

Waste heat recovery solutions

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Electrolysis pots require huge quantities of electricity, among which more than half (7 kWh/kg) is lost as heat. Even if such heat is mainly dissipated through the electrolysis pot structure, an important part of it goes through gases exhausted, composed of air with hydrogen fluoride content (HF), to the Gas Treatment Centre (GTC) treating those gases. Gases at pot outlet reach temperatures between 80°C and 170°C, depending on ambient temperature, plant intensity and pot operation.

For a GTC treating 2,000,000 Nm³/h of gas, a 30°C cooling of these gases would represent 21.8 MWth. An 80°C cooling (e.g. from 150°C to 70°C) would similarly represent 58 MWth.

Why gas cooling?

In hot countries such as the Persian Gulf countries, the latest developments in electrolysis pot technologies combined with extreme ambient temperatures have led to gas temperatures at pots outlet reaching up to 190°C.

This factor generates two major process

incompatibilities regarding gases cleaning.

First of all, the filter bag media (polyester felt) is suited for temperatures up to 140°C. Excess gas heat would cause media pyrolysis and a decreased lifetime to such filter bags. Other media suitable for such temperatures have been tested – such as PTFE – but they are far more expensive than polyester.

Furthermore, filtering efficiency is severely downgraded at high temperatures, whatever the filter bag media. **Fig 1** shows a direct correlation between gas temperature and HF emissions. With no gas cooling, HF emissions at GTC outlet in hot countries could reach 0.8-1 mgHF/Nm³ with classic filtering technologies, i.e. far above 1 mgHF/Nm³ commonly required by latest regulations such as BREF.

For these two reasons, gas cooling requires upstream filters.

An overview of existing gas cooling techniques

The most common technique for gas

cooling upstream filters is air dilution. Ambient air is drafted in the ductwork with the pot off-gases. Though efficient, it significantly increases total flow rate, thus requiring additional filters and increasing fans electrical consumption. Over the past decade, Fives Solios has been developing and supplying to aluminium plants other gas cooling techniques such as hairpin coolers, water injection and heat exchangers.

Among such techniques, only the heat exchanger allows heat recovery and re-use.

Inside the heat exchanger, the heat is transferred to a thermal medium; most of the time a liquid. This medium is generally in a closed network: It must transfer its heat to another medium before returning to the heat exchanger, at the design temperature.

If such closed network is connected to a waste heat recovery system, such heat is then transferred to the system. Otherwise, it must be returned to the environment, with aero coolers or seawater heat exchangers.

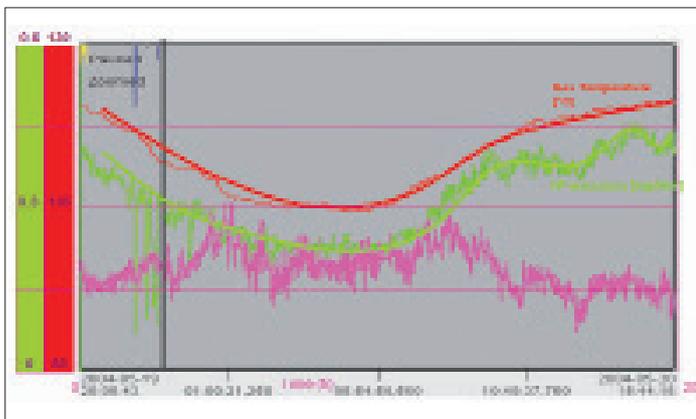


Fig 1. Relationship between HF emissions and gas temperature (measured in Alcoa Deschambault in 2004)

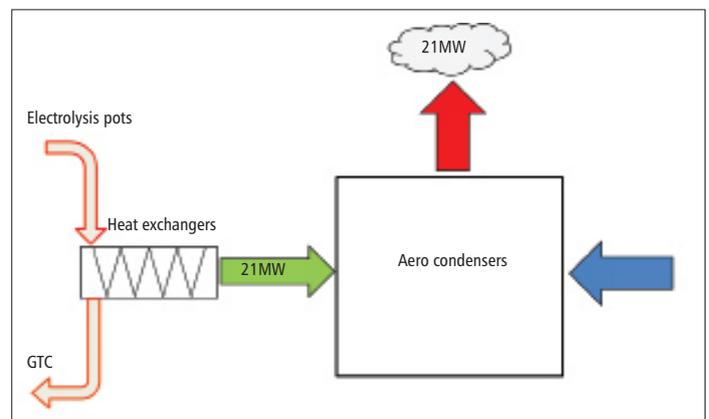


Fig 2. Process diagram: Gas cooling without heat recovery

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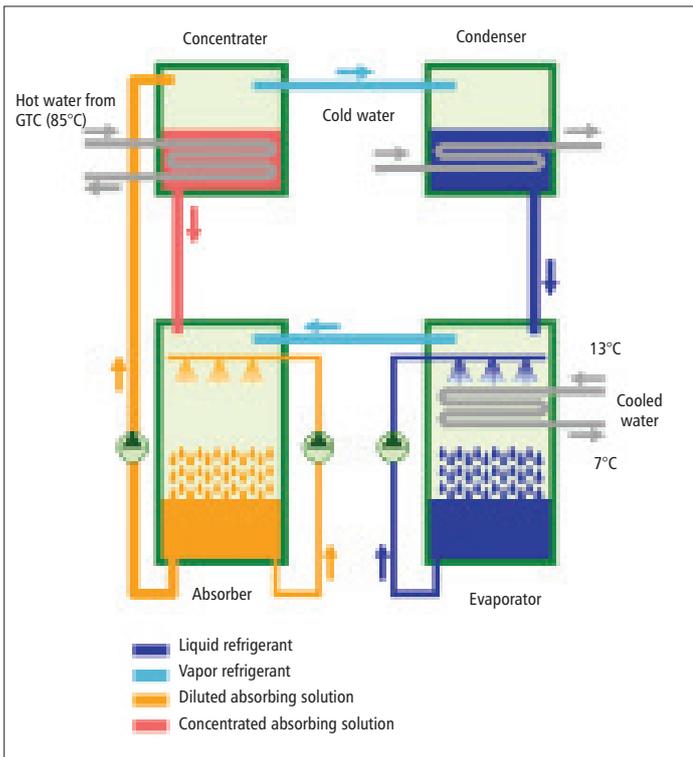


Fig 3. Hydraulic scheme absorption cooler

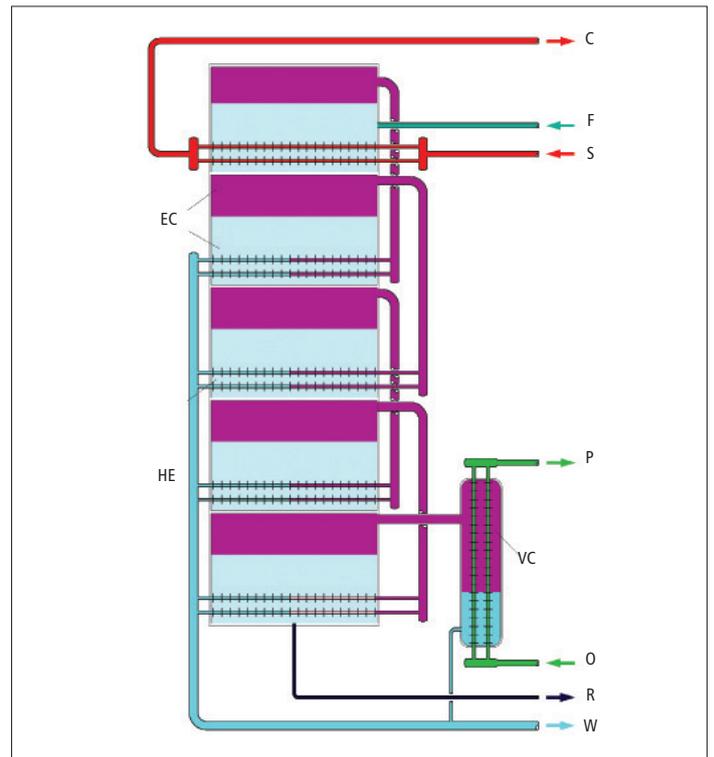


Fig 4. Multi effects distillation scheme

The main specificity of those gases is the highly fouling dust they contain. It implies not any heat exchanger can be used because of such a fouling. That is why Fives Solios has developed a specific heat exchanger for pot exhaust gases (Fig 2).

Recovering waste heat

There are several technologies dedicated to industrial waste heat re-use but not all are suitable for GTC off-gases, which present the specificity of very large flow rates and relatively low temperatures.

Below are the most common technologies for waste heat recovery on GTC flue gases. Calculations are based on a large recent smelter with four GTCs treating 2.10⁶ Nm³/h of off-gases (150°C at pots outlet). The gases temperature is dropped by 30°C unless specified otherwise.

Reusing heat by producing heat

The easiest, cheapest and most efficient way to re-use waste heat is... to heat! A heat source can only heat something up to its own temperature in theory, and rather 10°C less in practice (typical exchanger pinch to avoid over-costs).

For a recent smelter with four GTCs, a 30°C heat recovery with water would provide more than 85 MWth of free heat (21.8 MWth per GTC). Such excess heat is not required in the GTC process.

However, inside an aluminium smelter, some raw materials require pre-heating

and the recovered heat could possibly be reused for this purpose. However, this would require a very specific plant design to locate adjacently to the GTCs and the pre-heating area.

Other options could exist, such as selling such heat to another plant nearby, providing heating for plant offices or selling heat to a city for re-use in an urban heating network (applicable in cold and temperate countries).

Reusing heat by producing cold

However, hot countries are generally more interested in obtaining cold rather than heat. Cold can be obtained by absorption and adsorption machines which require an external heat input.

A working fluid with low boiling point, typically water, vaporises in a low pressure cell called an evaporator. Its vaporisation removes heat from the environment, thus creating cold. On the scheme above, chilled water, which passes through the evaporator, is cooled down from 15°C to 10°C.

The gas resulting from the evaporation is either absorbed by a liquid or adsorbed by a porous solid, mainly depending on the heat source temperature (80-120°C for absorbent such as lithium bromide solution, 65-80°C for adsorbent such as silica gel).

Once saturated, the liquid or solid is then heated by the external heat source (here GTC exhaust gases) in a generator,

and the working fluid is desorbed as a gas. The gaseous absorbant is sent back to the absorber through an expansion device, while the gaseous cycle fluid goes through another heat exchanger to condense again, thanks to a cold source (here liquid water connected to a cooling tower basin), and etc (Fig 3).

The coefficient of performance (COP) of such a machine is defined by the ratio between the amount of cold produced compared to the amount of heat used. Typical values for a simple effect absorption machine are 0.75 and for adsorption 0.6; for a double effect absorption machine this efficiency can reach 1.2.

Based on the electricity price of 43€/MWh (typical figure for Gulf area), replacing an air conditioning machine (COP = 2.8) with absorption machines (COP = 0.75) would save 1.38M€ on AC consumption for an existing plant.

For a new aluminium plant, considering four GTCs with 2.10⁶ Nm³/h of flue gases at 150°C each, and recovering only 30°C on those gases, the cold production could be above 90 MWth of cold at 5°C, using double effect absorption chillers that reach coefficient of performance (COP) of 1.1.

Producing drinking water by desalination

Hot countries can be exposed to a shortage of drinking water and may therefore be interested in desalination solutions.

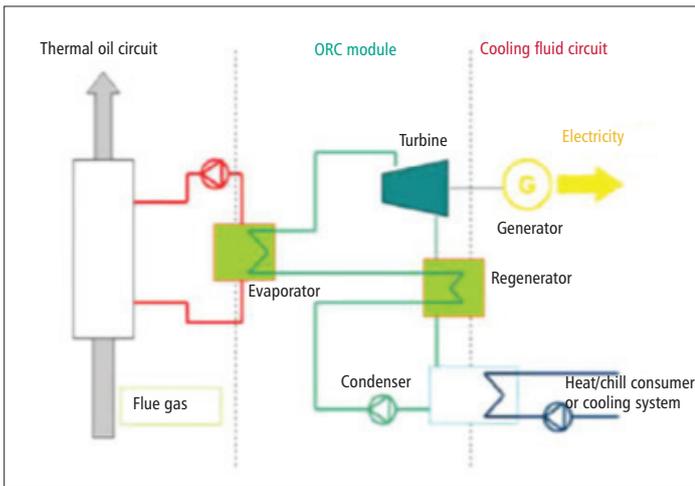


Fig 5. Rankine Cycle scheme

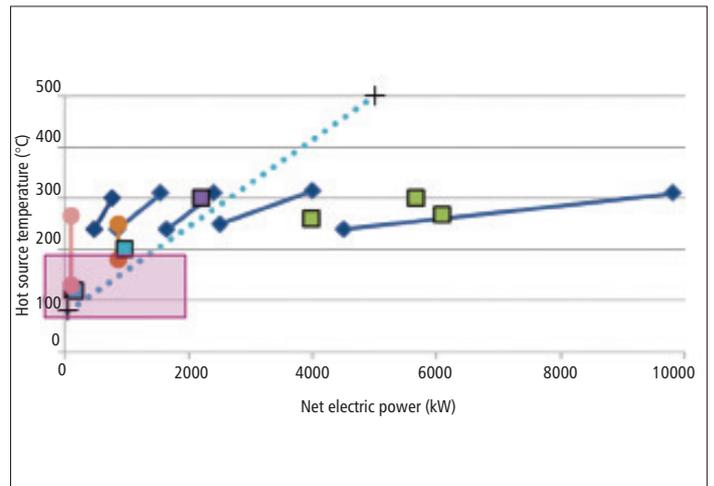


Fig 6. ORC proposed by suppliers in 2014 (purple square highlights the specific zone for GTC gases)

Among the various processes which exist to transform seawater into drinking water, multi-effect distillation requires heat. This process consists of evaporating seawater in several chambers whose pressures and temperatures are lower and lower.

In Fig 4, vapour is represented in pink, liquid seawater in pale blue and liquid distilled water in bright blue.

The vapour obtained from one chamber then crosses the next chamber via a pipe. As the temperature is colder than in the previous chamber, such vapour condenses in its pipe and the latent heat resulting from condensation is released in the chamber, vapourising the seawater. The required inputs are seawater (F), heat (S) in the first chamber to vapourise and relative cold (O) in the last one to condense.

The optimum heat source temperature for desalination is around 70 - 80°C. The more chambers a plant has, the better its yield is since in each new chamber the same amount of vapour is created as in the first one.

Thus technical and economic considerations generally limit the number of chambers to six when using waste heat. The number of chambers has to minimise the payback time and differs according to the heat source available, in our case it is close to three or four effects.

Building a multi-effect distillation plant near an aluminium factory would allow the desalination plant to have cheap heat and the smelter to sell this heat otherwise wasted. For four 2.10⁶ Nm³/h GTCs, more than 3.5.10⁶m³ of drinking water could be produced per year. If the same investor was to build the smelter and the water desalination plant, the pay-back for the MED plant alone would be 4.3 years.

Electricity production

Another way of using waste heat is to turn it into electricity. The idea is the same

as in thermoelectrical plants: A fluid is vapourised thanks to the heat source in the radiator (Fig 5), then expanded through a turbine connected to a generator that produces electricity.

Downstream in the turbine, the fluid is condensed in a cooler thanks to a heat sink and the liquid is pressurised by a pump, before going back to the radiator. More electricity is obtained at the generator than used by the pump because compressing a liquid requires much less energy than compressing a gas.

Unlike thermoelectrical plants whose working fluid is water, heat between 150 and 400°C needs an organic Rankine cycle (ORC) that uses a fluid other than water and requires less maintenance. Other cycles exist such as Kalina, using an ammonia-water mix, or supercritical ORC.

Those last two technologies are still in development whereas ORC is a mature technology. Despite being technically feasible, the

relatively low temperature of electrolysis cell gases (maximum 170°C in most recent smelters) and the cheap electricity accessible to smelters currently limit the payback of such configuration to 7-10 years. That is too much for an industrial application.

However, as cell manufacturers announce a further increase of gas temperatures for their future products, such an opportunity may become interesting in the near future.

Possible carbon taxation may also encourage the adaptation of this technology to smelters.

With four GTCs of 2.10⁶ Nm³/h with gases at 150°C, current technologies would allow recovering 190 MW of heat by cooling down gases by 65°C. Such heat would produce 16MW of electricity, thus producing from 50% to 75% of GTCs electrical consumption (Fig 6).

Conclusion

Besides the ecological point of view that a global effort to reduce our raw material and energy consumption is necessary, waste heat recovery is at middle term an important source of savings. Aluminium smelters have a great advantage compared to other sector plants, which enhances coupling: They run 24 hours a day, 365 days a year.

The best options are, depending on the plant location and before ORC becomes economically interesting, heating in cold countries, producing water in hot and dry countries and cooling in hot countries that do not need to desalinate water. ■

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