The effect of increased fractions of waste wood on water wall- and superheater corrosion - Combating corrosion by new materials and improved material selection

Applying organisation

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Project

This project will work closely together with the KME711/EM39299-1 project and is planned to share the same report. This since a majority of the obtained results will be directly compared to the results obtained in the KME711/EM39299-1 project. In addition, part of the work (i.e. the work related towards water wall corrosion) adds a new research direction to this project. However, we apply for this project as an extension to the KME711/EM39299-1 project.

Title

The effect of increased fractions of waste wood on water wall- and superheater corrosion - Combating corrosion by new materials and improved material selection
Extension to the KME711/EM39299-1 project

Summary

This project includes two parts; superheater corrosion (SH) and water wall corrosion (WW). The exposures will be performed in the biomass fired boiler at Örtoftaverket. The SH corrosion part will mimic the matrix currently being executed in KME711 (a waste fired boiler), enabling a comparison between the corrosiveness of the different fuels (biomass vs waste) and how the selection of materials can be optimized with respect to fuel quality. In addition, the plan is to stepwise increase the amount of waste wood in the fuel mix at Örtoftaverket, from 30% to 50% with a 10% yearly increase. We will investigate FeCrAl-alloys, state-of-art stainless steels and conventional materials during long term testing at different material temperatures. We will in

addition expose probes for the investigation of potential water wall corrosion problems. The stepwise increased fraction of waste wood is of special attention since the risk of Zn and Pb associated corrosion is expected to increase.

Motivation

The motivation for this project is by obvious reason similar to the motivation written in the KME711/EM39299-1 application. Hence, part of the motivation is directly transferred from the KME711/EM39299-1 project.

In order to increase green electricity production from combustion of biomass and waste high temperature corrosion of the pressure part materials in the boilers needs to be addressed. Compared to boilers burning fossil fuels, the electrical efficiency of biomass and waste fired boilers are considerably less. There is however a constant strive towards increasing the heat and power output from these boilers using renewable fuels or waste fractions.

Energy relevance

In the present project, we aim to investigate how the corrosivity of the flue gas varies with flue mix and how the design of the superheater section of the CFB boiler (going from a vertical to a horizontal design) affects the corrosion of the superheaters. By lowering the corrosion rate through new boiler design, an increase in the boiler steam data is enabled for future plants. Furthermore, this projects aims to test a new class of materials for these types of boilers (so called FeCrAl-alloys) as a way towards decreasing the corrosion rate of the superheaters. The work will be coordinated in collaboration with the KME709 and KME711/EM39299-1 projects, which also investigates the use of FeCrAl alloys for boiler applications. In addition, high performance stainless steels will also be investigated. Special focus will put on coatings and a newly developed Ni-base self-fluxing coating including formation of hard-phase which will be tested with the new generation coating technology HVAF (High Velocity Air Fuel). By this two-pronged approach; decreasing the corrosion by boiler design and an optimized material selection, the aim is to generate new knowledge for the construction of future boilers with increased electrical efficiency. With increased electrical efficiency of biomass and waste fired power plants their competitiveness towards fossil fuelled plants is increased and thus, the share of renewable energy in the energy system can be increased.

The corrosion exposures performed within this project will be directly compared to the corrosion exposures performed in the KME711/EM39299-1 project. Thus, by choosing, as far as possible, appropriate parameters, there will be a comparison between the different fuel mixes used in the two boilers (Händelöverket in KME711/EM39299-1 and Örtoftaverket in KME720, respectively) on the degree of corrosion attack. Furthermore, the stepwise increase of the waste wood fraction in the fuel mix used at Örtoftaverket will provide valuable knowledge about how the corrosion of both water walls and superheaters is affected by this increase. This project will also share information/knowledge about water wall corrosion with the KME708 project, focusing on water wall corrosion. This is primarily done by mutual presence in the reference groups of the two projects.

Industrial relevance, general applicability and implementation of the results

Since this project involves several industry partners, ranging from material manufactures to boiler manufactures and boiler owners, the project findings may rather swiftly be implemented or used by the project partners. The results are expected to visualize the corrosion performance of a set of new materials and coatings in relation to more conventional materials, the effect of a horizontal superheater pass on corrosion and also how the corrosivity is related to the fuel mix (by comparison with the KME711/EM39299-1 project). Furthermore, the stepwise increase of the fraction of waste wood in the fuel mix will give valuable information of how the corrosion attack changes as a result of this. The corrosion performance of the water walls in relation to the waste wood fraction will be of extra importance. The knowledge generated within the project will aid the involved companies in improving their products and thus, the knowledge and improvements (of e.g. new materials or boilers) obtained will be of value also outside of this project.

<u>News value of the project</u>

The news value of this project covers several different aspects. For instance, the comparably large matrix of materials (both new and commercial alloys) to be tested will generate important knowledge about the performance of these materials in this type of environment. Especially, the newly developed HVAF coatings and the FeCrAl alloys are of extra attention. Furthermore, the difference between a biomass and a waste fired boiler will explicitly be compared in this project. The collaboration between the KME711/EM39299-1 and KME720 project enables the project group to choose the parameters in such a way as a comparison between the two boilers, and thereby the different fuel mixes, can be made.

The stepwise increase of waste wood in the fuel mix performed in full scale commercial boiler render good opportunities to investigate how the corrosion attack is affect by the fraction of waste wood in the fuel mix. Thereby, this project may lead to the optimization of the fuel mix (with respect towards corrosivity and e.g. Pb and Zn levels).

Furthermore, the newly developed “clamp” testing technique is engaged in a second boiler (compared to the KME711/EM39299-1). With this technique, the test material is placed on top of the ordinary superheater tube and the material temperature of the test piece is controlled by the amount of insulation between the test clamp the superheater. The material temperature will be measured with a thermocouple, which lasts however only for an initial period. This technique enables long term corrosion testing with comparably low risk for the plant owner.

Background

The background for this project is by obvious reason similar to the motivation written in the KME711/EM39299-1 application. Hence, part of the motivation is directly transferred from the KME711/EM39299-1 project.

There is a constant strive for the use of cheaper fuels in commercial biomass fuelled plants. Waste wood is, compared to virgin biomass, such a cheaper fuel. However, the corrosion rate in these plants are usually increased when cheaper (and usually more corrosive) fuels are being burnt. The biomass plant in this study, the newly built boiler at Örtoftaverket, is burning a fuel mix containing about 30% waste wood (the rest being 55% wood chips and 15% peat). By increasing the amount of waste wood, the fuel economy is greatly improved. However, the risk of corrosion is elevated when the fraction of waste wood is increased. Not only does the waste wood contain high levels of alkali chlorides but also the Pb and Zn levels are usually much higher compared to other biomass fuels, e.g. wood chips. Thus, by increasing the amount of waste wood in the fuel mix, the corrosion risk of superheaters in general and water walls in particular is expected to increase.

Traditional CFB boilers burning difficult fuels are usually designed with vertical superheater banks after a radiation pass/empty shaft. With this design, the superheater bundle is usually subject towards flue gases with high velocity and thus, the risk of erosion damages. Furthermore, due to the geometry of the tubes, ash removal from the tubes is usually performed by steam generated soot blowers. This may further enhance the risk of erosion. A newly built CFB boiler, Örtoftaverket (see figure 1), by Foster Wheeler is designed with a horizontal pass. Hence, the superheaters in the flue gas stream are arranged hanging in a horizontal path. With this design, the flue gas velocity is much lower and cleaning by hammers instead of steam soot blowers can be deployed. This is expected to decrease the corrosion rate of the super-heater tubes installed in this section. Furthermore, the horizontal design enables a relatively fast and easy exchange of the superheaters. However, so far no corrosion tests have been performed, showing if the horizontal pass design actually displays improved corrosion resistance.

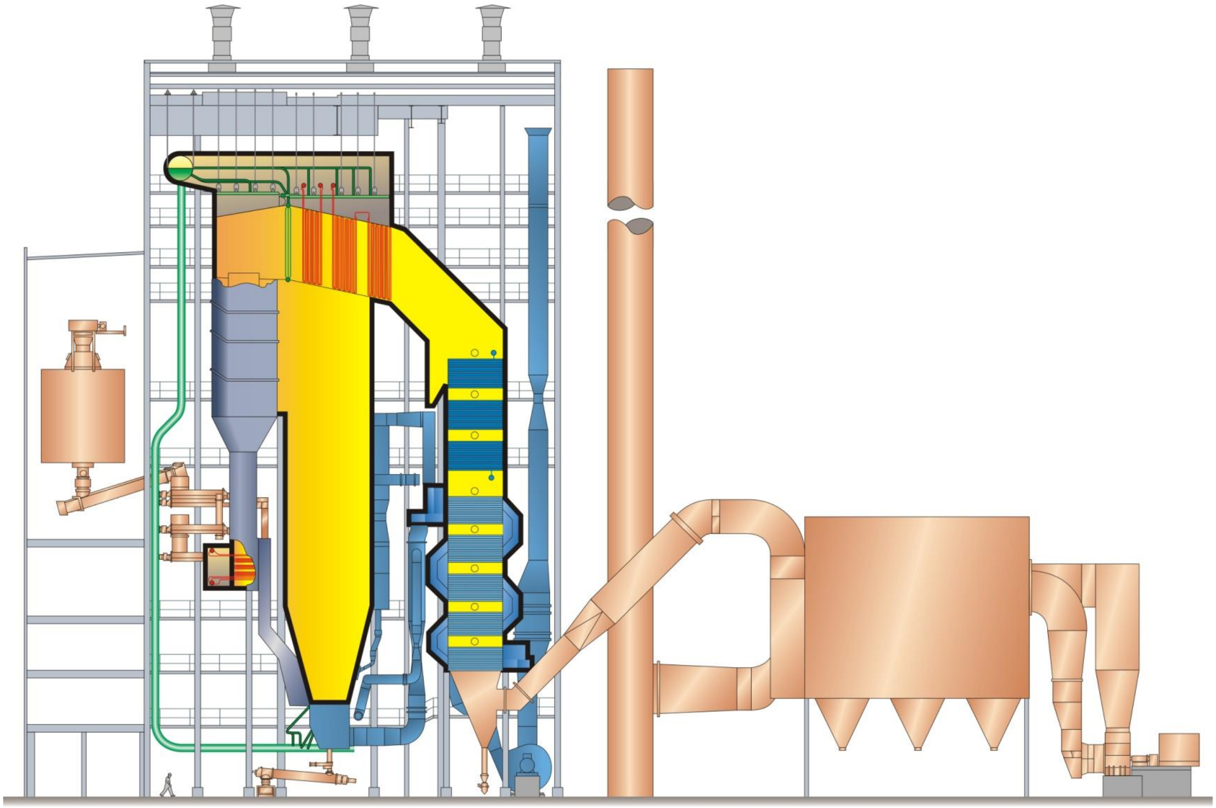

Figure 1: Örtoftaverket

State of the art

In this project we will investigate the corrosion performance of new materials and coatings, based on alumina forming alloys, in relation to more conventional materials. The ability of an alloy to resist high temperature corrosion is due to its capacity to form a protective oxide scale and corrosion properties depend on the growth rate, adhesion, chemical reactivity and mechanical properties of that scale. Only few oxides form protective scales, e.g., SiO_2, Fe_2O_3, Cr_2O_3 and their solid solutions, spinel oxides and α-Al_2O_3. However, in practice the number of oxides responsible for corrosion protection in biomass and waste fired boilers are far less and iron and chromium oxides are dominating. In the most corrosive parts of the boiler (i.e. the hottest part of the steam superheater) different classes of Cr_2O_3-forming alloys (i.e. stainless steels) are used. This is because chromia scales are far more protective than the iron oxide scales formed on, e.g. low alloy steels. Unfortunately, most chromia forming alloys behave relatively poorly in alkali chloride rich environments, which commonly is the case in biomass and waste fired boilers. Hence, when a chromia-forming alloy is exposed to alkali chlorides in the presence of water vapour and oxygen, the protective oxide reacts to form alkali chromate. Because this process depletes the protective scale in chromium, the chromia scale tends to be replaced by an iron-rich scale, causing a sudden acceleration of oxidation. The resulting "breakaway scale" is providing a much poorer corrosion protection compared to a chromia rich scale and is susceptible towards chlorine induced corrosion.

Alumina (α-Al_2O_3) scales are expected to be superior to chromia scales in biomass and waste combustion. However, alloys forming alumina scales are not widely used in combustion of biomass and waste. Also, commercial alumina formers are designed for higher temperatures and are known to be affected by internal oxidation and nitridation in the temperature range of interest (<700°C). However, recent (unpublished) research implies that the corrosion behaviour of commercial FeCrAlMo alloys may be superior to the best NiCr-base alloys in biomass and waste combustion environments. Since this class of materials has limited load bearing capacity at high temperatures and limited ductility at low temperature, they will likely be used as coatings or as the outer part of compound tubing, rather than as load bearing material, but applied in this way they have the potential to improve corrosion resistance dramatically. The coating technology has recently made advances and the project aim to investigate coatings performed with a new generation of coating technology, HVAF (High Velocity Air Fuel).

Goal (max 2 500 characters)

The overall goal of the project is to improve plant economy by enabling an increased green electricity production and optimum material selection. The material matrix includes commercial steels available today as well as future materials developed for this type of environment. This will be achieved by generating new knowledge about the following topics:

- To verify and quantify the corrosion rates for different superheater materials in superheaters with a horizontal design.
- Verify and compare the corrosion properties of a biomass fired boiler (Örtoftaverket) and waste fired boiler (Händelöverket in KME711/EM39299-1)
- Investigate how the corrosion performance of water walls is affected by a stepwise increase of the waste wood fraction in the fuel mix.

The goals of this project is direct related to the following goals stated in the program description:

Goal 3:
This project will explicitly examine several materials and their corrosion resistance when the fuel mix changes. The results will contribute to improve the material selection of superheaters and water walls so that materials with extended lifetime can be selected alternatively an extended fuel flexibility can be achieved. The results may also be used by material manufacturers to produce steel with optimized microstructural characteristics which better prevents the corrosion caused by the corrosive environment.

Goal6:
This project will investigate how the corrosion rate of several different steels/alloys changes with different fuels. With this knowledge, fuel flexibility and/or availability may be increased. Through an improved understanding of how corrosion is influenced by environmental and material-specific parameters new boiler designs, operating parameters and tools can be proposed.

Project plan

In this project several activities will be performed in order to achieve the stated goals. These activities can be divided into three major areas, focusing on different research and technical issues, namely;

- How does the corrosiveness of the flue gas vary with the fuel mix? Comparison between two similar boilers using different fuels and the investigation of how a stepwise increase of the waste wood fraction is affecting the corrosion.
- Investigate the corrosivity of the superheaters in a boiler with horizontal design of the superheater section using clamp testing
- Test the usability of novel FeCrAl alloys and coatings and compare these materials towards state-of-the-art stainless steels as well as conventional stainless steels and steels.

The specific details about materials, position in the boiler, exposure times etc. will be decided by the project group.

How does the corrosiveness of the flue gas vary with the fuel mix? Comparison between two similar boilers using different fuels and the investigation of how a stepwise increase of the waste wood fraction is affecting the corrosion

Within this project, we will investigate how an increase in the fraction of waste wood in the fuel mix will affect the corrosion rate. Both waster wall corrosion and superheater corrosion will be investigated. The plan is to stepwise increase the amount of waste wood in the fuel mix, going from 30% to 50% with a 10% yearly increase. The expected water wall corrosion is of special attention. This since the risk of Zn and Pb associated corrosion is of great interest and it is expected to increase with increased fractions of waste wood in the fuel mix.

Another activity is to compare the corrosion rates of the superheaters over time for the biomass and waste fired boilers in KME720 and KME711/EM39299-1, respectively. Thereby enabling a cross reference of how the fuel mix influences the corrosion rate. For both boilers, the superheater bundles are placed in a horizontal design and clamp exposures will be performed. In addition, we are also aiming to altering the flue gas chemistry by means of sulphur containing additives. These tests in the two boilers will be done with broad palette of techniques in order to following the chemistry and kinetics of flue gas, deposit and corrosion chemistry. In addition, fuel analysis will be performed by Kraftringen AB. The flue gas chemistry may, if available, be monitored by an on-line alkali probe (developed by Foster Wheeler and Metso Automation) together with HCl (g) and SO_2 (g) downstream raw gas measurements. The deposit formation and the corrosion attack will be analysed by means of deposit probes and corrosion probes, respectively. In addition, equilibrium calculations will be performed by Chalmers with aim to couple the fuel analysis with the deposit composition. By combining these two projects, performing similar corrosion probe tests some interesting questions could be raised. For instance, since both boilers have the possibility to add sulphur, the Cl/S ratio in the flue gas can be controlled. Since this ratio has been used as a "corrosion indicator", the aim is to compare the corrosion attack in the two boilers with respect to their Cl/S ratios. Is the Cl/S ratio a good measure in estimating the risk of corrosion?

Investigate the corrosivity of the superheaters in a boiler with horizontal design of the superheater section using clamp testing

As for the exposures performed within the KME711/EM39299-1 project, this project will also investigate the corrosion of the superheaters in a CFB boiler with a horizontal pass design. The corrosion tests will include commercial alloys well as newly developed alloys. The detailed selection of materials, exposure times, positions in the boiler, etc. will be decided by the project group and, as far as possible, be set in order to facilitate a fair comparison to the KME711/EM39299-1 project.

Test the usability of novel FeCrAl alloys and coatings and compare these materials towards state-of-the-art stainless steels as well as conventional stainless steels and steels.

In this project we will investigate a large matrix of different alloys relevant as superheater materials. This includes commercial steels available today but also newly developed materials by Sandvik (both Materials technology and Heating technology). The aim with this broad approach on material selection is twofold; seeking potential materials for future boilers with increased steam temperatures as well as finding more cost-effective materials for current steam data. All material suppliers (SHT, SMT and MH) will contribute to the project with the materials. For example, MH will supply a Ni-base self-fluxing coating including formation of hard-phase which will be tested with the new generation coating technology HVAF (High Velocity Air Fuel).

Evaluation of the exposed samples

The proposed project plan will render in a considerable amount of samples to be analyzed. Depending of what type of investigation, a wide range of analytical tools is available. Analysis of the corrosion products can be performed with Scanning Electron Microscopy (SEM) using high-resolution FEG-SEMs. Energy Dispersive X-ray analysis (EDX) can be used for chemical analysis. Cross sections of selected samples will, if applicable, be performed using a Broad Ion Beam (BIB). Grazing incidence angle X-ray diffraction, GI-XRD can be used for characterization of crystalline corrosion products. We will use a Siemens D-5000 instrument equipped with a Göbel mirror that allows us to detect down to 20 nm crystalline corrosion product layers. The composition of formed deposits may be evaluated by means of Ion Chromatography (IC) and Ion Coupled Plasma - Optical Emission Spectroscopy (ICP-OES). Material loss determination will be performed on the clamp samples. Samples will be analyzed both at Chalmers and at Foster Wheeler laboratories.

Staff

Part	Participants role in the project
Kraftringen AB	Responsible for boiler operation
Amec Foster Wheeler Energia OY	Responsible for clamp installation, water wall probe testing and will perform corrosion evaluation and analysis
Sandvik Heating Technology	Providing materials
Sandvik Materials Technology	Providing materials
MH Engineering	Providing materials
Fortum Värme	Attending meetings and provide knowledge to the project
Chalmers/HTC	Project leader. Responsible for short term corrosion testing, corrosion evaluation and analysis

Time schedule

The project will start in July 2015 and end (including final scientific and economic reporting) in April 2018. Installation of clamps in the superheater will be performed during the maintenance stop 2015 and 2016. Short term deposit and corrosion probe testing will be performed during 2015 and 2016. Corrosion probes for investigating the water wall corrosion will be installed 2015, 2016 and 2017.

Wastage measurements of the clamp samples will be performed after the outtakes 2016 and 2017. Corrosion analysis of selected samples will be performed continually as the exposed samples become available.

	2015				2016				2017				2018	
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2
Official start of project			X											
Clamp testing 30% waste wood			X	X	X	X								
Clamp testing 40% waste wood							X	X	X	X				
Deposit and corrosion probe testing at the superheater				X	X	X					X	X		
Water wall corrosion probe 30% waste wood			X	X										
Water wall corrosion probe 40% waste wood							X	X						
Water wall corrosion probe 50% waste wood											X	X		
Scientific analysis				X	X	X	X	X	X	X	X	X	X	
Final report													X	X

Industrial reference and financing

The industrial partners that will participate in the project are listed in the table below together with the amount of cash or in kind they are contributing with.

	Cash contribution	In-kind contribution	
Amec Foster Wheeler Energia OY		436 kSEK	
Kraftringen AB	152 kSEK	1970 kSEK	
Sandvik Heating Technology		260 kSEK	
Sandvik Materials Technology		180 kSEK	
MH Engineering		125 kSEK	
Total industrial contribution	**152 kSEK**	**2 971 kSEK**	**= 3 123 kSEK**
STEM financing	**101 kSEK**	**1 981 kSEK**	**= 2 082 kSEK**
Total cash in project: 2 234 kSEK, Total project volume: 5 205 kSEK			

As the boiler is running on a commercial schedule the project schedule needs to be adopt to this. This means that the companies involved may have cost before the official start date of the project. These costs are tied to the boiler revision stop summer of 2015 and the installation of "clamps" – samples and mounting of corrosion probes for the water walls. If the costs prior to the project start is not be approved, the project will lose a whole year, since the next major revision stop is scheduled for the summer 2016.

Material costs are related to the cost occurred for the purchase of the test materials. Consulting expenses are primarily related to the cost of building scaffolding in the boiler so that clamp samples can be fitted. In addition, other consulting services, such as engineering work, may occur. Travel costs are partly related to the cost of going to meetings and partly the cost of installing and removing the sample in the boiler (including for example, hotels and transport costs).

The costs associated to the post ”Utrustning” is related to:

Amec Foster wheeler: Building/maintenance of corrosion probes. The value of the probes are estimated to be 0 SEK after the project.

Kraftringen: Costs associated to collect data from analytical equipment and boiler operation