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AHEX- A NEW, COMBINED WASTE HEAT RECOVERY AND EMISSION CONTROL SYSTEM FOR ANODE BAKE FURNACES

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Abstract

Alstom has developed a new Fume Treatment Center (FTC) for improved emission control of Anode Bake Furnaces. The new compact FTC eliminates the conditioning tower with its use of compressed air and water with a patented heat exchanger system (AHEX) specially developed for the anode baking process. The adsorbent (alumina) is injected upstream the AHEX. This eliminates additional reactor stages downstream, and keeps the heat exchanger tubes free from fouling.

The AHEX started up in November 2011 at the anode bake plant at Alcoa Mosjøen, Norway and has demonstrated stable operation with gas temperatures cooled down to less than 100°C. Emission measurements document 10-20% less PAH-16 and significantly less HF despite a higher gas to alumina flow ratio in the AHEX system compared to the conventional FTC.

In addition, the AHEX system enables up to 5000 kW of thermal energy to be recovered at Alcoa Mosjøen.

Introduction

Anodes for use in aluminium smelting are made by mixing different sizes of petrol coke with pitch and then forming the anodes. After forming, the anodes ("Green anodes") must be baked and the pitch carbonized before use in a pot. In the baking process, the anodes are heated to approx. 1200°C and then cooled in a controlled way. This process predominantly takes place in open anode bake furnaces (ABF). The open furnace has replaced the earlier closed furnace, and the emissions are drastically reduced with better firing technology in the ABF, [2].

Still the main emissions from the anode baking furnace are PAH – polycyclic aromatic hydrocarbons, and HF (from recycled butts), SO_2 and carbon particulates. PAH evolve in the baking process as pitch is carbonized and important PAH compounds from ABF are naphthalene, phenantrene and dibenzoapyrene. PAH are potent atmospheric pollutants that consist of fused aromatic rings. Some of the compounds are carcinogenic, and are subject to emission levels set by government authorities. Emission levels are typically expressed as subsets of the various PAH's. PAH-16 and OSPAR 11 are subsets with 16(11) different PAH.

The principle behind the present FTC-technology is cooling of the gas in a conditioning tower, followed by adsorption of the condensed PAH and HF in a filter. In the conditioning tower, water is sprayed and compressed air is used to atomize the water in the gas stream for efficient cooling by evaporation. By cooling the gas, the various PAH condense and are thus collected by alumina in the reactor/filter. PAH's are volatile and the best collection is when the gas is cooled to the lowest possible temperature, although acceptable levels are reached at around 100-110°C.

<u>Challenges today:</u>
The conditioning tower (CT) technology has a number of issues that are problematic both from engineering, as well as an operational point of view.

- Corrosion challenges: Condensation of water in the system must be avoided as sulfur and HF would form strong acids, however, SO_3 may form acid dews at gas temperatures significantly above the operating temperatures of the CT. Corrosion resistant lining of CT and duct up to the filter reactor is necessary.
- Heavy deposits in duct downstream CT: Condensed tars collects in the bottom of the CT and even more so in the ducts downstream the CT and these ducts need to be cleaned 1-2 times per year
- Bag hydrolysis: – moisture from the CT is one of the main reasons for hydrolysis and short bag life of FTC
- Reactor erosion: – ceramic lining. Erosion of steel surfaces in filter reactors may develop and therefore severely exposed areas should be lined with ceramic tiles or equal
- Control of gas quantity in recirculation duct. Since the gas volume from the ABF can vary significantly, proper operation of an FTC often includes a duct for allowing gas being recycled across the filters to achieve stable operation of the filters. Control of this gas volume is often a challenge.
- Tar waste and effluents collect at CT bottom and has to be removed regularly. Disposal of this hazardous material needs special attention.
- Heavy foundation for CT

All these issues increase both the operational and capital costs of an FTC. To overcome the challenges with the cooling tower a heat exchanger was designed to cool the gas without any water consumption. Initial tests done in the ME had already revealed that the heat exchanger surfaces could be kept clean by injecting alumina. It was also realized that the emissions of tar components and HF could be controlled at the same time ref patent [1].

The development depended on a sustainable cost level of a reliable heat exchanger. Through a five year program such a heat exchanger was brought forward through the successful development of heat exchangers for pot gas [3,4] and finally it was decided to demonstrate the full scale heat exchanger (AHEX) for anode bake fumes at the Alcoa plant in Mosjøen. This demonstration AHEX started up in November 2011, and the results and the final integrated AHEX of the new fume treatment concept for anode baking flue gas for the future will be described in further details in the following.

Description of the new innovative AHEX system

The heart of the AHEX patented [1] fume treatment system is the cooling of the hot gas inside multiple water cooled steel tubes. As indicated on Figure 1 the hot gas containing the condensable fumes, enter the cooling tubes at the top where the fumes are mixed with alumina that is transported up through a pipe located in the center of the circular tube assembly. The hot fumes comprise condensable tar components, and through the cooling of the gas the fumes condense on the alumina surface. The gas also contains HF molecules that adsorb on the alumina.

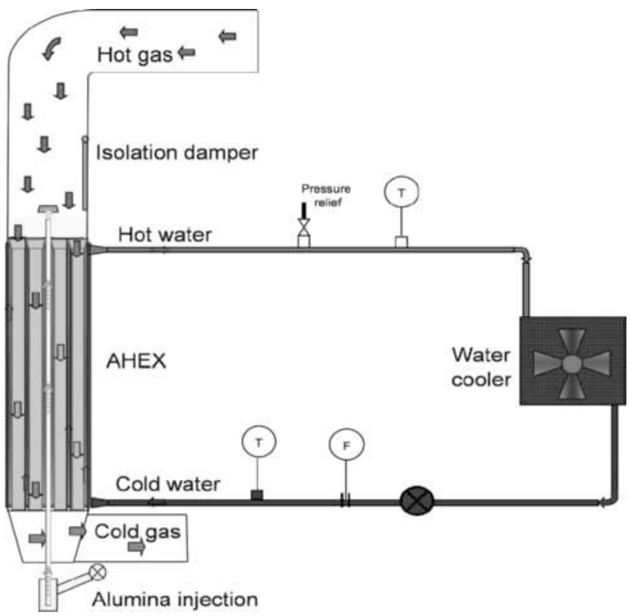


Figure 1: AHEX- the combined heat exchanger and tar condensation system

More than 90% to 95% of the HF and tar is expected to be adsorbed on the alumina inside the heat exchanger tubes due the efficient mixing of the alumina and fumes/ HF inside the tubes. This process is enhanced by the relatively long retention time, even gas/particle distribution, and short mixing length within the confined space of the multiple parallel tubes.

The dry process of the new AHEX FTC, allows the gas to be cooled to temperatures below 105°C, possibly even below 80°C. This allows for improved condensation of PAH and improved cleaning efficiency. A typical conditioning tower consumes 4-7 m3/h of water and 3-600 m3/h of compressed air. This is avoided with the AHEX.

The efficient collection of tar aerosols on the alumina particles reduces the risk for tar depositing on the heat exchanger surfaces. In addition the injected alumina will clean the surfaces from eventual deposits as demonstrated in the earlier trials in the ME which were the basis for the patent [1].

After leaving the heat exchanger the cooled gas (at less than 100°C) enters directly into the dry scrubber where the main part of the injected alumina is separated into the filter hopper and re-circulated directly back to the heat exchanger inlet. Primary alumina is injected in the filter compartment and collects on the bags in a final polishing stage to adsorb any trace components of tar fumes and HF. Through an overflow device in the filter hopper the re-circulated or spent alumina leaves the system to be sent to the electrolysis cells.

This two-stage counter current injection system is the main characteristic of the well-known patented Abart principle [5], and combined with the efficient combined heat exchanger/reactor, significant improvements in the gas emissions are documented in the following sections.

With the new AHEX concept integrated into the filter, there is no need for a conditioning tower with water injection. All the operational challenges related to the conditioning tower (corrosion, tar deposits, bag hydrolysis) are reduced or removed. The fumes go directly into the filter without the need for a duct from the conditioning tower to the filter.

The new FTC concept also draws heavily on Alstom's decentralized scrubbers (DDS) technology and features [6]. The new AHEX FTC can handle more variations in the gas flow than earlier systems, and there is no need for gas re-circulation.

Validation of concept

To demonstrate the full scale AHEX concept one (out of six) compartments at the existing Alcoa Mosjøen FTC was retrofitted with a heat exchanger. As shown in Figure 2 the gas bypasses the existing conditioning tower and flows directly into the top of the heat exchanger and further to one filter compartment (K1) that operates with the gas from the heat exchanger only.

Figure 2: The installed full scale demo AHEX FTC at Alcoa Mosjøen.

This compartment (K1) is therefore conveniently benchmarked with the remaining five compartments that operate as before on the conditioning tower. The measurements from the neighboring compartment (K2) are used as a reference in the full scale validation process.

The AHEX at Alcoa Mosjøen operates with water temperatures normally at 60°C in and 80-90°C out. The gas temperature in is normally 160-190°C, while the gas temperature out has normally been 90-100°C.

Results

The gas cooling taking place in the AHEX heats up a heat transfer fluid (actually a 50% glycol water mixture) to approximately 90°C. The fluid flows in a closed loop, and is typically cooled to approximately 60°C in a secondary heat exchanger as shown on Figure 1. The mass flow of heat transfer fluid is measured by a highly accurate electromagnetic Promag sensor, and fluid temperatures in and out are also measured with a high degree of accuracy.

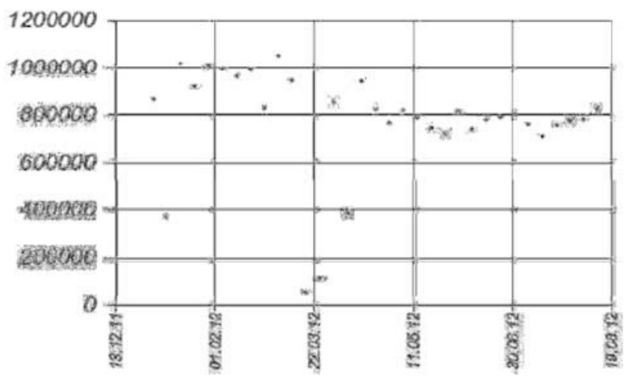


Figure 3. Heat absorbed by the heat transfer fluid, Q, in Watt versus time.

The heat absorbed by the water, Q, in Watt is therefore conveniently and accurately measured as the product of the fluid temperature difference in/out multiplied by the specific heat of the water glycol mixture and flow in kg/s. For the heat transfer fluid a specific heat value of approximately 3300 KJ/kgK has been used. The results are shown in Figure 3 where the weekly average heat transfer value is plotted versus time since the startup in November 2011.

As shown the heat transferred to the heat transfer fluid is in the range of 0.8 to 1 MW. This represents the heat recovered from one out of six compartments that can potentially be fitted with heat exchangers at Alcoa Mosjøen. The total recovered heat transfer potential is therefore in the range of 5 MW.

Neglecting a small fraction of heat loss, the heat absorbed in the water equals the heat flowing from the gas. The cooling of the gas in °C is measured, and the specific heat value of the gas is known (approximately 0,37 Wh/Nm3). Therefore, even if measuring the gas cooling due to stratification of the gas flow is challenging, the gas flow in Nm3/h can be estimated as shown in Figure 4 within an estimated +-10% accuracy.

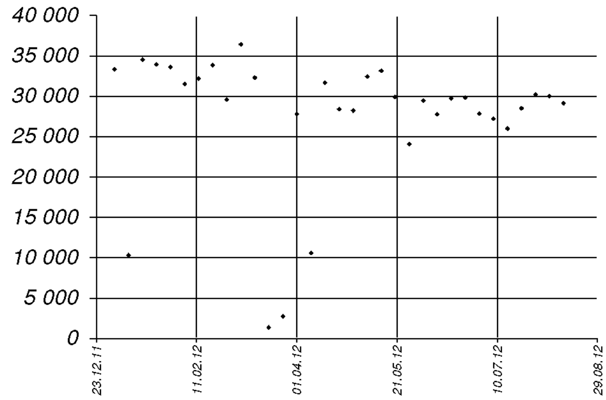


Figure 4. The Gas Flow, Nm3/h, versus time.

The total gas flow to the remaining compartments is measured with a venturi duct, and assuming the gas flow is divided equally by the remaining operating filter compartments, a 50% higher gas flow is estimated flowing in the AHEX compartment, K1 compared to the other compartments. The reason for the higher gas flow to the AHEX compartment is the lower pressure drop across the AHEX compared to the conditioning tower.

Measured heat transfer versus theory:

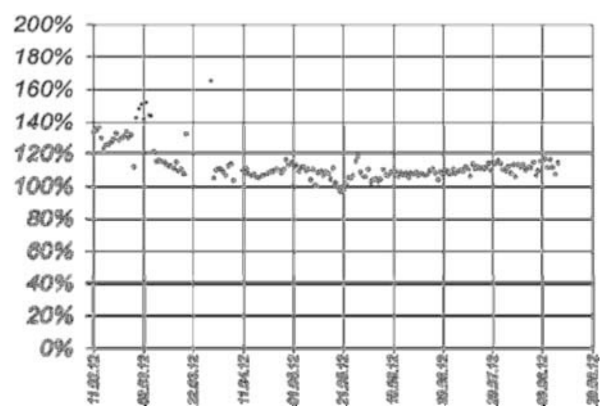


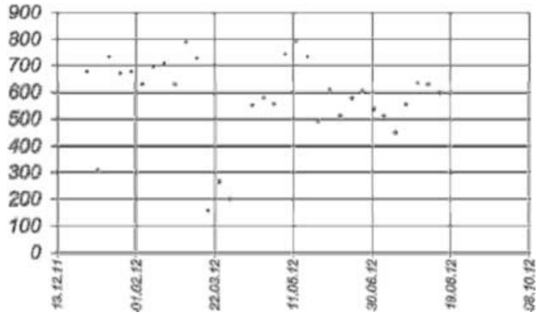
Figure 5 Measured heat transfer coefficient divided by the calculated heat transfer coefficient versus time.

Based on the measured heat flow, Q, the heat transfer coefficient, Um, is calculated by dividing Q with the heat transfer area, and the logarithmic mean temperature difference.

In Figure 5 Um is divided by the theoretical heat transfer coefficient calculated by know relationships from the literature, see [3]. A stable curve as shown indicates that the heat transfer coefficient is not degrading due to e.g. excessive dust deposits. This is also verified by several visual inspections of the heat exchanger surfaces, and also the fact the pressure drop is not increasing over time as shown in Figure 6.

Pressure drop (Pa):

Figure 6. Pressure drop over HEX, variation with time.



Even if there are some fluctuations in the measured pressure drop, it is evident from Figure 6 that the pressure drop is not increasing over time. This indicates that the heat exchanger is not blocked by tar residue. If tar residue were adhering to the HEX walls, the pressure drop would increase.

PAH removal efficency

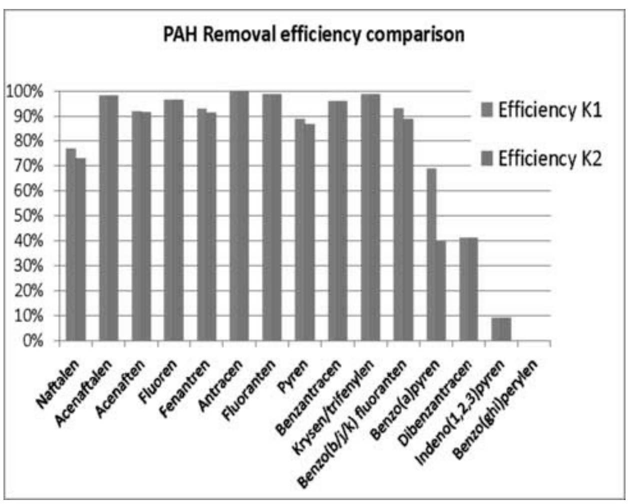


Figure 7. Cleaning efficiency of AHEX K1 compared with reference compartment K2.

Extractive PAH samples from the gas were collected with standard methods from the inlet to the conditioning tower and from the outlet of compartment K1 and K2. Based on this these measurements the efficiency can be calculated defined as:

Efficiency %= 100 (1-outlet /inlet concentration)

During the measurements the gas temperature from the AHEX were set identical to the conditioning tower outlet temperature to simplify the comparison of the AHEX concept with a conventional filter compartment. The measured efficiency of the AHEX can therefore be considered to be conservative since more PAH will be collected in an AHEX FTC if it had been operating at the lower gas temperatures it allows.

The samples were analyzed at an external laboratory through Gas chromatography–mass spectrometry (GC-MS) method, and Figure 7 shows the results. It is evident from Figure 7 that the AHEX compartment K1 has similar or better efficiency compared to the reference compartment K2, and in overall, the total efficiency for the PAH-16 gas components shown was measured to 18% better for the AHEX compartment.

In addition, as discussed above the gas flow through the AHEX compartment K1 was in the order of 50% higher than through the reference compartment K2 during the measurements. Therefore it can be calculated that the AHEX compartment K1 collects in the order of 70% more PAH in kg/h than the reference compartment K2.

Since the primary alumina flow to all of the compartments are identical, the higher content of tar collected in the AHEX system could be directly seen by looking at the used alumina. The used alumina from the AHEX compartment is much darker in color and kept a 50% higher content of PAH's.

HF emissions

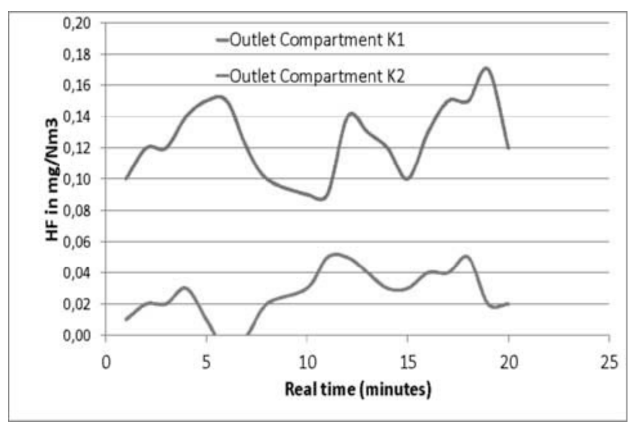


Figure 8 HF Emissions from AHEX (blue line), reference (red line) and inlet (green line)

HF emissions from the filter compartments were measured with a NEO portable HF analyzer, and the results are shown in Figure 8. HF emissions originate from the recycled butts used in the anode production. It is clear from the figure that the HF emission from the AHEX compartment K1 are significantly lower than from the reference compartment K2.

Future work

Waste heat recovery:

AHEX allows for waste heat recovery of slightly less than 1 MW per filter compartment. This number is of course dependent on the temperature of the fumes (and correspondingly on the efficiency of the ABF burners). The concentration of high value heat in one area allows for use of the waste heat. Such uses have been discussed earlier [2,3,4,6].

One example of efficient use of recovered waste heat recovery is the use of the water directly in e.g. district heating or sea water desalination. Another possibility is electricity production using an Organic Rankine Cycle (ORC) machine.

For the AHEX plant at Mosjøen, the hot water will be used for both district heating and for driving an ORC for electricity production. During the cold season, an extension from the plant's (and thus also the town's) district heating system to the AHEX is planned.

The integrated final concept:

Drawing on experience from the Alstom DDS concept[6], a further refinement of the concept has been designed. In the Alstom DDS concept, the alumina silo is integrated into the filter, and each filter compartment is controlled by its own fan. The concept is exemplified in Figure 9.

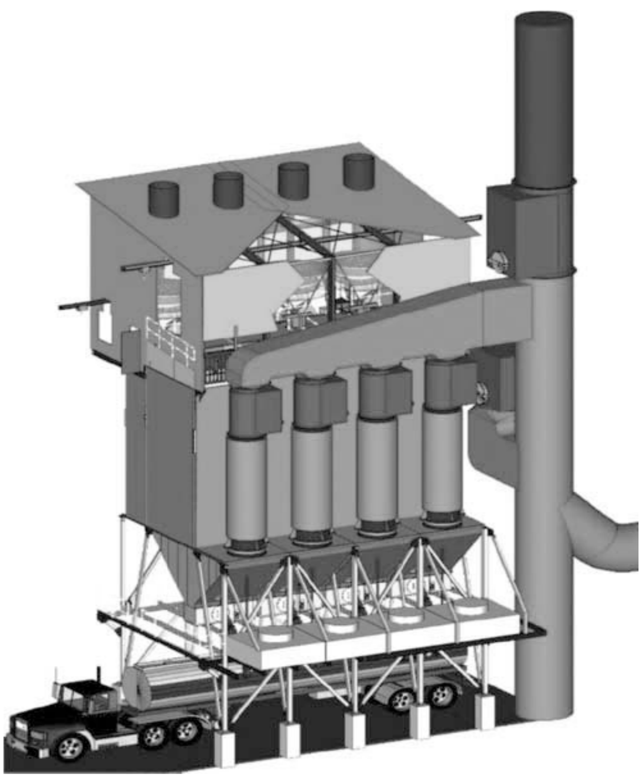


Figure 9 The integrated Alstom AHEX FTC

The final concept includes all of Alstom's developments and integrates the many smaller parts of an FTC into one machine. This means that the FTC will require smaller footprint. The concept will also allow for shorter construction time as it allows for shipment of the FTC in a number of modules that can be installed faster at the construction site. A modular bolted concept with smaller footprint also allows construction on an existing plant where the space can be limited.

Conclusion

A new concept for a fume treatment centre (FTC) is presented. The new concept is based on integrated heat exchangers for cooling of the gas. The heat exchanger also acts as a reactor where alumina adsorbs PAH, condensed tars and HF.

The new concept has been validated on a full scale demo-plant at Alcoa Mosjøen, and has been in operation since November 2011. The AHEX offers recovery of approximately 1 MWth heat pr. compartment.

The AHEX concept replaces the conditioning tower with a heat exchanger, and with this it removes a number of the issues associated with conditioning tower such as corrosion, tar handling etc.

The performance of the compartment with AHEX has been compared with another compartment running at the conditioning tower at the same temperature. The emission results show that the AHEX has better emission efficiency compared to the conventional compartment. This efficiency is achieved when the AHEX compartment handles 50% more gas than the conventional compartment.

The AHEX concept allows cooling the gas to below 100°C without the risk of corrosion of the duct and the filter. The improved cooling of the gas will allow for even higher emission efficiency of an FTC.

With the removal of the conditioning tower, the new and improved AHEX FTC concept allows for improved emission efficiency, as well as lower operational and capital costs.

In short the new compact AHEX is a game changer that reduces the emission of carcinogenic tars and gaseous fluorides, recovers waste heat, and reduces carbon footprint of the smelter. It eliminates handling of carcinogenic residues from tar drop outs in conditioning towers and ducts, and it adds "renewable" energy to the smelter.

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