Introduction

High titania slag is produced by the smelting of ilmenite and a suitable carbonaceous reductant in electric furnaces. Currently liquid slag is cast into large blocks, which take about 10 days to cool down before they can be crushed, milled and classified into two final products. The two products, chloride and sulphate grade slag, are differentiated according to their size. Granulation of titania slag has been identified as a possible alternative to the conventional block route. This paper discusses some of the work carried out at Exxaro Research and Development to investigate both wet and dry granulation of titania slag.

Wet granulation of titania slag

Description and operation of the wet granulation plant

Wet granulation of titania slag was carried out at the research and development facilities of Exxaro in Pretoria. Ilmenite was smelted in the 1.5 MW DC furnace at this facility. The typical titania slag tap mass was approximately one ton. A dedicated facility for the wet granulation of this slag was developed. A schematic diagram of this facility is shown in Figure 1. The wet granulation facility consisted of the following main components:

- Slurry tank
- Slurry pump
- Granulated slag
- Collecting tank
- Water supply
- PGR

Figure 1. Schematic diagram of the wet granulation pilot plant erected in Pretoria
• A granulation tank
• Pump for pumping the slurry
• Slurry tanks where the granulated slag was separated from water
• Water collection tank used to supply water to the granulation process
• Pump for pumping water to the blowing box
• Blowing box (designed by Paul Wurth).

Before tapping slag, the granulation plant was turned on and the water flows allowed to stabilize at the required flow and pressures. When liquid slag was tapped from the furnace it was impacted by high-pressure water jets from the blowing box. This is shown by the photograph in Figure 2. The slag stream is fragmented by the water stream into small particles that are suspended in the granulation tank. From there the slag-water slurry is pumped into the dewatering tank. All excess water is drained and the wet slag is recovered into bulk bags. The wet slag was subsequently dried in electrically heated drying pans. The water flows over from the dewatering tank into the collection tank, which serves as supply vessel for the granulation spray pump. By varying the number of open holes in the blowing box, as well as the spray water flow rate, the granulation water’s speed, pressure and flow rate can be manipulated to achieve the desired slag product properties.

A wide range of operating parameters was used to determine the influence of these parameters on the slag product characteristics. The trials were aimed at obtaining information on the following aspects:

• The optimum product distribution for maximizing product revenue (high CP/SP slag ratios)
• The influence of the different operating parameters on aspects such as minimizing oxidation of the slag
• Determining the parameters at which safe operation can still be guaranteed
• The effect of each of the variable process parameters on the product particle size distribution.

Results from the wet granulation of titania slag

To obtain the requisite product qualities, a relatively coarse product distribution after granulation (d50 of approximately 900 to 1000 μm) was required. This is done to ensure that no granulated SP slag is produced, as this product is oxidized and not suitable for the downstream sulphate process due to a high insoluble content, exceeding the required specifications. This relatively coarse wet granulated product requires screening of the ~850 μm fraction, followed by milling of the +850 μm fraction to produce milled CP and SP slag products. The optimum product distribution obtained from the granulation test work is shown in Figure 3. It is believed that the amount of SP slag can be further reduced by optimizing the milling process. The distribution of the products was as follows:

• Granulated CP slag (~47 %)
• Milled CP slag (~46 %)
• Milled SP slag (~7 %).

Typical chemical analyses of the expected wet granulated slag are shown in Table I. These products were obtained from tapped slag compositions comparable to South African ilmenite smelters. From the Ti2O3 results it is clear that some oxidation of the slag by water occurs.

Risks identified for implementing wet granulation technology

Five areas of potential concern were evaluated in terms of risk for the conventional block and wet granulation processes. These areas of concern are listed in Table II, with each of the cooling technologies evaluated in terms of these areas. Three criteria were used, that is high, medium and low risk. The technologies were rated in order of the assessed risk, with (1) indicating the lowest risk and (2) the highest risk, as shown in Table II.

For the chloride grade slag quality one of the important issues is the Ti2O3 content of the slag. During chlorination Ti3+ in the slag is oxidized to Ti4+. This is an exothermic

![Figure 2: Photograph of the wet granulation of titania slag](image)

![Figure 3: Optimum product mix](image)

### Table I

<table>
<thead>
<tr>
<th>Slag</th>
<th>Analyses (%)</th>
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<tr>
<td></td>
<td>FeO</td>
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<tr>
<td>Granulated CP (~850+106 μm)</td>
<td>9.7</td>
</tr>
<tr>
<td>Milled CP (~850+106 μm)</td>
<td>10.1</td>
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<tr>
<td>Milled SP (~106 μm)</td>
<td>10.6</td>
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reaction that contributes to the energy balance of the chlorinator. For this reason there is usually a minimum and maximum specification on the TiO$_2$ content of the slag. This requirement presents no problems for the block route. Some oxidation, however, takes place during wet granulation resulting in a lower TiO$_2$ content. The granulated slag has therefore a higher risk in this regard. The block route slag has already found acceptance in the market and as such is rated as the lower risk product.

For the sulphate grade slag quality the area of concern is the insoluble TiO$_2$ content of the slag. Once again this should not present a problem for the block route slag, although decrepitated slag does tend to approach and exceed the specified threshold level. The insoluble TiO$_2$ level of the granulated milled –106 μm fraction seems to be acceptable, but this needs verification.

To maximize revenue it is important that the minimum amount of slag for the sulphate route is produced, as this slag has a lower value. For wet granulation, it is expected that a chloride/sulphate grade split of approximately 92/8 can be attained. For the block route, it is believed that a chloride/ sulphate grade split of 85/15 can be attained.

In terms of the process complexity it is believed that wet granulation of the slag will be the simpler process. The reason for the block route being less favourable is that this process requires the processing of blocks that are 20 tons in size.

With regard to the safety of the various process options, it is believed that the block route is the most dangerous. This is due to the handling logistics of 20-ton blocks, as well as the potential of these blocks breaking with the subsequent ejection of hot liquid slag. For the wet granulation process the greatest danger lies in the dumping of an excessive amount of slag in the granulation tank, which could potentially lead to explosions. From the pilot plant trials no problems were encountered in this regard and it is believed that with the correct granulation plant design and practice this will not be a problem.

### Dry granulation of titania slag

**Description and operation of the dry granulation plant**

Dry granulation of titania slag was carried out at the 500 kW DC furnace on site. In this instance compressed air was used as granulation medium. Two rectangular guide plates placed on the slag taphole side of the furnace channelled granulated particles produced during the granulation trials. These guide plates (3 mm thickness) were 4.5 m high and 7.2 m in length. The guide plates opened up from the furnace at an angle of approximately 10 degrees. At a distance of 13.4 m in front of the slag taphole a water-cooled collision plate (4.5 m high) was placed to stop the granulated particles blasted in that direction. A ladle was placed underneath the slag taphole to contain slag that passed through the air blast and that was not granulated. The compressed air line available on site (approximately 5 bar pressure) was used to supply air for this configuration. Opening a valve at the air supply line controlled the airflow at the nozzle. The nozzle configuration consisted of a rectangular box, with two V-shaped lines cut in the front of the box to provide an exit for the air blast. The nozzle configuration was placed directly underneath the spout of the slag taphole. The nozzle could be swivelled so that the angle of the air blast could be changed. Figure 4 shows a photograph taken during the dry granulation of titania slag. The guiding plates can be seen, with the collision plate not visible in the photograph.

### Results from the dry granulation of titania slag

Individual granule particles produced from dry granulation were almost always spherical, sometimes elliptical and occasionally elongated and irregular. This is shown in Figure 5. Most of the granules are entirely hollow, while...
porous particles were also common, and less often massive (or dense) particles occur. Some of the granules have been fused or sintered together. The granules consisted predominantly of rutile, as identified by X-ray diffraction analyses. The rutile crystals can be clearly seen in Figure 6, as well as the hollow nature of the particles. Individual rutile grains and crystals are mainly densely packed and connected by small amounts of cementing material, which micro-analyses revealed to be FeTiMgMn-bearing CaAl-silicate or a FeTiMgMn-bearing Si-poor phase. The particles also contained an FeTi-oxide phase (small amounts of Mg, Al, Mn and Si may be present), which were identified by X-ray diffraction analyses as an M3O5-phase. Chemical analyses of the dry granulated slag indicated Ti2O3 contents of less than 5%.

**Risks identified for implementing dry granulation technology**

The following areas were identified as areas of concern for the utilization of dry granulation technology:

- High levels of oxidation obtained for granulation in air as indicated by the low levels of Ti2O3 present, as well as rutile being the major phase present.
- The majority of particles being porous or hollow, resulting in a low bulk density for the product. This low density could result in poor performance in the subsequent chlorination process. Utilization of such a product could have the effect of increased blowover in the fluidized bed reactor.

Based on this, it is believed that dry granulation technology is probably not suitable for the granulation of titania slag.

**Conclusions**

Wet granulation of titania slag has the potential of successfully replacing the conventional block route for the treatment of titania slag. This has been demonstrated by a number of experimental trials carried out at Exxaro’s pilot plant facilities. The major advantages of wet granulation over the conventional block route are as follows:

- Wet granulation will provide a superior product mix. A 92/8 CP to SP ratio is estimated compared to the projected 85/15 mix for the block route slag.
- Wet granulation is a less complex process as the liquid slag is immediately transformed into granules which are more easily handled and processed than the large 20 ton blocks of the conventional process.
- It is also believed that wet granulation provides a safer processing option than that of the block route.

The milling and screening of wet granulated products is an area that can be further optimized.

Dry granulation of titania slag does not appear feasible after the limited test work carried out. The main concerns identified thus far are the oxidation of the slag, as well as the decrease in density of the granulated product.

**Acknowledgements**

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**References**


