The First Rhodax Green Anode Plant in China

Christophe Bouché[1], Romuald Daligaux[2], Yves Moras[3], Barry Xian[4], Pei Song[5], Li Ning[6] and Li Zan Cheng[7]

1. Carbon Product Director,
2. Process & Technology Manager
3. Project Manager

Fives Solios, Givors, France

4. Project Manager
5. CEO of FAP EA

Fives, Shanghai, China

6. General Manager
7. Chief Process Engineer

Xinfa Carbon Group, Chipping, China

Corresponding author: christophe.bouche@fivesgroup.com

Abstract

In 2016, Xinfa awarded Fives a technology package comprising two-twin 60 tonne per hour Green Anode Plants (GAP) based on the Rhodax process. It was a premiere for such western breakthrough technology in China. These twin GAPs were part of an ambitious brand new integrated carbon plant from petroleum coke calcination to production of the prebaked anodes feeding 600 kA SAMI technology pot lines.

The latest version of this GAP technology has successfully been commissioned to produce anodes at the highest ever production rate, for high amperage pot technology. More than 20 years of capitalized experience combined with the evolution of the technologies, has allowed Fives to meet Xinfa's challenges:

- Higher environmental requirements with limited Volatile Organic Compound (VOC) and Polycyclic Aromatic Hydrocarbons (PAH) emissions
- Higher green anode plant Overall Equipment effectiveness (OEE) and stable anode quality

This paper will summarize the key project characteristics, challenges and lessons learnt as well as the performance achieved.

Keywords: Anode, Rhodax, Xinfa, Fives.

1. Introduction

Founded in 1972, Xinfa group is a modern large-scale enterprise integrating power generation, heat supply, alumina, primary aluminum and aluminum downstream processing industries.

Xinfa has an electrolytic aluminum production capacity of more than 4 million tonnes per year based on Chinese high amperage pot technology. This production is distributed over four main sites in the Chinese provinces of Shandong and Xinjiang.

The green anode plant project described in this paper is part of the Aluminum Smelter complex of Chiping city based in Shandong province.

2. Xinfa Aluminum Smelter in Chipping

The green anode plant is part of a new carbon plant project started in 2015. This new integrated carbon plant shown in figure 1 comprises a green coke storage area, shaft calciners, calcined petroleum coke (CPC), pitch and recycled materials storages, two green anode plants (GAP), two rodding shops, one green and baked anode storage area, two baking furnaces and one fume treatment center including SO_2 scrubbers.

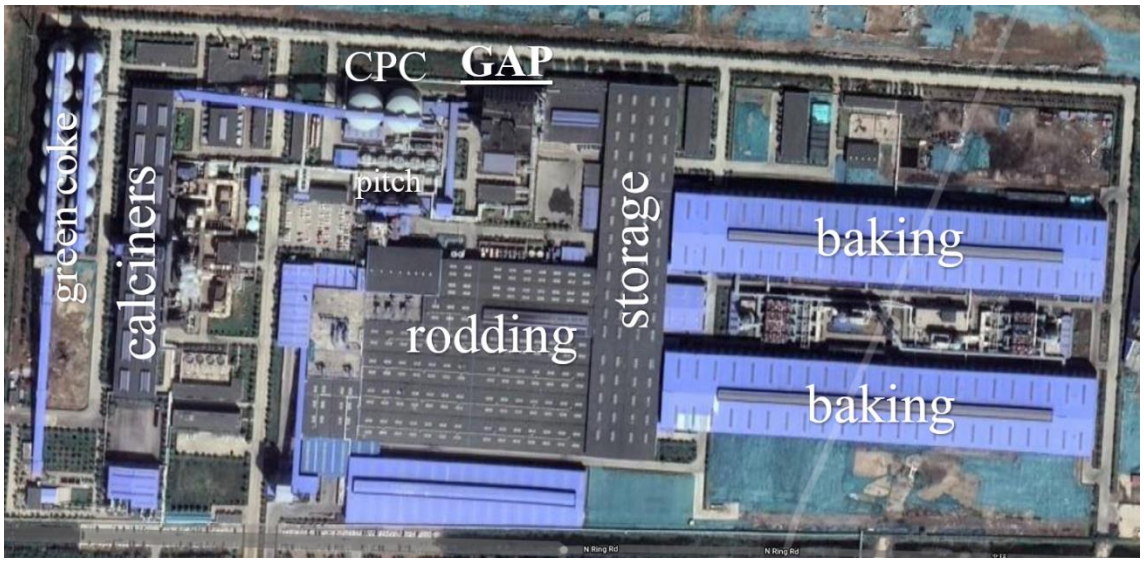


Figure 1. Xinfa, Chipping, New Carbon Plant
(Google maps, satellite view, image ©2021 CNES Airbus).

This carbon plant can produce 800,000 tonnes of baked anodes per year, feeding some of the older existing pot lines and the new SAMI SY600 pot lines commissioned in 2016 with an actual production capacity of more than one million tons of Aluminum per year.

Xinfa wished to build a state-of-the art carbon plant and selected the well-proven Rhodax based green anode plant technology [1], which was a premiere in China. In 2016, Fives Solios have then been awarded a technology package contract for two twin GAPs of 60 tph each. The contract included process definition, basic engineering, supervision, control system and integration of equipment bought out by Xinfa directly such as paste mixer and paste cooler. Fives Solios also supplied key proprietary pieces of equipment such as Rhodax crusher, fine grinding production unit, vibro-compactor, key process bag filters and the EOLIOS [2,3] pitch fume treatment system and cooperated with SAMI in charge of the detailed engineering.

3. RHODAX® Technology at a Glance

The Rhodax process is the result of two parallel developments started in early 90's. In early 2000's, Fives and Aluminum Pechiney (AP now Rio Tinto) joined their R&D efforts and co-patented the SCAP-RHODAX process (Figure 2) which consists 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
- Producing a recipe based on two size fractions only leading to a drastic flow sheet simplification

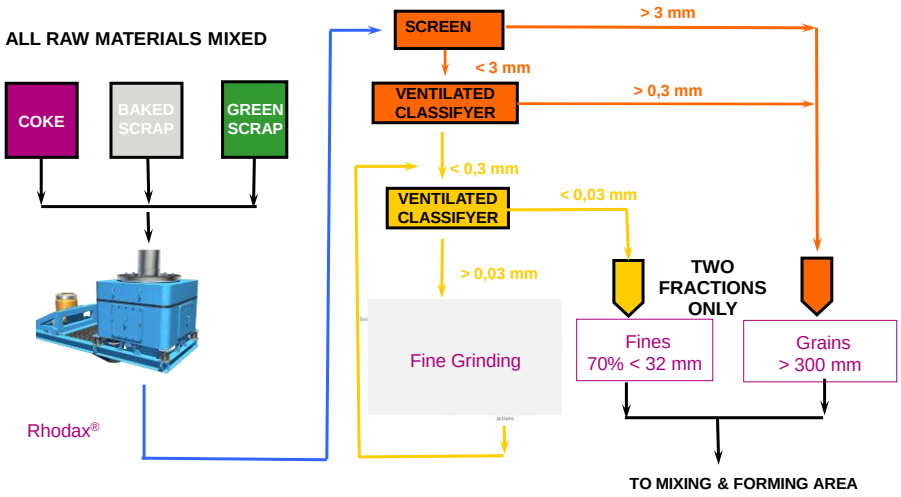


Figure 2. RHODAX® key process features.

The Rhodax process "naturally" delivers a dry mix recipe with a high Grain/Sand ratio (G/S), typically above or equal to 4, compared to typically less than 2 with other conventional processes. It has been proven to be a key factor to minimize anode thermal shock problems [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.

This circuit operates smoothly and continuously thanks to several process control loops managing the throughput level and the grains/fines silo balance. The simplification of the process shown in Figure 3 demonstrates a 40% reduction in equipment when compared to the conventional process.

4. RHODAX® Green Anode Plant References

Once the full-scale 35 t/h industrial prototype was successfully tested at the Dunkirk Aluminum plant in France, the first industrial application followed with the 35 tph green anode plant commissioning of Alba line 5 in Bahrain. In operation since 2005, this first operation combined the new Rhodax and the kneader/cooler mixing technologies.

Upon this successful start-up at Alba, and the one of the Intensive Mixing Cascade (IMC®) at Hunan & Sichuan Chuangyuan, the Sohar green anode plant combined both of these latest technologies and demonstrated good anode behavior on AP3x pot technology [4].

Then, in 2010, a 60 t/h single line green anode plant was successfully commissioned at the Qatalum smelter [5]. It was designed to fulfil the anode requirements of the 585,000 t/y metal capacity smelter based on Hydro HAL275 pot technology.

After the start-up of the above three references, the Rhodax process was selected by several other major aluminum producers:

- In 2012, with two 40 t/h green anode plants for Ma'aden in Saudi Arabia (AP4x pot technology) [6];
- In 2014/15, with one 35 t/h (Mahan) and one 52 t/h (Aditya) green anode plants for Hindalco in India (AP3x pot technology);
- Eventually in 2018/19, three new high capacity green anode plants were started:
    - One 55 t/h at Alba again, for Line 6 (EGA DX+Ultra 460 kA pot technology) [7];
    - And two 60 t/h at Xinfa with the new said "Rhodax S" process (SAMI 600 kA pot technology) as shown in figure 4.

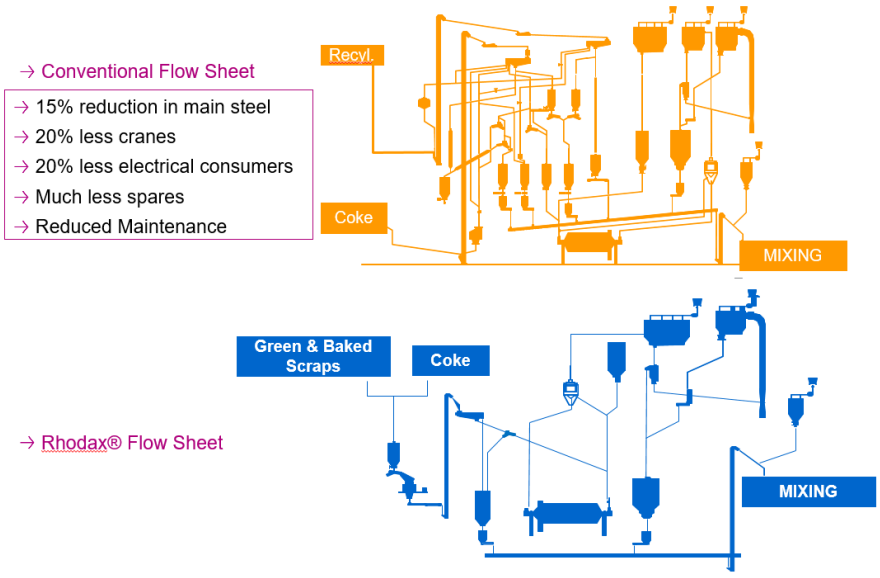


Figure 3. Comparison between conventional and RHODAX® flow sheets.

(a) (b)

Figure 4. (a) 3D External view & (b) Actual Building of the twin 60 t/h GAP at Xinfa.

5. Xinfa Rhodax Green Anode Plant: A Mix of Well-Proven & Innovative Technologies

For this project, an upgraded version of the Rhodax process – the Rhodax S - was proposed. This new version takes into consideration the large experience from the previous installations and aims at further improving the controllability of the process while maintaining the G/S at 4 for a full benefit on the thermal shock resistance of the anodes.

As shown in Figure 5, the scalping screen has one more cut size of 1 mm. This new size fraction goes to an overflow feeder coupled with a flow controller. This new arrangement replaces the first ventilated classifier in the initial version and help to better control the quantity of coke sent to the fine grinding unit.

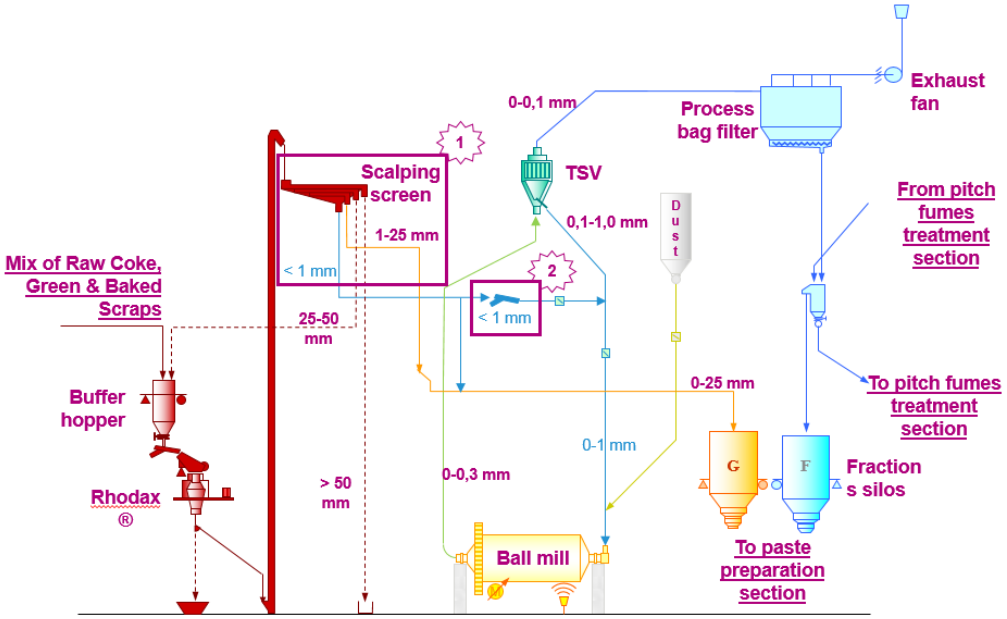


Figure 5. New Rhodax S Process Flowsheet.

In addition to this process upgrade, a new version of the Rhodax crusher – the Rhodax 4D - was also proposed to face the evolution and variability of the raw coke granulometry and to simplify the equipment mechanical design for easier maintenance.

In addition to these novelties and compared to the previous 60 t/h GAP at Qatalum, there were two main upgraded pieces of equipment:

- The vibro-compactor XELIOS 2.0 featured with nowadays-standard characteristics like counter pressure, dry vacuum and some more recent ones like:
    - A new transfer hopper
        - with rack-pinion for faster and more accurate positioning
        - with integrated pitch fume suction and capture system
    - On-line and real time anode height monitoring during compaction with associated control loop in order to stabilize the anode quality while reducing the vibration time
- The new Eirich RV33 model replacing the previous RV32 model initially designed for 60 t/h. It is slightly bigger and it was the first industrial application of this new model in that size range. This new design has been already successfully tested at Kitimat carbon plant in Canada with a smaller size range, the RV28 model. The mixing principles of this new design remain unchanged except for the pan slope, which is much smaller.

The rest of the process remains unchanged relying on well-proven pieces of equipment with characteristics detailed in Table 1 where a comparison is made between the previous 60 t/h GAP of Qatalum and the two 60 t/h GAP of Xinfa

Table 1. Equipment Characteristics for a 60 t/h GAP

Key Pieces of Equipment	60 t/h GAP at Qatalum 2010	60 t/h GAP at Xinfa 2018
Dry Material Crushing	Fives Rhodax 1100 40 – 80 t/h(1)	Fives Rhodax 1100 4D 40 – 80 t/h(1)
Dry Material Classification	Two Fives TSV dynamic classifiers of 1800 mm in diameter	Modified scalping screen with one extra 1 mm cut size & One Fives new TSV coke dynamic classifier of 1800 mm in diameter
Fine Grinding	One Fives ball mill of 3.0 m in diameter	One Fives ball mill of 3.0 m in diameter
Coke Preheating	One Fives Preheating screw with four Ø800 mm screws	One Koellemann preheating screw with four Ø950 mm screws(2)
Dry Material Dosing	Two loss-on-weight dosometers	One loss-and-weight dosometer for coarse fraction and one roto-weight dosometer for fine fraction(2)
Paste Mixing/Cooling	Eirich IMC® With two RV32	Eirich IMC® With two new RV33(2)
Anode Forming	Fives XELIOS 1.0 Vibrocompactor With 2 tables	Fives XELIOS 2.0 Vibrocompactor With 2 tables
Cooling tunnel	Fives Water Spraying Cooling tunnel with less than 90 min residence time and no water cooling tower	SAMI Water Pool Cooling system with 120 min residence time & water cooling tower(2)
Pitch fume treatment system	Fives EOLIOS with a combination of coke dry scrubber and Regenerative Thermal Oxidizer (RTO)	Fives EOLIOS with a combination of coke dry scrubber and Regenerative Thermal Oxidizer (RTO)

(1) Paste equivalent throughput depending on the raw material Particle Size Distribution (PSD)
(2) Xinfa scope under Fives technical specifications

Xinfa paid a particular attention on the environmental impact of the carbon plant. For the green anode plants, it means:

- Stringent emissions at the stack for both dust and VOC
- Special attention to operators' exposure inside the building

For this reason, the EOLIOS pitch fume treatment system [2,3] including the automatic RTO bypass was selected.

Finally, yet importantly, a lite version of AMELIOS Software [8,9] for green anode plant process and equipment performance monitoring was also included.

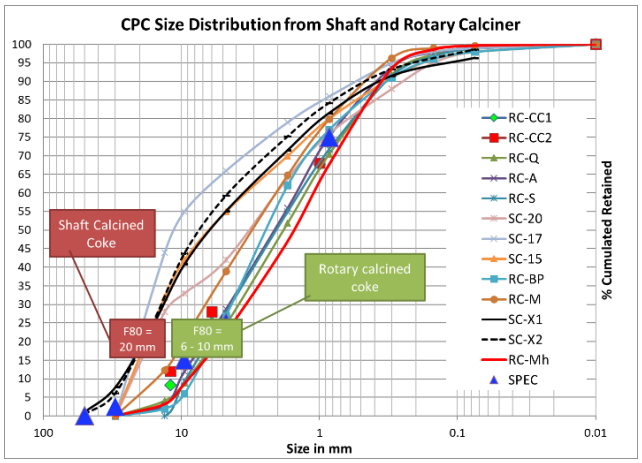
6. RHODAX 4D

The Rhodax crusher process benefit is now established but it was necessary to upgrade this equipment to face the evolution of the raw materials and to simplify the mechanical design for easier maintenance. In green anode plants, it is common to blend cokes from different sources and of different properties in order to average the coke quality (sulfur content or density for instance) and to optimize the raw material cost. In the past few years, shaft-calcined coke tends to be more popular due to its higher density. However, these cokes come with a very different Particle Size Distribution (PSD).

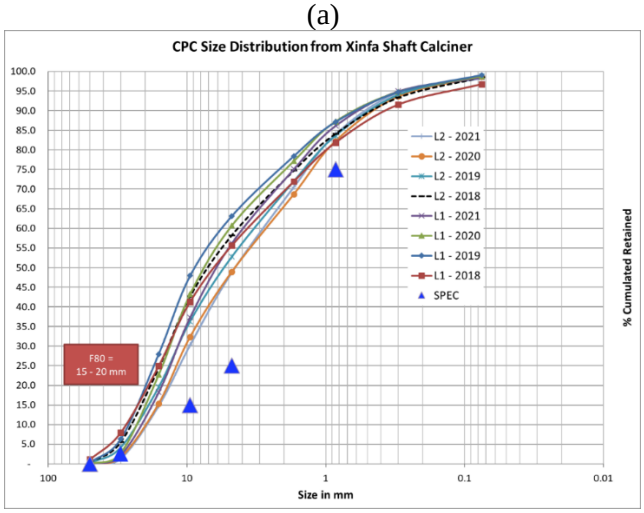
Based on our material samplings from various plants, as demonstrated in Figure 6-a, shaft-calcined coke PSD differs from that of rotary-calcined coke in two key aspects:

- A much coarser feed granulometry with an 80% passing (F80) around 20 mm compared with the 6 to 10 mm typically seen for rotary calcined coke,
- A much higher quantity of dust.

This was confirmed at Xinfa where 100% shaft calcined coke is processed (figure 6-b).



(a)



(b)

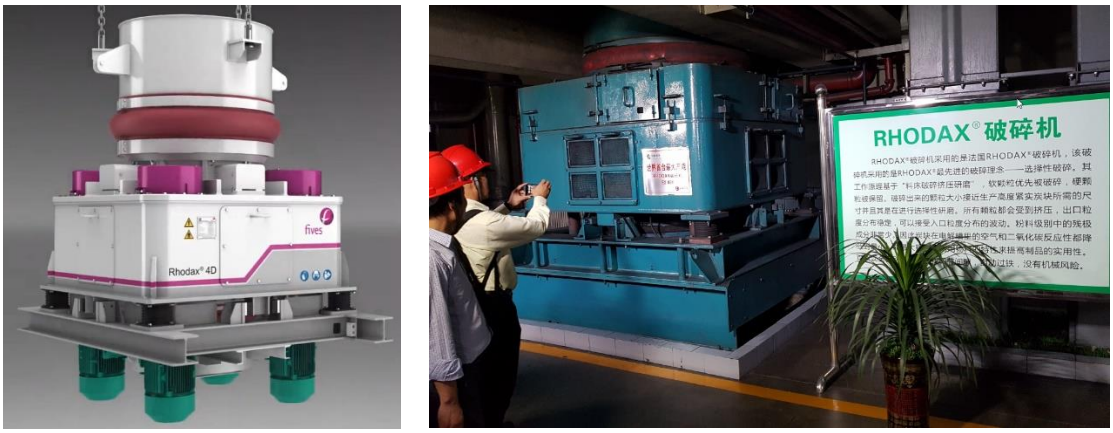
Figure 6. (a) Particle Size Distribution of Shaft and Rotary Calcined Cokes (RC = Rotary Calciner; SC = Shaft Calciner) ; (b) Particle Size Distribution of Shaft Calcined Coke used at Xinfa Chiping Carbon Plant.

A higher F80 means a higher particle size reduction ratio and therefore, higher crushing power requirements. The design of a crusher (crushing technology and the crushing power) is based on the feed material properties, the particle size reduction ratio and the targeted crushed particle shape.

Therefore, from both mechanical and process points of view, an evolution of the Rhodax crusher was necessary and this is why the Rhodax 4D (or 4 Drives, Figure 7) was developed. The 4-Drives technology brings:

- Mechanical simplifications (eliminates the synchronization belt and hydraulic rotary jack) to ease the maintenance;

- Increased flexibility (crushing power adaptation) thanks to 4 independent driving units synchronized using Variable Speed Drives (VSD);
- On-line monitoring for better control of wear, speed, vibration and power;
- Facilitated digitization of the equipment monitoring as a consequence.



(a) (b)

Figure 7. (a) 3D view of the Rhodax 4D; (b) Rhodax 4D at Xinfa.

After a period of testing and fine-tuning, the Rhodax 4D has been successfully commissioned in all the recent high capacity green anode plants at Xinfa (2 x 60 tph) and Alba line 6 (1 x 55 tph).

7. The Environment and Emission Performance

Since 2016, Chinese government monitors closely the environmental impact of industry in China and in particular in Shandong where there is a high concentration of large aluminum production units. Therefore, Xinfa requested the best available technology referenced in the BREF (Best European REFerences) [10] in force at the beginning of the project in order to contain the dust and pitch fume emissions and exposure.

Several dust collection systems were designed to maintain an optimum working environment and to limit dust stack emissions to less than 10 mg/Nm^3.

An EOLIOS pitch fume treatment system using a combination of a dry scrubber and a small RTO was used to limit the condensed tars and VOC below 5 mg/Nm^3.

Several new pitch fume suction points were designed around the vibrocompactor in order to collect the pitch fumes as close as possible to the source of emission and therefore to minimize the fugitive emissions. For instance, the paste transfer hopper is equipped with an integrated pitch fume suction system and retractable covers to close the hopper top during paste transfer to the molds.

Xinfa decided to further increase the pitch fume suction points by adding additional filters to maintain a very low level of pitch fume inside the closed building. This was very effective and resulted in one of the worldwide best ambiances in such green anode plant as illustrated in the figure 8.

(a) Rhodax Crusher

(b) RV33 Mixer

(c) Vibro-Compactor

(d) Anode Cooling Section

Figure 8. Typical GAP building ambiance.

All combined and after a period of adjustment and fine-tuning the results achieved were in-line with expectations as shown in table 2.

Table 2. Emission Results

Emission Monitored	Line 1 Pitch fume bag filter	Line 1 Other dust bag filter	Line 2 Pitch fume bag filter	Line 2 Other dust bag filter
Dust (mg/Nm^3)	2.8	4.5	2.1	< 10
VOC (mg/Nm^3)	4.3	ND	4.7	ND

8. Green Anode Plant Ramp-up and Production Performance

8.1 Green Anode Plant Ramp-up

The plant production ramp-up (figure 9) was one of the Fives's fastest ever with the first 5000 good anodes produced in less than 5 weeks after the plant start-up compared to more than 8 weeks on average previously.

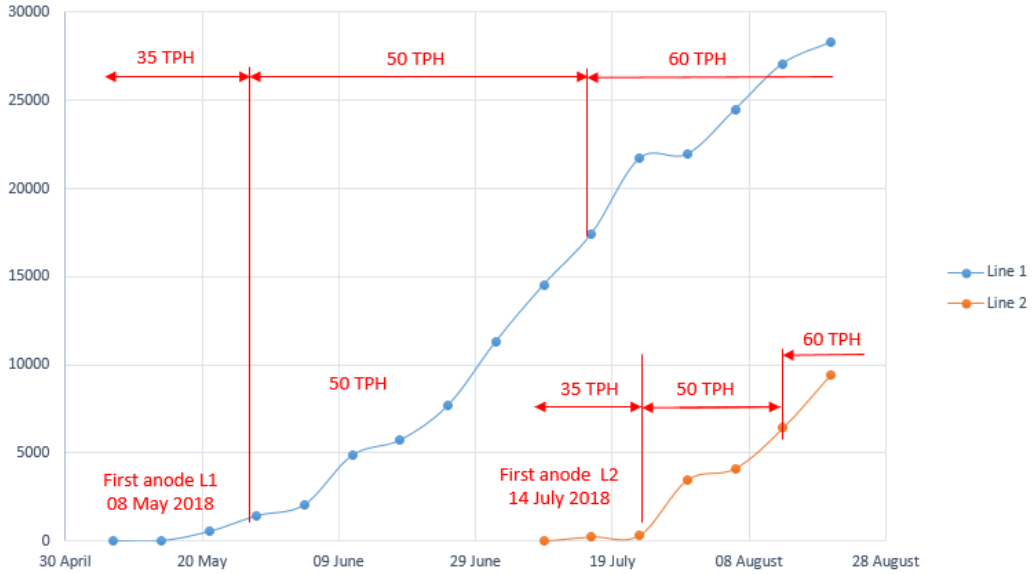


Figure 9. Line 1 and Line 2 production ramp-up in 2018 (Y-axis: # of Good anodes).

Several factors explained this performance:

- First of all, the human factor with:
  - The extreme reactivity of Xinfa's process and maintenance teams to correct the identified defects under the supervision of Fives's commissioning team
  - The ability of the Xinfa's team for training, to digest new western technologies and to collaborate with Fives's experts.
  - A facilitated communication between Fives's French and Chinese speakers and Xinfa's teams thanks to the new mobile technologies
- Then the technology itself:
  - The standardized plug-and-play automation programs for each process section.
  - A well-proven technology with already documented trouble-shooting and fine tuning guidelines

8.2 Green Anode Plant Performance Results

The official production performance tests were performed end of 2018/mid 2019. Table 3 summarizes the key performance test results. Globally, these figures indicate good performance, in-line with what can be expected from a proven technology combined with good operation and maintenance practices.

Line 1 was set-up at 60 t/h to produce anodes of more than 1500 kg and Line 2 at 50 t/h to produce anode close to 990 kg.

Table 3. Process Performance Test Results

Performance Test / Criteria	Line 1 (12/2018)	Line 2 (08/2019)
Plant Availability (%) / > 90%	99	97.8
Vibro-compactor Availability (%) / > 96%	99.7	99.9
Anode production rate (A/h) [> 42 (L1) & >50 (L2)]	46(1)	52(2)
Green anode density mean (g/cm3) / > 1.62	1.634	1.670

(1) Measurement based on cycle time only as it is not possible to reach 42 Anode per hour (A/h) with 1500 kg anode and 60 t/h paste plant

(2) Test performed at 50 t/h to produce 980 kg anodes

On a long run, after more than 3 years of operation, the green anode plant performance has been continuously improved by Xinfa's operation team and is now stabilized at a high level of production with very good anode quality. The three SY600 pot lines consuming these anodes show good performance with a mean current efficiency at 93.4% and a mean net carbon consumption of 402 kgC/tAl similar to other recent and similar applications in the Gulf countries.

The figure 10 gives more details on the anode production levels and anode quality.

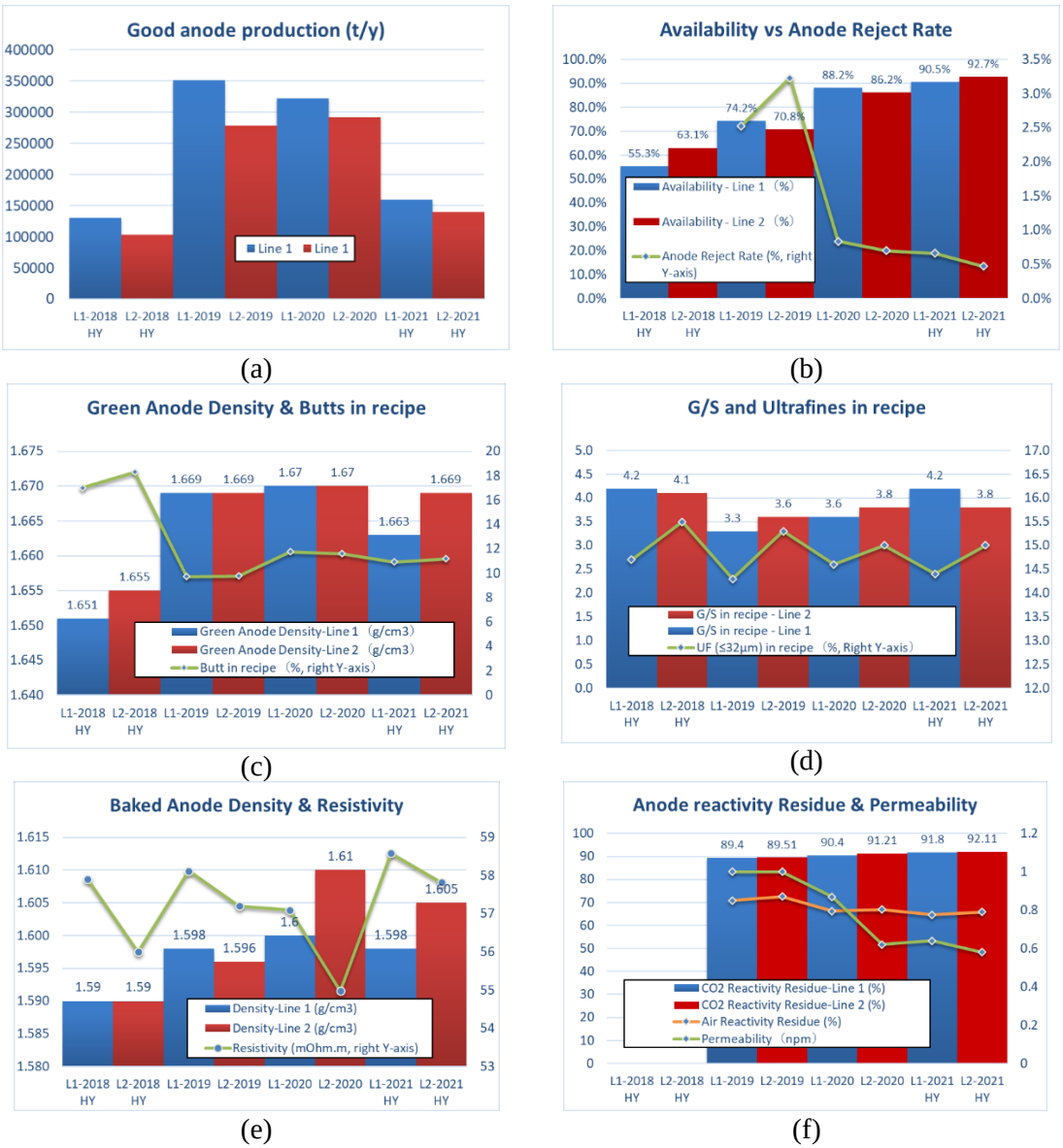


Figure 10. Long run process performance (HY = Half Year).

First, the uptime has continuously increased since start-up with decreasing green rejects. Green and baked anode densities are on a high range despite a very low level of butts in the recipe but with 100% shaft calcined known for its good density. G/S is stable around 4 as expected, CO_2 reactivity residue and Air permeability are very good leading to good anode behavior on the pots. Air reactivity residue and Resistivity are closer to the world average and without any information on the baking and the rodding shop operations, it is difficult to fully interpret these last two parameters.

Eventually, in 2019, Xinfa took the initiative to test the capacity limits of the green anode plant and performed several long trials (from 9467 anodes up to 28807 anodes batch) to push the throughput beyond the 60 t/h up to 63 t/h. Figure 11 shows the results on the green anode density, which was not statistically impacted by the increased paste plant throughput.

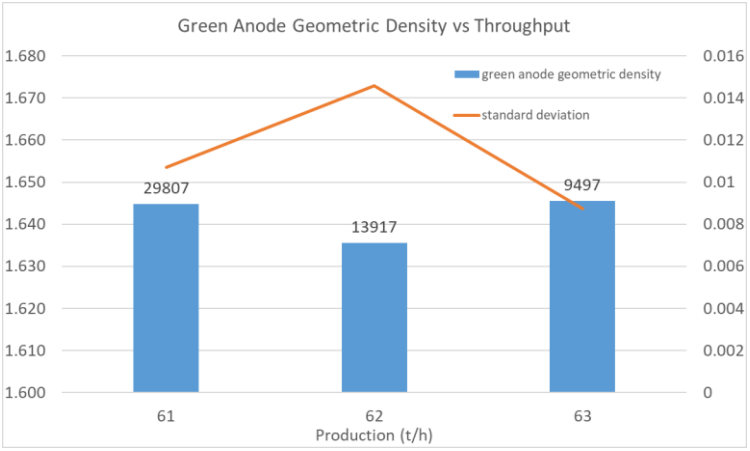


Figure 11. Line 1 Performance above 60 t/h (April – June 2019).

Thanks to these successful tests, the green anode plant throughput is, when necessary, pushed to 62 t/h in order to build up anode inventory.

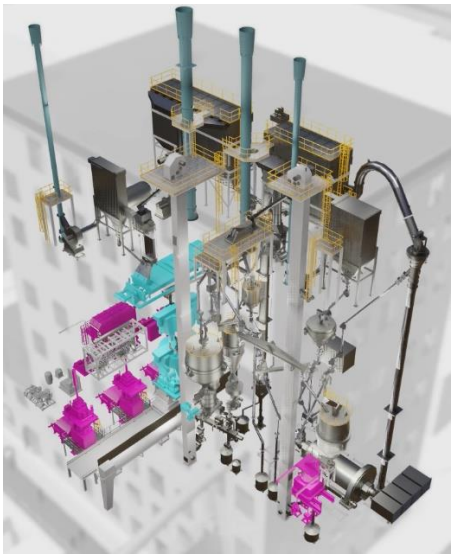


Figure 12. Up to 65 t/h single line for a future Xinfa phase 3.

Based on these results too, Fives designed and proposed to Xinfa for a future phase 3, a green anode with a capacity of 65 t/h (figure 12), a design very similar to the existing one except for the vibro-compactor, which comprises three tables instead of usually two tables to cope with the higher anode production rate at 65 t/h.

9. Conclusions

Rhodax process-based technology for green anode plants is well-proven and its performance is once again confirmed at Xinfa's Chiping aluminum smelter. It was a premiere for such technology in China and the collaboration between Fives, Xinfa and SAMI was very successful.

This reference was also the opportunity to enhance this technology with an improved version featured with innovations like the Rhodax 4D crusher, the Rhodax S process, the XELIOS 2.0 and new RV33 Eirich machine.

More than ever, carbon footprint as well as environmental impacts have become essential for modern aluminum smelters. In order to achieve that goal, it is necessary to maximize existing plant capacity utilization with high level of anode quality while limiting both plant emissions and rejects. This paper shows that Rhodax process technology, with repeated projects and continuous improvement achieved good performance aligned with these goals.

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