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CONCEPTS AND EXPERIENCES FOR HIGHER PLANT EFFICIENCY WITH MODERN ADVANCED BOILER AND INCINERATION TECHNOLOGY

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ABSTRACT
The efforts for reducing CO_2 Emissions into atmosphere and increasing costs for fossil fuels concepts are the drivers for Energy from Waste (EfW) facilities with higher plant efficiency.
In the past steam parameters for EfW were requested mainly at 40 bars and 400 °C (580 psi and 752 F). In case of coal fired power plants at the same location as the EfW facilities higher steam parameters at 90 bar, 520 °C (1305 psi, 968 F) have been used for the design of stoker and boiler. This long-term experience with higher steam parameters is the platform for the todays and future demand in higher plant efficiency.
Increase in EfW plant efficiency is achievable by increasing temperature and pressure of live steam going along with optimized combustion conditions when using well proven grate technology for waste incineration. On the other hand higher steam parameters result in higher corrosion rates on the boiler tubes and the optimization of the combustion conditions are limited by the burn out quality requirements of slag and flue gas. Advantages and disadvantages have therefore to be balanced carefully.
This paper will present different measures for optimized boiler and combustion conditions compared to an EfW plant with live steam at 40 bars and 400 °C (580 psi and 752 F) and 60% excess of combustion air. Plants operated at these conditions have very low maintenance costs created by corrosion of boiler tubes and show performance with very high availability.
The following parameters and experiences will be evaluated:
- reduction of excess air
- flue gas temperature at boiler outlet
- higher steam parameters (pressure and temperature)
- heating surfaces for steam superheating in the radiation boiler section
- steam reheating
- external superheaters using auxiliary fuels

The comparison of the different methods for increasing the efficiency together with resulting technology challenges incorporates the experiences from modern EfW reference facilities built in Naples/Italy, Ruedersdorf (Berlin)/Germany and Heringen/Germany.

Keywords: thermal treatment, Energy from Waste (EfW), boiler efficiency, electrical power output, CO_2 reduction

1. INTRODUCTION
In the existing EfW facilities around the world steam parameters at 40 bars and 400 °C (580 psi and 752 F) are most common and established as inlet parameters for a condensing type turbine together with steam condensation in an air cooled condenser. Corrosion on heating surfaces in direct contact with flue gases is undiscernible for EfW boilers operated with these steam parameters.
The corrosion potential in function of flue gas and heat exchanger tube surface temperature is illustrated in Figure 1 [1].

A distance to all corrosion risk areas is clearly visible for 40 bars and 400 °C (580 psi and 752 F).

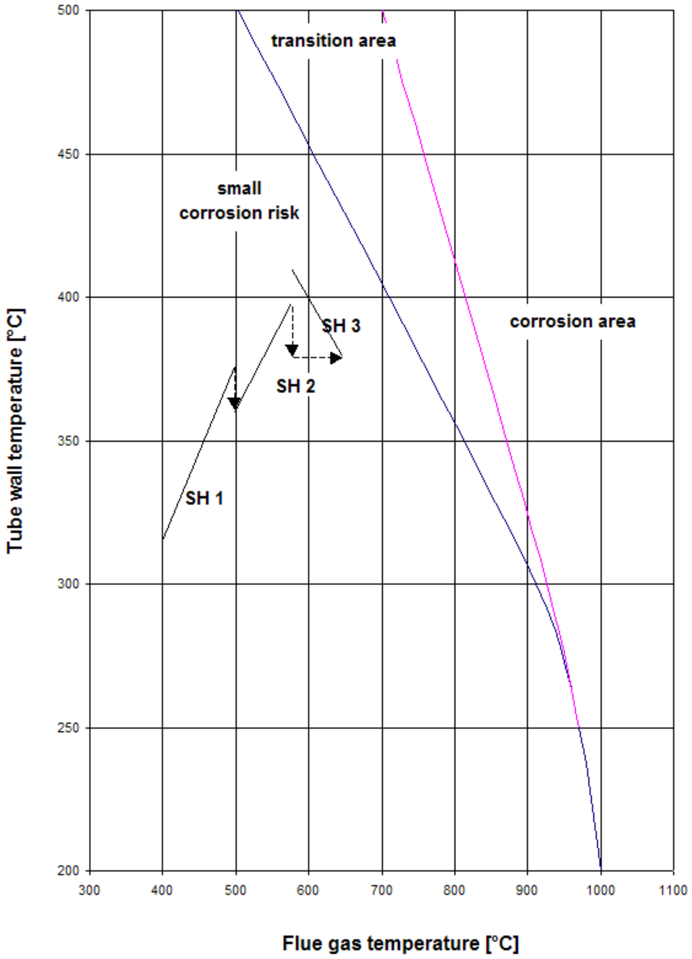


Figure 1- corrosion diagram [1]

As a base line for further comparison a facility is defined (basic solution) with the following design parameters:

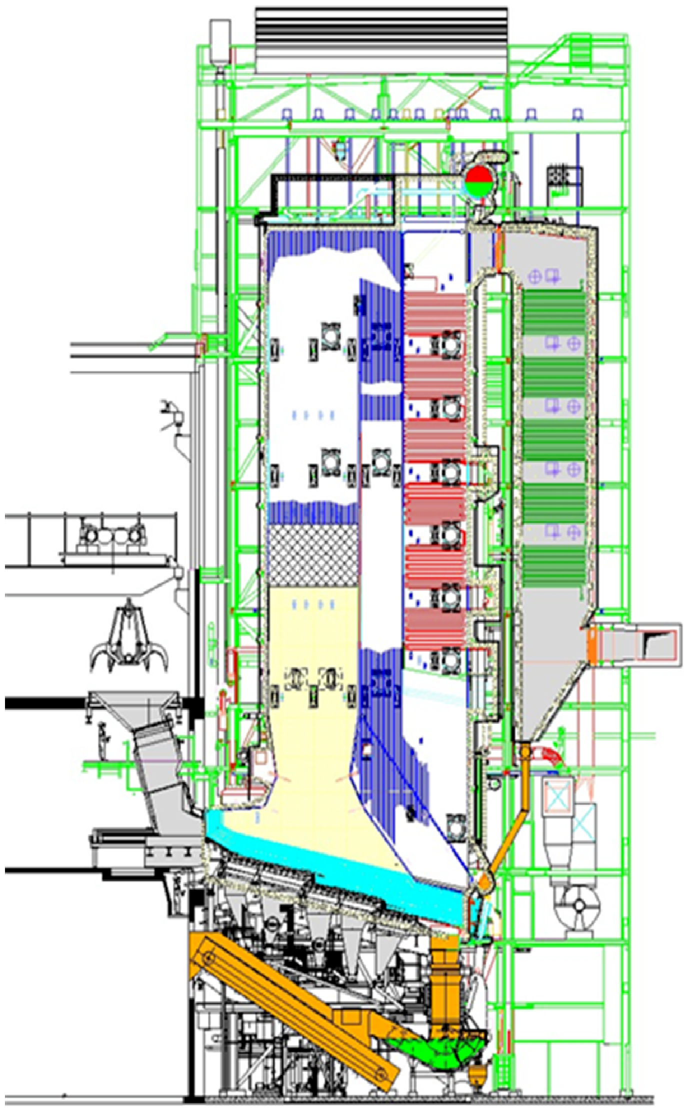
- live steam conditions from boiler to turbine inlet : 40 bars and 400 °C (580 psi and 752 F)
- steam pressure at turbine outlet : 0,1 bar (1,45 psi)
- boiler feed water temperature 130°C (266 F)
- flue gas temperature at boiler outlet : 190 °C (374 F)
- furnace excess air : 60%
- lower calorific value (LCV): 11 MJ/kg (4725 BTU/lb)
- Semi-dry flue gas cleaning system (FGC)

The boiler efficiency according to EN 12952, part 15 [2] for these basic conditions is 86,5% relating to LCV and 26,35 % for the gross power production.

In the following a view is taken on higher electrical efficiency of EfW plants. With examples from plants build recently an optimization potential can be identified in relation to the basic solution.

2. FURNACE EXCESS AIR REDUCTION

A new stoker and boiler unit was installed at the EfW plant in Hameln/Germany in the year 2006 -Figure 2-, replacing an existing unit from the year 1977. The flue gas cleaning (FGC) and steam-/ condensate system remained unchanged. The old unit was designed for an excess air of 1.9, allowing for increasing the thermal power of the new stoker and boiler unit from 30 to 40 MW at an excess air of 1.39 without changes to the FGC.



Gross heat release	MW	40
Throughput	Mg/h	12,0
LHV (MCR)	MJ/kg	12,0
LSt Pressure	bar	41
LSt Temperature	°C	400

Figure 2 - longitudinal boiler section EfW Hameln MK4.

The flue gas temperatures in the furnace and after burning zone were adjusted by means of flue gas recirculation to assure that there is no slagging of the membrane walls.
Furnace membrane walls and after burning zone are protected with SiC plates against corrosion. Inconel 625 cladding is used in the zone directly above the stoker and on the membrane walls in the first boiler pass above the refractory lining for a height of 5m (16 ft). Other areas of the membrane walls are unprotected.
The stoker unit consists of a two track forward moving stoker system type ‘Steinmueller’ each track with five independent zones over the stoker length and two integrated steps. Good burn-out of the flue gases and CO-Emission less than 20 mg/Nm³ related to dry flue gas condition were achieved with staged supply of secondary air and 10% recirculated flue gas, taken from behind the electrostatic precipitator.
Since start-up of operation until present day significant corrosion could not be observed in the furnace and the radiation boiler passes neither on protected nor unprotected membrane walls.
All superheater surfaces are arranged in the 3rd vertical pass and cleaned with steam operated soot blowers. Corrosion or erosion could not be discovered on boiler tubes in superheater 2 and 3 directly exposed to the soot blowers due to protection with tube shield elements.
Compared to the base solution the boiler efficiency is raised to 87,65% and gross power production to 26,63 % by furnace excess air reduction to 1,39.

3.TEMPERATURE OPTIMISATION AT BOILER OUTLET

A substantial enhancement in boiler efficiency can be achieved with lowering the boiler outlet temperature compared to the base solution. This available heat at boiler outlet can be used for primary and/or secondary air preheating.

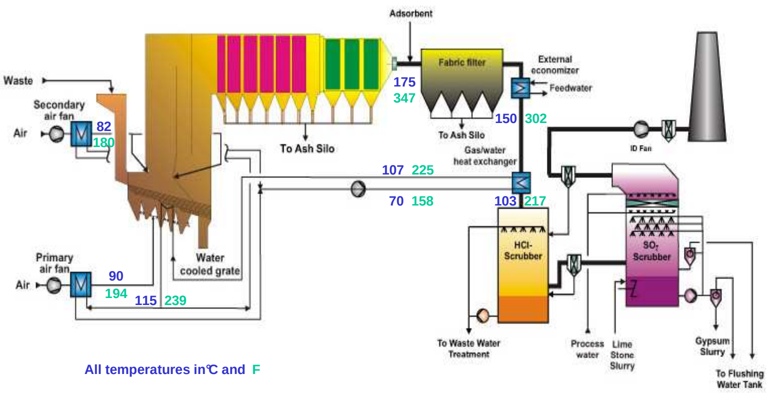


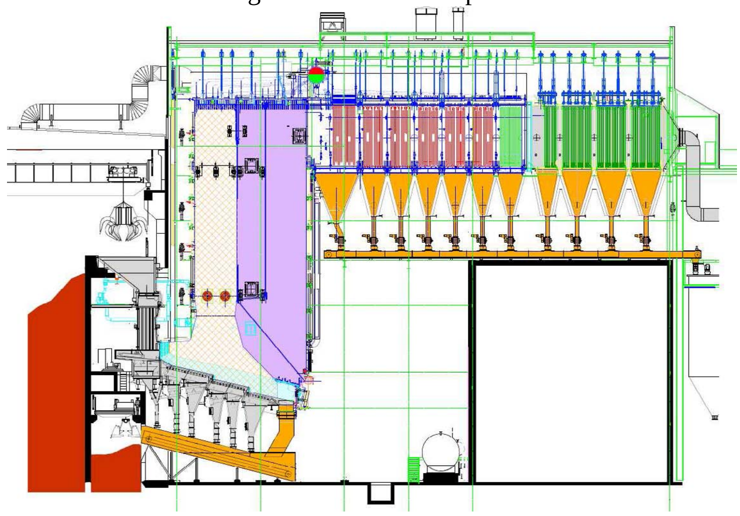
Figure 3 – schematic of EfW plant Arhus/Denmark with external heat exchangers.

Such a concept was realized in the new build line 4 in Arhus/Denmark (Figure 3). The flue gas temperature at boiler outlet is 180°C (356 F) at 100% load (design point DP) before entering a baghouse filter.

After this dedusting stage an external economizer is used for further flue gas cooling to 140°C (284 F) at a boiler feed water temperature of 130°C (266 F). The design of this external economizer for dedusted flue gas is compact compared to economizers located inside boiler.
Next is a further cooling step down to 100 °C (212 F). This flue gas heat exchanger has an enamel tube surface and PFA-foil protection. The heat from the flue gas is transferred to a cooling cycle, which is in addition taking the heat from the stoker bars cooling system. This PFA foil covered heat exchanger is regularly water cleaned to prevent ammonia salts from the SNCR from condensation and settling. The washing water is used as additional water in the FGC scrubber. This re-gained heat from the flue gas is used in the process for primary and secondary air preheating.
Temperature optimization at boiler outlet to 100°C compared to the base solution increased the boiler efficiency to 92,63% and gross power production to 28,14 %.
The EfW plant Arhus/Denmark is in operation since beginning of 2005. Noteworthy corrosion could not be detected. The whole furnace and after burning zone in the 1st boiler pass is protected with Inconel 625 cladding. After five years of operation there was no need for repair works on the cladding due to wear and tear.

4. EXTERNAL SUPERHEATER

A further variant to increase the electrical efficiency of the whole plant is the superheating of live steam from 400 °C (752 F) to 520 °C (968 F) in an external superheater using oil, gas or biomass. The corrosion risk for the superheater tubes is in this case comparable to the base solution as the final superheater is not in contact with flue gases from the EfW plant.



Gross heat release	MW	58,3
Throughput	Mg/h	17,5
LHV (MCR)	MJ/kg	12,0
LSt Pressure	bar	81
LSt Temperature	°C	520

Figure 4 – longitudinal boiler section EfW plant Heringen/Germany

The new EfW plant Heringen/Germany (Figure 4) consisting of two units with 58 MW thermal power for pre-sorted trash and an external superheating from 400 °C (752 F) to 520 °C (968 F), started operation in 2009. The selection of the steam temperature 520 °C (968 F) of the new units with existing gas-fired boilers, steam turbine island and boiler feed water system was made due to the existing site conditions.
The units are designed for 12 MJ/kg (5155 BTU/lb) LCV and a throughput of 17,5 t/h of normal household, commercial and industrial trash. The stoker is a two track system with water cooling for the first three of total five zones. Realized is a conventional 4 pass boiler with superheaters and economizers in horizontal arrangement. The external superheaters, Figure 5, consisting of a bottom fired natural gas boiler with natural draft are located in direct collateral position to the boiler.

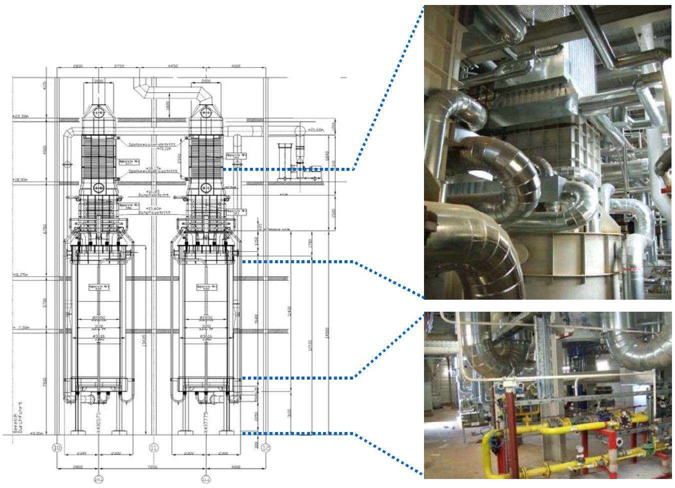


Figure 5 – external superheater EfW plant Heringen/Germany

The superheaters are designed for flue gas temperatures of approx. 1000°C (1832 F) as radiation surfaces for the final superheating and the following as conventional bundle heat surfaces. The flue gas is cooled down to approx. 150 °C (302 F) in the economizers before it is leaving via stack.

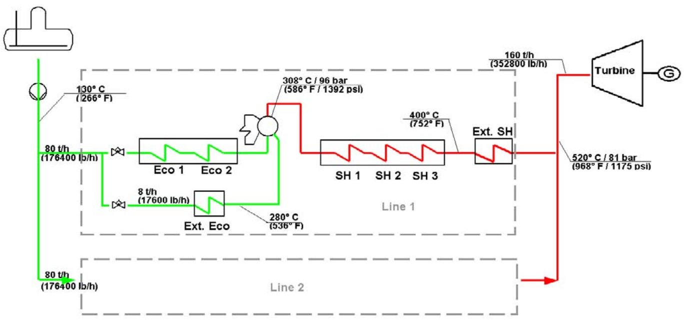
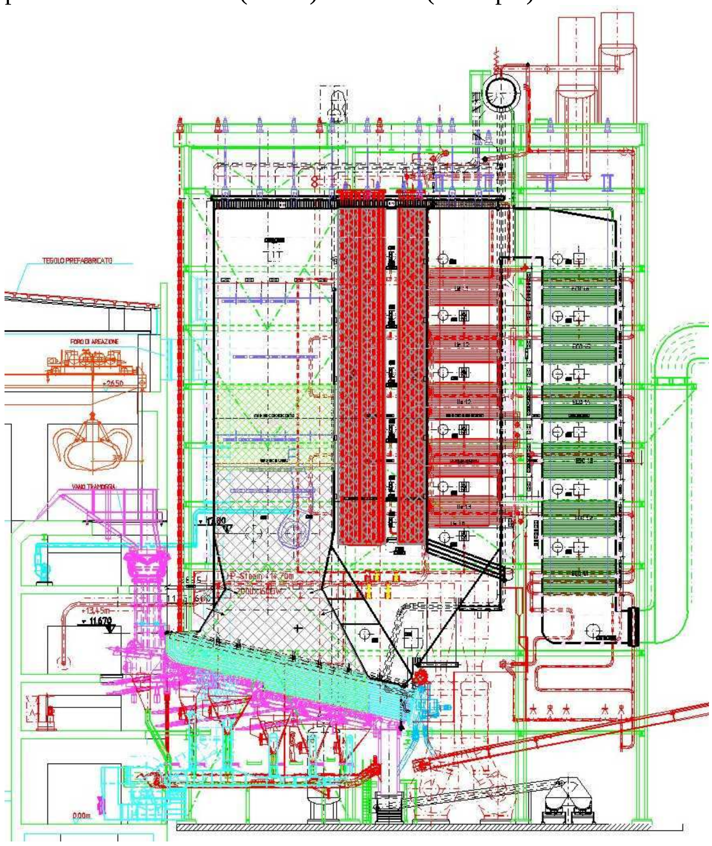


Figure 6 – heat flow diagram- EfW plant Heringen/Germany

Figure 6 presents the related heat flow diagram.
The temperature control principle for live steam is not as conventional by attemperators; it is done by load control of the natural gas burner. Already in start-up phase a control of +/- 4 K at steam turbine inlet was proven without any limitation.
The External superheater variant at similar conditions as the base solution has a boiler efficiency of 87,65% and a gross power production of 29,68 %.

5. HIGH STEAM PARAMETERS

The new EfW plant in Naples/Italy (figure 7) is in operation since beginning 2009 and has three lines with 113,3 MW thermal power each. The boilers are designed for high steam parameters of 500 °C (932 F) at 90 bar (1305 psi).



Gross heat release	MW	113
Throughput	Mg/h	27,1
LHV (MCR)	MJ/kg	15,1
LSt Pressure	bar	90
LSt Temperature	°C	500

Figure 7 – longitudinal boiler section EfW plant Naples/Italy

The boiler concept is a vertical boiler with final superheating stage by platen-type superheaters, arranged in the second boiler pass. The superheaters are located in a flue gas temperature zone above 800 °C (1472 F). This position could not be avoided as more than 50% of the total heat transferred from the flue gases is needed for the economizer and superheater heat

surfaces. A boiler according to the base solution (40 bars and 400 °C (580 psi and 752 F)) transfers only 37% of the total heat through the economizer and superheater heat surfaces. The remaining heat is transferred through the evaporator heat surfaces in the radiation passes.
It is evident from Figure 8, that for the platen-type superheaters at flue gas temperatures above 800 °C (1472 F) without additional corrosion protective measures high abrasion by corrosion can be expected.

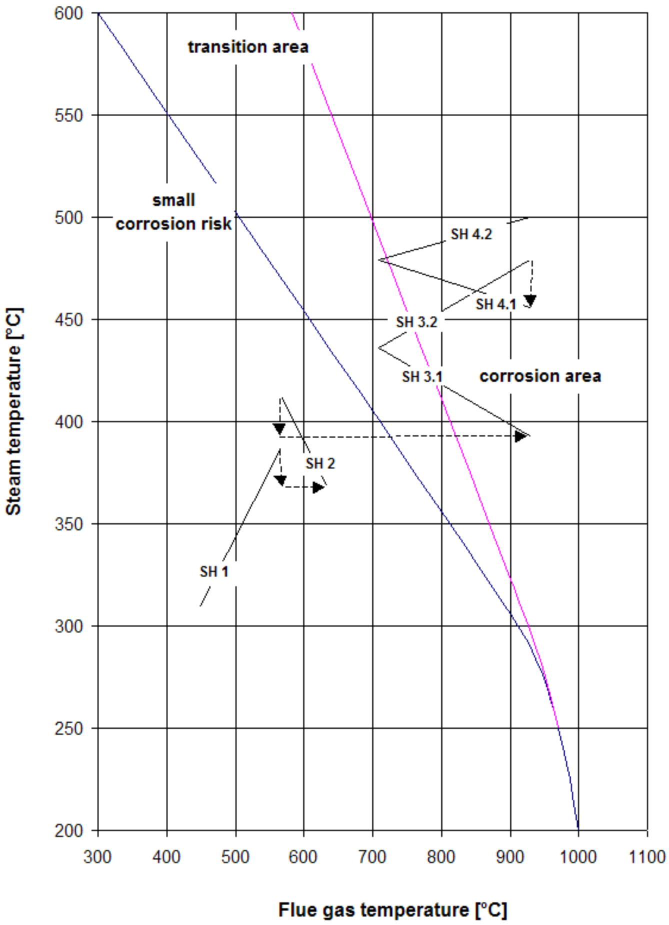


Figure 8 – corrosion diagram - EfW plant Naples/Italy

This is in conformity with experiences from other plants build by the predecessor companies of FBE in the seventies and eighties. Those plants operated with steam temperature of 500 °C (932 F) achieve 5.000 - 8.000 h of superheater life time.
For longer lifetimes these superheaters were protected with monolithic SiC concrete. This system has been used in the Stuttgart/Germany EfW-plant with success. 10 years of superheater lifetime could be achieved with those protected superheaters. This long lifetime could only be shown under the precondition of regular inspection and direct repair of cracks before the tube itself shows corrosion attacks.
Tests in various plants have shown in the past, that Inconel cladding as corrosion protection for platen-type superheaters is not recommendable. High tube surface temperatures are responsible for high abrasion of Inconel cladding.

Figure 9a – platen superheaters EfW plant Naples/Italy, transport to site

A first inspection of all three boilers in the Naples EfW facility in November 2009 (Figure 9a and 9b) has shown a good status of the monolithic SiC concrete protection of the platen-type superheaters.

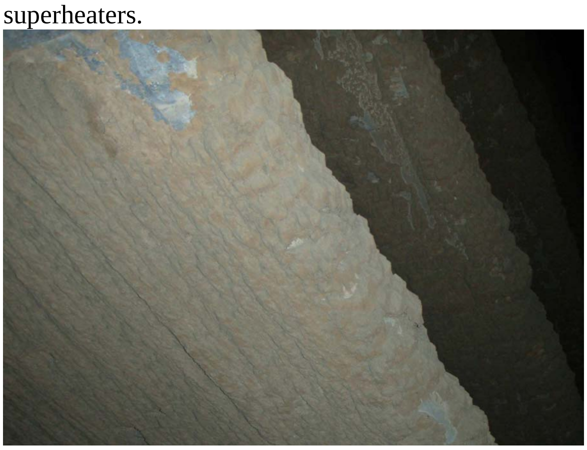


Figure 9b – platen superheaters EfW plant Naples/Italy, status November 2009

We expect a similar inspection and maintenance effort as in the Stuttgart EfW plant. For these higher steam parameters there is no change in boiler efficiency of 86,5%, but gross power production is climbing to 30,2 %.

6. BOILER WITH INTERMEDIATE REHEAT

The intermediate reheat concept was chosen for the Ruedersdorf (Berlin)/Germany EfW plant for high electrical efficiency. This intermediate reheat is shown in figure 10.
The heat surfaces for final superheater and intermediate super-heater need to be positioned (analog to Naples) in the second boiler pass as the heat taken by the economizer and superheater heat surfaces is higher than 50% of the total heat transferred from the flue gases. The platen-type superheaters of the Ruedersdorf (Berlin)/Germany EfW plant illustrated in figure

11 are protected by Inconel 625 cladding as wear plating. A steam temperature of 420 °C (788 F) allows this protection concept in contrast to the Naples EfW plant with 500 °C (932 F).

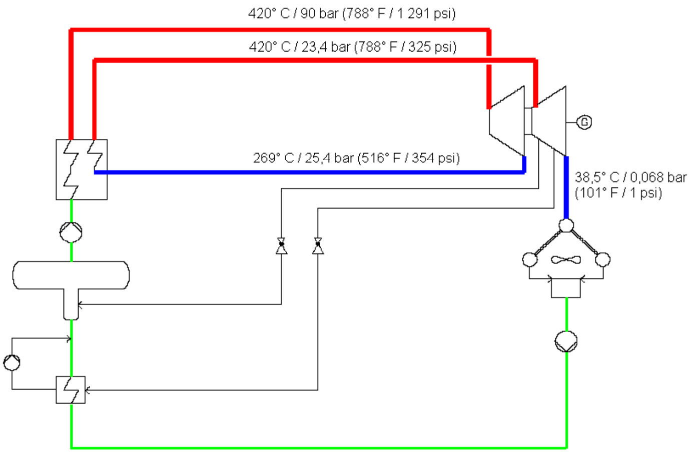
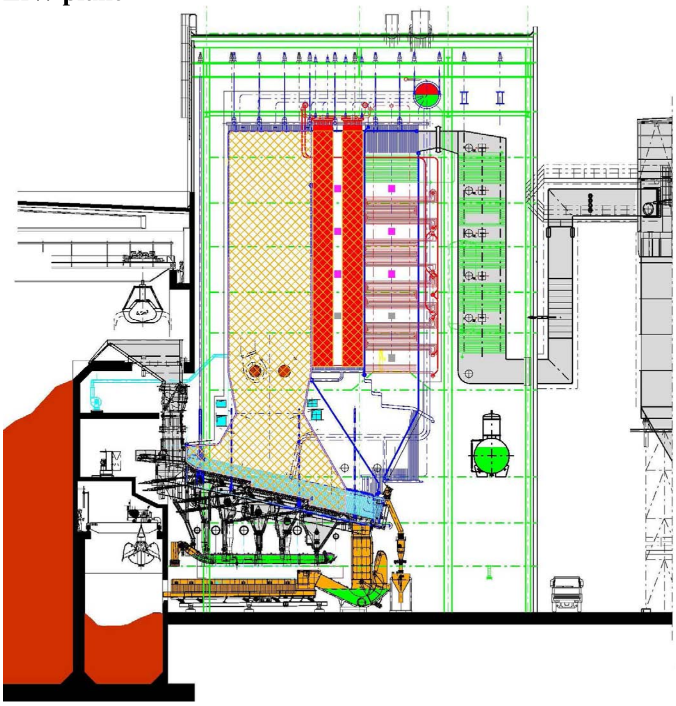


Figure 10 – heat schematic Ruedersdorf (Berlin)/Germany EfW plant



Gross heat release	MW	110
Throughput	Mg/h	27,3
LHV (MCR)	MJ/kg	14,5
LSt Pressure	bar	90
LSt Temperature	°C	420
Reheat Pressure	bar	24,4
Reheat Temperature	°C	420/273

Figure 11 – longitudinal boiler section Ruedersdorf (Berlin)/Germany EfW plant

In the temperature zone up to approx. 850 °C (1562 F) flue gas temperature and 420°C (788 F) steam temperature the material Inconel 625 may be serviceable. The Ruedersdorf (Berlin)/Germany EfW plant is in operation since middle 2008. Regular checks have been done with encouraging results so far. For a long term experience further operating hours need to be collected. Platen-type superheater with Inconel 625 cladding as wear protection instead of castable protection can be cleaned with pneumatic rappers. The construction of platen-type superheaters is shown in Figure 12a and 12b.

Figure 12 a – platen-type superheater

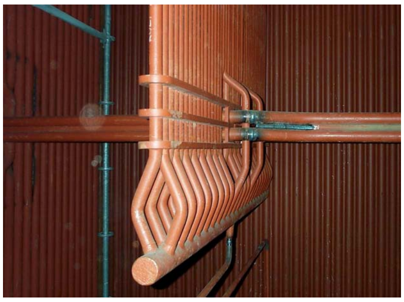


Figure 12 b – platen-type superheater with rapping system

Commissioning of a turbine island with intermediate reheat requires more complexity. Steam blowing for pipe cleaning has to be done over various ways for

- boiler high pressure part till high pressure turbine
- connecting tubes to the outlet of the high pressure turbine
- intermediate heat exchanger till inlet of the second turbine stage

After these measures the steam turbine with intermediate reheating could be taken safely into operation.

For intermediate reheat there is no change in boiler efficiency of 86,5%, but gross power production is grown to 29,9 %.

7. COMPARISON OF BOILER CONCEPTS

The results in efficiency of EFW-plants and the related gross power production are shown in table 1.

The calculations were made on unified conditions for:

(1) trash composition (as the base solution)
(2) turbine outlet pressure
(3) feed water temperature
(4) turbine isentropic efficiency
(5) condensate pre-heating

as well as further parameters for the water/-steam cycle.

		Basis	Var. 1	Var. 2	Var. 3	Var. 4	Var. 5
change compared to basis			Reduced Excess Air	Flue gas cooler	External Super-heating	High Steam param.	Steam Reheating
Temperature Live Steam	°C	400	400	400	520	500	420
Pressure Live Steam	Bar	40	40	40	90	90	90
Temperature Reheated Steam	°C	-	-	-	-	-	420
Pressure Reheated Steam	Bar	-	-	-	-	-	24
Flue Gas Temp. Boiler Outlet	°C	190	190	100	190	190	190
Excess Air	%	60	39	60	60	60	60
Boiler Efficiency	%	86,5	87,7	92,6	87,0	86,5	86,5
Boiler Efficiency related to Basis	%	100	101,3	107	100,5	100	100
Gross Electrical Efficiency	%	26,4	26,6	28,1	29,7	30,2	29,9
Gross Electrical Efficiency related to Basis	%	100	101,1	106,8	112,6	114,6	113,3

Table 1 – Comparison Base solution and Variants 1-5

The overall assessment of various stoker & boiler system solutions has to include - beside the energetic efficiency- the following aspects:

- operating performance
- availability
- costs for consumables
- investment and maintenance

	Basis	Var. 1	Var. 2	Var. 3	Var. 4	Var. 5
Change compared to Basis		Reduced Excess Air	Flue gas cooler	External Super-heating	High Steam param.	Steam Reheating
Electrical Power Production	0	0 to +	+	++	++	++
Costs for Consumables	0	0	0	- -	0	0
Life Time of Membranwalls 1st Pass without add. Corrosion Protection	0	0 to -	0	-	-	-
Life Time of Superheaters	0	0	0	0	-	-
Cost for Investment	0	0 to +	0 to -	0 to -	0 to -	-
Maintenance Costs	0	0	0	0	-	0 to -
Availability	0	0	0	0	-	0 to -
Continuous Operation Period	0	0	0	0	-	0

Legend : 0 comparable; + positive; ++ very positive; - negative; - - very negative

Table 2 – Comparison Base solution and Variants 1-5

Table 2 evaluates these criteria for each variant. The rating system-relative to the base solution and non-numeric-points out the impact or tendency of the variants for those criteria.

CONCLUSIONS

For the different variants presented, the following conclusions ca be drawn:

Furnace excess air reduction (Variant 1)

The reduction in excess air should – depending on the combustion system – be done as far as possible in order to reduce the flue gas loss of the boiler. The membrane walls of the after burning zone should be protected with Inconel 625 or as shown for the Hameln/Germany EfW plant concept, with reduced flue gas temperature by recirculation.

The reduction in excess air is equally possible for Variant 2-5 with similar effect and equivalent efficiency optimization.

Temperature optimization and additional flue gas cooling (Variant 2)

The type of flue gas system dictates the opportunities of this variant. In case of a semi-dry FGC system heat used for evaporation of lime milk cannot be recovered. When a flue gas heat exchanger is installed for cooling down the flue gases, it has to be cleaned during operation and washing water be captured. Compared to the base solution this variant is a good alternative without constraints to plant operation and maintenance costs. The investment in additional heat exchanger surfaces is offset to extra earnings in generated electric power. A combination with variant 3, 4 and 5 is possible without limitation for increase in efficiency.

External superheater (Variant 3)

This variant requires approx. 14,5% of the thermal power from trash in addition from an auxiliary fuel as gas, oil or biomass. The additional fuel represents an important part of the plant operation costs. Compared to the base solution there are no constraints to plant operation, maintenance costs and availability. The tube wall temperature of the membrane is due to higher pressure compared to the base solution approx. 50 K higher and the 1st pass has to be protected with Inconel 625.

High steam parameters (Variant 4)

Higher power output of this variant goes along with lower availability due to higher inspection and maintenance requirements for the platen-type superheaters.

Higher steam pressure compared to the base solution is causing the necessity for additional Inconel cladding in the 1st pass.

Intermediate reheat (Variant 5)

Characteristic for the intermediate reheat variant is a very high electric power output. It is an interesting solution without monolithic SiC concrete superheater protection necessity. Prove has to be provided for the lifetime of cladded platen-type superheaters. In case of evidence for sufficient long lifetime only the investment costs for cladded heat surfaces and the intermediate reheat compared to the base solution balance against a higher income in electric power sales. Availability and uninterrupted operation time we expect not to vary from the base solution.

Combination of Variants

The combination of the variants presented is leading to higher efficiencies as the single variant. On the other hand drawbacks need to be accepted for each advantage of individual variants and their multiple combinations.
General tendencies were shown starting from a base solution - with fixed parameters - for the purpose of comparison only to show the impact of the different variants. Higher boiler feed water temperatures and lower steam outlet pressures can increase the gross power production up to 30%.
Assessment of all advantages and disadvantages for each individual case is necessary to find an optimum solution.

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