

## The Continuous Optimization of the Primary Energy Input at AOS – A Story of Success

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### Abstract

Producing alumina at Aluminium Oxid Stade GmbH (AOS) has a long and successful history. In over 40 years of operation, engineers developed and delivered a series of optimizations regarding the specific primary energy consumption. The tube digester technology, invented by German engineers and applied on an industrial scale for the first time in Stade, was brought to an unprecedented performance level by its innovative cleaning methods, which led to a consistently high heat transfer, low pressure loss and excellent digester availability. Further improvements in recent years, such as the heat recovery from the exhaust gas stream of the salt heater, as well as the optimization of one of the fluid bed calciners and the installation of a combined heat and power generator (CHP), has led AOS to where it is now, a leading alumina refinery with regard to the energy consumption per ton of alumina.

**Keywords:** Energy optimization, Tube digester, alumina.

### 1. Introduction

Aluminium Oxid Stade GmbH (AOS) is an alumina refinery (Figure 1) with an annual production capacity of approximately 1 000 000 tonnes  $\text{Al}_2\text{O}_3$ . From 1970 to 1973, the plant was built with a designed annual production capacity of 600 000 tonnes  $\text{Al}_2\text{O}_3$ . Due to continuous optimizations of the process, smaller enhancements and the installation of an additional tube digester, the production has been increased to the present quantity. Apart from the ongoing increase in the production rate, engineers at AOS developed a series of optimizations to minimize the specific primary energy consumption.



Figure 1. Production area at AOS.

The basis for the plant's low primary energy consumption is firstly the tube reactor, and secondly the fluid bed calciner. The tube digester technology, developed by VAW and primarily used at AOS, makes digestion at temperatures as high as 270 °C possible. Therefore, practically all kinds of bauxite can be processed. Ever increasing energy costs, cleaning costs and environmental aspects led AOS to introduce their innovative cleaning methods, to install heat recovery systems and to build a combined heat and power generator.

## 2. The Tube Digester at AOS – Overview



Figure 2. AOS tube digester.

At AOS four high temperature tube digesters are operated independently at a digestion temperature of 270 °C (Figure 2). Digestion feed liquor and bauxite slurry are mixed prior to the digestion process and are pumped with a piston diaphragm pump through eight vapour heat exchangers using regenerative flash vapour (Figure 3). Final stage heating to 270 °C is then accomplished by using molten salt. After adding oxygen for the wet oxidation process and lime slurry to enhance the yield, the heated slurry runs through a retention time section to increase alumina extraction, before it enters a cascade of eight flash tanks. In each flash tank, vapour is recovered to heat the digester feed slurry stepwise in counter-current flow. In the last heat recovery step, the pregnant liquor leaving the cascade is fed to a heat exchanger transferring heat to the digestion feed slurry, which is entering. By using this heat recovery system, more than 75 % of the necessary digestion energy is provided.

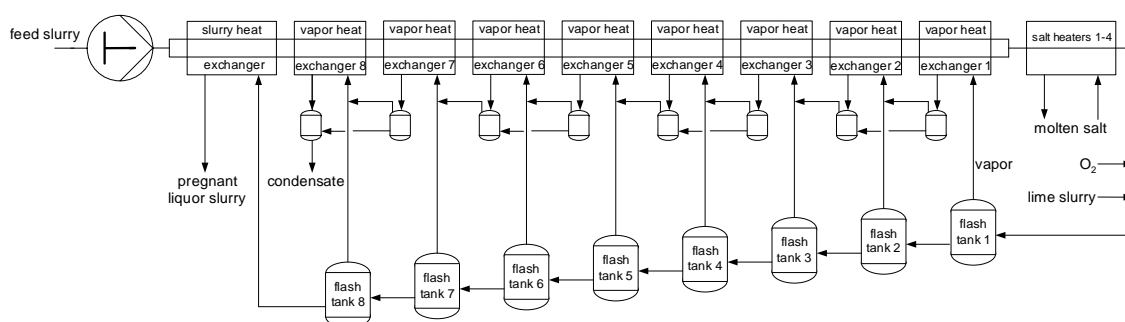


Figure 3. Schematic of the tube digester at AOS.

Throughout the operation of the digesters at AOS, optimizations of the flash tanks led to an excellent quality of the condensate leaving the digester heat exchangers. Typical conductivities of 80-100  $\mu\text{S}/\text{cm}$  during the lifetime of the digesters require minimal cleaning efforts in the regenerative flash system as well as the washing of the product stream with clean condensate from the digestion process. Thus, energy-intensive evaporation plants are unnecessary.

### **2.1. Advantages and Technical Challenges with the Digestion Technology**

The tube digester technology developed in the 1960s by VAW in Germany and applied at AOS since 1973 includes several advantages [4], [5] such as:

- Approximately 40 % less energy consumption compared to autoclaves under similar conditions due to the regenerative flash system and high turbulence in the digester pipes leading to an excellent heat and mass transfer and thus to a low need for caustic liquor for the digestion process.
- Using molten salt, which is heated with natural gas, the primary energy input is reduced.
- Clean condensate produced in the regenerative flash system of the digesters makes an evaporation plant unnecessary.
- Digestion temperatures up to 270 °C allow the use of practically all kinds of bauxite. Bauxites such as Weipa, Gove and Boké have been successfully processed at AOS.
- A high degree of automation due to continuous operation of the digesters leading to reduced labour intensity.

One challenge every Bayer digestion area has to face is rapid scaling of reactor surfaces by silica and titanate. Typically, the rate of chemical scale deposition increases in zones of stagnation. Even though the turbulence in the tube digester pipes is high – Reynolds numbers higher than  $1.4 \times 10^5$ , silica scale occurs in the low temperature sections and hard titanate scale at the high temperature end. Consequently, periodic shutdowns of the digester and de-scaling of the pipes are necessary to restore the heat transfer capacity and reduce the pressure loss.

At AOS, the digesters are operated independently, so that a shutdown of only one digester at a time is possible. De-scaling is usually done by acid treatment followed by mechanical cleaning. Originally, mechanical cleaning of the tubes at AOS was conducted by high-pressure water jet cleaning. During a shutdown, every return bend of the digester pipes had to be removed to provide access to the digester. The impact of this cleaning method on production is significant since it is time-consuming as well as labour and cost intensive. Additionally, high-pressure water jet cleaning could cause serious damage to the digester pipes since a water pressure of more than 1000 bar is necessary to break the hard titanate scales.

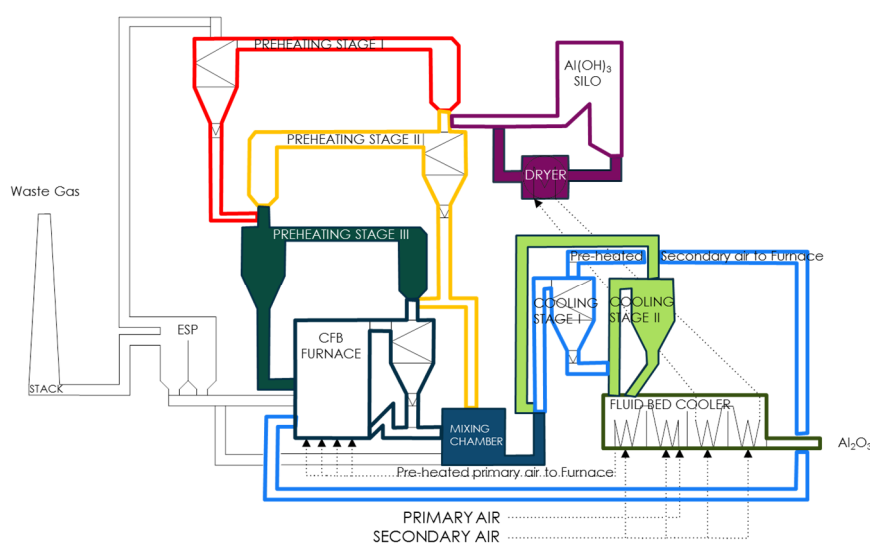
Consequently, cleaning methods were reviewed by AOS engineers with the aim of reducing the application of high-pressure water jet cleaning during digester shutdowns. The method of choice was pigging. Cleaning tools were tested and optimized and pig launchers and receivers were installed. Acid treatment followed by pigging made high-pressure cleaning of the digester pipes redundant. The result was a significant reduction in downtime, maintenance and operating costs.

Nowadays, digesters at AOS are shut down approximately every 1450 operating hours resulting in four short (one day) and two long time (four to five days) shut downs per year for cleaning and maintenance processes. Every cascade of flash tanks has to be cleaned twice a year. During the lifetime of the digesters, heat transfer is high and pressure loss, caused by scaling, is low, resulting in a minimum energy input, a full production rate and an excellent availability of the digesters of over 93 %.

### 3. Modification of a Fluid Bed Calciner

The circulating fluid bed calciner (CFB) technology was developed by Lurgi-VAW with the aim of minimum energy consumption in the calcination process. In 1973, AOS became the first refinery worldwide to apply this technology to 100 % of its production. Three calciners with a designed capacity of 650 mt<sub>Al<sub>2</sub>O<sub>3</sub></sub>/d each were installed.

Since the calcination process is still very energy intensive, optimizations of the calciners have been conducted to increase the throughput on the one hand, and reduce the energy demand on the other. In 2011, one calciner was modified by adding several heat recovery steps (Figure 4) [9].



**Figure 4. Modification of a fluid bed calciner [9].**

Aluminium hydroxide entering the plant is pre-dried in a dryer and then preheated in an additional step (preheating stage III), which leads to a cooler exhaust gas stream. Furthermore, the secondary air stream is additionally preheated by alumina leaving the calciner (cooling stage II). Aluminium hydroxide can also be bypassed using the heat of alumina in a mixing chamber. These changes resulted in an increase in the production capacity of over 10 % and a significant reduction in the primary energy demand of approximately 12 %.

### 4. Installation of a Combined Heat and Power Generator (CHP)

In several parts of the refinery steam is used as a heating medium. Before the installation of the CHP, steam was provided by three natural gas-fired steam boilers, and the total amount of electrical energy needed for the process was taken from the external electricity grid. Today, two combined heat and power generators with a power output of 15 MW each were installed to provide the plant with both electricity and steam. With the two CHPs it is possible to cover 100 % of the steam and about 95 % of the electricity demand at AOS.

AOS is now independent from the national grid, which is important because power outages in Germany are more likely due to the Renewable Energy Law. This law favours renewable energy over energy produced by conventional power plants and has the effect that the national grid tends to be more unstable.

Environmental as well as economic reasons drove the installation of the CHP. With the use of natural gas instead of brown and pit coal as fuel for electricity production, the CO<sub>2</sub> emissions were significantly reduced by 25 %.

Generally, the total efficiency of processes where heat and electricity are generated separately, is about 35 %. In contrast to a high-efficiency CHP, as is installed at AOS, the total efficiency can be increased to more than 80 %. To produce the same amount of electricity and heat in a separate processes, about 35 % more energy is needed compared to a CHP-process [6,8].

The comparison of a separated process (left part) and a combined process (right part) is illustrated in Figure 5 where the same amount of thermal and electrical energy is generated. The sum of all individual losses during the generation of thermal and electrical energy in the separated process is much higher than in a combined process. With optimal design and operation of a CHP plant, up to one third of the primary energy consumption can be saved in comparison to a separated generation of electrical and thermal energy.

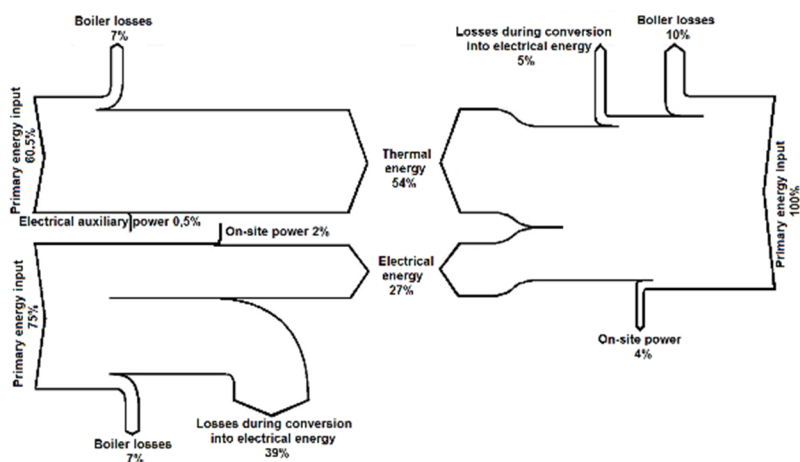


Figure 5. Energy flow of a separated process compared to a combined process [8].

At AOS it has been observed that the total primary energy input to produce steam and electricity for the process was reduced by approximately 18 %.

### 5. Heat Recovery at the Salt Heater



Figure 6. Heat recovery system at AOS.

To achieve the digestion temperature of 270 °C, AOS installed a salt heater, which is operated with natural gas. Following the combustion and subsequent heat transfer to the molten salt, the exhaust gas has a temperature of about 500 °C. In the first step, the heat energy in the exhaust gas is used in a tube bundle heat exchanger to preheat the combustion air. The exhaust gas, which is cooled in the first step, still has a temperature of about 250 °C. Because of the utilization of natural gas and the lack of sulphur, it is possible to cool the exhaust gas down to a temperature far below 100 °C, without producing condensate or even worse, sulphuric acid. The fact that the exhaust gas still has a high caloric energy and the possible cooling temperature of below 100 °C, led to a second heat recovery step, where a new plant section was installed. With the installation of a recuperator in the exhaust gas stream, it is now possible to further decrease the heat loss resulting from the hot exhaust gas and utilise the recovered energy for heating processes instead of steam.

The new plant section consists of a recuperator and a pressurized water system to transport the heat energy to where it is needed in the plant (Figure 7). For example, at AOS the recovered heat energy is applied to the diluter. Energy savings of more than 23.500 MWh/y are not uncommon, which is equivalent to about  $V_n = 2.13\text{m}^3$  of natural gas.

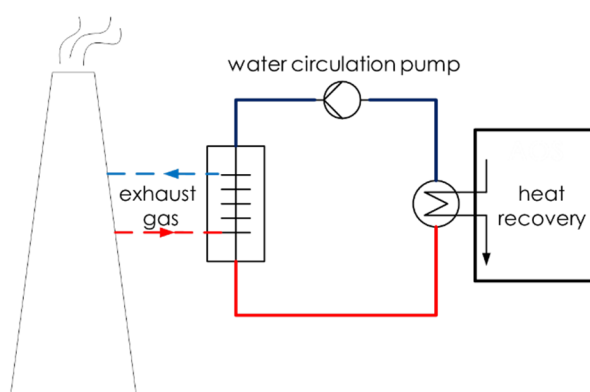


Figure 7. Schematic of the heat recovery system at the salt heater.

## 6. The Specific Total Primary Energy Consumption

In the last 10 years, AOS has been able to constantly decrease the specific total primary energy input. The increase in the annual production capacity to over 1 000 000 mt  $\text{Al}_2\text{O}_3$  in 2008 resulted in a significant reduction in the specific energy consumption, as illustrated in Figure 8.

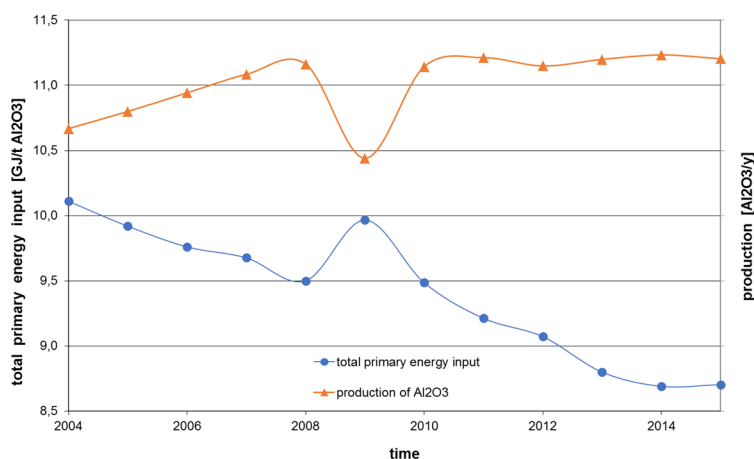


Figure 8. Total energy consumption per tonne alumina.

After 2008 the annual production rate remained at the same level except for 2009 (Figure 8). Due to difficulties with the alumina market, AOS was forced to reduce its production rate drastically, causing the primary energy input to shoot up. It is important to mention, that in 2010 the total primary energy consumption was at the same level as in 2008 at an identical alumina production rate. If there had not been any further optimizations after 2010, the specific total primary input would still be the same.

Figure 8 clearly illustrates that the total primary energy input has been significantly reduced since 2010 by the optimizations mentioned above, which are the modification of one fluid bed calciner in 2010/11, the installation of the CHP in 2012 and finally the installation of the heat recovery system at the salt heater. Further improvements such as the replacement of control valves by speed-controlled motors or the substitution of energy intensive lamps by LED lamps added to the savings.

Nevertheless, AOS still has the potential for further optimizations such as the modification of two calciners. Even though AOS would not reach the minimum total energy demand of a Greenfield 6 GJ/mt<sub>Al<sub>2</sub>O<sub>3</sub></sub> high temperature refinery postulated by Mach [10], AOS is still the leader in comparison to the average specific energy input in Europe and worldwide (Figure 9). By 2015, the average energy consumption per tonne alumina was 36 % higher worldwide, and 49 % higher than the Europe average compared to AOS's demand.

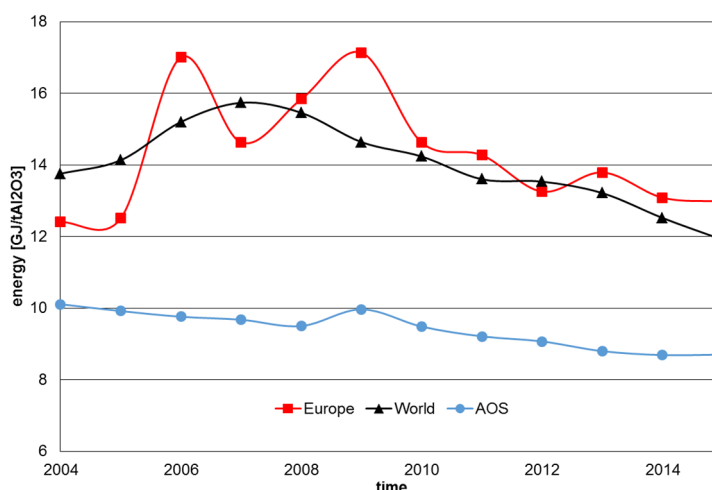


Figure 9. Comparison of the specific total primary energy input [7].

## 7. Conclusion

The foundation for the success of AOS regarding the primary energy consumption per ton of alumina was laid by German engineers over 40 years ago in the design of the tube digestion process. Then during the years of operation, engineers at AOS found multiple ways to optimize the process and reduce the primary energy demand as well as the CO<sub>2</sub> emissions. For instance, the operation and cleaning methods of the digesters were improved, one calciner was modified, a CHP was installed and a heat recovery system recovering heat from the exhaust gas stream of the salt heater was installed. Even though every refinery aims to keep the energy demand of its plant to a minimum, AOS is still well ahead of the average in both Europe and worldwide.

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