Anode Baking Furnace at Aluminium of Greece goes Smart and Green with a new FTC and FCS

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Abstract

Since 2017, Aluminium of Greece (AoG) has been modernizing its anode baking furnace (ABF) in order to minimize its environmental footprint. After a successful rebuild of the central casing of the ABF, AoG decided in 2019 to pursue the modernization with two major projects:

- Installation of a new fume treatment center (FTC) to cope with more stringent European emission regulation (BREF 2016),
- Installation of a new firing control system (FCS) to switch from heavy fuel oil (HFO) to natural gas (NG) in order to reduce CO_2 emissions.

FIVES technologies were selected for these two projects. The latest dry scrubbing filtration technology based on OZEOS filter modules and a new fumes cooling design were used for the FTC. The new FCS is equipped with the proven Low NOx injectors and a reduced number of ramps. FIVES technology packages included basic/detailed engineering and equipment supply. For the FTC, AoG was in charge of steel work fabrication and complete erection. For the FCS, AoG was responsible for all the modifications required in the brickwork of the ABF. Eventually, AoG commissioned both packages under FIVES supervision. Having both FCS and FTC on the same time and place, it was an opportunity for FIVES to implement some smart technologies like FCS-FTC synergy control philosophy and other digital tools like the ABF flue wall monitoring module. Despite COVID and as a consequence, reduced on-site supervision from FIVES, AoG and FIVES managed to successfully complete the project and achieve the required performances. This paper will summarize the key project characteristics, challenges and lessons learnt as well as the performance achieved.

Keywords: Anode baking furnace, FCS, FTC, OZEOS, Smart, Green, Fives, Mytilineos.

1. Introduction

MYTILINEOS is a leading global industrial and energy company with a strong presence in all five continents. The company operates four Business Units (BU), the Power & Gas BU, the Metallurgy BU, the Renewables & Storage Development BU and the Sustainable Engineering Solutions BU.

The Metallurgy BU of Mytilineos consists mainly of:

1. Aluminium of Greece, which is the largest vertically integrated alumina and aluminium producer in the European Union.
2. Delphi-Distomon, which is the second largest producer of bauxite in Greece and consequently in Europe, with an annual production up to 630 000 tonnes of bauxite, from underground construction sites only.
3. The subsidiary EPAL.ME, which is the largest independent producer of recycled aluminum, contributing to the company's focus on sustainability.

Aluminium of Greece was established in the 60s, and back then was part of the Pechiney Group.

Aluminium of Greece produces 900 000 tonnes of alumina and 190 000 tonnes of aluminum. The smelter division of the plant consists of the Potlines, Carbon Plant and Rodding Shop, Casthouse and Substation.

Since 2017, Aluminium of Greece (AoG) has been modernizing its anode baking furnace (ABF) in order to minimize its environmental footprint. After a successful rebuild of the central casing of the ABF, AoG decided in 2019 to pursue the modernization with two major projects:

- Installation of a new fume treatment center (FTC) to cope with more stringent European emission regulation (BREF 2016),
- Installation of a new firing control system (FCS) to switch from heavy fuel oil (HFO) to natural gas (NG) in order to reduce CO_2 emissions.

This paper deals with the details of these two projects from both a technology and an implementation point of view.

2. Firing Control System

The main reasons for converting the existing Heavy Fuel Oil (HFO) Firing Control System (FCS) to Natural Gas (NG) are:

- The technology of the old burning system is outdated.
- The environmental footprint is dramatically improved with the installation of natural gas.
- The significant ergonomic improvement of the new FCS.

AoG's Anode Baking Furnace (ABF) runs in a 26 h cycle and has 78 sections, 7 flue walls and 6 pits per section. The current flue wall's peephole dimensions were too small to fit the new FCS injectors. Moreover, as it is an old Pechiney design, the head walls have an opening on their top, in which the Exhaust Ramp (ER), Blowing Ramp (BR) and Cooling Ramp (CR) fit (Figure 3). So, prior to the installation of the new FCS, a lot of modifications needed to be done, as far as the brickwork is concerned, taking under consideration that:

- All modifications should be done during production and
- Cost of modifications should be kept as low as possible.

a. 1st Phase

In the first phase, which started at 05/01/2021 and ended at 20/02/2021, two (Figure 1, A & C) out of the total four flue wall top blocks were changed, with a new larger peephole. This was because Heavy Fuel Oil (HFO) injectors operate in counter flow (Figure 1, B & D), so changing the top blocks A & C will not affect the HFO injectors operation.

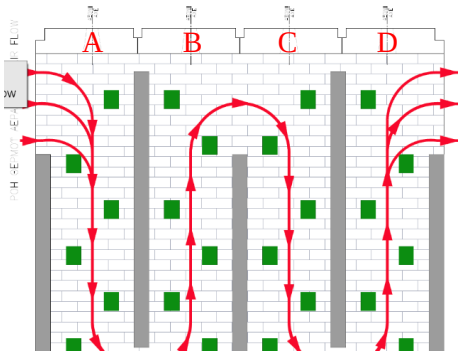


Figure 1. Flue wall side view.

During this period, 1 092 blocks, peepholes and peepholes covers in total were changed (Figure 2). All these changes were done during production, downstream of two fires. Consequently, every day two sections were modified. The configuration of the fires was not changed up to this point.

(a) **(b)**

Figure 2. Change of blocks A & C (a) peepholes, (b) peepholes covers.

b. 2nd Phase

In the 2nd phase, starting at 29/06/2021 until 07/08/2021, the top block D (Figure 1) was changed, and the headwall top openings (Figure 3a) were closed (Figure 3b & 3c), as with the new FCS equipment, they were not needed.

(a) **(b)** **(c)**

Figure 3. (a) Headwall top opening, (b) & (c) different stages of the head walls top opening closing.

So, the new configuration of the fires was: new ER, old Heating Ramp (HR), new Zero Point Ramp (ZPR) and finally new BR & CR. This configuration was kept like that until the complete

switch of all fires. In order for the HFO injectors to be able to operate with the larger peepholes, an adjustable item (Figure 4) was designed and placed on top of the new peephole.

Figure 4. Adjustable item.

To switch the furnace from HFO to NG, FIVES provided a new FCS and a Gas Pressure Reducer Skid (GPRS) to supply the gas to the ABF gas network located around the furnace.

To optimize the CAPEX, the choice was made for FIVES to supply new ramps such as Exhaust Ramps (ER) and Zero Point Ramps (ZPR) and for AoG to upgrade on their own, the existing Heating Ramps (HR) and Blowing Ramps (BR) using new components and technical package supplied by FIVES.

c. Reduced Number of Ramps

For the pre-heating zone, FIVES implements its latest ER design (Figure 5), combining the ER and Temperature and Pressure Ramp (TPR) in one equipment only, reducing the CAPEX and the OPEX while simplifying the maintenance and "moving" operations as only one ramp need to be moved and maintained.

Figure 5. New Exhaust Ramp design.

d. Proven Low NOx Injection

For the heating zone, FIVES provided the drawings to manufacture the gas pipe and to modify the existing HRs' mechanical structures. New electrical cabinets, all the gas components such as solenoid valves, sensors and the key components which are the gas injectors were also supplied.

One of the main drawback while switching from HFO to NG is the risk to produce more NOx if the injection technology is not properly designed. Therefore, FIVES' FCS are equipped with patented [1] low NOx gas injectors to reduce at the source the NOx emission and providing a better baking homogeneity compared to an "high speed" injection technology (Figure 6) [2]. In

service since 2014, these injectors limit the NOx emission under 100 mg/Nm^3 at the stack [3]. They are fully compatible with older FIVES systems but also with systems from other OEM as it was fully demonstrated by an end-user in Netherland at Vlissingen who after several successful trials confirming better baking homogeneity and lower NOx emission, replaced the injectors on its system from another OEM by FIVES' ones.

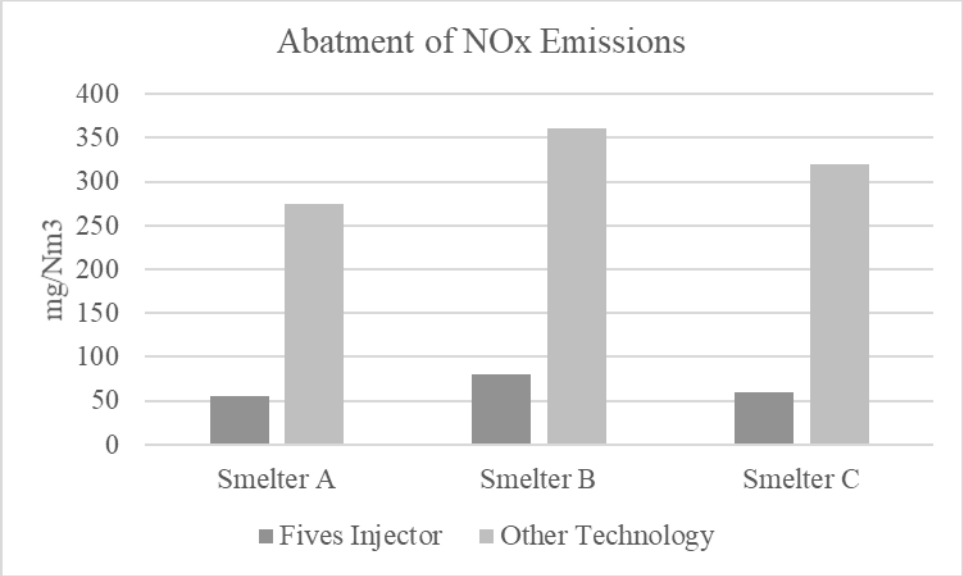


Figure 6. Abatement of NOx emission.

For the blowing zone, FIVES supplied new Zero Point Ramps (ZPR) and new electrical cabinets for the existing Blowing Ramps (BR). A Central Control System (CCS) running FIVES latest application software suite and a WiFi network were also installed. The pre-heating zone and the blowing zone are now controlled automatically instead of manually as with the previous HFO system.

e. Efficient Safety Management

The FCS safety is to the latest standard and in particular conform to the European Standard EN746-2 as the GPRS, ER and HR are equipped with Safety Integrated Programmable Logic Controllers (SIPLC) that communicate together and with the Fume Treatment Center (FTC) to manage in a complete integrated way the gas and furnace safety.

f. FCS Commissioning and Performances

The combustion of NG required more air for the same energy compare to Heavy Fuel Oil (HFO) and will produce more humid fume leading to a potential increase in the energy consumption. The temperature measure and injection points are different, as HFO injection was counter-current, whereas the NG injection is now co-current. The flame profiles are different: the HFO flame is more concentrated where a NG flame is longer and diluted, changing the heat distribution in the pit and the reading of the thermocouple used for the temperature control by the FCS HRs. For these reasons as part of the conversion project, AoG production team and FIVES experts worked together to readjust the whole process and the baking curves to keep a homogenous baking level and minimize the energy consumption.

The 1st fire with NG started its operation on 13/7/2021. The switch was done at once, meaning that all HR were switched in one day. The last 3 fires switched to NG during September of 2021.

3. Fume Treatment Center

Since the early 70s, FIVES has equipped more than 42 Anodes Baking Furnaces (ABF) all over the world with its own Fumes Treatment Centers (FTC). A majority of them is dedicated to modern open type furnaces with water cooling towers to cool down the fumes from around 200 to 105 °C and bag filters with reactors to inject, capture and recycle alumina.

From Mytilineos' point of view the environmental footprint of ABF should be improved, contributing to company's ESG principles. For that a brand-new FTC was decided to be installed and ordered to FIVES in February 2019.

a. FTC Key Figures

AoG aging Furnace, born in the middle of the 60s, is having a very high specific fumes flow (≈12 400 Nm^3/t anodes). Consequently it produces a high rate of fumes to be treated in the new FTC compared to its anodes baking capacity (100 kt/y of anodes). The FTC is therefore designed for 40 Nm^3/s of fumes at 83 to 178 °C and an underpressure at ABF outlet between 250 and 350 daPa.

The guaranteed emissions at FTC stack are by far the most stringent in the world [4]. Table 1 resumes the guaranties granted by Fives to AoG.

Table 1. AoG FTC guaranteed emissions values.

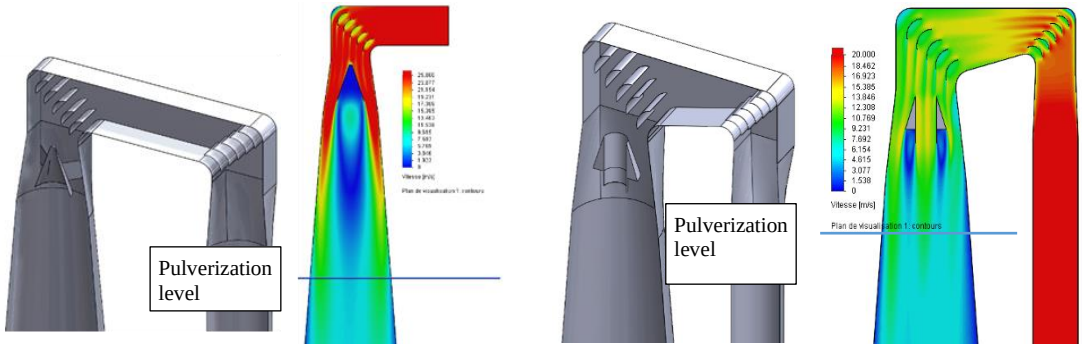
Property	Value
Total particulates – TP	< 5.0 mg/Nm^3
Total fluorides – F_T	< 0.7 mg/Nm^3
Gaseous fluoride – HF	< 0.4 mg/Nm^3
Benzo[a]pyrene	< 0.5 µg/Nm^3
PAH16 US EPA	< 2.5 mg/Nm^3
Carbon content in alumina	< 1 %

b. Cooling Tower

In order to improve the operation of its cooling towers, 10 years ago FIVES developed a new generation of cooling towers. The new design of the tower allows to:

- Reduce the height of the tower by reducing the turbulence zone between the inlet distribution devices and the level of water spraying at the entrance of the tower,
- Have a better aeraulic distribution of fumes with good contact with water droplets,
- Avoid water contact with the walls of the cooling tower,
- Have a total evaporation of water in smaller tower volume.

Figure 7 show the improvement in the fumes distribution between the old and the new configurations of the tower's inlet.



(a) **(b)**

Figure 7. (a) Old and (b) new design of cooling tower.

The inlet duct of cooling tower and distribution fumes device in cooling tower inlet have been modified in order to improve fumes distribution. Several configurations were studied using Fluent CFD.

The reduction in size (approx. 30 %) (Figure 8) of the tower is also the result of the use of another type of more efficient sprinkler nozzles with a maximum droplet size of less than 200 µm (D_{Sauter}<80 µm). The new nozzles studied and tested with our partner allow better atomization of the water by ensuring a very fine air/water mixture before the water exits from the nozzles in order to evaporate completely water droplets in a smaller tower volume.

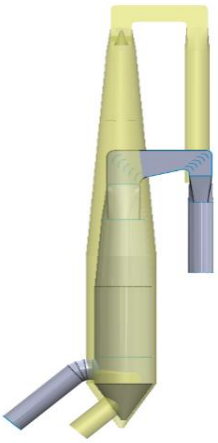


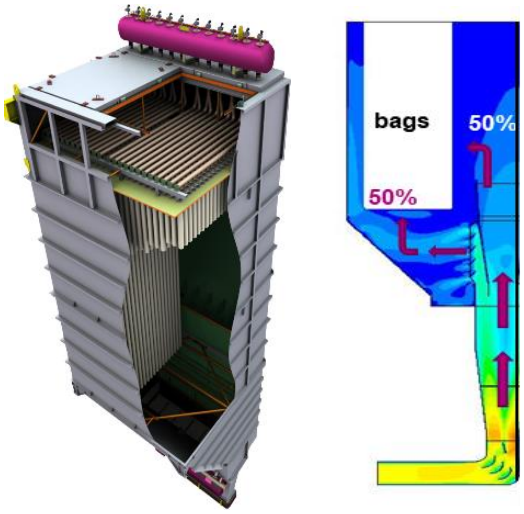
Figure 8. Cooling tower size comparison.

c. OZEOS Filters

OZEOS is the latest generation of Gas Treatment Center (GTC) or FTC scrubber that has been developed by FIVES over the last few years [5-6]. It features a more compact design that suits better the large gas volume treated by centralized GTCs and FTCs for modern high amperage pots and includes a low velocity reactor that reduces the risk of scaling, abrasion and alumina attrition. Low velocity allows to increase residence time of alumina, a parameter which positively drives fluoride and PAH scrubbing. OZEOS scrubber is equipped with bags that have a length up to 7.5 m for FTC made from Acrylic-omopolymer-Polyacrylonitrile and 8 m for GTC made from micro-denier polyester for best particulate filtration for each application. Besides it decreases the total pressure drop of the module and consequently reduces the power consumption of the Center.

An OZEOS module for FTC (Figure 9) is more than two times smaller than the one for GTC as far as the flow to be treated within FTC is 10 to 15 times lower than the one treated in GTC. Fresh

alumina is injected at the bottom of the filter (in the reactor) together with the recycled alumina coming from the filter's hopper with the fumes coming from the furnace. An arrangement of baffles allows splitting the gas flow in two streams: 50 % of the gas are directed towards the sides of the bags, 50 % at their bottom. This distribution ensures an ideal filtration, a homogeneous and thick alumina cake all along the bags and low pressure drops [7]. Fumes velocities and filtration velocities inside the module are respectively about 2 to 4 m/s and from 1.5 to 1.8 cm/s.



(a) **(b)**

Figure 9. (a) 3D view of a filter of OZEOS dry scrubber and (b) modeling of gas flow distribution with multi-points injection inside a filter.

Thanks to such arrangement inside filters and to automatic devices balancing fumes flows among the four filters (Figure 10), the FTC is ensured to operate in optimum conditions and to generate the lowest possible pollutants.

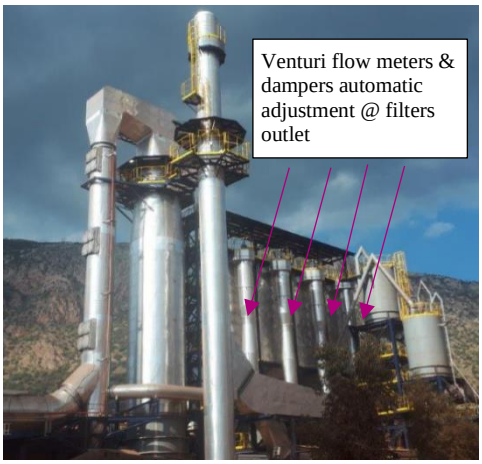


Figure 10. AoG FTC photo showing the filters outlet venturi measurements coupled to dampers opening control in order to automatically balance the flow among filters.

d. Installation & Commissioning

The FTC installation, erection and erection supervision were undertaken by AoG with the help of the detailed installation manuals and drawings provided by FIVES. The corresponding works were assigned to three main contractors responsible for the foundation construction, electrical works and mechanical erection respectively, with the latter being understandably the most

challenging in terms of part size handling, erection complexity, work safety issues and time to completion constraints. Naturally, many other subcontractors were employed to provide, for example, surveying services, insulation works, welding inspection services, painting, fabrication of the FTC steel structure, etc.

One of the biggest challenges was made apparent at the very start of the project: the limited space for storage and part pre-assembly. As other projects were evolving in the plant at the same period, the need for storage space grew enormously. The initial estimation of the space needed to receive the main elements (ducts, shells, devices & components, etc.) as well as for the pre-assembly of the filters, hoppers, cooling tower, stack, etc., was around 4 800 m^2. The materials delivered by FIVES consisted of no less than 55 40-foot containers. Securing the necessary space to lay these materials, required creative management from the supervision team which worked very efficiently with the relevant stakeholders (Figure 11).

Figure 11. Unloading materials from a container.

The same creative thinking was also applied by the main erection contractor who managed to use a confined space in a very creative manner in order to perform the prefabrication of the main FTC components/sub-assemblies like the filters, hoppers and main ducts (Figure 12).

(a) **(b)**

Figure 12. (a) Installation and (b) pre-assembly of the OZEOS filters.

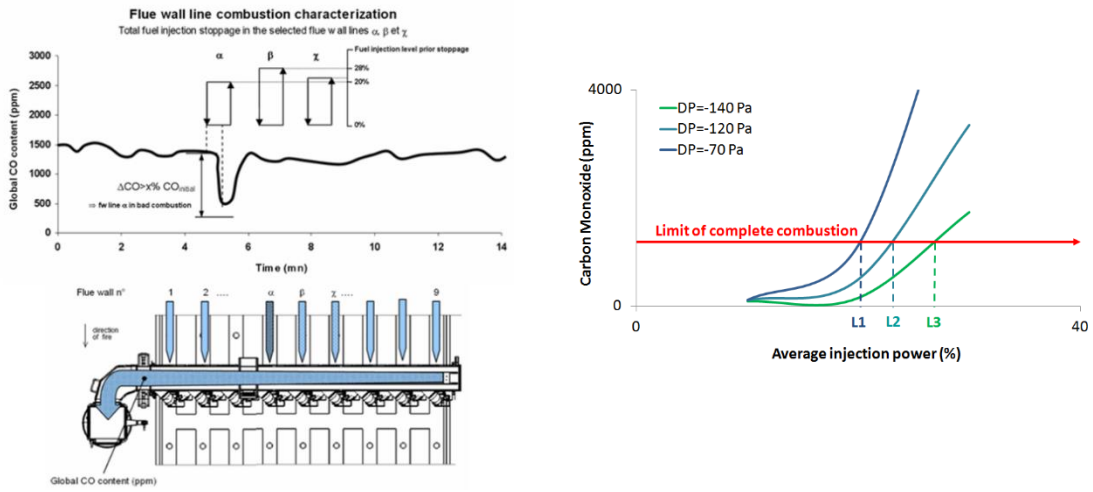
The last major challenge presented itself during the commissioning and concerned the tie-in of the new FTC installation to the working anode baking furnace (Figure 13). This task had been carefully planned in advance as the furnace could not stop its operation for more than six hours in order for the fires not to be put out. The preparation involved the complete cold- and hot-commissioning procedures for the new FTC as a single unit which resulted in the FTC being completely ready to fully receive and process the gases from the furnace. After that, the tie-in was completed within the scheduled timeframe without any incidents.

Figure 13. Flange welding at the tie-in.

4. FCS/FTC Applied Smart Solutions/Technologies

FIVES Firing Control System for anode baking furnace is controlled by central computers running advanced control functions to achieve consistent anode quality while reducing fuel consumption and PAH emissions. To achieve the best fuel consumption possible according to the target baking level and the furnace refractory condition, the FCS must burn completely the anode pitch volatile and the injected fuel while recovering as much energy as possible in the blowing zone.

For many years, the CO sensor is used to measure the quality of the combustion in both areas (pre-heating & heating zone) and FIVES' patented CO module [8] automatically detects the flue walls in CO excess as shown in Figure 14a and limits the unburnt residue by balancing the fuel air ratio per flue wall. To ensure the complete burning of the injected fuel, several modules in addition to the CO module will operate to avoid a flooding situation where there are too much fuel and not enough air to burn it. For example, the system always adjusts the level of injection in a flue wall line according to the level of oxygen provided by the draft at the exhaust ramp (Figure 14b).



(a) **(b)**

Figure 14. (a) Principle of combustion characterization by the CO module and (b) injection limits per flue wall line.

To ensure a complete anode pitch volatile burning, enough oxygen are mandatory along with an airflow hot enough to auto ignite these volatiles. The Pitch Burning module focus on reigniting properly the degassing after the fire moving and aligning it to move it smoothly forward in order to keep the anode temperature gradient under the acceptable limit, while ensuring a constant air flow to have always enough oxygen to burn the injected fuel and the anode pitch volatile.

The efficiency of the combustion and the safety in the anode baking furnace is highly dependent of the constant suction from the FTC and the efficiency of the fume treatment by the FTC is highly dependent of the fume content at the outlet of the furnace. Therefore, as this site is using both FIVES' FTC and FCS systems, FIVES has implemented its synergy modules between the FCS and the FTC to improve furnace safety and emission capture. For instance, when the FTC stops for any reason, the FCS is immediately informed to stop its fuel injection and to take additional measures to ensure as much draft as possible inside the furnace. The FTC stoppage is clearly highlighted on both FTC and FCS supervisory screens to inform the operator, so he can take the appropriate measure early on (Figure 15).

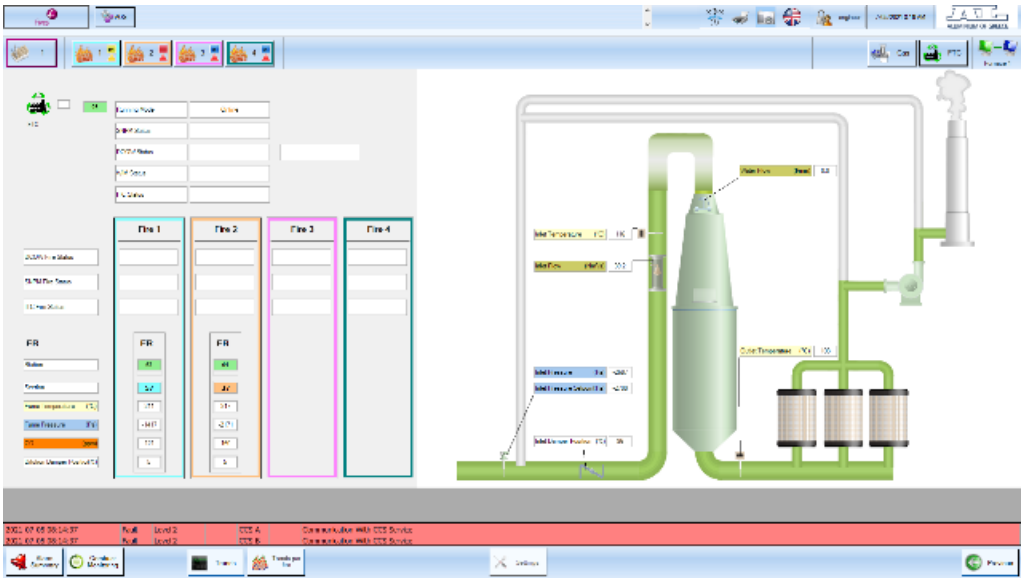


Figure 15. FTC screen on the FCS supervision.

To ensure low emission at the stack, the FTC must run in filtering mode. With the synergy module, the FCS checks its fume temperature and anticipates by predicting if there is a risk for the FTC to go in by-pass mode because of a too high temperature at the inlet of the cooling tower, before the next drop of temperature.

To keep the bottom of the FTC cooling tower in good condition and avoid acid attack, all the injected water must be evaporated before reaching the bottom. With the synergy module, the FTC is informed of any fire moving and can anticipate properly its water injection to protect its cooling tower while keeping an optimum outlet temperature for an efficient fume filtration.

Based on a process long experience, FIVES have developed the Amelios Suite [9], a digital solution closing the loop between carbon and smelting data. This software is a global solution built on individual technology bricks (Figure 16) including the Flue Wall Monitoring module.

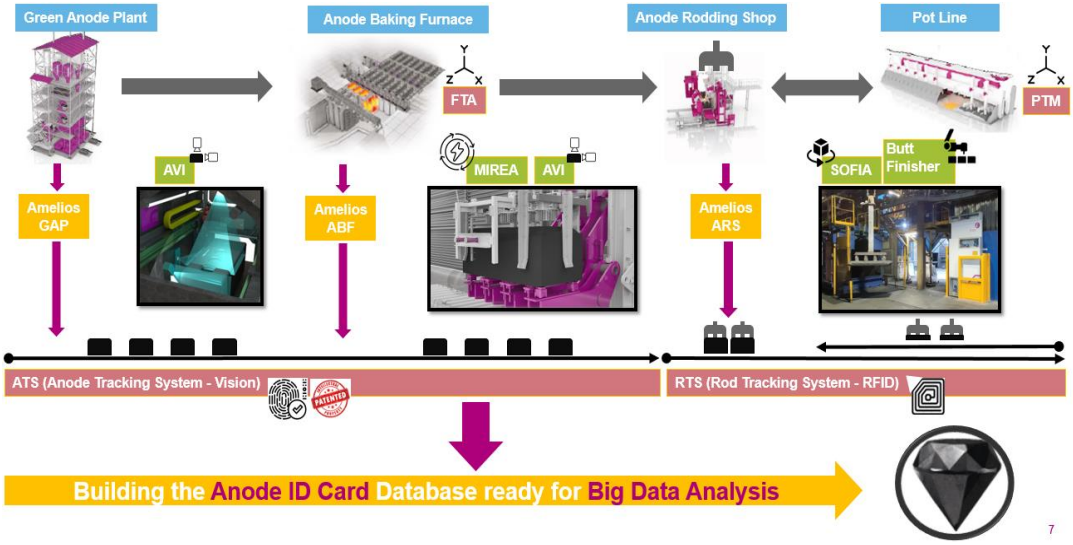


Figure 16. Amelios Suite.

The Flue Wall Monitoring module was installed as part of the FCS control system. It computes in field observations along with the baking data for refractory follow-up and maintenance planning. The deterioration of the refractory decreases the anode quality and increases the fuel consumption. The flue wall scoring helps identify flue walls in critical condition and schedule their maintenance or replacement [10]. By analyzing the baking data, the module highlights the flue walls to be checked in priority by the operator, who can fill an observation sheet according to objective criteria directly on the field on a tablet PC. All these data are compiled in reports for the maintenance and production team action as shown in Figure 17.

Figure 17. Flue wall status report and field observations sheet.

5. Conclusion

Regarding the new FCS, there is not much to say about its performance as AoG has moved back to HFO, given the current situation of natural gas market. Due to that, the performance tests of the new FCS are still pending.
Now as far as the FTC is concerned, its operation from day one up to now, is quite smooth and has improved dramatically the environmental footprint of the ABF.

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