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DEVELOPMENT ON ELECTROLYTIC CELL GAS COOLING

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Abstract

The construction of smelters in hot climates and the increase in pot amperage are forcing the industry to consider methods of cooling the gases upstream of the GTCs. In 2012, Fives Solios presented a paper describing four methods to cool down gases: dilution air, hairpin coolers, water spray cooling, and heat exchangers. At that time, some solutions were not fully validated with operational data. This paper will present the performance achieved with those technologies on existing sites: hairpins at Ma'aden smelter, water spray cooling at Sohar smelter and pilot heat exchanger at Hydro Ardal smelter. Cooling capacity, pressure drop across the cooling device and power consumption of auxiliaries will be compared. Maintenance issues will be discussed and ideas for improvement will be presented. The CAPEX and OPEX of each solution will be updated to provide an overview of the available solutions.

Introduction

Recently, the aluminum industry in GCC countries has continuously expanded as energy is abundant and affordable. Moreover, many plants boost their production capacity by pots amperage improvements. The combination of new electrolysis cells and high ambient temperatures has led to a significant gas heat increase entering Gas Treatment Center (GTC). It has also been demonstrated that fluoride emissions increase with higher gas temperature [1].

For at least these reasons, gas cooling has become necessary. It also leads to better performance in terms of operation, power consumption, GTC sizing and carbon footprint. This paper intends to describe and compare the different approaches of pot gas cooling already implemented and currently available.

Pot Gas Cooling Technologies

As explained in the introduction, improvements in electrolysis pot technologies, especially in hot countries, leads to pot gas temperatures within the range of 170-180°C, exceeding the maximum temperature rating of the polyester felt media commonly used for filter bags in GTCs (140°C). As shown on Figure 1, HF emissions significantly increase with the temperature of gases entering GTCs. As the gas dilution flow rates needed to achieve acceptable temperatures becomes too high for new pot technologies in these working conditions, this technology is no longer applicable as a stand-alone solution for modern smelters.

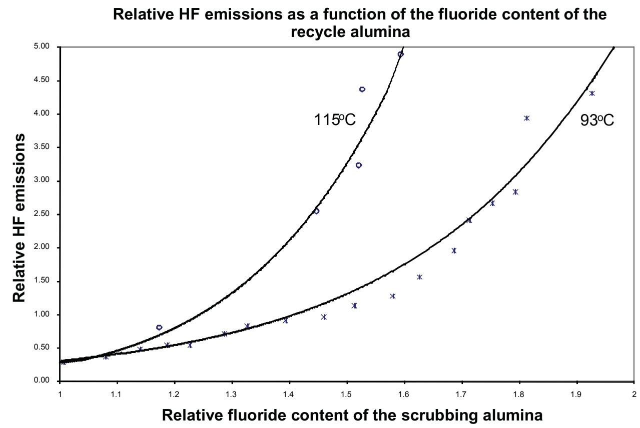

Figure 1: Relationship between HF Emissions and gas temperatures (from [1]).

Hairpin Coolers

The ductwork between electrolysis pot outlet and GTC entrance is up to 1400 meters of un-insulated pipes. The convection phenomenon along this ductwork leads to a 15 to 20°C temperature loss that is no longer enough for modern potline. Fives Solios recently patented [2] and implemented (Figure 2) the hairpin cooler system in order to increase the exchange surface between ambient air and gases with the highest temperature. As shown later, it can lead to a 5 to 15°C temperature drop (in addition to the 15-20°C of normal duct convection) that reduces the need for air dilution, therefore having an impact on GTC sizing.

Figure 2: Hairpin coolers on Ma'aden GTC1.

This technology implemented at Ma'aden GTC plant has shown its efficiency during the summer. Temperatures upstream and downstream, wind velocity, gas flow rate and ambient temperature have been continuously measured in August 2013 on several hairpins.

Measurement results give a satisfying agreement with theoretical expectations as shown on Figure 3, thus validating the calculation tool used by Fives Solios teams to estimate the hairpin temperature drop.

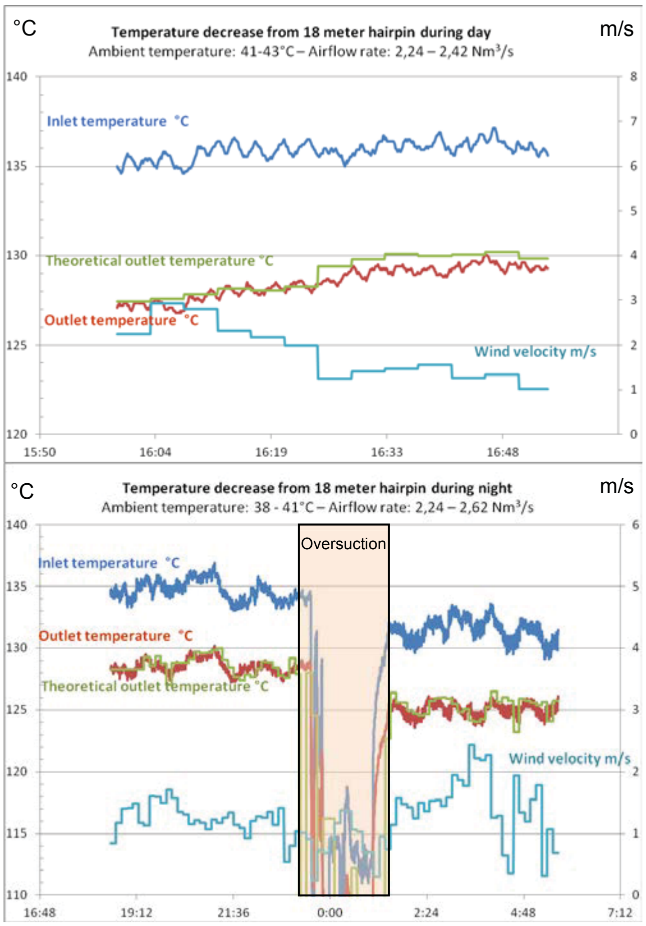

Figure 3: Graphs illustrating Ma'aden hairpin temperature decrease and the adequacy with theory.

The theoretical calculation takes into account all thermal loss phenomena, i.e. conduction, natural and forced convection, radiation and sunshine effects (depending on the latitude). The gas cooling measured is from 5° to 8°C, depending on wind velocity and external temperature. The theoretical differential temperatures calculated from inlet temperature are almost the same, with the predicted outlet temperature being about 1°C more pessimistic at times. It must be noted that the low inlet gas temperatures (130 to 136°C) and the low wind velocity (never exceeds 3 m/s, usually between 1 and 2 m/s) do not provide optimal conditions for gas cooling.

Using the same calculation tool that has been validated from these previous measurements, Table I shows some relevant cases for a nominal flow rate at 2.4 Nm^3/s and an external temperature at 45°C.

Table I: Table of theoretical temperatures using hairpin coolers.

Inlet temperature	Wind velocity	Predicted outlet temperature	
		without solar radiation	including solar radiation
150°C	2m/s	142,4°C	143,9°C
	5m/s	139,5°C	140,9°C
170°C	2m/s	160,9°C	162,4°C
	5m/s	156,6°C	158°C
190°C	2m/s	178°C	180,9°C
	5m/s	175,1°C	176,5°C

The hairpin system therefore can provide a 15°C decrease for highest inlet gas temperature scenario when gas cooling is the most required. As shown on the thermal picture Figure 4, the hottest temperatures are located in the hairpins at pot outlet involving the best heat transfer between gas and ambient.

Figure 4: Thermal picture of hairpin coolers.

Temperature decrease for hairpin coolers can now be predicted with high precision in order to fit with requirements. This solution offers optimum simplicity as it does not include additional mechanical equipment. It is therefore an ideal solution for future plants that need further temperature reductions. It also has no impact on GTC fans power consumption as the slight pressure drop increase is fully compensated by the actual gas volume decrease. It finally impacts the GTC sizing by reducing the filtering surface needed.

Water Spray Cooling

This gas cooling method is based on the installation of spray lances to finely atomize and vaporize water droplets inside the gas ductwork. Inspired from the Fumes Treatment Center's (FTC's) cooling tower, this technique is a cost-effective way to decrease hot gas temperature by 10°C to 30°C depending on smelters operating parameters and configuration.

This solution, as simple as it sounds, has been implemented only at two smelters for seasonal uses: Tomago Aluminium (Australia-2003) and Sohar Aluminium (Oman-2011) [3], because water injection in the ductwork can generate hard gray scale [4] and corrodes the gas ductwork. In order to avoid these issues, many parameters must be carefully reviewed (duct configuration, spraying nozzle type, quantity and position, gas flow and temperature, quantity and pressure of sprayed water, water droplet size distribution, compressed air pressure and flow rate, etc).

In addition to its 'know-how' on nozzles, Fives Solios has performed many Computational Fluid Dynamics (CFD) calculations in order to determine the optimum spaying nozzle position prior to realizing the Sohar Aluminium Project (Figure 5).

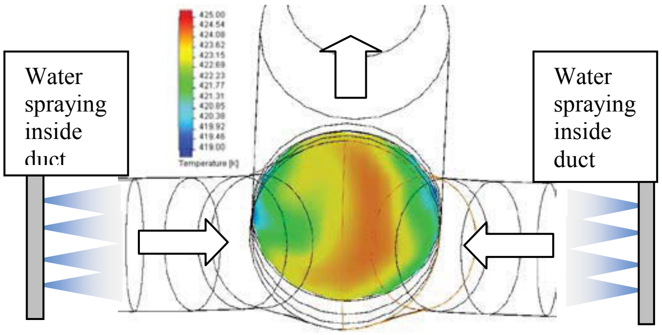

Figure 5: CFD modeling - Temperature profile in ductwork

As it was a revamping project, the temperature drop performance depended mostly on the ductwork configuration. Performance tests in 2011 showed that the system achieved the requested temperature drop (target at GTC entrance: 135°C) and all measurements were in concordance with projections: outlet temperature measured was 135°C (from 140°C to 155°C) and the water flow was about 5% less than theory. Moreover, inspection reports showed that despite slight scales constitution around nozzles, these were easy to maintain and did not affect the system's operation (Figure 6 and 7)


Figure 6: Spraying nozzle operation inside duct

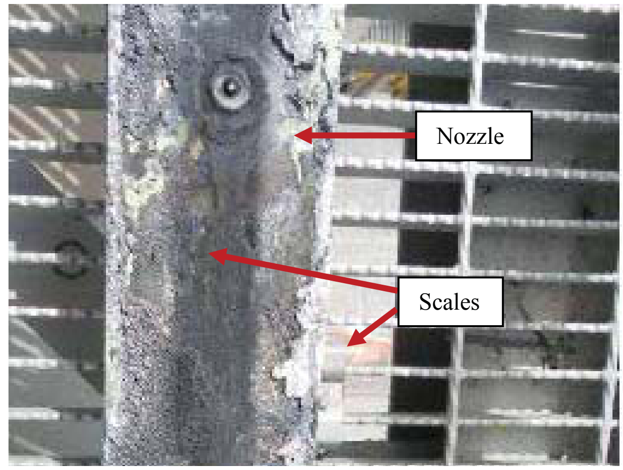

Figure 7: Spraying nozzle maintenance.

This solution is a cost effective way to decrease gas temperature in revamping projects as there is no need to modify fan performance or any other major modifications. However, this solution is not quite eco-friendly as it can require for one GTC up to 6 L/s of water. All the sprayed water is vaporized and carried as water vapor with the pot gases.

<u>Heat Exchanger (HEX) Cooling</u>

Heat exchanger development for GTCs has been one of Fives Solios's priorities for the last five years. By reducing electrolysis pot gas flow rate before entering GTC, heat exchangers can optimize GTC operating conditions and sizing.

Two heat exchanger prototypes have been implemented at Norsk Hydro aluminum plant in Øvre Årdal, Norway: a small unit (12 m²) and a large unit (129 m²) installed on five pots as shown on Figure 8.


Figure 8: Heat exchanger installed at Hydro's test center (TOS) in Øvre Årdal, Norway.

These prototypes consisted in a bundle of finned oval tubes equipped with rectangular fins. This HEX technology is characterized as having a high heat transfer coefficient for greatest compactness and low fouling [5].

The large unit (1400 mm x 1400 mm) was dimensioned for a nominal gas flow rate of 47,500 Nm^3/h at 140°C (72,000 Am^3/h), tested at constant gas flow rate for a period of one year, stopped for inspection and then tested at different fan speed. Cooling effect of the unit is depicted on Figure 9 and the overall heat transfer coefficient depicted on Figure 10, as calculated below:

$$U = \frac{Q}{A_{tot} \cdot LMTD} \qquad [W/m^2 \cdot K] \tag{1}$$

where Q is the heat duty, A_{tot} is the total heat transfer surface and LMTD is the logarithmic mean temperature driving force. It must be noted that during the first 2,000 hours working, the heat transfer coefficient decreases by about 10% due to particles settling on fin and tubes as a thin layer (from 50 to 200µm). This slight efficiency decrease is moderate and is better than in the theoretical predictions [6]: laboratory tests on annular fin-tubes have shown an asymptotic heat transfer decrease of 30% of the initial value. The difference may be due to the fin composition and the tube shape.

A slight increase in pressure drop has been also observed across the unit as an asymptote that stabilizes at approximately 33% above the initial (clean) value. This increase is considered as acceptable and was partially due to debris upstream of the HEX, which were easily removed when inspected. Although fouling leads to a low heat transfer coefficient decrease (10%) and an acceptable pressure drop increase (33%) as asymptotic values, it is recommended to occasionally clean the HEX with compressed air (once a year).

Concerning HEX maintenance during operation, it is possible to implement a rail system on each HEX unit. One HEX is composed of several units that are easily and independently removable as a drawer. Using a spare unit will allow the user to replace the fouled unit with a clean one in a short time.

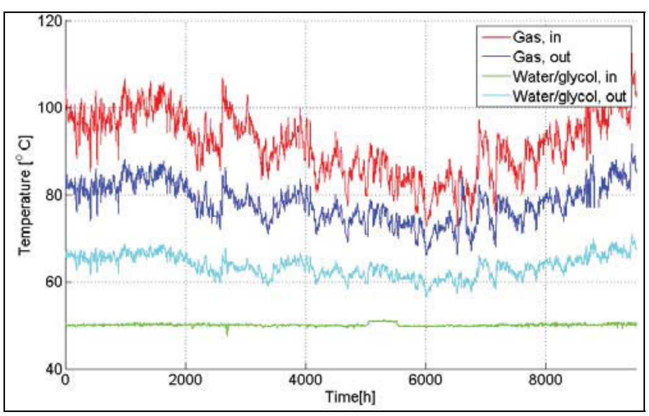

Figure 9: Process temperatures during the test run.

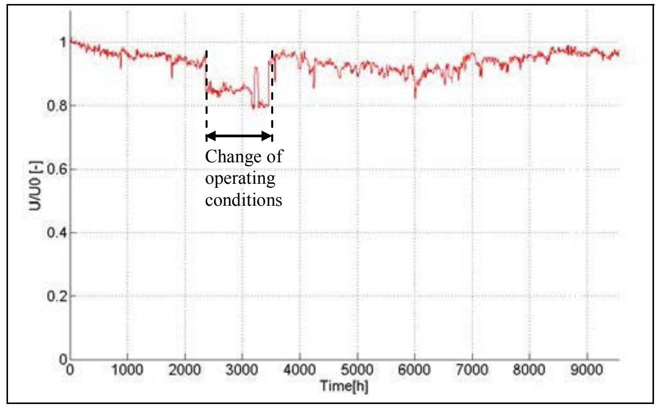

Figure 10: Development of the overall heat transfer coefficient.

Despite these good results in Øvre Årdal plant, the HEX configuration needs to be validated in severe conditions, i.e on wet and hot exhaust pot gas in Gulf countries smelters. As such, additional tests start on January 2014 in Alba smelter (Bahrain) on another test unit implemented on pot gas collector shown on Figure 11.

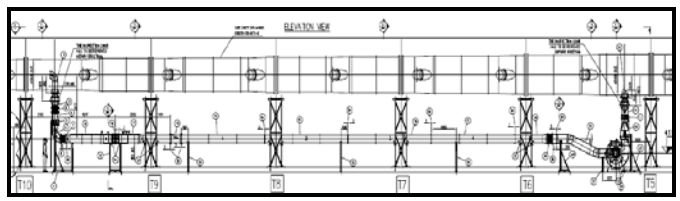

Figure 11: Heat exchanger test unit as implemented at Alba, Bahrain.

Cooling Technologies Summary Table

Table II summarizes the characteristics and pros & cons of each of the different available approaches.

CAPEX is based on Fives Solios's experience in engineering and delivering GTCs and their associated components. Complete GTC including main exhaust fans, discharge stack, upstream ducting and all internal alumina handling equipment costs 100%, used as the CAPEX reference in Table II.

The relative OPEX of the various solutions are also shown in the table overleaf. Water usage cost of \$2.50USD/m^3 is compared to power cost valued at \$0.04USD per kWh. 100% is the base fan power relative cost used as the OPEX reference in Table II.

Table II: Cooling Technologies Summary Table

Cooling system	Cooling capacity (in excess of 15-20 °C ductwork cooling)	CAPEX %	OPEX %		Advantages	Constraints	Preferred application
			Temperate Climates 25° C- 40°C	*Tropical Climates* 45°C-55°C			
Dilution air	Ideal for 5° to 15°C cooling.	+5.5 for ΔT°= 10°C +11 for ΔT°= 20°C +16.5 for ΔT°= 30°C	+20	+50	Easy to implement. No additional equipment Proven and low-risk solution	Not ideal for large temperature drop (≥20C). Increases size of GTC. Increase in power costs (ID Fans) when dilution is used for long periods. Increase total installed power	Smelters located in moderate climate with maximum ambient temperature of +/- 35°C. Frequencies of warm temperatures of +/-3 months out of 12.
Water spray cooling	10°C to 30°C with minimum temperature of 135°C after evaporation	+6.5	Compressor +8 Water usage +18 Total +26	Compressor +15 Water usage +36 Total +51	Does not increase GTC size.	Potential risks of corrosion and scales. Requires reliable instrumentation and good maintenance practices. Requires also compressed air with important consumption. Fresh water consumption	Retrofit on existing GTCs possible upstream if allowed by duct configuration. Where continuous operation is not required and dilution air can be used as back-up during cold season.
Heat exchangers	25°C to 40°C	+15	+16	+28	Does not increase the scrubber size. Lowest OPEX solution (without maintenance and repair costs) for hot climate for temperature drops greater than 25ºC. Can lower GTC inlet temperature to 110°C for better fluoride gas capture.	By-pass or modular concept design required and tube fouling to be monitored. Adds many new equipment that will add to maintenance work. CAPEX is high for applications where limited cooling is required (e.g. 5-15ºC)	Smelters in hot climates with gas cooling required at least 6 to 8 months per year. Ambient temperature of 30°C to 55°C. Retrofit on existing GTCs possible if upstream duct configurations allow.
Hairpin coolers (used with dilution)	5 to 15°C alone (up to 30°C with dilution)	+5	Dilution included +14	Dilution included +44	Simple No water required No impact on fan power Can be used in combination with dilution cooling. Low maintenance Low-risk solution	Limited cooling capacity.	Plants in hot climates with limited water supply (in combination with dilution air).

Conclusion

For all gas cooling systems, feedback from sites shows a good match between measurements and expected theory. However choosing an adequate gas cooling strategy for each site is not reduced to the simple question of the value of temperature drop but depends on many other parameters. Indeed, all gas cooling systems have their own benefits and disadvantages. That is why the selection must be done carefully in regard with the smelter's targets and country regulations. In many configurations, a combination of several techniques may be considered.

Hairpins installed in Ma'aden appear as a reliable and robust solution for a low temperature drop, as it needs no maintenance.

The water spraying gas cooling systems in operation for three summers (2011 to 2013) in Sohar show a better potential in terms of temperature drop capacities and can be an easy way to revamp many smelters.

With its flexibility and its high compactness, the heat exchanger seems to be the eco-friendly solution for future smelters. This gas cooling method has already been proved in "temperate countries" and tests in "hot countries with high humidity" are now being started.

This feedback from sites show that Fives Solios has a whole range of cost-effective techniques to manage gas temperature in the GTC ductwork, thus making air dilution almost an archaic solution for future eco-designed smelters.

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