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POSSIBLE USE OF 25 MW THERMAL ENERGY RECOVERED FROM THE POTGAS AT ALBA LINE 4

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Abstract

Many aluminium smelters currently choose amperage increase as a way to boost production over costly new plants. However, the increased pot amperage gives higher gas temperatures and higher gas flows to the Gas Treatment Centers (GTCs). The higher gas flows give capacity problems for the existing GTC's and high gas temperatures (above 115°C) lead to poor scrubbing efficiency in the dry scrubbers. For more than seven years Alstom has successfully developed and tested heat exchangers to cool the pot gas including self-cleaning heat exchangers that has been in continuous operation for 6 years.

In December 2013, Alba awarded Alstom a contract to supply and install heat exchangers and more filter capacity to existing GTCs installed at Potline 4. This marks a breakthrough for the heat exchanger technology that enables Alba to increase the amperage with low HF emissions. In addition, this opens up the possibility of the development of technologies to utilize 25 MW of thermal energy from the pot gas. Sea water desalination, electricity production, absorption chillers or preheating/drying of raw materials are assessed for utilizing the waste heat.

Introduction

Boosting the aluminium production by amperage increase (creep) is a common and often an attractive way to optimize the operation of an existing smelter. This may be done gradually in small steps, but eventually some modifications in the equipment will be necessary.

One of the consequences of amperage creep is typically increased potgas temperatures. Elevated pot gas temperatures may give too high HF emissions [1] and/or failure or reduced lifetime of the filter bags since they are prone to increased hydrolysis as the temperature and humidity increases.

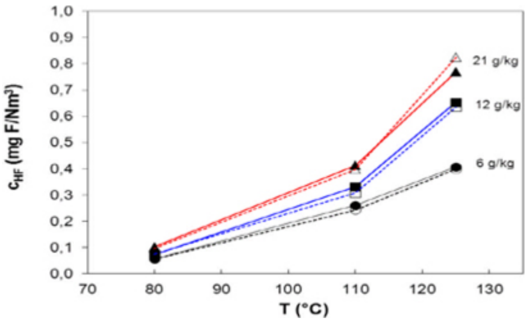

Figure 1: Chemical regeneration of HF from the filter cake as a function of water humidity and gas temperature [1].

The figure above illustrates the strong influence of temperature on HF emissions and humidity as demonstrated in the laboratory. The regenerated HF in the dust cake will leave the dry scrubber and is one of the main contributors to the high HF emissions observed at temperature levels exceeding 110 to 115°C. This has also been verified in industrial scale [4].

The trend in the industry is also higher potgas temperatures in green field smelters which are increasingly located in hot and humid locations resulting in peak pot gas temperatures in the range 150 to 200°C. The potgas is cooled in the ducting to the GTCs (typically 10-15°C), but still significant additional cooling of the potgas is required

Cooling can be achieved in several ways and Qassab et.al [4] reviews various methods including air dilution, water spray injection and heat exchanger (HEX) technology. HEX was found to be the most attractive method for the case study – Alba line 4 upgrade, where full scale HEX technology is currently being implemented for the first time.

An additional benefit unique to the HEX technology is the option to recover the heat removed from the potgas. Approximately 25 MW of waste heat will be available for recovery and utilization from Alba line 4 when the HEXs are in full operation during spring 2015. The waste heat will be in the form of hot water at temperatures typically ranging from 90°C to 60°C entering the HEX in a closed loop (see figure 2) below.

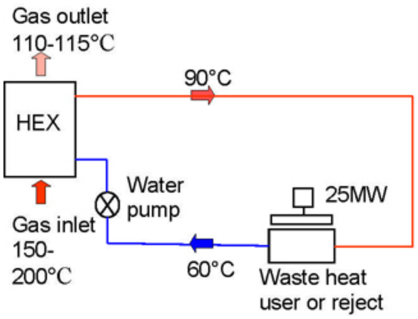

Figure 2. HEX - Simplified Process Flow Diagram.

The 25 MW waste heat from Alba line 4 is extracted from one of the 5 existing potlines, and represents alone a potentially attractive quantity of energy for use in e.g. desalination plants to produce fresh water. Other alternatives for utilization of the waste heat that will be reviewed below are waste heat utilization in chillers, power production, preheating/drying of raw materials and, for cold climates, district heating.

Use of hot water for district heating in cold climates is a clear straightforward use of the waste heat, but suffers from a limited heating season. The other options mentioned above can in most cases be utilized full year in hot climates, but requires some additional conversion of the waste heat to make it useful. The various methods and alternatives for conversion of the 25 MW waste heat at Alba to useful energy is assessed below.

HEX pot gas cooling– A Review

Formation of hard grey scale is one of the main challenges in a gas treatment facility including the possibility of insulating deposits forming on the heat exchanger surfaces. Other potential challenges are wear from abrasive alumina dust, and corrosion from SO_3 condensation.

Several heat exchanger tests have therefore been conducted over long periods of time to check for any detrimental effects from operation on real potgas. Several of these tests have been reported at earlier TMS conferences as shown in the table 1 below.

Table 1: Alstom tube-in-shell heat exchangers tested or in operation.

Start and location	Duration months	Size (kW)	HEX type	No pots	TMS ref.
2008 –ME	6 + 18	30	EHEX	1	[2]
2009 – Alcoa	70	150	EHEX	8	[3]
2009 – Alcoa	65	30	MHEX	1	[-]
2010 – Alcoa	60	250	IHEX	20	[-]
2011 – Alba	50	400	IHEX	20	[4]
2011 – Alcoa	40	800	AHEX	anode	[5]
2015 – Alba	0	8x 3000	EHEX	8x33	NA

The last entry in the table refers to the ongoing full scale installation at Alba line 4 and is shown for comparison purposes. Second last entry refers to the anode bake heat exchanger AHEX and is strictly not relevant for potgas as it in this case also includes an automatic patented [10] cleaning system based on alumina injection.

The column labelled "HEX type" indicates the configuration and location of the heat exchangers. EHEX, MHEX, IHEX and AHEX refers to External HEX, Mini HEX, Integrated HEX and Anode bake HEX respectively. For potgas the preferred type is normally the IHEX integrated into each GTC compartment, since this normally is less costly and give added benefits for the reactor located directly upstream [9]. However, for existing plants it may not be possible to install the IHEX due to space limitations, and in this case the EHEX can in most cases be fitted into the duct system e.g. as shown in figure 4.

The MHEX is designed for installation on individual pots and can potentially improve the gas flow distribution from the pots and it is located closer to the pots which may increase the energy recovery potential due to higher gas temperatures.

Figure 3 shows the inlet to the tube-in-shell heat exchanger. This geometry is used to reduce risk of deposits and is also easy to inspect and clean if necessary. The potgas enters the tubes through the patented [7] conical shaped inlets shown and flows though parallel straight tubes of length (1-6 m). All tubes are immersed into a common cooling water jacket or shell surrounding the tubes.

Even the smallest heat exchanger connected to one pot only will typically include at least 10-50 tubes depending on the diameter chosen. Each tube will feel approximately the same water temperatures on the steel surface outside as long as the water distribution is controlled. Similarly the gas distribution will be very similar into each tube which is aided by the inlet cone. The inlet cone also minimizes the inlet turbulence and deposits 1-2 diameters downstream normally observed without the cone.

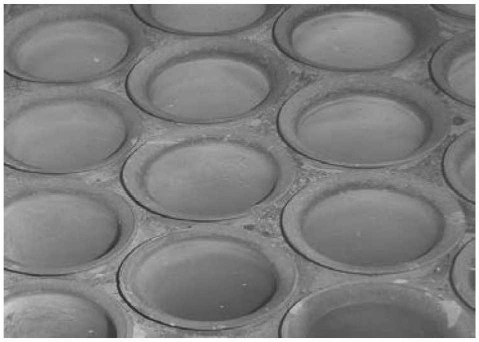

Figure 3 Tube-in-shell heat exchanger shown with patented [7] inlet cones.

Another benefit of the tube-in-shell HEX geometry is that it simplifies the sizing up to larger gas flows. In principle, all that is necessary is to add more tubes in parallel to maintain the same gas flow into each tube as before and insert them into a larger shell or add more HEX units.

Figure 3 is taken after more than 26 months operation, but even after 70 months of operation no cleaning of the heat exchanger surfaces has been necessary as observed from the constant heat transfer and pressure drop over this extended period of time. The parallel flow configuration combined with the straight tubes and flow inlet is able to keep the surfaces clean and stable over indefinite periods of time. Only a slight protective dust layer is observed with constant thickness over time.

It should also be mentioned that none of the heat exchangers for potgas have experienced any problems with wear or corrosion. Still, it is recommended to design the heat exchangers with N-1 or bypass options and include proper access doors for inspection and maintenance, see figure 4.

HEX at Alba – Going Industrial

In December 2013, a contract was signed with Alba to provide 4 EHEXs and 2 Abart-C-308 compartments for one of two GTC in potline 4. In April 2014 the original 4 EHEX project was extended to include the second GTC. Figure 4 shows one of the 8 EHEX which currently are under installation for the two GTCs. Each EHEX is designed for high gas temperatures and are able to cool 3 MW each. The cooling system has been prepared for added capacity in case of future amperage creep.

Since 2011 an integrated HEX has been in operation at Alba [4] without issues, and this has demonstrated the robustness of the technology. The final design of the full scale EHEX includes more than 1000 pipes packed densely in the shell. The HEXs at Alba are 3.5 meter in diameter, 4 meter long and will weigh more than 35 tons each. The number and size of the heat exchangers has been optimized according to both transport and cooling requirements. The EHEX shall be installed during normal operation of the potline.

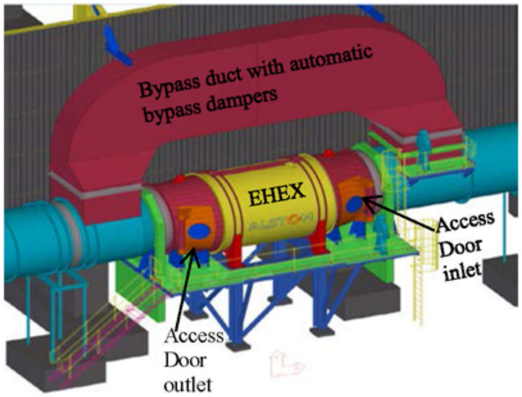

Figure 4: Horizontal EHEX located in main duct before crossover at Alba line 4 (1 out of 8 EHEX's is shown).

For the full scale heat exchanger project, careful detailed documentation was prepared, and a complete Hazop (Hazards and Operability)-study was performed of the process and all subsystems.

Each EHEX has a dedicated and independent pump and dry air cooler system, with a standby pump for the group of four EHEX pr GTC. Careful studies of possible hazards during operation of pumps & valves and of the bypass operation was performed. No major hazards were found, but several smaller findings related to accidental loss of power or air was identified and rectified.

As shown in Figure 4, the EHEX is equipped with a bypass duct. In case of failure of both the dedicated and the standby water pumps, the gas will be directed automatically to the bypass duct. Automatic operation of the bypass dampers is ensured in all situations. The bypass duct also enables inspection of the EHEX without interrupting the electrolysis. Three out of four EHEX in operation is sufficient to cool the gas, and two heat exchangers alone will also manage most temperature scenarios.

Utilization of Recovered Energy

The recovered energy at Alba Pot line 4 will presently be dissipated in several (8) large dry air coolers (DAC). With the large quantities of thermal energy, the question of how to utilize the energy is raised. The reason for investment in heat exchangers for cooling the gas is primarily to protect the filter bags and to reduce the HF emissions as mentioned earlier. As a by-product low grade waste heat is available for "free". The use of low grade waste heat is in general challenging, but several means of the utilization have been suggested [3] such as:

- District heating
- District cooling through absorption chiller conversion
- Preheating/drying of raw materials
- Desalination
- Power production in Organic Rankine machines (ORCs)

In many cases utilization of the waste heat requires an infrastructure and systems that can be more easily implemented at a green field smelter. Still, as in the case of Alcoa Mosjøen a step by step approach will be described where the goal is to implement all the waste heat at an existing smelter. Also smaller applications may be found where part of the heat is used only and the rest is dissipated.

In the following some energy utilization alternatives are discussed.

Hot water – District heating

In cold climates, district heating is an obvious candidate for utilization of the recovered energy. It readily replaces other fuel sources such as oil and gas. Investments in infrastructure (piping, pumps) etc. is needed to supply the heat to internal and external consumers of the heat.

At Alcoa Mosjøen, the heat exchangers from Alstom are connected to the existing district heating systems which are currently heated mostly by 2 x 9 MW LNG burners [3]. Alstom's heat exchangers at Alcoa Mosjøen (see table 1) already reduce a significant part of heating season where the LNG gas is needed.

In 2014, the existing district heating infrastructure was upgraded to include the AHEX connected to one compartment in the anode bake fume treatment center adding approximately 6-800 kW energy recovery to the system. In the long run all the LNG gas currently used can be replaced with recovered heat from the smelter off gases, and the aim at Alcoa Mosjøen is to build up the energy recovery capacity step by step.

The main heating season at Alcoa Mosjøen lasts typically from September to May, but some heating is required all year with peak loads during a few winter months. In the summer time significant surplus of heat from the heat exchangers will be available and one potential use of this heat is to produce power in and Organic Rankine Cycle machine. One such machine is currently under testing at Alcoa Mosjøen as the first of its kind connected to an aluminium smelter. Some initial results are shown below.

Hot water conversion to cool water- District Cooling

In hot climates district cooling systems are increasingly used to cool buildings and even entire communities adding to the efficiency , reliability, and reducing the cost of the overall cooling system. The operation cost of the cooling system can be further reduced by converting the waste heat from the potgas to cold water in an absorption chiller assuming that the distance to the consumers of cooling are in relative vicinity of the smelter.

Conversion of waste heat to cold water in an absorption chiller is an alternative to the conventional compressor cooling machine used extensively today. Typically a Li-Br mixture with water is used to adsorb heat to produce cold water at 4-10°C that can be transported in district cooling systems to cool buildings and other processes. The waste heat is used in the cooling process to strip off the water from the LI-Br water binary mixture before the concentrate is returned to the absorber for another cooling cycle.

The absorption cooling process is one of the oldest principles of cooling known and was used extensively before the compressor cooling cycle was introduced. The compressor made it possible to produce cooling in smaller and less costly machines, but at the added cost of electrical power for running the compressor. Therefore when waste heat is available for “free” the increased cost of the absorption chiller can be attractive due to the lower operation cost. Absorption chillers are also know for low maintenance, high reliability, long lifetime and are inherently silent which also add to the attractiveness of these machines.

The coefficient of performance (COP) of the absorption chiller is defined as the amount of cooling produced compared to the heat input. A COP of approximately 0,4-0,5 may be realistic for a typical smelter site [11], i.e. for Alba line 4 in the order of 10-15 MW of cold water can be produced from the 25 MW of waste heat available. To produce a similar quantity of cold water with a conventional compressor based cooler could require additional electrical power consumption in the order of 3 MWel.

Many of the new smelters are located in hot climates where cooling is required all year, and the waste heat available is more or less in phase with the seasonal variations in cooling requirements. Still, more cooling than required internally for the smelter can be produced. Additional cooling may be sold to the community nearby or be used in cooling of inlet air to gas turbines [8].

In 2011 a study was done to check the feasibility to replace the existing compressor based air condition units with absorption cooling units at an existing motor control (MCC) room located adjacent to a HEX system in a typical smelter site in the Middle East, and an investment rate of return of 22 to 28% was calculated [11]. The total cooling load in this case was in the range of 50-100kWth and this will only consume a small part of the cooling that can potentially be produced, and illustrates that part utilization of the total waste heat can also be attractive.

Hot water – Desalination

Many aluminium plants in Middle East include a desalination plant integrated with the plant’s power plant. Normally a part of the steam produced in the power plant is extracted at typically 120°C and used for heating the desalination plant. The feasibility of replacing the extracted steam from the power plant and use recovered energy from a HEX system from a AP 40 potline located in the Middle East to heat the desalination process was studied [6].

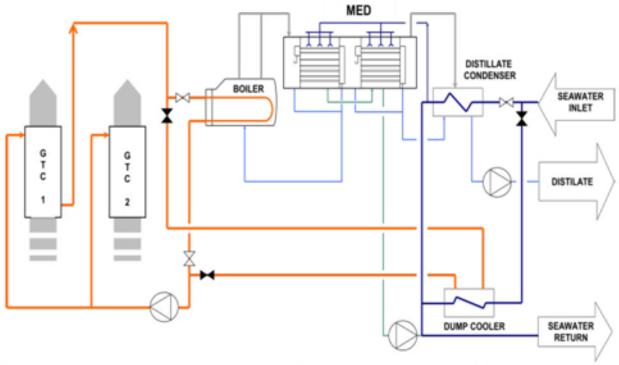

Figure 5 – HEX – Multi Effect Distillation (MED) interconnection diagram [6].

The influence of varying seasonal and daily temperatures and corresponding variations in the waste heat availability was studied in particular. In general the waste heat temperature range extracted from the potgas matches well the temperature requirements in the desalination process. Too high temperatures (above 100-110°C) may give issues with corrosion from the sea water brine.

Figure 5 illustrates the connection diagram used in the study. The HEXs supply the waste heat from the AP 40 potline to a steam generator that heats the conventional multi effect desalination (MED) process.

Two cases were assessed:

1) MED with 2 effects for production of water for internal aluminium smelter use only, and

2) MED with 8 effects for maximum production of water from the available waste heat assuming all the water can be sold to external clients.

As shown in figure 6, lower production cost of water was calculated with heat recovery compared to with steam extraction for both cases:

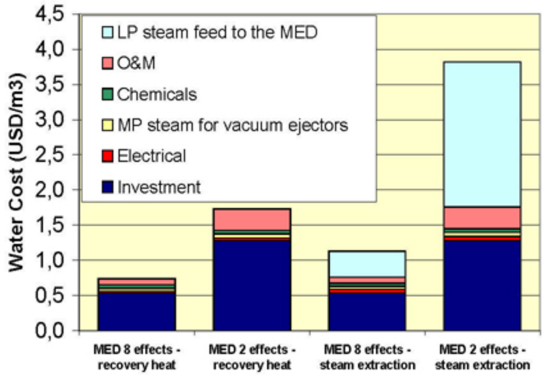

Figure 6 – Specific water production cost for desalination with energy recovery versus steam extraction [6].

As shown the production cost of water is highly dependent on the scale of production with lower cost for larger units. Still, a small size desalination plant for internal smelter use based on a self-reliant supply of water will always be a clear advantage. Also the cost of water from an external supplier will depend on location etc. of the plant.

Preheating/drying of raw materials

Direct heating or drying of raw materials or processes internally on the plant or nearby plants will always be the best option if the heat consumer can match the low temperature heat source supply and quantity that can be provided from the hot water at 80-90°C.

A number of possibilities could be explored such as:

Pot line:

- Preheating of Alumina before entering the pot cells
- Preheating of anodes

Carbon plant:

- Pitch oil heating : normally the pitch oil is kept at +200°C . One possibility to explore is to use high temperature heat pumps to produce + 200°C heating from the hot water, however at the cost of power for operating the heat pump.
- Drying /preheating of coke and other feedstock that keeps lower temperature than 90°C.

Alumina refinery:

- In many cases the alumina refinery is more or less integrated into the smelter site. Many parts of the alumina refinery could potentially benefit from drying/preheating.

Power plant:

- Integrated power plants could benefit from preheating of e.g. feed water.
- Converting waste heat to cooling has been discussed to cool gas turbine inlet [5].

Further studies are needed to valorize the above possibilities, and surly many other options can be evaluated not known at this stage.

Electricity production from hot water

The hot water from a HEX normally holds a temperature of 80-90°C. Traditionally such temperatures are not useful for electricity production. With the ORC technology, this may change.

Power production with ORC uses the Organic Rankine Cycle for power production. Instead of steam, an organic liquid of low boiling point is used. The organic liquid is typically a refrigerant. Hot water at 80-100°C may thus be used as a heating source for power production. ORC machines are available in a wide range. The smallest produce a few kW, the largest many MW.

The efficiency in the ORC unit can be measured by dividing the power produced (P) by the heat input (Q_{in}) to the machine, using the equation below:

$$\frac{P}{Q_{in}}$$

The heat can be calculated as $Q_{in} = mc_p\Delta T$ where m is the water mass flow, c_p is the water heat capacity and ΔT is the water temperature difference in and out of the ORC machine. The maximum efficiency is defined by the Carnot Equation:

$$1-\frac{T_c}{T_h}$$

where T_c is the "average" temperature of the cooling water to the ORC unit and T_h is the "average" hot water temperature. For many reasons the Carnot efficiency will never be reached in an ORC machine, and depending on the available temperatures, efficiencies in the range 6-7% has been achieved at Alcoa Mosjøen so far. From higher temperature processes where thermal oil can be used, higher efficiencies can be reached.

Experiences with ORC machines.

To gain experience with the ORC technology, Alstom Norway installed an ORC machine at the AHEX facility at Alcoa Mosjøen. The installation was part supported by the Norwegian energy saving authority – Enova. The machine at Alcoa is rated to produce up to 50 kW of electricity. The organic liquid used is R245fa, a medium with no ozone depletion and low global warming potential.

Figure 7: The container size ORC machine connected to the anode bake heat exchanger (AHEX) at Alcoa Mosjøen.

The ORC machine was installed in June 2013 and the efficiency was carefully studied during the summer. Much as expected it was found that the amount of power produced depends on hot water temperature and flow rates of water, see figure 8. The maximum power produced was 44 kW based on a heat input from the AHEX in the range 6-800 kW.

In addition to the hot water to and from the AHEX, the ORC machine must be connected to cooling water. The temperature and flow of cooling water is important for high efficiency. Figure 8 shows generated electric power at different flow rates and water temperatures. The variations in fume temperatures are not considered, and represent an error in the figure. From the figure it is seen that (as expected) lower flow rates produce less power.

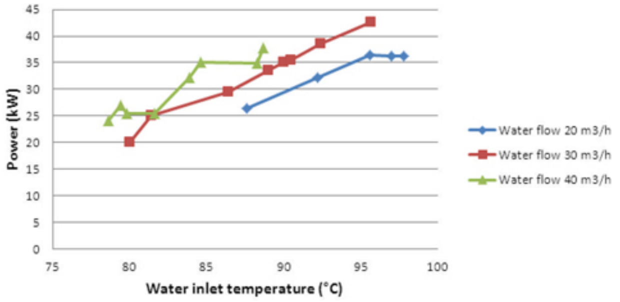

Figure 8: Power produced at Mosjøen ORC at different hot water flow rates and water inlet temperatures.

Optimization – Temperature variations.

The ORC in Mosjøen is installed at the FTC. The temperatures of the fumes from the FTC vary much more (50-70°C over some hours) compared to a GTC (10 -20°C over a year). Gas cooling (for better fume cleaning) is the main purpose of the AHEX. High water temperature from the AHEX is advantageous for power production, but not necessarily an advantage for the operation of the FTC. Such optimization has not yet been performed in Mosjøen. An ORC has however, the advantage of being more tolerant than many other generators when thermal load varies.

Full scale considerations

If we use Alba HEX as an example, the 25 MW of thermal energy can be converted to electricity using an ORC machine. If we consider efficiency of 6%, 1.5 MW of electricity can be generated.

As discussed, the temperature difference between hot water and cooling water is important for the efficiency. An obvious drawback at Alba is cooling water at relatively high temperatures (30-40°C in the summer based on sea water cooling and even higher from a dry air cooler). The advantage is more recoverable energy compared to colder climates. In colder climates, an ORC can achieve higher efficiency due to colder cooling water, but the recovered energy will be lower due to better cooling of the gas ducts. The commercial case for an ORC or not requires a thorough review of all aspects of the installation costs.

Conclusion

The robust tube- in-shell heat exchanger developed for potgas [3, 4,5] has now operated for up to 6 years without stopping or interruption for cleaning. The first large installation of this heat exchanger technology for a full pot line are now under startup at Alba line 4 and facilitates recovery of up to 25 MW hot water. The reason to install the heat exchanger is mainly to cool the pot gas to get the benefits from lower emissions and lower footprint and operation cost of the gas treatment center [4].

Various energy recovery utilization alternatives of the waste heat "by product" may be selected depending on the specific needs and location of the plants. Some alternatives are mature such as desalination, while others such as the ORC power production machine may be more challenging to implement.

Novel results from the ORC test unit at Alcoa Mosjøen have shown its ability to produce electrical power from temperatures even lower than 80°C. However, the overall efficiency of the ORC machine is low at these temperature levels, and the corresponding investment rate of return for an ORC machine challenging at the current cost level of electricity.

Energy will however be scarcer in the future, i.e. waste heat sources will be increasingly attractive. Already today several ways to utilize the heat can be attractive from a payback perspective. In addition energy recovery responds to several social and technological challenges:

- It reduces the overall carbon footprint of the plant since the recovered energy replaces another source of fossil fuels either directly or indirectly.
- It typically connects the plant to the surrounding community e.g. directly with district heating or district cooling systems. This can improve the relationship to the community and reduce negative impacts of pollution opinions etc.
- It adds employment for operation of the energy recovery systems and adds the general competence of the site.
- It reduces the overall energy cost of the smelter site.

For Alba line 4 the 25 MW of waste heat can produce 15 MW of cold water to a district cooling system, or produce potable water through a desalination process at lower cost than from competitive processes.

On this basis pot gas waste heat utilization seems to be feasible. As the first to implement the HEX technology in full scale Alba can take advantage of the possibilities that arise when 25 MW of waste heat is available for "free" during spring 2015.

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