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POT GAS COOLING TECHNOLOGIES

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Abstract

The development of cooling techniques to reduce the temperature of the pot gas has been increased enormously by the suppliers of pot gas treatment plants, since the proven cooling concept by dilution air doubles the size of the GTC's in GCC countries. Alternative options are evaporative cooling by water injection and the use of heat exchangers, however both have the risk of fouling and scaling. Danieli Corus studied several possibilities with their pros and cons to determine the optimal way of cooling the pot gas and developed a new concept of cooling. To maintain the highest availability for GTC's is one of the major topics for designs with cooled pot gas.

Introduction

Dilution with ambient air is the proven method to cool the pot gas in moderate and (sub-)tropical climates. However it will increase the size of the GTC's to an unacceptable level with respect to the CAPEX for countries with high ambient air temperature, such as in the Middle East. This effect is exaggerated by increased pot capacity and temperature through amperage creep. The pot gas temperature in these scenarios may increase to 180-200 °C and dilution with ambient air of 50 °C can more than double the total gas volume and the required filter surface area of the baghouse. Cooling of the gas is required prior to the GTC inlet due to the temperature limitation of the polyester filter bags of 135 °C. Continuously cooling the gas under these extreme conditions during long summer periods requires a solidly designed cooling system. This cooling system could be further enhanced to cool the gas even more to the reported favorable fluoride reactivity temperature of around 110-115 °C [1], which would support emission control and further CAPEX reduction as will explained in this paper. This case is taken as a basis to compare to other alternatives.

Whatever the solution for cooling the pot gas will be, the design should not interfere with the normal smelter operation and must not affect the availability of GTC systems (note that 'availability' refers to the number of hours a plant is operational, divided by the number of hours gas treatment is required over the period of e.g. a year, expressed as a %). In other words, fouling or scaling should be avoided or controlled in such a manner to minimize risks to production.

Danieli Corus is unbiased in the choice between water injection (WI) and heat exchanger (HX) technologies and thus the evaluation is reliant on information obtained from practical experience at aluminum smelters. We understand that the plant at Sohar, Oman installed a cooling system based on water injection on a full scale basis, while HXs have only been demonstrated as pilot test or small scale cooling of the gas to one filter module in moderate climates. A lack of references creates uncertainty of the behavior of those cooling installations in the long term and backup systems should be available to guarantee low temperatures at all times. Especially in tropical areas with high humidity such as Africa, Australia and India, the risk of scaling and corrosion will be higher considering the water dew point in the pot gas. What then should be the choice of the smelter?

The pros and cons for each system are described with particular attention to the risks in case of an uncontrolled situation. Based on the investigation, Danieli Corus developed and opted for a new type of gas cooling for this specific application.

Water Injection

Cooling gas by vaporization of water is a well-known technique, but its application to pot gas cooling is new and long term references do not exist. The technology is owned and patented by Pechiney / Rio Tinto Alcan but can be licensed to potential vendors. The in-duct system is equipped with two-phase nozzles using compressed air to generate very fine water droplets that require minimal residence time to evaporate. Normally a 100 micron droplet will require 1 second of residence time to fully evaporate. This is equivalent to 20-30 meters inlet ducting at gas velocities of 20-30 m/s, which is readily available in most GTCs. The short vaporization length is due to atomized water droplets which create more surface contact area with the hot pot gas resulting in rapid heat transfer and quicker cooling.

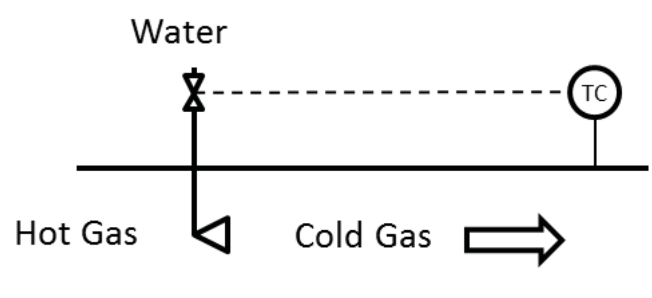

Figure 1 – Principle of Water Injection

The WI system (see Figure 1) was first trialed at the summer of 2003/2004 at Tomago Aluminium in NSW, Australia [2] and was followed by a demonstration project in Saint Jean de Mauriene, France. The system was also commercially installed at Sohar in Oman; however till now, no long term operation results have been published. We should take into consideration that thus far all the WI systems have been used to cool the gas below 135 °C and not to maintain temperatures of around 115 °C. Naturally, the evaporation will be more difficult at lower temperatures with increasing water vapor concentrations and greater risks of scaling. Plugging the nozzles should be avoided at all times, since the water will hit the walls and will produce scale. Control of the amount of water in relation to the temperature drop should be monitored at all times to detect malfunctioning of any of the nozzles.

The water is injected in the raw gas stream in the main collector ducts and once scaling starts to form, it will be difficult to remove unless a parallel duct with WI will be available as standby. Nozzles can be regularly checked and replaced by new lances without causing much disruption to the performance. Regardless it needs consistent and thorough housekeeping with an integrated monitoring system.

Pros

- Low CAPEX
- Relatively little system resistance (pressure drop)

Cons

- Redundancy requires additional ducting
- Regular check on nozzles is required
- At least 30 m of duct length needed
- Cleaning scaling when present?
- Continuous supply of potable (desalinated) water
- Increased risk of hydrolysis of polyester filter bags
- Increase risk acidic corrosion

Heat Exchanger

HXs exist in many types and configurations which could be applied to many processes requiring cooling of hot gas. The concept as it applies to primary aluminum pot gas has been considered for decades as discussed in Journal of Metals in 1984, 13th International Heat Transfer Conference [3] and TMS 2009 and 2010 [1, 4]. However, it took considerable time to actually witness HXs to cool pot gas because diluting the pot gas with ambient air has sufficed for the locations with moderate climate conditions. For warmer or hot climates, HX prototypes have been tested with reasonable results after one year testing. HXs could be located at the pot outlet, in the branches, before each filter module and main collector duct before the GTC. It would be easy just to extrapolate these demonstrations to the commercial scale, but the question remains as to whether the tests results gained in moderate climates are also valid for hot climates? It will only be a matter of time but someone will take the risk of installing HXs. What will be their potential risk?

Corrosion and/or erosion of the tubes, scaling and reduced heat transfer could occur in the long run and this might be acceptable as long as measures are available to resolve those issues without stopping the unit completely. HXs located at the pots or before each module could be replaced much easier as there is built-in redundancy. The HX at the pot can be replaced by temporarily stopping its operation, but this effect is marginal with respect to the large number of pots or a complete potline. The HX before the modules can be exchanged using the n-1 configuration of the GTC operation. Depending on the type of HX, i.e. shell and tube or finned convection banks, repair or replacement could be expensive. To cool the pot gas in the collector main would only be possible when a 100% redundancy is installed or parts of the HX can be exchanged, cleaned or repaired while still maintaining operation.

Thus far, demonstrated HXs are shell and tube and finned convection banks using a cooling medium like water or a water/ glycol mixture. The cooling medium can flow through the tubes or in the shell because both options have been tested by various suppliers. In either case, the heat in the pot gas is transferred to a liquid and then the heat in the liquid is released to the atmosphere by ambient air. This may seem odd to have a liquid as an intermediate medium to transport the heat between gas streams because it is an added step. Why not install a gas/gas HX? The answer is simple, the size of such HX would be very large, difficult to integrate and very expensive. However, one should be aware of the size of the secondary heat exchangers required for the air/liquid/air heat transfer because it forms part of the entire package for HXs.

Pros

- Cooling to optimal temperature
- No rise of the vapor concentration

Cons

- High Capex
- Footprint of secondary heat exchangers
- Power consumption of secondary heat exchangers
- Primary HX system resistance (pressure loss)
- Maintenance, repairs?
- Monitoring corrosion

Comparison – Water Injection vs. Heat Exchanger

As a design basis Danieli Corus (DC) used a GTC with our proprietary Low Pressure modules, with the ability to treat 1.7 million Nm^3/h with a maximum pot gas temperature of 184 °C, a maximum ambient air temperature of 49 °C and a controlled inlet temperature to the GTC of 115 °C. Recall that using dilution air is not a practical option for hot climates as demonstrated in the CAPEX difference between dilution air, WI and HX (Table 1). In the case where dilution air is considered to cool pot gases to 135 °C, the number of required modules is still substantially more than a HX or WI system. An outside option to cool the dilution air prior to mixing does reduce the CAPEX but the difference is still too large to accept this as a viable option. From the CAPEX evaluation, the only feasible options for cooling the pot gas are the HX and WI.

Table 1 – CAPEX comparison of Water Injection, Diluation Air and the application of a Heat Exchanger for Pot Gas Cooling

Method of Cooling	Number of Filter Modules	Relative CAPEX
Ambient Dilution Air to 115°C	25	+92%
Chilled Dilution Air at 0°C to 115°C *(reference only)*	20	+63%
Ambient Dilution Air to 135°C (reference only)	20	+53%
Heat Exchanger	12	+17%
Water Injection	12	+7%
Baseline (reference at 115°C)	12	-

The cooling systems should be designed to meet specified GTC performance requirements for the maximum specified temperature, even though these might occur just one single day or a single hour during the entire year. Hence the cooling system will be overdesigned to accommodate operating conditions for the majority of the year. How does that impact the GTC design? Does the day and night ambient temperature rhythm have influence? To investigate the true operational costs of the WI and the HX, hourly weather conditions were obtained for a Saudi Arabia site location and modeled with the potline characteristics (Figure 2).

The annual OPEX accounts for the following:

- Costs for desalinated water and power consumption of 0.40 Euro/m^3 and 0.03 Euro/kW·hr respectively
- Additional power consumption of the ID fan to overcome extra system resistance generated by HX/WI. Estimated to be 1000 Pa for the HX and 400 Pa for the WI during maximum operating conditions.
- Power consumption of the secondary air coolers required for HX
- Compressed air requirement to operate the WI spray nozzles
- Exhaust fans with fluctuating mechanical efficiency
- Cooling effects by natural convection are excluded
- Additional flow contribution from venting, leakage, pot feed systems, etc are excluded.
- A 40°C temperature increase of the recirculating liquid in the HX loop
- Pot gas exit temperature estimated at 135°C + Ambient

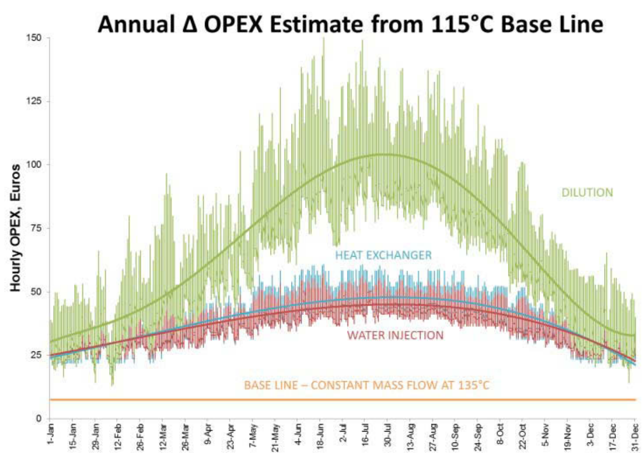

Figure 2 – Operating Cost Comparison for Pot Gas Cooling Technologies over a year

The fluctuations of the three lines in Figure 2 are due to the temperature swings from day to night. Figure 2 also shows that OPEX peaks during summer months when ambient air temperatures are highest. The additional power consumption using dilution air is due to the ID fan only since higher gas volumes require more filter modules. It is assumed in the estimate that filter modules are turned on / off as required when using ambient dilution air to maintain a relatively stable pressure drop (dP) over the baghouse.

In Table 2, the annual additional operating costs of the cooling systems are shown and should be added to the base line fan power consumption of 1,284,700 Euro/year.

The OPEX is sensitive to the cost of electrical power. For example, a € 0.01/kW·h increase will push the additional annual OPEX totals by 18% and 33% for WI and HX respectively. The WI option is more sensitive to the desalinated water cost. From Table 2, the WI and HX alternatives are at a similar level for operational costs. Some general practical observations for each alternative are stated in Table 3:

Table 2 – Operating Cost Comparison for Pot Gas Cooling Technologies

OPEX for Dilution Air to 115°C	**Cost**
Additional main exhaust fan power consumption	€ 598,100
TOTAL	**€ 598,100**
OPEX for Water Injection to 115°C	
Additional main exhaust fan power consumption	€ 61,200
Desalinated water consumption	€ 149,900
Valve rack water pump operation	€ 5,000
Valve rack compressed air consumption	€ 112,500
TOTAL	**€ 328,600**
OPEX for Heat Exchanger to 115°C	
Additional main exhaust fan power consumption	€ 99,700
Recirculating water pump operation	€ 44,100
Secondary HX (Fin Fan cooler assumed)	€ 196,600
TOTAL	**€ 340,400**

Table 3 – Practical Observations

Criteria	Water Injection	Heat Exchanger
Failure of equipment. Redundancy option.	Backup spray nozzles and pumps included.	Heat exchanger per module or inline replaceable cooling tubes, plates etc.
Additional plot area required for equipment	Minor space required for valve rack. Could be more if water reservoir required.	Significant plot area required for secondary HX.
Scale production and maintenance.	Water injection known to cause scale production if applied to dirty gas stream.	Turbulence within HX can cause scale production.
Energy recovery	None.	Possible by means of ORC, or low grade heat for offices, homes, etc.
Acidic corrosion (HF or Sulfuric)	Increases dew point temperature. Localized areas (injection nozzle) where condensation could occur.	Localized area (cooling water inlet) where cold temperature shell could cause condensation.
Maintenance	Routine maintenance required for spray nozzle condition, scale production and cleanout.	Routine maintenance required on heat exchange surfaces.

Waste Heat Recovery

The heat captured by the HX can be re-used as energy for other purposes. Based on the actual available heat absorbed on an annual basis, the energy available ranges from 17 to 45 MW_t, with an average of 31 MW_t. This figure is based on actual heat available as calculated from the hourly operational data and not just a theoretical figure based on maximum operating conditions. The heat can be converted to generate power by use of Organic Rankin Cycle (ORC) but the efficiency would only be 5-6%, resulting in an average 1.7 MW_e of produced power. This would provide a 450,000 Euro per year recovery based on 0.03 Euro/kWh. The installed capacity of the ORC should be based on the 45 MW_t, whereas the average will be only 69% of this number, leaving a significant part of the ORC installed capacity not being used during the majority of the year. The Return on Investment (ROI) for such ORC plants range from 7 to 11 years. The power prices are relatively low at the location of the aluminum smelters because the electrolysis process of producing aluminum in itself is an extremely large consumer of electricity. Therefore, it is very unlikely that the ROI for such investment will be accepted by the customers. Of course the heat can also be applied for desalination [5] or other purposes.

Developed Heat Exchanger Concept

The biggest concern for most owners and smelter operators would be the loss of cooling or indirectly scrubbing capacity as a result of possible scaling and corrosion issues linked to the use of heat exchangers. Since there is a lack of long term references to a commercial scale HX operating in hot climates, uncertainty exists around the availability, maintenance and repair. Formation of scaling might be detected from increased pressure drop or rising temperature of cooling medium, but corrosion issues and general wear will be difficult to inspect, especially with a shell and tube designs.

Most HX concepts tested are based on a single HX per module providing the operator the option to shut down one module at a time for maintenance or inspection. However, repairing a HX will be costly and time consuming so it is recommended that a spare HX be available. Direct and quick replacement of the HX will allow the scrubbing process to continue with little disruption and repair of the malfunctioning HX could be executed at specialized offsite workshops. Then the question would be how many HX's should a smelter hold on stock?

The solution to this challenge is solved by the latest development of DC. The new HX will be placed in the main collector duct in the raw gas stream and consist of several retractable independent plates. The HX consists of plates situated next to each other and installed in rows, following the length of the duct. A coolant, such as water or water/glycol mixture will be heated up by the pot gas. The heat is removed to the atmosphere and the circulating medium is cooled down by the use of secondary air coolers. A chiller option (reversed refrigerator) or vaporization/condensing system can also be applied. See Figure 3 and Figure 4.

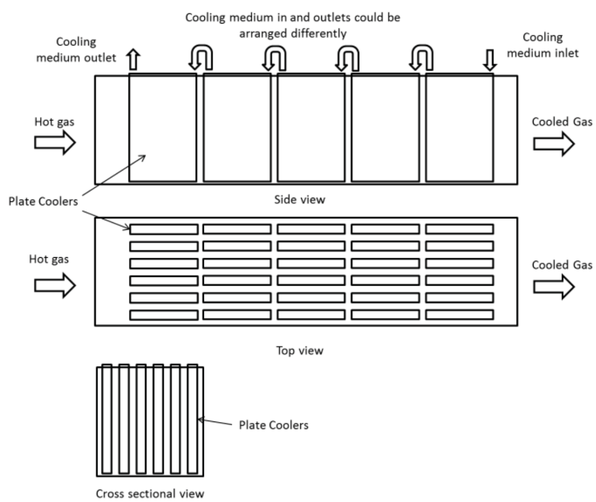

Figure 3 – Plate cooler–based Heat Exchanger Concept

An overhead monorail could lift the plates for inspection or cleaning on a spacious work platform. Since the ducting is under vacuum conditions, the operators can work safely with no pot gas escaping out of the duct. Instead some of the ambient air will be extracted from the atmosphere into the duct and diluted with the GTC inlet gas. The design of the HX will allow for a maximum amount of 5% of this additional ambient gas to the GTC inlet gas. The plates are made of mild steel and could be easy disconnected from the series of plates while not disrupting the gas cooling.

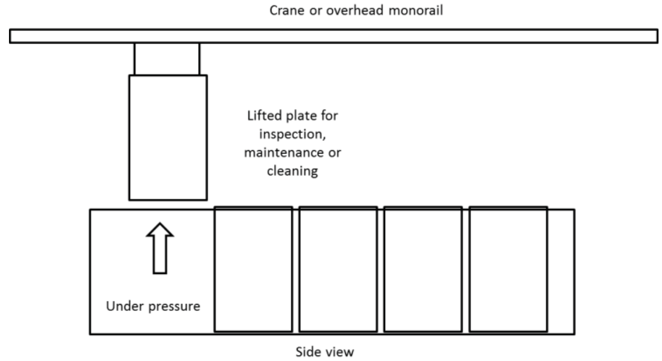

Figure 4 – Interchangeability of Plates

When needed, the plates can be cleaned or inspected and replaced when required, creating a high availability for the new HX. The multitude of plates makes it possible to have defined zones with lower cooling temperatures to control scaling on a specific location, if scaling occurs. Coatings with excellent release properties can be used to minimize scaling on the plates or it's possible that different coatings can be utilized at different locations. This new concept offers great flexibility to adapt to every situation and is able to maintain the desired gas outlet temperature at all times. The quantity of plates will be based on the maximum summer condition where the most thermal energy will have to be removed from the pot gas. This will coincide with the largest system resistance since the quantity of plates is directly associated the frictional losses. However, as the GTC operation enters periods of more temperate climates, the number of installed plates could be removed to ensure the minimal pressure drop at all times. This new system is easy to inspect, easy to maintain with unlimited availability.

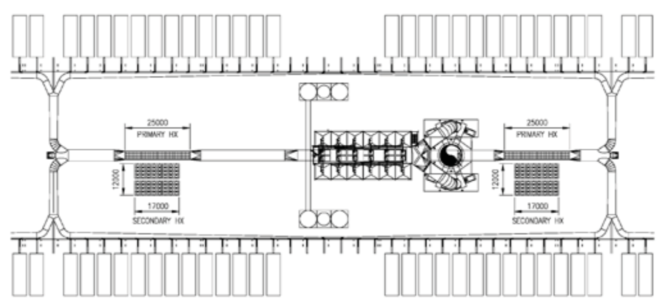

Figure 5 – GTC lay–out with primary HX and secondary air coolers

Conclusion

Cooling the pot gas at smelters in GCC countries with dilution air requires extraordinary CAPEX and OPEX costs, and hence is not the most economical and practical solution. Instead, water injection (WI) and heat exchanger (HX) systems might be utilized at GTC's to cool the pot gas to around 110-115 °C. However, no long term full scale experience is available to prove their durability and longevity. WI has been demonstrated to cool the gas to 135 °C to protect the filter bags but no operational data is available for cooling to 115 °C which is likely to have additional challenges.

Investment for a HX system will be higher than WI, but the operational costs are of the same magnitude based on hourly climate conditions. Power generation from the recovered heat does not have sufficient payback and cannot be justified based on the assumed power price of 0.03 Euro/kW·hr.. The newly developed DC modular HX is simple and easy to monitor. The next step would be a series of demonstrations to assess scale management and to evaluate its performance in hot climate conditions.

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