Rhodax green anode plants - 10 years of success

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Abstract

Over the last 10 years, Fives Green Anode Plant technology has been based on the Rhodax process. The Rhodax Crusher key characteristics are linked to in-bed compressive grinding which allows a selective crushing for higher green and baked anode density. The Rhodax process delivers a dry mix recipe with a high grain/sand (G/S) ratio to minimize thermal shocks of anodes. The simplification of the process is significant with respect to conventional processes and makes it a cost effective solution in terms of CAPEX and OPEX. With today seven plants under operation serving the production of more than 2.6 Mtpy of primary aluminum, this process has demonstrated its ability to produce high quality baked anodes with strong benefits on the energy consumption, thermal shocks and carbon consumption in pots. This ultimate process solution is proposed as a global package technology on a turnkey basis all over the world: Gulf, India, China, Russia, etc. As EPC contractor, Fives offers pioneering and cost effective solution for Green Anode Plant which combines high performance and sustainable development.

Keywords: Rhodax; Green anode plant; thermal shock; grain/sand ratio; Fives.

1. Introduction

With more than 200 years of industrial history, close to 8000 employees and 100 subsidiaries worldwide, **Fives** designs and supplies machines, process equipment and production lines for the world's biggest industrial players, in aerospace, automotive and manufacturing industries, cement, energy, logistics, steel, glass and of course in the **aluminum sectors**.

In the aluminum sector, Fives covers several fields of expertise:

- **Carbon** with the turnkey supply of Green anode plants (GAP), Crushing recycling units, Firing control systems, Fume treatment centers (FTC), Furnace tending assemblies (FTA), Anode rodding shops or Liquid pitch terminals ,
- **Reduction** with Gas treatment centers (GTC), Pot tending machines (PTM), Cathode transport cranes, Anode changing cranes, Anode beam raising frames, various pot equipment, Alumina transport systems and Bath treatment plants
- **Casthouse** with a thermal and turnkey expertise

With more than 50 references, the carbon sector flagship is the green anode plant. It is typically proposed with extended battery limits including, crushing & recycling unit, raw material storage, paste plant, forming, cooling tunnel and all associated utilities. For the past 10 years, Fives green anode plant technology has been based on the RHODAX® process.

2. RHODAX® history

The Rhodax process is the results of two parallel developments started in early 90's.
On one side, Aluminium Pechiney (AP now **Rio Tinto**) was validating a new concept of high Grain/Sand ratio (ratio [+300 µm] / [30-300 µm] far above 4 compared to usually not more than 2) which has been proven to be a key factor to minimize anode thermal shock problems [1].

On the other side, Solios Carbone (now **Fives**) had developed a new crusher for the mineral processing applications, the Rhodax, which key characteristics are linked to the in-bed compressive grinding principle:

- The outlet particle size distribution (PSD) is almost insensitive to the inlet PSD (graph in the upper part of Figure 1).
- Selective crushing takes place by preserving the hard and coarse feed particles (mostly baked scraps) while crushing preferably the weaker, porous or pre-cracked particles (mostly raw coke). In carbon anodes application, it prevents also from producing fine particles from the baked scraps.

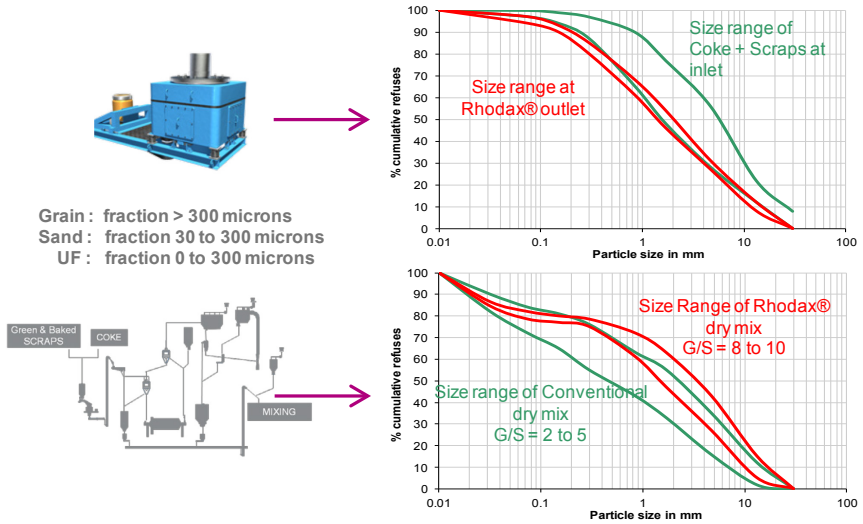

Figure 1. RHODAX® process – particle size distribution.

In early 2000's, Fives and AP joined their R&D efforts and co-patented the SCAP-RHODAX process (Figure 2) which consisted mainly in:

- Mixing all solids (raw coke, green and baked scraps) to crush them all together at the same time without any detrimental impact on anode quality (like for instance, impact of baked scraps sodium dissemination in the binder matrix)
- Producing a recipe based on two size fractions only leading to a drastic flow sheet simplification

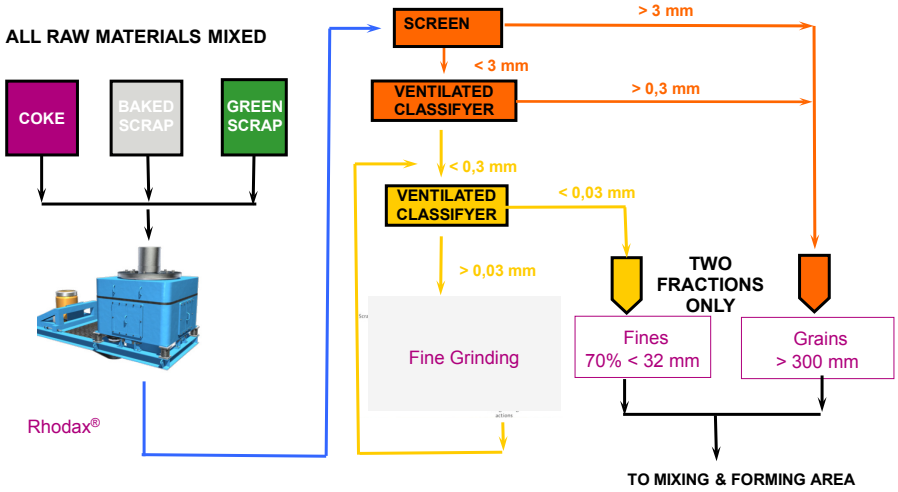

Figure 2. RHODAX® key process features.

A full scale 35 t/h industrial prototype was successfully tested along 2002-2004 at Aluminium Dunkerque in France [2]. Design and operation concepts were validated and the achieved baked anode quality was found at least as good as with conventional process [3].

The Rhodax process "naturally" delivers a dry mix recipe with a high G/S ratio (graph in the lower part of Figure 1). It collects the sand fraction produced from the raw coke by the Rhodax crusher in order to produce the final fines fraction and finally leads to a higher bulk density of the dry mix recipe.

3. RHODAX® process flow sheet

Figure 3 shows a typical process flow sheet of the dry mix preparation line. It consists of:

- one variable gap and speed Rhodax crusher fed with 0-80 mm dry mix (raw coke and scraps together),
- two variable speed TSV dynamic classifiers: the first one to select the sand fraction (S), the second one to collect the fine fraction,
- one variable speed and fully air swept ball mill.

The dry aggregate final product consists of two fractions only – Grains from 0.3 to 30 mm and Fines from 0 to 80 µm (⇔ 6 000 BLAINE) with a G/S ratio (+300 µm / [30-300 µm]) above 5. The fractions are stored in two buffer silos equipped with loss-in-weight dosimeters.

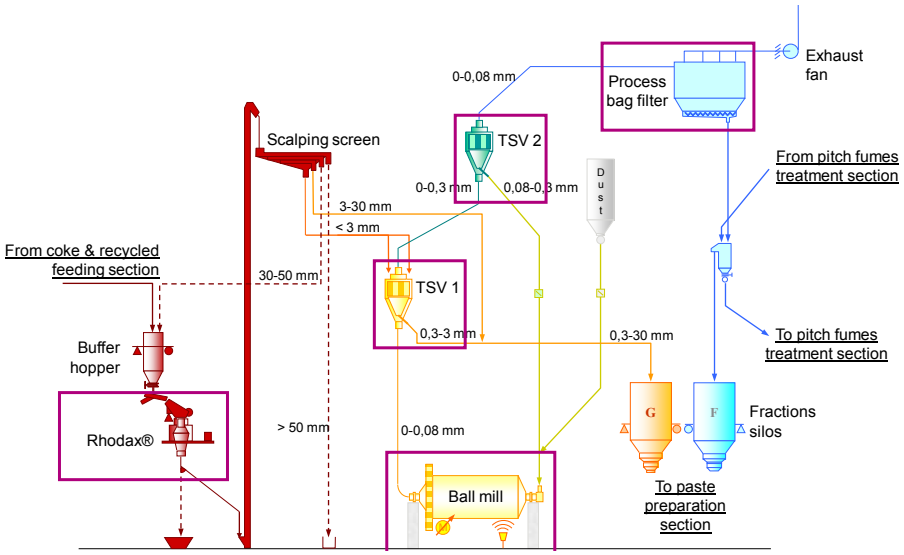

Figure 3. RHODAX® dry mix preparation line.

This circuit operates smoothly and continuously thanks to several regulatory control loops managing the throughput level and the grains/fines silo balance. There is no more ball mill stop and go even at low throughput. For instance, at Qatalum [4], the circuit is flexible enough to operate continuously at 30 t/h or 60 t/h and with no significant impact on dry mix size distribution as shown in Figure 4.

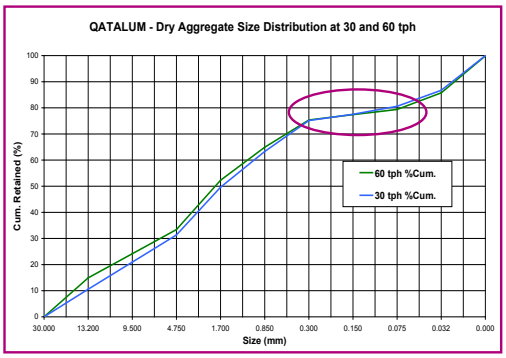

Figure 4. QATALUM Dry mix recipe at 60 and 30 t/h.

The simplification of the process shown in Figure 5 is very significant with 40 % less items compared to conventional process.

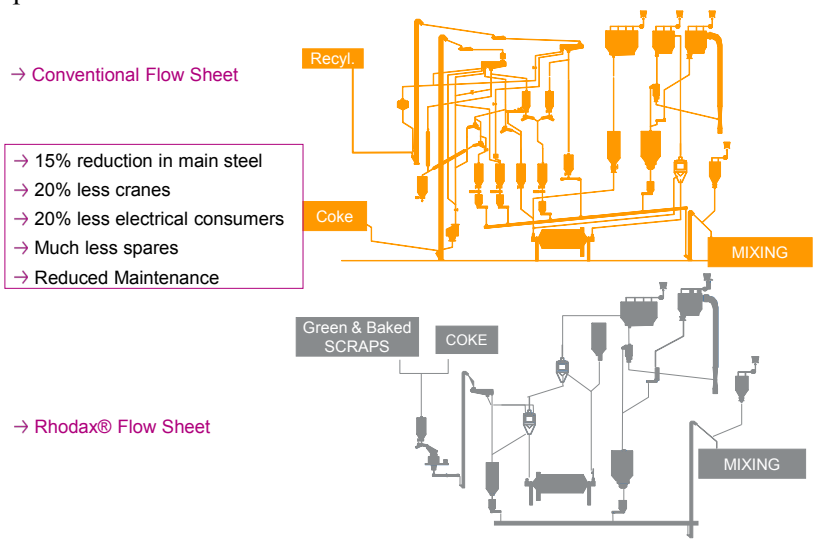

Figure 5. Comparison between conventional and RHODAX® flow sheet.

Rhodax green anode plants have been supplied with two types of mixing technology: Kneader + Eirich cooler or Intensive Mixing Cascade (IMC®) with two Eirich mixers.

4. RHODAX® green anode plant references

The first industrial application came with the 35 t/h green anode plant of ALBA Line 5 in Bahrain [5]. In operation since 2005, this first operation combines the new Rhodax and conventional kneader/cooler mixing technologies. The performance achieved confirmed those established with the pilot plant with a G/S above 7, high baked anode density, low permeability and low electrical resistivity [6].

Figure 6. ALBA Line 5 – 2005.

Upon the successes of the Rhodax process start-up at the Alba line 5, and of the IMC® Chinese references [6], the SOHAR anode plant specified by Aluminium Pechiney Technology, was the first opportunity, to combine these two breaking through technologies. The first anode was produced in March 2008 and the plant performs beyond expectations at full 36 t/h capacity [7].

Then in 2010, the first single line 60 t/h green anode plant ever, was successfully commissioned at the Qatalum smelter [4]. Designed to fulfil the anode requirements of the 585 000 tpy metal capacity smelter, this single process line is again based on the combination of both Rhodax® and IMC® technologies.

Figure 7. QATALUM – 2010.

Definitely proven technology after the success of the above 3 references, the Rhodax process was selected by several other major aluminium producers:

- In 2012, with two 40 tph green anode plants for MA'ADEN in Saudi Arabia,
- In 2014, with one 35 tph green anode plant for HINDALCO Mahan in India ,
- In 2015, with one 52 tph green anode plant for HINDALCO Aditya in India.

All together, these references represent more than **1.5 Million tonnes of anodes** installed capacity, **60 % of newly installed capacity** outside China and **2.6 Million tonnes of Aluminium**.

5. RHODAX® green anode plant performance

After 10 years of industrial references, representative results on baked anode properties have been compiled. The key baked anode properties having a direct/indirect effect on the electrolysis process

(Figure 8) like Energy consumption, Thermal Shock or Carbon consumption are analyzed and compared to a worldwide benchmark [8].

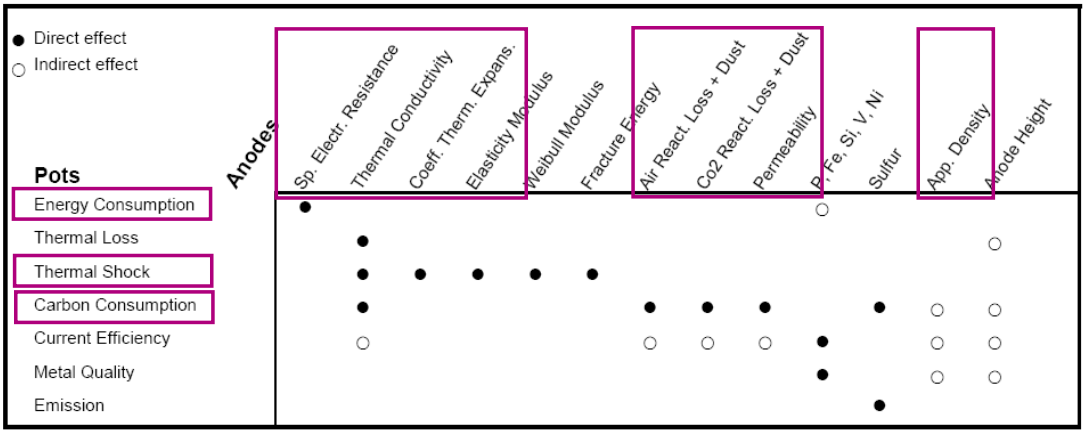

Table 1 Effects of anode properties on the electrolysis process

Figure 8. Impact of baked anode properties on pots operation [8].

For each of the baked anode properties selected, mean values from Rhodax based carbon sector were compared to the corresponding mean values for the World and two more sources from Chinese producers (A and C) [9], in which no butts was used

In Figure 9, Rhodax based baked anode density and specific electrical resistance are among the best-in-class ranging respectively from 1.58 to 1.60 g/cm3 and below 54 µẅm.

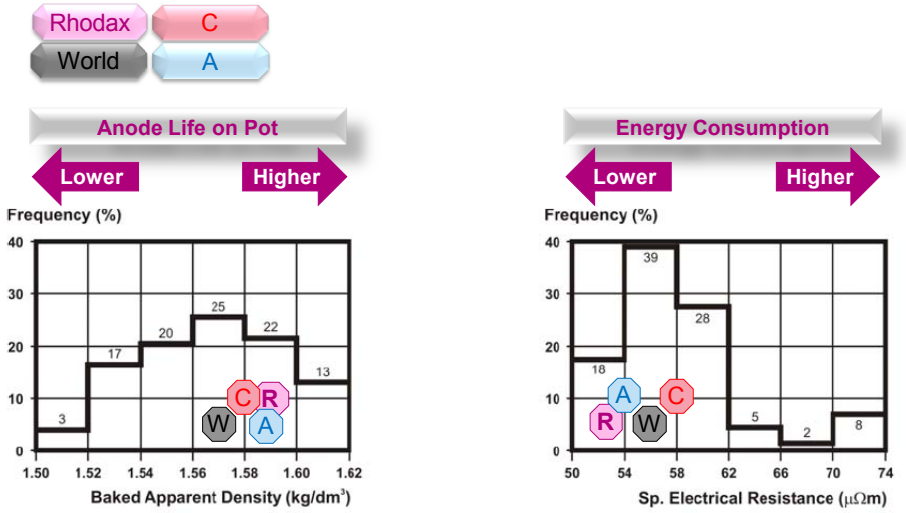

Figure 9. Baked apparent density and specific electrical resistance.

Figure 10 shows a scatter plot with Flexural strength on Y-axis and compressive Strength on X-axis. Again Rhodax® based baked anodes are in the best-in-class cluster.

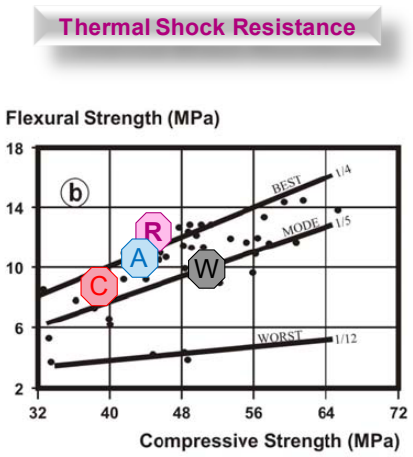

Figure 10. Compressive and flexural strengths.

In Figure 11, CO_2 and Air reactivity residues are shown. Rhodax based baked anodes show very good level with values ranging respectively from 90 to 95 % and 75 to 80 %. The high Air reactivity residues for Eastern baked anodes (A and C) seem to correspond to anode produced with raw coke only.

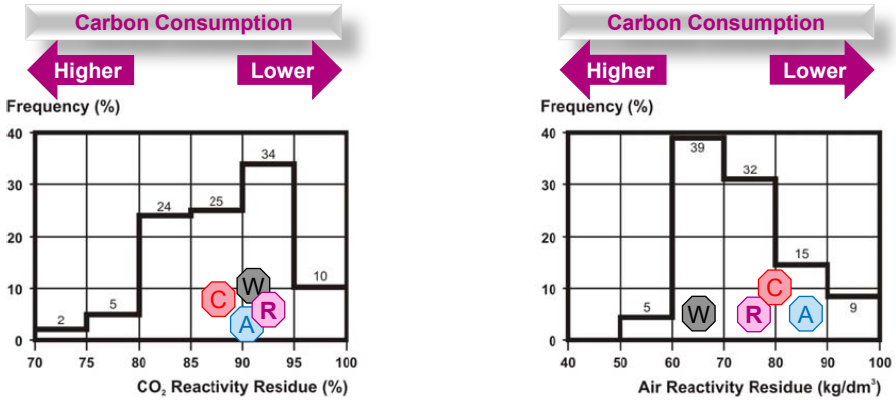

Figure 11. CO_2 and Air reactivity residues.

Finally, Figure 12 shows two more scatter plots (mean vs standard deviation), one for CO2 reactivity and the other for Air permeability for which Rhodax based anodes appear to be again in the best-in-class cluster with low values and high stability.

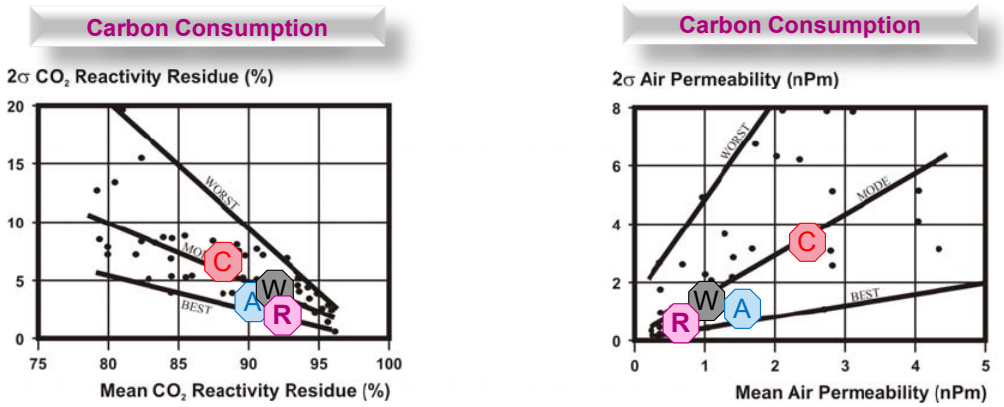

Figure 12. CO2 reactivity and permeability means vs standard deviation values.

In addition to these good baked anode properties, reduction operators report very low number of occurrences of anode problem on the pots (like dusting, TSR, …) even under severe operating conditions.

6. RHODAX® process – new challenges

Fives is committed in the development of eco-designed solutions which combine high performance and sustainable development, such as Eolios, the efficient pitch fumes treatment solution based on a combination of Dry Scrubbing and RTO [10][11], or Amelios [12][13], the sustainable plant performance tool.

The Horomill (Figure 13) is another emblematic example of Fives efforts in developing eco-designed solution: It is an energy efficient grinding technology based on the same in-bed compressive grinding principle as in roller presses, vertical mills or Rhodax crusher. This high pressure grinding mill has been marketed for more than 20 years. With applications in cement and slag processing industry, more than 50 mills are today in operation with throughput ranging from 10 to several hundred t/h.

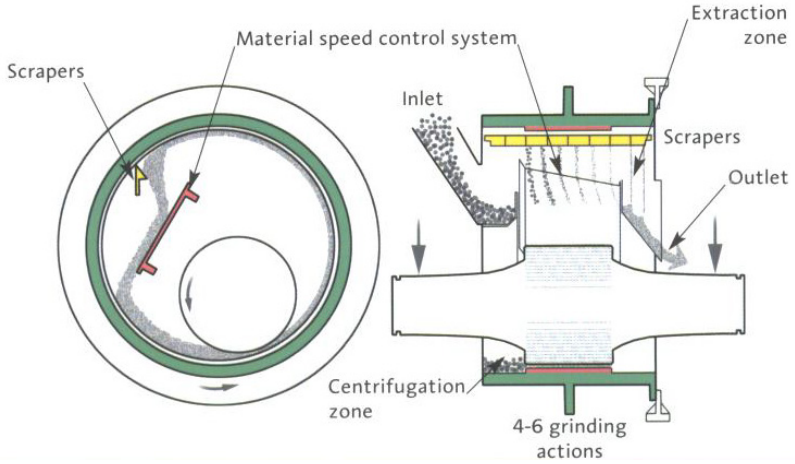

Figure 13. HOROMILL principle.

The Horomill was tested successfully at pilot scale for conventional green anode plant process in 1995 but no industrial applications were decided at that time as Horomill was a brand new piece of equipment. New pilot scale tests were conducted in 2013-2014 for Rhodax process this time. The very positive results obtained combined to 20 years of experience with Horomill led to the decision to put this solution on the market. As shown in Figure 14, the Rhodax process flowsheet has been slightly adapted to integrate this new mill which is not air swept but working by gravity.

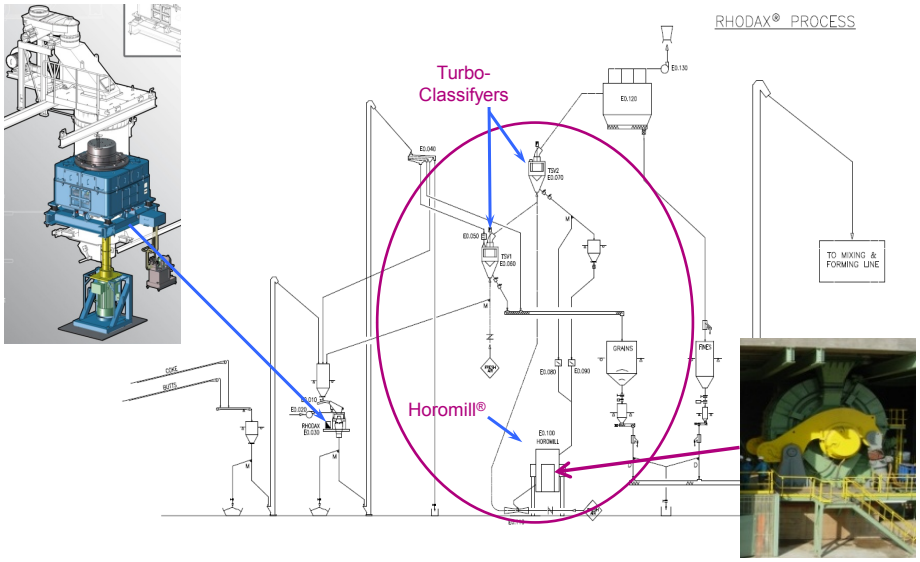

Figure 14. RHODAX + HOROMILL flowsheet.

As shown in Figure 15, the grinding efficiency of the Horomill is 40 % lower than the ball mill and similar to the vertical mill which is in the same grinding class (pressure vs compactness). However, when considering the energy consumption of the whole grinding circuit (including fan power and other equipments like dynamic classifiers or crushers), the Horomill solution appears to be the most efficient.

kWh/t	Rhodax + Ball Mill	Cone Crusher + Vert. Mill	Rhodax + Horomill
Grinding mill	63	39	39
Filter Fan	8	25	12
Others equipments	8	13	8
Total	**78**	**77**	**59**

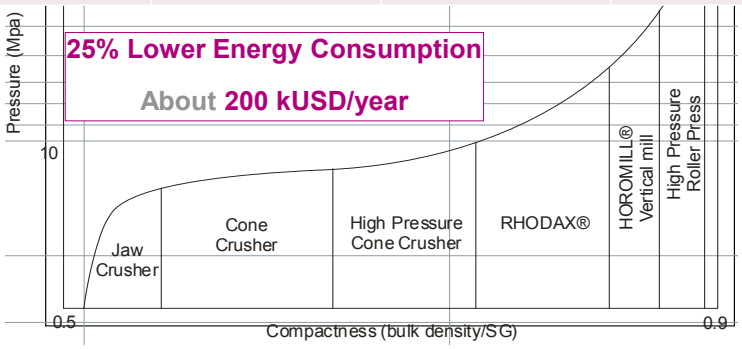

Figure 15. Specific energy consumption for several grinding circuits.

On top of that, the Horomill brings some other interesting technical advantages like:

- very small footprint in the plant,
- almost no iron pollution,
- low noise level (below 85 dBA at 1 m)

7. Conclusion

The Rhodax process which has been jointly developed by AP and FIVES in the early 2000's is now recognized as the state of the art in dry mix preparation for green anodes. After 10 years of history,

with 7 green anode plant references, representing more than 1 500 000 mtpy of anode production, the Rhodax based baked anode properties are proved to be among the best-in-class and a major contribution to pot operation performance. It accounts why the main key player in the aluminium primary industry out of China have adopted this technology.

A further improvement is now proposed with the integration of the Horomill in place of the ball mill for the production of fines, in order to lower the grinding energy consumption, avoid the iron pollution and reduce the noise level.

8. References

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