Electrolytic Cell Fume Cooling Technology: Case Study in Ma'aden Aluminium

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Abstract

The temperature of fumes entering Gas Treatment Centers (GTCs), play a significant role in determining the scrubbing efficiency of GTCs. As pot gas temperature exceeds 115 °C, fluoride emissions increase in GTC stacks. This has always been a major challenge for the smelters located in hot climatic conditions especially in Middle East regions. Ma'aden has four (4) GTCs supplied by Fives serving 180 pots each, running at an amperage as high as 389 kA. In Ma'aden Aluminium, apart from traditional dilution dampers, Fives have provided hairpin type duct work for each pot to cool down the fume temperatures before entering the GTC. Being the first smelter to have such a unique kind of fume cooling system in temperate zone like Eastern Province of Saudi Arabia, we will share the performance of this system during five years of operation with potline amperage increase from 370 to 390 kA.

Keywords: Gas Treatment Center, scrubbing efficiency, fume cooling technology, fluoride emission, hairpin ducts.

1. Introduction

Ma'aden Aluminium is the first vertically integrated primary aluminum smelter in Gulf Cooperation Council (GCC) countries with its own bauxite mining, alumina refinery, smelter, cast house and rolling mill. It is the first aluminium smelter in Saudi Arabia located in Eastern Province's, Ras Al-Khair industrial city. The pot technology is AP37. The first hot metal was tapped in December 2012 and the two potlines attained its full capacity operation in July 2014 with 720 pots. Since then the amperage has increased from 370 to 389 kA.

The smelter is provided with 4 GTCs supplied by Fives (Solios), each GTC designed to handle 2 450 000 Nm^3/h gas suction from 180 pots [1]. Each GTC is composed of eighteen (18) TGT-RI alumina dry scrubber modules and six (6) induced draft fans (ID fans) that are designed to maintain at all times a 2.6 Nm^3/s flowrate at each pot outlet. Furthermore, each GTC is provided with a boosted suction system to double from 2.6 to 5.2 Nm^3/s the gas flow extracted at pots during anode change or metal siphoning in order to reduce roof emissions in the potroom. Considering the high summer ambient temperature (up to 55 °C) and maximum pot gas temperature (190 °C), pot gas cooling is required to ensure the GTC inlet temperature never exceeds 135 °C. In Ma'aden, this is achieved by combining hairpin ducts (one at each pot) with dilution air.

The high temperature of pot gases at GTC inlet is a common problem in all aluminium smelters located in hot climatic zones like GCC. In general, the higher the temperature, the higher is the concentration of gaseous fluoride in the treated gas. With all the smelters looking forward to increase potline current in order to achieve maximum production, GTCs also have to prepare themselves competitively in order to meet the environmental norms which are becoming more stringent day by day.

Figures 1 and 2 show long established correlations between gaseous emissions from GTC stack with respect to inlet gas temperatures and humidity in various studies done earlier in this respect. Going forward we will study how Ma'aden GTC correlates to these hypothetical studies and performance of gas cooling system in Ma'aden GTCs.

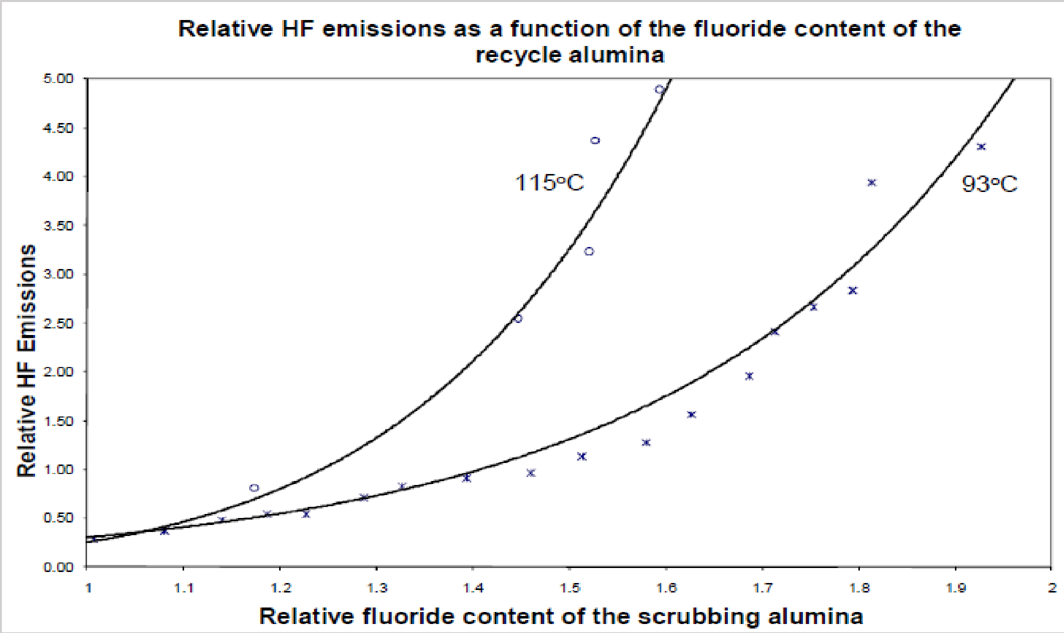

Figure 1. Relationship between HF emission and gas temperature [2].

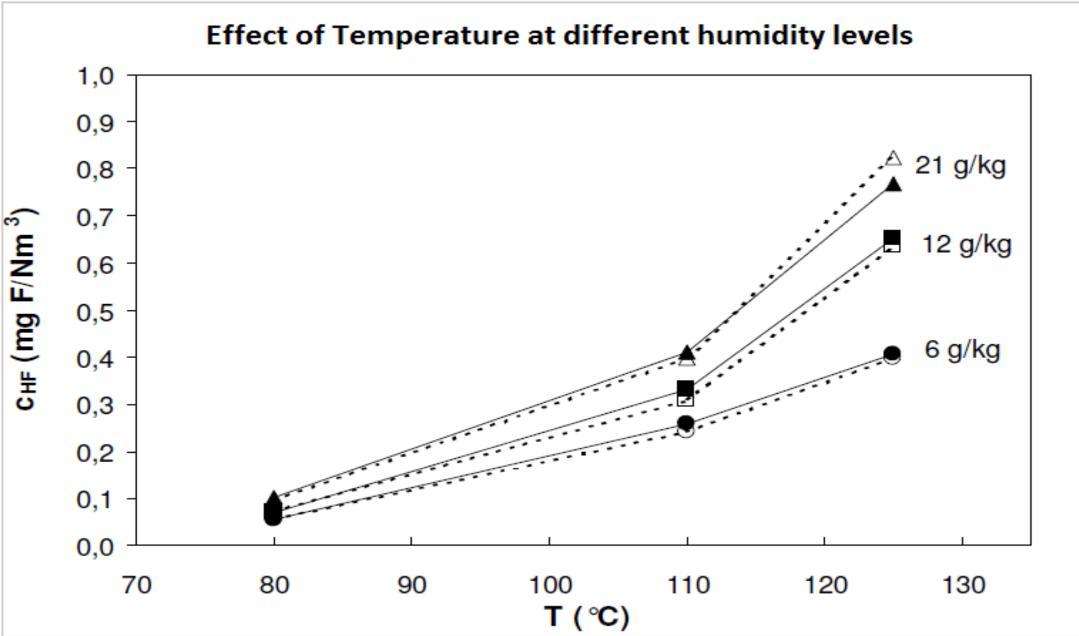

Figure 2. Relationship between HF emission and gas temperature at different humidity [3].

The temperature of exhaust gases generated from pots in Ma'aden were found to be varying between 120 - 160 °C with few pots up to 170 °C (Figure 3) and the fluoride composition at GTC inlet varying from 200 - 250 mg/Nm^3. In Figure 3, the pots located towards the south of A-Room and B-Room tend to be inclined towards higher range of temperature because of high temperature during start-up of pots in GTC-2.

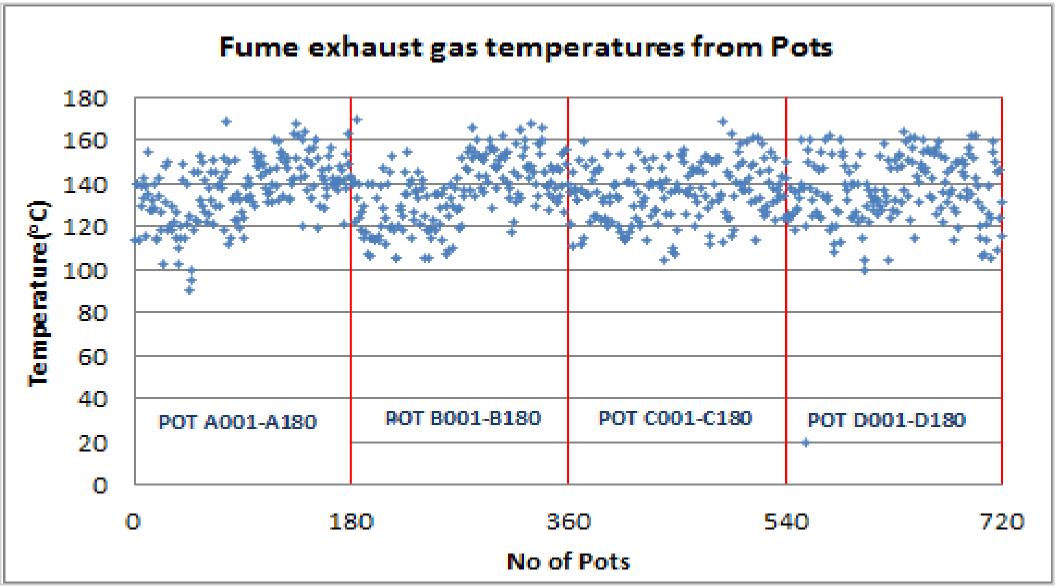

Figure 3. Distribution plot of pots exhaust temperatures in each pot room.

The temperature curve in Figure 4, an average of pot fume temperature recorded in 4 GTC inlets, offers strong relationship between the ambient temperature and GTC inlet temperature in Ma'aden. While gaseous fluoride emissions from GTC were maintained at an average of 0.25 mg/Nm^3 in winter from October to March and 0.5 mg/Nm^3 from April to September. In summer of year 2014 the average fluoride emissions were maintained well within 0.60 mg/Nm^3 but in 2015, there were several instances of emissions crossing 0.65 mg/Nm^3. High LOI content in alumina from refinery during initial days of startup was a contributing cause to this, which also increased fluoride adsorption in alumina which is evident from Figure 5. The highest inlet temperature recorded in Ma'aden GTC so far has been 135 °C.

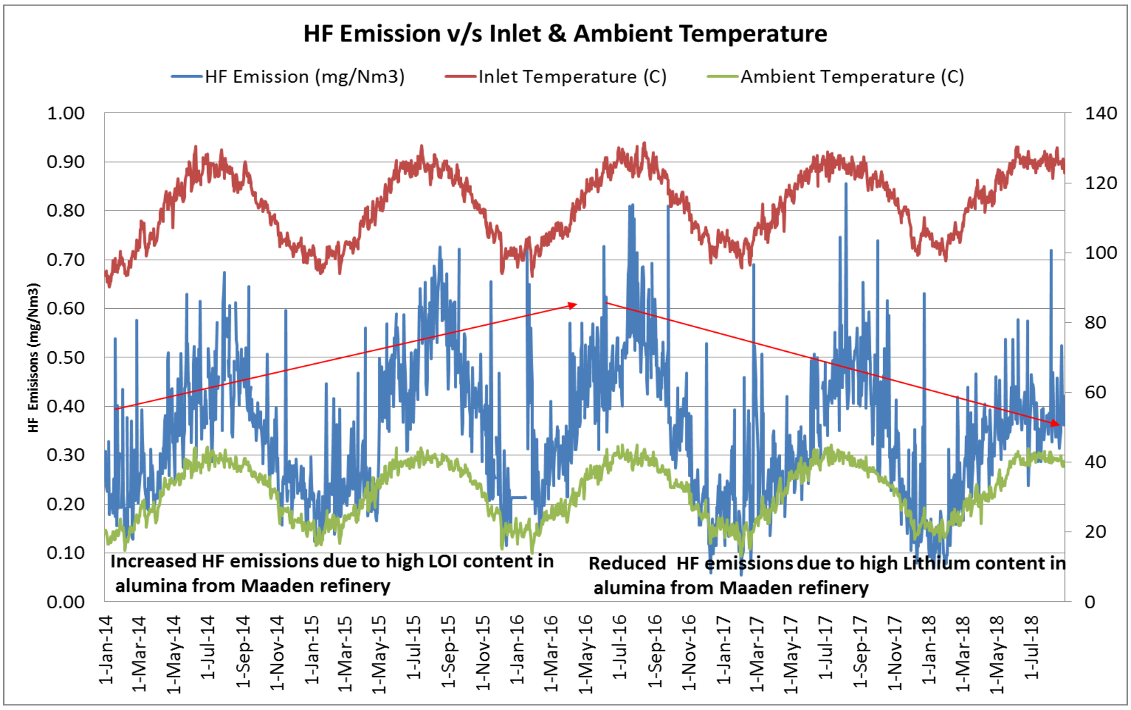

Figure 4. The scrubbing efficiency of GTC varying with temperature.

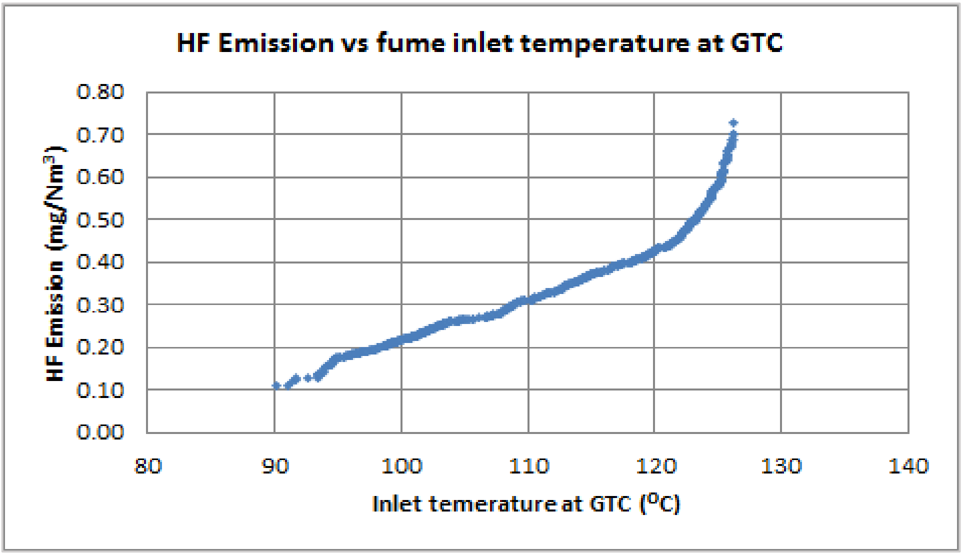

Figure 5. Relative increase in fluoride emission at GTC stacks with increasing temperature in Ma'aden GTCs (average of 4 GTCs).

The inlet temperatures as high as 130 °C in GTCs are not only disparaging to the filter bags made of polyester needle felt filter media but also increases the gaseous emission from stack exponentially which is evident with the very own data of Ma'aden GTCs (Figure 5). Though the problem with filter media can be addressed by choosing other high temperature resistant filter media which will obviously increase operation cost but this will only help GTC to withstand high temperatures but not to control stack emissions. Hence reducing the temperature of gases at the inlet of GTC itself seems to be the most effective and cost competent solution.
The traditional solution to cool down the gaseous temperature in GTC inlet has been air dilution dampers. However this solution has its own limitations.

1. The opening of air dilution dampers to collect ambient air reduces the suction from pots thereby increasing the roof emissions.
2. The additional volume of air drawn from the atmosphere increases pressure drop across the filters and increases auxiliary power consumption.
3. The humidity present in ambient air when comes in contact with alumina fines increases the possibility of scale deposition in filters.
4. As per OEM study the additional air flow increases the size of GTC up to 30 – 40 % as well as auxiliary power consumption vs. a baseline of a cold weather smelting location.

2. Fume Cooling System in Ma'aden

The pot gas cooling system in Ma'aden is a combination of hairpin ducts and air dilution dampers. Each GTC is provided with 6 sets of dilution dampers with two layers of protection, one on each side of collector duct and another on main duct, interlocked with inlet temperature transmitter which forces the dilution dampers to open when the fume temperature exceeds 130 °C.

The functioning of gas cooling system in Ma'aden is based on phenomenon of natural convection. The higher the surface area the better is the heat dissipation to atmosphere.

The extension of duct work (Figure 6) from the pot outlet to the collector duct is the key to this design. The extended length of pot ducts offers increased surface area for heat exchange between fumes and ambient air by natural convection. These ducts increase the overall path of gaseous flow by 14 meters.

Figure 6. Hairpin type duct cooling system with air dilution damper in Ma'aden GTC.

The key factors for the success of this design are

1. Positioning of the duct immediately at pot outlet, where the fume temperature is maximum and provides higher heat dissipation given the fact that higher the temperature difference, rate of heat dissipation will also be proportionately higher.
2. The cylindrical area of cross section of the ducts with regular bends which offer maximum surface area available for heat transfer to the atmosphere.
3. Relatively lower velocity of fumes inside the ducts with bends and pressure drop lower than 100 Pa.

3. Performance of Hairpin Ducts

The performance of Ma'aden gas cooling system was measured on one of the hottest days in summer when the ambient temperature was around 48 °C. The efficiency of gas cooling system was found to be the best on pots with high exhaust gas temperatures. In some instances the temperature drop in hairpin cooling ducts was found to be up to 11 - 12 °C. The efficiency of the system is also highly dependent on the ambient temperature, wind velocity and direction of sunlight. After 3 years of operation, no signs of scaling has been observed which is evident by infrared thermography with no cold spots discovered (Figure 9).

The following figures are the thermo graphic images taken at each elbow joint of the hairpin type duct work in one of the pots, A-087.

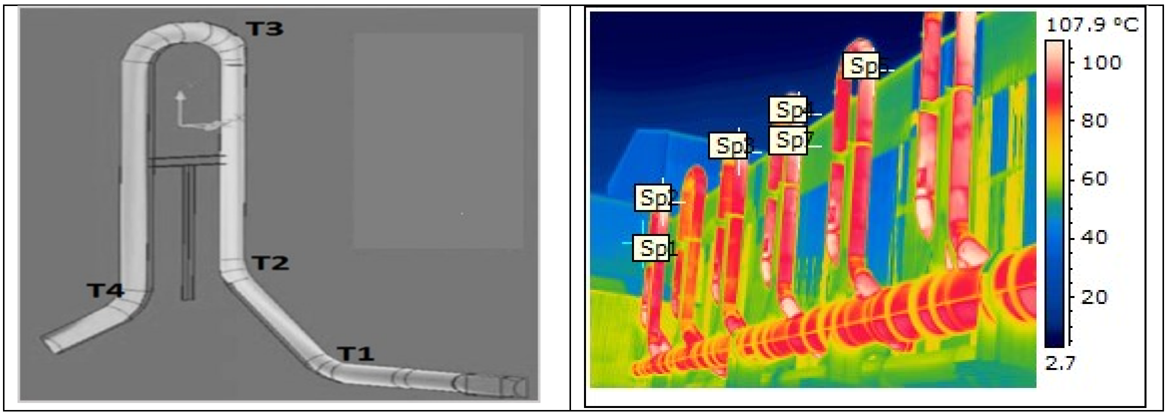

Figure 9. Representation of hairpin ducts with elbow joints at four positions.

The four transition elbow joints on the hairpin ducts serve a key purpose to the design. The bends (1st elbow from pots towards the branch duct, 2nd upward elbow at start of pins, 3rd 180° elbow at top of pins and 4th elbow at transition to main duct) all serves to increase heat exchange by forcing gas contact with pipe wall. The momentum of the gas forces it against the wall of ducts at the outer edge of each turn where it is exposed to lower ambient temperature and tends to loose heat. This is very evident in the infrared thermography images.

Table-1. Temperature drop in hairpin type ducts from one end to another (°C).

Pot No	T1	T2	T4	ΔT (T1-T4)
A-086	112	113.2	107.6	4.4
A-087	122.6	116.2	110.5	12.1
A-088	113.7	106.6	102.1	11.6
A-089	109.6	103.1	97.9	11.7
A-090	116.2	110.7	107.7	8.5

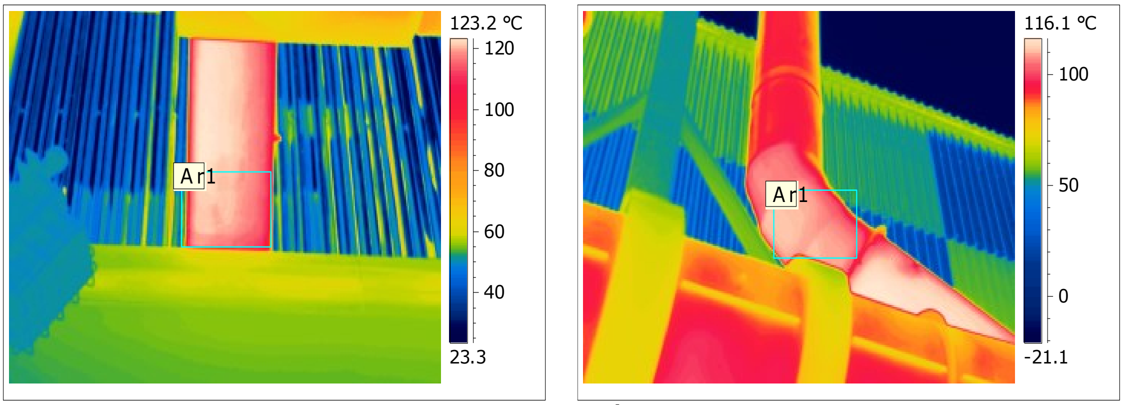

Figure 8. Thermographic image at the 1st and 4th elbow joint of hairpin duct, Pot A-087 (122.6 - 110 °C).

4. Conclusion

The hairpin type extended ducts system offers a very robust and reliable cooling system to pot line exhaust gases with a one-time capital investment. It has minimum operation and maintenance cost and it provides an energy efficient solution which makes it more competitive with the present day requirement. In Ma'aden, after 3 years of operation, with peak temperatures at pot outlets up to 170 °C and GTC inlet up to 130 °C, the dilution dampers have been hardly used. Though the efficiency of gas cooling system varies with seasonal ambient temperature and wind velocity, the system is successful to deliver the desired results. In future, with potline current increase in Ma'aden, it will be interesting to monitor the performance and efficiency of gas cooling system and if the significance of air dilution dampers will increase at higher amperage when Ma'aden smelter amperage will increase to 410 kA.

5. References

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