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Environmental and Operating Benefits of a New Fume Treatment System at a Restarted Anode Plant

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Abstract

Having acquired a brown field manufacturing site in 2012, Century Aluminum, US, (Century) set about building a state-of-the-art aluminium anode manufacturing plant in Vlissingen, NL, meeting the latest environmental, safety and operational standards.

Realised in less than one year, the new fume treatment system (FTS), comprising three regenerative thermal oxidisers (RTO) in combination with wet desulphurization technology, ensures the most cost-effective solution and lowest exhaust gas emissions values.

Lowest CAPEX and OPEX costs were the primary considerations for this FTS configuration - the first ever on a baking furnace worldwide.

This paper describes the evolution of the FTS design, the technical and commercial benefits of this solution, and how it was successfully integrated into the new anode production facility in record-breaking time.

Introduction

Century purchased the anode manufacturing assets of Zeeland Aluminum Company (Zalco) in Vlissingen, Rotterdam, NL, to produce carbon anodes for its aluminum smelter pot lines located in Iceland.

A major investment project was established to bring the Vlissingen manufacturing site in line with latest safety and environmental regulations.

The option of using the existing combined gas and FTS was initially assessed. However, owing to upcoming stricter emissions limits and the reduced air flow (without pot lines), re-activation of the existing FTS was soon discounted. Instead, Century elected to purchase a new, state-of-the-art FTS in accordance with its corporate environmental policy and local authority requirements. This meant that not only VOC and PAH had to be treated but also compliance with strict local requirements for SOx and HF/fluoride components. As a result, in addition to the VOC/PAH treatment, a SOx and HF treatment stage had to be installed, whilst - of course, keeping additional capital and operational costs to a minimum.

Emissions Sources

The fumes which have to be treated come from two open top anode baking furnaces. These furnaces can be operated totally independent from each other resulting in a maximum total air volume of 110,000 Nm^3/h. Depending on the specific anode recipe, varying concentrations of pollutants can occur. For example, HF (which occurs due to the use of used butts) can vary from 50 to 115 mg/Nm^3 within a short time. SO$_2$, from the coke and pitch was estimated to reach mean values of up to 310 mg/Nm^3 with even higher peaks possible. In order to comply with future stricter emission limits, the maximum allowed emission levels for HF and SO$_2$ were fixed by Century at less than 3 mg/Nm^3 and less than 50 mg/Nm^3 respectively – both unusually strict emissions limit for this kind of industry.

Table 1 shows the furnace exhaust gas composition of the two sources and the specified emission limits after the treatment.

Furnace Exhaust Gas Concentration 1) and Specified Stack Emissions 2)			
Exhaust Gas Pollutant	**Unit**	**Total Raw Gas Levels**	**Specified Limit**
VOC *(FID)*	**mg/Nm³**	**200-1,500**	**-**
B(a)P	**mg/Nm³**	**6.0-21.0**	**< 0.05**
PAH *(EPA16)*	**mg/Nm³**	**2.0**	**< 1**
TOC	**mg/Nm³**	**-**	**< 20**
Benzene	**mg/Nm³**	**10.0**	**< 1**
CO	**mg/Nm³**	**500-1,000**	**< 100**
HF *(Gaseous)*	**mg/Nm³**	**50-115**	**< 3**
SOx *(as SO$_2$)*	**mg/Nm³**	**310**	**< 50**
Dust 4) ***(soot, tar excl. PAH, and <5% incombustible inorganics)***	**mg/Nm³**	**100**	**< 20**
Total volume flow	**Nm³/h**	**87,000 – 110,000**	

Notes:
1) Data supplied by Century
2) Half-hour mean values at real O$_2$ values
4) Guaranteed value assumes incombustible inorganic dust level from furnaces is below 5mg/Nm^3

Table 1: Baking furnace exhaust gas concentration and required emissions values

The emissions limits for other pollutants, such as VOC, benzene and PAH, are typical for anode baking furnaces.

Fume Treatment Technology

Owing to the composition of the fumes from the furnaces (see Table 1) various different types of treatment processes had to be combined. A matrix comparison, based on the specific needs and conditions on site, showed that application of a three-stage treatment system would be necessary. The first stage comprised a packed-bed filter unit which was especially designed to collect fine particles such as soot or tar droplets in order to prevent the downstream systems from clogging. Downstream of the pre-filter an RTO system was required to reduce the organic pollutants, mainly VOC, CO, PAH and benzene. Unlike all existing FTS for anode baking furnaces a third treatment stage was then required after the RTO. Here , a scrubber for acid gas components was installed owing to the strict emission limits for SO_2 and HF (see Table 1)

This was the first application of a wet scrubber in an FTS for anode baking furnaces. As a result, during the course of the project, several options were considered and compared.

The final layout of the installed FTS is shown in Figure 2 and Figure 3.

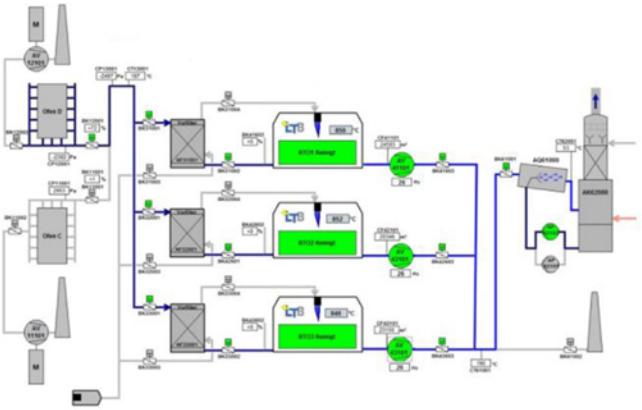

Figure 1: Simplified flowchart of the FTS

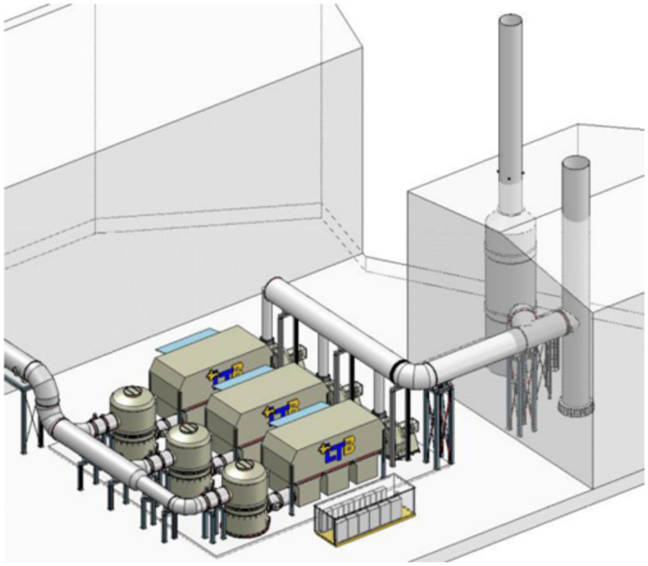

Figure 2: Overview of the FTS (arrangement drawing)

Pre-Filter Unit

In order to protect the high efficiency ceramic heat-exchanger media of the RTO system from clogging and irreversible damage, a pre-filter was installed upstream of the RTO. The pre-filter comprises a bed of ceramic filter media. Tar droplets and soot, coming from the anode baking furnace, are separated from the gas flow to the RTO system in the ceramic media. At certain intervals depending on inlet concentration, the pre-filter is cleaned via a so called "Bake-Out Mode". Hot air is guided through the pre-filter in reverse flow causing the organic deposits to evaporate. The steamed-off organics from the pre-filter media, which have a high calorific value, are than re-used as a fuel in the RTO, injected into the RTO by means of a specially-designed annular-gap burner.

One of the pre-filter units is shown in Figure 3.

Figure 3: Pre-filter unit

RTO System

The Regenerative Thermal Oxidation (RTO) system is well-proven, state-of-the-art technology for the efficient treatment of process and exhaust emissions such as VOC, CO and benzene / PAH.

However, to cope with the difficult conditions typically found in the exhaust gases of baking furnaces, the standard RTO design has to be modified to meet these higher requirements.

The objective of the proposed FTS system design was to meet the stringent emissions levels for organic substances - especially benzene, PAH and CO - on the one hand, and to cope with the tar droplets and condensates contained in the fume gases on the other.

This was accomplished using specially-modified ROxiTHERM™ RTO system.

To ensure sufficient residence time of the exhaust gases in the combustion chamber, the chamber volume was designed with special mixing devices in the combustion chamber to ensure the correct residence time, turbulence and to minimise edge-flow effects in order to achieve the required performance.

The valve systems had to be extremely tight to reduce leakage. This tightness has to be ensured during all operating modes, even during "bake-out" where temperatures can reach up to 500°C. A unique, temperature resistant, double-sealing system, which is also purged with clean gases to prevent leakage, was used. This sealing system guarantees minimum leakage of process gases into the clean gases and ensures compliance with the emissions levels.

Condensed and accumulated organic pollutants at the inlet of the ceramic media, which could be gasified at the "bake-out" temperature, are removed via the "bake-out" procedure.

Hot gas from the combustion chamber is guided through the beds until the required temperature of 400..450°C (max. 500°C possible) is achieved at the cold inlet of the beds.

After a suitable retention time all organic pollutants are steamed-off. The energy value is utilized in the RTO, which reduces the fuel consumption. This is performed with a special annular gap burner to secure optimum oxidation of the pollutants.

For regular purification via "bake-out" a redundant concept was installed. Rather than just 2 lines, the FTS was designed with an additional third line. During normal operation, all 3 lines are running with fumes. Should one particular line require cleaning, it can be taken out of normal operation and the fumes are then treated by the two remaining lines. After completing the "bake-out", the system is then switched back to normal 3-line operation.

Redundancy

One key issue in this project was the availability of the FTS i.e. the effectiveness of the redundancy concept. Since 99% availability for a single RTO is not possible owing to the composition of the fumes, a system involving at least two RTO lines has to be installed. Here, the emissions levels still have to be met even if one of the two RTOs fails or if is undergoing maintenance and the whole fume flow is channeled to the single RTO system. Whilst RTO systems already exist which can handle the double flow for a limited period of time (so-called "TwinMode™"), inevitably the cleaning efficiency drops down slightly during this mode of operation, and this was not acceptable for this project. As a consequence, in this case, a decision was made to go with an RTO system comprising three individual parallel RTO lines, each equipped with its own pre-filter unit.

The advantage of this configuration is that during normal operation each pre-filter-RTO system runs at the energetic optimum and still has its full capacity and cleaning efficiency if one system is in cleaning mode or undergoing maintenance.

Wet Scrubber

For the abatement of SO_2 and HF there are several technologies which all have specific advantages and disadvantages. The following methods were evaluated during the project using a matrix comparision method:

- Dry scrubber using calcium-hydroxide
- Dry scrubber using sodium-bicarbonate
- Wet scrubber using limestone
- Wet scrubber using seawater
- Wet scrubber using sodium-hydroxide

Both of the dry scrubbing solutions comprise a dosing system for the dry neutralizing agent, a mixing and reaction zone and a baghouse filter for collection of the reacted powder. There are some differences in the reaction agent and the optimum operating temperature between the two systems but otherwise they are very similar. Both dry scrubbers produce a solid waste product which requires subsequent disposal.

In contrast, all the wet scrubbing technologies use a scrubber in which water and the neutralizing agent are distributed. The gaseous pollutants are dissolved in the scrubbing water and neutralized by the reactant agent. Thus, a liquid effluent has to be disposed of, possibly after additional external chemical treatment. The three systems under comparison differ mainly in the use of the neutralizing agent for the acid gas components. These are sodium hydrogen (added as a 20 to 50% solution), calcium-carbonate (added as a limestone slurry) and seawater (which uses its natural content of several carbonates as neutralizing agent).

Owing to the location of the anode manufacturing plant immediately adjacent to the industrial harbor, the use of a seawater scrubber system was discussed and debated intensively during the initial engineering phase.

However, despite the obvious benefits and practicalities of using cost-free seawater, the main disadvantage is the relatively low natural carbonate concentration and, hence, the tremendous amount of seawater which has to be used. This option would have required huge piping installations and pump systems which would have resulted higher OPEX and CAPEX. Furthermore the seawater needs a special treatment prior to use in the scrubber to prevent the scrubber internals and the peripheral equipment from experiencing biological fouling and corrosion. Expressed in annual costs this would have led to investment costs which were 2.5 times higher and annual operating costs which would have been almost 3 times higher for the seawater scrubber compared to a "conventional" sodium hydroxide scrubber.

The dry scrubbing solutions were judged to be unattractive owing to the very high investment costs for the bulk handling, transportation and bag-house filtration.

Table 2 lists the different SO_2 and HF abatement technologies in terms of capital costs (CAPEX) and operating costs (OPEX).

	Calcium hydroxide ($Ca(OH)_2$) (Dry Scrubber)	Sodium carbonate ($NaHCO_3$) Seawater Scrubber	Sodium hydroxide (NaOH)	Sodium carbonate ($NaHCO_3$) (Dry Scrubber)	Calcium carbonate ($CaCO_3$)
INVEST 1)	3,500	650	950	3,500	3,743
Operator CAPEX 2)	100	2,140 3)	75	100	200
Total CAPEX	**3,600**	**2,790**	**1,025**	**3,600**	**3,943**
Annual OPEX	628	980	355	869	504
Annual CAPEX 4)	350	279	103	360	394
Total Annual Cost	**988**	**1,259**	**458**	**1,229**	**898**

Notes:

Design Case: Two furnaces, average conditions; 87,000 Nm^3/h; SO_2: 300=>50 mg/Nm^3; HF: 80=>3 mg/Nm^3

1) *Scrubber equipment, i.e. scrubber housing, scrubber internals, storage tanks, ductwork, control, etc.*

2) *Additional equipment and investment, e.g. special concrete work, surrounding site modifications, etc.*

3) *Including piping from/to sea;Excluding exhaust gas reheating*

4) *10 years depreciation period*

Table 2: OPEX and CAPEX of different desulfurization technologies

Ultimately, a decision was made to use a spray-scrubbing system incorporating sodium-hydroxide as the neutralizing agent.

Figure 4 shows the scrubber unit during installation and Figure 5 the inside of the scrubber with multi-stage spraying nozzles.

Figure 4: Scrubber system during erection

Figure 5: Scrubber internals

Project Execution

Past average completion times for similar FTS projects at LTB have been typically between one to three years. Influencing factors include the number of related parties, the project execution principle and associated documentation. Close cooperation between customer and supplier - based on confidence and faith – resulted in a record-braking execution time for this project. Moreover, flat organisational structures on both sides enabled quick decisions with minimum bureaucracy a effective project management system operated by the supplier ensuring short execution times.

Figure 6: Loading of the baking furnace with the first anodes

<u>Tough schedule</u>

Initial contact occurred in mid-2012 and the basic concept was discussed and finalized during the autumn of 2012. The various technical opportunities and the in-house know-how of the supplier enabled the customer to assess all the possible options. After several modification during the tendering phase the supplier was selected just before Christmas 2012.

A purchase order was placed in January 2013 and the complete plant was ready for operation in November 2013. The first anode was produced on November 29, 2013. Figure 7 shows the completed FTS with pre-filter units, RTO and the wet-scrubber located in a building in the background.

Close Cooperation with Authorities

Normally, application for operating permit would take several months. However, close contact with the authorities was established form the outset with assistance of an experienced engineering office. The open policy of Century - and the intention to not just fulfil regulation but to realize a state-of-the-art plant- enabled faster decisions, and hence permission to start the execution of the works. The authorities scrutinized all relevant steps and received open and straightforward answers in each case. This created a strong bond and sense of trust with the authorities in Zeeland which Century Aluminum continues to nurture to this day.

Figure 7: FTS after completion

Results from Operation

Emissions Values

After more than one year of operation the FTS continues to show a very good performance, in particular the scrubber system which is running without any major problems. The measured pollutant concentrations are all in line with the specified and guaranteed emission limits - or even far below.

Table 3 lists a summary of the average measurement results and the official emissions limits.

Component	Unit	Average measurement result	Emission limit values	Verification
Benzene	[mg/Nm^3]	<0.1	1	fulfilled
	[g/h]	<5	110	fulfilled
Fluoride (HF)	[mg/Nm^3]	<0.1	3	fulfilled
	[g/h]	<0.005	330	fulfilled
Particulate bound fluoride	[mg/Nm^3]	<0. 1	5	fulfilled
	[g/h]	<0.001	550	fulfilled
Hydrocarbons	[mgC/Nm^3]	<2	20	fulfilled
	[kg/h]	<0.2	2.2	fulfilled
Nitrogen oxide	[mg/Nm^3]	46	250	fulfilled
	[kg/h]	3.7	27.5	fulfilled
PAH (16 EPA)	[µg/Nm^3]	40	1000	fulfilled
	[g/h]	3.3	110	fulfilled
Benzopyrene	[µg/Nm^3]	<0.1	50	fulfilled
	[g/h]	<0.1	5.5	fulfilled
Sulfur dioxide (SO_2)	[mg/Nm^3]	<1	50	fulfilled
	[kg/h]	<0.1	5.5	fulfilled
PCDD/F (lowerbound)	[ng TEQ/ Nm^3]		0.1	fulfilled
Mercury	[mg/Nm^3]	<0.003	0.05	fulfilled
	[g/h]	0.001	-	-

Table 3: Required and measured emissions levels during operation (taken from official measurement report)

Operating Expenses

The operating expenses have also evolved as expected, i.e. the consumptions of the major resources have remained within the calculated values. There was only one phase during start-up where the consumption of sodium hydroxide was much higher than expected but this was due to a much higher SO_2 input during the start-up and first optimization of the furnaces. It should be mentioned that even during this operation the SO_2 concentration in the clean gas was far below the emissions limits. Table 4 shows the average operation costs (OPEX conditions) at stable FTS operation.

FTS Operating Conditions / Consumption Rates			
Consumable	**Unit**	**Single Furnace (with 2 RTOs)**	**Two Furnaces (with 3 RTOs)**
Exhaust Flow Rate	**Nm^3/h**	**43,000**	**87,000**
RTO Fuel Consumption [1)]	**kW**	**500**	**900**
RTO Fuel Consumption [2)]	**kW**	**0**	**0**
Electrical Consumption	**kW**	**300**	**570**
Compressed Air Consumption	**Nm^3/h**	**40**	**60**
Process Water Consumption	**m^3/h**	**5 - 35**	**10 – 70**
NaOH Consumption	**kg/h**	**100**	**200**
Waste Water	**m^3/h**	**ca. 1,5**	**ca. 3**

Notes:
[1)] *Fresh air operation (zero VOC content)*
[2)] *Autothermal operation*

Table 4: Average OPEX conditions at stable operation

Conclusion

The new FTS is one of the most modern of its kind in the world today and has raised the bar for best available technology (BAT). This is based not only on the very low emissions but also on the highly competitive capital and operating expenses.

Furthermore the extremely short execution time enables Aluminum Companies to react very fast on market demands and to build-up new capacities quickly. This could be an economical advantage, in this case, combined with an ecological milestone.

"Absolutely breathtaking" was the comment of Jim Taylor, Project Manager, Century Aluminum.