The use of heavy-medium separation in the processing of iron ores

by H. C. VOGES*, B.Sc. (Visitor)

SYNOPSIS

The paper discusses various aspects of the application of heavy-medium separation to the processing of hematite ore at Sishen and Thabazimbi. The two main factors to be borne in mind in the design of a plant for such beneficiation are the low unit value of the iron ore produced and the high separation densities required. The four factors of importance in the avoidance of high viscosity in the ferrosilicon medium are discussed in turn.

SAMEVATTING

Die referaat handel oor verskillende aspekte van die toepassing van swaarmediumskeiding op die verwerking van hematieterts by Sishen en Thabazimbi. Die twee hooffaktore wat by die ontwerp van 'n aanleg vir sodanige veredeling in gedagte gehou moet word, is die lae eenheidswaarde van die ystererts wat geproduseer word en die hoë skeidingsdigthede wat nodig is. Die vier belangrike faktore in verband met die voorkoming van 'n hoë viskositeit in die ferrosilikonmedium word volledig bespreek.

The two main factors to be considered in the design of a plant for the beneficiation of iron ore are the low unit value of the product and the high separation densities required.

LOW UNIT VALUE OF IRON ORE

The major iron-ore producers of the world mine massive high-grade ore-bodies, and sell their products after only crushing and screening of their run-of-mine ore. Without the sacrifice of ore reserves, this is not possible with South African deposits. The relatively long overland distances prohibit the transport of low-grade ore products, and, to be competitive, the run-of-mine ore must be beneficiated at the lowest possible cost.

Because of the higher capital and operational costs involved in the beneficiation of fine ore, the beneficiation is done after the minimum amount of crushing, and the product is crushed after beneficiation. At Sishen, the top size of ore for beneficiation is 90 mm.

Since it is believed that multi-stage crushing produces less fines than one-stage crushing does, two-stage crushing is used to produce minus 90 mm ore at the present Sishen plant, and three-stage crushing at the export plant. To ensure maximum utilization of each unit in the plant, there are large surge stockpiles between the units.

To keep maintenance labour to a minimum, attempts are made to subdivide each unit into independent 'streams' so that the maintenance can be done by a small labour force on a rotating basis.

Because of the large top-size of ore to be beneficiated, and because of the belief that a higher separation efficiency is obtainable when a narrow size range of material is beneficiated, the minus 90 mm ore is screeened into four size fractions for separate beneficiation, i.e., 90-30/25 mm, 30/25-8 mm, 8-5 mm, and -5 mm. The second and fourth of these fractions are in the final size ranges required, while the other two have to be crushed after beneficiation. The two coarser fractions are treated in drum separators, and the two finer fractions in heavy-medium cyclones.

Operational labour is kept to a minimum by the use of centralized control rooms and, where possible, automatic control.

To prevent the high cost of medium losses, use is made of large product screen areas, a sufficient volume of wash water, and two-stage magnetic recovery of ferrosilicon out of the dilute medium. It may be of interest to diamond and uranium producers that the yield in the drum plants is over 90 per cent, and, even in the fines cyclone plant, as high as 75 per cent by mass.

HIGH SEPARATION DENSITIES

The specific gravity of high-grade hematite ore is between 4,9 and 5,1, while the gangue material associated with the ore has specific gravities down to 2,8. Partly ferruginized ore can have specific gravities anywhere between these two extremes. The two main gangue minerals are SiO_2 and Al_2O_3, and there is a marked linear relationship between the percentage of these and specific gravity. The blast-furnace operator specifies concentrates of 5 per cent $SiO_2+Al_2O_3$ or lower for lumpy ore, and 6,5 per cent $SiO_2+Al_2O_3$ for straight sinter feed ore. Overseas customers may require these to have even lower assays in order to 'sweeten' their total blend of ore.

This, depending on the amount of intermediate-quality ore present in the run-of-mine ore, determines the separation cut-point required, which can be as high as 3,8 g/cm ^{3}. An ore particle of this density will still assay 35 per cent $SiO_2+Al_2O_3$.

Because of this high cut-point requirement, special demands are made of the densifiers, and special care must be taken to prevent high viscosity and consequent inefficient separation.

Densification of the Medium

In the drum plants, spiral classifiers were used in the past for densification of the dilute medium. In the cyclone plants, where a finer medium is used, a number of large spiral densifiers would have been required to give the densification required, and 'centrifugal densifiers' have been installed instead. These cyclone-like densifiers are relatively low-priced and small, and can be controlled by means of the feed and by underflow and overflow valves. They are pump-fed and are high-capacity units, capable of thickening

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even cyclone 60 grade ferrosilicon to densities of 4,0 g/cm^3. To facilitate densification, the feed-preparation screens have a large drainage area.

Prevention of High Viscosity

If high viscosity is to be avoided in the medium, the following factors are important.

1. Selection of the correct ferrosilicon.
2. Prevention of contamination of the medium by fine ore.
3. Maintaining the quality of the medium in circulation.
4. Demagnetizing.

Selection of Ferrosilicon

With milled ferrosilicon, it is impossible for the specific gravity of the circulating medium to be higher than 3,3 without having too high a viscosity for efficient separation. With good spheroidized ferrosilicon, a specific gravity of 3,8, or even 3,9, can be reached before the viscosity becomes too high.

When ferrosilicon was still imported, Iscor used to receive samples of consignments in advance, and consignments of acceptable quality were selected on the basis of these samples. At that stage, a new process for the manufacture of 'rounded' ferrosilicon was developed at the pilot plant, and plant-scale tests were carried out, Dr Beeton being in charge of the project. The quality of ferrosilicon manufactured in South Africa by the same process as that used for the imported ferrosilicon is high.

The drum separators at Thabazimbi use the special coarse-grade ferrosilicon, and the present drum plants at Sishen use what is referred to as Sishen Special Coarse. The difference is in the lower percentage of minus 325 mesh material in the Sishen Special Coarse. At Sishen, the medium losses are very low owing to the very smooth surfaces of Sishen ore, with the result that the retention time of the medium in the plant is very long, and the percentage of superfine medium becomes too high.

At Thabazimbi, a mixture of cyclone 60 and magnetite is used for the cyclone plant; at Sishen, milled 100D is used in the present cyclone plant, and cyclone 60 or cyclone 40 is to be used in the export cyclone plant.

Prevention of Contamination by Fine Ore

In the screening plant before beneficiation, the screening is done under high-pressure water sprays. Each of the different size fractions for beneficiation is conveyed to a surge stockpile, from where it is fed to the beneficiation plant. In passing through the stockpile, some breakdown of the ore occurs, and sticky clay not removed in the initial washing process is rubbed loose. These fines are washed off on the feed-preparation screens.

After beneficiation, the products pass over the medium-recovery screens. The first section of the screen, without spray water, recovers medium of the correct density, while the second section, with spray water, recovers dilute medium. The dilute medium is passed through magnetic separators for the removal of slimes and fine ore before densification. Provision is also made for the bleeding off of correct medium into the dilute medium for additional cleaning.

The maximum allowable amount of non-magnetics is considered to be 7 per cent in the circulating medium of the coarse drum plant and 5 per cent in that of the medium drum plant.

Maintaining the Quality of the Medium

Owing to the low losses and consequential long retention time of ferrosilicon in the Sishen drum plants, the percentage of superfine medium becomes too high. Provision is made in the new drum plants for periodic classification of the medium in circulation and for transfer of the superfine fraction to the medium circuits of the cyclone plant. Classification is done by means of a centrifugal densifier, and transfer by means of pumping.

New Special Coarse grade ferrosilicon contains about 40 per cent minus 325 mesh material. Without classification, the content of minus 325 mesh material in the Sishen drum plants increases to nearly 90 per cent. Good results can be obtained with circulating medium that has between 50 and 60 per cent minus 325 mesh material.

Deterioration of medium in circulation also occurs through corrosion, especially during the summer, when high temperatures are experienced both at Sishen and Thabazimbi. Corrosion always starts during plant shut-down periods, when the medium is stored wet. Heat develops in the stored medium and, once the process of corrosion has started on a batch of ferrosilicon, it will start much more easily and earlier during the next shut-down period. Symptoms of corrosion are the release of hydrogen bubbles, cementing of the stored ferrosilicon, and lowering of the dry specific gravity of the medium. The difficulty of reproducing the corrosion reaction in the laboratory has hampered the search for an inhibitor, but, to prevent corrosion, the stored ferrosilicon is kept under a layer of water, lime is added, and the layer stored is kept to a minimum depth.

Demagnetizing the Medium

At the high circulating densities in the drum plants, poorly demagnetized medium will have a much higher viscosity and practically no beneficiation of the ore will occur. In one instance at Thabazimbi, the $SiO_2+Al_2O_3$ assays of feed, sinks, and floats were identical within 1 per cent as a result of a defective demagnetizer. This sort of thing is avoided by a system of frequent inspections of the demagnetizers.

HANDLING AND STORAGE

Because of the large quantities of iron ore to be produced by the heavy-medium plants, the quantities of ferrosilicon handled daily are more than can be handled manually. A mechanical handling system has therefore been introduced in which containers are stored and transported on trays. The storage is important in that considerable losses and deterioration of ferrosilicon can occur if it is not properly stored. Some of the containers are damaged during transport, and rain on such containers can start corrosion even before the ferrosilicon is fed into the plant.

SCREENCLOTH

The blinding of product screen decks can result in considerable losses of ferrosilicon. A polyurethane screen cloth that was recently tested appears to be promising.

DISCUSSION OF THE ABOVE PAPER

J. UYS*

The author has presented a most interesting and informative paper. His statements regarding the unit value of the product, and the operating and capital costs of heavy-medium plants for the treatment of iron ore require further discussion.

Based on available data, the capital and treatment costs per tonne are directly related to the mean particle diameter of the feed. The smaller this figure, the higher the unit operating and capital costs.

Iron ore plants currently in the design stage provide the following capital cost data:

Bath-type separation plants R2000-R2500 per tonne per hour throughout.

Centrifugal-type separation plants R6000-R7000 per tonne per hour throughout.

The operating costs of plants treating, say, plus 25 mm and minus 6 mm material are in the same ratio as are the capital costs. This additional cost for plants treating the fines fraction relates to additional screening area — both for feed preparation and product drainage and rinsing duties, additional rinsing water requirements resulting in larger magnetic-medium recovery circuits, together with additional medium volumetric requirements, etc. The comparative figures given in Table I make interesting reading.

The above comments and data on capital and operating costs stress the importance of treating the ore at as large a size as possible, commensurate with factors such as washability data, coupled with valuable mineral liberation sizes, etc.

Commercial bath-type heavy-medium separators can comfortably accept lump sizes substantially in excess of the 90 mm maximum lump size at present treated at Sishen.

A final point to be considered under cost considerations is the possibility of additional recovery of the *in situ* ore-body, in particular in underground sections employing block-caving mining methods. The use of heavy-medium separation improved the efficiency of underground recovery at Thabazimbi by as much as 20 per cent.

Other design considerations quoted by the author do not warrant further discussion, except the following.

Screen Areas

The screen sizing, with particular reference to the minus 5 mm size fraction, is particularly important when considering the slabby nature of the Sishen ore and the resultant blinding of the stainless-steel wedge-wire screening panels. This blinding problem is partly compensated for by over-designing of the sieve-bend and screen areas, although the final solution appears to be the utilization of polyurethane screening panels. The vertical acceleration factor of 3,5 to 4,0 G is extremely important in these screening duties.

Generally the following screen sizing formulas are normally applied on screening duties at 0,5 mm:

Capacity of the feed-preparation screen (C)

$$C = 12\,\sqrt[3]{da^2 \times SG^2 pr}\ \text{t/h/(m of width)}$$

Capacity of the product screen (C)

$$C = 8\,\sqrt[3]{da^2 \times SG^2 pr}\ \text{t/h/(m of width)}$$

where

da=average grain size of product + 0,5 mm in feed,

$SG\ pr$=specific gravity of the average grain.

The average grain size (da) or mean particle diameter is normally obtained from a computer programme based on size-grading analysis.

Magnetic Recovery Circuit

The design of the magnetic separator provides for a magnetic field strength of 750 G at a point 50 mm from the drum shell immmediately below the permanent magnets. This results in a very efficient ferrosilicon recovery unit when operated at the following maxima (applicable to a drum diameter of 915 mm):

Volume=82 m^3/h/m of width

Solids=26 t/h/m of width.

The present trend in the design of magnetic recovery circuits provides for cyclonic volume reduction ahead of the secondary magnetic separators, the cyclone overflow being used as primary wash water on the product screens. This refinement in design results not only in more efficient recovery of the ferrosilicon but also lowers the overall capital cost of the installation.

In referring to the high cut-point requirements for efficient iron ore separation, the author deals at length with the factors having a direct bearing on this requirement, the medium densification requirement being particularly significant. The densification efficiency of the

*Fraser & Chalmers (S.A.) (Pty) Ltd.

TABLE I

REQUIREMENTS FOR THE TREATMENT OF DIFFERENT—SIZED FEED MATERIAL

Feed		Make-up water		Circulating medium		Magnetic separators		Power		Structural steelwork		Plate work	
Size mm	t/h	m^3/h	m^3/t/(t/h)	m^3/h	m^3/(t/h)	Width mm	mm/(t/h)	Installed kW	kW/(t/h)	t	t/(t/h)	t	t/(t/h)
—90 + 25	520	480	0,92	425	0,81	7317	14,0	1400	2,7	220	0,42	45	0,09
—5 + 0,5	200	440	2,20	534	2,67	7317	36,5	1469	7,35	240	1,20	38	0,19

centrifugal densifier has resulted in Fraser & Chalmers standardizing on this unit on all heavy-medium separation plants requiring densification. The development of the centrifugal densifier contributed largely to the successful operation of heavy-medium plants doing extremely delicate separations on feeds with very low gravity differentials between valuable mineral and gangue material. The sizing of heavy medium required for this type of separation precludes the use of conventional spiral classifier densifiers. It can safely be postulated that, without the centrifugal densifier, these heavy-medium applications would have been unsuccessful.

Further factors discussed by the author, namely, correct grade of ferrosilicon, medium contamination, and demagnetization are all perfectly valid and require no further comment.

However, the remaining factor, which relates to the correct choice of heavy-medium separatory vessels, requires further discussion. Regarding bath-type separators, the following design features related to operating efficiencies are important:

(1) sufficient pool area and depth,
(2) efficient facilities for the removal of sinks on ores with mass yields in excess of 90 per cent,
(3) correct ratios of heavy medium to ore, with sufficient volumetric capacity for the removal of floats,
(4) maintaining the heavy medium in stable suspension without excessive pool turbulence.

On centrifugal-type separators, the following design features are important.

(1) Head requirements, which depend on the percentage near-gravity material distribution at the desired cut-point. This head requirement can vary between 9 and 30 times the internal diameter of the separator.
(2) Shape and size of the inlet to the centrifugal separator.
(3) Cross-sectional areas of product outlets for sinks and floats.

Proper attention to the above design parameters will ensure that both types of separator perform at maximum efficiencies with acceptable E.p.m. values and minimum misplacement to both the sinks and floats products.

In conclusion, a plea is directed at the research institutions to investigate and to develop a 'creaming off' unit for the removal of high specific-gravity material ahead of conventional heavy-medium separation. This is currently practised in some of the collieries in Australia that produce coking coal, which use water-only cyclones on feeds up to 25 mm in size, the refuse product from this separation being further upgraded in treatment plants using conventional centrifugal separators.

C. B. PARKER*

I would like to remark on a few points of mutual interest in Mr Voges's paper.

Densification of the Medium

Our experience at Premier Mine in using Velco cyclonic densifiers was not satisfactory. We had only just over 4 m of head available, and got inadequate densification plus repeated blocking of the 25 mm outlet. We tried pumping, and, at a pressure of 207 kPa, densification was satisfactory but blockages still remained a major problem.

We use two Driessen cones of 250 mm diameter, which produce a spigot density of 3,2 g/cm^3. This is adequate as the density of our operating medium is 2,6 g/cm^3.

Corrosion of the Medium

On the matter of corrosion, I did find, when running a cone of 1,524 m diameter using special coarse atomized ferrosilicon, that 5 kg of sodium nitrite per tonne of ferrosilicon for 6 days and then 1 kg per day killed the corrosion. We first thought that the corrosion was started by a biological process as there is no mistaking the smell of hydrogen sulphide! Further investigation indicated that the corrosion was probably due to new rainwater runoff filling the storage dam, as the pH value of the water was 10 and the ambient temperature high.

Demagnetizing the Medium

We have found that atomized ferrosilicon needs only $2\frac{1}{2}$ times the coil strength required with milled ferrosilicon.

I would like further information from Mr Voges on what instruments are used and what is measured in their frequent inspection of the demagnetizers.

Screencloth

Our present experience in the use of polyurethane screen mats, with a 5 by 0,5 mm slit running with the flow, indicate that gradings on 0,5 mm square compare satisfactorily with a stainless-steel mat, but ferrosilicon losses are 10 per cent lower. This is probably due to less blinding as the polyurethane mat flexes better.

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Conference on Ion Exchange

The Society of Chemical Industry is to hold a Conference on the Theory and Practice of Ion Exchange from 25th to 30th July, 1976, at the University of Cambridge. The conference language will be English.

The topics to be discussed will fall broadly under the following subject headings:

Structure and Properties of Ion Exchangers.

Applications of Ion Exchange.

Process and Plant Design.

Further information is available from the Society of Chemical Industry, 14 Belgrave Square, London SWIX 8 PS, United Kingdom.