RHODAX®
INERTIAL CONE CRUSHER

A NEW CONCEPT IN CRUSHING/GRINDING TECHNOLOGY

MASTERING TECHNOLOGY AND PROCESS

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1 – LIMITATIONS OF CONVENTIONAL TECHNOLOGY

In general, the crushing forces in a cone crusher are applied by means of two crushing surfaces, which are moving in a rapidly constrained path.

The bowl supports the stationary surface (bowl liner). The moving surface (mantle) protecting the central cone (head) nutates inside the bowl around a pivot point. The nutating action is achieved through an eccentric assembly mounted at the base of the head.

Particle size distribution of the material at the discharge depends on the minimum distance between the liners at the discharge, known as the closed-side setting (CSS). The CSS must be adjusted regularly to compensate for liner wear in order to control the product quality.

There are some limitations with cone crushers :

- There is a limit to the size of material that can be produced in conventional cone crushers. Typically, this limit is about 10 mm. When producing finer sizes, the structural rigidity and fixed motion of these machines can generate very high forces causing significant energy losses due to agglomeration of particles in the crushing chamber and to elastic deformation of the crusher.

  This situation gives rise to excessive stress levels and reduces the effective life of crusher components. Furthermore, it is not practically possible to design machines with sufficient mechanical strength to achieve reduction ratios higher than 7.

- Large pieces of non-crushable material (i.e. tramp iron) going through the crushing chamber are detrimental to the operation and the reliability of cone crushers. The occurrence of excessively hard rock may give rise to the same problems (i.e. critical size pebbles).

  As a result, cone crushers are equipped with a protection system to allow the bowl or the head to yield if tramp material enters the crushing chamber. However, such system is never entirely reliable.

In the late 80's, considerable attention has been directed to inter-particle comminution, when the breakage forces are transmitted into a bed of particles so that the particles break against one another, rather than as a result of being caught between two crushing surfaces.

This technology has been widely accepted, mainly in the cement industry for grinding clinker and slag, with the high pressure grinding rolls and the vertical roller mills.

However, in the mineral industry, materials are usually very abrasive and operating costs are prohibitive due to significant wear ratios.

2 – RHODAX® PRINCIPLE

The concept of Rhodax® is the culmination of a comprehensive research and development programme started in the early 90's.

The 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 to the bowl by means of tie rods and ball joints. The bowl is supported by elastic suspensions to minimise the transmission of vibrations to the environment. No extensive foundations are required for the installation of the Rhodax®.

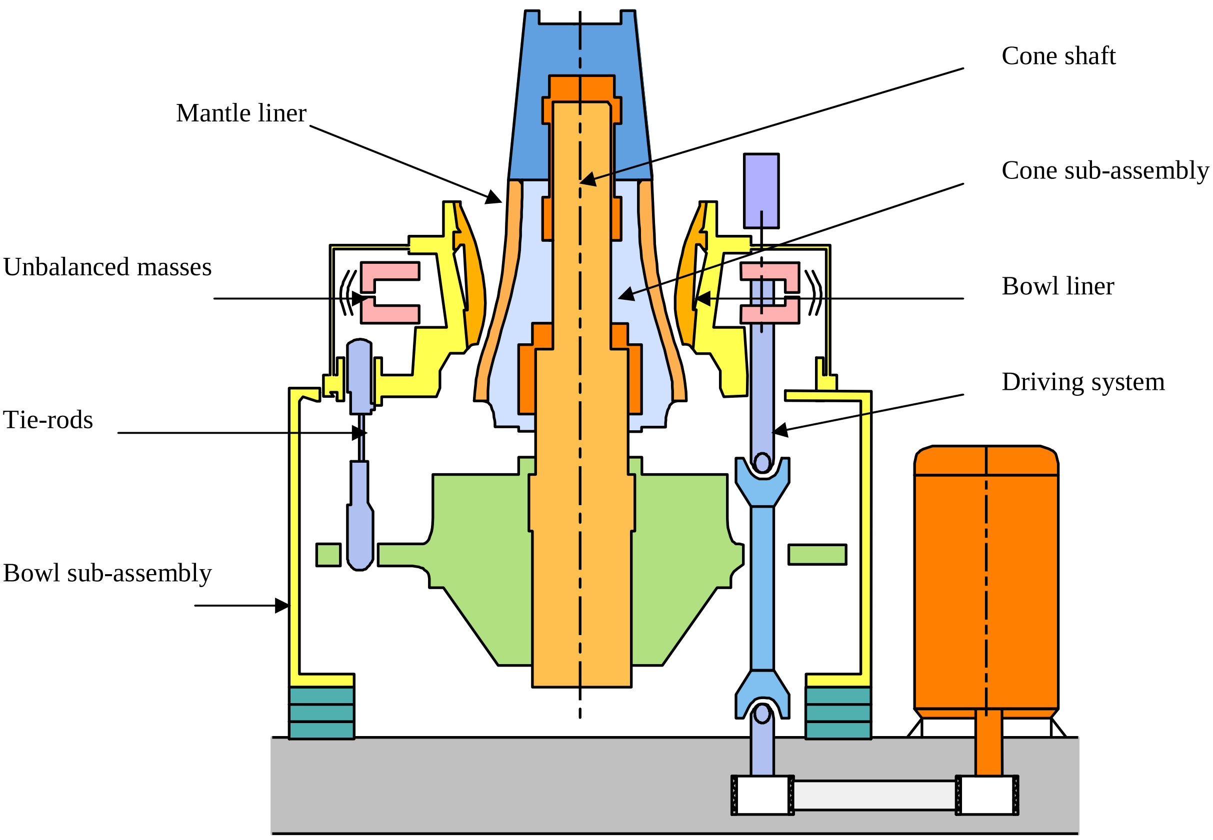


Figure 1 : Sectional View of RHODAX®

The moving part in a cone crusher is the mantle, which is driven by an eccentric assembly. The maximum movement of the mantle, known as stroke, is fixed and the crushing force uncontrolled.
In contrast, the driven part of the Rhodax® is the bowl while the cone subassembly 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.

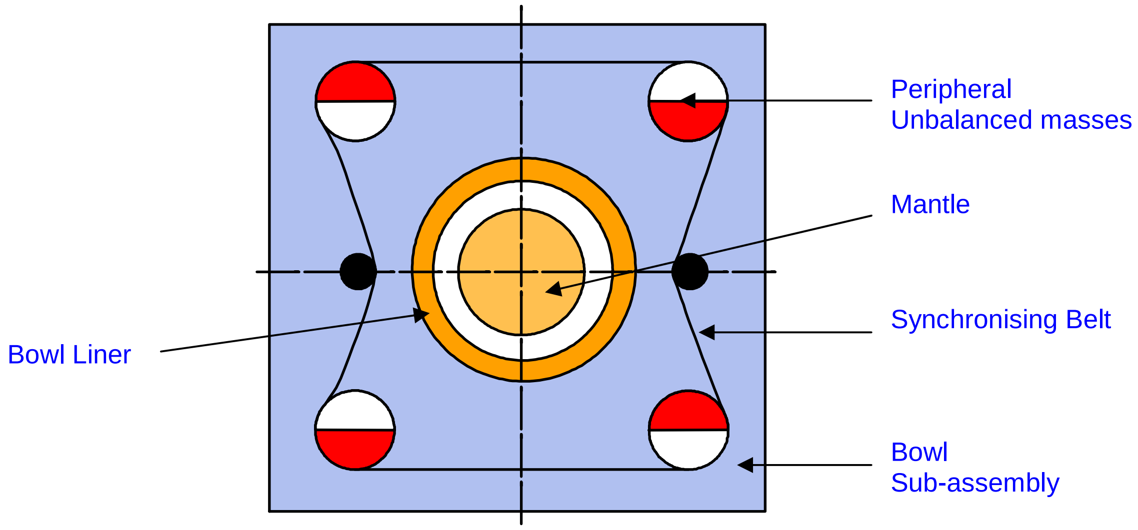


Figure 2 : Top View of RHODAX®

The bowl describes a horizontal circular motion caused by the rotation of peripheral unbalanced masses (see figures 2 and 3). The masses are synchronised 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.

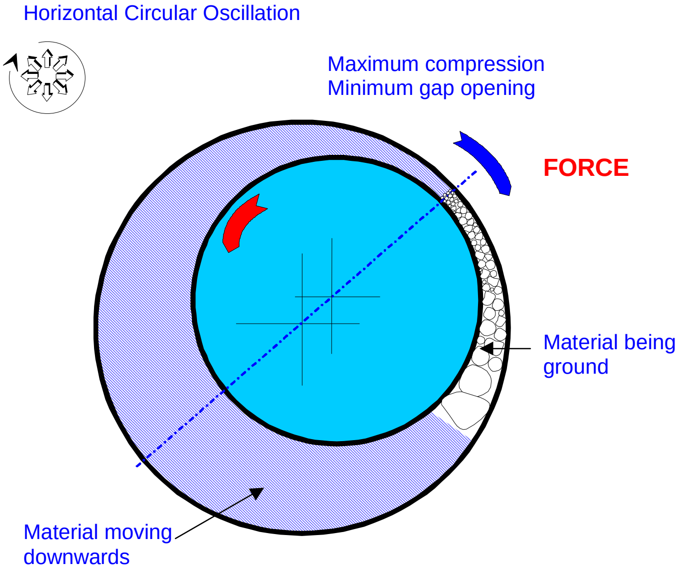


Figure 3 : RHODAX® Principle

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.

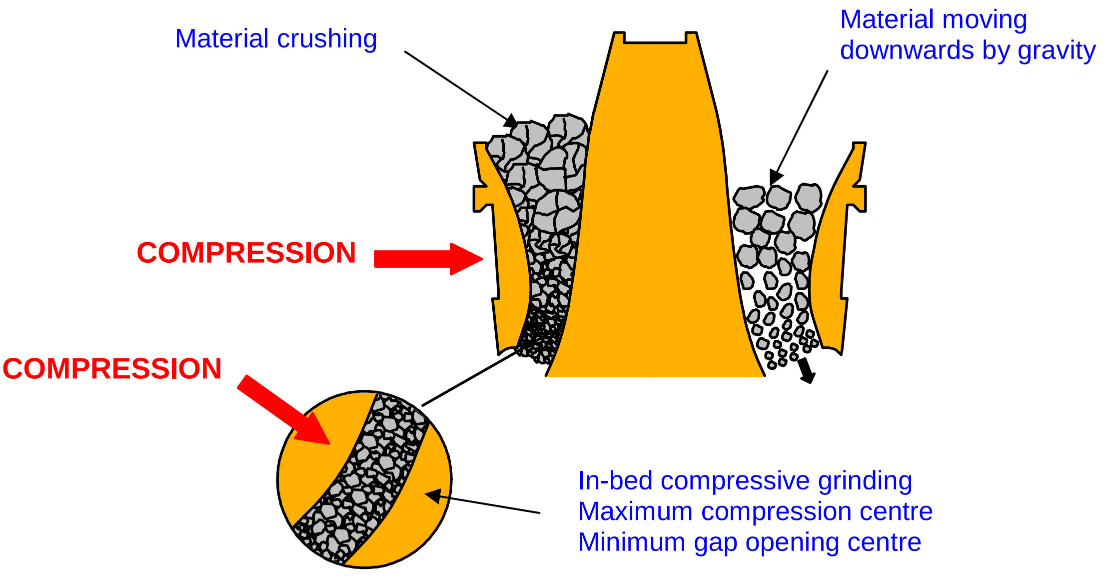


Figure 4 : RHODAX® principle

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 Rhodax® is a multi-compression material bed machine.

The following three parameters can be changed on the Rhodax® :

- the gap opening between mantle and bowl liner
- the speed of rotation 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 allows also 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 speed of rotation 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 rotational 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 (nominal speed).

Alternatively, if the process dictates to 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. With the exception of Rhodax® 300 HP and Rhodax® 450 HP) on which the grinding force is controlled by a frequency variator on the motor.

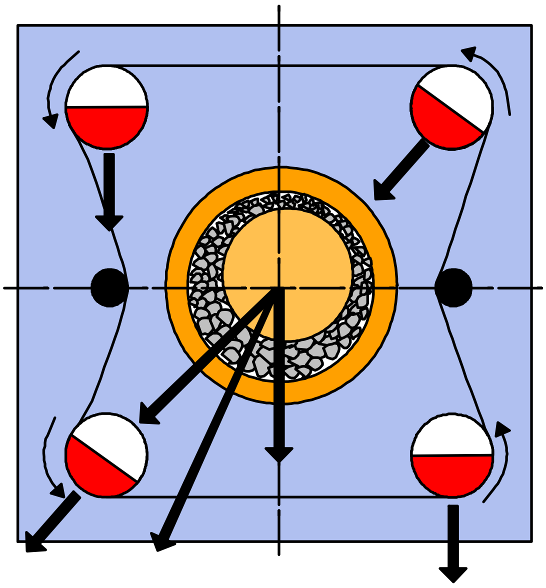


Figure 5 : Intermediate Phasing Position of Unbalanced Masses

Various tests were conducted with limestone in open circuit at different speeds and gap openings. The results summarised in figure 6 show that the reduction ratio is essentially independent of the gap opening and is a strong function of the rotational speed of the masses.

This confirmed that breakage is taking place by inter-particle crushing in the compressed bed and hence is only a function of the pressure applied on the bed.

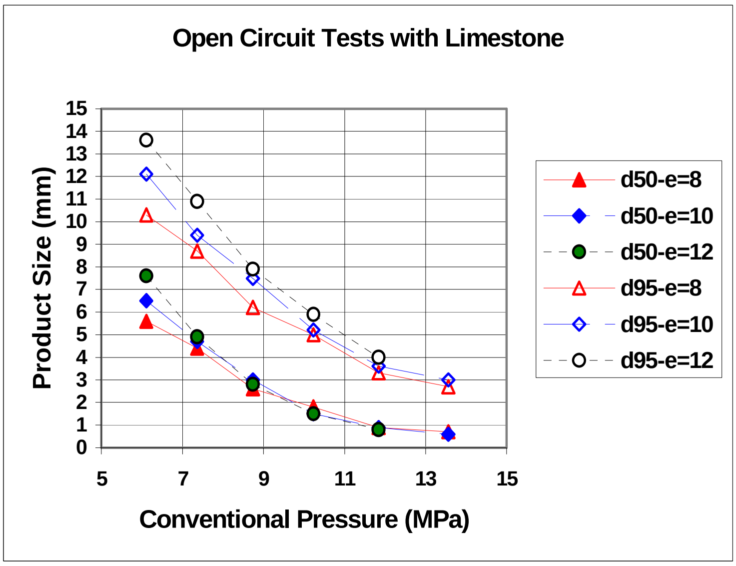


Figure 6 : Tests in Open Circuit

This important feature makes it possible to use the Rhodax® for the production of very fine material, without limitation, unlike the conventional crushers where the gap opening (CSS) has direct influence on the product size distribution, and cannot be practically reduced below 5 to 10 mm.

3 – MAIN FEATURES

➢ ***Full control of the process***

The three parameters (gap opening, speed and phasing of the unbalanced masses) enable the operator to completely control the process :

→ control of the flow (and power) mainly by the gap

→ control of particle size distribution (and power) mainly by the phasing and speed of rotation of the masses. The rotational speed also influences the flow to a lesser degree.

By manipulation of the above parameters, the operator can control accurately the size distribution of the final product.

➢ ***Extended liner life***

In the Rhodax grinding chamber a pure compression force is applied on the bed of material. Due to the absence of direct impact on the liners, a much harder liner can be tolerated than in conventional crushing equipment. At the moment, the Rhodax is supplied with a mantle liner made of 20% high chromium forged steel and a bowl liner made of martensitic steel, resulting in a substantial improved wear life.

Another positive factor influencing the wear life, is the fact that in an interparticle comminution process, there is far less interaction between the particles and the wear surface.

➢ ***Energy saving***

Inter-particle comminution is more energy efficient than conventional technologies. This is also true with the Rhodax® in the area of fine crushing and coarse grinding.

To compare the Rhodax® with the ball mill in the dry process (the reference), the following ratio can be used :

τ = specific energy of the ball mill/specific energy of the Rhodax®

The higher the ratio, the higher the energy saving (i.e. $\tau = 2$ means that the Rhodax® is 50% more efficient than the ball mill in the dry process for the same purpose).

Although it is not easy to compare energy consumption for the size ranges considered (a few millimetres), all the tests have shown energy savings between 10 and 35% (see graph below).

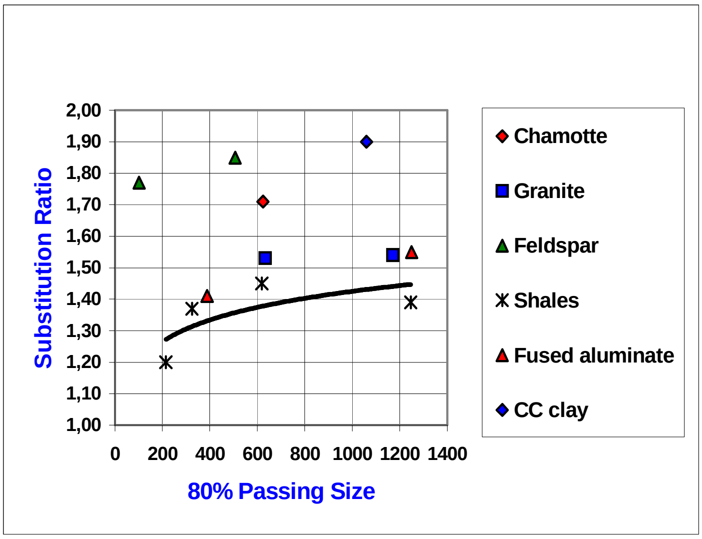


Figure 7 :
Energy Savings with Rhodax®

4 – PROCESS ADVANTAGES

4.1. High Reduction Ratio

The Rhodax® is well known for its high reduction ratio of up to 100:1 depending on the application. The high reduction ratio is achieved through the unique designed crushing chamber profile. Every consecutive pass through the chamber starts as a compression comminution process and ends as an interparticle grinding process.

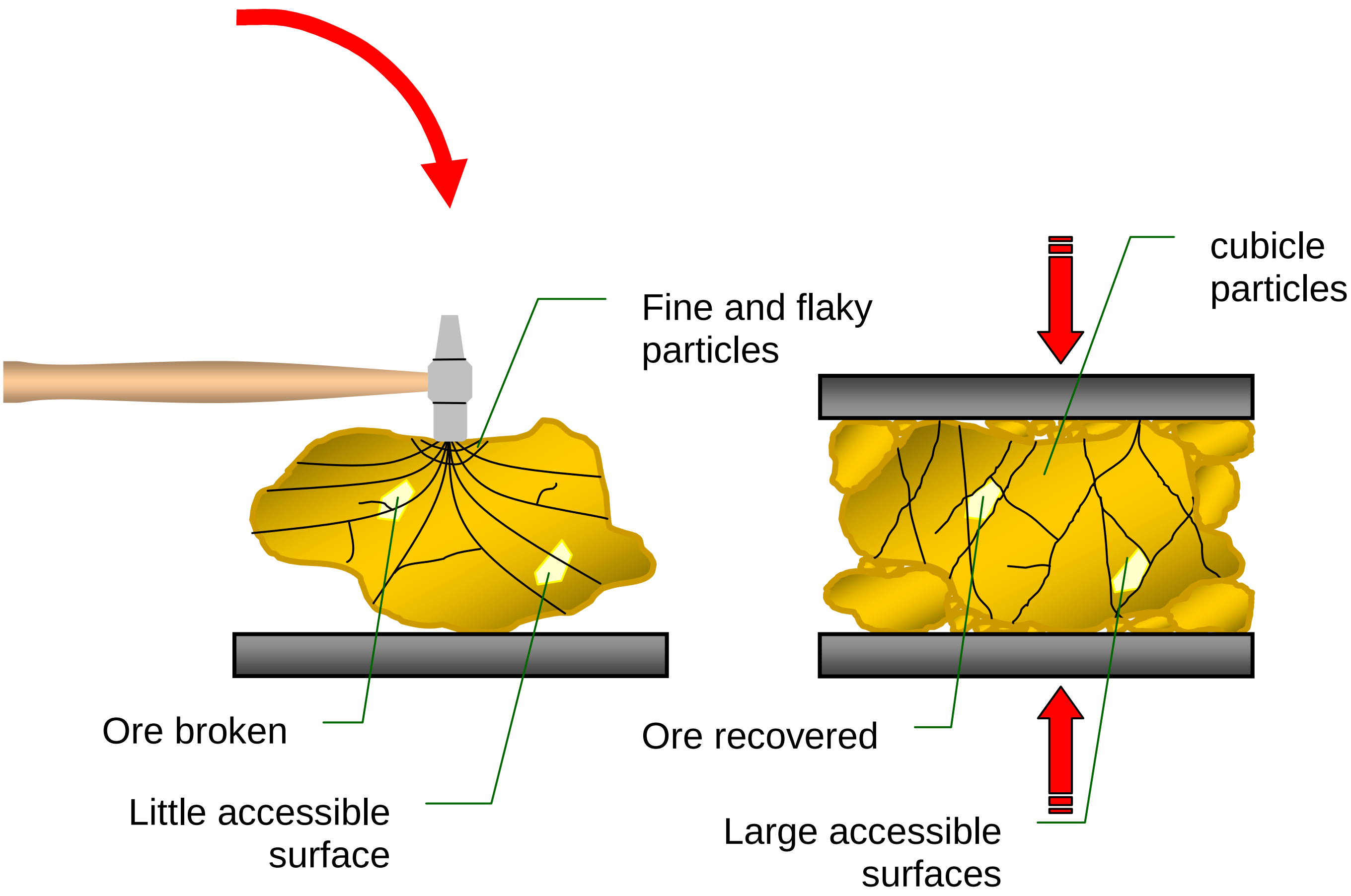
The nominal gap setting has hardly got any influence o the actual product size, which proves the interparticle effect and typically a 40mm gap setting can produce a 1mm product.

4.2. Liberation Effect

The following two aspects are the main contributing effects to the liberation of precious minerals:

- → The grinding force applied to the product is controllable by means of speed of rotation, resultant unbalance mass and the gap setting.
- → As a result of the interparticle bed, compression force is applied from all directions.

The combination of these two items result in cracks that are formed along the natural grain boundaries, instead of a shattering accross the natural grain, as can be seen in the following two illustrations.



5 – APPLICATIONS WITH RHODAX®

The Rhodax® has been developed to obtain products that could not easily be obtained with existing technology, especially when treating hard and abrasive materials. By design, the Rhodax® covers both crushers and primary mills applications (i.e. tertiary and quaternary crushers or rod mills). The Rhodax® achieves its best yield when running in closed circuit with a 1 mm aperture screen.

5.1. Industrial Minerals

To start the development of the Rhodax®, Fives FCB decided to focus on the industrial minerals industry, mainly because most products are processed dry. A typical application is the milling of fired clay (chamotte) for use in the ceramic industry (sanitary ware).

Two machines were commissioned in 1996. They are working in closed circuit with a screen. Both machines were installed to replace two or three stages of crushing/milling. Results are summarised in Table 1.

	RHODAX® 300 HP	RHODAX® 450 HP
FEED SIZE	100% < 50 mm	100% < 50 mm
FINAL PRODUCT	100% < 800 µm	100% < 500 µm
THROUGHPUT	2 t/h	4 t/h
NET POWER DRAW	15 kW	35 kW
ENERGY SAVING	Approx. 20%	Approx. 25%
POLLUTION by WEAR	80 g/t	80 g/t

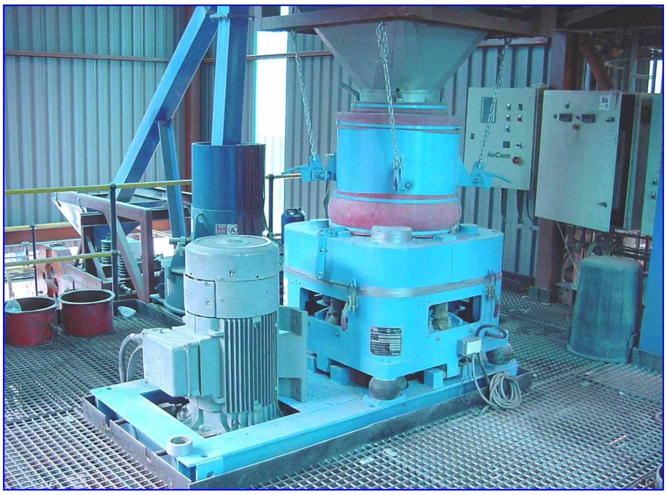
TABLE 1 : Performances with Fired Clay

Another advantage of the Rhodax® is the low steel contamination of the final product (three to four times lower). This reduces considerably the need for large magnetic separation equipment and avoids staining of the final product (limestone, calcined clay).

**RHODAX® 300 HP
MILLING OF CHAMOTTE**

5.2. Mining Industry

Fives FCB has decided to approach this important market by installing a pilot unit in South Africa (Rhodax® 300 HP). Various ores can be tested in closed circuit with a screen.



RHODAX® 300 HP PILOT UNIT

Specific applications are being investigated with the Rhodax® :

- reduction of number of crushing/milling stages in a milling circuit
- crushing of critical size pebbles for autogenous milling circuits
- crushing of gold bearing waste rock, with the potential for improved recovery with coarser product size distributions. This effect of better liberation is due to the formation of micro-cracks along the grain boundaries.

5.2.1 Diamond Division

Tests were also conducted with kimberlite ore. Consequently, a Rhodax® 600 HP (132 kW) has been installed in a diamond pilot plant to test the effect of inter particle crushing on the liberation of diamonds (differential breakage). The plant is operated in the wet process.

RHODAX® 600 HP KIMBERLITE ORE

5.2.2. Platinum Division

A recent installation of a Rhodax 1000HP in the Platinum Industry was successfully commissioned. Selected mainly for its high reduction ratio, the Rhodax is used to crush the platinum matte. The converted matte is passed through another Rhodax 450HP before it enters the ball mill in the refinery.

	RHODAX® 1000 HP
FEED SIZE	100% < 110 mm
FINAL PRODUCT	100% < 2,4 mm
THROUGHPUT	70 t/h
NET POWER DRAW	290 kW

5.3. Aluminium Industry

The Rhodax® is used in different applications for the Aluminium Industry :

- for coke crushing and grinding in the anode plant, with the Rhodax® 450 HP (55 kW)
- for carbon scraps crushing
- for carbon lining paste crushing.

5.4. Steel slags

Slags are produced in many pyro-metallurgical operations. Steel slags are produced during steel manufacturing process. The slag is a hard, dense material and contain significant amounts of tramp iron. The relative insensitivity of the Rhodax® to tramp iron is a distinctive advantage for this application.

The Rhodax® 1000 HP (440 kW) was commissioned in January 1997. The results of the plant with a Rhodax® in closed circuit with a screen are summarised below :

FEED SIZE	100% < 150 mm
FINAL PRODUCT	100% < 20 mm
FREE IRON	+/- 4% (up to 80 mm)
THROUGHPUT	130 t/h
NET POWER DRAW	300 kW

Table 2 : Performances with Steel Slag

Magnets were installed on the fresh feed belt and on the circulating load belt.

The first magnet cannot remove all tramp iron efficiently from the fresh feed. Therefore, one must allow for some tramp iron through the crusher (1 to 2%). It is liberated by crushing and removed by the second magnet installed on the circulating load.

After three years of operation, the same company ordered a second Rhodax® 1000 HP for the production of aggregates from blast furnace slag. This unit was commissioned in September 2001. The results are summarised below (open circuit) :

FEED SIZE	20 – 150 mm
FINAL PRODUCT	60% < 20 mm
THROUGHPUT	170 t/h
POWER DRAW	200 kW

Table 3 : Performances with Blast Furnace Slag

RHODAX® 1000 HP
BLAST FURNACE SLAG

5.5. Titanium Slag

There is a world-wide trend towards the use of the chlorination process for the production of titanium dioxide. Titanium slag is produced by a smelting process. The slag (100% < 100 mm) must then be milled to produce a (106-850) µm fraction. The minus 106 µm fraction must be as small as possible.

The Rhodax® offers the unique possibility to perfectly control the grinding force, and to continuously adapt it to the variations of the characteristics of the slag.

One plant equipped with one Rhodax® 1000 LP 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 600% to reduce the production of the minus 106 µm fraction and increase the recovery rate.

RHODAX® 1000 LP
TITANIUM SLAG

5.6. Aggregates Industry

In the last two years, several applications have been investigated in the production of aggregates. Two Rhodax® 1000 LP have been commissioned in France and in Norway, and the results are promising. Main objectives are as follows :

- reduction of operating costs (wear costs)
- improved cubicity of all size fractions
- reduction of crushing stages
- reduction of amount of fines in 0 - 4 mm fraction.

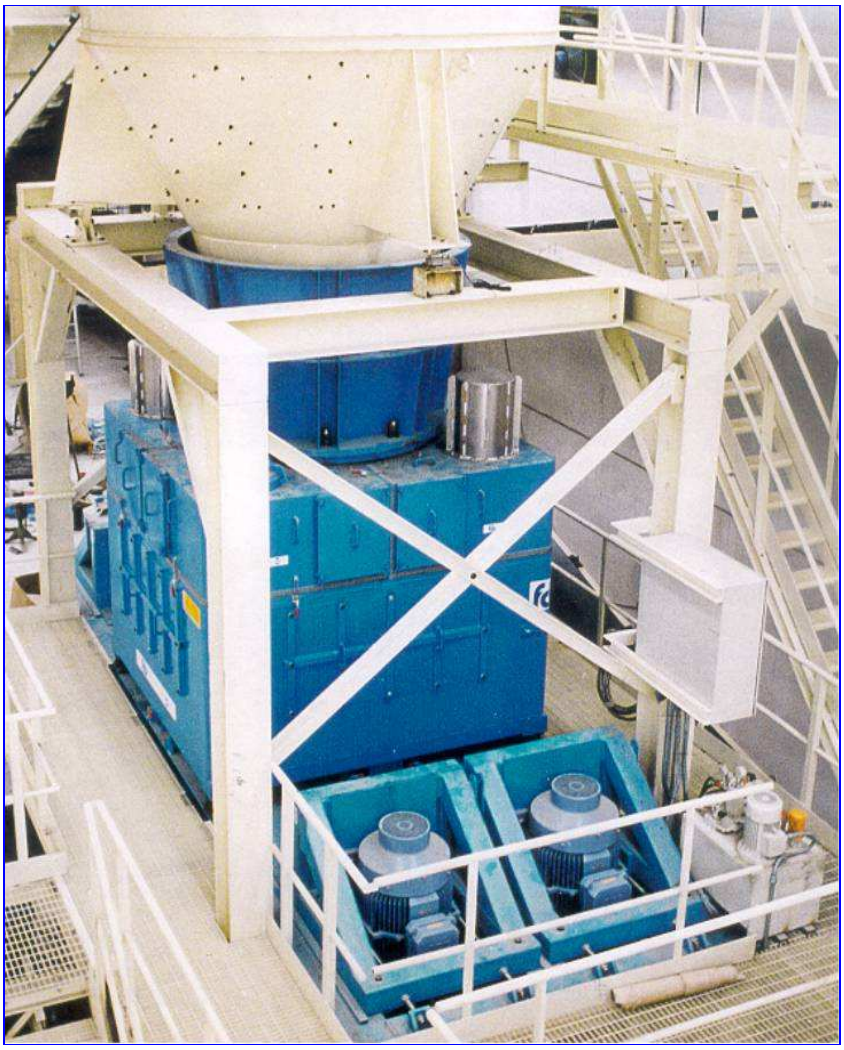
6 – EQUIPMENT RANGE

	Cone Diameter (mm)	Maximum Feed Size (mm)	Power (kW)	Capacity (*) (tph)	Nominal Gap (mm)
Rhodax® 300 HP	300	30	30	10	12
Rhodax® 450 HP	450	60	55	30	18
Rhodax® 600 HP	600	90	132	60	24
Rhodax® 1000 LP	1000	150	200	180	40
Rhodax® 1000 HP/MP	1000	150	400/320	240	40

(*) Capacities given in this table are flow rates through the Rhodax® when crushing dry, clean material with bulk density of 1600 kg/m3 in closed circuit. Factors which may affect capacity include hardness, moisture content, size distribution of the feed material, final product size.

CRUSHING AND GRINDING

RHODAX® (World-wide Patents)



Fives FCB can also supply the following equipment:

- HOROMILL® horizontal Roller Mills
- Ball Mills and Ball Race Mills
- Autogenous & Semi-Autogenous Mills
- TSV™ Air Dynamic Classifiers
- Cement Kilns, cyclone preheaters and precalciners
- Cement Plants on Turnkey Basis