

High temperature corrosion in waste-wood fired boilers Translation of version approved by EM

Applying organization : Vattenfall Research and Development AB

Organisation number : 556390-5891

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Co-applicants : Vattenfall AB Nordic Heat – Carl Nordenskjöld; E.ON (Värme Sverige and Climate and renewables UK) - Anna Jonasson and Colin Davis; Foster Wheeler Energia OY – Edgardo Coda Zabetta; Sandvik Heating Technology – Dilip Chandrasekaran; Sandvik Materials Technology – Jan Högberg

KTH Pamela Henderson, KIMAB Rikard Norling, SP Anders Hjörnhede.

Project: Continuation of projects KME 508/KME 512 Furnace wall corrosion in biomass-fired boilers at higher steam temperatures and pressures/ Fuel additives to reduce corrosion at elevated steam data in biomass boilers

Title: High temperature corrosion in waste-wood fired boilers . Part 1. Project 39270-1

Summary

(aim, goal, project content, expected results and how project is to be performed)

The aim is to reduce high temperature corrosion in heat and power boilers that burn predominantly waste (recycled) wood. Most of the effort will be directed towards furnace walls. The main goal is to reduce furnace wall corrosion caused by combustion of waste wood in a cost-effective way. A secondary goal is to evaluate materials suitable for superheaters. Information on corrosion rates of different materials will be obtained from power boilers burning mainly waste wood or similar fuel mixes. A range of different materials including newly developed alumina-forming alloys will be tested. The effect of fuel quality will be investigated. Advanced microscopy is performed after testing to investigate the results. The expected results are information on how the corrosion rate varies with the material and fuel mix and a greater understanding of fuel chemistry on the corrosion of furnace walls.

Motivation

What is the problem area. How can the results from the project be implemented and adopted ?

Increasing use is being made of waste wood as a fuel in heat and power boilers, because it is cheaper than virgin wood. However waste wood causes more corrosion problems, especially in the furnace where there is a lack of oxygen (low NO_x combustion). This project seeks to find cost effective ways of reducing the corrosion, thus saving maintenance costs, or increasing fuel flexibility. It also seeks to evaluate materials produced by Swedish steel companies. Tests will be performed with a number of different materials to evaluate the reduction in corrosion.

The project contributes very strongly to the KME goal of improved fuel flexibility by enabling the combustion of problematic fuels (e.g. fuels causing increased corrosion) while maintaining electrical efficiency (steam temperature). This project contributes specifically to the following goals :-

Utvärderat exponeringar och applikationstester av olika material i syfte att utveckla förbättrade materiallösningar som bidrar till en ökad bränsleflexibilitet och ökad elproduktion. / Evaluation of different exposed materials and coatings to increase fuel flexibility and increase electricity production

Förslag till åtgärder och lösningar för att minska överhettar- och eldstadskorrosion, ska ha tagits fram/Make suggestions for reducing superheater and furnace wall corrosion

The academic goal of this project includes two Ph.Ds (Jesper Ejenstam 2014 Yousef Alipour 2015) and one Licentiate (Annika Talus 2016).

Energy relevance

Serious corrosion problems are often a hindrance to using waste wood or other waste-products as a fuel because of high chlorine and heavy metal contents. As a consequence waste- derived fuels are often combusted in heat and power boilers with low steam data (low efficiency). The results of this project will enable waste wood and other waste-derived fuels to be utilized at higher steam pressures and temperatures thus increasing the amount of electricity produced from renewables.

Industrial relevance

Boiler manufacturers will be able to produce boilers utilizing waste wood with a higher efficiency, if it is known how to control their corrosion problems. Power companies will be able to use greater amounts of waste wood in the fuel mix, thus reducing their operating costs.

This project investigates the use of advanced Swedish steels for reducing corrosion in a more cost effective way. Swedish manufacturers (Sandvik) will be able to sell more steel to the power industry.

News value

Very little research has been performed on furnace corrosion in waste wood-fired heat and power boilers. The previous KME projects in this area, KME 508 and KME 512, produced many new results and this project will be a continuation of those projects. The results of short-term tests with digested sewage sludge (made during the previous project KME 508) will be further investigated with new techniques. Investigation of new materials will be performed in a full-scale boiler. In addition the relatively new instruments/techniques of GD-OES (glow discharge optical emission spectroscopy) and FIB (focused ion beam) will be developed and used for more precise mechanistic studies. Thermo-Calc thermodynamic equilibrium modelling will be used to simulate Ni- and Fe- alloys in a waste wood environment and compare to actual results.

Implementation of results

The expected results will be information on how corrosion can be reduced with use of the right materials or control of the fuel quality.

The results can be implemented by boiler manufacturers to increase fuel flexibility or electrical efficiency in new boilers or by power producers to increase fuel flexibility or reduce costs, by the use of better materials like weld overlays or compound tubes. The materials are developed and supplied by Swedish companies and would be available commercially for use in Sweden or for export on the international market.

The difference in corrosivity of waste wood of different chemical compositions and the difference in corrosion rates caused by different proportions of waste wood (20%-100%) can be used by power companies when purchasing wood and waste wood to decide on appropriate proportions and suppliers.

The GD-OES technique will be developed and readily available for use in analysing specimens from biomass-fired boilers in a rapid and cost effective manner. It is anticipated that it will be widely used in forthcoming studies of corrosion in power boilers.

General applicability

The results concern fuel chemistry (e.g. Pb and Cl contents) and materials and are applicable to all plants firing waste wood and biomass-waste wood mixtures. They will also give valuable information to plants burning other sorts of waste (household or industrial).

The project group comprises academics and industrial partners who are experts in their own areas (corrosion in biomass-fired boilers, boiler construction, manufacturing of advanced materials, heat and power production) and have an excellent ability to carry out the project. They have successfully performed previous KME projects. The project has a direct link to the environment quality goal called "Limited climate impact" by reducing CO₂ emissions.

Background

The combustion of biomass and waste is making an increasing contribution to Sweden's energy production and reduces the dependence on non-renewable sources. In order to reduce operating costs (which is especially important when electricity prices are low) low quality fuels like waste (recycled) wood are often utilized instead of forest residues (virgin biomass). Waste wood consists of by-products from consumption, like demolition and building waste and often contains traces of paint or plastics or other polymers. This gives rise to a n increase in the amount of chlorine, zinc and lead in the fuel and increases the corrosion risk to the boiler components, when compared to virgin biomass.

Problems have been experienced with furnace wall corrosion with waste wood contents as low as 20% in combination with low-NO_x combustion and advanced steam conditions of about 140bar/540°C (KME 508 final report). In Vattenfall's 100MWth bubbling fluidized bed boiler using 100% waste wood in Idbäcken, Nyköping, corrosion rates of up to 1.5 mm a year were measured on the low-alloy steel walls made of 16Mo3. This corrosion rate gives a lifetime of 3 years and a new furnace wall for a boiler of this size costs around 25 MSEK.

The walls have since then been overlay welded with the nickel –base alloy IN 625 to reduce the corrosion, but even this alloy corrodes (albeit at a lower rate) so the problem is not solved. In addition, Ni-base alloys are expensive. KME-508 resulted in a number of recommendations to reduce furnace wall corrosion, but the work needs to be taken further. This project will be a continuation of KME 508 (and also of KME 512).

Work within KME 508 showed that coatings of austenitic stainless steels can be a competitive alternative to Ni-base alloys and preliminary results with alumina forming alloys (as opposed to chromia-forming ones) showed that these FeCrAl alloys had very low corrosion rates at boiler wall temperatures (400°C), matching those of the Ni-base alloys. These alternatives need to be evaluated further so that boiler owners and manufacturers can have the confidence to use them instead of traditional Ni-base alloys. New alumina forming alloys manufactured by Sandvik Heating Technology and advanced steels from Sandvik Materials Technology will also be evaluated.

Initial results from KME 512 showed that the Pb content of the fuel influences the corrosion rate of the low steel (more lead gives more corrosion). However lead is not found at or near the corrosion front in this material. The lead and chlorine levels in waste wood varies according to origin /supplier of the fuel. While

the suppliers cannot be mentioned (because this is competitive information) the corrosion caused by waste wood having different characteristic chemical compositions can be investigated. (The effect of Pb content will be investigated in a Värmeforsk (SEBRA) project in which virgin wood is doped with known quantities of Pb and evaluated in a laboratory scale furnace. This project will build on the knowledge obtained)

Some questions to be answered by the project

- Are there materials available that perform as well as conventional Ni-base alloys, but are cheaper?
- Are there materials that perform better than conventional Ni-base alloys but are more cost effective (i.e. with little or no cost increase)
- How (by what mechanisms) does sewage sludge affect the initial corrosion process ?
- By how much does the chemical composition of waste wood affect the corrosion for a low alloyed steel and a high alloyed steel or Ni-alloy ? (Find extreme cases of waste wood , say low Pb and Cl versus high Pb and Cl)
- How does Pb participate in the corrosion process ?

Goals

The aim of the project is to reduce high temperature corrosion in heat and power boilers that burn predominantly waste (recycled) wood. Most of the effort will be directed towards furnace walls.

The main goal is to reduce furnace wall corrosion caused by combustion of waste wood in a cost-effective way. This could be by :-

(1) Finding wall coating materials that are more cost-effective than conventional Ni-base alloys (i.e. cheaper or more corrosion resistant). A cost or corrosion rate reduction of 20% is aimed at.

(2) obtaining a better understanding between fuel quality (fuel chemistry) and corrosion

(3) From results of short-term testing (performed in 508) with digested sewage sludge decide to proceed (or not) with long-term testing of sludge as an additive, i.e decision to run part 2.

A secondary goal is to evaluate materials suitable for superheaters when burning recycled wood. Superheaters close to the furnace region experiencing high flue gas temperatures (and therefore susceptible to high corrosion rates) are the main focus.

Project plan

Project participants:

Vattenfall Research and Development (VRD) Pamela Henderson is project manager

Others : Vattenfall Nordic Heat, KTH, KIMAB, SP, Sandvik Materials Technology, Sandvik Heating Technology, E.ON, Fortum, foster Wheeler. (more details given later in document)

Corrosion testing will be performed by Vattenfall Research and Development at Vattenfall's BFB (bubbling fluidized bed) 100MWth boiler in Nyköping. This boiler runs on 100% waste wood and high corrosion rates have been measured in the lower furnace region, which is where the corrosion testing will be performed. Most corrosion testing, lasting about 6 weeks (1000 h) will be performed with probes. Vattenfall has developed a special probe for this purpose , which contains 4 specimens and can be inserted vertically into slits made in the fins between two tubes in the furnace wall.

Corrosion measurements will be made with different materials developed and delivered during the project by Sandvik, with normal boiler wall steel (16 Mo3) and conventional Ni-base overlay weld material (IN 625) used for comparison. The Sandvik materials include newly developed alumina-forming alloys and austenitic stainless steels like 3R12 (304L) and Sanicro 28. Sandvik will also supply material knowledge and advice.

Some tubes may be welded in the furnace wall for long term evaluation. Samples from these tubes can only be taken once a year and the tubes experience all the fuel qualities available during that period. However, this method gives really long-term data (one operating year is about 6500 h). A small amount of corrosion testing will be made with a probe near the first superheater after the furnace.

SP will perform short-term corrosion tests with different qualities of waste wood (high Pb, high Cl and lower Pb lower Cl) which are commercially available. The waste wood will be supplied by Vattenfall AB from fuel available for firing in the Nyköping plant. The tests will be performed in SPs laboratory scale fluidised bed reactor, which was used successfully in KME 512.

E.ON (UK and Sweden) and Foster Wheeler will provide corrosion rate information on a range of different alloys including 16Mo3, Ni-base alloy IN 625, austenitic stainless steels and newly developed materials. The information will come from a number of different fluidised bed boilers running on low amounts (15-20%) of waste wood, high amounts (100%) of waste wood and some other waste-derived fuels. Corrosion rates and fuel composition will be provided. This will give information on corrosion rate with fuel quality. Fortum will perform activities intended to reduce furnace wall corrosion in boilers burning waste-derived fuels. This could be for example, using a fuel additive like sludge or welding in coated compound tubes, but the exact activity will be decided later.

KTH and KIMAB will analyse the deposits and corroded specimens from Vattenfall and SP. KTH will work in the project during 2014-5 until Yousef Alipour qualifies for his PhD and hands the rest of the analysis over to KIMAB. The analyses will be made with Scanning Electron Microscopy with Energy Dispersive Spectrometry (SEM-EDS). FIB (focused ion beam) will be used to prepare fresh sections of the corrosion front beneath the oxide layer. This technique was successfully used initially in the previous project (KME 508). X-ray diffraction (XRD) will be used to identify crystalline phases. KTH will also perform equilibrium thermodynamic modelling with Thermo-Calc for predicting thermodynamically stable phases present in Fe- and Ni-alloys. The preliminary Thermo-Calc modelling performed in KME 508 will be extended to include additional alloy components such as Cr, Al, and Mo and the environment can be altered to simulate the fuel changes for example with the addition of an additive. The results of the thermodynamic modelling will be compared to the experimental results from microscopy. The results will give more insight to the corrosion mechanisms operating in different materials and the initial effect of fuel additives like sewage sludge.

The GD-OES method will be developed and used by Swerea KIMAB to obtain chemical depth profiles from the samples.

By using a combination of measured corrosion rates, fuel analyses and the above-mentioned analysis techniques information will be acquired to obtain a better understanding of fuel quality and corrosion, fuel additives and corrosion and identify and understand materials that are more cost-effective than conventional Ni-base alloys.

Staff

Vattenfall Research and Development: Pamela Henderson (project manager). Annika Stålenheim, Mattias Mattsson. All part-time

Vattenfall Nordic Heat: Carl Nordenskjöld, Christer Forsberg. All part-time

KTH: Yousef Alipour Full time from September 2014 to January 2016. Jesper Ejenstam part time Sept-dec 2014. Peter Szakalos part time Sept 2014-Dec 2015.

KIMAB : Rikard Norling and Annika Talus. All part-time.

SP: Anders Hjörnhede (part-time)

Sandvik Group: Jan Högberg, Dilip Chandrasekaran All part-time

E.On : Bengt-Åke Andersson, Anna Jonasson and Colin Davis. All part-time

Foster Wheeler: Edgardo Coda Zabetta, Jouni Mahanen and Kyösti Vänskä. All part-time

Fortum Värme : Eva-Katrin Lindman . Part time

Göteborg Energi: Ulf Hagman. Cash contribution

Ph. D Jesper Ejenstam December 2014. Ph.D Yousef Alipour November 2015. Licentiate Annika Talus February 2016. (Ph.D Annika Talus December 2018)

High temperature corrosion in waste wood fired boilers. – Project proposal in 2 stages

It was originally intended to run the project until 2018, but the project manager was forced to divide the project into two parts, where the first finishes in 2016.

The project group intends to decide on the continuation of the project (part 2) by early 2016, at the latest.

Part 2 involves long term testing with sewage sludge

Time plan for part 1 and part 2.

	2014		2015				2016				2017				18
Part 1	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1
Manufacture and supply of material specimens	X	X	X	X											
Writing final papers Ph.D thesis and exam KTH	X	X													
Continued analysis and Thermocalc KTH	X	X	X	X											
Kick-off meeting Oct 2014		X													
Corrosion probe testing 1		X													
Corrosion probe testing 2			X	X											
Analysis of corrosion specimens KTH			X	X											
Welding in coated panels at plant				X	X										
Year one project and ref group annual meeting					X										
Writing final papers Ph.D thesis and exam KTH				X	X	X									
Hand-over KTH -> KIMAB						X	X								
Corrosion probe testing 3						X									
Reserve corrosion probe testing							X								
Licentiate examination KIMAB							X								
Year two project and ref group annual meeting. Toll gate. Decision to proceed according to original plans or to finish project during 2016								X							
Corrosion testing at SP (fuel quality)							X	X							
Analysis of specimens KIMAB and reporting							X	X	X	X					
Compar. corr. rates fuel mixtures and plants									X	X					
Final reporting of part 1 (if project ends 2016)									X	X					
Final project and ref group meeting -2016 end										X					
Part 2 – not written yet															
Continued analysis of specimens KIMAB											X	X	X	X	
Corrosion testing with sewage sludge											X	X			
Corrosion testing 4											X				
Year 3 project and ref group annual meeting												X			
Compar. corr. rates fuel mixtures and plants												X	X		
Final reporting – 2018 end														X	X
Final project and ref group meeting															X
Ph.D examination KIMAB															Q4

Financing

	Andel i kronor och procent av projektets totala kostnader/år						
FINANSIÄR	2014	2015	2016	2017	2018	Total	(%)
Energimyndigheten	568 434	1 386 735	1 007 838	0	0	2 963 007	40
AB Fortum Värme samägt med Sto	30 000	60 000	50 000	0	0	140 000	2
AB Sandvik Materials Technology	100 000	160 000	80 000	0	0	340 000	5
E.ON Värme Sverige AB	140 000	160 000	40 000	0	0	340 000	5
Foster Wheeler OY	180 000	120 000	40 000	0	0	340 000	5
Göteborg Energi AB	0	30 000	0	0	0	30 000	0
Sandvik Heating Technology AB	100 000	220 000	80 000	0	0	400 000	5
Vattenfall AB	80 000	350 000	400 000	0	0	830 000	11
Vattenfall Research and Developm	300 000	900 000	800 000	0	0	2 000 000	27
SUMMA	1 498 434	3 386 735	2 497 838	0	0	7 383 007	100

Budget break-down Industrial partners

		Salary	Equipment	Material	Laboratory	Travel	Indirect costs	Total
VRD	2014	230 000	20 000		30 000	20 000		300 000
	2015	740 000	50 000		60 000	50 000		900 000
	2016	640 000	50 000		60 000	50 000		800 000
	Total	1 610 000	120 000	0	150 000	120 000	0	2 000 000
VNH	2014	80 000						80 000
	2015	350 000						350 000
	2016	400 000						400 000
	Total	830 000	0	0	0	0	0	830 000
Sandvik Heating	2014	75 000		20 000		5 000		100 000
	2015	190 000		20 000		10 000		220 000
	2016	70 000				10 000		80 000
	Total	335 000	0	40 000	0	25 000	0	400 000
Sandvik Materials	2014	75 000		20 000		5 000		100 000
	2015	130 000		20 000		10 000		160 000
	2016	70 000				10 000		80 000
	Total	275 000	0	40 000	0	25 000	0	340 000
E.ON	2014	120 000		15 000		5 000		140 000
	2015	150 000				10 000		160 000
	2016	30 000				10 000		40 000
	Total	300 000	0	15 000	0	25 000	0	340 000
Foster Wheeler	2014	150 000				30 000		180 000
	2015	90 000				30 000		120 000
	2016	30 000				10 000		40 000
	Total	270 000	0	0	0	70 000	0	340 000
Fortum	2014	30 000						30 000
	2015	60 000						60 000
	2016	50 000						50 000
	Total	140 000	0	0	0	0	0	140 000

Allowable costs – academic partners

		Salary	Equipment	Material	Laboratory	Travel	Indirect costs	Total
KTH	2014	289 852	35 000	5 000	19 493	15 000	124 089	488 434
	2015	766 926	55 000	5 000	48 346	30 000	383 463	1 288 735
	2016	63 444	4 500		8 172		31 722	107 838
	Total	1 120 222	94 500	10 000	76 011	45 000	539 274	1 885 007
SP	2014	20 000				2 000		22 000
	2015	29 000				4 000		33 000
	2016	170 000	35 000	5 000	5 000	5 000		220 000
	Total	219 000	35 000	5 000	5 000	11 000	0	275 000
KIMAB	2014	50 000	8 000					58 000
	2015	75 000	20 000					95 000
	2016	560 000	100 000			20 000		680 000
	Total	685 000	128 000	0	0	20 000	0	833 000

Translation of official application 2014-003151 (final version 2014-06-10) to Energimyndigheten. This is not an official document .

Pamela Henderson

2014-11-07