The influence of the quality of ferrosilicon on the rheology of dense medium and the ability to reach higher densities

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Synopsis

The dense medium beneficiation of heavy metal oxide ores such as iron ore is usually done by heavy medium separation in cyclones, static baths (Wemco drum) and nowadays with Larcodems. At Sishen Iron Ore Mine the first Larcodem was installed to beneficiate iron ore and a good comparison can be made between the Larcodem and Wemco drum after a three-year production period. A comparison will be made in this paper on the production performance of the Larcodem against the Wemco drum concentrating on the throughput and the high densities of 4.2 achieved. Performance problems encountered during the commissioning of the Larcodem and the rectification will be discussed as well as the production cost. The flow lines of the Larcodem module will be discussed and special emphases will be put on the changes made after commissioning to be able to keep the vortex in the Larcodem constant at a density of 4.2. All the advantageous and disadvantageous will be listed.

Introduction

The beneficiation of heavy metal oxides, such as iron ore, is usually performed with heavy medium separation in cyclones, static baths and lately with Larcodems. Atomized ferrosilicon is most suitable as a heavy medium at densities above 3 600 kg/m^3 whereas a mixture of milled and atomized ferrosilicon is suitable at densities below 3 600 kg/m^3. When a beneficiation plant is operated at densities higher than 3600 kg/m^3, the quality of the ferrosilicon particles is an important factor that influences the control of the beneficiation process. Therefore, it is important to know how the rheology would be affected by the ferrosilicon quality as it also influences the control of the process at these elevated densities.

Background

The Kumba Resources Sishen Iron Ore Mine in South Africa produces 26.5 Mt iron ore per annum from its beneficiation plant. The orebody consists mainly of laminated and massive type hematite ore that is crushed down to –90 mm before being beneficiated by means of a combination of Wemco drums, Larcodem and dense medium cyclone separators.

The need for higher densities

When the percentage of high-density gangue[2] is higher than normal in the run-of-mine (ROM), a higher separation density is necessary to produce a product to specification. Certain ore types of this quality in the Sishen reserves require a separating density higher than 4 000 kg/m^3, whereas densities would normally average 3 600 kg/m^3 when beneficiating ores of normal high-density gangue content.

Sink and float tests conducted on the ROM material at Sishen revealed some interesting characteristics. In the waste fraction (density < 3 600 kg/m^3), it was found that the %Fe was <21% (Figure 1). Similarly, for the product fraction (density >3 000 kg/m^3), the percentage Fe varied between 35% and 67.2%. The bulk of the material (88%) actually had a density greater than 4 000 kg/m^3 and a Fe content that varied between 63% and 67.2%. At a density interval of 3 600 to 4 000 kg/m^3, the Fe content varied from 37% to 60% with an average of 45%.

The question of whether or not the final product will meet the quality specification is largely dependent on the mass percentage of

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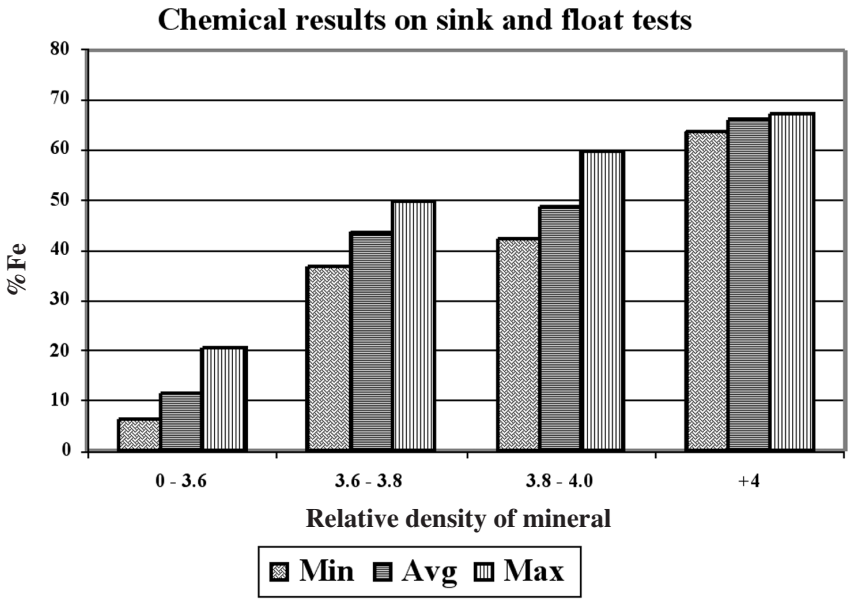


Figure 1—Percentage Fe in different particle densities

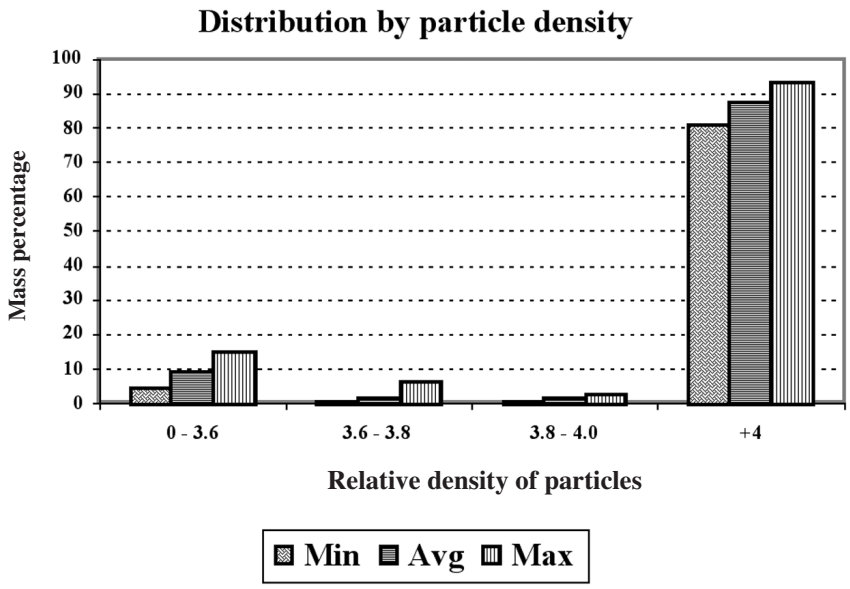


Figure 2—Mass per cent distribution by particle density of final product

particles with a particle density in the range 3 600 kg/m^3 to 4000 kg/m^3 that reports to the product. The mass percentage was found to vary from 0.8% to 9% (Figure 2) with an average of 3.2%.

The Fe specification of the lumpy ore product (-25 mm + 8 mm) at Sishen is >66%. If the near density material[1] exceeds 6%, it becomes difficult to reach the product Fe specification. Normally the near density material in the ROM can be reduced by lowering the ratio of material mined in areas known to contain a high percentage of near density material. On occasion, when this is not possible, the only means of producing a product to specification is to increase the operating densities during the beneficiation process.

In the past, reaching and monitoring densities higher than 3 700 kg/m^3 proved difficult, due to increased medium viscosity that influenced the beneficiation characteristics, making it difficult to pump the media.

Rheology of the medium

The rheology of the medium is influenced by four factors, namely: medium density, percentage slimes (% -200 μm non magnetic material), ferrosilicon particle sphericity and the percentage ferrosilicon particles that are smaller than 45 μm (Figure 3). At circulating densities below 3 200 kg/m^3 the operating range of these factors overlap to such an extent

that a large operating window for the medium circuit exists. With an increase in circulating density the operating window becomes smaller and the influence that these variables have on the process becomes more apparent. Therefore, it is critical that all the factors mentioned above that influence the medium are measured on a regular basis if the process is prone to operate at higher densities. These critical factors influence the process in the sense that they can increase viscosity or cause instability of the dense medium.

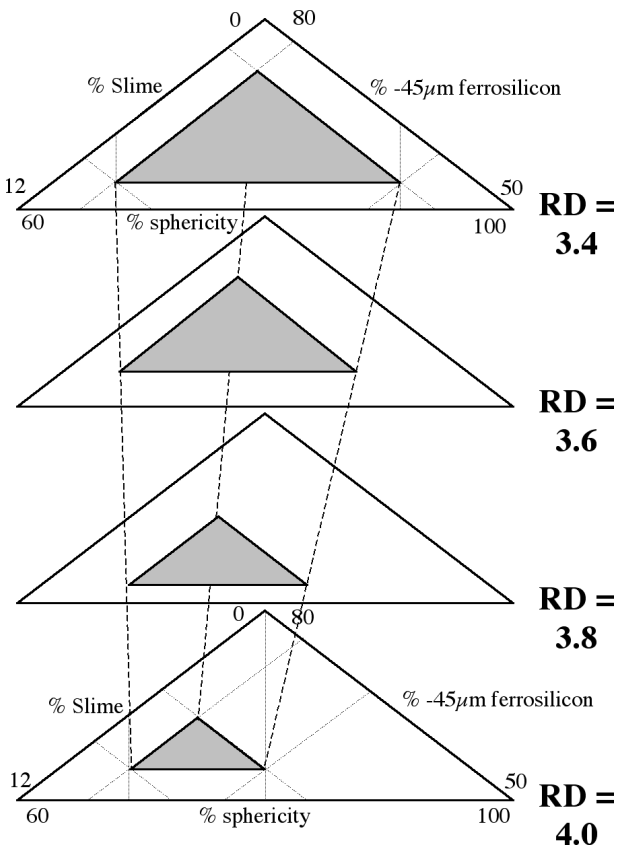


Figure 3—Schematic explanation of variables on rheology of medium

Degradation of ferrosilicon particles in the dense medium

With the standard steam atomized ferrosilicon, a density of 3 700 kg/m^3 was reached on certain occasions but it was only possible to sustain a constant density of 3 600 kg/m^3. Densities above 3 600 kg/m^3 caused very high viscosity problems that influenced the characteristics of the beneficiation process. The only property that could be controlled at that stage was the percentage slime present in the circulating correct medium. The plant was set up in such a way that most of the slimes could be removed from the circulating media, which helped in achieving a density of 3 700 kg/m^3.

All the factors that could influence the high viscosity situation were examined. These included density of medium, amount of slimes, sphericity of media and the percentage -45 μm ferrosilicon media. The acceptable amount of -45 μm ferrosilicon particles required to achieve the correct differential in the cyclone and drum plant respectively is 62% and 55% although only ferrosilicon media with a -45 μm percentage less than 20% was added to the circuit. Samples taken of the correct media indicated that the percentage—45 μm increased to 75% (Figure 4). This is one of the critical factors that influence viscosity and stability at Sishen, and the elevated values led to high viscosities at medium densities above 3 600 kg/m^3.

Thus, removal of excess slimes from the correct medium did not eliminate the viscosity problem. In fact the increase in the finer ferrosilicon fraction actually contributed to a greater degree to the increased viscosity. Investigation showed that the cause of the degradation was caused by a combination of the atomising process and the raw materials used to produce the ferrosilicon particles.

In the standard process, steam is used to atomize the ferrosilicon and the high percentage free carbon in the raw material is believed to have reacted to form gases, resulting in hollow particles and grain boundary porosity (Figures 5 and 6).

These particles (the hollow and the smaller solid particles) are then degraded during the beneficiation process, resulting in an increase in the percentage -45 μm fraction and lowering of the sphericity (Figures 7, 8, 9 and 10) of the ferrosilicon particles in circulation.

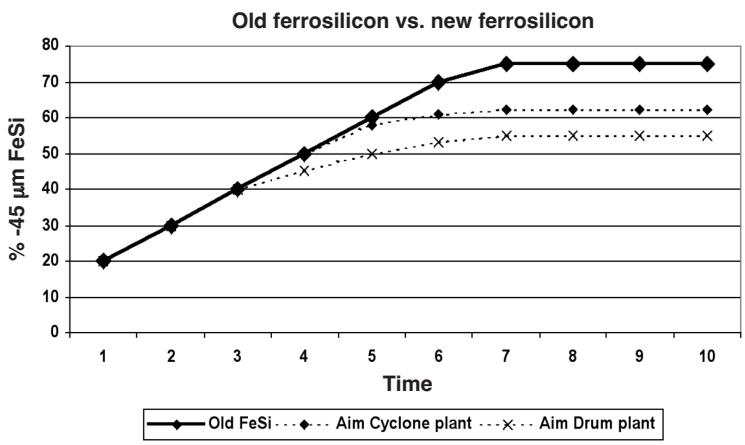


Figure 4—The increase of the finer fraction ferrosilicon in the correct medium

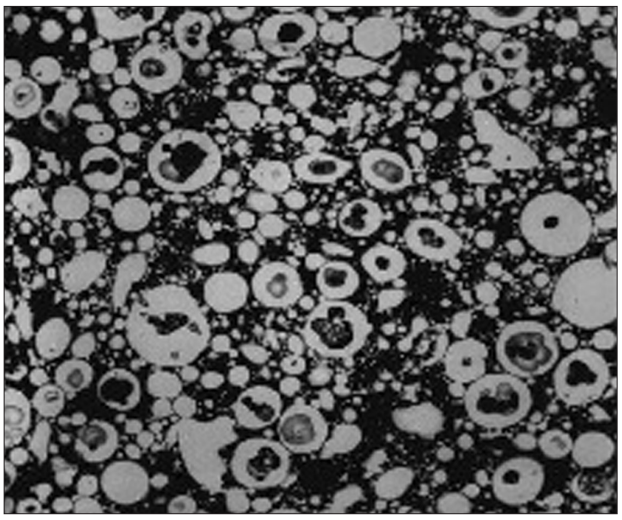


Figure 5—Hollow particles in unused ferrosilicon

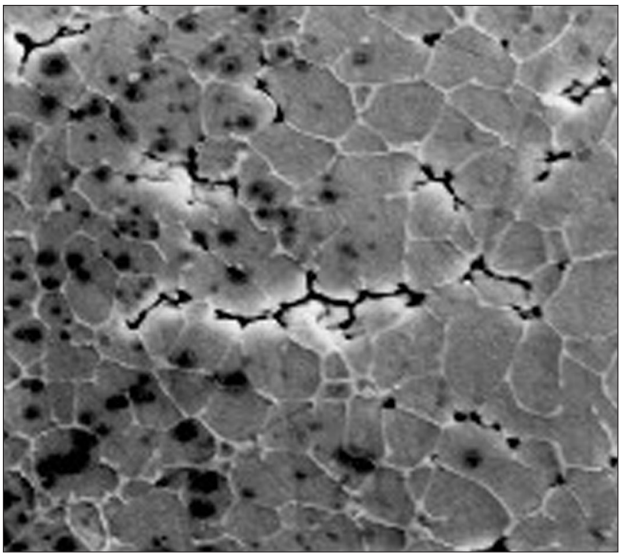


Figure 6—Grain boundary porosity in unused ferrosilicon

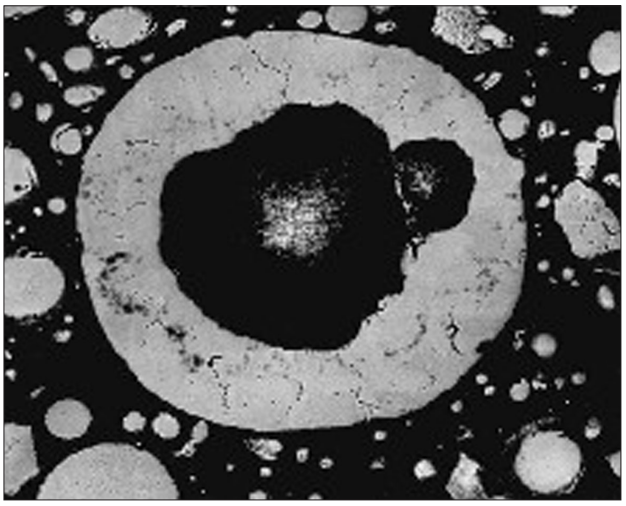


Figure 7—Hollow particle with grain boundary porosity

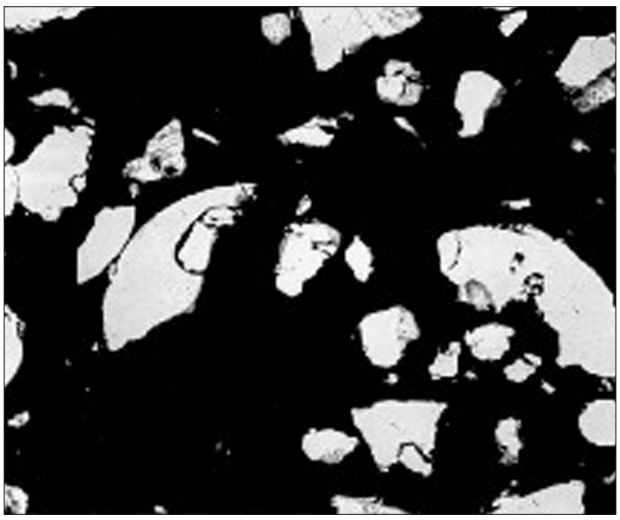
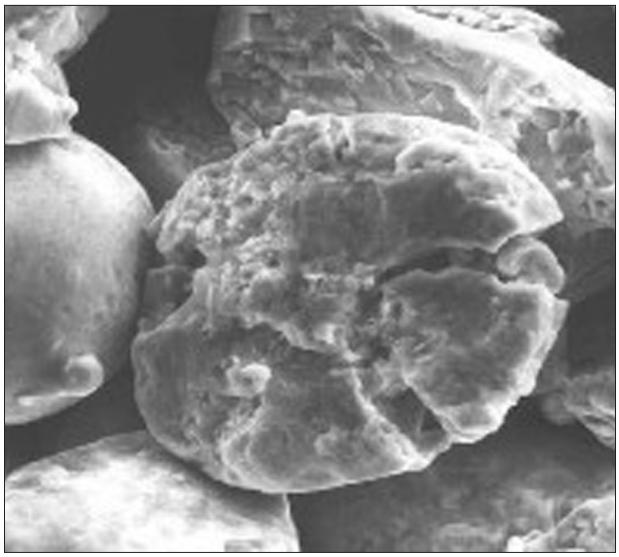
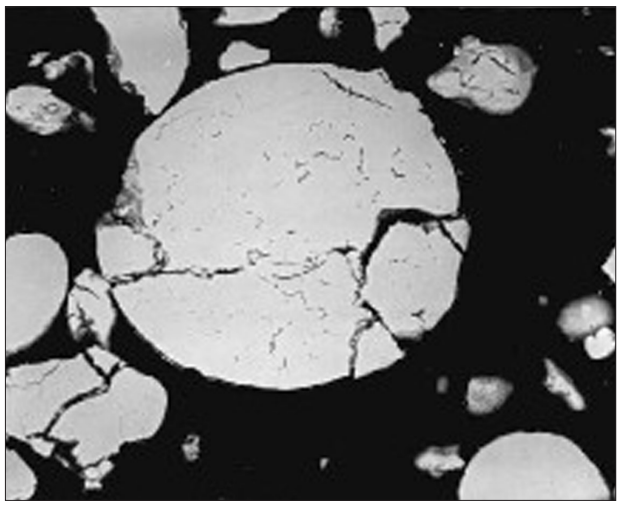


Figure 8—Degraded particles in the media



Figures 9—Solid particles started to degrade in the circulating media



Figures 10—Solid particles started to degrade in the circulating media

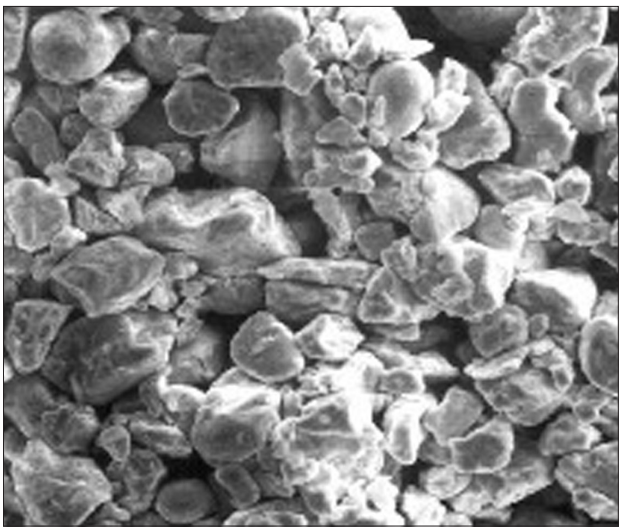


Figure 11—Used ferrosilicon showing the sphericity problem

The degraded particles thus increased the percentage of the -45 μm ferrosilicon fraction up to 75%. This is believed to be one of the factors that increased the viscosity of the circulating media. The degradation of the particles also caused a decrease in the sphericity of the circulating media and thus contributed to an increase in the viscosity of the media (Figure 11). The decreased sphericity of the ferrosilicon particles in the correct media makes it more difficult to remove the slimes from the circulating media and this again increases the viscosity.

It became apparent that an alteration to the physical properties of the ferrosilicon, i.e. improve sphericity, was necessary to reach sustainable densities exceeding 3 600 kg/m^3. A ferrosilicon with no hollow particles and no grain boundary porosity would therefore be the ideal to run the plant at higher densities.

The improved ferrosilicon

A process that uses nitrogen to atomize the ferrosilicon and raw material with a very low carbon content (0.02% C max) was found and adopted by Kumba Resources. The new process thus eliminated the problems caused by the previous atomization process, thus allowing the plant to achieve higher densities. The introduction of the new ferrosilicon to the plant resulted in a significant change in operating conditions.

The previous viscosity problem then changed to an instability problem and all safeguards that were built into the plant to overcome the viscosity problem had to be changed to overcome the stability problem.

Problems with the improved ferrosilicon

The improved ferrosilicon caused some new problems in the plant. With time, as the new ferrosilicon was introduced to the plant, the viscosity problem changed into a stability problem.

The new ferrosilicon did not lose its sphericity with time and no degradation of the particles occurred (Figure 12).

Tests showed that the new ferrosilicon particles did not break down and thus retained their sphericity. The spherical particles did not hinder the removal of the slimes through the densifiers. This resulted in a low percentage slimes (0.8%) in the circulating media. The culmination of all these factors decreased the viscosity to such an extent that the plant was in a state of instability. The beneficiation characteristics were influenced and many changes had to be made. All the changes that were in place to remove the excess slimes had to be changed back to keep as much slimes as possible in the plant. These changes made it possible to increase the percentage slimes to between 6% and 8% and made the control in the plant acceptable. The instability of the medium appeared to worsen after prolonged production.

The improved ferrosilicon, however, possessed overall better sphericity, which resulted in better slime control in the circulating media. Whereas the specification of the -45 μm fraction for the old ferrosilicon was between 0% and 20%, for the new ferrosilicon it was increased to between 45% and 55% for the drum plant and 55% and 65% for the cyclone plant (Figure 13).

A few tests did reveal though that the -45 μm ferrosilicon fraction in the circulating media dropped as low as 22% (Figure 13).

This very low percentage of the finer fraction of ferrosilicon in the circulating media caused instability in the circulating media and needed to be rectified. After many changes in the way the process was controlled, optimum results were achieved by increasing the density to 3 800 kg/m^3 and higher. This kept the plant running but still there was instability in the process due to the lowered finer fraction.

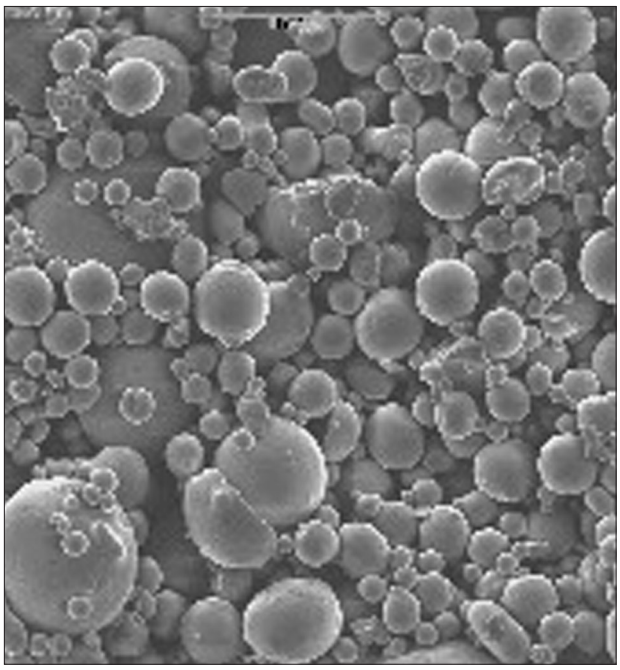


Figure 12—Improved ferrosilicon particles showing the sphericity and that no breakdown occurred after six months in the plant

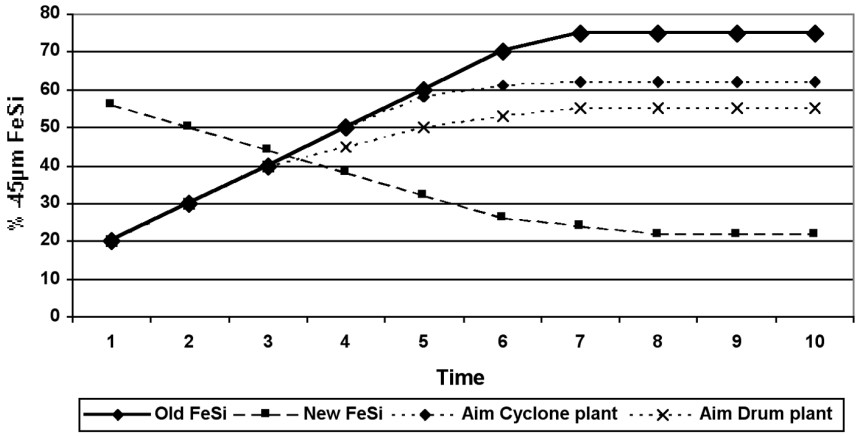


Figure 13—The decrease of the finer fraction ferrosilicon in the correct medium with the new ferrosilicon

Table I

Distribution of finer ferrosilicon particles in plant

Apparatus	% -45 µm in feed	% -45 µm in underflow	% -45 µm in overflow
Magnetic separator	78%	40%	5%
Product screens	45%	5%	55%
Waste screen	45%	5%	25%
Densifier	52%	1%	96%

Loss of the finer ferrosilicon fraction

It is well known that the loss of ferrosilicon occurs mainly at the product and waste screen overflow and at the secondary magnetic separator. It was generally accepted that the complete fractional distribution of the ferrosilicon particles is lost equally during the beneficiation process.

Samples were taken in the plant at different flow lines and analyses. Out of these analyses it was clear that the finer fraction ferrosilicon particles are concentrated in the dilute medium. Loss of ferrosilicon over the product screen and the magnetic separator is mostly of the finer fraction.

The loss of the finer fraction of ferrosilicon resulted in the low (22%) percentage of ferrosilicon circulating in a module causing an unstable medium that influenced the beneficiation characteristics and caused operational problems.

The higher densities helped to control the plant but the spray water on the product and waste screens had to be improved to keep the loss of the finer fraction to a minimum over the screens.

New magnetic separators were installed to recover more of the ferrosilicon. The operating procedures of the latter were reviewed and improvements were made to their efficiency by maintaining a constant feed at the correct concentration of ferrosilicon.

The factors mentioned above caused an increase in the finer ferrosilicon fraction of the media to 40% and resulted in a more controllable plant by keeping the density above 3 600 kg/m^3.

With a new media flow line developed for the Larcodem, drum plant and cyclone plant, higher densities can be maintained and a density of 4 200 kg/m^3 was reached on occasion and 4 100 kg/m^3 was easily maintained in the Larcodem circuit.

Conclusion

When operating a beneficiation plant at relative densities higher than 3 600 kg/m^3 the quality of the ferrosilicon particles is an important factor that influences the control of the beneficiation process. The following aspects are extremely important if densities above 3 600 kg/m^3 are needed in a beneficiation plant, namely: shape of the particle, physical strength of ferrosilicon particle, the percentage -45 µm ferrosilicon particles and percentage slimes. By introducing the improved ferrosilicon to overcome the viscosity problem occurring at densities from 3 600 kg/m^3 and higher, a stability problem might occur that must be overcome before a stable media for normal production can be achieved. The greatest achievement from all the changes that were made was the ability to reach and maintain the higher densities of 4 100 kg/m^3. This was only possible due to the changes made to the metallurgical characteristics of the ferrosilicon.

With a new media flow line developed, specifically for the improved ferrosilicon, a density above 3 600 kg/m^3 could easily be reached and 4 100 kg/m^3 can be maintained. Instability problems that resulted due to the loss of finer ferrosilicon particles, previously non-apparent to the degradation of coarse particles to replace finer losses, were overcome by changing the flow line and altering the specification for the improved ferrosilicon to a higher percentage -45 µm particle.

References

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3. Myburgh, H.A. Sishen Iron Ore Mine, Combination of in-house reports. ◆