Challenges in the production of mineral products—QEMSCAN® analysis as an aide to metallurgical troubleshooting

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For a process plant operator the question of ‘what next’ in terms of feed characteristics will always be at the top of the list. Changes in feed material to a process plant happens as a rule and is generally worse towards the end of a mine’s life, when miners are looking for every possible tonne of ore. Quantitative evaluation of material by scanning electron microscopy (QEMSCAN®) has been a valuable aide in metallurgical troubleshooting. At Exxaro KZN Sands ilmenite is fed to smelters for producing high titania slag and low manganese pig iron. The quality of the slag and metal produced is largely dependent on the quality of the raw materials used. It was found that ilmenite quality as well as recoveries deteriorated as mining progressed into new areas. Quality and recovery of rutile at the dry mill was affected even more negatively. An investigation was conducted to find the root cause of the quality and recovery issues as well as to evaluate possible options for improving the process performance. The first step was to go back to basics and ensure every piece of equipment was operating normally. Secondly, laboratory as well as pilot-scale test work supported by QEMSCAN® analysis was conducted to understand the mineralogical drivers. Following the identification of the mineralogical issues associated with the new mining area, processing options to improve quality as well as recovery, were evaluated.

Introduction

The Hillendale mine is located close to Richards Bay next to the town of Esikhaweni. The orebody is varied in terms of mineral assemblage and thus also processing behaviour. As the mine moves into the final stages of its life, the ability to blend out problematic assemblages through mine planning becomes limited.

Heavy minerals are mined at Hillendale mine by monitoring the high slimes ore which flows down trenches to pumping stations. The ore is beneficiated in a gravity separation circuit to produce heavy mineral concentrate (HMC) with sand tails being returned to reconstruct the mined dunes with the slimes fraction disposed in a slimes dam. HMC from Hillendale mine is further beneficiated at the minerals separation plant using a wet high intensity magnetic separation circuit (WHIMS) to produce crude ilmenite. The crude ilmenite is dried and separated magnetically in a circuit using rare earth drum magnetic separators to produce final zircon and rutile products.

Ilmenite processing impact observed

For the purpose of this paper two periods of reduced ilmenite processing performance will be discussed. Performance of the ilmenite processing plant can be defined in terms of the ilmenite mineral recovery as well as the final smelter grade produced. These two concepts are related, with the production of a higher grade ilmenite leading to a lower recovery. In the case of smelter feed ilmenite there is, however, more than one critical contaminant dictating possible recovery. In the two distinct periods with low recovery it was first the Cr₂O₃ specification that constrained recovery and for a second period the constraint shifted to SiO₂. Figure 1 shows the Cr₂O₃ and SiO₂ trends for the ilmenite processing plant as well as in the dry mill’s rutile production circuits. The use of QEMSCAN® analysis to identify the mineralogical drivers leading to reduced plant performance is shown.

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QEMSCAN® analysis used to identify mineralogical issues

QEMSCAN® is a SEM-based technology in which an electron beam generates an energy dispersive X-ray spectrum which is detected and compared against a reference library of mineral compositions and mixtures. Following the establishment of the QEMSCAN® capability in EXXARO, several samples were analysed to aid in the investigation into reduced ilmenite recovery. To illustrate the investigations, aided by QEMSCAN® analysis, the two material types found to be problematic will be discussed separately.

First material type with a quality constraint

Laboratory tests were conducted on the material to find the cause of the performance issues on the plant. Samples of the problematic crude ilmenite as well as normal crude ilmenite were fractionated using a lift type Carpco magnetic separator and the fractions produced analysed on the QEMSCAN®. Figure 2 shows the Carpco fractionation result for the two samples (normal and type 1 respectively).

From Figure 2 it can be seen that ‘type 1’ material had progressively lower mass pull to the magnetic fraction when compared to normal ilmenite. This would imply that the type 1 material has a slightly lower magnetic susceptibility. Figure 3 shows the TiO2 content per particle frequency distributions for the two samples, normal ilmenite and type 1, based on the QEMSCAN® analysis.

From the plots in Figure 3 the normal crude ilmenite has a chemical distribution lower in TiO2 content compared to that of type 1 material. The increase in type 1 material’s TiO2 content can explain the lower magnetic susceptibility compared to the normal crude ilmenite as seen in Figure 2. The presence of more ilmenite particles with high TiO2 levels would be indicative of chemical weathering.

Figure 4 shows the distribution of Cr2O3 containing minerals in the different low susceptibility magnetic fractions produced on the Carpco magnetic separator. The low susceptibility fraction is shown as it is normally the process stream where the most ilmenite is lost in the process plant. Figure 5 shows the ilmenite mineral distribution for the same magnetic fractions as shown in Figure 4.

From Figure 4 it can be seen that a higher total percentage of the chromite resides in the low susceptibility fraction for the type 1 material, compared to normal crude ilmenite. From Figure 5 it can be seen that more of the ilmenite in type 1 material reports to the low susceptibility fractions when compared with the normal ilmenite. Type 1 material thus yields lower ilmenite product recovery due to a greater extent of chromite and ilmenite mineral overlap in terms of magnetic susceptibility compared to the normal crude ilmenite processed.

The QEMSCAN® added value to the investigation by enabling the identification of ilmenite particles of elevated TiO2 content. The QEMSCAN® also allowed quantification
of different types of chromite minerals present in low quantities in the material. The QEMSCAN® information combined with metallurgical test work assisted in understanding of the mineralogical reasons behind changes experienced in the processing plants.

Second material type with a quality constraint

As shown in Figure 1, a second period was entered where the plant production constraint moved from Cr₂O₃ to the required SiO₂ specification. To investigate the high SiO₂ in the ilmenite, plant samples of the crude ilmenite as well as the final ilmenite produced were analysed using the QEMSCAN®. Separation tests were also done to evaluate separation characteristics of the material (type 2) and to allow comparison with normal crude ilmenite. These separation tests were conducted using rare earth drum type magnets similar to the equipment used in the actual magnetic separation processing plant. For the test a multiple splitter box was used in place of the conventional splitter arrangement. The multiple splitter box allowed several fractions to be obtained from the mineral fan produced as material passed over the drum magnet.

Figure 6 represents the QEMSCAN® data showing the elemental deportment of Si to the minerals present in the magnet feed and product. It can be seen that the majority of the Si in the feed is present as garnet minerals with coatings and leucoxene (TiAlSi-intergrowth) also being significant contributing minerals.

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From Table I it is clear that the garnet in the feed is large in relation to the ilmenite particles which represent the bulk of the particles in the sample. The difference in average size of the particles explains the effective rejection on the large diameter rare earth drum magnets where centrifugal forces would preferentially reject larger particles to the nonmagnetic fraction. Only fine grained garnet minerals end up in the final ilmenite product. Other Si containing minerals are very small and if liberated would have probably been removed in the desliming stages of primary processing. Figure 7 shows a particle view generated based on the analyses from the QEMSCAN®. The particles were ordered as to focus on ilmenite particles containing siliceous FeAl coatings and leucoxene. To assist visual interpretation, the ilmenite phase was shaded out with the siliceous FeAl coatings and leucoxene phase represented by a darker colour. From Figure 6 these two minerals were identified as the main contributors to the high SiO₂ in the final ilmenite sample.
From Figure 7 the textural association between the Siliceous FeAl coatings, leucoxene and the ilmenite phase can be seen. It is clear that the contaminants are attached to the ilmenite grains and normal beneficiation separation techniques will be inefficient. Figure 8 shows the cumulative SiO$_2$ in the magnetic fraction as a function of the mass % to the magnetic fraction for normal as well as type 2 crude ilmenite based on the pilot rare earth drum test work.

Figure 8 shows that the removal of SiO$_2$ is efficient for type 2 materials at low susceptibility fractions where the major quantities of garnet and other SiO$_2$ containing discrete mineral particles are rejected. This is evident from the slope of the curve at mass recoveries to the magnetic fraction of above 75%. To clean the ilmenite further after the majority of liberated minerals are rejected is inefficient as the slope of the curve for values below 75% indicates. If the SiO$_2$ content needs to be reduced to levels of around 0.9%, which is required for good quality smelter feed, significant loss of product mass is experienced. For the normal crude ilmenite these is not a constraint with the feed sample’s SiO$_2$ levels already within acceptable limits.

**Processing options available**

For type 2 material the physical removal of coatings by attritioning was tested on a laboratory scale. Following the attritioning the material was processed using a similar test set-up on the rare earth drum magnets as done in previous test work. Figure 9 compares the separation performance of the attritioned and unattritioned material to illustrate the improvement achieved.

From Figure 9 it can be seen that by attritioning an improvement was achieved, increasing the mass yield from around 41% to 56%. Implementing this solution on the plant would, however, require significant capital and operating cost. From geological information available it was found that the section of the orebody prone to heavy coatings was not extensive enough to justify capital expenditure. Blending can also solve the SiO$_2$ quality issue and allow higher yields by moving the quality constraint from SiO$_2$ to Cr$_2$O$_3$. Even though there may not be scope in the mining operation to blend different ore types, stockpiled crude ilmenite available can be used for this purpose. Figure 10 illustrates the impact of blending on the mass recovered to the magnetic product.

From Figure 10 it can be seen that by blending the two material types as feed to the processing circuit mass recovery of up to 73% can be obtained, compared to the average mass recoveries if the two material types would have been separately processed of 58%. Due to the efficiency of the blending solution and the low cost, it was implemented as the solution to resolving the reduced recoveries due to high SiO$_2$.

**Processing impact on rutile**

**Description of the dry mill of the mineral separation plant**

As described earlier, the heavy minerals concentrate first enters the feed preparation circuit where oversize material (larger than 0.85 mm) and magnetite are removed. Ilmenite is produced by magnetic separation in the WHIMS circuit as described. The WHIMS nonmagnetic fraction is cleaned to reject quartz, some leucoxene and most of the aluminium silicate minerals using gravity separation. Figure 11 gives a summarized material flow for the dry mill plant.

The cleaned nonmagnetic fraction is dried and fed to the primary electrostatic separation circuit for a primary split of conducting minerals and non-conducting minerals. The zircon rich, nonconductive stream is leached with sulphuric acid in a kiln reactor to remove iron staining from the surface of the zircon particle. After the acid is washed off the material it is further cleaned by rejecting any...
removing low density contaminants such as quartz, leucoxene and aluminium silicate minerals. The upgraded zircon rich stream enters the final stage of electrostatic separation where the final zircon product is produced. The remainder is returned to the primary electrostatic circuit as a circulating load.

The rutile rich stream (from the primary electrostatic circuit) is subjected to an acid attrition circuit. The purpose is to remove staining on particles in order to prepare them for the final stage of electrostatic separation where final rutile product is produced. The remainder is returned back to the primary electrostatic circuit as a circulating load.

The impact experienced

Two distinct periods were also experienced. The first period was characterized by heavy iron staining on the zircon particles. This dropped the efficiency of separation in the primary electrostatic circuit and led to lower quality feed going to the rutile and zircon circuits. Since no hot acid leaching is done on the rutile rich stream (only cold acid attritioning), the rutile circuit had great difficulty in producing rutile to specification.

During the second period, however, iron staining was not a big problem. The rutile circuit had difficulty in producing rutile within the SiO₂ specification, even when the zircon content was dropped to as low as 0.5%. The effect on rutile production is shown in Figure 12 where typical production was given a baseline value of 100% and the reduction in production shown relative to this baseline.

A secondary effect of low separating efficiencies is that circulating loads in the plant increase. As the rutile circuit was affected most, circulation of especially rutile and leucoxene increased, resulting in higher feed rates to the rutile circuit. Higher feed to the rutile circuit placed additional load on the rutile attritioner, leading to reduced retention times and thus reduced attritioning efficiency. The first reaction to this sudden drop in production was to do the basic circuit checks and to do thorough plant inspections. Machines were surveyed and all machine and process parameters were optimized to ensure optimal separation. Different circuit control philosophies were tested but no real improvements could be made.

Feed characterization

The reason for the significant drop in production was not fully understood. Apart from some stained zircon, the optical microscope could not provide the necessary explanation. Samples analysed by QEMSCAN®, however, gave some useful explanations. From the QEMSCAN® analysis high levels of mineral coating and attachments could be identified. Since the electrostatic separation processes utilizes mineral particle surface conductivity differences as basis for separation coatings may severely affect the separation efficiency. This is shown on Figure 13 on a few selected rutile particles.

Possible solutions

To maintain production levels when treating the problematic feed material, the processing plant efficiency had to be improved to compensate for the deteriorated mineral properties. The following two considerations directed the strategy followed:

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• QEMSCAN® images revealed the existence of rutile particles coated and intergrown by mainly leucoxene and AlFe-silicates. Since the residence time in the rutile attritioner is not optimal, installing a bigger attritioner was one obvious improvement to consider.
• Higher efficiency high tension roll (HTR) machines existed but their potential impact was unknown.

To test the effect of attritioning time on subsequent electrostatic separation, a sample of the rutile rich stream from the primary electrostatic circuit was split into five equal fractions. Each fraction was attritioned in a laboratory scale attritioner at different durations. The attritioned samples were compared by subjecting them to the same electrostatic and magnetic separation circuit on laboratory-scale equipment. The circuit consisted of a single pass of electrostatic separation, followed by a single pass on a rare-earth roll separator and a final single pass of electrostatic separation. Figure 14 below summarizes the results obtained from the test work. A plant attritioned sample was also taken and subjected to the laboratory electrostatic test circuit. This was done to compare the plant attritioner to the laboratory-scale attritioner and the data point for this sample is indicated on Figure 14 by a square.

The performance of an alternative HTR separator was compared to existing HTR separators. A laboratory-scale CoronaStat unit was used. It was tested against a full-scale CoronaStat and the difference in separation efficiency was within 2%. The performance of the laboratory-scale CoronaStat was then compared to that of a full-scale unit of the older HTR separator. The CoronaStat efficiency was found to be about 15–20% (absolute) higher.

A secondary benefit that could be obtained by replacing the older HTR separators in the circuit with CoronaStat separators was that the flow of the returns to the primary electrostatic circuit could be reduced. Reduced loading on the primary separation circuit would result in improved separation efficiency. A third benefit was that the reduced circulating loads throughout the plant would result in a lower feed rate to the rutile attritioning circuit, thus increasing residence time. Test work showed that by installing CoronStat separators the rutile yield would increase by 14.5%. Since the installation of CoronaStat HTR units promised higher efficiencies, reduced circulating loads and longer attritioning times, it was decided to only install the improved separators before any upgrade to the attritioner was considered. The impact of the lower recycling loads on the average retention time in the attrition unit is indicated on Figure 14.

Post implementation results

Figure 15 illustrate the improvements in rutile production achieved following the implementation of the plant improvements.

During the onset of separation problems, rutile production dropped to an average of 38% below baseline production as seen on Figure 15. Following the commissioning of the CoronaStat units, rutile production went almost back to baseline production. The returns stream from the rutile circuit to the primary electrostatic circuit reduced by about two-thirds. This significantly reduced the loads in that circuit, presenting the opportunity to make a few process flow changes. After these changes, rutile production made another step change to 19% above baseline production. This step change was due to improved separation efficiencies in the primary circuit, resulting in better feed quality to the attritioning circuit. Following the improvements in separation, the feed rate to the attritioning circuit reduced by 25% which caused the residence time in the attritioner to increase.

Conclusions

This paper showed how QEMSCAN® technology can be used as an input to process troubleshooting. By studying the mineralogy and getting quantitative data on mineralogical properties of samples, root causes for observed processing behaviour can be determined. The QEMSCAN® can give information about mineral associations, elemental deportment to different minerals in a sample, mineral sizing information, and mineral assemblage of a sample. These analyses are over and above the visual mapping of particles in a sample. This paper presented some case studies to illustrate the value of the technique to augment traditional metallurgical test work in the problem solving process.

It is concluded that the QEMSCAN® as an analytic technique can add value to minerals processing operations as was illustrated by applications on ilmenite as well as rutile processing investigations.
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