Design, Construction, Start-up and Commissioning of a State-of-the-Art Water-Cooled Grate WtE-Plant for Örebro, Sweden

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Abstract

In 2001, SEGHERS was awarded the contract for the design and construction of the furnace and heat recovery system of a new, 330 tons per day WtE-plant in Orebro, Sweden. A wide variety of municipal and industrial wastes (including electronic waste, demolition waste, car fluff, filters, plastic and rubber...) will be treated. The design point corresponds to an average heating value (HHV) of 13.1 MJ/kg (5600 Btu/Lb).

The first part of the paper addresses the engineering and construction phase of the project, which took 15 months in total. Key decisions and design options, including the choice and characteristics of a partially water-cooled grate, the use of the cooling water heat (with implications on plant efficiency) and the design features resulting in a low-NOx WtE plant are discussed in detail.

The second part of the paper focuses on the construction and commissioning of the plant.

Finally, the plant performance is documented. The main results are compared with the guaranteed values and the differences are discussed. The performance of the water-cooled grate is compared to that of other WtE plants.
Introduction

In 2001, the joint venture SEGHERS-PEAB was awarded the contract for the design and construction of the furnace and heat recovery system of a new, 330 tons per day WtE-plant in Örebro, Sweden by Sydkraft AB. The Sydkraft Group consists of 60 operating subsidiaries with approximately 5,300 employees working with electricity sales, electricity distribution, electricity production, natural gas, LPG, heat, cooling, water and sewage systems and energy, materials recovery from waste, energy trading and communications solutions. In May 2001, Sydkraft AB became part of Germany’s E.ON Group, which is listed on the Frankfurt and New York stock exchanges. The joint venture partner PEAB Sverge AB is a leading Swedish civil construction company.

Sydkraft already operated a 100 TPD rotary kiln for hazardous waste incineration in Örebro and needed a new incinerator for sorted municipal and industrial waste. Due to recycling of the inert fraction (among others glass) and the wet organic fraction (kitchen and garden waste), and due to the high industrial waste content, the average heating value of the waste is high (5600 Btu/Lb). The thermal efficiency of the plant and low NOx emissions were Sydkraft’s main selection criteria. These criteria combined with the high heating value of the waste, demanded a specific plant design.

Plant Description and Key Numbers

The Örebro plant consists of a single train moving grate furnace with integrated steam boiler and a state-of-the-art flue gas cleaning system (separate contract). The steam is used for power generation in a back pressure turbine. From the turbine the steam goes to a condenser in which energy is recovered for a district heating system (see Figure 1). The new facility has a horizontal boiler with 3 empty passes and a mechanical cleaning system (rapping device) in the last radiation pass and the convection section; soot blowers are not used.
The plant will burn domestic waste together with a variety of industrial wastes:

- Car fluff
- Oil Filters
- Electronic waste
- Paints, oils
- Plastics and rubber

**Figure 1: Process Flow Diagram**

**Combustion Diagram**

**Figure 2: Combustion Diagram**
The plant also has a system to inject water containing organic contaminants (such as solvents and oils) and concentrates into the furnace. Waste steam is used to atomize these flows in the furnace. The heating value of the total waste mixture (LHV) can be as high as 17 MJ/kg or 7300 Btu/lb (see combustion diagram in Figure 2).

Key Numbers of the Örebro Facility:

<table>
<thead>
<tr>
<th>Capacity</th>
<th>330 TPD</th>
</tr>
</thead>
<tbody>
<tr>
<td>LHV</td>
<td>5600 Btu/lb</td>
</tr>
<tr>
<td>Minimum thermal efficiency of steam boiler (determined according to DIN1942)</td>
<td>82%</td>
</tr>
<tr>
<td>Max. flue gas temperature at exit of boiler</td>
<td>210 °C (410 °F)</td>
</tr>
<tr>
<td>Steam conditions</td>
<td></td>
</tr>
<tr>
<td>• Pressure</td>
<td>40 barg (580 psi)</td>
</tr>
<tr>
<td>• Temperature</td>
<td>400 °C (752 °F)</td>
</tr>
<tr>
<td>Back pressure steam for district heating, pressure:</td>
<td>8 barg (116 psi)</td>
</tr>
<tr>
<td>Net electricity generation</td>
<td>6200 kW</td>
</tr>
<tr>
<td>Energy in steam for district heating</td>
<td>85 MM Btu/h</td>
</tr>
<tr>
<td>Flue gas emissions limits at exit of boiler:</td>
<td>Dry, 11% O₂</td>
</tr>
<tr>
<td>• Daily averages</td>
<td></td>
</tr>
<tr>
<td>• Dust</td>
<td>5 g/Nm³</td>
</tr>
<tr>
<td>• CO</td>
<td>50 mg/Nm³</td>
</tr>
<tr>
<td>• NOₓ</td>
<td>150 mg/Nm³</td>
</tr>
<tr>
<td>• D/F</td>
<td>5 ng TEQ/Nm³</td>
</tr>
<tr>
<td>• ½ hour emission limits</td>
<td></td>
</tr>
<tr>
<td>• CO</td>
<td>100 mg/Nm³</td>
</tr>
<tr>
<td>• NOₓ</td>
<td>400 mg/Nm³</td>
</tr>
<tr>
<td>Max TOC for slag, siftings and boiler ashes</td>
<td>3%</td>
</tr>
</tbody>
</table>

Table 1: Key numbers

The daily average NOₓ level of 150 mg/Nm³ is lower than the current EU standard of 200 mg/Nm3, which is applicable for existing plants with a capacity of more than 6 ton/hour from 28 December 2005 and for new plants from 28 December 2002.
Main Features and Advantages

Seghers proposed a combination of a partially water cooled grate, flue gas recirculation and an SNCR to cope with the high heating value and the strict requirements on \( \text{NO}_x \) emissions and boiler efficiency.

**Water-cooled grate**

The grate consists of three water-cooled elements (element 1 to 3) and two air-cooled elements (element 4 and 5). The grate tiles in elements 1, 2 and 3 consist of a solid plate, which incorporates a water circuit (see Figure 3). The cooling water is forced through the tiles by means of a pump and circulates in a closed loop.

![Figure 3: Water Cooled Tiles](image)

The water-cooled grate systems allows independent selection of the quantity of primary air, without compromising the lifetime of the grate bars. This allows reducing the excess air in the furnace and increases as such the efficiency of the boiler. The energy recovered by means of the cooling water is transferred to the district heating system (see Figure 1).

An additional advantage is that the tiles are kept at a lower temperature, which increases their lifetime substantially. This is particularly important for this facility in view of the high heating value of the waste.

The air-cooled elements consist of fixed, tumbling and sliding tiles. The tumbling tiles – a unique feature of the Seghers Multi Stage Grate – assure proper mixing of the waste on the grate (Figure 4). This is important to obtain a complete burnout of the waste.
The above described design of the grate (i.e. containing a water-cooled and an air-cooled part) provides the necessary flexibility to treat waste with relatively low heating value on the one hand and high heating value on the other in an optimal manner.

**Flue gas recirculation**

10% of the flue gas is separated from the flue gas flow downstream of the bag filter at a temperature of 140°C (280°F) and is recirculated to the furnace by means of a dedicated speed controlled fan. The recirculated flue gas is injected at the inlet of the first empty pass of the boiler, through multiple nozzles on both sides of the empty pass. The position, size and number of nozzles is determined in function of the results of a CFD study covering the complete empty pass. The secondary air is also introduced in the flue gas at the inlet of the first empty pass of the boiler. For the secondary air, Seghers chose to use two injection banks on each side of the empty pass (allowing an optimized 'staged combustion'). The position, size and number of nozzles of both air and flue gas is determined in function of the results of a CFD study covering the complete empty pass (see Figure 5 and Figure 6).
The optimization of the combustion and post-combustion process with this air/flue gas injection system, results in a complete burnout of the flue gases above the air/flue gas injection (elimination of a hot column). This achievement is explained by the following facts:

- 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

Flue gas recirculation, improves the efficiency of the boiler since part of the combustion air is replaced by flue gas. Less combustion air means less flue gas to the stack and therefore less stack losses.
Less combustion air also means less $O_2$ in the flue gas which results in lower NO$_x$ formation. The equilibrium of the following chemical reaction is pushed towards the left in case of lower $O_2$ in the flue gas.

$$N_2 + O_2 \leftrightarrow 2 \text{ NO}$$

The flue gas recirculation together with a multi level SNCR system will result in a NO$_x$ level within the imposed emission limit.

**SNCR**

The SNCR system is a ammonia based system: at a temperature of around 900°C (1650 °F) the following reaction takes place

$$2 \text{ NH}_3 + 3 \text{ NO} \leftrightarrow \frac{5}{2} \text{ N}_2 + 3 \text{ H}_2\text{O}$$

To control the excess NH$_3$ a combination of a feed forward and a feed backward control system is used.

Ammonia is dosed based on:
- NO$_x$ measurement downstream of the bag filter (feed backward)
- Thermal load: a higher thermal load results in higher NOx-formation (feed forward)

Also, the injection level is selected based on the temperature measurements in the first empty pass of the boiler

**Project Execution**

The erection of the mechanical equipment started early January 2002. The important milestones of the erection are shown below and were all met.

- Delivery of the incineration grate: 23 January 2002
- Start boiler erection: 23 March 2002
- Completed pressure test for boiler: 26 June 2002

Commissioning was started on schedule. However the period foreseen for steam blasting had to be extended until 13 January 2003 due to of the very stringent requirements of the turbine supplier.

At the same time the erection of the condenser was completed and the introduction of waste inside the grate began at 16 January 2003.
Figure 7: Erection of grate

Figure 8: Plant construction
Plant performance and summary of results

Thanks to the introduction of recirculated flue gas, the oxygen content of the flue gases can be controlled at around 7%. CO emissions vary between 10 and 20 mg/Nm³ Dry, 11% O₂ (11.2 ppm - 22.4 ppm Dry, 7% O₂). The boiler efficiency (determined according to DIN1942) is 82.4%. The effect of the flue gas recirculation on the thermal efficiency of the Örebro plant is about 1.5% (i.e. the efficiency increases with 1.5% due to flue gas recirculation).

The SNCR system is not yet started at the time of writing. The NOx emissions fluctuated in a range from 180-230 mg/Nm³ (122 – 156 ppm, Dry, 7% O₂) at the boiler outlet without SNCR. The typical NOx value of a modern WtE facility without flue gas recirculation and without SNCR is currently around 300-350 mg/Nm³ (204 – 238 ppm Dry, 7% O₂). Based on experience in other plants, it is expected that the NOx-reduction efficiency of the SNCR-system will be around 50% and that therefore the NOx value of 150 mg/Nm³ will be met.

For what the lifetime of the grate tiles is concerned, we have to refer to experience with the same water-cooled system in other plants. On one plant in Germany no replacement of the tiles were necessary for 32,000 hours, with an heating value that is higher than it is in the Örebro-plant.

The commissioning tests have shown that the intensity of the cooling of the water-cooled tiles has an impact on the combustion process. Particularly when the heating value of the waste mix is lower then 11 MJ/kg (4730 Btu/lb), the cooling intensity can be reduced. As such, the water-cooled grate offers an additional control parameter, which can be used to obtain optimal combustion characteristics for a changing heating value.

Our experience in Örebro and other WtE plants with high calorific waste leads us to conclude that a hybrid grate (i.e. combination of air cooled with water cooled) is advisable for a heating value range of 10 – 18 MJ/kg (4300- 7740 Btu/lb). An overview of heating value ranges with the corresponding grate type is given in Table 2.
Water-cooled tiles can be installed on almost any grate as a retrofit in order to adapt the grate to a rise of the heating value over the years.

<table>
<thead>
<tr>
<th>Type of grate tile</th>
<th>Heating value range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air cooled grate</td>
<td>6 – 14 MJ/kg</td>
</tr>
<tr>
<td>Hybrid (partly water cooled)</td>
<td>10 – 18 MJ/kg</td>
</tr>
<tr>
<td>Water-cooled only</td>
<td>15 – 30 MJ/kg</td>
</tr>
</tbody>
</table>

Table 2: Overview of heating value ranges

CONCLUSIONS

The characteristic design of the grate (containing both an air-cooled and water-cooled section) has made an optimized combustion of the waste with the given variation in LHV (10.5 – 17 MJ/kg) possible. It is highly flexible and allows a rapid adaptation of the combustion parameters in case a variation in the type of waste occurs.

In Örebro, flue gas recirculation has proven to be an effective way to increase the thermal efficiency of the system and to keep NOx emissions low.

References:
