Wet heavy mineral pilot plant design, assembly, commissioning and operation for a remote location

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Introduction

The aim of the bulk sample processing campaign was to produce 500 tons of representative heavy mineral concentrate (HMC) from the Ranobe deposit at reasonable grade and recovery within one year to satisfy further processing needs.

- **Representative HMC**—the average total heavy mineral (THM) grade of the deposit is around 6.5% with slimes (<45 micron material) content around 5%. A higher grade area (>9% THM) with no overburden except for 300 mm of topsoil was selected as feed material to the bulk sample processing campaign. This feed material was regarded as representative based on sample analysis from nearby drill locations as well as drill sample composites. Limited variation in terms of drill depth ensured that the feed material that was extracted from a depth of down to 5 metres from the surface was still representative. More than 5 000 tons of feed material was to be processed to produce the required HMC.

- **Reasonable grade and recovery**—the concentrate produced from the bulk sample processing campaign needed to be representative in terms of valuable heavy mineral recovery of above 90% and concentrate grade above 90% THM.

- **Time frame**—the pilot plant was prepared within 2 months, transportation took one month, site-establishment, assembly and commissioning were achieved in one month, operation to produce the required tons was seven months and closure was done in one month.

- **Further processing needs**—the HMC was to be further processed into ilmenite, higher grade ilmenite, zircon and rutile. The ilmenite would be smelted to ensure that a marketable high titanium slag can be produced as one of the main aims of the bankable feasibility study of the Toliara Sands Project.

To accomplish this aim at a reasonable cost the pilot plant design had to fulfill certain key requirements.

Pilot plant design

**Modularity and mobility**

The pilot plant was constructed on two standard 6 x 2.4 metre container floors for ease of transportation. Three sump pump units are bolted on each floor. Each sump pump has its spiral module that bolts on top. Three floors at different heights connect these two triple sets with each other, as shown in Figure 2. A single cat ladder connects the three floors vertically. The spiral distributors bolt on top of the spiral modules. This design allows for easy
replacement of spirals or even other units such as an upcurrent classifier, if necessary. All the pumps and motors are controlled from a central control panel. Safety rails, lights, hoist, fire extinguishers, and additional walkways are added to ease and safeguard operation, as shown in Figure 3.

Ten containers (6 x 2.4 m) supplied the necessary structure and equipment to sustain operations for the campaign period. Refer to Table I for a brief description of the main items.

**Flexibility**

All pumps were equipped with variable speed drives for optimum control to balance the slurry flow through the plant. Pressured water from thickener overflow together with flow meters provided fresh water feed control to the various sumps. The rotary vain feeder could also be adjusted to control dry feed rate to the pilot plant.

**Sampling**

The pilot plant was equipped with pneumatic samplers on all spiral feeds, as well as tails cyclone underflow and concentrate cyclone underflow. The spiral product pipes at the bottom of the spirals were placed in dedicated positions above the sump levels for total circuit sampling.

**Quick assembly**

Due to its modular design the main structure assembled in less than two days. A crane was required for this phase.

**Process support functions**

The pilot plant was equipped with a dry lab (Carpco, sample splitters, scales, drying oven, screen shaker) and wet lab (shaking table and attritioner) to provide the required process support.

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**Suitable flowsheet**

To ensure that the four spiral circuit, as shown in Figure 5, that was suggested by the prefeasibility study team, would be sufficient for primary concentration of the Ranobe deposit, it was decided to assemble the entire pilot plant while still at Exxaro R&D’s facility and process several drill sample composites from the Ranobe deposit. Reasonable THM grades and recoveries where achieved during this stage, which gave the necessary confidence in the design to proceed. The good visual separation is depicted in Figure 4.

**Reasonable and consistent throughput**

A rotary vain feeder and conveyor provided a constant moist material (2% moisture average) feed rate of 8 to 10 ton per hour to the feed box where it was slurried. A

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**Table I**

<table>
<thead>
<tr>
<th>Container 1</th>
<th>Container 6</th>
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<tbody>
<tr>
<td>Diesel generators x2</td>
<td>Feed hopper and plant structure</td>
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<tr>
<td>Container 2</td>
<td>Container 7</td>
</tr>
<tr>
<td>2 spiral modules and plant structure</td>
<td>Thickener and 2 feed conveyors</td>
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<tr>
<td>Container 3</td>
<td>Container 8</td>
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<tr>
<td>4 spiral modules and plant structure</td>
<td>Sample processing lab</td>
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<tr>
<td>Container 4</td>
<td>Container 9</td>
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<tr>
<td>Plant floor 1 with 3 pump sumps</td>
<td>Office container</td>
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<tr>
<td>Container 5</td>
<td>Container 10</td>
</tr>
<tr>
<td>Plant floor 2 with 3 pump sumps</td>
<td>Spares container</td>
</tr>
</tbody>
</table>
A trommel screen was used to remove roots and 4 mm oversize in the slurred feed. A desliming cyclone on the feed slurry produced a slimes cut that was flocculated and thickened for slime drying evaluation. The tails and concentrate streams were dewatered with cyclones.

Once the design requirements were met and preliminary evaluation proven successful, it was time to set the bulk sample processing campaign procedure in motion.

**Procedure**

**Pre-assembly and hot commissioning**

This is mentioned in the previous section as part of the design confirmation.

**Disassembly and transportation**

The pilot plant was disassembled, loaded into the 10 containers and transported from Exxaro R&D in Pretoria to the predetermined location at the Ranobe deposit. The container transportation was done with standard double link trucks from Pretoria to Durban. From Durban it was shipped to the Port of Toliara. Due to the poor road conditions 6 x 6 trucks were required to move containers one at a time to the pilot plant site from the Port of Toliara.

**Site establishment**

Prior to the arrival of the containers civil work at the planned processing site was required. The pilot plant is supported by three concrete plinths (1) that were to be cured before assembly of the pilot plant could proceed. Refer to Figure 6a and 6b with matching reference numbers. Smaller plinths were required for all the other containers to ensure that they were level. A ring road (2) for HMC loading was prepared. A water tower (3) and ablution block (4) (showers, basins, toilets, French drain and septic tank) were built. A drink water network was laid from the water tower. The water tower was in turn fed from a borehole (5) –95 m deep. A separate bathroom (6) was built for the operational supervisor and other expatriate visitors. Certain high utilization containers were covered with a local thatch (7). Staff and worker temporary housing in the form of tents (8) (large army and smaller dome) and temporary prefabricated thatch houses (9) were assembled. The operational supervisor was accommodated in a container and expatriate visitors slept under the open sky under mosquito nets. A wood-pole fence (10) from locally available material was constructed all around the site. A local contractor was appointed for the civil work of the above-mentioned items.

**Pilot plant assembly**

The assembly of the pilot plant included not only the combination of previously mentioned modules and surrounding steel structure (11), but it also included cabling from generator container (12) to all the different points, earth cabling for lightning protection on the pilot plant, assemblage of the thickener tank (13) with flocculant make-up tank, piping inside and outside the plant for slurry and slimes, make-up water dam (14) fed from borehole with piping, conveyor (15) for filling the feedhopper, a conveyor (16) for feeding the feed box of the trommel screen, digging of a spillage water dam (17) to optimize water recovery, and digging of several slimes drying ponds (18). A team of seven expatriates and 10 locals were responsible for this stage.

**Commissioning**

After the pilot plant was totally assembled it was commissioned in stages, starting with the electrical connections right through to the slurry flow to the final tails.
cyclone. The material was first circulated in a closed loop by combining the tails and concentrate cyclone underflows into the feed sump to perform the necessary system checks. One ton of HMC was produced before the assembly team returned to South Africa. Figure 7 shows the assembly team and first ton of HMC.

Operation
The top soil (300 mm) was first removed for rehabilitation purposes. The feed material was dug by 30 alternating labourers with shovels. A feed pit was dug to a maximum of five metres deep in 1 x 1 metre steps into the pit. The feed material was manually loaded and hauled by truck to the feed conveyor where it was manually stockpiled. The stockpiled feed was loaded with shovels onto the feed conveyor that filled the feedhopper, which in turn fed the rotary vane feeder that supplied the constant feed to the pilot plant spiral circuit. The sand tails were dewatered with a cyclone and backfilled the previously dug pits. Slimes were flocculated in a partitioned thickener tank and pumped to paddocks for drying characteristics evaluation. The dry slimes were stockpiled for rehabilitation. The concentrate was dewatered with a cyclone and spread out on five metre diameter PVC sheets for sun drying before loading into bulk bags. The HMC bulk bags were uploaded by a 6 x 6 truck with hoist and transported to the Port of Toliarı, 6 tons of HMC at a time. These bags were loaded into containers and shipped back to South Africa, final destination Exxaro R&D, Pretoria.

The bulk sample processing campaign procedure was, however, not easy sailing and was associated with various unique challenges.

Challenges faced during this procedure

Environmental approval
A full environmental impact assessment had to be completed and submitted three months in advance of the site establishment and approved before the full operation commenced. A document describing the intended process and preventative actions on all possible environmental risks was submitted in November 2005. Due to the large technical barrier (Madagascar has no established mining culture) and language barrier (French speaking with limited English capabilities) the approval of this document jeopardized the progress of the mission. Approval of formal operational status was achieved only in April 2006. The result was that during the commissioning period more HMC was produced than planned.

Exportation from South Africa and importation into Madagascar
An arrangement was made with the Madagascar import authorities to treat the 10 containers as a temporary import, which required upfront additional administration. As a standard during equipment exportation to another country there should be a detailed list of all the components in the assignment. In this case a clear distinction was to be made to the purpose of each component and whether it was a consumable or a temporary import for taxation purposes. It came, however, as a surprise that each separate component from the bolt to the pilot plant safety rail should have its own barcode which should be listed (over 2 000 separate parts). Barcode labels had to be generated at short notice, and all the components had to be unpacked and labelled. A further requirement enforced by the goods inspector (SGS in this case) was that all the goods were to be packed into the containers while a representative was present. The classification of certain goods as hazardous (fire extinguishers) also came as a surprise. This placed additional pressure on an already tight schedule.

Civil preparation contract
The standard contracting process of Exxaro was followed for the required civil work as preparation for the assembly of the pilot plant. Several possible service providers were identified during a visit in October 2005. They were all keen to supply a quote for the civil works under discussion. At the close of the formal tender process at the end of November 2005 there were no replies from any of the possible suppliers. After further investigation it was realized that all understood the scope of work but none understood the contractual terms, especially where BEE (black economic empowerment) requirements were mentioned. This caused them to refrain from supplying a formal reply. After renegotiation there was only one supplier still interested. They had to commence with work in early January to be completed in February when the containers arrive on site. Due to communication breakdown with the supplier’s subcontractors and bad weather (cyclones), there was no civil work done until the assembly team arrived on site in February 2006. No borehole was in place for water provision as agreed. The assembly team started with the site layout and giving required direction to the civil work contractor and his team, as well as installing the borehole pump and generator. This caused more than a two-week delay in the planned schedule.

Poor road conditions
During the preparation visit in October 2005 various discussions were held with the contractor responsible for the transportation of the 10 containers from the port to the site. The contractor was aware that the general road conditions were poor, with deep ditches in the main road and thick sand on the secondary roads. After some cyclonic weather activity at the end of January 2006 in Toliarı, associated with some heavy rains (Figure 8), the initially arranged trucks were unable to make one trip. Two 6 x 6 trucks were brought from the capital of Antananarivo (1 200 km) to provide the required transportation service (Figure 9). The transportation of the 10 containers took two weeks longer than planned.

Figure 7. Commissioning of pilot plant—the assembly team at the first ton of HMC
Remoteness of the site

Although the site was just 60 km away from the town of Toliara, it took well over two hours drive due to the poor road conditions and human activities on the sides of the road. Cellphone reception was available only one hour’s drive away from site. Satellite communication was used as the only communication alternative (not 100% reliable) since two-way radios were incapable of communicating further than 2 km. This had a serious impact on the risk assessment in case of a serious injury on site. Being at a remote place implied that the operation had to be self-sustaining in all the major services. Power was generated with two diesel generators, a 150 kVA during pilot plant production hours and 40 kVA during non-production hours, depicted in Figure 10. The diesel was trucked to site and delivery was 9 000 litre at a time. Drinkable water was extracted from a 95 m deep borehole at a maximum of 30 m³/h.

Availability of spares

Not only the remoteness but also the availability of quality spares in the best hardware shops of Toliara was a challenge. No piping or pumps were available, any available steel profile was seven times more expensive than in South Africa, and electrical components were 20 times the price compared to South Africa. Safety equipment was non-existent. Only a few spare parts could be bought in the capital of Antananarivo and sent by taxi to Toliara, which took two weeks. Spare parts air freighted from South-Africa to Toliara took anything between two to three months. With this in mind, the team had to be innovative in problem solving, example depicted in Figure 11.

Feed hopper design

Although it was beneficial in many regards to pre-commission the pilot plant circuit and confirm process efficiency prior to transportation, it was done with dry sand. The slightly damp sand that was being shovelled and fed to the pilot plant on site had totally different flow characteristics, and constant material flow could not be achieved through the rotary vain feeder. The LIMS was regarded as redundant (due to the magnetite being below 0.5% of THM) and the motor and gearbox were scavenged.
and modified to act as material agitator above the rotary vain feeder. This was not the most robust design but was a working solution, depicted in Figure 12.

**Manual mining, people, food, language barriers**

All the digging, loading, and stockpiling was done by 35 labourers on a ten hour day shift, five days a week (Figure 13). There were five labourers to supply the required feed rates to the pilot plant which usually ran slightly longer than 10 hours a day to make up for plant shits. Another five labourers supported the other parts of the pilot operation, that is, sand tails backfilling, HMC drying, HMC bagging and slimes management. Fifteen people from the capital of Antananarivo, some with formal tertiary education, acted as supervisors of the above mentioned 45 labourers, some as translators, plant operators, sample analysis assistants or cooks and others as vehicle drivers. With only two translators, with limited English, communication was challenging initially since most communication had to be translated into French and then into Malagasy (Toliara dialect). The other challenge in this case was to supply these men with food on a daily basis—each labourer consumed close to a kilogram of rice at a single meal.

**Lack of safety culture**

Most of the local labourers haven’t seen a pump in their lives and the belief was (prior to level 1 training) that the pilot plant transformed brown sand into black sand. The greatest challenge was not to inform and train the people but rather to create the necessary safety culture associated with the process. They wore their hard-point safety boots, hard hats, radiation monitor, dust mask and safety goggles as work status symbols. After training and retraining, almost every worker was able to explain why he is wearing what gear by means of a basic HIRA (hazard identification risk assessment process). When they are in the camp after work they would work with the axe and the shovel as if they never had any training.

Another aspect that needed some consideration was the health and environment. There were quite a lot of centipedes, scorpions and spiders running around that caused several non-lost time injuries. HIRAs had to be altered to cater for the different environment. Another risk was malaria: there were eight incidents of positive malaria. Those labourers who received the medication, were ready within half a day to return to work. The operational supervisor (expatriate), however, contracted malaria while the test indicators showed that he was negative; this put him out of action for a week.

**Pilot plant operator**

The pilot plant operator had to be electrically competent to adhere to Exxaro’s life insurance policy in case of an accident since electrical shock was identified as the highest risk of the pilot plant operation. A millwright was appointed as the operational supervisor. He was briefly trained in the metallurgical aspects of the circuit and the targets of 90% THM grade and 90% THM recovery was set. However, after some shaking table evaluation it showed that THM recoveries were in the low 80s, indicating that the plant’s metallurgical performance was below industry standard. After careful mineralogical analysis (done at Exxaro R&D) of the different process streams it was found that the feed THM consisted of more than 15% goethite. This unwanted mineral had low recoveries on the spirals, causing the low THM recoveries. After calculation of zircon, rutile and ilmenite recoveries it was confirmed that the pilot plant recoveries were well above industry standard.

**Encroachment**

The pilot plant provided the only diesel generator sound during the day and electrical lighting during the night for a 15 km radius. This attracted a lot of attention from the local communities.
population who saw it as a possible source of gain. The great amounts of water in a fairly arid region got the most attention. Some of the civil work contractors were caught exchanging the water for food at the fence. The safety risks had to be considered.

Each challenge resulted in valuable lessons that was learned, which will be discussed in the next section.

Valuable lessons learned

Environmental impact assessment
- When dealing with Madagascar authorities don’t assume normal approval periods (three months) and start well in advance with discussions and documentation
- Great effort needs to go into establishment of clear understanding of associated technical issues, which involves several face-to-face discussions. A good technical translator will aid the process greatly.

Proper precommissioning
- After the precommissioning and circuit confirmation in South Africa all the pipes were marked, which greatly aided the assembly in Madagascar where there were hundreds of pipes lying around after the containers were unpacked.
- The correct flocculant could be identified beforehand by isolation of the slimes during precommissioning.
- 80% of the pilot plant’s temporary shuts in Madagascar were caused by some problem relating to the constant feed to the pilot plant. If the flow problems associated with damp to wet sand could be identified during the precommissioning phase, a much more robust design could have been implemented that would have saved many non-production hours.

Exportation from South Africa and importation into Madagascar
- Make a thorough study of the specifics of the whole temporary importation procedure before attempting to begin the actual importation process.
- Arrange formal discussions with each member in the entire chain, even those in Madagascar (translator required).
- Do not assume that the contracted freight forwarder will handle everything.
- During the actual process manage it intensively with over communication.
- Make sure that all parties involved have similar dangerous goods classifications.
- Understand the tax implications if the temporary import period is exceeded
- Make an effort to ensure accurate technical translation (example: CB/circuit breaker was translated as CB radios. The assignment was held back while waiting for necessary approval documentation).
- When bringing containers in, make sure that they are well marked with the correct external markings and easily distinguishable so as not to get lost at the port. See Figure 14.
- Arrange with the Port Authority and the transport service provider to move the containers in a specific sequence. The first container that arrives on site must have the necessary start-up equipment and tools.
- Spare parts air freighted to Toliara took 2–3 months to get to site. Ensure that critical spare parts are available on all major production equipment. In all cases it was more effective to take spare parts (below 100 kg) through with hand luggage and pay the cost of overweight, or transport parts as unaccompanied luggage.

The contracting process in Madagascar
- The standard contractual terms had to be adjusted and simplified to make them applicable to the average service provider in Madagascar.
- Personal contact and communication are far more valued than any formal document.
- To ensure that the work is done on time, it needs to start long in advance and has to be regularly checked and the necessary direction has to be provided. This has to be done in person since telephonic and e-mail communication’s effectiveness is low.
- Understand the interaction between the various service suppliers and be sensitive to creating a bad business relationship due to non-performance from the service supplier. The business community of Toliara is a small society and news travels fast.
- If a bad business relationship is created it will affect other potential business relationships in the future.

Poor roads and remoteness
- To drive in the thick sands on the secondary road takes a fair amount of skill and full concentration. Dedicated drivers are to be used who are not intensively involved in the operation of the pilot plant. They would also be responsible for carrying out the necessary vehicle inspections prior to a trip.
- Ensure that the satellite communication system is working properly and that the operation of the phone is fully understood by several key personnel.
- An emergency response plan should be in place and understood by every person on site. The stipulated

Figure 14. All of the containers were clearly marked and numbered
emergency procedure has to be closely followed to validate an insurance claim should there be any medical emergency, which always has cost implications.

• There are different emergency response plans for the local people and the expatriates and these should be well understood by key personnel.
• There is no direct air link between Toliara and Johannesburg and special permission has to be granted for pickup in case of an emergency.

Manual mining, people, food, language barriers

• It was noticed that there was also a certain class distinction between different ethnic groups in Madagascar itself. This caused some conflict initially during the ‘storming’ phase of the project. A mature local respected person who knows both ‘worlds’ well will aid greatly in dealing with these situations; this was unknown to the expatriates involved.
• The option to do manual shovelling compared to mechanical shovelling was beneficial in terms of the flexibility of the operation. For example, during a plant maintenance shutdown, labourers could be used to carry out other functions such as rehabilitation of already ‘mined’ areas or building a thatch roof over a container.
• Getting to know certain key phrases in the local language cut out the translator; this saved time and also created respect.
• The utilization of local labour rather than mechanical shovelling and the income it generated for the village’s families involved had a positive influence. Village men were in competition for the job, which created the necessary environment of performance.
• In general the Malagasy people who were involved in the project were hardworking, honest, eager and learned fast. This was a great contributor to the progress made during the 7-month operational period.
• The Malagasy people generally believe in the supernatural. In certain cases they make use of a strong locally brewed alcoholic drink in their rituals and daily activities, which jeopardized the safety of the workers. This had, to be dealt with in a very assertive yet respectful manner and was tactfully handled by a respected local project team member. This aspect becomes especially complex if the work and non-work areas are on the same site. The temporary accommodation for workers should ideally be off site and everyone should be tested at random for alcohol in the morning prior work.
• Buying food from the local communities (sheep, cattle, maize, chicken, beans) was more economical compared to purchasing food in Toliara. It was much fresher and it could be stored in a fridge with reliable power supply (own generators). Rice and some vegetables still had to be purchased in Toliara though.
• In terms of the selection of expatriates—be very thorough and selective, since it is a demanding environment, with a high degree of discomfort, long working hours, high concentration work, a possibility of malaria, group friction, miscommunication with locals, etc.

Safety

• It will take a few years and some effort for the people to develop the necessary safety culture.
• High safety standards need to be maintained to compensate for ignorance. The use of a critical task instruction that was developed for each worker, who is evaluated bi-monthly on these tasks, was one of the ways in which the lack was addressed.
• Keep people away from high risk areas by clear demarcation and enforcing demarcation, for example the construction area during the assembling of the pilot plant by an overhead crane.
• Appoint a dedicated person (preferably a qualified local) to ensure that the medical supplies are sufficient and who is able to treat minor injuries such as insect bites, scratches and bruises.
• Make sure that the malaria indicators test for all types of malaria that are present in the area and make sure to apply the necessary preventative measures, even during extended periods.
• Another safety aspect to consider is that of encroachment of the local population into the mining area once development activity starts. People with no training or protective clothing could be exposed to high risk environments. This will have to be carefully managed.

Impact of pilot plant image on local society

• The pilot plant was regularly visited by mayors of the local communities, leaders of the Toliara province, the minister of environment, WWF representatives, etc. The visual impact of the plant can either build or break a company’s reputation. This was one of the reasons why high SHE (safety health and environment) standards were pursued.
• The pilot plant was assembled more on a longer-term installation standard (one year) rather than a short-term installation standard (one month). The standard followed greatly influenced the visual quality and durability of the site establishment, example indicated in Figure 15.

Conclusion

The aim of the bulk sample processing campaign was achieved through team effort. Although many challenges were faced during this campaign, each one was overcome and valuable lessons were learned. These lessons could act as guidelines to be considered for any future pilot plant operations at remote sites in other countries.