Performance of Gas Treatment Centers in the Shadow of Amperage Increase in Alba

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Abstract

Alba's commitment toward environmental safety manifests in the mere size of its investment at dry scrubbing plant by owning 10 of them. This paper will use total fluoride emitted from the exhaust stack, and fluorination rates of those plants to gauge their performance in the shadow of potline operating amperage increase. Also, this paper will review the upgrades done and future upgrades required in those plants, and challenges overcome to eliminate amperage increase burden and minimize its negative effect on the environment.

Keywords: Dry scrubbing, Gas treatment center (GTC), Potline current increase, Fluoride emissions.

1. Introduction

Aluminum Bahrain (Alba) is the largest aluminum smelter in the world outside China. Alba recently reached a benchmark in production with a 1.54 million tonnes per year after the latest expansion of production Line 6. The contribution of Line 6 was about 560 000 tonnes while the remaining production can be attributed to the other potlines. The proportional relation between operating current and aluminum production indicates that considerable production increase was the result of current increase.

Today Alba owns 10 dry scrubbing plants to handle the pot off gases, as the production increased, so did the byproduct of the smelting process. This meant a larger load to be carried by the gas treatment plants and a possible insufficiency in emission handling. Alba's commitment to the highest environmental standards pushed the rectification of that problem as all resources were provided for a set of upgrades of the gas treatment centers in order to keep up with amperage increase.

Gas treatment centers (GTCs) are dry scrubbing plants that are meant to recover fluoride from pot off-gases, remove excess heat from electrolysis process in pots, and to supply potroom with alumina enriched with recovered fluoride which is called fluorinated or secondary alumina. A GTC plant can be divided into three sections, first the fresh alumina handling system, in which alumina is stored and transported to the filters reactor. The second part is the gas handling system where the fluorine is adsorbed by fresh alumina that is injected in the reactor, and it is also where gas particulates are constrained from escaping to the environment by fabric bag filters. Secondary alumina handling system is the third section in which fluorinated alumina is stored and supplied to the potroom pot feeding system. Figure 1 shows the process flow of alumina and off-gases through different GTC sections.

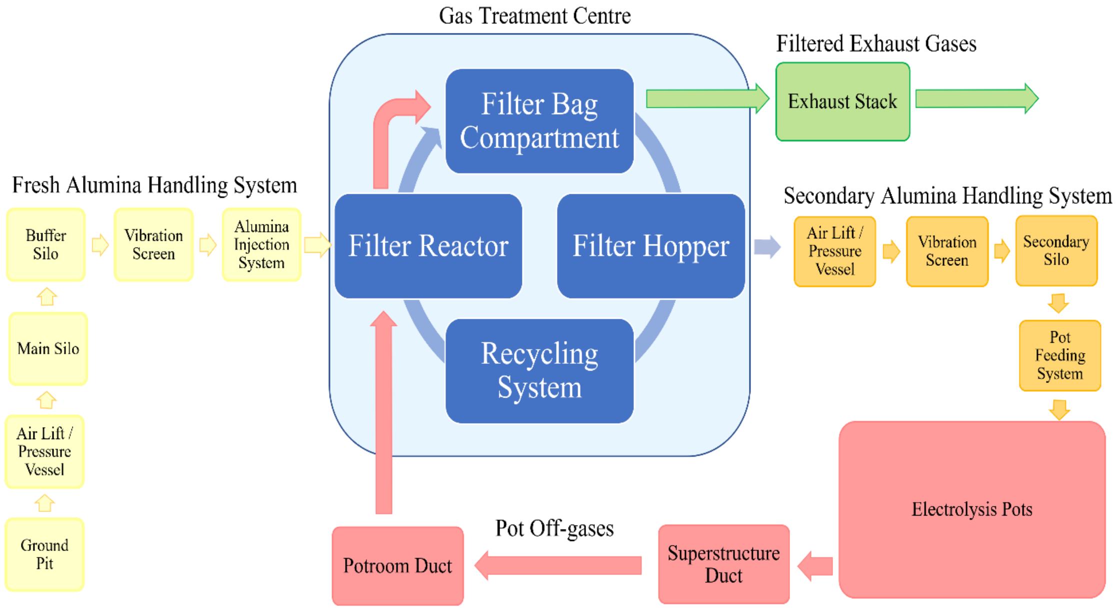

Figure 1. Flow diagram of GTC process.

GTC is a dry scrubbing plant that runs on the principle of adsorption which is the ability of solid particles (alumina in this case) to attract and trap gas molecules (hydrogen fluoride) at its surface. In addition to its environmental benefits of significantly reducing the harmful fluoride emissions [1, 2], dry scrubbing plants have a big economical effect as well through reducing the required amount of the costly additional excess aluminum fluoride (AlF_3) in electrolysis cell molten bath.

2. Line 4 Gas Treatment Centers

ABB systems (Flakt systems for aluminum industry) are used in Line 4 gas treatment centers GTC 1 and GTC 2. These plants were initially designed for a 300-kA line where 25 t/h alumina feed per plant would have been sufficient. However, as the amperage increased, so did the alumina required to feed the line and to keep emissions within the range of 0.7 mg/Nm^3 of hydrogen fluoride and 1.2 mg/Nm^3 of total fluoride emissions. Figure 2 shows how alumina feed increased during amperage increase through the years in Line 4.

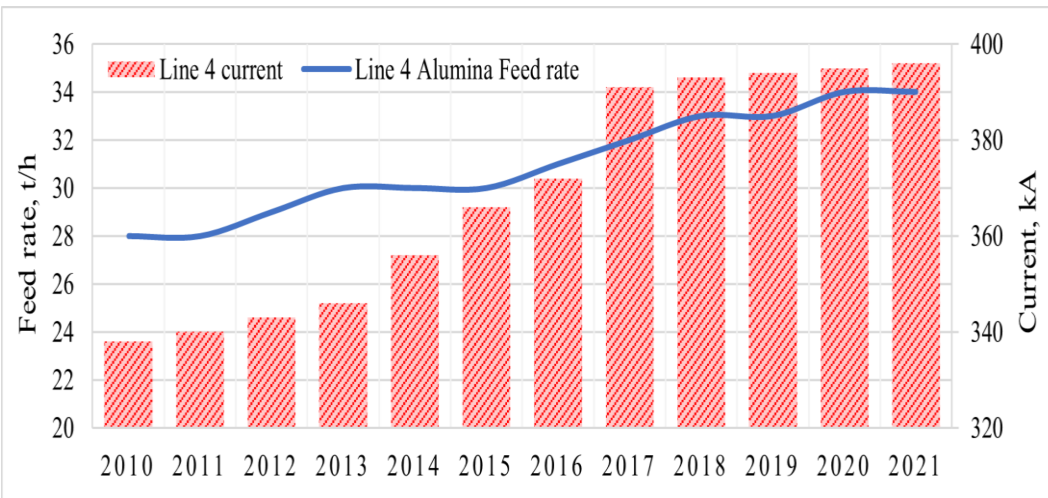

Figure 2. Behavior of alumina feed rate with amperage increase.

2.1 Line 4 Upgrade

At Line 4 start-up, the nominal feed rate was 25.6 t/h and as amperage increase progressed, the required alumina feed rate rapidly approached the plants' maxima. This was the first bottleneck in Line 4 GTC performance, obstructing the plan for amperage increase. Table 1 shows required alumina feed rates, and gas flow corresponding to several operating amperage stages. Hence, upgrade in alumina handling capacity (fluorinated and fresh) which included a major overhaul to the handling system where a new airlifts, blowers, air slides, dust collectors and vibrator screens of higher capacity were equipped pushing the capacity to 45 t/h overshooting the 420 kA feed rate requirements.

Table 1. Line 4 GTC requirements at deferent stages of operating amperage.

Current (kA)	Minimum requirements of	
	Alumina feed (t/h)	Gas flow (Nm^3/s)
370	34	346
395	36	360 Nm^3/s
420	38	375 Nm^3/s

Other limitations of GTC performance were: gas suction capability, high inlet gas temperature, and filtration area requirements. To eliminate these bottlenecks; in addition to an extra inducted draft (ID) fan, a gas cooling system (EHEX), and two ABART filters were built. Table 2 details the change in Line 4 GTC performance before and after the upgrade.

Table 2. Line 4 performance comparison before and after upgrades.

Parameter	Initial performance	After upgrade
Number of filters	16	18
Total filtration area (m^2)	25344	26819
Number of exhaust fans	4	5
Gas flow from one pot (Nm^3/s)	2.3	>2.6
Gas temperature (°C)	140	120
Fresh airlift capacity (t/h)	25.6	45
Secondary airlift capacity (t/h)	25.6	48

2.1.1 ABART Filters

The newly constructed filters are the well-known Alstom Best Available Recovery Technology (ABART**).** These are dry scrubbing plants that utilizes gas reactor design with flow conditions that result in optimal mixing of gas and recirculated alumina. Alumina is injected in two stages, where fluorinated alumina is recycled back into the reactor, while fresh alumina is used as last scrubbing effort by injecting it at the bag filter compartment. The reliability and efficiency of this technology, achieved in Alba's existing Fume Treatment Plant (FTP 4) [3], justified the selection of this technology for the upgrade. The new filters added a total of 1475 m^2 of filtration area.

2.1.2 iHEX System

In 2011 a feasibility study of the prototype of Internal Heat Exchanger (iHEX) system concluded on the success of such cooling system [4]. The study mentioned how this cooling system managed to cool air without an additional air volume (dilution), or moisture (evaporative cooling). This meant that reduced gas temperature and increased density with low additional restriction, thus a longer filter bag life, would be expected, a reduced fan power consumption, lower scaling, and lower hydrogen fluoride formation. In addition, this system had a lower operating and maintenance cost of alternatives with similar or lower cooling efficiency. The prototype was an internal heat exchanger, mounted in the filter reactor resulting in pressure drop around 0.5 Pa, where pumps circulate the shell side water through heat dumping unit.

The system was stable, consistent, and proved its efficiency in gas cooling; however, if this system was to be applied, 16 iHEX systems would be required per GTC. Each system would have its own piping, pumps, heat dumping units. This meant scaled up complexity, maintenance requirements, and costs. Thus, Alba opted for the next stage of development in HEX systems, the EHEX.

2.1.3 EHEX System

The upgrade that aimed to reduce the elevated temperature of GTC inlet gases, is a gas cooling system External Heat Exchanger (EHEX) that features shell-and-tube heat exchanger design with the utilization of water as shell side fluid (Figure 3) to extract heat from potroom gases. This system is fixed directly on the potroom duct, with only 4 EHEX systems per GTC. Water circulating systems and heat dumping units are centralized in one location for easy reach and maintenance. Each EHEX can reduce gas temperature by about 30 °C with a heat removal capacity of 3.2 MW. As can be seen in Figure 7, and Figure 8**,** the system helped lowering the average gas temperature in Line 4 GTCs inlet from an average of 140 °C to lower than 120 °C. which is the threshold where the filter bag life and alumina-fluoride adsorption rate are significantly reduced.

2.1.4 Challenges of EHEX

This new system introduced new challenges and tasks to the plants. For starters, the system needs to be periodically cleaned to maintain the efficiency of heat transfer. Cleaning needs to be preceded by a system shutdown which cannot be done in summertime. Thus, all cleaning jobs are scheduled in the winter when one EHEX system is usually not required. Another challenge was the sudden drop in water circulation system pressure. This was caused by leakage of steam vapor as the pressure increases when water evaporates during heat absorption, this meant a continuous water level monitoring is required.

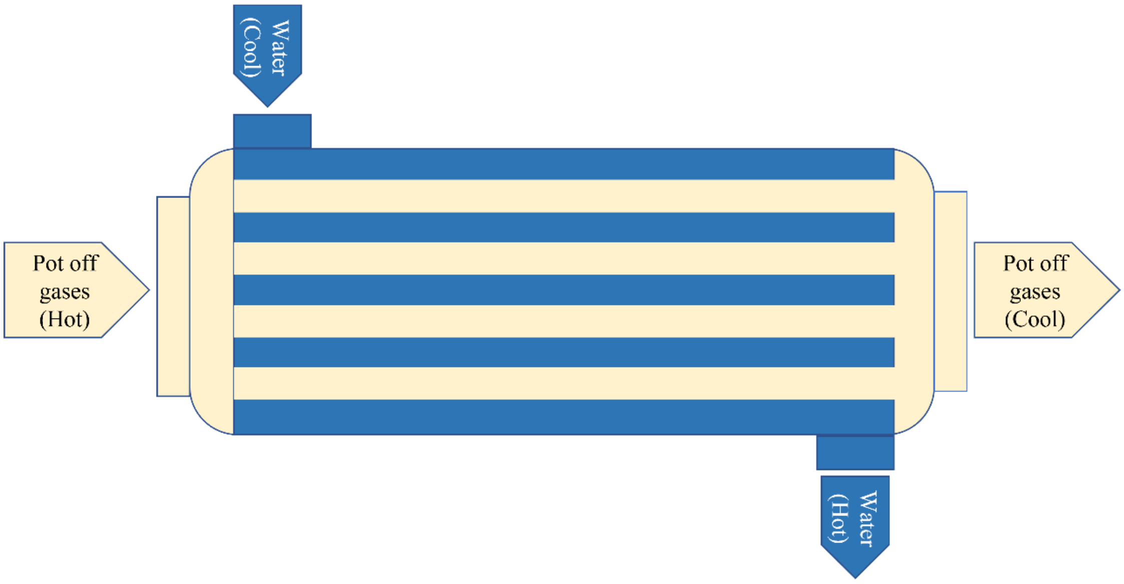

Figure 3. Schematic of shell-and-tube heat exchanger.

2.2 Line 4 GTC Performance

Total fluoride emissions from GTC stack (gaseous, and particulate) are used as an overall performance indicator where; Line 4 plants are limited to emit less than 1.2 mg/Nm^3 of fluoride to the environment.

2.2.1 Line 4 Fluoride Emission

Figure 4 shows the performance of GTC 1 and 2 as Line 4 amperage rose over time. The effect of upgrades is clear as the trends settle below the limit despite the sudden peaks which occurred due to challenges that will be discussed later.

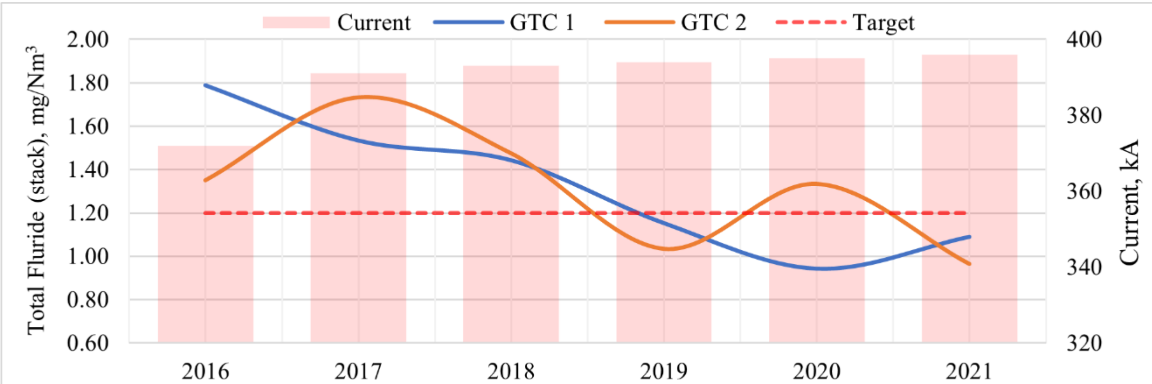

Figure 4. Line 4 GTC fluoride emission with amperage increase.

That level of performance is confirmed when looking at the roof vent emission of the potline in Figure 5. HF levels remained well below the limit, even though total fluoride touched the limit in 2017 during the same challenging period when GTC 2 stack emission witnessed a jump, but it normalized back after issues had been resolved.

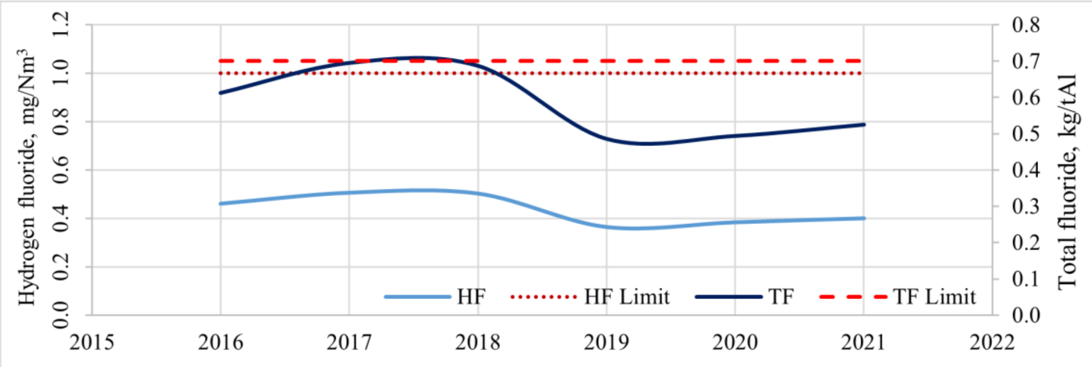

Figure 5 Line 4 roof vent emissions.

2.2.2 Line 4 Fluorination Rate

Fluorination rate is the percentage of weight of fluoride in the secondary alumina. GTCs usually are designed to have fluorination rate of 1.7 %. Figure 6 shows how fluorination was trending down until the upgrades shifted the direction of the trend upwards, reaching and maintaining the targets afterwards. It is clear from the graph as well, how stable fluorination performance of the GTCs became as the line amperage stabilized after 2017. This indicates the capability of the plants to properly handle potroom off-gases at this volume.

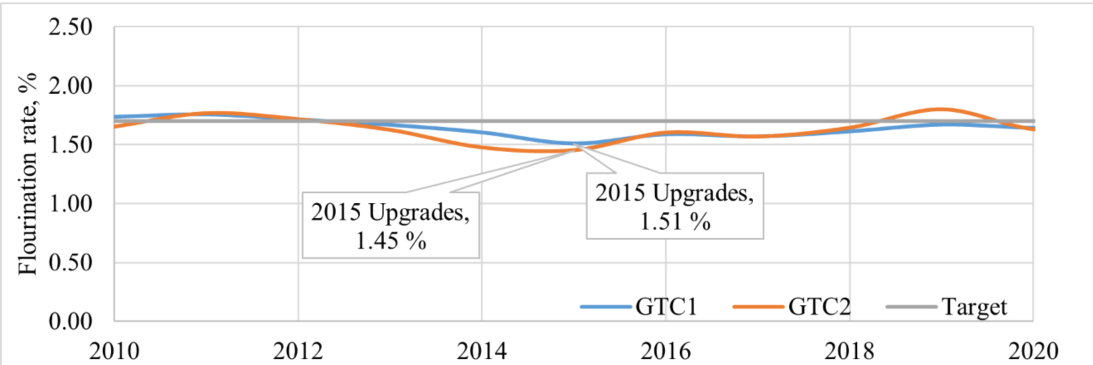

Figure 6. Fluorination rate of Line 4 plants.

2.3 Line 4 Gas Temperature

The graphs of the gas temperature at GTC inlet (Figure 7 and Figure 8), shows the impact of EHEX system. Average temperature of both GTCs decreased below the 120 °C filter bag maximum limit. This reduced the stress on the bag filters, especially during sizzling summer heat and gave more room for future amperage increase.

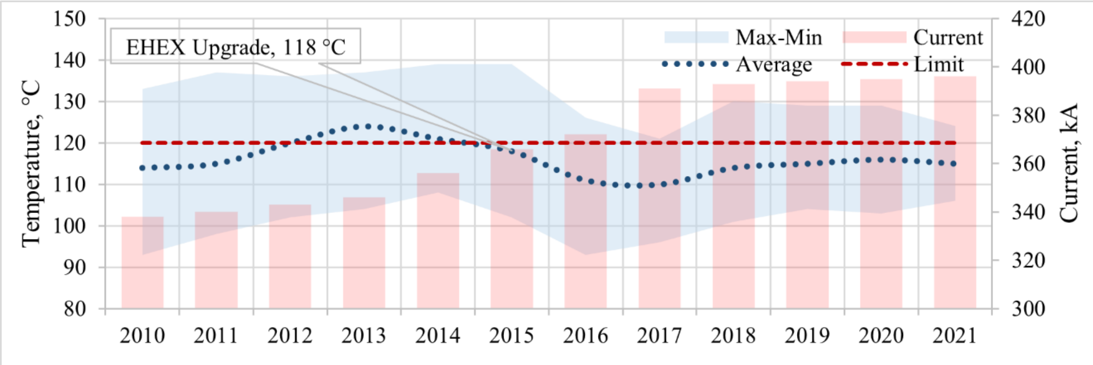

Figure 7. Temperature trend of GTC 1 inlet gas.

It can be clearly seen that the temperatures were trending upwards until 2015, when the temperature average dropped and stayed consistently below 120 °C as a result of the EHEX system. It is worth noticing as well that the temperature reduction was accompanied with continuous amperage increase.

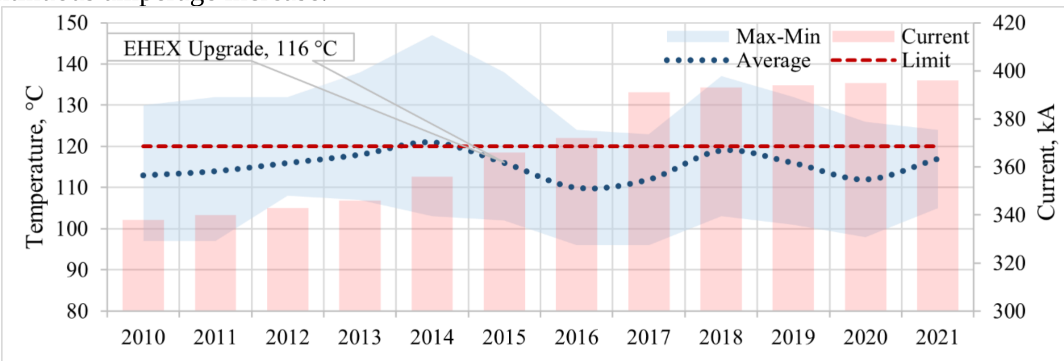

Figure 8.Temperature trend of GTC 2 inlet gas.

3. Line 5 Gas Treatment Centers

The fifth production line in Alba uses the TGT technology from SOILIOS in GTC 3 and 4. Both plants feature similar design and performance, targeting lower than 0.5 mg/Nm^3 of hydrogen fluoride and 0.8 mg/Nm^3 total fluoride emissions. Line 5, although it started up at higher current, faced similar fate as Line 4 in terms of amperage increase.

3.1 Line 5 Upgrade

To achieve the targeted amperage increase, while continuing to adhere to the emission target, a smaller modification was needed on GTC 3 and 4 in comparison to GTC 1 and 2. The starting performance parameters can be seen in Table 3 which shows the initial data and the change in performance in those plants.

Table 3. Line 5 performance comparison before and after upgrades.

Parameters	Initial performance	After upgrade
Number of filters	16	16
Total Filtration area (m^2)	33920	33920
Number of exhaust fans	4	5
Gas flow from one pot (Nm^3/s)	2.5	>2.6
Pot outlet gas temperature (°C)	150	165

Fresh airlift capacity (t/h)	40	40
Secondary airlift capacity (t/h)	34.8	50

In GTC 3 and 4, the initial capability tests showed that one of the bottlenecks was the alumina handling system, where the fluorinated alumina air lifts were not able to supply the required alumina, in addition to the fact that they do not operate simultaneously if required. The other limitation was the gas suction capability. Table 4 lists the feed rates and gas flow requirements in Line 5 plants in stages as the amperage increases. While fresh alumina handling system could meet the required 42 t/h for 395 kA, if pushed further, this was not the case of the fluorinated alumina handling system.

Table 4. Feed rate and gas flow requirements with amperage increase.

Current (kA)	Minimum requirements of	
	Alumina Feed	Gas flow (Nm^3/s)
370	38r	403
395	42	420
420	44	437

The upgrade included replacing an airlift with a higher capacity one. It also included the modification of both airlift connections in a way that enables them to be operated simultaneously, thus further increasing the system potential capacity if both airlifts were to be operated at the same time. This modification was a way of future proofing, as the new fluorinated alumina system capacity (50 t/h) exceeds the requirements for 420 kA as shown in Table 4. Table 5 summarizes the upgrades done in line 5 GTCs.

Table 5. Summary of upgrades done at GTC 3 and 4.

	Alumina handling system				Gas collection	
	Fresh		Fluorinated		Suction	Cooling
	Airlift	Screen	Airlift	vibrating screen	ID fans	EHEX
Upgrades done	-	Replaced one and added a second.	Replaced one to reach 50 t/h	Replaced particle selector with vibrating screen system.	Added a fifth to reach 2.6 Nm^3/s-pot	-

3.2 Gas Treatment Center Performance

Line 5 stack emissions are limited to be lower than 0.8 mg/Nm^3 of total fluoride, the limitation being lower than in Line 4 despite the larger gas volume handled and the higher initial operating current is a result of advancements in dry scrubbing technology over the years.

4. Line 5 Fluoride Emission

In GTC 3 and 4 as shown in Figure 9, the trends kept decreasing after the upgrades, until that ended in a sudden shift around 2017, where operational challenges that will be discussed later were found to be the cause. After overcoming these challenges, the trend peaks and shifts back to be decreasing until eventually reaching lower than the limit. As a result of plants upgrade, performance improvement kept progressing despite the continuous amperage increase.

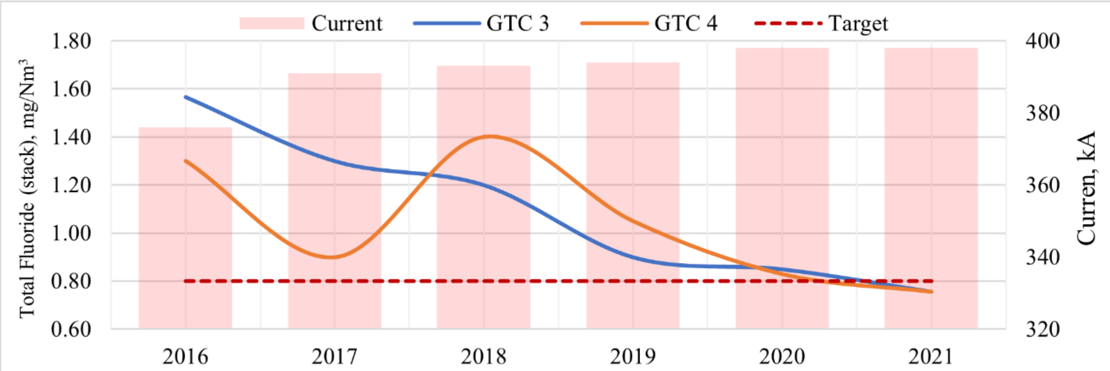

Figure 9. Line 5 GTC fluoride emission amperage increase.

For a comprehensive overview of GTC performance, roof vent emissions are represented in Figure10, HF emissions were kept in a similar range during that time. On the other hand, the total fluorides exceeded the limit in 2016 just before the stack emission peak occurred.

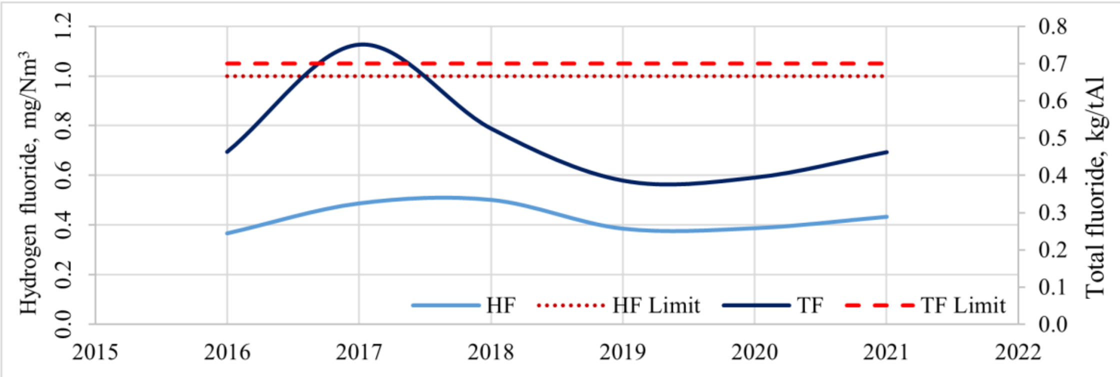

Figure 10. line 5 roof vent emissions.

4.1 Line 5 Fluorination Rate

While fluorination kept decreasing because of alumina handling limitations as the current increased, Figure 11 shows how the increment of alumina handling capacity helped reaching and maintaining the fluorination target. Also, recently fluorination rates are maintained within small deviation from the target as the current was stabilized.

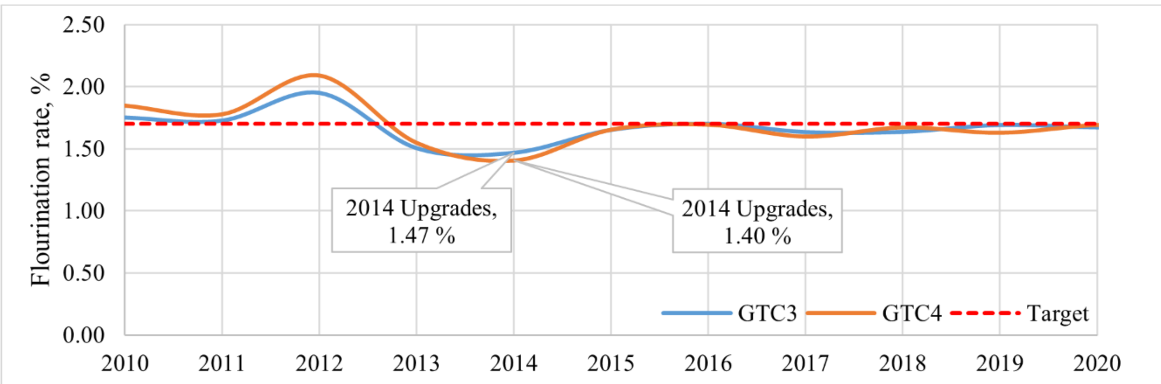

Figure 11. Fluorination rate of Line 5 plants.

5. Challenges

During any plant upgrade, many issues and challenges could be encountered, some of which may affect plants performance. The main challenges occurred during GTCs upgrade are listed next:

5.1 Filter Bag Life

Because of the higher gas flow, maintaining relatively similar bag deferential pressure to prior to flow increment despite a higher air to cloth ratio meant increasing air pulsing frequency. This greatly effects filter bag life. The effect of bag premature failure can be seen in the sudden rise of fluoride emission in Line 4 after 2019 (Figure 4) and the peak of GTC 4 emission after 2017 (Figure 9); this was not avoidable as the amperage increase was fast and started prior to GT modifications.

5.2 Pulsing System

Other contributing factor of GTC 4 emission rise after 2017 (Figure 9) was the failure of the pulsing system as the higher frequency pulsing in addition to age deterioration caused this sudden failure.

5.3 Feed System

As the fresh alumina feed rate of Line 5 exceeded the design set point, a high fluctuation and a difference between the request quantity and the actual feed was found to be causing part GTC 4 emissions rise after 2017 (Figure 9). This problem was found to be proportional to the feed rate (the higher it is from the design set point). The issue is to be addressed in the upcoming upgrade (Table 6).

5.4 Pot Outlet Dampers

When a study was carried out to investigate the root cause of the imbalance of gas flow distribution inside Line 4 GTC filter compartment, it was found that the setting of pot dampers was causing low and nonuniform pot draft distribution, resulting in low draft from each potroom set, which led to the alumina accumulation in some compartments disturbing their flow balance. Other suspicions pointed toward the effect of EHEX on pot draft, especially considering that the system excludes some pots. Despite the semi-annual balancing, this issue remains and the search for a permanent solution continues. Figure 12 shows the draft before and after adjusting pot dampers and installing a modified larger and round damper in Line 4.

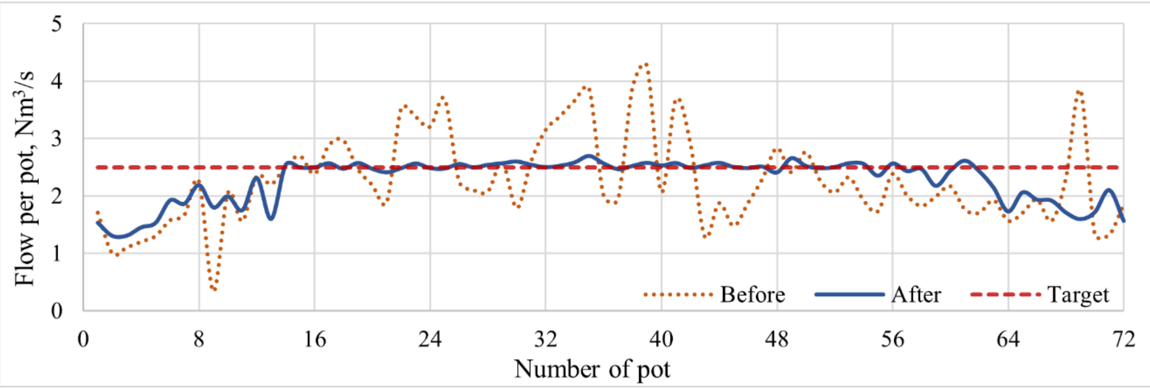

Figure 12. Pot draft distribution of potroom 7, set 1.

6. GTCs Next Phase Upgrade

An upcoming patch of modifications are in sight as progress in the road to 420 kA continues. Despite the earlier upgrades, there are still many performance bottlenecks. A study was conducted on Line 4 and Line 5 GTCs at beginning of 2022 in order to accurately assess their present condition, to identify performance bottlenecks and to lay the blueprint of upgrade strategy for the upcoming phases. Table 6 shows some of the findings of the study including the expected heat load generated per hour inside the pots through electric charge resistance and as a byproduct of chemical reactions in addition to the expected outlet temperatures at each amperage increase stage. It is worth that these temperatures will be reduced before entering the GTC's through heat loss from the ducts to the environment and by either EHEX system in line 4 and dilution dampers in line 5. The study indicated that priorities and upgrade of Line 4 GTCs will be different to Line-5 due to present status of each plant.

Table 6. Debottlenecking study findings.

Current kA	Heat load kWh	Pot flow rate (Nm^3/s)						
		2.3	2.4	2.5	2.6	2.64	2.68	2.7
400	738	171	166	162	158	156	155	154
405	782	178	173	168	164	163	161	160
410	801	181	176	171	167	165	164	163
415	826	185	180	175	170	169	167	166
420	843	187	182	177	173	171	169	168
		Pot outlet temperature (°C)						

Current and forecast conditions at Line 4.
Current and forecast conditions at Line 5.

6.1 Future Upgrade of Line 4 GTCs

The main finding of the study regarding Line 4 is the insufficient capacity of alumina handling system in these plants. It was concluded that the system is nearly operating at full capacity, and this would likely be the first bottleneck to arise. Preparation and planning to face this bottleneck have already started. In addition, the forecast elevated temperatures of pot outlet gasses at 415-420 kA as shown in Table 6 would present another bottleneck. This increase in temperatures is expected to contribute to increasing fluoride emissions up to 30 % in addition to other effects such as reducing filter bag life. There are multiple solutions being studied to address this challenge, i.e., installation of additional EHEX, upgrading filter bags to extended surface bags (ESB) [5] or adding more filter compartments. The final decision will be based on technology maturity level and the return on investment.

6.2 Future Upgrade of Line 5 GTCs

The elevated pot outlet gas temperature in Line 5 presents the main bottleneck moving forward, as the absence of EHEX system and the moderate cooling capacity of dilution dampers result in a higher inlet gas temperatures relative to Line 4 GTCs. The main challenge will be replacing dilution dampers with EHEX system or extended surface bags or adding extra filters to the plants. Also, similar to Line 4, alumina handling system in Line 5 is expected to present a bottleneck which will be addressed soon as well.

7. Conclusions

Through carefully evaluating the stated data of GTC's performance pre and post upgrade it is safe to say that the fruits of the investment in GTC upgrades were harvested. The applied solutions proved to be effective as the performance was maintained if not improved during current increase. ALBA's next goal is to obtain a similar result after reaching the next current milestone of 420 kA.

8. References

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