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RENEWABLE ENERGY AT SUSTAINABLE COST USING A COMBINED HEAT AND POWER WTE-FACILITY IN THE PAPER INDUSTRY

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ABSTRACT

In March 2008, Keppel Seghers started the engineering, supply, construction and commissioning of a Combined Heat and Power (CHP) Waste-to-Energy (WtE) plant in Åmotfors (Sweden). When completed in 2010 the plant will process close to 74,000 tons per year of household waste (average LHV = 10.5 MJ/kg) and limited quantities of (demolition) wood resulting in a yearly production of about 108,700 MWh of steam, 12,100 MWh of heat and 13,400 MWh of electricity. Herewith, the Åmotfors WtE-CHP is sized to meet the joined energy needs of the local paper production, neighboring industries and buildings at an overall net plant efficiency of almost 65%.

The WtE-CHP will offer state-of-the-art combustion and energy recovering technology, featuring Keppel Seghers' proprietary Air-Cooled Grate, SIGMA combustion control and integrated boiler. Waste is fed into the combustion line with an automatic crane system. To surpass the stringent EU emission requirements, a semi-dry flue gas cleaning system equipped with Keppel Seghers' Rotary Atomizer was selected as economic type of process for purifying the combustion gas from the given waste mixture. Furthermore a low NO_x-emission of 135 mg/Nm³ (11%O₂,dry) as imposed by Swedish law is achieved by SNCR.

The plant engineering is described with a focus on the overall energy recovery. As stable steam supply to the paper mill and the district heating system needs to be assured under all conditions the design includes for supporting process measures such as combustion air preheating, steam

accumulation, turbine bypassing, buffering of the main condenser and back-up energy supply from an auxiliary fuel boiler. Additionally, external conditions can trigger distinct plant operation modes. A selected number of them are elaborated featuring the WtE-plant's capability to conciliate a strong fluctuating steam demand with the typical intrinsic inertia of a waste-fired boiler.

With prices for fossil fuels increasing over the years, the cost for generating process steam and heat has become dominant and for paper mills even makes the overall difference in viability. As will be documented in this paper, the decision to build the Åmotfors WtE-CHP was taken by Nordic Paper after a quest for significant cost-cutting in the production of process energy. Moreover, the use of industrial and household waste as fuel brings along the advantage of becoming largely independent from evolutions on the international oil and gas markets. By opening up the possibility for a long-term secured local (waste) fuel supply at fixed rates, WtE-technology offers a reliable alternative to maintain locally based industrial production sites. The Nordic Paper mills in Åmotfors are therefore now the first in Sweden to include a waste-fired CHP on a paper production site.

1. INTRODUCTION

In general, the (European) first-generation WtE-plants – often owned and operated by public (municipal) companies – have been conceived as stand-alone facilities with a main purpose to combust the residual household waste from the local

area. Any generated energy (i.e. electricity) was thereby considered rather a by-product, what explains the modest plant efficiencies (< 24%). This is also clearly reflected in the income of such type of public owned WtE-plants, being far more dependent on gate fees than on revenues from electricity sale [1]. As in a public context these fees are indirectly being paid by the community through taxes or contributions, the viability of the plant is in fact secured without a strong need for optimizing the energy output.

However, with climate policies currently gaining strong importance in a lot of countries, focus is clearly set on increasing the energy recovery efficiency of industrial processes. WtE-technology is also affected by this evolution, explaining current attempts to (gradually) increase boiler design parameters s.a. evaporation (drum) pressure and superheated steam temperature above the WtE- 'standard' of 40 bar and 400°C resp. In this regard the challenge remains to keep high-temperature chlorine-induced corrosion under control, i.e. a problem typically associated with waste-fired boilers [2]. Proven technologies such as the Keppel Seghers Prism [3] have contributed to development in the field of corrosion abatement.

Nevertheless, there is still a way to go if WtE-boilers are to be brought up to the thermal heat recovery level of conventional power plant boilers. Strategies of a more generic kind to increase WtE-plant efficiency are therefore to be equally considered, such as including for external superheating [4] or introducing the concept of WtE into an industrial environment. The latter strategy allows WtE-plants to serve as sources of CHP, supplying process steam, heat and electricity to surrounding energy consumers. In this way a large gain in effective use of energy from waste is achieved on the short-term and furthermore, carbon footprints of intensive industries are reduced by replacing fossil fuels and gas.

From the perspective of waste management itself, it is illustrated within a European context that WtE is the indispensable complement for integrated waste management 'chains' including mechanical and/or biological waste pre-treatment operations. The efficiency level of a WtE-plant combusting the end-of-chain residual waste indeed rapidly becomes the key parameter for recovering the relatively high net energy losses from the pre-treatment. For e.g. in [5] it is illustrated that an advanced integrated waste management even requires CHP-levels of efficiency for positive CO₂ control.

Which 'concept' after all is the most suitable for a particular WtE-project depends on a number of 'drivers' constituting the economy of a plant. Switching to renewable energy sources (incl. energy from waste) is supported by the EU and national governments through financial stimuli s.a. green power certificates (EU). Whereas a subsidizing policy obviously allows the financial models of WtE-plants to become less dependent on the international economic – i.e. oil market – situation, the local context in turn becomes overall determining for the viability/turnover of a WtE-plant. A combination of factors s.a. project development type (private vs. public), available amounts of waste, gate fee per ton of waste, energy

delivery potential, market rates for energy and (fossil) fuels, disposal costs for (industrial) waste and residues etc. is then determining for a particular plant design, somewhere in a range between 'low-energetic & municipal' and 'high-energetic & industrial'.

2. PLANT DESIGN

2.1 Combustion Diagram

The WtE-plant is intended for the combustion of unsorted household waste, containing about 20-35 wt% moisture and generating about 15-35 wt% (on dry matter) of ash. With waste from Norwegian and Swedish origin, the composition is rather similar to the European average with LHV between 8 – 14 MJ/kg (Fig.1). A limited amount of waste (max. 15wt%) can be replaced in the future by (treated) demolition wood. As the pulp for the paper production is supplied from elsewhere, no waste rejects from pulp preparation are available on the site in Åmotfors for combustion in the WtE-CHP. Allowing for a nominal waste throughput of 9.5 t/h at LHV=10.5 MJ/kg, the WtE-plant is tailored for a thermal output of 27.8 MW at 100% capacity. (MCR = Max Continuous Rating).

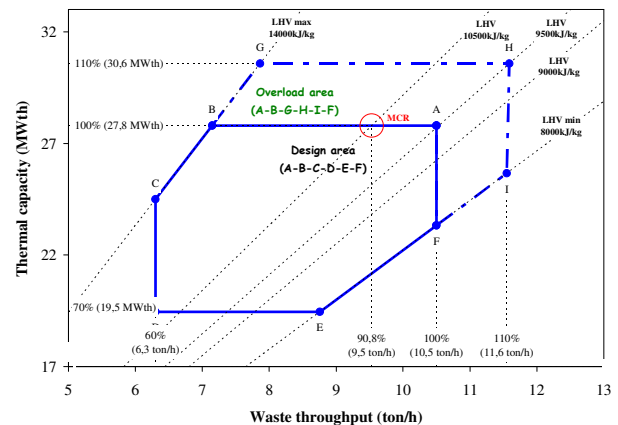


Fig.1 Combustion Diagram

2.2 Combustion Grate

The combustion grate included in the plant is of the Keppel Seghers air-cooled type and has a width of 3.9 m, resulting in about 42m² of combustion surface under an inclination of 21°. Built together from 5 modular elements, the grate's design is optimized such that all consecutive physico-chemical stages in the combustion process are at best supported (i.e. drying, gasifying, combusting and burn-out of the waste). Each element is covered with tiles of high durability, row per row mechanically connected to each other over the whole width of the grate and moving simultaneously (Fig. 2). Two moving tile rows are alternated with a single row of fixed tiles. Moving tiles perform either sliding or tumbling movements whereby the

former move the waste forward and the latter help to ensure sufficient primary air penetration by mechanically poking the waste. This has turned out particularly advantageous in cases of dense waste with low LHV coming in unexpectedly. The tumbling action promotes waste burn-out and contributes to production of slag with good quality. In controlling the combustion, sliding and tumbling actions can be adapted separately.

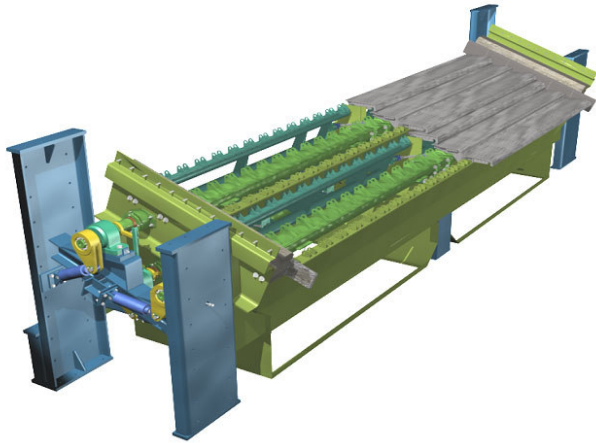


Fig.2 Modular Element of Air-Cooled Grate.

2.3 Integrated Steam Boiler

The Åmotfors WtE-CHP is designed with an adiabatic combustion temperature of 1200°C in the furnace. A separate (frequency controlled) primary air supply is installed per grate element. The primary air is taken on top of the boiler and further preheated up to 110°C using steam of 6 barg at 175°C. After injection of secondary air the combustion gasses enter the steam boiler for heat recovery.

The Keppel Seghers integrated boiler design (Fig. 3) contains 3 vertical passes and a final vertical duct, hosting the economizer section (not shown). Boiler feed water enters the economizers at 125°C. The third vertical pass contains a protection evaporator screen and 4 superheater bundles to bring the steam temperature up to 380°C. The refractory concept is composed of low cement castables and inconnel cladding, combining a first-pass temperature of >850°C with adequate membrane wall protection.

2.4 Flue Gas Cleaning

In order to achieve the NO_x-emission of 135 mg/Nm³ (dry, 11%O₂) as imposed by Swedish law, a recirculation duct from exit ID-fan to right below the secondary air injection nozzles is foreseen. This allows recycling up to 15% of the flue gas flow over the SNCR-zone. The SNCR contains 4 levels of which 2 are in permanent operation, injecting an aqueous solution of ammonia (NH₄OH). The recirculation furthermore results in a reduced oxygen concentration of about 6% at the boiler outlet and a boiler efficiency improvement of about 1.3%. Keppel

Seghers has successfully engineered and constructed similar systems before in the WtE-plants of INDAVER (Beveren, Belgium) and at SAKAB in (Örebrö, Sweden).

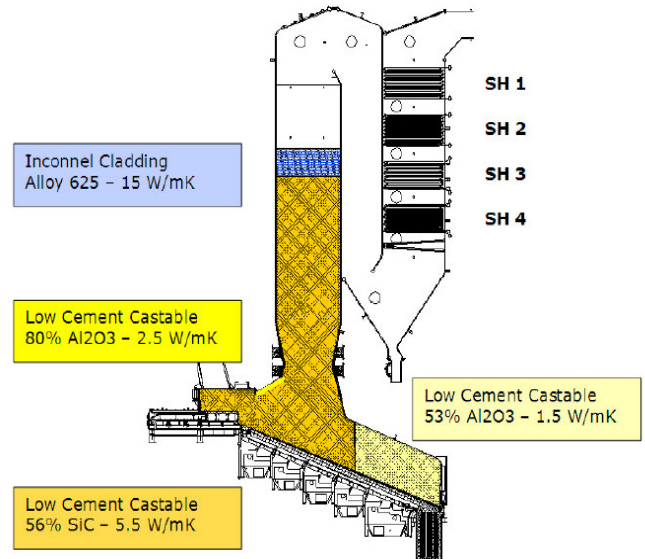


Fig.3 Vertical boiler design and boiler protection materials with indication of chemical & thermal properties

Downstream, the flue gas flow of about 57,000 Nm³/h enters a semi-wet scrubbing system at a controlled temperature of 260°C. Lime milk is extremely fine dispersed in a reactor vessel by means of the Keppel Seghers Rotary Atomizer disk (Figure 4) rotating at a speed of about 10,000 rpm to remove acidic gas pollutants (HCl and SO_x). The temperature of the gas is simultaneously reduced to 140°C at the reactor gas outlet. Due to the partially wet treatment, part of the fly ash – containing also adsorbed heavy metal species – is removed with the reaction products at the bottom of the reactor. Most of the dust is however eliminated in a bagfilter after supplementary addition of active carbon to capture the remaining heavy metals, dioxins, furans and VOCs.

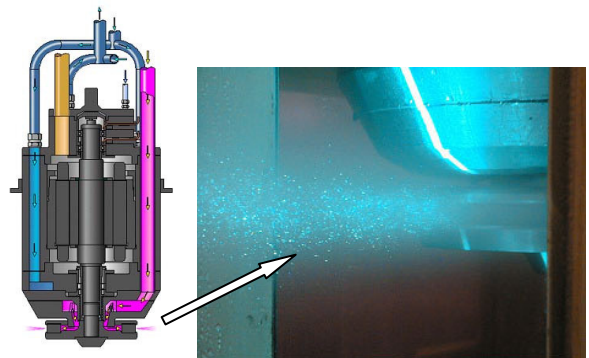


Fig.4 Keppel Seghers Atomizer: (a) principle of cooling water and lime milk injection, (b) rotating disk dispersing lime milk at 10,000 rpm

2.5 Layout

Due to limited dimensions of the process building, the Åmotfors CHP-WtE is an example of a low-footprint layout. This has however affected the process design. Both the superheated steam temperature (380°C) and the flue gas temperature at the outlet of the boiler (260°C) are a direct consequence of process building (and hence boiler size) restrictions.

2.6 Heat & Power

The main purpose of the WtE-CHP is the supply of process steam (6 barg, 217°C). A flow of about 23 tons per hour must keep up the normal production of two paper machines. A district heating system requires 0.6 – 2.5 MWth, depending on the season of the year, with exceptional peak demands up to 4 MWth. A few smaller consumers are also tied into the steam cycle but as they consume negligible amounts of energy they are further not being discussed.

The operational steam demand from the paper mills (nominated PM5 & PM6) is fast fluctuating. Furthermore, one paper machine in turn is taken out of duty on a regular basis during short time for standard maintenance, causing sudden drop in steam consumption with 50%. Typically expected steam statistics are included in Annex A. Real variations of +/- 6.5 % on the average demand are common for two paper mills during periods of continuous normal operation (data from January 2009).

The steam cycle configuration is shown in Figure 5 below. WtE-boilers are inherently slow reacting steam generators with a typical range for thermal 'tuning' between 70 and 100% (excl. auxiliary fuel). Measures for securing steam flow in both directions, i.e. from waste boiler to paper mills and vice versa, are hence taken in the Åmotfors WtE-CHP design.

Under nominal (average) plant operation the superheated steam from the boiler (40 barg, 380°C) is fed into the HP-stage of the turbine, where it is expanded to a pressure of 6 barg. About 2/3rd of the total steam flow is exported to the paper mills, while the remaining 1/3rd continues its expansion through the LP-stage of the turbine down to a backpressure of 1.2 bara. The cooling of the turbine condenser evacuates the condensing heat. Part of this energy is recovered in the district heating at 90°C. When normal heat supply to the district heating is required (2.5 MWth or less) this temperature is more than sufficient. However, in winter times when the heat demand can peak up to 4 MWth also an elevated temperature of 120°C needs to be achieved. In these cases steam at 217°C is taken from the 6 barg steam header to heat up the water from the DH in a separate heat exchanger.

Any deviation from the average steam demand is compensated by the steam accumulator (if demand < production). The back-up boiler is (only) used in those situations when the demand > production with the steam accumulator depleted. Regarding the steam accumulator, an

assessment based on all possible limiting plant operation modes identified the need for assigning 3 distinctive steam (dis)charging modes to the control of the 6 barg steam header: a slow-charging (+ 4 tph), a slow- discharging (- 4 tph) and a fast-discharging (-8 tph) mode. Reference (setpoint) level for steam cycle control was set at 50%-charging level of the steam accumulator.

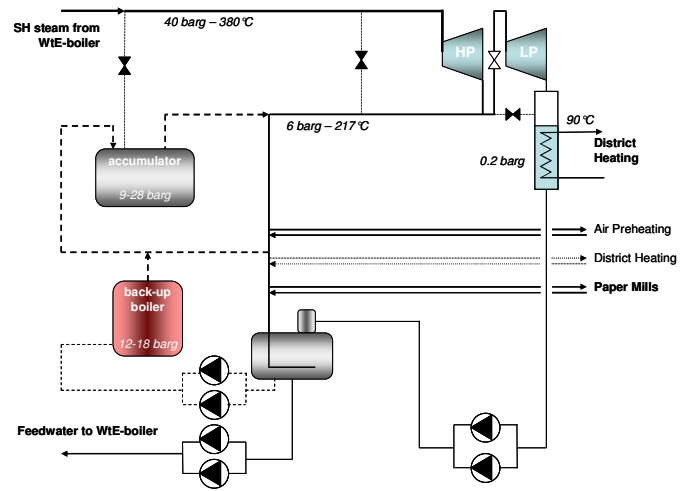


Fig.5 Steam & Condensate Cycle

Control priority is under all conditions assigned to the supply of steam to the paper mill and the steam consumers within the WtE-CHP (mainly primary air pre-heaters), assuring stable and continuous combustion conditions. In second instance, the control system steers towards recharging the accumulator with steam excess restored over a longer operation period. A constant pressure on the 6 barg steam header is thereby always maintained.

The turbine condenser is designed for a maximum heat removal of 5 MWth whereas the effective heat consumption by the DH accounts maximally 4 MWth (peak consumption). In order to avoid continuous influence from the steam cycle on the combustion control the WtE-boiler on average sends out slightly more steam to the turbine than strictly required by the paper mills and the DH. In situations whereby the steam accumulator is fully loaded, this amount of heat is 'destroyed' in the condenser. However, in the converse case with a depleted steam accumulator this margin is elegantly used to reduce the thermal load setpoint on the condenser and hence to increase the steam provision of 6 barg from the turbine immediately. Although this steam cycle design points out a slight loss of energy when evaluating it in terms of 'steady-state', it facilitates the continuous evolution from one operation mode to the other for real plant operation. Anticipating to the inherent slow reaction time of the WtE-boiler and favoring accumulator charging over longer plant operation periods are two key principles of the steam cycle design.

In case the condenser can no longer compensate for shortage in export steam, the back-up boiler (using auxiliary fuel) switches on automatically for fast-recharging of the accumulator. Fully bypassing the HP stage of the turbine is the ultimate back-up solution to keep up the pressure on the 6 barg steam header. But as this situation is considered as very exceptional the latter was only withheld as manual operation possibility not to complicate the plant control.

3. PLANT ECONOMY

The main motivations to build the WtE-CHP were: 1) to realize a significant annual cost saving and 2) to establish an independent and secure source of process energy for the Nordic Paper mill site. With the WtE-CHP revenues are now being generated for about 5.2 Million EUR per year. Gate fees constitute the major part ($\pm 72\%$), while sale of heat ($\pm 11\%$) and electricity ($\pm 17\%$) are completing the picture. The gross electricity output of the WtE-CHP is fully exported to the grid, from where about 900 kWel is taken back to cover for the own electricity consumption. Since the produced steam is being used on site it is for now not considered as revenue, although it contributes for about 50% (absolute) to overall plant efficiency. This allows a clear direct comparison in terms of saving with the old situation of oil fired boilers.

With no revenues at all and a sole purpose to produce steam, the latter is associated with a pure operational expense of about 6.1 Million EUR per year. The total annually expected cost for the WtE-CHP on the other hand amounts ± 7 Million EUR, distributed in entries as shown in Figure 6. Depreciation of investment and maintenance costs are also taken into account. Balancing the revenues against the costs finally shows that 1.8 Million EUR per year is required for production of paper mill steam.

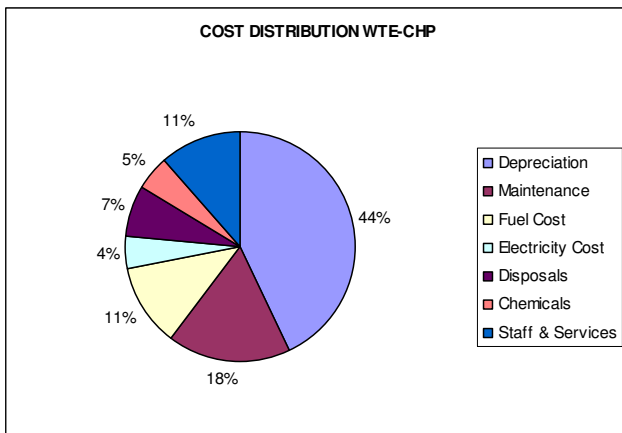


Fig.6 Cost Distribution WtE-CHP

4. CONCLUSIONS

For energy intensive industries WtE-technology is an interesting option for the production of auxiliary steam, heat and electricity. By means of adequate steam cycle equipment waste boilers can be introduced also in small and medium-scale industrial environments with rapidly changing steam demands such as paper industries. However, due to the large difference in response time between slow-reacting steam production and fast-changing steam consumption, conciliation needs to be made between high energetic plant efficiency and operational flexibility.

The replacement of existing auxiliary steam boilers by a WtE-CHP allows for a drastic reduction in operational cost down to 30% of the original level, depending on local technical and budgetary conditions. The use of waste as fuel furthermore allows large independency from the international fossil fuel markets.

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ANNEX A

STEAM STATISTICS

	Steam from WtE-boiler (1)	Internal Steam Consumption	Steam Available	Actual steam requirement (2)	Steam Balance: Production vs. Consumption	Accumulator Reserve (3)	Excess Steam (4)	Back-up Steam Requirement (5)
	t/hr	t/hr	t/hr	t/hr	t/hr	ton	t/hr	t/hr
average	30,00	9,92	20,08	20,08	0,00	4,66	0,30	-0,27
stdev	1,59	0,58	1,69	1,34	2,19	3,62	0,97	0,87
min	25,65	8,92	14,89	12,91	-6,28	0,00	0,00	-6,28
5%-perc.	27,31	9,02	17,27	17,08	-3,31	0,00	0,00	-2,42
95%-perc	32,56	10,82	22,78	21,57	3,89	9,00	2,65	0,00
max	37,05	10,92	27,86	22,62	9,35	9,00	8,36	0,00

- (1) Figures from WtE-boiler of similar size + superposed random generations.
- (2) Actual data measured for 2 Paper Mills (January 2009).
- (3) Reference = steam accumulator 50% charged.
- (4) Steam accumulator 100% charged.
- (5) From back-up boiler, in case steam accumulator depleted.