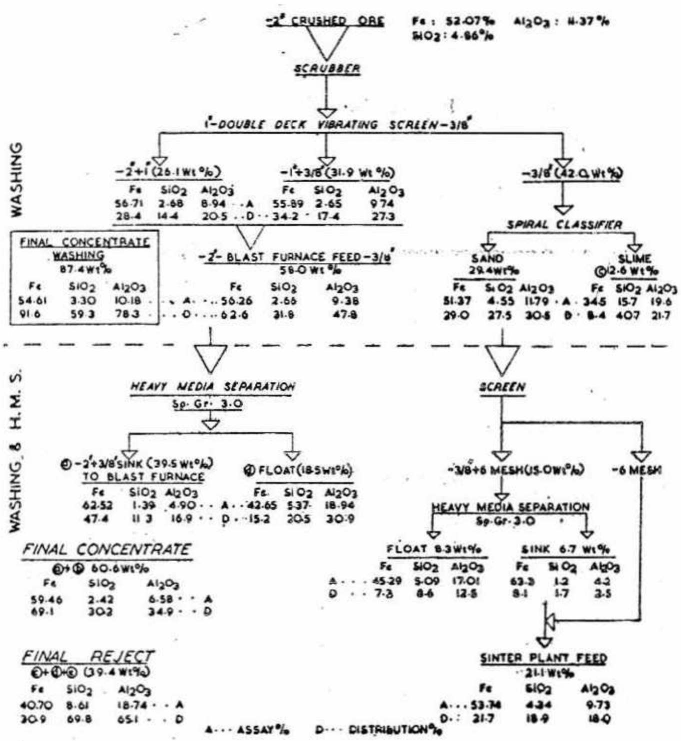
APPENDIX I

BENEFICIATION OF BARSUA IRON ORES
Rourkela steel plant flowsheet no. 1 for −3in size



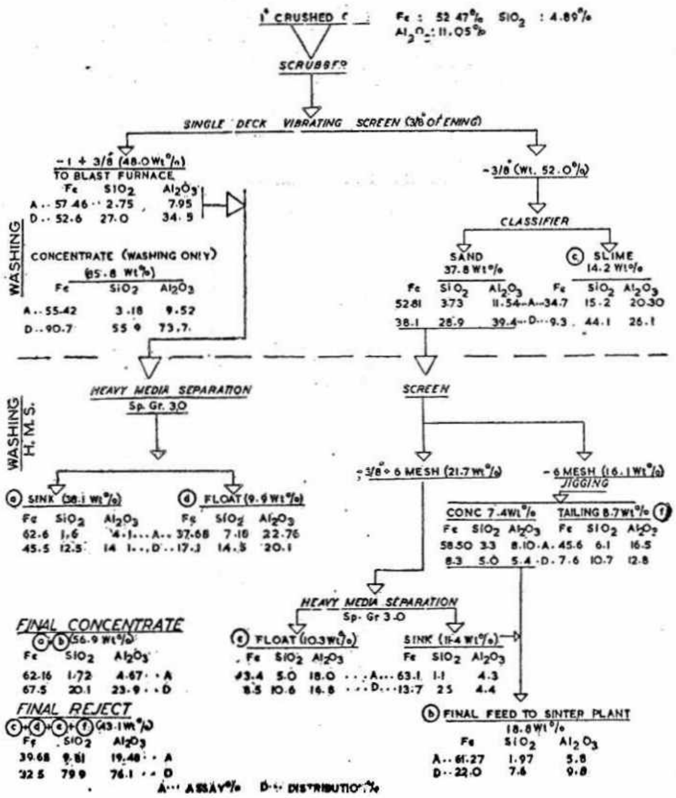
APPENDIX II

BENEFICIATION OF BARSUA IRON ORES
Rourkela steel plant flowsheet no. 2 for −2in size



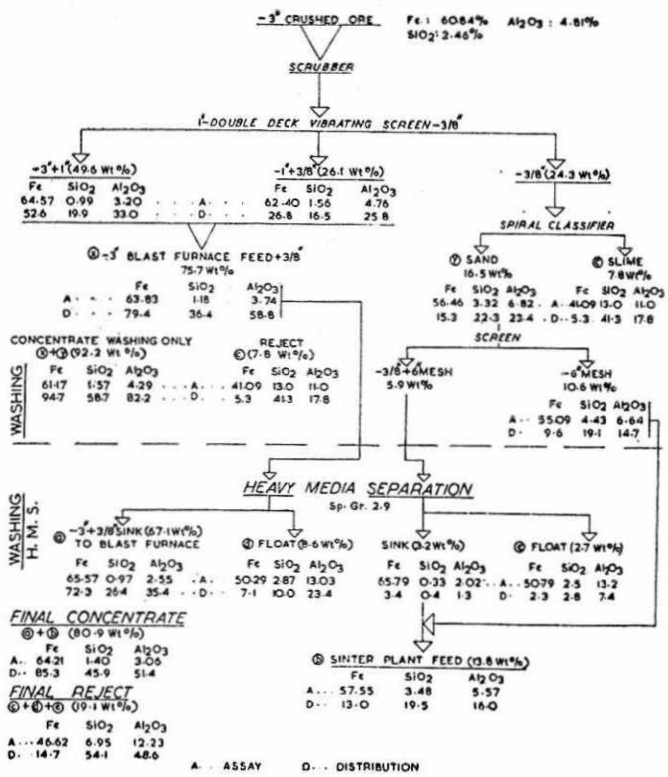
APPENDIX III

BENEFICIATION OF BARSUA IRON ORES
Rourkela steel plant flowsheet no. 3 for −1in size



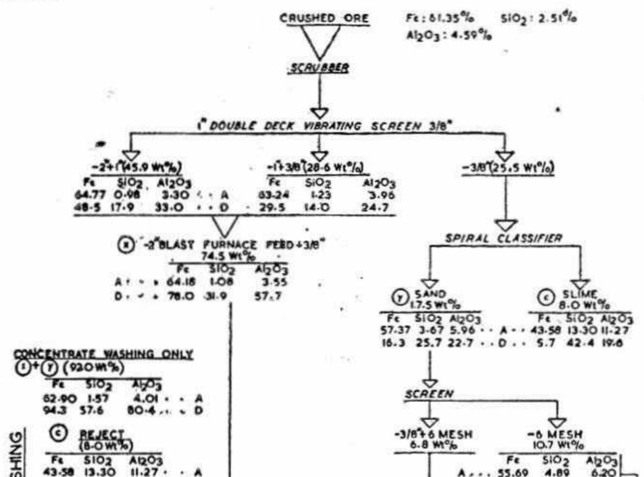
APPENDIX IV

BENEFICIATION OF KIRIBURU IRON ORES
National Mineral Development Corporation flowsheet no. 1 for −3in size



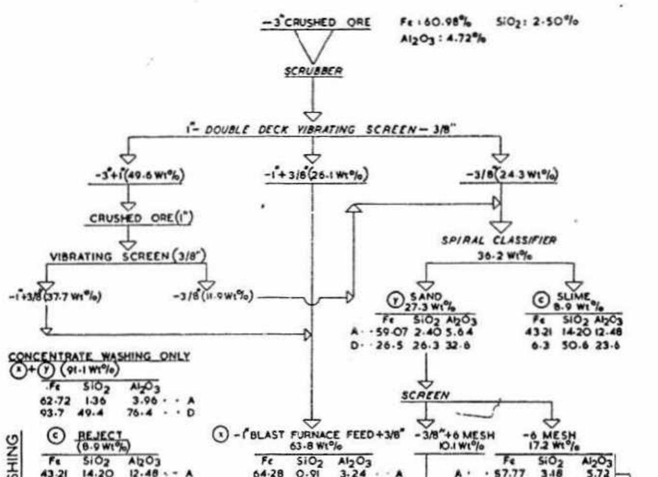
APPENDIX V

BENEFICIATION OF KIRIBURU IRON ORES
National Mineral Development Corporation flowsheet no. 2 for −2in size



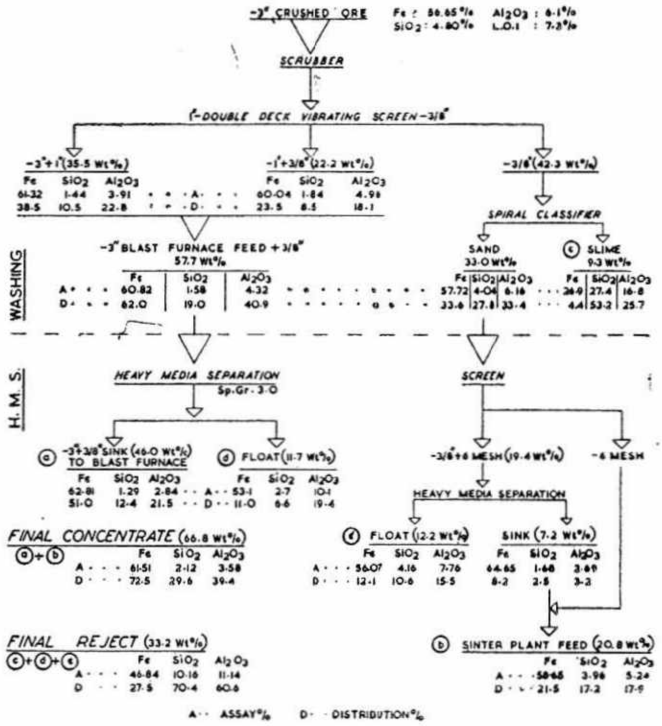
APPENDIX VI

BENEFICIATION OF KIRIBURU IRON OERS
National Mineral Development Corporation flowsheet no. 3 for −1in size



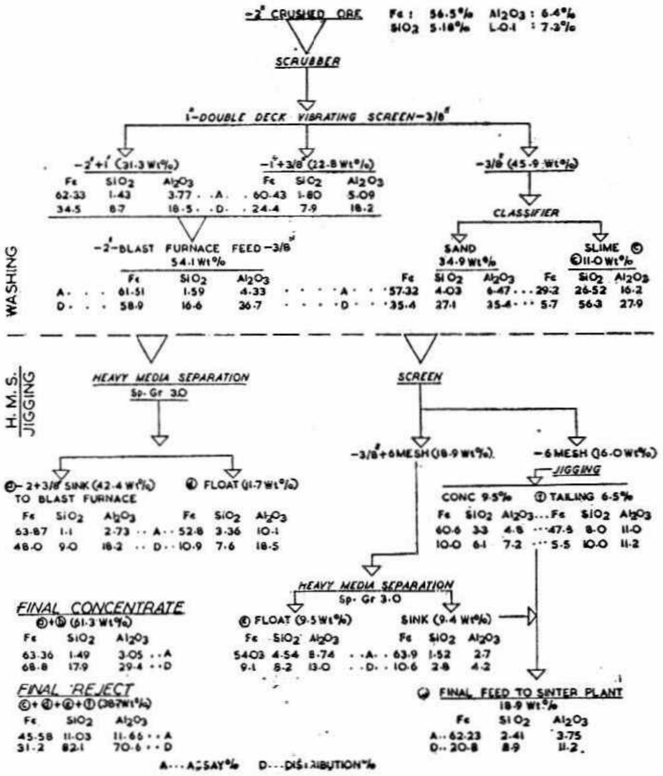
APPENDIX VII

BENEFICIATION OF BOLANI IRON ORES
Durgapur steel plant flowsheet no. 1 for −3in size



APPENDIX VIII

BENEFICIATION OF BOLANI IRON ORES
Durgapur steel plant flowsheet no. 2 for −2in size



APPENDIX IX

BENEFICIATION OF BOLANI IRON ORES
Durgapur steel plant flowsheet no. 3 for −1½in size