Rhodax® interparticle crusher maximizes chloride slag production with a minimum generation of fines

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One of the key products produced by the mineral sands industry is the titanium dioxide slag, a process that requires grinding of a coarse product down to a valuable saleable product. Traditional methods have included the vertical roller mill in tandem with dynamic air classifiers and, alternatively, two-stage grinding and crushing through an AG mill in closed circuit with a dynamic classifier and secondary gyradisc crushers.

The products produced, commonly known as chloride and sulphate slag, are differentiated by the particle size distribution of the final product. The more valuable chloride slag must, by specification, be a product sized in the range between 850 and 100 microns—the more fines generated in the grinding process, the less higher valuable final chloride slag is produced.

This paper will explore a technology that is new to both the mineral sands and to other mineral processing industries. Inter particle comminution, or IPC as it is known, has been applied in the cement industry to improve the performance of clinker grinding mills. The principle is to create a process of material on material comminution under high pressure that fractures the material along the grain boundaries rather than breaking it smaller than a gap setting in the crushing.

The process is now looked at for the TiO₂ slag producers because of the potential benefits of energy savings and with a minimal generation of minus 100-micron fines.

Discussions will revolve around the design and functionality of the Rhodax® both from a process and maintenance perspective, a typical test regime and results on slag grinding. The development of the flowsheet necessary for the process will be examined, the ancillary equipment required and finally the scale-up from the test to an industrial plant will be investigated.

Full-scale results of an operating plant will also be given showing the benefits that can be realized.

A promising new flowsheet with fines reintroduction to the Rhodax® crusher will be presented.

**Rhodax principle**

Rhodax® is an inertial cone crusher. The bowl sub-assembly (bowl) consists of a frame supporting the bowl liner. The cone sub-assembly (cone) consists of a structure supporting a vertical shaft and the cone (head), protected by the mantle. The cone is suspended from the bowl by means of tie rods and ball joints. The bowl is supported by elastic suspensions to minimize the transmission of vibrations to the environment. No extensive foundations are required for the installation of the Rhodax. *(see Figure 1)*

The driven part of the Rhodax is the bowl while the cone sub-assembly is suspended via tie rods and allowed to deflect as a result of the applied grinding force. The mantle (cone liner) is free to rotate around the centre shaft.

The bowl describes a horizontal circular motion caused by the rotation of peripheral unbalanced masses *(Figure 2).* The masses are synchronized and create a perfectly controlled force. The controlled inertia force makes the Rhodax® insensitive to non-crushable material, unlike the direct mechanical force in conventional equipment.

Rhodax is a multi-compression bed machine. In operation, the horizontal circular motion generates a cycle in which both parts of the crushing chamber move towards and away from each other. During each cycle, the material undergoes the breaking force, followed by a separation phase when the material can move lower in the chamber until the next compression cycle *(Figure 3).*

While moving downwards by gravity through the chamber, the material is subjected to a series of 3 to 6 compression cycles. This slows down the progression of the material and a material bed is formed in the lower part of the crushing chamber, where the nominal pressure is applied.

The following three parameters can be adjusted on the Rhodax:

- the gap opening between mantle and bowl liner
- the rotation speed of the unbalanced masses
- the phasing of the unbalanced masses

The gap controls mainly the flow of material through the unit, and indirectly controls the power. The gap is controlled hydraulically by adjusting the vertical position of the mantle sub-assembly mounted on sliding sleeves. This system also allows the operator to compensate for liner wear when the machine is in operation. Finally, the crushing surfaces have steep angles at the bottom of the chamber and the large release stroke allows easy removal of large tramp pieces.

The rotation speed and the phasing of the unbalanced masses impose the breaking force, control the product size distribution and therefore the power absorbed by the
machine. The speed is adjusted for each application. When maximum pressure on the bed is required (up to 50 MPa), the Rhodax® is operated at maximum speed. Alternatively, if the process must operate at low pressure (i.e., for the production of material with a minimum of fines), the speed will be as low as possible, compatible with process stability. The phasing of the masses can also be adjusted by remote control by means of hydraulic rotating jacks to maintain the grinding force at the optimum for the process.

The combination of these two items results in cracks that are formed along the natural grain boundaries, instead of a shattering across the natural grain (Figure 4).

**Rhodax on titanium slag results**

There is a world-wide trend towards the use of the chlorination process (CP) for the production of titanium dioxide. Titanium slag is produced by a smelting process. The slag (100% < 100 μm) must then be milled to produce a 100–850 μm fraction. The minus 100 μm fraction must be as small as possible. Finer products can be treated using a most costly sulphate process (SP).
One plant equipped with one Rhodax 1000 LP (Low Pressure) is in operation in Norway. For this application (minimum of fines), the speed of rotation of the Rhodax is extremely low and the circulating load is 400 to 600% to reduce the production of the minus 100 μm fraction and increase the titanium recovery rate.

The process flow diagram is given in Figure 6.

A simplified flow chart is represented in Figure 7.

The CP quality production is approximately 70–80% of the raw material, depending on the fine quantity (<100 μm) in the raw product. The classic solution with conventional crusher offers 60–65% recovery. The CP slag flow is about 30 t/h for 40 t/h of raw material.

The main characteristics of the raw material are:

- Bond work index = 6.8 kWh/ton @ 400 μm
- Abrasiveness YGP = 140 mg/kg.

The titanium oxide raw material has been tested in fcb.ciment laboratories on a Rhodax 300 test rig. The results obtained on the test rig help to design the industrial plant. The fcb.ciment test rig replicates the industrial conditions and produces grain size equivalent to the industrial Rhodax (see Figure 8). The capacity scaling-up factor between the pilot machine (Rhodax® 300) and the industrial machine (Rhodax® 1000) is about 20.

It is worth noting that the Rhodax produces a very small amount of fines, with 200 t/h of feeding material (0–20 mm, D50=10 mm virtually no particles finer than 100 μm), the crushed material is a 0–15 mm D50=2.8 mm with only 2% finer than 100 μm (see Figure 9). This does not change with product quality changes, thanks to adjusting parameters of the Rhodax (opening gap, rotation speed, phasing adjustment).
The future process

The Tinfos flowsheet was made by screening specialists and the bed interparticle crushing knowledge was poor at that stage. The Rhodax was used to apply the minimum force onto the material but we then discovered that it was possible to reduce even more the production of fines and increase the yield in producing some specific grain size fractions.

Regarding specifically at the ilmenite slag problem, the production of $-850 \mu m +106 \mu m$ versus $-106 \mu m$. In other words, we need to increase the grinding slope of the final product ($-850 \mu m$), as shown in Figure 10.

To increase the grinding slope, one must look at what the in-bed compressive theory says. In this theory, the compactness (bulk density/S.G.) of the bed of material increases with the pressure applied on it. The compactness evolution is due to the grain size modifications. For given material characteristics, this law is as shown in Figure 11.

The PSD slope is linked to these trends. If the trend shifts to the left (e.g. moist material), the slope will be less. The way to increase the slope is to shift the trend to the right side. One of the easiest ways is to increase the initial compactness (e.g. get more fines in the interparticle crusher feed).
RHODAX® INTERPARTICLE CRUSHER MAXIMIZES CHLORIDE SLAG PRODUCTION

Figure 9. PSD of the inlet and outlet products

Figure 10. Required slope increase of final product to get a 15% yield

Figure 11. Compactness evolution with pressure for different material characteristics
The best way to get more fines in the crusher feed is not to increase fines contents from the previous crushing stages. We can indeed reintroduce a certain portion of the fines produced by the Rhodax itself. This new crusher feed will lead to a new steady state where the fines generation is less and coarse fraction production increases (see process Figure 12).

**Conclusion**

The Rhodax offers the unique possibility to perfectly controlling the grinding force, and continuously to adapt it to the variations of the characteristics of the titanium slag because of the several adjusting parameters of the Rhodax:

- the gap opening between mantle and bowl liner
- the rotation speed of the unbalanced masses
- the phasing of the unbalanced masses.

Fines production (<100 μm) is drastically reduced in the Rhodax crusher: only 2% of fines are produced against 5–10% in the concurrent solutions (cone crusher, hammer crusher, roller crusher...). Whatever the slag quality is, the Rhodax parameters are adjusted to limit fines production and to enhance the titanium oxide recovery. Rhodax increases by 20% the recovery against classic crushing systems.

Latest comprehensive developments in interparticle crushing and grinding show that reintroduction of fines in the process should even lead to better and optimized yields. FCB has successfully installed two HOROMILL® mills working in such process in calcium carbonate industry.

**References**

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