RETROFIT OF WtE BOILER: CASE STUDY ON BONN PLANT

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Abstract

The implementation of the European-directive requiring a residence time of at least two seconds at a temperature above 850°C (1562°F), the change in waste characteristics, and the pursuit of higher thermal efficiencies has pushed many of the existing WtE plants in Europe to their operational limits. Most existing WtE plants were not designed to operate under these conditions and may require modifications to the combustion system.

Within the SEGHERSbetter technology (SEGHERS) company, the SEGHERS-IBB-Prism was developed to deal with the cause of these problems, which are essentially related to insufficient mixing and burnout of the flue gases in the combustion area. In the Boiler Prism the flue gas flow is divided into two parallel flows prior to entering the first radiant pass of the boiler. This division is achieved by means of a prism shaped construction, which is water-cooled and integrated with the natural circulation system of the boiler. Additional secondary air injection nozzles are fitted in the prism. This technology results in a more uniform flue gas temperature and a complete combustion of the flue gas immediately above the prism. In the Bonn Plant, these improvements in the combustion process resulted in a decrease of the fireside cleaning requirements of more than 50%.
Introduction

Thermal conversion of municipal solid waste is a very complex process. In Europe, modern stoker-fired incineration plants, based on proven technology, are recognized as the most economical, reliable and environmentally sound solution for waste treatment. Plants operate in full compliance with the stringent EU emission standards. A modern WtE plant is designed to accommodate high calorific waste (due to increased recycling and/or the use of RDF), is operating at higher combustion temperature and reduced excess air levels (in order to obtain an increased thermal efficiency) and is designed to maintain a residence time of at least two seconds at a temperature above 850°C (1562°F). Some of the older WtE plants are not fully prepared for this developments and a number of problems became apparent:

- High carbon monoxide corrosion rates on the water-walls of the first two radiant passes of the boiler
- Increased corrosion on the heating surfaces of the super heater
- Increased slagging of the heating surfaces of the boiler and deterioration of the refractory lining (resulting in reduced plant availability or short operation periods between manual cleaning).

The cause of these problems is the presence of a column (or layers) of partially unburned hot gases in the radiation pass. This column contains higher levels of carbon monoxide due to the poor mixing with oxygen and contains sticky dust particles due to the high flue gas temperature (dust particles in plastic phase). To counter these problems, several new technologies have been developed and implemented over the last years, e.g.:

- Protection of corrosion exposed surfaces by
  - new refractory lining concepts (air-swept)
  - high alloy overlay welding (Inconel 625 -622-628)
  - plasma spray coating
  - high-alloy compound tubes
- New cleaning techniques (curative)
  - high impact cleaning by linear explosion
  - water washing during operation

These measures focus on the symptoms of the problems rather than the cause and are therefore only a temporary or partial solution. Several systems were developed and tested in praxis, dealing with the causes of the problems

- Tangential injection of secondary air (Von Roll, Babcock)
o Rotating secondary air injection cylinder (Temelli)

o Steam injection (Krüger / Schwandorf)

The SEGHER S-IBB-Prism belongs to the technologies that deal with the cause of the problems by optimizing the combustion process in the first pass of the integrated boiler. The Boiler Prism results in a uniform distribution and complete burnout of the flue gas at the entrance of the first radiant pass of the boiler. The first Boiler Prism was installed in 1997 on one train of the MSW-incineration plant in Bonn, Germany. The project-specific mathematical models for the heterogeneous solid waste combustion calculations were developed at the Institute of Environmental Process Engineering and Plant Design at the University of Essen, under the direction of Professor Klaus Görner, PhD. The results of the Boiler Prism on the first train exceeded all expectations and resulted in an order for the installation of this system on the two remaining trains in 1998 and 1999.

**Process Description of the SEGHERS-IBB-Prism**

In the SEGHERS-IBB-Prism, the flue gas flow is divided in two partial flows “A” and “B” prior to entering in the radiant pass of the boiler. This division is achieved by means of a membrane-wall construction, with the shape of a prism, which is water-cooled and integrated with the natural circulation system of the boiler and protected with refractory lining (Fig. 1 Principles of SEGHERS-IBB-Prism).
Secondary air is injected into the divided flue gas streams “A” and “B”, through multiple secondary air nozzles. The secondary air injection nozzles are not only installed in the boiler front- and rear wall, but also on both sides of the prism.

The optimization of the combustion and post-combustion process with this new secondary air injection system, results in a complete burnout of the flue gases just above the prism (elimination of the hot column). This achievement is explained by the following facts:

- Improved flue gas / air mixing due to the reduction of the necessary penetration depth of the secondary air jet to nearly \( \frac{1}{4} \) of the original depth.
- Injection through a large number of smaller nozzles with lower individual air flow, permitting a much quicker heating of the secondary air to the required reaction temperature for CO-oxidation of approximately 600°C (1100°F).
- Creation of an optimal post-combustion reaction chamber with targeted oxygen supply in a highly turbulent stream

Since the prism is located in a very turbulent and high temperature zone, its membrane walls are water cooled and protected with a ceramic coating. The water-cooling is guaranteed by integrating the waterside of the Prism in the natural circulation system of the boiler. Furthermore the secondary air nozzles of the prism contain an on-line cleaning system to prevent slag built-up on the nozzles. This is achieved by periodically blowing low-pressure steam, into the air nozzles. The fast expansion of the water in the steam removes any slag deposit on the secondary air nozzle during operation.

**Additional Advantages for Process Control**

Just above the SEGHERS-IBB-Prism, a thermocouple is installed in both flow sections (A & B). The purpose of this temperature measurement is to maintain a homogeneous flue gas temperature in flue gas Sections A and B by means of a variable secondary airflow. When a flue gas temperature increase is observed in Section A, the secondary airflow for Section A is automatically increased until the temperature set-point is re-established. At the same time, secondary airflow for Section “B” is reduced in order to keep the total secondary airflow constant. This control mechanism helps to accomplish the goal of a homogeneous temperature and a quick and complete burnout. The overall air supply is controlled by the furnace-boiler control system in function of a specific set of process parameters (steam production, \( O_2 \) in the flue gases, flue gas temperature...).
An additional, important feature of the Boiler Prism is that this type of secondary air injection system responds very rapidly to modifications in combustion conditions such as a shift in the heat-release profile on the grate: When high calorific waste is suddenly entering the furnace, combustion of the waste will already start on the first part of the grate and the flue gas temperature in section “A” will rise above the set-point. The system recognizes this temperature imbalance and reacts accordingly as described above. The opposite will occur when low calorific waste is introduced and combustion on the grate is delayed towards the middle of the grate. This feature can be used as an early warning system indicating the type of waste entering the furnace and as such become an integral part of a fast combustion control system [1].

Experience with the Boiler Prism on the Bonn WtE Plant

The first SEGHERS-IBB-Prism was installed in 1997 on the first train of the MSW-incineration plant in Bonn, Germany. The project-specific mathematical models were developed in collaboration with the University of Essen. The results of these calculations were further used to establish boundary conditions for numerous three-dimensional Computational Fluid Dynamic (CFD) simulations of the furnace and combustion chamber and first radiation pass of the boiler, with different waste characteristics. The geometry of the furnace and first pass of the boiler of the Bonn waste incineration plant generated for the CFD calculations is presented in Figure 2.

Fig. 2: Furnace geometry for CFD calculations
Flue gas temperature, $O_2$ and CO concentrations, and velocity distribution were calculated with and without the "prism". Calculations were made in relation to the optimization of the secondary air nozzles for this installation with regard to their number, diameter, location and inclination. From the results of the simulations with and without the prism, the following improvements with the prism can be observed [2]:

- Very uniform flow patterns in the first pass of the boiler, above the prism, and in particular the absence of the recirculation zone. (See Fig. 3: Velocity Profile)
- Improved mixing between the flue gases and the secondary air. The distributions of flue gas temperature, oxygen and CO are more uniform. Reduction of temperature differences in the cross section just above the prism from more than 200°C (temperature difference of 360°F) to less than 100°C (temperature difference of 180°F). The difference between the highest and lowest $O_2$ and CO-concentration also became substantially smaller.

![With Prism](image1)

![Without Prism](image2)

Fig. 3: Influence of SEGHERS-IBB-Prism on flue gas velocity in the first radiant pass.

After construction and commissioning of the Boiler Prism in the Bonn plant, validation of the applied calculation models was possible during a measurement campaign. The measured temperature difference in the cross-section above the Prism was approx. 100°C (temperature difference of 180°F). The measured oxygen concentrations were also very close to the predicted concentrations. The calculations clearly illustrated the strong influence of the secondary air injection on the combustion results.
The first line of the plant in Bonn now operates for more than 20,000 hours without problems. The results of the Boiler Prism in the first line exceeded all expectations and resulted in an additional order for a prism for Line 2 in 1998 and on Line 3 in 1999. The installation of the Prism in Bonn resulted in the following major improvements:

- The combustion process is fully completed at 2-3 m above the prism and no flame breakouts could be seen in the upper section of the radiant pass.
- Clear reduction of the corrosion potential by minimizing the presence of CO-layers in the flue gas flow.
- Virtually equal flue gas temperature at the outlet of Section “A” and Section “B” and consequently a homogeneous flue gas temperature in the first boiler pass.
- Considerable reduction of dust carry-over from the furnace into the boiler due to the reduced amount of primary air under the grate.
- Substantial reduction of fouling of the boiler heating surfaces as a result of the complete burnout, the even flue gas temperature distribution and thus the absence of hot gas layers together with the reduced presence of sticky dust particles. After 9,000 operating hours of the Bonn Plant, the flue gas temperature at the inlet of the convection heating surfaces had only increased from 560°C (1040°F) to 585°C (1085°F), i.e. only 25°C (45°F) compared to the usual observed increase by more than 100°C (180°F).
- Important increase of the operation periods between two shut-downs for manual cleaning from 3,300 hours before to more than 8,000 hours after the installation of the prism. Only some slight and very localized slagging was observed on the lower header of the prism, however the majority of these deposits breaks down during operation. Any residual deposits can be removed easily manually during yearly overhaul. (see Figure 5).
It should be mentioned that all these improvements have been positively influenced by the fact that at the same time all incineration lines were equipped with water-cooled grates. Water-cooled grate systems offer the additional advantage of complete freedom in selecting the ratio between primary and secondary air distribution, without compromising the lifetime of the grate bars.

In meanwhile, SEGHERS has applied the Boiler Prism in other WtE plants in Europe such as the newly constructed plant in Manheim, Germany.
CONCLUSIONS

The SEGHERS-IBB-Prism is a cost-effective solution for high corrosion and slagging rates in WtE heat recovery boilers. In the Bonn plant, the system resulted in an increase of more than 100% of the operation periods between two shut-downs for manual cleaning of the boiler. The system also has additional advantages such as an improved process control system. The SEGHERS-IBB-Prism can be retrofitted on an existing facility or can be part of the initial plant design.

References:
