Waste Heat Recovery Using the Example of Slag Fuming

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1. Introduction ....................................................................................................... 329

1.1. Waste Heat Recovery downstream Ausmelt Process .................................... 330

1.2. Waste Heat Recovery downstream Isasmelt Process .................................... 331

2. Principle of a Waste Heat Recovery System .................................................. 333

3. Water Distribution ............................................................................................ 333

4. Technologies for Waste Heat Recovery Systems ........................................... 334

4.1. Cooled Upper Furnace Part for the Ausmelt Process ................................. 334

4.2. Water Cooled Damper ..................................................................................... 335

4.3. Thermal Expansion ........................................................................................... 335

4.4. Hammering Cleaning System .......................................................................... 336

5. Summary ............................................................................................................ 338

Abstract

This article describes state of the art technologies for waste heat recovery systems or waste heat boilers respectively downstream pyro-metallurgical processes in the non-ferrous industry. The technologies are based on conducted plant applications. One objective is a modified Ausmelt furnace design as an integrated part of the waste heat boiler system. Different heating surface designs which are adapted to the process conditions are described as well. The hammering cleaning system for the fouling control of the heating surfaces and the adjustment of the cooling efficiency is introduced. The thermal expansion is another objective of this article. Furthermore possible improvements and developments for waste heat boiler systems in the non-ferrous industry are shown.

1. Introduction

The Oschatz group was founded in 1849 and is one of the last private owned waste heat boiler companies. Oschatz is active in the non-ferrous, the iron and steel, the chemical and the environmental industry and offers process gas cooling solutions for these industry sectors. It has subsidiaries for standardized detail engineering, manufacturing, erection and has representatives all over the world. Oschatz has an independent market position and is in close dialogue with the plant operators in accordance with their individual operational requirements and needs. In the Oschatz history of up to now more than 160 years the company has changed from a subsupplier to a general contractor and developed to an independent, innovative partner of plant operators.
For the non-ferrous industry Oschatz develops and supplies waste heat boilers downstream Ausmelt process, Isasmelt process, Flash Smelting process, Fluidized Bed Roasting and Cyclone Smelting etc. Figure 1 shows some of the corresponding waste heat boiler geometries.

The following two principle sketches show the typical waste heat boilers downstream Ausmelt and Isasmelt process. These units are designed according to state of the art waste heat boiler technologies.

1.1. Waste Heat Recovery downstream Ausmelt Process

The Ausmelt process is often used for the fuming of slag to extract the desired metals. The off gas flow in waste heat boilers downstream Ausmelt process is usually between 15,000 Nm³/h and 120,000 Nm³/h. The off gas temperature range at the waste heat boiler inlet is between 1,100 °C and 1,600 °C and is cooled down to 650 °C up to 750 °C at the bottom of the second vertical radiation shaft. At the end of the horizontal section the temperature is between 300 °C and 400 °C.
Figure 2 shows the typical geometry of a waste heat boiler downstream Ausmelt furnace. It consists of two vertical radiation shafts and one horizontal convection section which contains heating surface bundles installed cross to the off gas flow.

The general layout in figure 2 shows the combination of three evaporative cooling installations in one waste heat boiler:

- furnace shell gas cooling,
- radiative gas cooling and
- convective gas cooling.

The design basis of the furnace shell gas cooling is the experience with the reactor cooling of Electric Arc Furnaces (EAF) and Contop Cyclones.

In the hopper section of the waste heat boiler the dust can be separated into a product and a recycle portion.

1.2. Waste Heat Recovery downstream Isasmelt Process

The off gas flow to be handled in waste heat boilers downstream Isasmelt processes is between 15,000 Nm³/h and 140,000 Nm³/h. The inlet temperature range is usually between 1,000 °C and 1,500 °C. The outlet temperature at the bottom of the second vertical shaft is 650 °C to 750 °C and at the outlet of the horizontal section it is usually between 300 °C to 400 °C depending on the load case. The waste heat boiler has three sections: two vertical radiation shafts and one horizontal convection section as an option. A principle layout of a waste heat boiler downstream Isasmelt process is shown in figure 3.

The off gas flow conditions at the top of a vertical waste heat boiler have been optimized by a special design with regard to build ups and a homogeneous off gas flow. In figure 4 a photo of the research works attempted in this field is shown. The photo shows the gas flow test arrangement which was prepared by the Chair in Flow Mechanics at the University of Essen in Germany. In figure 3 the final design is shown. This design has been approved in waste heat boilers downstream Isasmelt process e.g. for the Aurubis AG in Germany, the Yunnan Copper Corporation in China, Mopani Copper Mines Plc in Zambia or the Southern Peru Copper Corporation.

The off gas velocity at the waste heat boiler inlet should be less than 10 m/s to get sufficient heat transmission conditions and a homogeneous temperature profile. Another option to control the off gas temperature is a spray cooling system with spray nozzles installed directly into the gas flow or an air cooler. The standard installation location of this system is usually in the second shaft of a vertical waste heat boiler. A horizontal convection section connected to the second vertical shaft which contains heating surface bundles in the gas flow cross section is an alternative to this system. A higher steam generation is the advantage of this option.

At the inlet of the horizontal convection section the temperature should be between 600 °C and 700 °C. In this temperature range the dust characteristic usually changes. The dust gets less sticky and drier which is also depending on the process conditions and the dust composition. With these superior dust properties the heating surface bundles are easier to clean and thus the heat transmission improves.
Figure 3: General layout of a waste heat boiler downstream Isasmelt process

Figure 4: Flow modelling at the simulated top of a vertical waste heat boiler by the Chair in Flow Mechanics at the University of Essen, Germany
2. Principle of a Waste Heat Recovery System

The primary process gas handling is the main purpose of a waste heat boiler. The process gas temperature has to be cooled down to a level that allows a further treatment for example in a bag house, an electrostatic precipitator or for the sulphur recovery. In the non-ferrous industry the dust in the process gas is sticky. The sticky gas components have to be converted from the molten to the solid phase in the waste heat boiler in order to allow a further off gas treatment. The dust has to be removed from the heating surfaces and has to be discharged continuously.

The conversion from \( \text{SO}_2 \) to \( \text{SO}_3 \) in the process off gas should be avoided to minimize the risk of sulphur corrosion on the tubes. An effective protection against this kind of corrosion is to keep the heating surface walls’ and elements’ temperature above the dew point. This is realized by a water/steam operating pressure between 40 – 70 bar. The corresponding saturated steam temperature then is between 250 – 285 °C and the tube wall temperature is nearly the same and uniform.

With the heat which is recovered by a waste heat boiler through the process gas cooling steam is generated. The heat of the steam can be converted into power which is usually used for the concentrate drying of the own process or for the profitable supply of electricity to a public network.

3. Water Distribution

The water circulation system of a waste heat boiler system can be natural, forced or a combination of both. The natural circulation system is self-sustaining and driven by the off gas heat. If the natural and the forced circulation system are combined the pump capacities and thus the electrical power consumption for the pump drives of the forced circulation system are less. This fact saves investment and operation costs.

The circulation water flow begins at the steam drum and then goes through the suction line to the circulation pump group. Two pumps are usually used. One pump is in continuous operation and the other one is in stand by function. The pump in operation is driven by an electric motor. The stand-by pump either has an electric motor as a drive with a redundant energy supply or a steam turbine which is fed by internally or externally generated steam. Through the main discharge lines the pump supplies the water to the different evaporator heating surfaces.

In order to get a uniform water flow admission and cooling effect the distributors of the different heating surfaces are equipped with La Mont-Nozzles. The steam is generated by the heat absorption of the heating surfaces. In the heating surfaces a part of the circulating water evaporates and the generated water/steam mixture flows downstream the main lines back to the steam drum. Water and steam are separated in the steam drum and the separated water is returned to the circulation system. The generated saturated steam is dried by a demister which is installed in the steam drum. In the demister water droplets are formed on the steel meshes and fall back into the water. The saturated steam is directed out of the steam drum in a separate line downstream the demister. The water in the steam drum has to be kept at a constant level. For this purpose the amount of evaporated water has to be compensated with a feed water system.

Each heating surface is equipped with one distributor and one collector. The water flow direction is from the distributor through the heating surface to the collector. A necessary condition for the tube protection is a uniform water flow profile and a sufficient water supply for each tube. This is realized by La Mont-Nozzles in the distributors.
4. Technologies for Waste Heat Recovery Systems

4.1. Cooled Upper Furnace Part for the Ausmelt Process

The furnaces in the non-ferrous industry are exposed to high bath and off gas temperatures, bath splashing and thermal reactions. The furnace refractory lining is a wear and tear part and its lifetime mainly influences the profitability of a non-ferrous plant. For the re-lining of the furnace the plant has to be shut down and every shut down causes production and profit losses. The furnace design has been modified to increase the brickwork lifetime. Therefore the upper furnace part has been replaced by a boiler tube design and this part is connected to the water circulation system of the waste heat boiler.

This modified upper furnace part ensures a sufficient cooling of the outer furnace shell. After a short operation time the bath splashing of the process covers the furnace shell tube wall with a thin slag layer. The slag layer then cools down, gets hard, clamps on the surface and protects the tubes.

The design is based on Oschatz's experiences with water cooled roofs and shells for Electric Arc Furnaces since the seventies. The first boiler tube type shell was built for the Contop Process of the Klöckner-Humboldt-Deutz AG in Germany in the early nineties. It is used for the smelting of copper concentrates and was installed in Texas, USA. Another one was built for the Harzer Zink GmbH in Germany and is used for the zinc-recycling of Electric Arc Furnace dust.

In the mid nineties the first tube type furnace roof for a waste heat boiler downstream Isasmelt process was installed. The design replaced the existing technology with copper or alloyed metal blocks and increased the lifetime of the furnace roof significantly. As a consequence this design was also used for the following waste heat boilers downstream Isasmelt processes e.g. for the Yunnan Copper Corporation and China Yunnan Metallurgical Group Corporation, for the Aurubis AG in Germany, for Mopani Copper Mines Plc in Zambia and for the Southern Peru Copper Corporation.

A principle sketch of a cooled Ausmelt furnace shell is shown in figure 5. The successful commissioning of the first shell was in 1998.

The roof construction design and the furnace shell ensure a high stability of the slag layer which replaces the brick lining during plant operation. The layer thickness is mainly influenced by the tube arrangement.
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4.2. Water Cooled Damper

Maintenance works at the waste heat boiler usually require a complete plant shut down which always means profit losses. For short term maintenance works Oschatz developed a solution by disconnecting the furnace from the waste heat boiler. A condition for the execution of these short term works without stopping the whole process is to prevent the gas flow to the waste heat boiler and to keep the furnace bath warm.

For this reason Oschatz designed a water cooled damper which can be inserted between the waste heat boiler furnace roof and the inlet of the uptake shaft. The damper insertion is enabled by a so called cooling screen which is installed at the uptake inlet. The cooling screen is equipped with an expansion joint and liftable. When the screen is on its highest position the cooled damper can be inserted. The damper is movable on railways and driven by an electric motor. In the damper end position the gas flow from the furnace into the boiler is stopped and the heat loss of the bath is minimised. The furnace roof is connected to the circulation water system but can be operated independent with a separate water supply. The damper is only connected to this separate water supply.

During the heating up phase of the furnace and the process operation the furnace bricklining moves upwards while the waste heat boiler bottom moves downwards.

4.3. Thermal Expansion

Compared to conventional boilers for the iron and steel and the chemical industry the waste heat boilers for the non-ferrous industry are characterized by the sticky dust in the off gas. The dust behaviour can lead to blockages on the waste heat boiler tube bundles and accretions on the tube walls. The heaviness of the blockages and accretions is depending on constructional conditions at the waste heat boiler gas side and on the process gas temperature. To work against the fouling the heating surface design is optimized. In addition special heating surface cleaning devices are applied. They are shown in figure 6 and 7. In general it is difficult to achieve a conventional heat transmission in waste heat boilers for the non-ferrous industry despite the above described measures. The fouling effect is compensated by an enlargement of the waste heat boiler. This waste heat boiler enlargement also enables possible plant capacity increases in the future. It allows the later installation of additional heating surfaces in form of bundles which can be realized in a short time period which minimises the plant shut down time and prevents additional investment costs and profit losses accordingly.

The thermal expansion is an important issue for these enlarged waste heat boilers. With the boiler supporting structure the material stress should be minimized. Old types of supports showed signs of wear after a few years of operation. In figure 2 and 3 state of the art spring hangers at the top of vertical waste heat boilers are shown. For the horizontal section of a waste heat boiler pendulum supports are used. These pendulum supports are flexible in the expansion direction of the waste heat boiler. Between the waste heat boiler and the drag chain conveyor for the horizontal boiler section a connection plate channel is installed. The channel is equipped with a sliding sealing which is available even after decades of operation. Another technology to compensate for the thermal expansion is expansion joints. Their main installation locations are areas where the waste heat boiler has to be enabled to expand freely or where different tempered materials have to be connected to each other. Expansion joints are installed at the following locations of a waste boiler:

- transition furnace roof to boiler uptake,
- connection furnace to the cooled upper furnace part (waste heat boiler downstream Ausmelt furnace),
• connection cooling hood to the uptake shaft (waste heat boiler downstream Ausmelt furnace),
• second vertical radiation shaft outlet.

4.4. Hammering Cleaning System

Due to the sticky dust characteristic and the high dust load which are generated in non-ferrous industry smelting processes the application of a heating surface cleaning system for the waste heat boiler walls and bundles is indispensable. During the process the dust deposits on the tubes of the heating surface bundles and the tube walls. The deposits hinder the heat transmission to the water circulation system. As a consequence the off gas outlet temperature increases. Thus the waste heat boiler cleaning has to be regular and effective. The following two types of cleaning devices are used:

• mechanical hammering cleaning devices driven by electric motors,
• pneumatic hammering cleaning devices driven by pneumatic actuators.

The number of hammering cleaning devices driven by one electric motor is dependent on the waste heat boiler constructional design:

• single hammering cleaning devices with one motor drive and one shaft,
• multiple hammering cleaning devices with one motor drive and one shaft with two or three devices,
• bundle hammering cleaning devices with one motor drive and one shaft with up to 20 devices next to each other.

![Figure 6: Side view of a single mechanical hammering cleaning device](image-url)
Figure 6 shows a mechanical hammering cleaning device. The device is fixed at a rotatable cogwheel. The bracket for the hammer is welded on a web plate at the tube wall. The shaft over the cogwheel is driven by an electrical motor. The rotation of the shaft is transferred to the wheel via a fixed disc on the shaft. This disc has seven bores for bolts and the bolts indent with the cogwheel when the rotation begins. The hammer is lifted by this mechanism. When the last bolt leaves the cogwheel the hammer swings back and hits the anvil. The vibration of the hit is transmitted to the tube bundles or walls so that the dust deposits are loosened and the dust falls off. For multiple hammering cleaning devices the hammer arms have an offset to each other so that the hammers hit at different times. This protects the electrical motor against overloading. The position and number of the fitted bolts determine the swing height of the hammer head and thus the impact force to the anvil. The impact force should be strong enough to clean the tube walls and bundles but should also be not too high because the bolts are a wear and tear part. The appropriate adjustment is based on the experience with the dust behaviour and load of plants in operation.

Pneumatically operated hammering cleaning devices are used at inclined tube walls. Depending on the inclination angle this system can be more effective than the mechanical one. The mechanical hammering cleaning system has a higher required space due to the needed acceleration distance. The cleaning effect is too low if this space is not sufficient.

Figure 7: Side view of a single pneumatic hammering cleaning device
The pneumatical cleaning devices are consisting of:

- one pestle mounted on a special bearing plate on the tube wall,
- one pneumatic impacter for direct pestle actuating.

In figure 7 the impactor of the heating surface cleaning device is a pneumatic hammer. The pneumatic piston is pushed by compressed air against one or two springs. By a fast releasing of the air under the piston the hammering effect is induced. This is done through a solenoid valve. The piston then is shot against an impact plate by springs and the impact is transmitted to the pestle.

5. Summary

In this article waste heat boiler systems for the non-ferrous industry have been described on plant applications downstream Ausmelt process for slag fuming and the Isasmelt process. Further the industrial requirements for these plants have been discussed and some special issues have been shown in more detail such as the cooled upper furnace part of the Ausmelt furnace, the thermal expansion and the different heating surface cleaning systems.

Because of the special dust characteristic of the process gases of non-ferrous smelting applications innovative gas cooling technologies are required in this industry field. Process capacity increases by the means of concentrate changes, higher off gas throughput and furnace off gas temperatures presuppose that the waste heat boiler systems have to be adaptable. The basis for a further development of waste heat boilers in this industry field is the experience with plants in operation. In the non-ferrous industry various beginning points for improvements in the waste heat boiler off gas treatment can be found. The focus must be the optimisation of existing plants and the continuous development of new technologies.