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HEX RETROFIT ENABLES SMELTER CAPACITY EXPANSION

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Abstract

Aluminium Bahrain (Alba) is one of the largest producers of primary high quality aluminium in the world, and continues to consider further expansions such as the planned new line 6. In parallel the amperage on the existing AP30 pot lines 4 and 5 will be increased further.

A vary typical bottleneck in the amperage creep projects concerns limitations on gas flow and temperature to the existing gas treatment centers (GTCs). Cooling can be provided by adding dilution air, or water injection, but in both cases additional scaling, HF emissions and higher costs are expected, as well as the potential for reduced lifetime of filter bags due to increased hydrolysis.

A new way to consider is to install heat exchangers that are integrated into each compartment in the existing GTCs (IHEXs) to cool the potgas. Stable heat transfer and pressure drop, and successful avoidance of scaling are demonstrated. The performance is compared to the HEX data collected for 26 months at Alcoa Mosjøen.

Introduction

Emissions of the pot gas increase with the potgas temperature, and cooling is necessary especially in hot climates such as Bahrain, and already today the potgas temperatures of Alba potlines 4 and 5 are close to the maximum tolerable for the filter bags. With an amperage increase on these pots, the gas temperatures are expected to increase proportionally, and gas cooling would be needed. Several gas cooling options have been explored, and will be discussed.

Since the first paper on energy recovery on potgas using Alstoms Heat exchanger (HEX) technology in 2009 [1] the HEX has developed from prototype into full scale demonstration units that has operated continuously and successfully since June 2009 at Alcoa Mosjøen without any need for cleaning of potgas exposed heat exchange surfaces. In addition, the many benefits of the HEX have become more acknowledged among several pot technology providers and aluminium producers. The HEX technology is therefore rapidly becoming the preferred emerging. The main reasons for this are:

1) Stable potgas flow through GTC:
The HEX provides for controlled cooling of the gas temperature into the GTC without applying water sprays and/or adding dilution air into the gas stream. Therefore the flow of alumina and gas can be fine tuned independent of hot or cold seasons, and consequently there will be no need for adding or shutting down filter compartments over the year. The indirect cooling with the HEX also avoids adding humidity into the pot gas with less risk of scaling, corrosion and HF induced emissions from the filter dust cake[3].

2) Reduced footprint and size of GTC:
Indirect cooling with the HEX reduces the volume of the pot gas proportionally with the absolute gas temperature. In addition added gas volume from dilution air or evaporated water is avoided. Both reductions in gas volume reduce proportionally the size of the gas treatment systems downstream of the HEX.

3) Reduced main fan power consumption
The main fan power consumption, the dominating power consumer in the GTC, is proportional to the gas volume times the pressure drop of the system. As shown later, the Alstom HEX adds only minimal pressure drop to the system, and in this case power reductions of up to 50% of the dilution air cooled alternative is calculated.

4) Hex integration (iHEX)
The HEX technology has evolved into a fully integrated patent filed solution (iHEX) that is located in each reactor in front of the alumina injector as shown in Figure 1. This will reduce the risk of alumina fall out in the reactors and improve the gas distribution inside and between the reactors. The integration of the HEX into the reactor also provides for easy maintenance access to the HEX with the use of existing shut off and access facilities. The iHEX would also meet the N-1 redundancy principle since one complete compartment including one iHEX is always redundant.

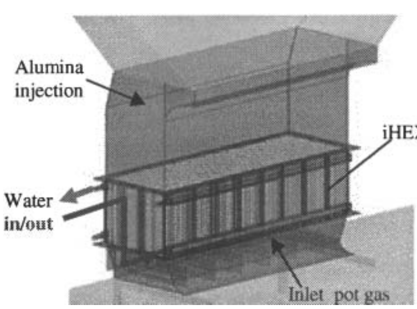

Figure 1 Alba iHEX retrofit

5) Waste heat recovery
With the HEX hot water typically in the range 80 to 110°C is available for many energy recovery options such as in hot climates: desalination, air conditioning by absorption chillers and power production (Organic Rankine Cycle). In cold climates the hot water is conveniently used for heating of buildings. As exemplified in [2] the utilization of waste heat can improve the overall specific energy consumption for a smelter with 2-3%.

The option to explore utilization of the hot water is always there at a later stage even if dumping the heat is done in the initial stage.

In this case dumping the heat may be done efficiently with dump heat exchangers located on the side of the GTC (see Figure 2).

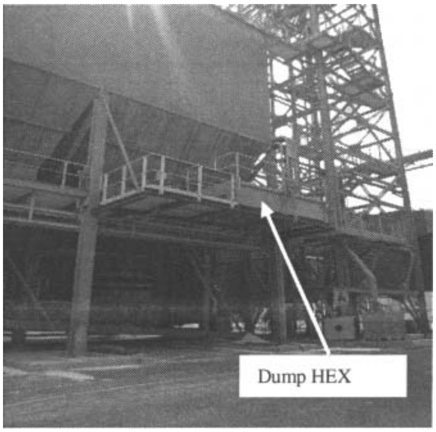

Figure 2. Dump heat exchanger integrated on the side of the GTC at Alba.

In the present paper the advantages of items 1 though 4 above have been explored to demonstrate the viability of the HEX option to enable the suggested amperage increase on line 4. The results from one iHEX installed in April 2010 on compartment 1 at line 4 at Alba is discussed and compared to the HEX at Alcoa Mosjøen. Retrofit of iHEX gives additional challenges compared to the standard green field installation, but excellent performance is demonstrated also for the Alba iHEX as discussed below.

GTC challenges for smelter expansion

The Alba Smelter Complex has been expanded several times since it was first built in 1971. It now consists of five (5) Potlines, three (3) Carbon Plants, two (2) Cast Houses, and various Auxiliary Smelter Facilities. There is also a 2,200 MW dedicated Power Plant, a 550,000 tpy Coke Calcining plant, a Water Desalination Plant, and a Marine Terminal.

The most recent major expansion was the addition of Potline #5, which was executed between 2002 and 2005, using AP-30 technology operating at a nominal design current of 330 kA. It also included major new Carbon, Cast House, and infrastructure facilities, and as a result increased overall plant annual production to a nominal 875,000 tonnes.

Potline #5 with 336 cell was started up in early 2005. Between 2005 and 2011, potline current was increased gradually to 351 kA, which is the present operating condition. This involved an increase in anode length, and other minor process control refinements. However, Alba did not make any major changes to the original Potline #5 equipment during this period. Potline #4 consists of 288 AP-30 pots, designed to operate at 295 kA, but currently operating at 341 kA.

When operating at the higher current, the reduction cells would generate additional heat that would need to be dissipated. In particular, increased heat loss at the bath/metal interface on the pot side walls would be required to sustain sufficient frozen bath to protect the sidewalls of the pot cathode lining system to enhance convection cooling of the pot sidewalls. Alba has decided that the Forced Air Cooling system to be included in this study would be based on a proven design from an approved technology provider.

Design Criteria for GTC Upgrade - GTC Inlet Gas Temperature

Operating the reduction cells at >360 to 400 kA would result in an increased off-gas temperature entering the existing GTCs. To counter the effects related to the increased inlet gas temperature, upgrade of the existing systems would be required to sustain GTC performance.

Alstom iHEX technology.

The proposed amperage increase project to 390 kAmp for line 4 and 5 is continuing, after several independent studies concluded with the viability of the project during the spring of 2011.

As shown in Figure 3 line 4 is a classic double H configuration with two 16 compartmentalized GTCs in the middle each collecting gas from 144 pots.

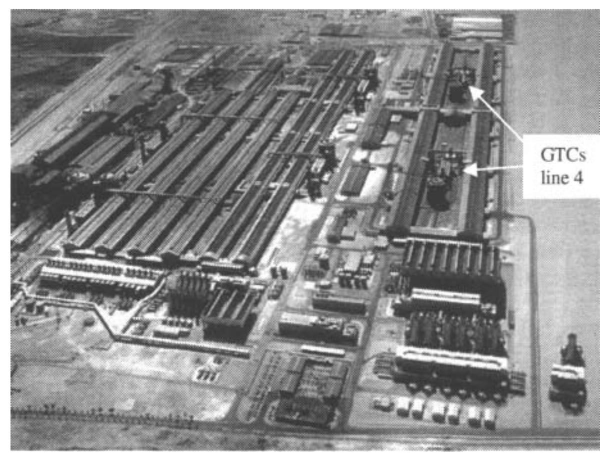

Figure 3: Aluminium Bahrain, ALBA potlines [4].

For the current study it was decided on a set of basic specifications (see table 1) that are not necessarily the same as for the final expansion project. The main purpose of this study is to show the viability of the iHEX in a clear way at industrial level.

As shown in Table 1, the impact of the amperage creep on the gas temperatures is clear, and the ability of the GTCs to handle this change must be studied. Already at the present operation the gas temperatures challenge the emission levels especially during the hot season, and as seen the projected future GTC temperatures are way above the temperature tolerable for the filter bags. In fact to maintain the same total emission level after the amperage creep, the GTC gas temperature should be reduced. Therefore a maximum GTC temperature of 120°C during the peak design condition is specified.

Gas cooling from 175 to 120°C represents a peak design cooling load of 25 MW per GTC. The corresponding cooling load for the future average case (140 to 120°C) is 10 MW per GTC. During the average case much more energy can be extracted without any additional cost since the cooling system is designed for the peak case. The average heat recovery potential is therefore at least in the range of 20 MW per GTC.

Table 1: Estimated pot gas temperatures:

	Present average	Future average	Future design
Current, kA	330	390	390
Gas Flow, $Nm^3/s/pot$	2.3	2.6	2.6
Ambient temp. °C	35	35	55
Pot gas exit temp. °C	150	155	195
GTC gas temp. °C	125	140	175

In Table 1 ambient temperatures have been selected considering that the local ambient temperatures in the smelter area can be 5-10°C higher than the average ambient air temperatures.

Several methods to cool the gas can be considered. The indirect cooling with an iHEX provides for clear advantages since no dilution air is added that require additional filter compartments, fans ducts etc. Based on the merits in December 2010 it was agreed to demonstrate the iHEX in one compartment in line 4.

The installation of the demonstration unit was executed according to the project schedule, and startup of the test was in April 2011.

iHEX experience at Alba

The iHEX is equal in design to the other successful HEX designs reported by Alstom earlier [1, 2]. The location of the iHEX is new, it is now integrated into the reactor inlet of the GTC filter compartment as shown in Figure 1. At the present time at Alba line 4 only one iHEX unit is installed to demonstrate stability and consistent good performance for the specific conditions in this smelter.

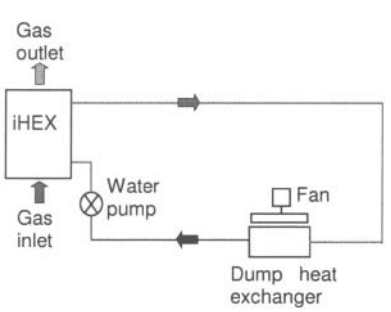

Figure 4. iHEX - Simplified Process Flow Diagram.

As with the previous HEX installations the dirty pot gas flows into straight parallel tubes with a patented inlet to minimize scaling and deposits. The water flows on the outside of the tubes and thereby cooling the pot gas as indicated in the flow sheet (Figure 4).

This design has been so successful that no cleaning of the HEX tubes has been necessary even for the HEX at Mosjøen that was put in operation in May 2009. No scaling or deposits except from a fine protective dust layer is observed as shown in Figure 4 after 26 month of operation.

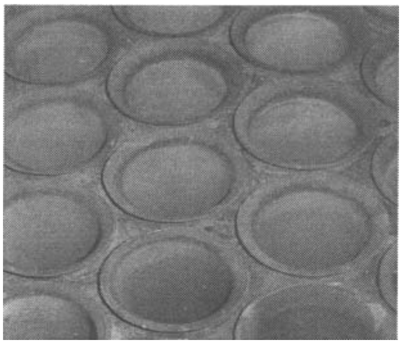

Figure 5: Inspection of heat transfer surface after 26 month operation at Alcoa Mosjøen without any cleaning.

The clean surfaces are also observed in the iHEX at Alba and Mosjøen as verified by several independent technology providers inspecting during several site visits. The avoidance of scaling and deposits brings stable and good heat transfer and low pressure losses consistent with the earlier measurements [1,2].

In Figure 6 the heat transfer ratio, HR, is shown. The HR is defined in [1] and is the measured heat transfer divided by the theoretical predicted heat transfer. As can be seen in Figure 6 the heat transfer measured at Alba is stable and slightly above the measured heat transfer at Mosjøen shown in red. The difference is most likely caused by small deviations in the experimental measurements.

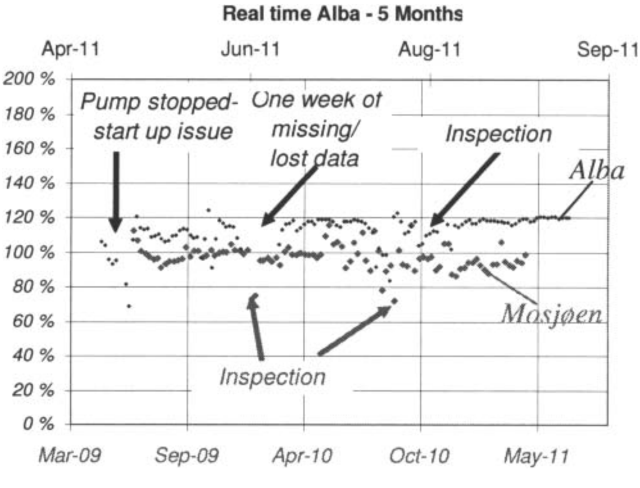

Figure 6 ; Heat transfer ratio measured at Alba compared to Alcoa Mosjøen

As indicated in Figure 6, the water pump in one instance stopped for no apparent reason during the start up at Alba and could be restarted again. Some data was lost in the data collection process as indicated. A few inspections also show up on the data scatter as seen.

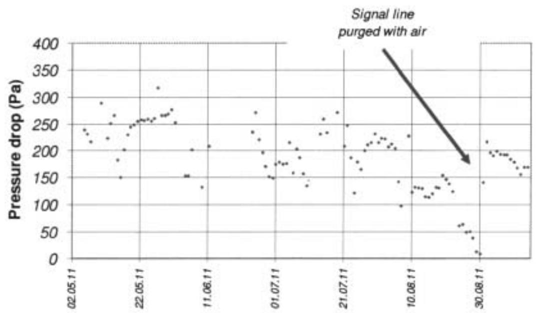

Figure 7 ; Pressure drop measured at Alba.

The measured pressure drop for the iHEX is very low - as shown in Figure 7 in the range of 200-250 Pa only. Since the demonstration iHEX at Alba is installed in one compartment only, the low pressure loss will not affect the flow distribution significantly. In fact, during the retrofit the inlet to the reactor was improved, and after measuring the gas flow in the individual compartments, higher gas flow was measured in the iHEX compartment.

As indicated on Figure 7, the scatter in the data points in large mostly due to the low pressure drop level that brings challenges to the accuracy of the measurements. In addition, the signal lines tend to plug over time. One such event is shown on the Figure where the pressure drop has leveled out at less than 150 Pa. After purging the signal lines the measured pressure drop was back at the average level of approximately 220Pa.

Effects of Pot Gas Temperatures on HF emissions

The effect of pot gas temperatures on emissions from dry scrubbers for potlines (GTC) is readily seen systematically varying both daily and seasonal. As the gas temperature exceeds 100°C the rise in gaseous fluoride (HF) emission becomes significant and shows an exponential increase with temperature. Such a HF emission scenario impacts GTC sizing and design.

As the potgas temperature is linearly related with ambient temperature at the smelters, plants located in hotter climates will need larger GTC's (as discussed above) to meet environmental legislation than plants in cooler climates.

The iHEX installation at Alba has allowed Alstom to run testing campaigns where gas temperatures into the reactor of the GTC compartment could be altered by running the iHEX in different modes by reducing the effect of the dry air coolers by switching off the cooler fans.

During the test campaigns there were no measurements of the pot gas HF concentration levels, however, HF emission monitors in the GTC stack showed stable levels during testing periods indicating that inlet HF levels was reasonable stable

A portable HF analyzer (Figure 8) was used for measuring the HF concentration in the gas.

Figure 8: Portable HF monitor from Neo Monitors AS

A response time of typically 20-30 minutes for the HF analyzer was seen (Figure 9) when the instrument was connected to the outlet of a filter compartment of the GTC. As the outlet gas of the compartment is drawn through the analyzer the air inside the instrument will be replaced with gas and in addition HF will adsorb on the surfaces of the instrument exposed to the HF gas. The effect is that the recorded HF value will be lower than the real HF value until a stable level is reached. Similarly when a HF gas concentration decreases the analyzer respond by adding (desorbing) HF to the analyzed gas and the HF reading is higher than the real value until stabilization.

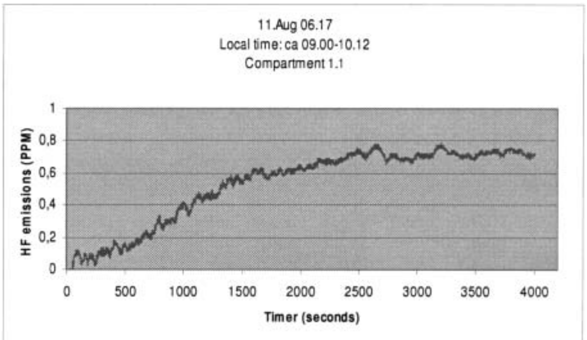

Figure 9: HF analyzer and the typical response time for low HF concentration levels.

The test campaign was performed during day time as seen from the graph of Figure 10. After a period of stable HF emission level in the morning the temperature of the gas was altered to achieve a stable level at approximately 120°C after which the temperature was reduced by increasing the effect of the heat dumping. In the late afternoon the heat dumping was again reduced and with a resulting HF emission level increase. The test was ended by setting the temperature of the gas to normal operating level at approximately 110 °C.

Between the stable temperature regions at the beginning and in the middle of the test campaign the HF reading from the analyzer suffers from response time deviations. It can be seen that at e.g. the intermediate gas temperature level of 115 °C the relative HF reading show less than 1.4 when the gas temperature and HF emission are increasing while the HF reading is almost 1.5 when gas temperature is decreasing. This demonstrates the effect of adsorption and desorption of HF in the instrument during transient conditions.

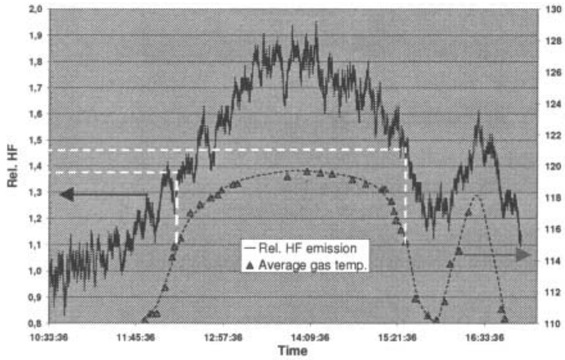

Figure 10: Relative HF emission from iHEX filter compartment as inlet gas temperatures varies

Effects of gas mass flow variations with variation of gas temperature have also to be considered as well as general dry scrubber process inertia. It is important to get a stable HF reading when comparing the result between various gas temperature levels.

This test campaign demonstrates and confirms the previous Alstom lab tests [3] that the HF emission from dry scrubbers operating with alumina is strongly related and seems to follow an exponential relation with gas temperature. The Figure 11 below shows the HF emission trend with gas temperature. As the temperature of the gas entering the reactor was increased from 110°C up to 120°C (an increase of 10°C) the instrument reading shows approximately 150% increase of the HF emission from the filter.

Below 100°C this gas temperature effect is moderate however, as it increases above the level of 115°C at the inlet of a GTC the HF stack emission is expected to follow an exponential increase.

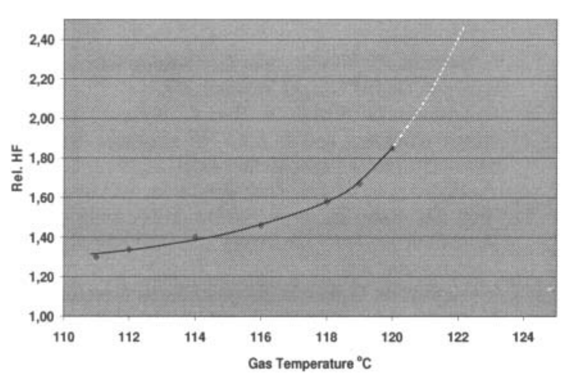

Figure 11: Trending relation for HF emission and gas temperature

Smelter expansion- gas cooling comparisons

To cool the pot gas to maximum 120°C at the GTC inlet, three alternatives have been evaluated:

1) Gas cooling with iHEX
2) Gas cooling with dilution air
3) Gas cooling with water spray to 145°C, and further cooling with dilution air.

The basic specification for the future GTC requirements is given in Table 1. In this table the columns with future design parameters gives the requirements for the sizing of the cooling systems, while the future average column specifies the average conditions for evaluation of the average power consumption of the systems including the power consumption for the GTC main fans.

The first column in Table 1 defines the existing GTC operation which is already running at maximum capacity, i.e. all future additional gas volumes requires additional filter surface. All the cooling alternatives including the iHEX are sized to meet the basic requirement of maximum 120°C at the peak conditions. In this case the future requirements in filter area (A_2) can be estimated by applying the state of gas law assuming perfect homogeneous gas and simple mass balances as shown:

Case 1 (iHEX alternative):

Increased filter surface ratio, A_2/A_1:

$$A_2/A_1= (2.6/2.3)(120+273)/(125+273)=1.11$$

This shows that the filter surface needs to be increased with 11 %, corresponding to 1 to 2 compartments, to maintain the same air to cloth ratio after the amperage increase.

In this case the main fan power is estimated readily for the existing operation assuming a fan efficiency of 75% and a pressure drop of the GTC system of 5 kPa, i.e.:

$$P_1= 5* 2.3*144* (273+125)/273/0.75= 3219 \text{ kW}$$

The increased fan power ratio, P_2/P_1, is found readily by multiplying the increased filter gas volume by the increased pressure drop due to the iHEX:

$$P_2/P_1= (A_2/A_1)(5.5/5)= 1.22$$

As shown it is assumed that the future pressure drop has increased with 0.5 kPa. Most of this corresponds to the predicted pressure drop of the iHEX. This pressure drop is almost twice the measured pressure drop demonstrated in Figure 7, but is calculated based on the predicted iHEX size required for the future max specified in Table 1, i.e. a cooling from 175 to 120 °C.

I.e. the future main fan power requirement is:

$$P_2= 1.22*3219 = 3927 \text{ kW}$$

Similar calculations can be done for the dilution air and the water spray/dilution air alternatives, but in both cases an energy balance for the mixing of dilution air and/or water evaporation must be added. As shown in Table 2 the added dilution air volumes increase the filter surface requirements significantly.

Table 2: Aluminium smelter gas cooling alternatives
(Numbers pr GTC)

Case	iHEX	Dilution only	Water + dilution
Number of added compartments	2	17	10
Main fan power requirements, kW	3927	6633	5786

In the above estimates many important elements are neglected such as added pressure drop in existing ducting and pot superstructures. In addition it is clear that the large dilution air volumes in case 2 and 3 requires large footprints for additional compartments, and added main fan capacity etc. This is much lesser of an issue in the iHEX alternative, and it is possible that the existing main fans can be used as they are in this case.

For the dilution air alternatives the large seasonal variations in gas flow will add not only labor cost to operate and adjust the GTCs continually. This will reduce the fan efficiency since more losses in the regulation of the main fans must be expected.

It should be noted that the total HF emissions in kg/ton aluminium will increase significantly for alternative 2 and 3 compared to the iHEX alternative even with the same GTC gas temperature due to the dilution air. The HF inlet concentration is higher, but at the same time more alumina is available in each compartment in the iHEX alternative leading to lower emissions under otherwise identical conditions.

For the water spray alternative significant consumption of water must be accounted for during peak cooling loads, upto 22 m^3/h. More significant is the large volume of compressed air that must be available at short notice. For these situations short time demands (2-3 hrs) of up to 84 m^3/min, 7 bar compressor air for atomization of the water may be needed. Additional compressor capacity may therefore have to be installed either dedicated for the water spray system, or in the compressor central with possible additional piping to the water injection points.

Detailed cost calculations are not provided here, but the numbers shown in Table 2 will bring significantly lower investment cost and main fan power consumption for the iHEX alternative compared to the other alternatives.

Regarding the operation cost, the dump HEX will add 5-10 kW in power consumption per compartment, and some maintenance requirements must be foreseen to repair and clean the dump HEXs. The water pumps are not expected to add much to the operation cost. Cleaning of the HEX tubes at a frequency of 1-2 years may be a reasonable worst case assumption, adding annual operation and maintenance hours related to the iHEX system in the range of one full time operator pr GTC.

Conclusion

The viability of the iHEX to enable the smelter amperage creep expansion project at Alba has been demonstrated with the following main characteristics:

1) Stable potgas flow through GTC:
2) Reduced footprint and size of GTC:
3) Reduced main fan power consumption
4) Hex integration (iHEX)
5) Possible utilization of 20 MW low grade waste heat pr GTC.

The performance of the iHEX has been measured on actual conditions at line 4, and the excellent performance (stable heat transfer and low pressure drop) have been demonstrated.

The experimental setup enables selection of the pot gas temperature independent from seasonal or other pot related parameters by controlling the cooling water temperature. This has confirmed that the HF emission levels from GTCs are strongly related with pot gas temperatures. Above temperature levels of 110-115°C the HF emission rises sharply and may double with a rise of 10°C.

The estimated filter size requirements and corresponding investments and main fan power consumptions are significantly lower for the iHEX gas cooling alternative than the other options investigated.

Some maintenance cost must be expected for the iHEX system, but compared to the alternatives the maintenance is expected to be less, due to the stable gas flow into the GTCs, and less compartments to operate.

The iHEX is an important new tool to help smelters increase amperage with minimal capital expenditure.

References

1. A. Sørhuus, G. Wedde. "Pot Gas Energy Recovery and Emission control". Light Metals 2009.
2. A. Sørhuus, G. Wedde, K. Rye, G. Nyland "Increased energy efficiency and reduced HF emissions with new heat exchanger". Light Metals 2010.
3. A. Heiberg, G.Wedde, O.K. Bøckman, S.O.Strømmen. "Pot gas fume as a source of HF emission from aluminium smelters- laboratory and field investigations. Light metals 1999.
4. M. H. Ghaith, G.Wedde. Experiences and performance of dry scrubbing at ALBA. Light Metals 1998.