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Engineering balanced sustainability™
Solid Recovered Fuel Power Station Eisenhüttenstadt for the Energy Supply of a Paper Machine

Kai Redemann and Leo Homann

1. Introduction

The Propapier PM 2 AG is a 100 % subsidiary company of the Progroup AG, based in Offenbach/Queich in Germany. The Progroup AG company is present at nine locations in Europe. Core business of the Progroup AG is the production and distribution of corrugated cardboard and corrugated board raw paper. In this line of business it is the market leader in central Europe.

The company planned to build a new papermill, called PM 2, in the city of Eisenhüttenstadt (Germany), south of Frankfurt/Oder. The site is situated 4 km from the river Oder, near to the Polish border. It is located in an industrial area next to the Oder-Spree canal, north of Eisenhüttenstadt on an area formally used as storage space, gravel-pit and for railway sidings. For the supply of the PM 2 with electricity and heat, a co-generation plant, the so called HKW Eisenhüttenstadt, was planned at the same site.
Paper production is an energy intensive industry. In this project the corrugated board raw paper is produced from 100 % recovered paper of different qualities. For the raw paper production the recovered paper is disintegrated in a water bath. The fibers are cleaned and conditioned for the utilization in the papermill. The fibers are sprayed in a thin solution on a sieve. The paper-slurry is mechanically dewatered and further dried on a series of steam heated drums. After that the paper is rolled to large roles and is tailored to the required sizes. For the drying of the paper the PM 2 needs about 140 t/h of steam and furthermore has a total electricity demand of 42 MW.

From the paper production about 30,000 Mg of coarse rejects and 49,500 Mg fine rejects arise per year. These rejects have a lower heating value of 16,800 kJ/kg and 5,800 kJ/kg, respectively and shall be utilized in a co-generation plant to cover the energy demand of the papermill.

2. Thermal Utilization of Residues from the Paper Production and SRF in fluidized bed combustors

In principle the typical technologies known from the thermal treatment of municipal solid waste are applicable for the thermal utilization of residues from the paper industry. The most commonly used technologies are the grate firing systems and fluidized bed combustors.

Grate systems are a well proven technology. Their advantages are their robust construction, ability to handle large fuel particles and contraries as well as a comparatively simple fuel feeding [1]. Here the thermal utilization of SRF in fluidized bed combustors are characterized by the following advantages:

- Fuels with a broad(er) bandwidth of heating values can be utilized
- Fluctuations in the heating value are tolerated easily by the combustion system
- Solid, pasty, liquid as well as gaseous fuel can be utilized in fluidized bed combustors
- The turbulence in the combustor, combined with the large heat capacity of the solids inventory inside the combustor lead to a homogeneous temperature distribution and good gas mixing throughout the combustor. This leads to a virtual complete oxidation of the fuel.
- The even temperature distribution in the combustor with no hot-spots leads to a low NOx formation in the combustor. The availability of an appropriate temperature region and a good mixing makes the utilization of an SNCR system an efficient solution for even lower NOx emissions.
- Limestone may be utilized for a pre-desulphurization, where necessary.
- Overall the fluidized bed combustion technology provides an off gas quality with low pollutant concentrations, making the necessary flue gas cleaning less cost intensive.

Compared to grate firing systems in fluidized bed combustors

- higher steam parameters
- higher overall electrical efficiencies
- higher specific thermal output per footprint area
- higher thermal input per line

can be established [1].
On the other hand, following pre-conditions and drawbacks have to be considered, when using fluidized bed combustors:

- Strict regulations regarding the particle size (max. edge length) have to be obeyed.
- The fuel shall contain only a limited amount of contraries (metal, glass, stones). They may lead to problems in the fuel feeding and the ash discharge.
- Although almost no moving part exist in a CFBC, the continuous circulation of bed material at high temperatures may lead to erosion at some parts of the plant, especially in the bed material cooler. Special attention has to be paid to these critical components.

Further drawbacks of fluidized bed combustors compared to grate firing systems are

- a higher apparative amount and
- higher power requirements.

When waste shall be utilized thermally in CFBCs the requirements regarding the fuel particle size and low contrary amount often imply a pre-treatment of the fuel, which may be cost intensive. The rejects from the paper industry generally accrue in a form in which they need no or only very limited treatment for the utilization in fluidized bed combustors.

Because paper production is not only energy intensive, but also comes with a large release of waste water, papermills are often closely connected to water treatment plants. The sludge from these treatment plants, although it may be also used in grate firing systems, can be utilized ideal in fluidized bed combustors.

3. Concept Development for the Eisenhüttenstadt Plant

For the Propapier papermill PM 2 at the site of Eisenhüttenstadt an energy supply unit had to be built. Pöyry Deutschland was assigned as the general Planner for concept development, general design and for the supervision of construction and commissioning of such a plant. The necessary process steam generation and steam parameters are given by the design of the papermill.

- steam pressure: 8 bar(a)
- steam temperature: 175 – 190 °C
- steam demand: 140 t/h

Based on these parameters, the most economic concept for the coverage of the PM 2 energy demand had to be identified and implemented.

3.1. SRF incineration system selection

Provided that the rejects from the paper production shall be utilized for the steam supply of the papermill, a decision between a grate firing system and CFBC had to be made. In consideration of the comparison discussed in chapter 2, a fluidized bed combustor was preferred over a grate system for the following reasons:

- For the steam demand of the papermill two grate fired lines would have been necessary, whereas a FBC with one line is sufficient.
• With a FBC a multi-fuel-concept could be established, which utilizes
  * rejects from the papermill
  * solid recovered fuel and
  * hard coal
  as main fuels for the combustor, giving a more flexible and reliable steam production.
• In a FBC the sewage sludge of the neighboring sewage treatment plant can be utilized ideal.
• The rejects from the paper production already have a quality, which can easily be utilized in a FBC.

3.2. Selection of the Plan Design

To identify the most economic solution for the energy supply of the PM 2, four different main concepts were surveyed by Pöyry.

Case A – Steam generation by low pressure steam generators and purchase of electricity on the market.

Case B – Installation of a gas- and steam turbine, which are dimensioned such that the total electricity demand is covered and the additional purchase of electricity is minimized.

Case C – Installation of a solid recovered fuel (SRF) fired circulating fluidized bed combustor (CFBC).

Case D – Installation of a plant according to case C, combined with a gas- and steam turbine to further minimize the additional purchase of electricity.

As summarized in Table 1, cases A und B imply a utilization or deposition of the rejects offsite. Cases A und C focus on the steam supply of the papermill, whereby in case C some electricity may be produced as a by-product. In cases B and D the whole energy demand of the papermill is covered (almost) completely by the own energy supply plant.

For the selection of the best plant design, the cases described above as well as a number of further variations have been analyzed by Pöyry. Mass and heat balance calculations for the whole water steam cycle and cash value calculations for the whole process, including all supply and disposal costs where take as basis for the assessing.

<table>
<thead>
<tr>
<th>case</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>steam supply</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>electricity supply</td>
<td>X</td>
<td>(X)</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>rejects utilization</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

After analyzing all cases and their variations, it could be shown that case C (a SRF fired CFBC) gives the lowest energy cost for the supply of the PM 2. For the given boundary conditions it could further be shown that under economic aspects the plant ought to be run at full load all the time, even if the steam can not be utilized in the papermill and has to be condensed.

In order to maximize the electricity generation, combined with a maximum plant availability and a single line setup, a 150 MWth CFBC has been selected. For the live steam of the boiler the following parameters have been chosen:
- live steam amount: approx. 175 t/h
- live steam temperature: 470 °C
- live steam pressure: 70 bar(a)

Based on these parameters, the co-generation plant erected in Eisenhüttenstadt is the world largest SRF fired circulating fluidized bed combustor!

### 3.3. Design of the Water Steam Cycle

Boundary conditions which had to be considered for the design of the water steam cycle were:
- efficient/economic operation of the steam turbine in all operating conditions
- consideration of all cases of steam demand including outage of various components
- coverage of steam demand fluctuations during paper tear at the papermill

A paper tear at the papermill is characterized by a rapid decrease of the steam demand to roughly one quarter of the value corresponding to normal operation. During the following restart of the machine, the steam demand rapidly rises to 130 % and drops after a couple of minutes to the normal value.

Throughout all operating conditions the steam pressure level has to be maintained with high accuracy. At the same time the electricity generations had to be maximized, to cover the electricity demand of the papermill as much as possible.

Based on a series of mass and heat balance calculations, the optimal turbine compensator combination could be evaluated by Pöyry. The general arrangement is sketched in Figure 1 below.

![Figure 1: Setup of the Turbine Condensator combination](image-url)
The mass and heat balance calculations showed that the demands of the water steam cycle can be fulfilled best by an installation of a controlled extraction-condensing turbine. The steam, generated in the boiler of the CFBC, is lead into the high pressure part of the turbine. From the turbine a part of the steam is extracted on the pressure level of the papermill and is lead to the papermill via a pipe bridge. The residual steam is further utilized for electricity generation in the condensing part of the turbine.

For economical reasons the CFBC ought to run at full load all the time. Therefore the design of the condensing system had to consider a minimal steam consumption of the PM 2, e.g. during revision or a longer process stops, with ongoing steam production of the CFBC. Pöyry could show that for the optimal design the condensing part of the turbine is to dimension such that during a minimal steam consumption of the PM 2 under normal operating conditions and a concurrent maximum steam generation of the CFBC, the whole steam can be utilized for electricity generation. On the one hand a larger condensing part of the turbine would enable the plant to generate more electricity by the utilization of excessive steam during downtimes of the papermill. But on the other hand this does not outweigh the efficiency losses due to a less optimal design of the turbine for cases with normal operation of the PM 2.

As mentioned before, on an economical basis the SRF boiler should keep operating at 100 % load during a (short term) downtime of the papermill. In addition the mechanical stress of combustor and boiler arising from frequent heating-up and cooling-down should be avoided. To be able to condense the steam during outage of the PM 2 or of the turbine, an auxiliary condenser is installed. Via a by-pass station the steam supply of the middle pressure steam line is ensured during an outage of the steam turbine.

During an outage of the PM 2 and the turbine at the same time, the steam can not be condensed completely. Because the operation of the CFBC is uneconomic during a (longer) concurrent downtime of turbine and papermill, the excessive steam is blown off and it can be decided if the plant has to be shut down.

### 3.4. Steam Supply of the Papermill

During a paper tear the steam demand of the papermill is subjected to large fluctuations. The time dependent development of the steam demand depends on the type and location of the paper tear. In general, the steam demand drops to a minimum (~ 25 %) in less to 15 minutes and stays there for a couple of minutes. After that it rises to a maximum (~130 %) within two to three minutes and drops after roughly ten minutes to the initial value. The rapid changes of the steam demand can not be followed by the CFBC boiler due to its slow load alternation characteristic.

Pöyry Deutschland surveyed possible solutions for the steam supply of the papermill during and after a paper tear. With the auxiliary condenser the excessive steam can be condensed. For the covering of the maximum steam demand of the PM 2 after a paper tear a steam accumulator or a shell boiler are possible solutions.

Steam accumulators operate on the principle of pressure gradients. High pressure steam from an additional tapping on the steam turbine heats up a (large) water volume, leading to an increase of pressure and temperature in the accumulator. The stored energy can later be used for the release of additional steam on a lower pressure level. The loading of the accumulator ought to be done during the phase where the papermill has the minimum steam demand.
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In a shell boiler a (large) water volume is heated up by oil burners under a certain (steam) pressure. When additional steam is needed, it can be released quickly from the shell boiler on a lower pressure level. Since the heating up takes a certain time, the shell boiler needs to be kept warm.

Because it was planned to use a low-pressure steam generator for the heating of buildings, start up of the CFBC boiler and for other services, a shell boiler was to be installed anyway. A steam accumulator would have been an additional component. Pöyry could show that a larger shell boiler is more cost efficient than an additional steam accumulator.

Under normal operation the shell boiler is kept warm for a quick start-up, supplementing medium pressure steam when needed by the papermill.

3.5. Auxiliary Steam Supply

The papermills commissioning was scheduled roughly one year earlier than the co-generation plants commissioning. For the transition period a steam line was build across the Oder-Spree canal to the power plant park of the Vulkan Energiewirtschaft Oderbrücke GmbH (VEO), which supplies the industry complex of ArcelorMittal in Eisenhüttenstadt.

Via this auxiliary steam line the PM2 was supplied for the first months, until the commissioning of the co-generation plant was completed. The auxiliary steam is linked to the medium pressure steam system of the plant. It was agreed with VEO that condensates returned from the papermill have to be purified and losses have to be refilled before the condensates are returned to the VEO plant.

The early supply of steam to the papermill causes that all necessary components for the steam transfer to the papermill as well as all components for the processing of the condensates had to be in operation one year earlier than the rest of the plant. Therefore the time schedule for the erection of the plant was split into two phases, one phase for the preliminary supply of the papermill with steam and a second phase for the erection and commissioning of the rest of the plant.

4. Plant Layout and Process description

4.1. Fuel delivery and bunker

The plant layout realized in Eisenhüttenstadt is shown in Figure 2. Aim was to establish a compact layout, under consideration of the truck traffic supplying the co-generation plant with SRF as well as the truck traffic for the supply of the papermill and for transporting the produced paper.

To disentangle the traffic towards and from the combustion plant and the papermill, which is located left of the site depicted in Figure 2, the bunker was located in the north-east of the site. With this setup enough cueing space is gained on site and the papermill traffic is separate from the plant traffic. Trucks heading for the papermill stay on the road southwest of the plant, while trucks heading for the bunker turn right at the first road junction.

All trucks have to enter and leave the site via the scale at the gate. Trucks heading for the fuel bunker pass a radio activity measurement, installed in the north-east of the plant. Guided by a traffic light system the trucks approach the fuel bunker (UEB) and dump the SRF. To ensure the quality of the delivered fuel, some of the truck loads are inspected afore in the fuel delivery area.
The bunker is equipped with a separate stacking area to optimize its storage capacity. The fuel is handled by two bridge cranes, equipped with 16 m³ orange peel type grabs. Beside free digging, stacking and fuel feeding, the cranes also ensure the mixing of the fuel and may assist during a fire in the bunker. For fire detection and fire fighting an infra-red camera system, coupled with two fire-extinguishing water cannons and a sprinkler system are installed. For the supply of fire fight water, water tanks (USJ) and pumps (USG) are installed in the north-east of the site, to the right of the bunker.

Part of the combustion air is taken from the bunker during normal operation of the plant. During downtimes, an auxiliary bunker ventilation system on the roof of the bunker ensures an underpressure in the bunker at all times.

4.2. Main Combustion Line

The fuel crane in the bunker puts the fuel into two feeding hoppers. Form there the SRF is dosed into the CFBC by screw feeders, dosing conveyors and a pneumatic transport system. The whole dosing equipment is installed beneath the feeding hoppers in the concrete bunker building.

The CFBC, sketched in Figure 3, is located in the boiler house (UHA) and mainly consists of the combustion chamber, a primary gas cyclone, the return leg, a bed material cooler and the post-combustion chamber.

Fuel is blown into the hot fluidized bed inside the combustion chamber. The fluidizing air constantly entrains solids from the combustor into the primary cyclone, where the
bed material is separated from the gas phase. Via the return leg and the bed material cooler the solids are returned into the combustion chamber and the hot flue gases are led into the boiler.

The boiler has a vertical part with evaporators and a horizontal part with evaporators and superheaters. The bed material cooler, extracting heat from the circulating bed material, is equipped with evaporators and superheaters as well. Behind the horizontal boiler, the flue gas is pre-dedusted by a multi-cyclone, before entering the economizer.

Bed material is drawn from the bottom of the combustion chamber and sieved to a coarse and a fine bed material fraction. The coarse bed material fraction is put into containers and driven off for disposal. The some of the fine bed material is recirculated into the combustion chamber. The excess material is put into storage silos and is also driven off for disposal. Whenever necessary, limestone may be added to the combustion chamber for a primary desulphurization, e.g. during the firing of hard coal. Make-up sand may be added for the control of the bed material quality.

Coming from the economizer the flue gases are cleaned in the flue gas cleaning (UVJ), using the Novel Integrated Desulfurization (NID) Technology, sketched in Figure 4. Quick lime and activated carbon are conditioned with water in a mixer and are injected into the flue gas stream. Pollutants in the flue gas are bound to these solids and are removed from the gas stream together with the dust on a bag-house filter. The clean flue gas is sucked through the ID fan and is released to the atmosphere via the stack on the south-west of the plant.

Residues from the combustion (fine bed material and boiler ash) as well as the product from the flue gas treatment are transported via pneumatic transport to the storage silos (HTP), located next to the flue gas cleaning. Here the residues are loaded onto truck and driven off for disposal.
4.3. Steam Utilization and Distribution

Via the pipe bridge (UBR) the live steam is lead from the boiler to the steam turbine in the power house (UMA), located south-east to the boiler house. The generated medium pressure steam is lead from the power house to the papermill via a second pipe bridge, which goes from the power house to the north-east of the site and ends on the so called base plate route, passing the site on its north-east boarder. On this route, the steam is led to the papermill.

The steam not utilized in the papermill is used in the turbine for further electricity generation. In the power house the equipment for the treatment of the condensates as well as for the generation of demineralized water is installed as well.

4.4. Auxiliary Facilities

All switchgears, batteries and smaller transformers as well as the control room are accommodated in the switchgear building (UAB).

Sewage sludge as well as hard coal is delivered by truck to the sewage sludge storage (UEH) and the coal reception (UEF), respectively. Fuel oil is stored in two 100 m³ tank in the fuel oil storage (UEJ) and a 25 % ammonia-water solution for the SNCR in ammonia water storage (UVK).

5. Awarding, Erection and Commissioning

Initially it was planned to award the scope of supply and service for the whole plant to two general contractors, one lot for civil works and one for process technology. Due to the situation on the market in 2007, only one general contractor for the process part would have been available. Therefore this lot was split into ten lots, listed in Table 2. The main tender documents were placed on the market end of 2007. Following table summarizes the awarding time schedule:

![Figure 4: Sketch of Flue Gas Cleaning (NID-System)](image-url)
At the time of the awarding procedure the international banking crisis was on its peak. As a consequence, the project financing became eminently difficult and the Propapier AG was looking for a partner to enter the project. Due to the uncertainty in the future project constellation additional stipulations with the contractors had to be made and the initial project start was delayed (e.g. for lot 1 for about 10 weeks).

The Propower GmbH, founded for the erection and ownership of the co-generation plant, was bought by the EnBW Energie Baden-Württemberg AG, which was already designated for the operation of the plant. With this new partner the financial situation of the project was clarified and the erection and commissioning of the plant was carried out under the head of the EnBW.

After the preparation of the plant site and a harsh winter, which caused further delays, the civil work concentrated on the completion of all buildings and components necessary for an early steam delivery to the PM 2. With a construction start of the boiler house in April 2009 the mounting freedom for lot 3 was achieved in October 2009. In parallel the switchgear building, pipe bridges, the fuel oil storage, the auxiliary steam generator etc. had to be constructed.

To fulfill the tight time schedule the installation of process, electrical and control equipment was carried out almost in parallel in this project phase as well as throughout the whole project. To avoid collisions and to ensure an effective work procedure, a detailed coordination of the suppliers’ actions by the construction supervision was necessary. However, the process-steam supply of the PM 2 via the VEO external steam pipeline could be established in time until the scheduled date at February, 15th 2010.

The installation start of lot 1, marked by the installation of first boiler house pillar, could be carried out a few days earlier than initially scheduled, on October, 4th 2009. Further milestones of the plant erection are summarized in the following table:

<table>
<thead>
<tr>
<th>date</th>
<th>milestone</th>
</tr>
</thead>
<tbody>
<tr>
<td>04.09.2009</td>
<td>installation first boiler house pillar</td>
</tr>
<tr>
<td>29.10.2009</td>
<td>installation boiler drum</td>
</tr>
<tr>
<td>24.03.2010</td>
<td>boiler pressure test</td>
</tr>
<tr>
<td>12.08.2010</td>
<td>start cold commissioning lot 1</td>
</tr>
<tr>
<td>13.10.2010</td>
<td>first oil fire in combustor</td>
</tr>
<tr>
<td>26.11.2010</td>
<td>first SRF fire in combustor</td>
</tr>
<tr>
<td>09.12.2010</td>
<td>first steam on turbine</td>
</tr>
<tr>
<td>18.12.2010</td>
<td>first synchronization generator</td>
</tr>
<tr>
<td>14.03.2011</td>
<td>end trail operation for complete plant</td>
</tr>
</tbody>
</table>

The achieved date for the end of the trail operation is exactly the date scheduled in the framework time schedule, which was set up by Pöyry in May 2009.
The figures given above show that all major aims of the plants construction and commissioning could be satisfied. Most important is that the steam supply of the papermill could be established in time for its commissioning and production start, as well as the timely end of the plants trail operation. This surely results from the successful and effective site supervision and in particular from the skill and outstanding performance of the suppliers.

6. References
