A NEW CONCEPT TO IMPROVE THE ELECTRICAL EFFICIENCY BASED ON THE COMBUSTION PROCESS IN THE WASTE FUEL BED ON A GRATE

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EXECUTIVE SUMMARY

Energy recovery from waste can reduce emissions of greenhouse gas and other gaseous, liquid and solid pollutants, has a great potential for assisting in meeting the Kyoto obligations, and can significantly contribute to a sustainable development. On the basis of the assessment year 2007, the municipal waste sector in the EU 27 could contribute up to 32% to the EU 27 reduction target for 2020.

With increasing focus on power production and favourable tariffs in many markets there is a need for maximizing electricity delivery to the grid. Increasing the steam parameter, as temperature and pressure, will result in a better performance of the steam turbine and thereby a better electrical output.

Lately, Babcock & Wilcox have developed a new technology and received a world patent. The basic idea is to improve the electrical efficiency by increasing the steam data. Especially, the steam temperature can be increased without the risk of super heater corrosion. The new concept can be fully integrated in the boiler and from the outside the waste fired power plant has the same layout as the classic waste to energy plant.

The idea is to separate the flue from the grate into two or more fractions having one fraction of the flue gas with a high heat flux and a low chlorine concentration. This isolated portion of the flue gas may be directed to a separate super heater section, where it can raise the steam temperature. The elevated super heater steam temperature could then increase the electrical efficiency of the waste fired power plant. The goal is to achieve an increase of 50°C to 100°C and total electrical efficiency of more than 30% with no influence on the normal operation.

The basic idea of the SteamBoost™ concept is to use all the advantages of a modern waste fired power plant combined with an integrated final superheater, as shown in Figure 2. The final superheating increases the steam data to for example 500°C and 80 bar and results in an increase in electrical efficiency of 3 percentage points.

INTRODUCTION

The main risks associated with increasing the steam parameters are corrosion and fouling in the boiler. The latter can be controlled by modern boiler cleaning equipment [2], whereas corrosion is destructive for the boiler and plant operation and is still a unpredictable process. Today, we face requirements for plant availability up to 8300 hours per year. The operational hours are one of the most important factors for the plant owner, because this factor is the basis for the plant owner's yearly income and thereby whether or not it is profitable business. This fact results in very conservative development where the investors tend to choose well-proven technology in order to minimise the financial risk.

The lifetime of super heater tubes is one of the critical parameters. New materials, on line boiler cleaning and design tools such as CFD modelling have resulted in more progressive steam data and thereby an increase in electrical efficiency. These developments have resulted in a steam data increase to 425°C and 65 bar depending on fuel property [2].

THE BASIC IDEA AND PATENT

Waste incineration is one of the most complex combustion processes. The processes in a burning fuel bed include: drying, ignition, pyrolysis, gasification, solid and gas combustion. Figure 1 is a simplified illustration of the different processes in a fuel bed on a grate.

Pyrolysis gases will be released in the ignition zone due to a quick heating of the top waste layer before the combustion starts. A large zone on the middle of the grates is sub-stoichiometric and results in formation of gasification products, like CO and H_2. The burnout of these gases is controlled by the turbulence created by the secondary air added in the furnace ceiling and at the entrance of the post combustion chamber – the patented VoluMix™ system. Thus pure gas phase combustion is achieved right above the waste layer where a relatively large part of the total energy is released from the waste. The burnout of these gases, soot and particles leaving the bed forms the radiant flames above the grate.

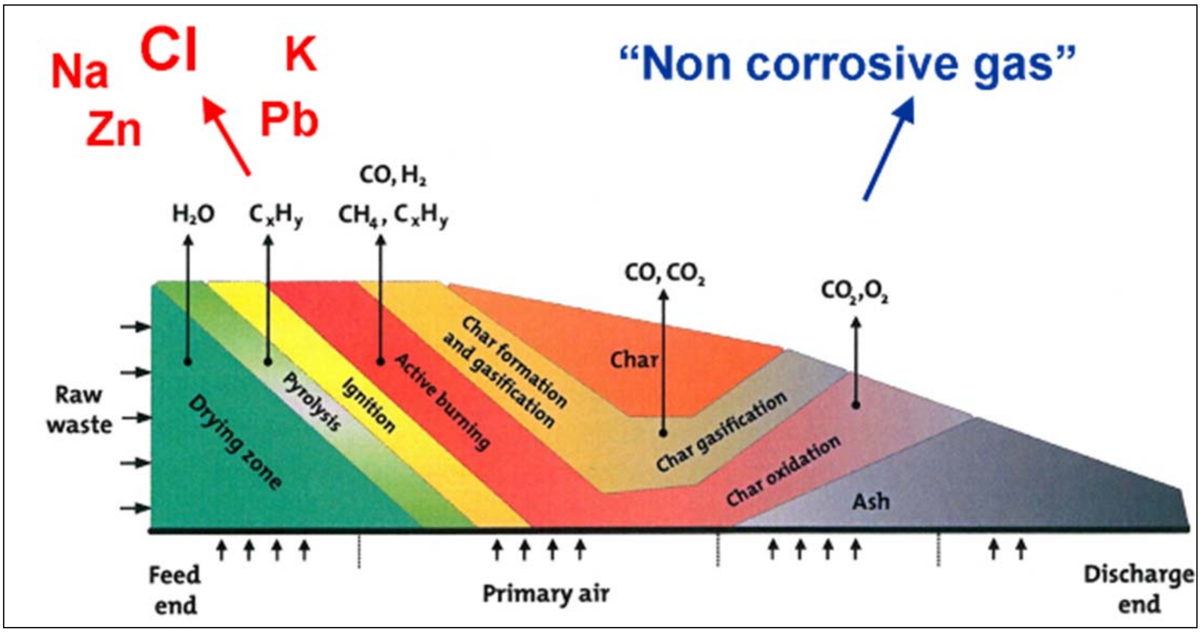


Figure 1 Schematic view of the fuel bed combustion process and the potential release of the volatile elements Cl, Na, K, Pb, Zn and S to the flue gas in the first part of the furnace.

The chemical composition of the waste includes a number of trace species Cl, Na, K, Pb, Zn and S that will be released to the gas phase during the combustion process. The split between bottom ash and flue gas for the species does not differ much for different types of household wastes. About 90% of the chlorine and about half of Pb and Zn are released to the gas phase. More than 75% of S is released. Approximately, 10% of Na and 33% of K is typically released [3].

The release of the volatile elements Cl, Na, K, Pb, Zn and S to the flue gas and the aerosol formation from those volatile elements is of special interest. The volatile elements are present in ash deposit layers at high concentrations where they may form a complex textured layer of different sulphate and chloride salts (Na, K, Ca, Fe and Zn) able to induce high corrosion rates. Deposits with a high Cl content, in particular, induce a high corrosion rate on boiler tubes.

It is well known that volatilisation of chlorine increases rapidly with the increase in temperature and nearly full volatilisation is achieved at 900 °C. This temperature is typically lower than the maximum temperature in the active burning zone. Moreover, Cl has been seen to promote volatilisation of alkali and heavy metals and to lower the melting temperature of ashes [3].

The release of chlorides from the fuel into the flue gas depends on the properties of the chlorine / chloride bearing components and of the firing conditions. The overall distribution is illustrated in Figure 1, where the first part of the grate and fuel bed contain the ignition, pyrolysis/devolatilisation, burning zones. The major parts of the corrosive species are released in the first part of the combustion grate and thereby in the front of the furnace. The rear parts of the grate are characterised by a burnout of a relatively clean char, thereby releasing relatively clean combustion products which are much less corrosive.

This phenomenon can be applied to split up the flue gases from the grate into two or more fractions, one of which exhibits high heat flux and a low chlorine concentration. That fraction could then be used in a high temperature super heater to increase the steam temperature and thereby the electrical efficiency of waste fired power plants, see Figure 2. The concept is named SteamBoost™ [4].

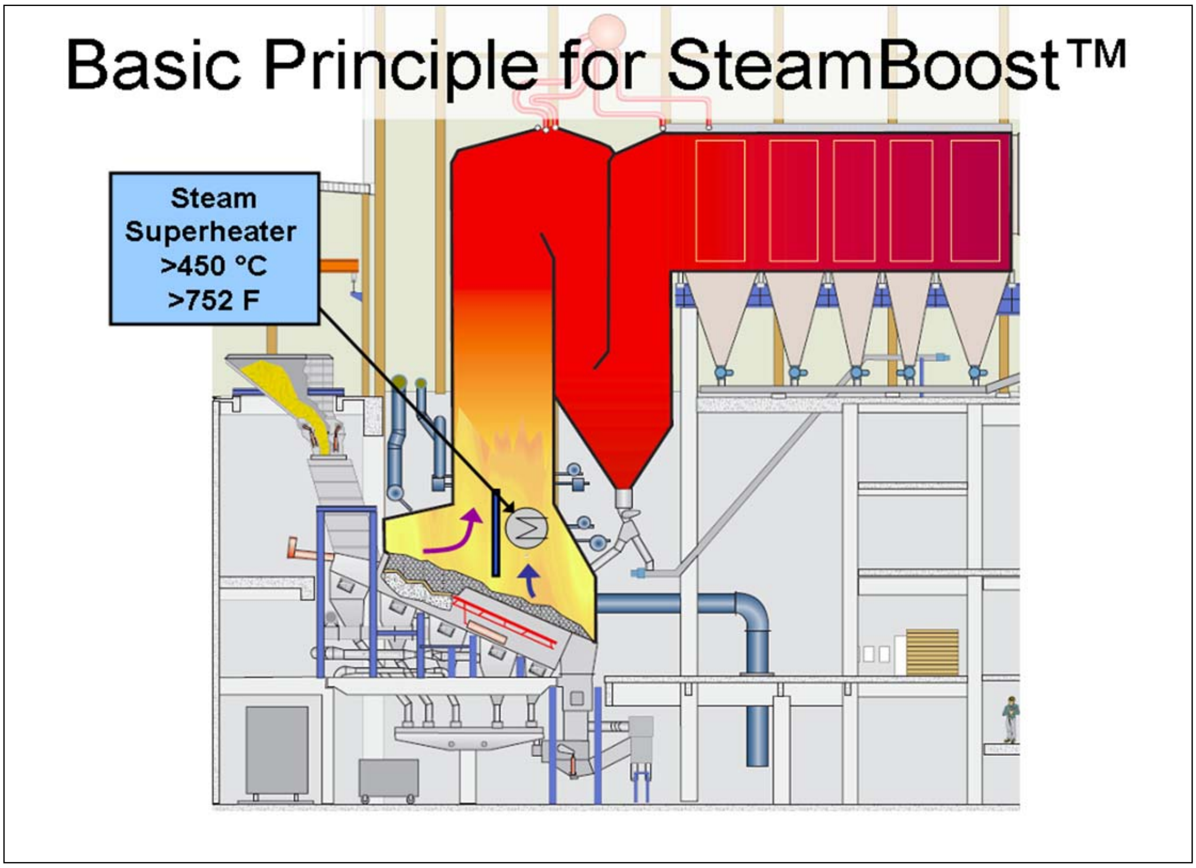


Figure 2 Generic waste fired power plant with two-stage furnace and SteamBoost™ super heater.

The CHEC Research Centre, Department of Chemical and Biochemical Engineering at the Technical University of Denmark have carried out full scale experiments in order to verify the Cl release profile in a typical waste fired power plant.

The objective of the study was to measure a concentration profile of the elements Cl, Na, K, Zn, Pb and S as a function of the location on the grate in a waste to energy boiler. A heat flux and chlorine release profile along the grate will provide information on the position where the heat is released with the lowest concentrations of corrosion promoting species in the flue gas. This will test the basic idea of separating the flue gas from the grate into two or more fractions while having one fraction of the flue gas with a relatively high heat flux and a low chlorine concentration.

Measurements were conducted at Vestforbrænding Unit 5 - a heat and power generating waste fired power plant in Copenhagen, Denmark. The plant was commissioned in 1998 and can process up to 30 tonnes per hour. The location of the measuring positions (1-6) relative to the grate is shown in figure 3 right. The measurements were performed by inserting a suction probe into the designated ports L2, L3, L4 and L5. All the detailed information about the test and the instrumentation is found in reference [3, 5].

RESULTS AND DISCUSSION

Figure 3 left, shows the gas temperatures measured at ports 1-5 and in the top of the first draught – the position is named EBK1. The highest average temperature is measured in port 3 followed by a decrease in temperature at ports 4 and 5. This corresponds well to the location at the end of the flame front between ports 3 and 4.

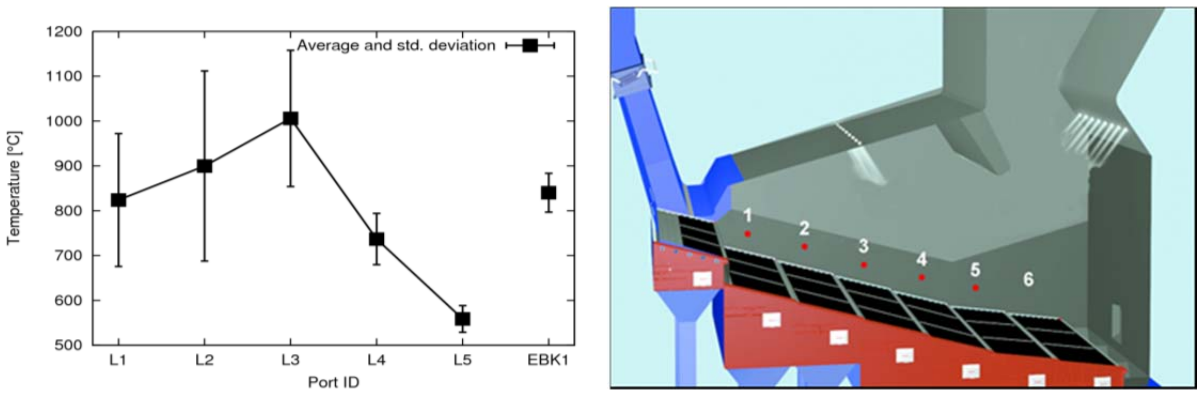


Figure 3 Temperature measurements, Concentration of CO, CO_2 and O_2 along ports L1-L5 and in first draught (EBK1).

Figure 4 show the concentration of respectively chlorine and sulphur in the flue gases. The concentrations of Cl and S peak at port 2 and then decrease at the remaining ports. Especially S was seen to be significantly lower at port 3 than at ports 1 and 2. The values measured at the top of the first draught represent average concentrations of the flue gas as the flue gas is presumed to be well-mixed at this stage.

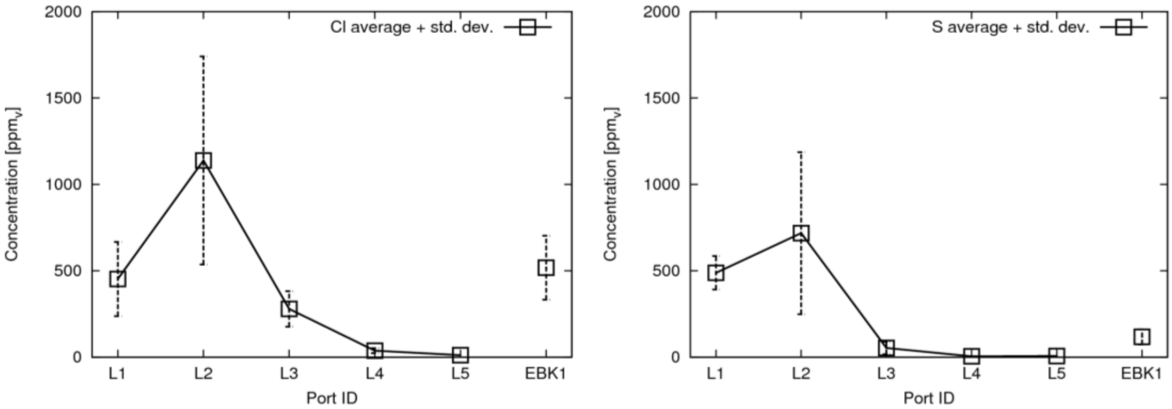


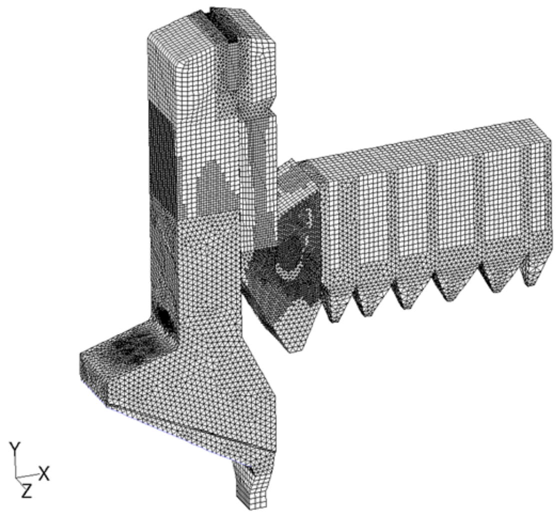
Figure 4 Chlorine and sulphur concentrations at ports 1-5.

A position between port 3½ and 4 will give favourable conditions for a final super heater. The Cl and S levels are very low and the temperatures of the flue gas are in the range of 800 °C.

THE NUMERICAL LABORATORY - CFD SIMULATION

CFD simulation is an effective method for evaluating different design alternatives that are otherwise too expensive, time consuming or impossible to test. The final improvement of electricity production will be determined in the coming test period on a full scale installation, which is currently planned to be carried out at the waste to energy plant Affald Plus Næstved Unit 4 with a nominal capacity of 8 t/h. In order to study the possibilities for implementing the system at the plant, a CFD simulation was carried out. In the figure to the right, the mesh for unit 4 is shown.

The flow field is represented by velocity vectors. Figure 5 shows the velocity vectors in the centre of the first row of the jets from the symmetry plane. The plot, on the left, is the original built furnace, and, on the right, the furnace is divided into 2 chambers by a wall.



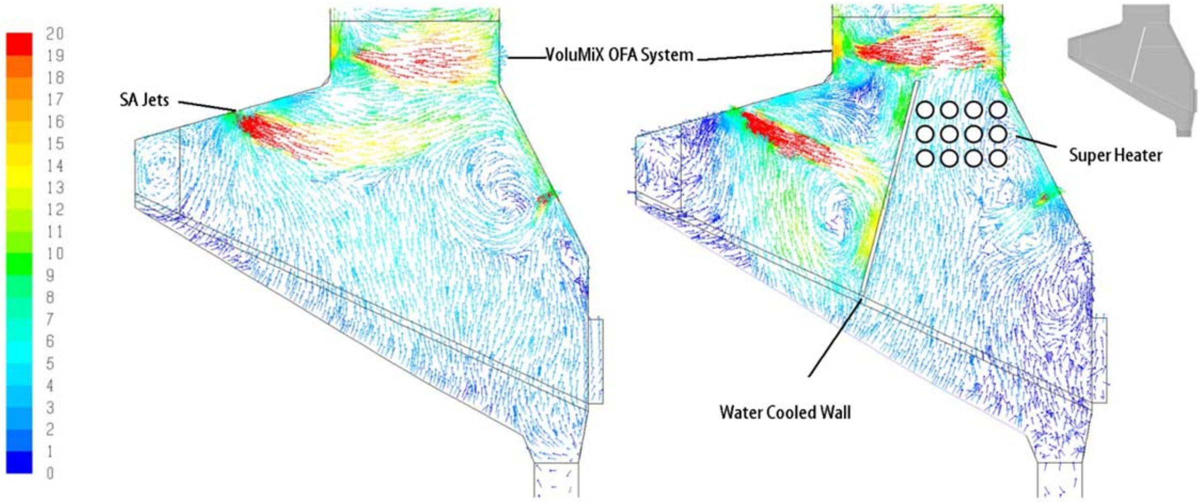


Figure 5 Velocity [m/s] vector plot, in a plane with jets, close to the centre of the furnace.

Introducing a separation wall across the furnace will divide the flow into more or less two separate rooms. In the first room, the SA jets in the ceiling are still moving hot gases to the front of the furnace, thereby ensuring a stable ignition. The direction and speed must be adjusted in order to avoid particle impingement, resulting in slagging problems on the new wall. When the two streams of flue gases enter the post combustion chamber, they are mixed by the VoluMix™ secondary air system for final burnout. The reason for placing the jets in this section is the requirement of turbulent conditions that ensure complete burn out of the CO coming from the furnace.

The computed temperature distribution in the furnace is shown in figure 6. The large vortex, seen on the velocity vector plots figure 12, is reflected in the temperature distribution.

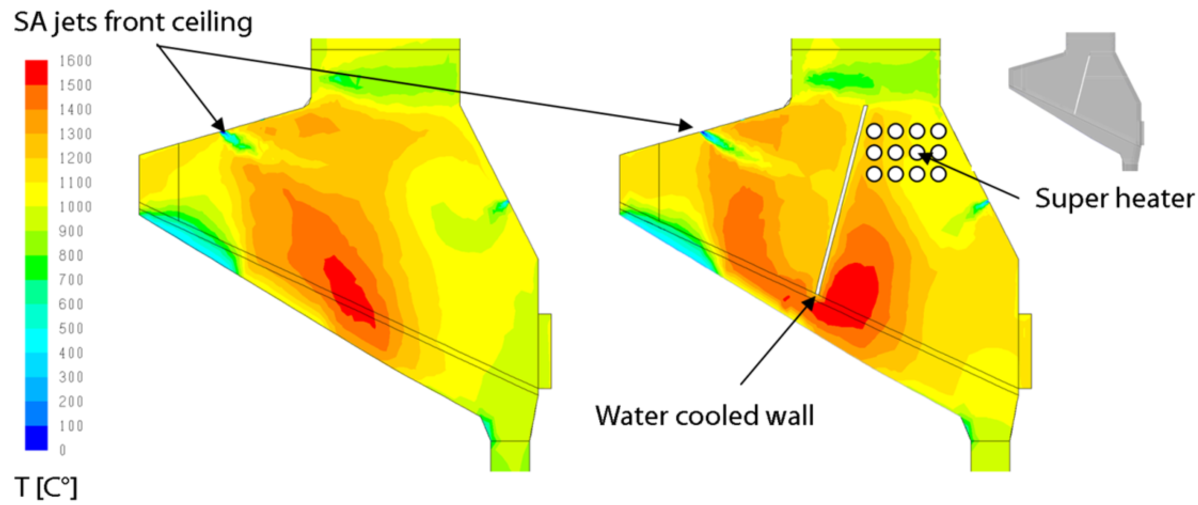


Figure 6 Gas temperature distributions in the centre of the furnace.

In the second room, the gas temperatures are quite high above grate 3 as a result of the burning char, which is the dominating component in the fuel bed at this position along the grate. The tube bundles will be located in an area with relatively high flue gas temperatures in the range of 800°C to 1100°C. The main flow of hot gases goes directly towards the SteamBoost™ super heater, thereby ensuring maximum heat transfer to the steam. On the other hand, this could give slagging problems depending on the ash composition.

Affald Plus line 4 has a steam production of 30 t/h at 405°C and 54 bars. The objective is to increase the super heating temperature by +50°C, and in this case this corresponds to an energy input of 1 MW or 4% of the fuel energy input. The CFD simulation indicates that it will be possible to extract at least 1 to 1½ MW in the final super heater SteamBoost™.

NEW FLOW PRINCIPLE

In the previous studies, one of the ideas was to separate the flue gas from the grate into two streams with a water cooled membrane. These studies showed that the SteamBoost™ concept is feasible, but with some challenges regarding the construction of the wall and possible fouling problems.

Developing the idea a step further is to create a virtual flow wall within the furnace – thereby separating the flue gas into the corrosive and non-corrosive flue gas. The new idea is to remove the water cooled wall in the furnace and redesign the secondary combustion air supplied to the front and the back of the furnace. These changes will change the flow field allowing the “clean“ flue gas to stay “clean” and also show the best position of the super heater in the furnace.

To get an idea of where in the furnace the concentrations of the corrosive species are located, it is chosen to use the result from the measurements conducted at Vestforbrænding 5 and shown in figure 4. The release concentrations from the different grates in ppm can be seen in the table below.

Species [ppm]	Grate 1	Grate 2	Grate 3	Grate 4
Cl	500	700	0	0
K	150	300	100	0
Na	100	200	100	0

The different species are released in the CFD model as inactive species in the gaseous phase and and mixed due to turbulence and diffusions with the flue gas and combustion air thereby reducing the concentration of the species in question. The ideal gas law is assumed to calculate the density of K and Na.

As indicated in the table, the high concentrations of corrosive species are found in the area around grate 1 and 2. Furthermore, the release of Cl from grate 3 and 4 is close to zero and one would therefore expect a low concentration of Cl in the back of the furnace – but due to the recirculation zone in the back of the furnace, see velocity vector plot figure 5, the concentration of Cl is relatively high. This is caused by the flow from the front secondary air nozzles.

So the challenge is to reduce and finally eliminate the recirculation zone and thus creating the “clean” zone at the back of the furnace enabling the placement of the super heater. The new idea is to introduce a flow of air in the opposite direction and thereby creating a barrier of air which hopefully will reduce or eliminate the recirculation zone. Several CFD simulations have been performed where several designs and placement of rows of nozzles or gabs in the back wall of the furnace have been tested.

CFD results obtained with air slice or gab as illustrated in figure 7 show that the recirculation zone is only reduced. On the other hand, it is clear that the concentration of the corrosive species in the area where the super heater is thought to be placed is reduced.

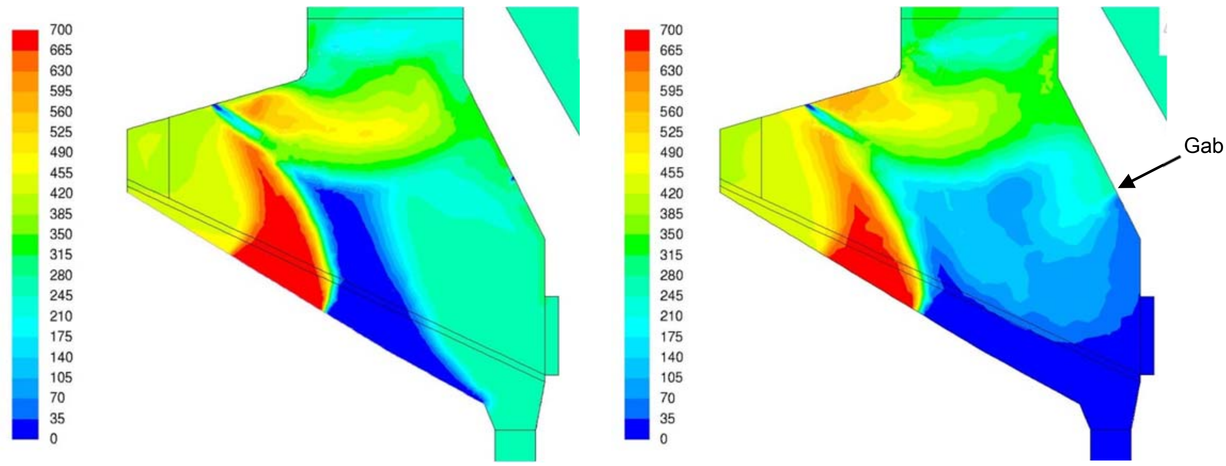


Figure 7 Chlorine [ppm] concentration profiles before and after changing the flow field.

The calculation shows that it is possible to reduce the concentration of the corrosive species by 75 % with this new idea for the steam boost concept – further change to the distribution of the secondary air may even push the concentration further down. One idea is to reduce the flow from the front nozzles and thereby reducing the strength of the recirculation zone at the back of the furnace. This has to be done without compromising the main purpose of these nozzles which are to control the fuel ignition process in the furnace.

CONCLUSION

A new patent concept named SteamBoost™ is under development. The final objective is to achieve an electrical efficiency between 27% and 33%, depending on the design of the cooling system for the condenser.

The idea is to divide the flue gas from the grate into two fractions, having one fraction of the flue gas with a high corrosive content of chlorine and another fraction with a low chlorine concentration. The test, carried out on an operating waste fired power plant, supports this concept. The low corrosive part of the flue gas may be directed to a separate super heater section, where it raises the steam temperature.

CFD calculations have been made to visualize the concentration of the corrosive species, chlorine, sodium and potassium in the gaseous phase in the furnace. The CFD calculations indicate that it is possible to extract at least 4% of the fuel energy input in a final super heater. New simulations demonstrates that special flow arrangement in the rear part of the furnace can keep the concentration of corrosive spices at very low levels and thereby eliminate the need for a physical wall.

ACKNOWLEDGEMENT

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