

# Beneficiation, sintering, and processing of raw materials for the iron and steel industry

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## BENEFICIATION OF IRON ORES

BENEFICIATION of iron ores relates not only to enrichment of the metal content but also to improvements in physical characteristics of the ore charged into the blast-furnace. The latter is achieved by crushing, sizing, and agglomeration of resultant fines, etc. It is universally recognized that preparation of sized iron-ore burden and use of fluxed sinter in iron production can achieve (i) reduction in coke rate by reducing the metallurgical load on the blast-furnace by better utilization of available heat and (ii) increased productivity.

India possesses vast reserves of iron ore. All the existing iron and steel plants in the country utilize hematitic ores, though a few deposits of magnetite are also being considered for utilization.

Until very recently only hand-mining was employed to prepare iron ore of uniform size and composition for smooth blast-furnace operation. The ore fines produced at mine sites were rejected. The ever increasing demand for iron ore by the expanding iron and steel industry in the country cannot obviously be easily met by selective hand-mining. Mechanized mining is now gradually taking the place of hand-mining for higher ore production. This has consequently created several problems which need careful studies. Mechanized mining cannot distinguish between poor and good ore, with the result that the run-of-mine ore will be of poorer quality and higher in gangue than the selected hand-mined ore.

Crushing and screening will have to be employed for preparing sized ore. For this purpose, ore handling plants employing crushing and dry screening have been set up by the various iron and steel plants. These plants have not been able to give satisfactory performance owing to the extremely sticky nature of iron ores treated, particularly during the rainy season. Not only do the screens get blinded, but even chutes, crushers, etc. also give serious trouble and heavily reduce the output of screened sized ore required for iron production.

Screening may be done either dry or wet, depending upon the nature and amount of fines in the ore as well as their moisture content. Drying the ore will certainly eliminate the sticky nature of the ore, but the fines containing high gangue will get into the coarse fractions, going to the blast-furnace. Drying is in no way cheaper than washing and wet screening with its distinct advantages. Though the dried ore will screen well, there will be very little fines as most of it will be in the + fraction due to balling. Under the monsoon conditions obtaining in India, wet screening should therefore be preferred for ore handling, particularly during the rainy season when the ore delivered to the screening plant would be highly sticky.

When fines are firmly adhering to lumpy ore, it would be advantageous to scrub the ore in a blade or other type of washer to loosen the fines before wet screening. When wet screening is preceded by scrubbing, the entire operation is called 'washing'. Fines obtained as screen under-

## SYNOPSIS

*Results of pilot plant beneficiation studies undertaken on Indian iron ores as well as limestone are briefly outlined. Studies on Indian iron ores have indicated that washing is an absolute necessity to solve the problem of handling sticky and wet ore, and also to yield sized lumpy ore free from adhered fines for blast-furnace charging. Heavy media separation and jigging of the washed products, if employed can further improve the grade of iron ores by decreasing their silica and alumina contents. It has also been shown that upgrading of fines usually high in silica and alumina by gravity methods is essential, although in some cases washed lumps may not need further upgrading. Sinters, both fluxed and unfluxed, with good strength can be produced with both washed and upgraded iron ore fines, but sinters made from washed fines may not be of acceptable chemical composition. The economic evaluation of beneficiation in terms of savings in blast-furnace practice by using beneficiated iron ores is outlined.*

*Comprehensive laboratory and pilot plant investigations made on the low-grade Indian limestone by froth flotation have indicated that these can be economically upgraded to decrease the silica content below 2.5% with over 90% recovery of limestone in the concentrate. The concentrate after agglomeration by briquetting or pelletizing can be used as a metallurgical flux in steelmaking.*

*A short description of the integrated pilot plant installed at the National Metallurgical Laboratory which has involved a capital expenditure of over a million dollars, is also given.*

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size after washing are normally dewatered in a classifier where, apart from water removal, very fine slimy material which is invariably high in gangue is also eliminated, improving the quality of screen undersize for subsequent utilization. It may be interesting to note that in the case of Bolani ore, about 56% of the silica and 28% of the alumina contained in the ore could be rejected in the slime. Thus washing, besides overcoming the difficulties encountered in ore-handling plants due to the sticky nature of ore, provides a clean sized ore free from adhering fines for the blast-furnace and a classifier product free from slime for the sinter plant. Any upgrading achieved by this treatment should be considered only as supplementary benefit in the case of Indian iron ores.

Another aspect of considerable importance to iron-ore beneficiation in India is the possibility of lowering of alumina content of the ore. Control of the alumina content of the blast-furnace charge is necessary to obtain a fluid slag of proper composition for production of quality pig iron.

Depending on the nature of the ore, alumina may be present as (i) fine clayey material adhering to the coarse pieces and filling up the natural cavities in the ore, and/or (ii) lumpy lateritic material. Predominance of one or the other depends on the nature of ore deposits and also on the mining methods employed. It is the general experience that alumina present as clayey material is reduced by washing, whereas if present in the form of laterite

TABLE I Chemical analyses of run-of-mine ores, %

Ore	Fe	SiO <sub>2</sub>	Al <sub>2</sub> O <sub>3</sub>	Loss on ignition
Tisco ores				
(i) Noamundi hard	64.2	1.90	3.7	3.82
(ii) " soft	60.5	2.3	5.5	6.6
(iii) Joda	61.6	2.7	4.3	5.4
(iv) Gurumahisani	56.8	4.0	4.65	10.0
(v) Badampahar	59.2	2.9	3.4	8.4
Bolani ore				
(for Durgapur)	56.6	5.00	6.3	7.3
Barsua ore				
(for Rourkela)	52.18	4.80	11.34	9.08
Rajhara ore				
(for Bhilai)	57.0	7.04	6.76	5.3
Kiriburu ore				
(for export)	60.96	2.40	4.50	5.30
Salem magnetite	36.51	44.88	1.35	—

it cannot be adequately separated by mere washing. Laterites are generally found as cappings overlying iron ore deposits and may not very often persist at lower depths. However, in some cases, laterite has also been found interspersed in the ore body at lower depths. Owing to the adoption of mechanized mining methods, part of the lateritic ore would be inevitably mined along with good ore for many years to come. As such, reduction in alumina content by the removal of laterite assumes great importance. Systematic research investigations conducted for the last few years at the National Metallurgical Laboratory have indicated that gravity methods of ore-dressing can be successfully employed to decrease the laterite in the ore to yield an upgraded product substantially low in alumina.

To utilize the large amount of iron-ore fines produced during mechanized mining and in the ore-handling plants, the provision of sintering facilities has been proposed in almost all the steel plants. Generally the fines have higher alumina and silica contents than the lumpy ore. Sinter made from such aluminous fines using coke breeze high in ash will be metallurgically unsuitable for blast-furnace use. However, if these fines, after beneficiation, are used for producing self-fluxing or super-fluxing sinters, maximum advantages (economic as well as operational) could be achieved in the blast-furnace. Sintering characteristics of Indian iron ore fines have also been comprehensively studied at the National Metallurgical Laboratory.

Comprehensive investigations were undertaken in the Laboratory on 100-ton representative run-of-mine ore samples from the various mines supplying iron ores to the Tata Iron and Steel Co. Ltd, the Durgapur, Rourkela, and Bhilai iron and steel plants, and from the Kiriburu mines. The samples were collected in such a way as to represent as best as possible the type of ore that would be mined for the next 15 to 20 years. In these investigations, the following aspects were studied in detail :

- (1) Screenability.
- (2) Washing.
- (3) Upgrading of washed products employing gravity methods.
- (4) Sintering of fines.
- (5) Economic evaluation of beneficiation.

Investigations were also undertaken on beneficiation of low grade magnetite ore from Salem.

In the present paper, some general observations have been presented which are based on the experimental results obtained on Indian iron ores.

TABLE II Dry screening

	-2+ $\frac{3}{8}$ in fraction			- $\frac{3}{8}$ in fraction				
	wt % Fe	SiO <sub>2</sub>	Al <sub>2</sub> O <sub>3</sub>	wt % Fe	SiO <sub>2</sub>	Al <sub>2</sub> O <sub>3</sub>		
Tisco ores								
Bolani	74.9	62.98	2.52	3.64	25.1	57.21	2.85	5.75
Barsua	56.5	60.43	2.17	5.32	43.5	52.78	7.56	8.03
Rajhara	66.5	55.11	3.49	9.73	33.5	46.06	7.58	14.58
Kiriburu	70.7	61.69	4.02	5.72	29.3	49.50	14.80	9.18
	71.5	62.45	1.39	4.10	28.5	57.24	4.93	5.5

#### Experimental results

Table I gives the chemical analyses of the iron ores studied in the Laboratory.

Apart from the magnetite ore from Salem (Madras State), most of the iron ores contained hematite and goethite as principal iron minerals with laterite in varying amounts. Alumina content of these ores, which was generally high, was mainly contributed by the presence of laterite, although clay and feldspars were also present to some extent. In all the hematitic ore samples, the alumina content was generally higher than the silica content, except in the Rajhara ore and total insolubles (Al<sub>2</sub>O<sub>3</sub>+SiO<sub>2</sub>) varied from 5.6% to 16.14%. Attention may be drawn to the loss on ignition, which varied from 3.82% to 10.00%, indicating the predominance of hydrated iron oxides in the soft ores.

#### Dry screening

As stated earlier, crushing and dry screening facilities have been provided at the mines or steelworks for the preparation of sized ore for the blast-furnace as well as for obtaining requisite fines for sinter plant.

It has been the general experience of the steel plants that serious operational difficulties are encountered in handling, screening, and in maintaining uniform quantum of flow of the ore especially during the rainy season when the ore delivered to the plants is very sticky. The screens, particularly the fine ones, get more or less totally blinded making screening highly inefficient with consequent increase in the amount of fines in the coarser fractions. During dry weather, screenability does improve somewhat but is often hampered at times badly, in the case of mechanized mined ore contaminated with sub-soil water.

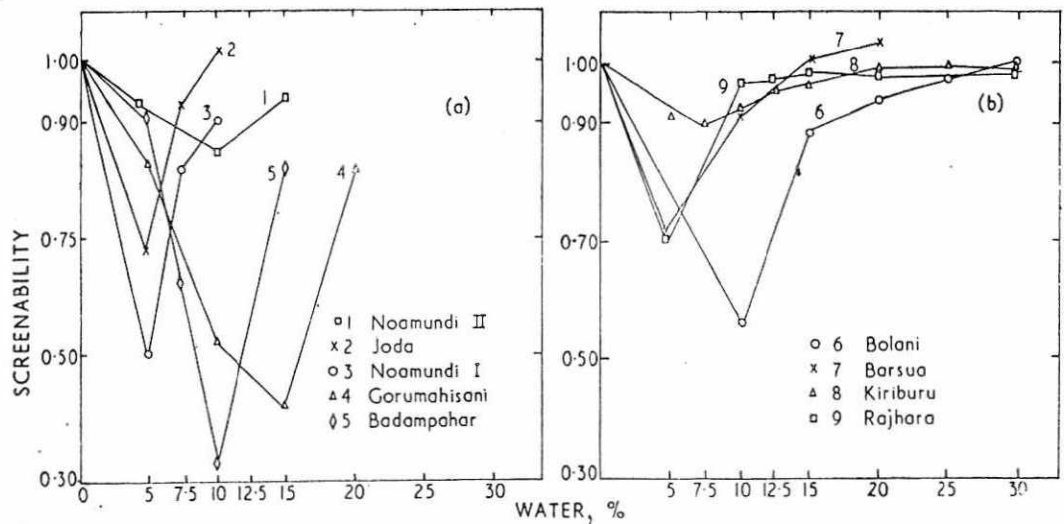
Chemical analyses of lumpy and fine fractions obtained after crushing and dry screening are recorded in Table II.

As expected, the finer fractions were distinctly of poor grades with higher insoluble contents than the lumpy fractions.

#### Screenability

Since considerable screening difficulties were experienced during the rainy season, studies were undertaken to find out the effect of varying moisture content on the screenability of ores. For this purpose, dry representative crushed ore samples were screened over a  $\frac{3}{8}$ in vibrating screen and the two fractions were weighed in each case. These two fractions were then mixed with a known amount of water and screening performed as before. The screened fractions were weighed after drying. This procedure was repeated varying the moisture content. The ratio of the - $\frac{3}{8}$ in fraction obtained after screening to that present in the dry ore was taken as a measure of screenability of the ore. The results obtained are graphically represented in Figs. 1a and 1b.

It was observed that screenability initially decreased with increase in moisture content, reached a minimum, and then increased. In other words, for every ore, depending upon its nature and the amount of fines present,



1 Screenability v. water content, ores as shown

there is an optimum water content above which screening becomes efficient.

#### Washing

For wet and sticky ores, wet screening is the obvious choice to ensure successful screening operation. When sticky fines are closely adhering to the lumps, scrubbing the ore will assist in loosening these fine particles before screening. The screen undersize is dewatered in a cross-flow classifier, where slime high in insolubles is eliminated. Thus washing, besides facilitating handling problem of sticky ores, helps to decrease the insoluble content of washed products.

To study the washing characteristics of different ores, the crushed ore ( $-2$  in size) was fed to a scrubber at the rate of  $1\frac{1}{2}$ – $2$  tons/h. The ore scrubbed with water was wet-screened on a double deck vibrating screen having 1 in and  $\frac{3}{8}$  in openings. The  $-\frac{3}{8}$  in screen undersize was dewatered in a crossflow classifier where  $-\frac{3}{8}$  in sand and very fine material (slime) were separated.

The results obtained after washing are summarized in Table III.

By washing (scrubbing followed by wet screening) a clean sized washed product free from adhering fines for direct charging to the blast-furnace and a properly classified free-flowing product (fines) for sintering were obtained after rejection of the slime, which was in all cases exceedingly high in insolubles (alumina+silica) content.

There was only a slight increase in the iron content of the washed product, but the total rejection of alumina and silica in the slime was quite considerable. The overall silica removal was higher than that of alumina. However, the extent of this slight preferential elimination of silica over alumina after washing was not likely materially to affect blast-furnace operation adversely when balanced against overall advantages accruing through washing.

Compared to dry-screened products (Table II), the washed products were of improved grades. Although the fines obtained after washing were of better grade than the dry-screened fines, these were still high in insoluble contents; the sinter produced from such fines would be poorer with respect to chemical composition than the washed lumpy ore.

From these studies, it can be broadly stated that mere washing may yield in some cases a lumpy ore fraction of acceptable chemical composition for blast-furnace use, whereas washed fines which are high in

insolubles invariably need further upgrading by gravity methods for production of quality sinter in order to get the maximum metallurgical advantages in blast-furnaces.

#### Upgrading of washed products by gravity methods

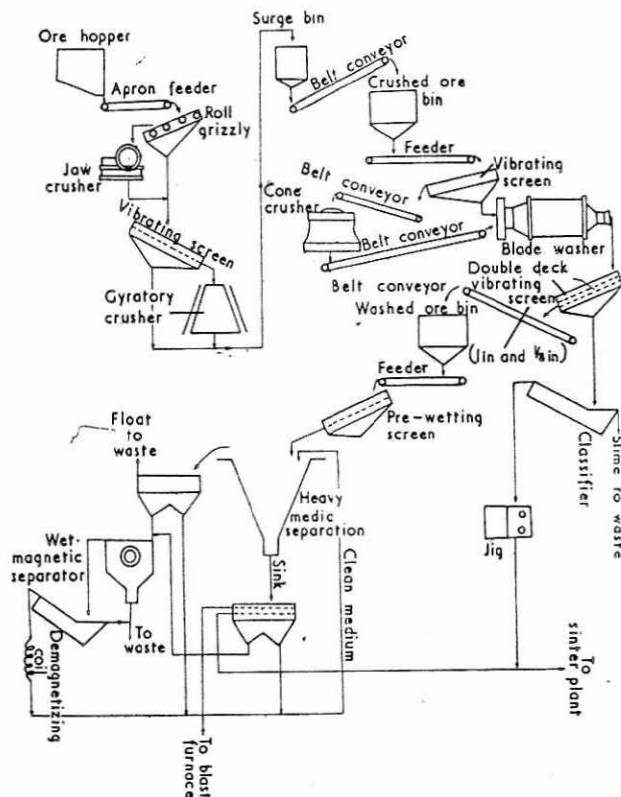
In order to produce pig iron of desired quality and to operate the blast-furnace at a high and uniform level of production, it is essential to use raw materials of good and consistent quality. In view of the limited resources of metallurgical grade of coal, any effort made to reduce the coke rate in the blast-furnace should be encouraged. This can be achieved by several methods, of which the more important are: (i) reducing the ash content of coal, (ii) using properly sized burden, (iii) decreasing the gangue content of iron ores and fluxes charged into the blast-furnace, and (iv) using self-fluxing sinters. It is considered uneconomical to bring down the ash in coal by washing, below a certain optimum. The other important way of reducing coke rate is to reduce the slag volume by decreasing the silica and alumina contents of ore and fluxes. As Indian iron ores are generally high in alumina, reduction of the silica content of limestone, etc. may not be desirable as it will act as a corrective for final alumina content of blast-furnace slag. It is the general experience in India that a 1% decrease in insoluble contents of ore results in increased iron production of 2.5%. Thus any effort made in reducing the gangue content of ore will result in high iron production output with lower coke and flux rates.

Keeping these factors in view, the methods employed to upgrade these ores are briefly outlined. As stated earlier, gravity methods can be successfully employed in reducing acid insoluble contents of iron ores and thus improving their grade with respect to iron.

Laterite, the main source of alumina in Indian iron ores, could be easily separated employing heavy media separation after washing. For carrying out these studies, a suspension of finely ground galena/ferrosilicon in water was prepared to give a medium of 2.9 or 3.0 sp. gr. Washed  $-2+\frac{3}{8}$  in and  $-\frac{3}{8}+6$  mesh fractions were separately subjected to a heavy-media separation process.

The  $-6$  mesh fractions of classifier sands were treated in jigs.

For ready comparison and evaluation, the results of washing and upgrading of washed products by heavy-media separation/jigging, are summarized in flowsheets (Appendixes I–V), which are self-explanatory. Heavy-media separation of the washed ore was found to decrease the alumina content substantially in the final beneficiated



2 General flow sheet for beneficiation of Indian hematitic iron ores

sized ore charged to the blast-furnace. There was also a marked improvement in their iron content and a reduction in the total alumina and silica. The classifier sand obtained after washing was very high in silica and alumina, which could be further reduced by heavy-media separation of  $-3/8$  in  $+6$  mesh and jigging of  $-6$  mesh fractions. The beneficiated fines are considered highly suitable for sintering.

Thus, when washing of  $-2$  in ore was followed by heavy-media separation and jigging, there was substantial improvement in grade and considerable decrease in their total alumina and silica contents. The extent of alumina removal was such that the final alumina in the slag should fall within optimum limits due to lower alumina/silica in the coke ash. Should, however, the alumina content of the slag increase beyond the optimum levels, additions of quartzite or banded hematite quartz or the use of high silica limestone could be advantageously made.

One important point that emerged from these studies was that washing alone might or might not give a satisfactory product for use in the blast-furnace, whereas if heavy-media separation/jigging were employed after washing, the blast-furnace could always be assured of a product of uniform composition, in spite of slight variations in the nature of the ore fed to the beneficiation plant.

A general flowsheet for beneficiation of Indian hematitic iron ores is given in Fig. 2.

#### Beneficiation of magnetite from Salem

As the problem of beneficiation of magnetite is entirely different from that of hematitic iron ores discussed earlier, the results of studies on magnetite are briefly described.

The magnetite sample, assaying 36.51% Fe and 44.88%  $\text{SiO}_2$  had quartz as the chief gangue mineral and grinding to about 65 mesh size liberated most of magnetite from

TABLE III Results of washing

	Wt. %	Assay %			Dist. %		
		Fe	$\text{SiO}_2$	$\text{Al}_2\text{O}_3$	Fe	$\text{SiO}_2$	$\text{Al}_2\text{O}_3$
<i>Tisco ores</i>							
$-2'' + 3/8''$	68.7	63.4	1.63	3.16	70.8	43.1	52.1
$-3/8''$ sand	21.4	59.8	2.60	5.60	20.8	21.4	28.7
Slime	9.9	52.3	9.33	8.09	8.4	35.5	19.2
<i>Bolani</i>							
$-2'' + 3/8''$	54.1	61.5	1.59	4.33	58.9	16.6	36.7
$-3/8''$ sand	34.9	57.3	4.03	6.47	35.4	27.1	35.4
Slime	11.0	29.2	26.52	16.20	5.7	56.3	27.9
<i>Barsua</i>							
$-2'' + 3/8''$	58.0	56.3	2.66	9.38	62.6	31.8	47.8
$-3/8''$ sand	29.4	51.4	4.55	11.79	29.0	27.5	30.5
Slime	12.6	34.5	15.70	19.60	8.4	40.7	21.7
<i>Rajhara</i>							
$-2'' + 3/8''$	65.9	61.1	3.40	4.46	71.5	31.3	46.0
$-3/8''$ sand	26.3	52.3	10.86	8.51	24.5	39.8	35.0
Slime	7.8	28.9	26.55	15.56	4.0	28.9	19.0
<i>Kiriburu</i>							
$-2'' + 3/8''$	74.5	64.2	1.08	3.55	78.0	31.9	57.7
$-3/8''$ sand	17.5	57.4	3.87	5.96	16.3	25.7	22.7
Slime	8.0	43.6	13.30	11.27	5.7	42.4	19.6

it. Wet magnetic separation of the sample ground to  $-65$  mesh yielded a magnetite concentrate assaying 70.4% Fe and 2.74%  $\text{SiO}_2$  with nearly 89% Fe recovery.

The concentrate obtained could be agglomerated by sintering, briquetting, or pelletizing for use in iron smelting.

#### Sintering of fines

Mechanized mining, crushing, and screening adopted for meeting the increased demands of iron ore necessarily produce larger proportions of fines ranging from 25% to 45%. These fines are invariably higher in gangue content as compared to the lumpy fraction. Based on considerations of cost alone, it is essential to utilize these fines after sintering, for iron production. However, it may be stated that sinter produced from unbeneficiated dry-screened fines will hardly be of any metallurgical value from the point of view of higher iron production and lower coke and flux rates due to its higher gangue content.

It is therefore the considered opinion of the authors that beneficiation of fines by washing followed by a gravity method of concentration is essential before sintering. Apart from this, it is desirable to produce self- or super-fluxing sinters incorporating all the necessary fluxes needed in the blast-furnace in order to obtain maximum benefits.

It is generally known that for each unit of  $\text{CaCO}_3$  incorporated in sinter, the effective carbon saving in the blast-furnace is 0.26 units. As such, the use of fluxed sinter achieves the twin objectives of higher iron production and lower coke rate by (i) the elimination of free or combined moisture, (ii) preslagging of acid constituents, (iii) its low FeO content as compared to a non-fluxed sinter, and (iv) most important of all, by effecting the endothermic calcination of limestone and dolomite outside the blast-furnace and also thereby decreasing the quantity of  $\text{CO}_2$  in the upper stack of the furnace thus lowering solution loss of carbon and favouring the reduction of iron oxide by CO.

Sintering characteristics of iron-ore fines obtained from the various mines have been investigated in detail; variables such as fuel content of mix, moisture content, return fines, as well as flux additions have been studied.

Production of good sinter depends upon three main factors: (i) coke or fuel content of the charge which controls the sintering temperature in the bed, (ii) moisture content of the charge which controls the permeability of the bed and thereby the rate of sintering, and (iii) time and mode of initial ignition which have a marked influence on the overall fuel economy as well as on the quality of sinter.

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, yielding a fused sinter characterized by large voids, glazed surfaces, and reduced porosity.

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

Other important factors governing the quality of sinter are the chemical analyses of raw materials, their sizing, method of mixing, laying of the sinter bed, and the amount of circulating load.

Extensive studies were made in the National Metallurgical Laboratory on the sintering characteristics of Indian iron ore fines. Results of some trials obtained under optimum conditions are recorded in Table IV and chemical analyses of corresponding sinters in Table V.

The results indicated in general that the strength of unfluxed sinters, made of washed or unwashed ore fines, did not change appreciably under respective optimum conditions. In other words, sinters of good strength could be made with both unwashed and washed ore fines. On the other hand, it was found that with unwashed ore fines, the fluxed sinters obtained were of poorer strength as compared with those made from washed and/or upgraded fines. It should therefore be concluded that it would be difficult to make fluxed sinter of good strength from unwashed ore fines.

No marked deterioration in sinter strength was noticed when part of limestone was replaced by dolomite to increase the MgO content of the blast-furnace slag.

TABLE IV Results of sintering

	Coke %	Water %	Return fines added %	Flux%	Basicity ratio CaO/SiO <sub>2</sub>	Rate of sintering, in/min	Return fines made, wt-%	Shatter stability, %	- $\frac{1}{4}$ in sinter after shatter, wt-%
<i>Noamundi, Tisco</i>									
1. Unwashed	4	7	20	—	—	0.95	16.8	58.9	6.4
2. Unwashed	4	7	20	13.7	2.0	0.86	16.3	46.1	9.8
				LS and D	$\frac{\text{CaO}+\text{MgO}}{\text{SiO}_2}$				
3. Washed	4	7	25	—	—	0.68	18.6	64.8	9.7
4. Washed	3.5	7	20	10.2	2.0	0.76	20.4	63.2	9.4
				LS and D	$\frac{\text{CaO}+\text{MgO}}{\text{SiO}_2}$				
<i>Bolani</i>									
5. Unwashed	4	8	20	—	—	1.13	19.4	52.2	6.8
6. Unwashed	4	8	25	13.2	1.2	1.00	18.6	42.2	9.5
7. Washed	4	7	20	—	—	0.93	20.6	51.8	8.1
8. Washed	3	7	25	10.13	1.2	1.0	21.5	50.1	7.9
9. Washed	3	7	25	7.2	1.3	0.91	23.5	51.7	9.4
				1.8 D	$\frac{\text{CaO}+\text{MgO}}{\text{SiO}_2}$				
10. Bolani washed and concentrated	4	7	20	—	—	0.73	22.3	55.5	6.0
11. do	3	7	25	7.06	1.2	0.77	25.3	60.5	6.5
<i>Bursua</i>									
12. Washed	4	7	25	—	—	0.95	22.6	52.6	11.3
13. Washed	4	7	25	13.95	1.6	1.00	17.0	69.6	5.2
14. Washed	4	7	25	4.48	1.3	0.83	23.4	59.2	8.5
				1.49 D	$\frac{\text{CaO}+\text{MgO}}{\text{SiO}_2}$				
15. Washed and beneficiated	4	7	25	—	—	0.80	24.1	51.2	9.7
16. Washed and beneficiated	4	7	25	6.13	1.2	0.73	17.2	65.5	5.8
<i>Rajhara</i>									
17. Washed	4	7	25	—	—	0.80	24.6	68.1	7.3
18. Washed	3.5	7	25	14.1	1.0	0.90	26.3	59.4	6.6
19. Washed	3.5	7	25	11.1	1.0	1.00	25.0	58.1	8.6
20. Washed and beneficiated	4.5	7	25	—	—	0.90	22.0	54.3	5.7
21. Washed and beneficiated	4.0	7	25	12.57	1.6	0.82	25.4	61.0	7.3
<i>Kiriburu</i>									
22. Washed	4	7	25	—	—	0.95	18.8	62.9	9.4
23. Washed	3	7	20	10.05	1.4	0.95	21.4	67.7	9.9
24. Washed	3.5	7	20	7.9	1.6	0.95	18.1	61.7	9.0
				2.0 D	$\frac{\text{CaO}+\text{MgO}}{\text{SiO}_2}$				
				LS=Limestone D=Dolomite					

TABLE V Chemical analyses of sinters, %

No.	Total Fe	FeO	SiO <sub>2</sub>	Al <sub>2</sub> O <sub>3</sub>	CaO	MgO
1.	61.8	21.3	5.8	4.8	0.5	1.0
2.	52.6	9.1	6.5	6.2	10.3	1.8
3.	—	—	—	—	—	—
4.	55.3	9.7	4.8	7.8	7.4	1.6
5.	57.5	24.9	9.2	9.7	1.3	0.9
6.	—	—	—	—	—	—
7.	61.3	23.8	5.6	8.4	1.2	0.7
8.	52.9	11.0	6.6	7.4	9.1	1.3
9.	54.3	9.1	6.2	6.4	6.9	1.9
10.	63.9	21.6	4.2	5.3	1.0	0.9
11.	59.2	10.5	5.0	4.8	5.6	0.6
12.	56.2	15.2	6.2	13.3	0.6	0.9
13.	47.1	7.6	7.4	12.8	11.6	1.4
14.	52.5	11.1	6.2	10.7	5.6	2.1
15.	62.7	12.7	3.8	7.0	0.5	0.7
16.	59.1	11.7	4.7	5.6	5.4	1.0
17.	52.7	14.5	15.1	7.8	0.8	1.3
18.	43.7	7.3	15.1	7.6	14.0	3.0
19.	44.8	8.6	14.2	8.6	14.0	3.6
20.	59.3	19.3	5.8	6.9	0.7	1.0
21.	51.8	8.1	7.9	4.4	10.5	2.5
22.	59.8	19.6	5.8	7.4	2.7	1.4
23.	54.0	4.3	6.6	6.0	9.6	1.8
24.	55.2	7.8	6.7	6.0	10.2	2.3

Table V shows that sinters made from unwashed ore fines were very high in total silica and alumina contents, making them metallurgically unsuitable for use in the blast-furnace. Even sinters made from fines obtained after washing only were of poor chemical composition, whereas the use of washed and upgraded fines yielded sinters of good chemical composition similar to washed lumpy ores.

Another significant observation was that fluxed sinters invariably had a higher degree of oxidation, as indicated by their FeO contents.

### Conclusions

In general, it can be concluded that since Indian iron ores as mechanically mined at present, particularly from the top benches, are of a sticky nature, especially during the rainy season, dry screening in ore crushing plants will not be efficient. The screens, especially the finer ones, will heavily blind, making screening highly ineffective with a consequent increase in the amount of fines in the coarser fractions. The fines obtained will be very high in silica plus alumina, which will increase further after sintering. It will therefore not be advisable to sinter such low-grade fines.

Washing of the ore, besides assisting in the problem of handling of sticky ores, will also yield clean, sized, washed lumpy ore free from adhering fines and a properly classified product free from slime.

Although washing preferentially removes more silica than alumina, it is not likely to affect blast-furnace operation adversely when balanced against the distinct overall advantages gained by washing.

Washed lumpy fractions, which are generally high in iron, are in some cases high in alumina also. Heavy-media separation has been found to decrease the alumina content substantially in the beneficiated lumps. In the case of washed fines, gravity methods of beneficiation are absolutely essential to yield a product suitable for good sinter-making as the fines are invariably high in alumina and silica and low in iron.

The extent of alumina removal by beneficiation methods is such that the final alumina in the blast-furnace slag should normally fall within optimum limits. However, should the alumina content increase beyond the limit, the addition of quartz, banded hematite quartz, or high-silica limestone can be advantageously resorted to.

Sinters of good strength can be obtained from ore fines in all cases. However, sinters, both fluxed and non-fluxed, of acceptable chemical composition and good metallurgical grade can generally be obtained only with washed and upgraded fines.

The overall economics of washing and upgrading of iron ores has to be evaluated taking into consideration both the increased cost of ore due to beneficiation and the ultimate reduced cost of production of pig iron in the blast-furnace by means of lower coke and flux rates and slag volume and higher production by the use of upgraded ore.

It is difficult to determine these figures unless operational data are available for practices employed in the various iron and steelworks. However, for convenience of calculations, certain assumptions are made which may be considered to be fairly realistic to give correct trends.

The assumptions made are :

- (i) Cost of raw ore as mined is taken at Rs. 5/tonne
- (ii) Beneficiation plant is assumed to operate with a daily rated capacity of 14 000 tonnes of run-of-mine ore.
- (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 supplies.
- (iv) For every 1% reduction in the alumina content of the ore achieved by beneficiation, the coke and flux rates should decrease by 40 kg and 60 kg respectively per tonne of pig iron made, and the increase in production of pig iron would be about 2.5%. As a result of these factors, the overall saving per tonne of pig iron produced would be Rs. 4 after allowing for depreciation, etc.

The calculations based on these assumptions for different iron ores are recorded in Table VI. The increased benefits to be obtained by the use of beneficiated ores are obvious.

### BENEFICIATION OF LIMESTONE

Limestone has many industrial uses, the most important being in the manufacture of cement and in the metallurgical industry for use as a flux. Limestone used as a metallurgical flux in the iron and steel industry in particular should conform to certain physical and chemical specifications. For use in iron blast-furnaces, certain flexibility in its optimum silica content is permitted in view of the aluminous gangue of Indian iron ores and the resulting need for dilution of alumina in blast-furnace slags. On the other hand, for steelmaking, a high-grade limestone low in silica, phosphorus, and sulphur is essential.

When considering the suitability of limestone for use as a flux in steelmaking, it is the available lime that is of prime importance. As each additional 1% of silica reduces the available lime by 2.5%, it is essential that a flux should contain as low a silica content as possible to ensure maximum available lime for flux purposes.

Apart from this, high silica content causes greater consumption of limestone, resulting in the formation of a thick insulating layer of slag over the molten metal which adversely affects heat transfer, apart from damage to the furnace roof lining through upward heat deflection. Use of high silica limestone increases slag volume and therefore lowers productivity.

The demand for limestone has increased many times owing to the rapid expansion of the iron and steel and cement industries. As the reserves of high-grade limestone are limited in the vicinity of iron and steel plants, the necessity has arisen for beneficiating the low-grade

limestones to make them suitable as flux for steelmaking.

On the basis of extensive studies made in the National Metallurgical Laboratory on behalf of the Tata Iron and Steel Co. Ltd and Hindustan Steel Ltd, it has been found that low-grade limestones can be upgraded by flotation to give a concentrate acceptable to the steel industry. The concentrates which are in form of fines can be agglomerated by briquetting or pelletizing for use in steelmaking.

#### Samples

Four low-grade limestone samples from Purnapani Quar-

ries, Sundergarh Dist., Orissa, were investigated for HSL and one sample from the Birmitrapur area for TISCO.

Chemical analyses of the samples are recorded in Table VII.

Calcite was the principal carbonate mineral in all the samples, with small amounts of dolomite. Quartz was the predominant gangue mineral, followed by chlorite, phlogopite, muscovite, and feldspar. In general, it was found that there was fair liberation of gangue from carbonates at about 150 mesh.

Chemical and mineralogical examinations showed that the problem of beneficiation consisted in the elimination

TABLE VI Economic evaluation of beneficiation of Indian iron ores

	Crushing, dry screening, and utilization of fines			Crushing, dry screening, and rejection of fines (— $\frac{1}{2}$ in)			Crushing, washing, wet screening, and dewatering of fines			Crushing, washing, wet screening, and concentration of fines only			Crushing, washing, wet screening, concentration of both lumps and fines			Remarks	
	Fe	SiO <sub>2</sub>	Al <sub>2</sub> O <sub>3</sub>	Fe	SiO <sub>2</sub>	Al <sub>2</sub> O <sub>3</sub>	Fe	SiO <sub>2</sub>	Al <sub>2</sub> O <sub>3</sub>	Fe	SiO <sub>2</sub>	Al <sub>2</sub> O <sub>3</sub>	Fe	SiO <sub>2</sub>	Al <sub>2</sub> O <sub>3</sub>		
1. Analysis of ore/beneficiated ore, %																	
(a) Tisco ores	61.5	2.6	4.17	63.0	2.5	3.64*	62.5	1.8	3.74	—	—	—	†	64.0	1.5	2.95	* — $\frac{1}{2}$ in rejected. † Beneficiation of lumps only.
(b) Bolani ore	56.5	5.2	6.40	59.8	2.3	5.33	59.9	2.6	5.17	61.6	1.8	4.18	63.4	1.5	3.05		
(c) Barsua ore	52.5	4.9	11.05	56.2	3.4	9.35	55.4	3.2	9.52	58.5	2.5	7.34	62.2	1.7	4.67		
(d) Rajhara ore	56.3	7.2	6.39	61.7	4.0	5.72*	58.6	5.5	5.62	60.9	3.7	4.75	63.1	2.6	3.62	* — $\frac{1}{2}$ in rejected.	
(e) Kiriburu ore	61.0	2.4	4.50	62.5	1.4	4.10	62.9	1.6	4.01	63.8	1.2	3.67	65.1	1.0	2.90		
2. Yield, tonnes/day																	
(a) Tisco ores	14 000 (100%)			10 486 (74.9%)			12 614 (90.1%)			—			11 312 (80.8%)			(c) Washing and upgrading at 1in size.	
(b) Bolani ore	14 000 (100%)			9 128 (65.2%)			12 460 (89.0%)			10 220 (73.0%)			8 400 (61.3%)				
(c) Barsua ore	14 000 (100%)			7 798 (55.7%)			12 012 (85.8%)			9 352 (66.8%)			7 965 (56.9%)				
(d) Rajhara ore	14 000 (100%)			9 898 (70.7%)			12 908 (92.2%)			11 648 (83.2%)			10 290 (73.5%)				
(e) Kiriburu ore	14 000 (100%)			10 010 (71.5%)			12 880 (92.0%)			11 910 (85.1%)			10 330 (73.8%)				
3. Total cost per tonne prepared ore including capital, depreciation, operation, etc., Rs																	
(a) Tisco ores	6.074			8.061			7.144			—			8.625				
(b) Bolani ore	6.074			9.316			7.202			9.450			12.150				
(c) Barsua ore	6.074			10.759			7.464			10.291			12.776				
(d) Rajhara ore	6.074			8.591			6.981			8.376			10.108				
(e) Kiriburu ore	6.074			8.494			6.996			8.189			10.056				
4. Tonnes of ore required per tonne of pig iron																	
(a) Tisco ores	1.568			1.531			1.543			—			1.496				
(b) Bolani ore	1.706			1.614			1.611			1.563			1.522				
(c) Barsua ore	1.838			1.716			1.740			1.647			1.551				
(d) Rajhara ore	1.712			1.563			1.645			1.583			1.528				
(e) Kiriburu ore	1.581			1.544			1.532			1.512			1.480				
5. Cost of ore required per tonne of pig iron, Rs																	
(a) Tisco ores	9.521			12.340			11.020			—			12.900				
(b) Bolani ore	10.360			15.030			11.600			14.770			18.490				
(c) Barsua ore	11.162			18.470			12.980			16.930			19.810				
(d) Rajhara ore	10.400			13.430			11.490			13.260			15.440				
(e) Kiriburu ore	9.607			13.110			10.730			12.380			14.890				
6. Difference in alumina content, %																	
(a) Tisco ores	—			0.53			0.43			—			1.22				
(b) Bolani ore	—			1.07			1.23			2.22			3.35				
(c) Barsua ore	—			1.70			1.53			3.71			6.38				
(d) Rajhara ore	—			0.67			0.77			1.64			2.77				
(e) Kiriburu ore	—			0.40			0.49			0.83			1.60				
7. Expected saving in production cost per tonne of pig iron, Rs																	
(a) Tisco ores	—			2.12			1.72			—			4.88				
(b) Bolani ore	—			4.28			4.92			8.88			13.40				
(c) Barsua ore	—			6.80			6.12			14.84			25.52				
(d) Rajhara ore	—			3.35			3.85			8.20			13.85				
(e) Kiriburu ore	—			2.00			2.45			4.15			8.00				

TABLE VII Chemical analyses of limestone samples, %

	CaO	MgO	SiO <sub>2</sub>	Al <sub>2</sub> O <sub>3</sub>	Fe <sub>2</sub> O <sub>3</sub>
Purnapani 1	46.0	4.8	7.0	1.7	0.65
" 2	43.8	4.2	11.4	2.8	0.99
" 3	41.7	4.0	13.7	2.2	1.00
" 4	41.0	5.4	14.0	3.1	1.10
Birmitrapur	45.3	3.1	7.8	1.9	1.10

of siliceous gangue from calcite. The nature of association of calcite and the gangue in the sample suggested that froth flotation was the only practical method that could be employed for the separation.

Separation of calcite from siliceous minerals, especially from quartz, can easily be effected by flotation using fatty acids or their soaps as collectors, keeping the gangue depressed with or without sodium silicate. This technique was successfully employed for beneficiating the low-grade limestone samples.

Results obtained with different samples are shown in Table VIII, from which it will be seen that the concentrates were of high grade with low silica.

Successful utilization of limestone concentrates, which were in the form of fines, depended upon the development of the process of agglomeration for proper handling during charging in steel furnaces. Briquettes or pellets made from the concentrates were found to have sufficient strength for this purpose. Trials with the concentrate briquettes were successfully made in steel melting furnaces of 90 tons and 250 tons capacity.

Based on experimental results obtained and the conclusions reached, a general flowsheet formulated for setting up commercial beneficiation plants is given in Fig. 3.

It is estimated that the overall beneficiation cost per tonne of limestone concentrate in the form of briquettes or pellets would be between Rs. 12 and Rs. 15 for a plant capable of treating 250 tonnes of low-grade limestone per day. This cost includes depreciation, interest, operating cost, etc., but excludes the cost of raw limestone.

#### MINERAL BENEFICIATION PILOT PLANT OF THE NATIONAL METALLURGICAL LABORATORY

Systematic research carried out in the National Metallurgical Laboratory during the past 12 years on the beneficiation of more than 200 samples of low-grade ores from different parts of India has indicated that most of them can be upgraded to the required specifications. It is necessary to translate the laboratory work on to a pilot plant scale before commercial plants can be set up in the country.

The pilot plant, apart from yielding data on the technical feasibility of the Laboratory processes, would provide sufficient economic and design data for setting up commercial plants. Besides this, it is expensive and time-consuming to send large quantities of ores abroad for pilot-plant tests, which are generally a prerequisite for setting up commercial plants. Demonstration of processes on a pilot-plant scale induces confidence in industrialists in putting up large-scale plants. The pilot plant installed in the National Metallurgical Laboratory is expected to fill the gap between the processes developed in the Laboratory and their industrial application. The design of the pilot plant naturally depends upon the beneficiation characteristics of the ores to be treated.

Based on the methods found necessary for treatment of different types of ores, a flexible flowsheet has been developed for the pilot plant, so that it is capable of treating all types of ore by suitable modifications in the

TABLE VIII Beneficiation results of limestone samples

Sample	Assay, %					Distribution % CaO
	CaO	MgO	SiO <sub>2</sub>	Al <sub>2</sub> O <sub>3</sub>	Fe <sub>2</sub> O <sub>3</sub>	
Purnapani 1	49.7	5.2	1.92	1.2	0.5	99.3
" 2	50.1	4.5	1.44	0.8	0.9	94.4
" 3	49.8	4.7	2.20	1.0	1.0	95.0
" 4	48.9	4.8	2.53	1.3	1.3	95.9
Birmitrapur	50.5	3.2	2.30	1.0	0.7	95.1

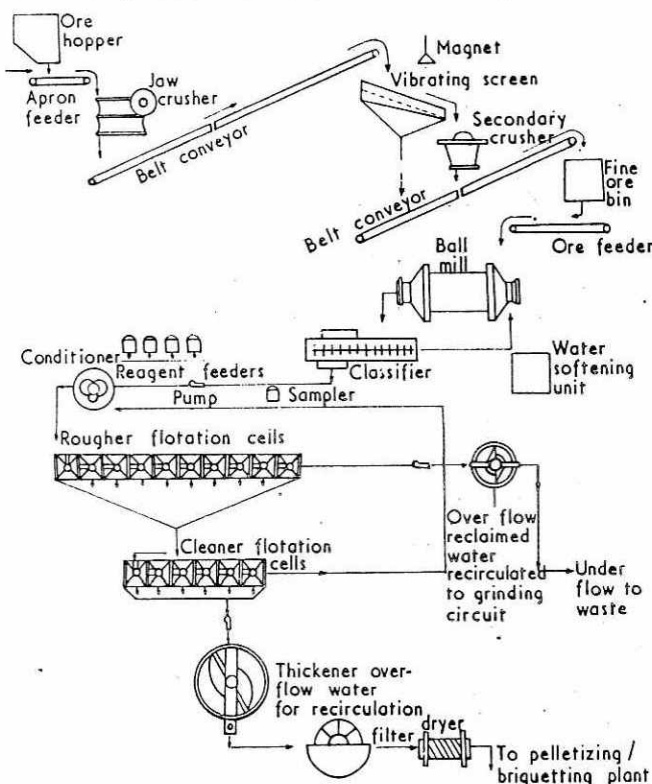
inter-flow of materials. The development of the flow-sheet, drawing up of specifications of equipment, designing of the layout, and installation of the plant including water and power supplies have been done entirely by the staff of the National Metallurgical Laboratory.

The pilot plant installed at a capital cost of Rs. 5 millions (a million dollars) is located in an area of 6 acres of land. A diagrammatic flowsheet of the pilot plant is given in Fig. 4. The plant is divided into different sections : A crushing ; B washing and grinding ; C reduction roast and magnetic separation ; D heavy-media separation ; E flotation ; F jigging, tabling, and Humphrey's spiral treatment, etc. ; G thickening, filtering, and drying ; H high-intensity magnetic and electrostatic separation ; and J agglomeration.

Photographs showing sections of the pilot plant are given in Figs. 5, 6, 7, 8 and 9.

#### Section A : Crushing

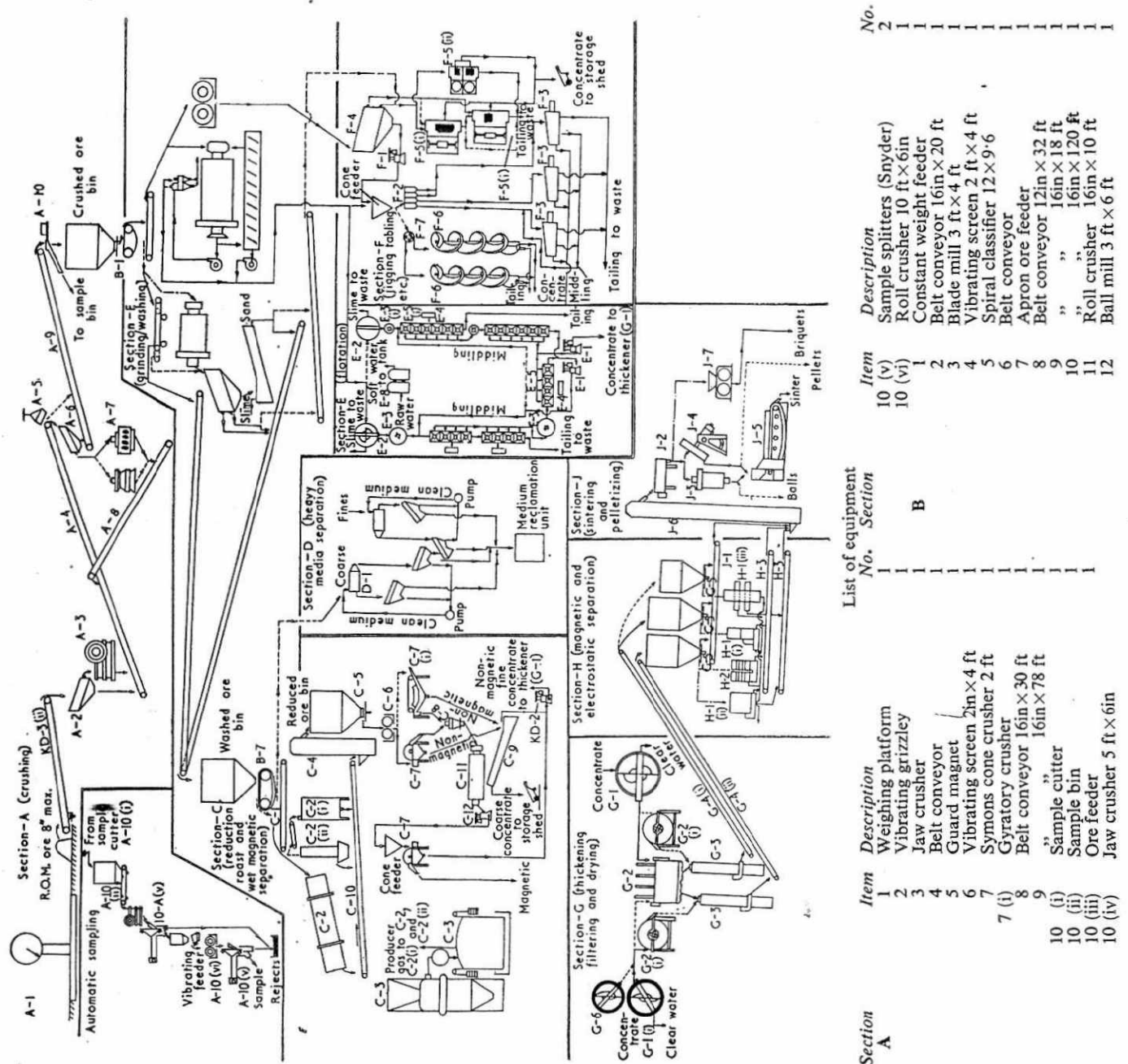
Ore from the railway siding is transported by two 5-ton tilting trucks, weighed on a weighbridge, and then unloaded into a hopper, before feeding to the vibrating grizzly. The oversize is crushed in a jaw crusher. The crusher discharge and the grizzly undersize are conveyed to a single-deck vibrating screen. A guard magnet over the belt removes tramp iron. The oversize is crushed in a secondary short-head cone crusher or gyratory crusher TY type, and joins the main conveyor. The screen undersize is transported to the crushed ore bin by an inclined



3 General flowsheet for setting up commercial beneficiation plants



4 Diagrammatic flowsheet of pilot plant

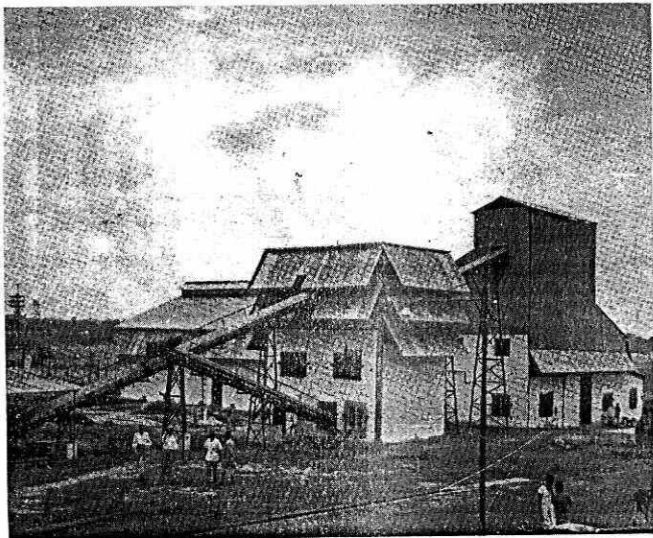


No.	Section	Item	Description
1	C	13	Rake classifier 18x14
1		14	Cyclone classifier
1		15	Sand pump 2in
1		1	Belt conveyor 16 in x 25 ft
1		2 (i)	Rotary kiln 36 x 30 ft
1		2 (ii)	Multiple hearth furnace
1		3	Vertical furnace
1		4	Gas producer (not shown)
1		5	Bucket elevator 35 ft
1		6	Disk feeder 2 ft
1		7	Roll crusher 12in x 8 ft
2		7 (i)	Electromagnetic separator
1		8	Demagnetizing coil
1		9	Spiral classifier 9in x 5 ft 6in

1	10	Belt conveyor 16in x 65 ft
1	11	Rod mill 16in x 4in
1	12	Vertical sand pump 1 1/2
1	13	Gas holder 20 000 ft <sup>3</sup>
2	1	Vertical sand pump
2	2	Hydro classifier 4 ft
2	3	Conditioner 3 ft x 4 ft
4	4	Wet reagent feeder
3	5	Flotation (4) cell unit
2	5 (i)	(6) "
2	6	Automatic pulp sampler
1	7	Dry reagent feeder
1	8	Water softening unit
1	2	Vertical sand pump 1 1/2
1	3	Hydrozizer 4in x 4in - 4 com
1	3	Shaking table 7 ft 6in x 3 ft 6in
2	4	Vibrating screen 2 ft x 4 ft
5 (i)	5 (i)	Jig (Harz type) 16in x 32 ft
5 (ii)	5 (ii)	Mineral jig 8in x 12in Duplex
2	6	Spiral concentrator
1	7	Pulp distributor 4 com
1	1	Thickener 16 ft x 8 ft
1	1 (i)	" " x 6 ft
2	2 (i)	Disk filter 4 ft x 4 disks
2	2 (i)	Drum filter 4 ft x 2 ft 6 ft
3	3 (i)	Rotary dryer x 10 ft
4 (i)	4 (i)	" " x 15 ft
4 (ii)	4 (ii)	Belt conveyor 12in x 105 ft
1	5	Disk feeder 18in
1	6	Hydro classifier 6 ft
1	1	Magnetic separator
1	1 (i)	" " (Duplex)
1	1 (ii)	" " (cross belt)
1	1 (iii)	" " (cross belt)
2	2	Electrostatic separators
1	3	Belt conveyor 12in x 25 ft
1	2	Belt conveyor 12in x 25 ft
1	3	Paddle mixer 3 ft x 8 ft
1	4	Balling drum 2 ft x 4 ft
1	5	Pelletizing disk 5 ft
1	6	Sinter strand
1	7	Bucket elevator 38 ft
1	7	Briquetting press

No.	Section	Item	Description
2	B	10 (v)	Sample splitters (Snyder)
1		10 (vi)	Roll crusher 10 ft x 6in
1		1	Constant weight feeder
1		2	Belt conveyor 16in x 20 ft
1		3	Blade mill 3 ft x 4 ft
1		4	Vibrating screen 2 ft x 4 ft
1		5	Spiral classifier 12 x 9.6
1		6	Belt conveyor
1		7	Apron ore feeder
1		8	Belt conveyor 12in x 32 ft
1		9	" " 16in x 18 ft
1		10	" " 16in x 120 ft
1	11	Roll crusher 16in x 10 ft	
1	12	Ball mill 3 ft x 6 ft	

No.	Section	Item	Description
1	A	1	Weighing platform
1		2	Vibrating grizzly
1		3	Jaw crusher
1		4	Belt conveyor
1		5	Guard magnet
1		6	Symons cone crusher 2in x 4 ft
1		7	Gyratory crusher
1		7 (i)	Belt conveyor 16in x 30 ft
1		8	" " 16in x 78 ft
1		9	Sample cutter
1		10 (i)	Sample bin
1		10 (ii)	Sample bin
1		10 (iii)	Ore feeder
1		10 (iv)	Jaw crusher 5 ft x 6in



5 General view of the crushing, conveying and screening sections

belt conveyor. Provision has been made for collecting a representative sample by a sampling unit located at the discharge end of the conveyor belt. Secondary crushing may not be necessary when the ore has to be handled in the washing, heavy-media and reduction roast sections, and arrangements are made to bypass the screen in such cases.

This section has a capacity of 5-10 tons of ore per hour.

#### Section B : Washing and grinding

The washing unit of 2 tons/h capacity consists of a scrubber, wet screen, and a classifier to prepare different fractions for heavy-media separation and reduction roast.

The grinding unit of 1 ton/h capacity consists of a roll crusher for preparing the ore for jigging, tabling, etc., and a ball mill in closed circuit with a rake or cyclone classifier.

A constant-weight feeder feeds ore from the bin to a reversible belt conveyor which can deliver the ore in one direction to the scrubber and in the other to the ball mill and roll crusher. Grinding can be done in two stages, the primary in rod mills, the discharge from which goes to a classifier and then to the ball mill.

If no washing or wet screening is necessary, ore can be directly conveyed to the washed-ore bin feeding the ore to the reduction furnaces in Section C.

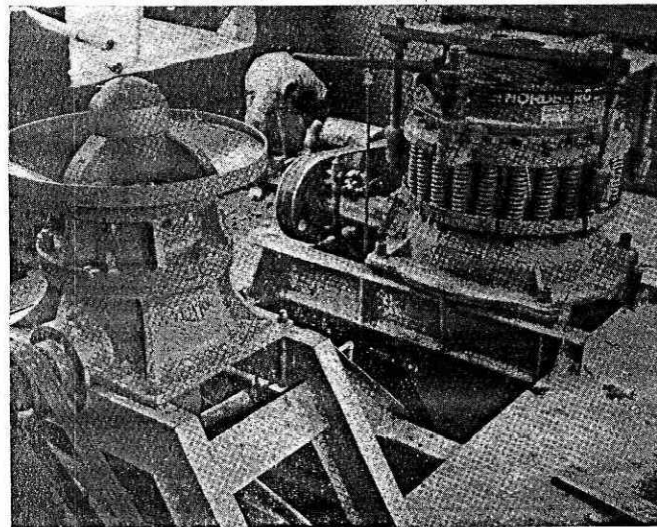
Scrubbing of the ore containing clayey material is carried out in a scrubber, which discharges on to a double-deck vibrating screen. The screen undersize goes to an Akins-type spiral classifier for dewatering and removal of slimy material. The screen and classifier discharge products are conveyed to the washed-ore bin for further treatment in Section C or D. There is provision for taking the classifier discharge to Section F for jigging through a bypass belt conveyor. If scrubbing is not necessary, there is provision for carrying the ore direct from the reversible belt to the vibrating screen.

The reversible belt can feed ore either to the ball mill or the roll crusher through a suitably designed chute. The ball mill works in closed circuit with a rake or a cyclone classifier. The classifier overflow will be pumped to the flotation and other sections.

The roll crusher discharge is treated in Section F.

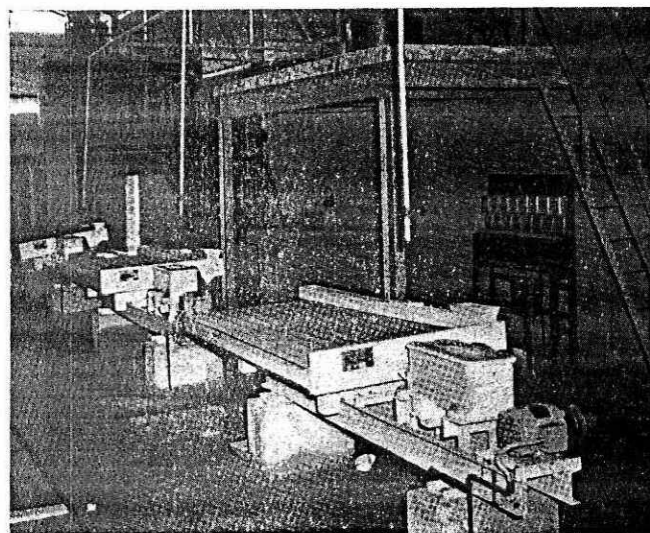
#### Section C : Reduction roast and magnetic separation

Ore from the washed-ore bin, either washed or direct

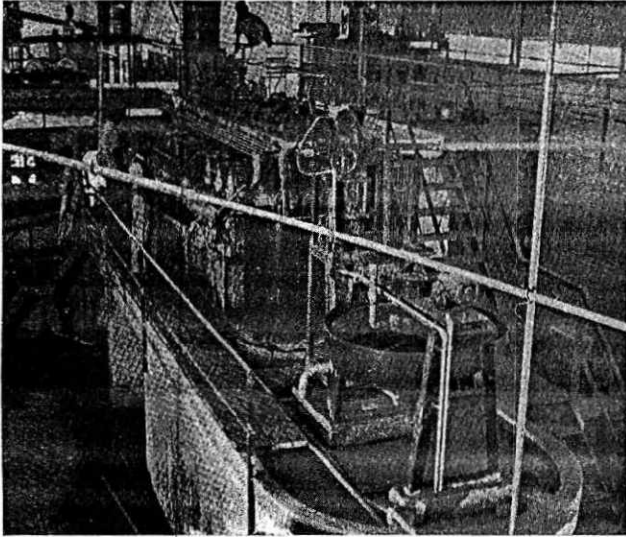


6 A close view of cone and gyratory crushers

from the crushed-ore bin, is fed to a rotary furnace, a vertical reduction kiln, or a multiple-hearth furnace through an apron feeder and a reversible belt. Gas from a gas producer is employed for magnetizing reduction of the ore. The furnace operates at a maximum temperature of 650°C and is instrumented for recording of temperature, pressure, and volume of gas employed. Reduced ore, collected through a water seal, is elevated to a reduced-ore bin by a bucket elevator with perforated buckets to drain off water. The reduced ore is fed by a disk feeder at the bottom of the bin to a roll crusher, the crusher discharge being subjected to wet magnetic separation using a drum/belt-type magnetic separator. The non-magnetic fraction is dewatered using a spiral classifier and then conveyed to a bin or dryer by a portable belt conveyor. The magnetic product after demagnetizing is ground in a small rod mill, the mill discharge being subjected to further magnetic separation. The magnetic product is stockpiled, whereas the non-magnetic product is sent to Section G for thickening, filtering, and drying. The non-magnetic slime from the dewatering classifier may also join this product. The capacity of this section is 1-2 tonnes of ore per hour.



7 Gravity section showing the arrangement of tables, Humphrey's spirals



8 Flotation section, thickeners and filters

#### Section D : Heavy-media separation

This section is capable of treating about 5-10 tonnes of ore per hour.

The coarse fraction ( $-2+\frac{1}{8}$  in) from the washed ore bin is fed into the separating vessel containing ferrosilicon medium. The float and sink products are separately discharged on to the drainage screens, which yield a clean medium for re-use and a dilute medium in the latter part of the screen. This dilute medium is cleaned in a medium recovery unit consisting of magnetic separators, densifiers, etc. for re-use in the section.

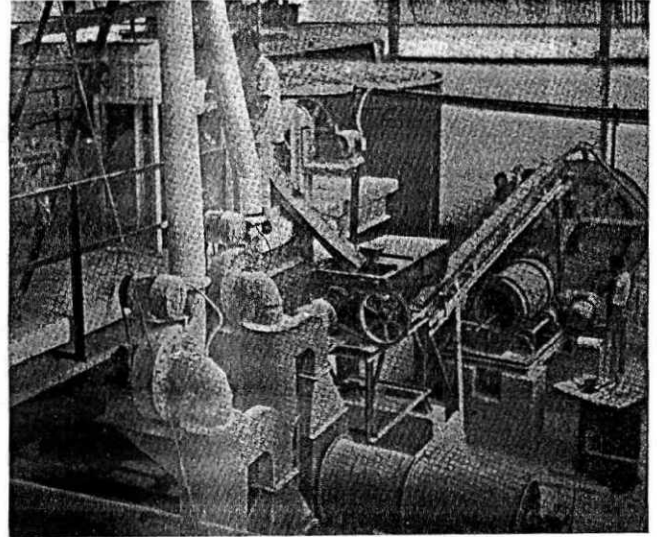
#### Section E : Flotation

The overflow from the classifier working in closed circuit with the rod mill forms the feed for flotation section. It is deslimed, if necessary, in a bowl-type hydroclassifier before conditioning with reagents for flotation. Flotation is carried out in three 4-cell units, the first two being used for roughing and the last for cleaning. Provision is also made for recleaning in smaller cells. The units are flexible enough for sufficient cleaning and recirculation of middling products. Wet reagent feeders accurately deliver predetermined quantities of flotation reagents to the cells. Automatic pulp samplers have been provided for sampling flotation concentrate and tailing. A water-softening unit is provided for supplying soft water for flotation. The concentrate is pumped to Section G, for thickening, filtering, and drying. The capacity of this section is 1 ton/h.

#### Section F : Jigging, tabling, and Humphrey's spirals

The roll crusher discharge or rod mill classifier overflow from Section B is the feed for this section, depending on the treatment. If jigging and tabling are to be employed, the roll crusher discharge is passed over a double-deck vibrating screen, the screen oversize products being subjected to jigging separately. The undersize from the screen, as well as any jig middling, after being ground in the rod mill in Section C, is classified in the hydro-sizer for tabling. Three Wilfley-type tables (half size) are installed, two having sand decks and the third a slime deck. The concentrates are dewatered in settling tanks and then conveyed to Section G for drying.

The rod mill classifier overflow is sized in the hydro-sizer and then subjected to tabling, or directly subjected



9 Dryers, mixer and pelletizers

to Humphrey's spiral treatment after desliming. The concentrates will be dewatered as before.

#### Section G : Thickening, filtering, and drying

This section consists of two thickeners, a 4-disk filter capable of filtering four different products, two drum-type filters, two rotary dryers, and three bins with disk feeders at the bottom.

The products from any of the earlier sections that require thickening, filtering, and drying are brought to this section and are finally stored in bins. This section has a capacity of about 1.0 ton/h.

#### Section H : Magnetic and electrostatic separation

The rod mill-classifier overflow is subjected to sizing in the hydrosizer and the classified products are mixed together to give two close-sized products. These are dried in two rotary dryers and stored in two bins (Section G) separately. Alternatively, the ore can be dry-ground in a ball mill in closed circuit with an air classifier for treatment in this section.

Two units each of high intensity induced roll magnetic separators are provided to treat separately the sized samples in the two bins. Two portable conveyors are used to transport the tailings to a dumping place. The capacity of this section is 2 tons/h.

#### Section J : Agglomeration

Concentrates obtained by any of the methods indicated, except by heavy-media separation, may need to be agglomerated to make them suitable for the market. Sintering, briquetting, or pelletizing is employed for this purpose, depending on the nature of the concentrate using a continuous sinter machine, disk and drum type pelletizers, or briquetting press.

A conveyor belt collects the concentrates, and other raw materials from the bins in Section G and conveys the mix to a paddle mixer. The mix then passes on to any of the three agglomerating units, as desired.

Adequate facilities are provided for preparing samples for sieve analysis, chemical analysis, etc. apart from the automatic sampling unit near the crushed ore bin. The former includes a jaw crusher, roll crusher, cone and ring type crusher, pulverizer, a sieve shaker with a set of standard sieves, etc.

For physical and chemical analyses of the ore samples before and during pilot plant work, a small control laboratory is provided with facilities for petrological and microscopical studies, X-ray fluorescence analysis, thermal analysis, etc., in addition to wet chemical analyses.

A small workshop for attending to the maintenance and repairs required for the pilot plant has also been set up with suitable machinery and equipment.

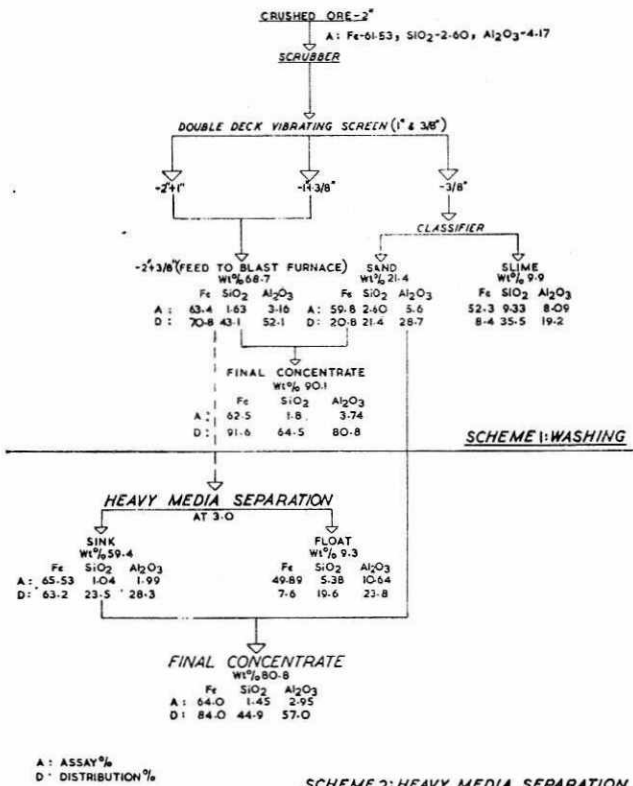
This integrated pilot plant is capable of continuous three-shift operation and is one of the largest of its kind anywhere.

**ACKNOWLEDGMENTS**

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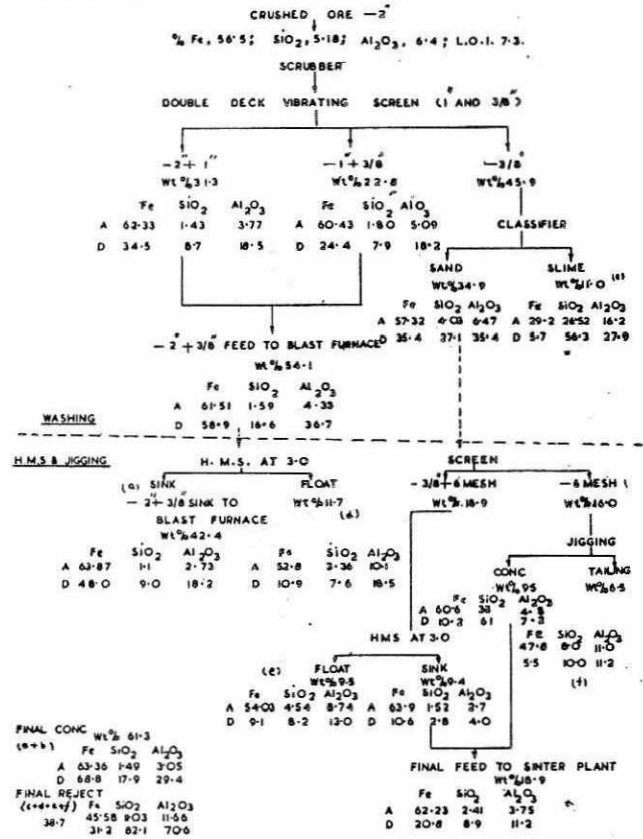
**APPENDIX I**

**BENEFICIATION OF IRON ORES FROM TISCO MINES, -2 IN SIZE**  
Flowsheet No. 1



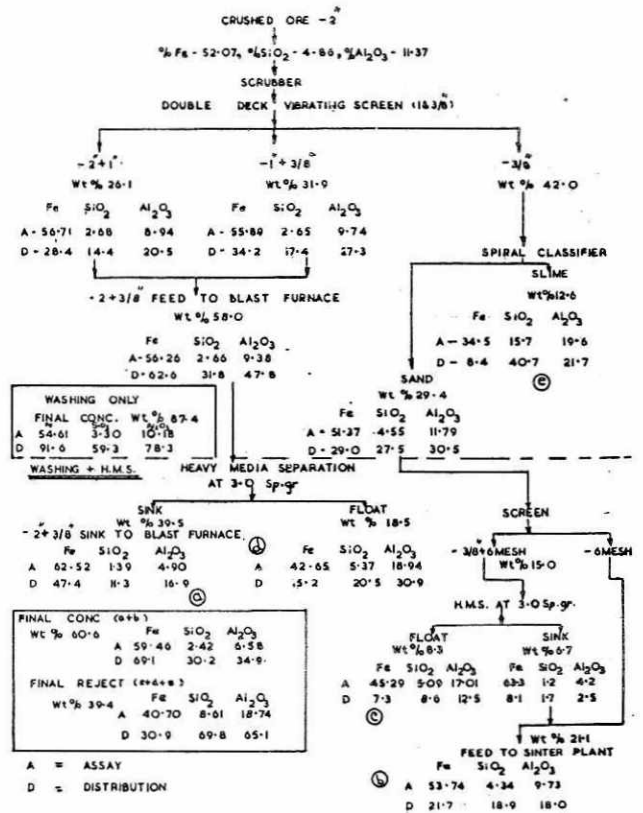
**APPENDIX II**

**SUMMARY OF RESULTS OF BENEFICIATION OF BOLANI IRON ORES, -2 IN SIZE**  
Flowsheet No. 2



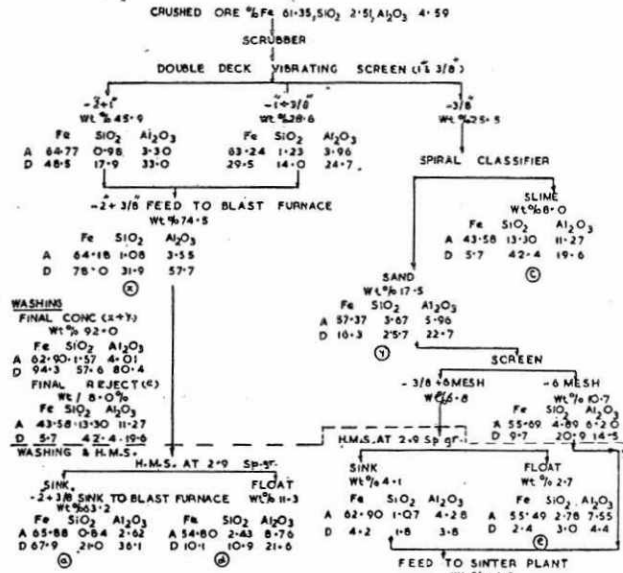
**APPENDIX III**

**SUMMARY OF RESULTS OF BENEFICIATION OF BARSUA IRON ORES, -2 IN SIZE**  
Flowsheet No. 3



### APPENDIX IV

SUMMARY OF RESULTS OF BENEFICIATION OF KIRIBURU IRON ORES, -2 IN IN  
Flowsheet No. 4



### APPENDIX V

BENEFICIATION OF RAJHARA IRON ORES, -2 IN SIZE  
Flowsheet No. 5

