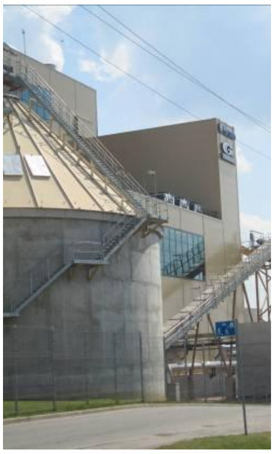
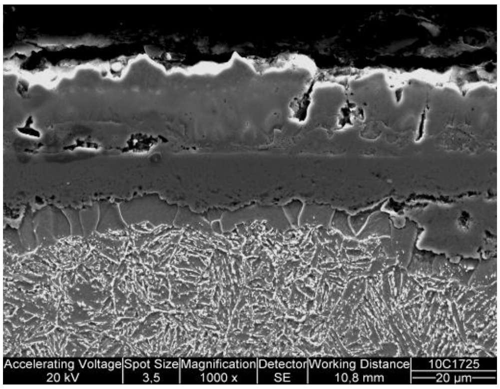
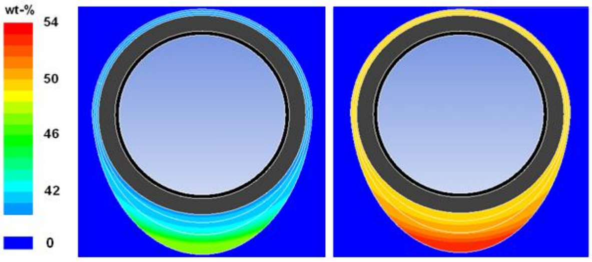
RESEARCH REPORT

VTT-R-02825-11







High performance materials and corrosion control for efficient and low emission biomass and waste combustion (HICOR) – final report

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Confidentiality: Public

Report's title

High performance materials and corrosion control for efficient and low emission biomass and waste combustion – final report

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Summary

Cost efficient performance of alloys for the heat transfer elements is crucial for economy, efficiency and long service life of advanced future boilers. This is particularly the case in combustion of corrosive renewable biomass or waste-based fuels in air or oxygen to reduce CO_2 emissions in the emerging sustainable energy systems. Materials will set the limits to the cost, performance and attainable efficiency of such systems. To support optimal materials selection, the HICOR project aimed at improving understanding of materials performance and corrosion mechanisms affecting boilers in biomass, co-firing and oxy-firing conditions.

An extensive test program under selected atmospheres has been carried out at the Åbo Akademi University and VTT. The results can be utilised in overhauls, retrofits and planning of future energy production with high efficiency and near zero emission. Exposure tests provide the background information for the material selection, especially for oxyfuel combustion, where the construction of demo plant (Ciuden) is starting in near future and material questions are, at least partly, still open.

The implementation of on-line corrosion probe was successful and using this probe, the measurement campaign in Tartu CHP-plant together with Fortum was carried out. The in-service experience with the on-line corrosion probe has provided added confidence to the technology amongst the utility owners and boiler suppliers. The co-operation with on-line corrosion monitoring has been continued between VTT, Fortum and Tartu power plant after the end of HICOR project.

Thermal modelling has been applied to predict the flue gas and material temperatures in boiler components, supported by extended databases for the applied thermodynamic modelling tools (Aalto University, VTT). The development work of reaction rate modelling (reaction kinetics) was also initiated during the project.

Confidentiality	Public

Tampere 21.6.2011

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Preface

The report summarises the work done within the HICOR project, Tekes decision 40118/08, during the project years 2008-2011. The detailed results are presented in the separate reports of Åbo Akademi University, Aalto University and VTT.
The authors wish to thank Tekes, Fortum Oyj and Foster Wheeler Energy Oy for the financial support.

Tampere, June 2011

Authors

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1 Introduction

The project aimed at improving understanding of materials performance and corrosion mechanisms affecting boilers under biomass, co-firing and oxy-firing conditions. For this purpose, laboratory scale corrosion testing was conducted under simulated service conditions at Åbo Akademi University and VTT Technical Research Centre of Finland. To complement testing, Aalto University made the first estimation of trends and correlations from obtained exposure test results and atmospheres (thicknesses, mass changes, atmosphere, salts, time, temperature) using meta-analysis and reactive search algorithms.

The results were used to assess the performance and durability of a range of materials that were selected for the evaluation together with the industrial partners. The outcome can be utilised in overhauls, retrofits and planning of highly efficient future energy production with low to near zero emissions.

Corrosion measurements have typically been based on comparing the mass of test coupons before and after exposure to the testing environment. Mass loss can then be converted into material loss, but a major disadvantage of the indicated mass change is lacking information on the instantaneous corrosion rate. For more information on the instantaneous corrosion rates, different monitoring techniques are being developed. In the HICOR project one of the main aims was to implement an on-line corrosion probe for on-site measurements at plant. The implementation of the corrosion probe was successful, and a measurement campaign was carried out at the Tartu power plant of Fortum. The duration of campaign was 84 days (2016 hours during the period of 7.4.-30.6.2010), and it proved the usability of the corrosion probe in monitoring the operational conditions, e.g. changes in fuel quality.

Thermodynamic modelling was used to estimate the melting behaviour of deposits used in the experimental part of the project, and to develop computational fluid dynamics (CFD) simulation tools. Thermal modelling has been applied to predict the flue gas and material temperatures in boiler components, supported by extended databases for the applied thermodynamic modelling tools (Aalto University, VTT). The development work of reaction rate modelling (reaction kinetics) was also initiated during the project.

2 Project accomplishments

The HICOR project was divided into three main work packages:

- high temperature exposure tests
- implementation and development of an on-line corrosion monitoring system
- thermodynamic modelling.

2.1 High temperature exposure tests

High temperature exposure testing was done in three application areas; waste/bio, co-firing and oxyfuel conditions. Tables 1 and 2 summarise used test temperatures and conditions for each application areas. The test materials are listed in Table 3, and the full test matrix is shown in Appendix 1. The sample cross-sections were studied with optical and scanning electron microscope (SEM). The composition of oxide layers was determined with energy dispersive spectroscopy (EDS). In addition, selected oxide scales were analysed with glow discharge optical emission spectroscopy (GDOES). Based on obtained results, corrosion depth, mass change and microstructural analyses, comparison principles of structural materials and models for lifetime analyses can be made for failure prevention and in-plant applications. The following chapters give an overview of obtained results under different exposure atmospheres. Detailed descriptions of the exposure tests in different conditions are presented in separate reports [1,2].

Table 1. Corrosion testing temperatures for the selected application areas

Application temp, °C	**500**	**570**	**600**	**650**
A. Waste/biomass	x	x	x	
B. Co-firing		x	x	x
C. Oxyfuel			x	x

Table 2. Test conditions and synthetic salts and gases for the selected applications areas. As a reference gas for oxyfuel in longer exposures.*

Application	**Salt composition (wt-%)**	**Gas atmosphere**
Waste/bio	$KCl+5ZnCl_2+5PbCl_2$	Synthetic air
Co-firing	$CaO-14CaSO_4-1KCl$, KCl	Synthetic air
Oxyfuel	$CaCO_3-15CaSO_4$, $CaSO_4$, no salt	60% CO_2-4% O_2-10/30% H_2O-N_2, 60 % CO_2 – 4% O_2- 30% H_2O-Ar, 16 % CO_2 – 2% O_2- 8% H_2O- N_2*

Table 3. Nominal compositions of tested alloys (wt-%).

Alloy	**Fe**	**Cr**	**Ni**	**Mo**	**Mn**	**Si**	**V**	**C**	**Nb**	**Al**	**P**	**S**	**Ti**	**Co**	**W**	**Cu**
10CrMo9-10	95.96	2.16	0.06	0.93	0.48	0.26	0.01	0.08	0.01	0.01	0.01	0.01		<0.01	>0.01	0.02
10CrMo9-10(UA)	95.93	2.08	0.09	0.86	0.47	0.32	0.01	0.10	0.01	0.02	0.01	0.01		0.01	<0.01	0.08
X20CrMoV11-1	85.95	11.26	0.54	1.00	0.48	0.24	0.30	0.20			0.01	0.01				
TP347HFG	66.19	18.30	11.7	0.23	1.64	0.41	0.05	0.08	0.92	0.02	0.03	0.00	<0.01	0.09	0.01	0.33
TP347HFG(CN)	66.70	18.60	11.6	0.04	1.56	0.40	0.09	0.07	0.77	0.01	0.03	0.00	<0.01	0.09	<0.01	0.03
HR3C	51.98	26.10	19.46		1.22	0.43			0.69	0.12						
Sanicro 25	43.64	23.56	24.08		0.59										5.30	2.83
A263	0.37	20.39	50.74	5.35	0.26	0.23				0.50			2.29	19.86		
A617	1.07	22.94	52.43	9.19		0.10				1.17			0.44	12.67		

2.1.1 Testing in simulated bio/waste conditions

Two types of 10CrMo9-10 and TP347HFG steels and X20CrMoV11-1 steel were exposed at 500, 570 and 600°C with $90KCl+5ZnCl_2+PbCl_2$ deposit in air. Figure 1 presents the mean oxide layer thickness for the tested samples. All materials suffered accelerated corrosion, Figure 1. The steel TP347HFG performed better at the lowest test temperature, 500°C, however, the oxide scale was still significant (~30 µm).

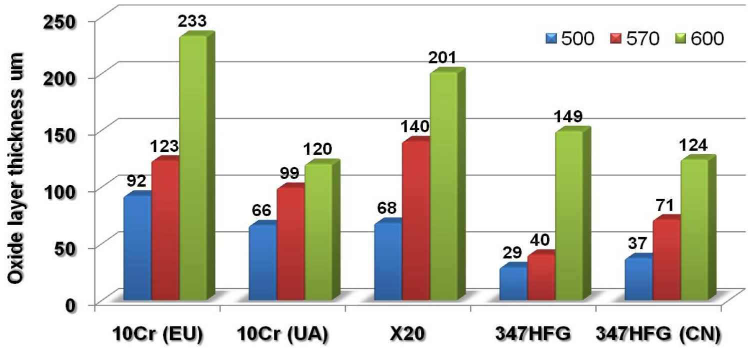


Figure 1. Mean oxide layer thickness after 168 h exposure test with 90KCl+5ZnCl$_2$+PbCl$_2$ deposit in ambient air.

2.1.2 Testing in simulated co-firing conditions

The tests were performed at 570, 600 and 650°C with KCl and 85CaO-14CaSO$_4$-KCl deposits in air. Exposed alloys, depending on exposure temperature, were 10CrMo9-10, X20CrMoV11-1, TP347HFG, HR3C, Sanicro 25, A263 and A617. All the tested alloys suffered corrosion in exposure tests with KCl. The 85CaO-14CaSO$_4$-KCl salt mixture appeared to be less corrosive than pure KCl. Figure 2 shows as an example the oxide scales formed on Sanicro 25 surface after 168 h exposure tests. The mean oxide layer thickness on the tested alloys is shown in Figure 3.

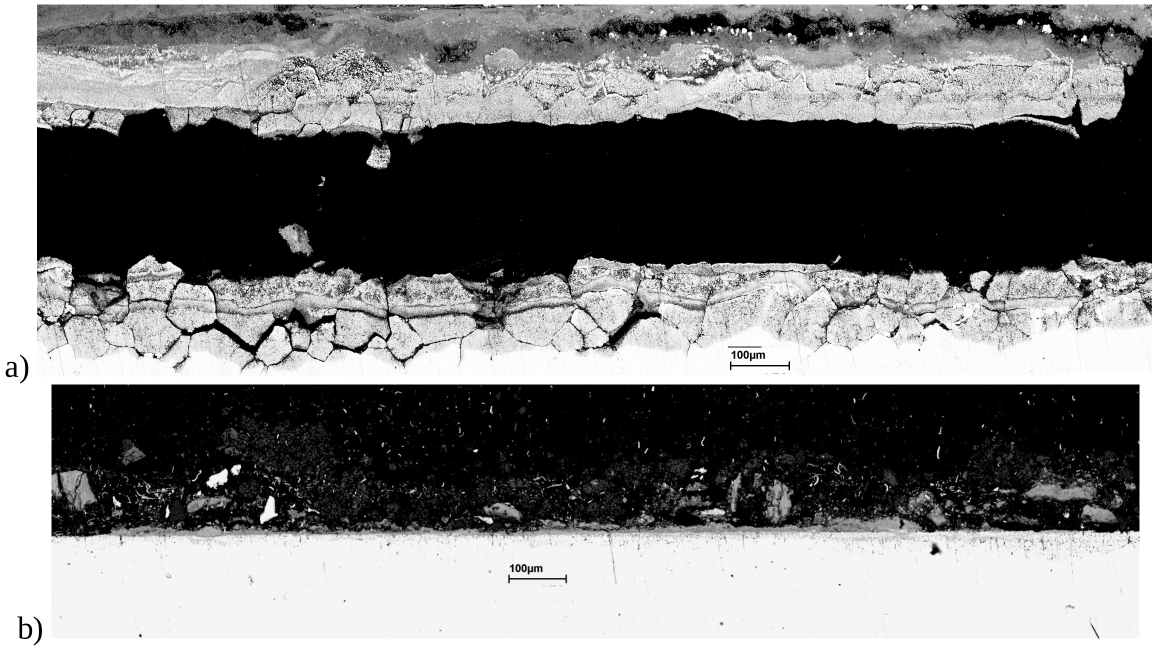
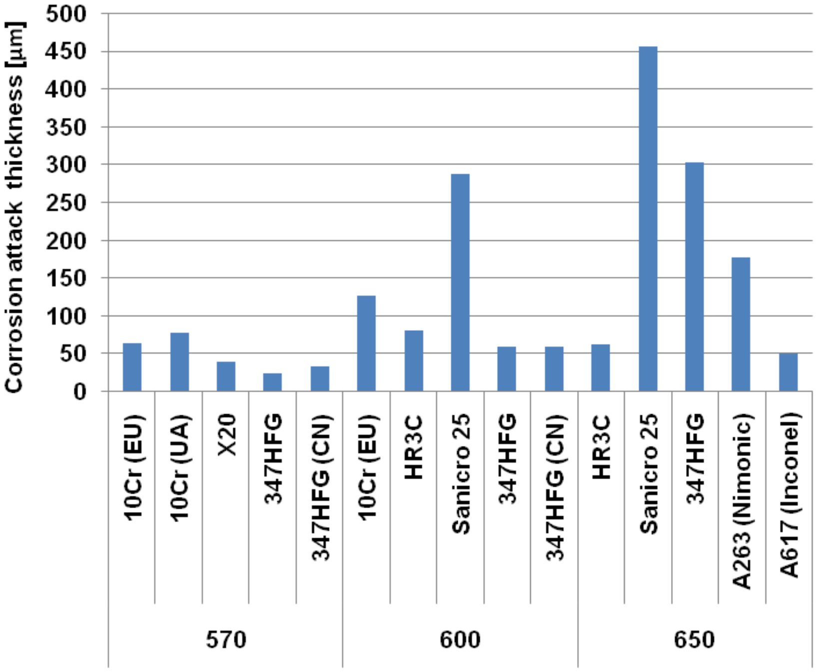
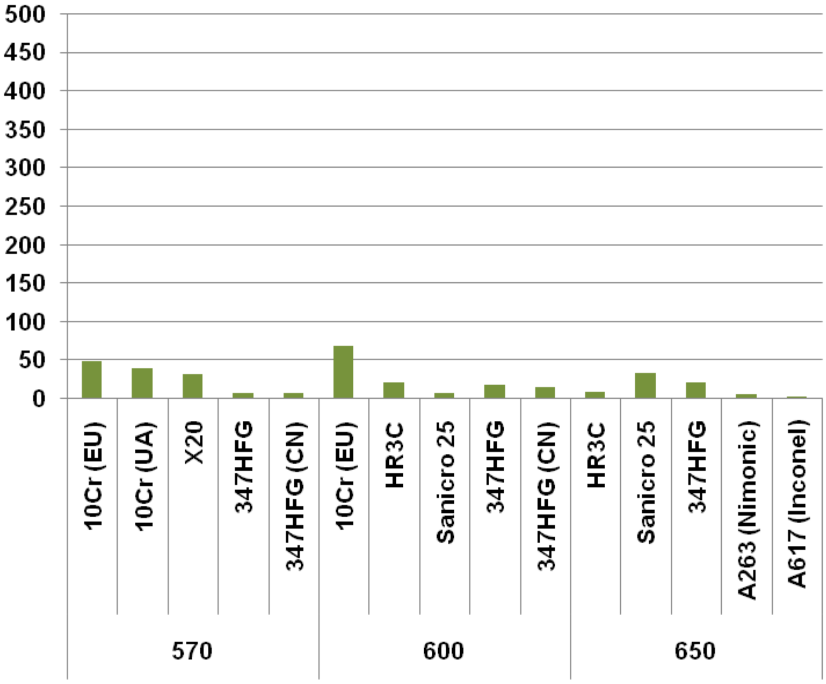


Figure 2. Oxide layers formed on Sanicro 25 after168 exposure test, a) with KCl at 650°C and b) with 85CaO-14CaSO$_4$-KCl at 600°C.



a)



b)

Figure 3. Mean oxide layer thickness after 168 h exposure test with a) KCl and b) 90KCl+5ZnCl$_2$+PbCl$_2$ deposit in ambient air.

2.1.3 Testing in simulated oxyfuel conditions

Exposure testing was performed at 600 and 650ºC under simulated oxyfuel combustion conditions up to 1000 h, and the results were compared to corresponding results from simulated air fired coal combustion conditions. The tested materials were X20CrMoV11-1, TP347HFG, HR3C, Sanicro 25, A263 and A617.

The results suggest that without added impurities like sulphur and chlorides, the simulated oxyfuel conditions do not result in more severe corrosion than the air firing environment. In more realistic oxyfuel case, flue gas recirculation would considerably increase the concentration of these impurities. Corrosion and microstructural changes like carburisation may also affect the damage mechanisms of boiler materials (e.g. creep, fatigue properties), and thus decrease the expected component life.

No carburisation of the metal substrate was observed after exposure to simulated oxyfuel gas atmospheres without deposit, although some carbon enrichment was detected near the oxide-surface interface after 1000 h exposure. With extended exposure time, the oxide scale properties may change to enable metal carburisation. Both water vapour and carbonate deposit, $CaCO_3$-$CaSO_4$, seem to affect the materials performance. The oxy-fuel combustion atmosphere without water vapour did not show any negative influence on the tested materials. The exposure with deposit in 60% CO_2-30% H_2O-4% O_2-Ar/N_2 gas at 650°C resulted in corrosion of all tested alloys and clear carburisation of steels X20CrMoV11-1 and TP347HFG. Figure 4 shows an example of metal carburisation with 85$CaCO_3$-15$CaSO_4$ at 650°C in gas containing 60%CO_2 and 30%H_2O. Table 4 summarises observed oxide thickness level after 1000 h tests.

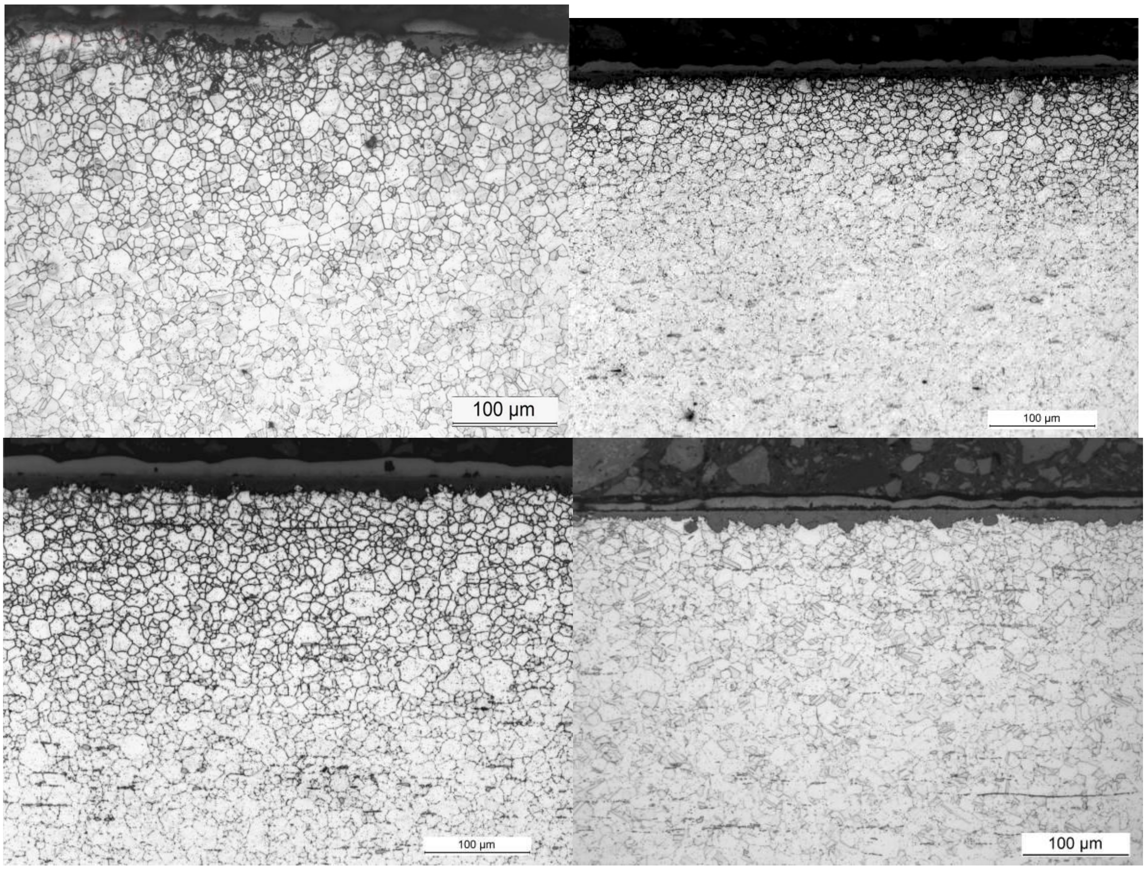


Figure 4. The micrographs of the etched TP347HFG samples after a) 168, b) 500 and c) 1000 h exposure tests with 85$CaCO_3$-15$CaSO_4$ at 650°C in gas containing 60%CO_2 and 30%H_2O,. As a reference (d) is shown the micrograph after 1000 h at 650°C exposed in simulated air combustion conditions.

Table 4. Summary of the observed oxide thickness on the tested materials after 1000 h of exposure, from direct and other (e.g. weight change) measurements

Material	Environment	Oxide 600°C	Oxide 650°C	Notes
X20CrMoV11-1	Air firing, gas only Oxyfuel, gas only with deposit	~ 35 µm ~ 40 µm -	~ 50 µm ~ 55 µm ~ 50 µm *	Non-protective Fe-rich oxide on top surface
TP347HFG	Air firing, gas only Oxyfuel, gas only with deposit	< 1 µm 0.1-4 µm -	~ 30 µm ~ 20 µm ~ 27 µm *	Cr-rich oxide on top surface at 600°C, varies at 650°C
HR3C	Air firing, gas only Oxyfuel, gas only with deposit	0.2-0.5 µm 0.1-0.2 µm -	~ 0.5-1 µm ~ 1 µm ~ 5 µm	Cr-rich oxide on top surface at 600°C; Cr- or Fe-rich at 650°C
Sanicro 25	Air firing, gas only Oxyfuel, gas only with deposit	0.1-0.2 µm ~ 0.2 µm -	0.4 - 1 µm 0.5 - 1 µm ~ 2 - 6 µm	Cr-rich oxide on top surface
A263	Air firing, gas only Oxyfuel, gas only with deposit	< 0.2 µm < 0.2 µm -	~ 0.5 µm ~ 0.5 µm ~ 2 µm	Cr-rich oxide on top surface
A617	Air firing, gas only Oxyfuel, gas only with deposit	< 0.2 µm < 0.2 µm -	~ 0.5 µm ~ 0.6 µm -	Cr-rich oxide on top surface

* with observed carburisation in the metal

2.1.4 Meta-analysis results

Meta-analysis is the statistical procedure for combining data from multiple studies. When the treatment effect or effect size is consistent from one study to the next, meta-analysis can be used to identify this common effect. When the effect varies from one study to the next, meta-analysis may be used to identify the reason for the variation [3]. Aalto University made the first estimation of trends and X-correlations from obtained exposure test results and atmospheres (thicknesses, mass changes, atmosphere, salts, time, temperature) using meta-analysis and reactive search algorithms (RSA). Figure 5 illustrates the basic idea of analyses.

Both mass changes and oxide thickness were analysed using meta-analysis and the most critical factors, time and temperature, were revealed. Table 5 summarises analysed factors. A consistent set of data is required to make definitive conclusions. To future analyses more experimental work is needed to fill the gaps in composition and parameters.

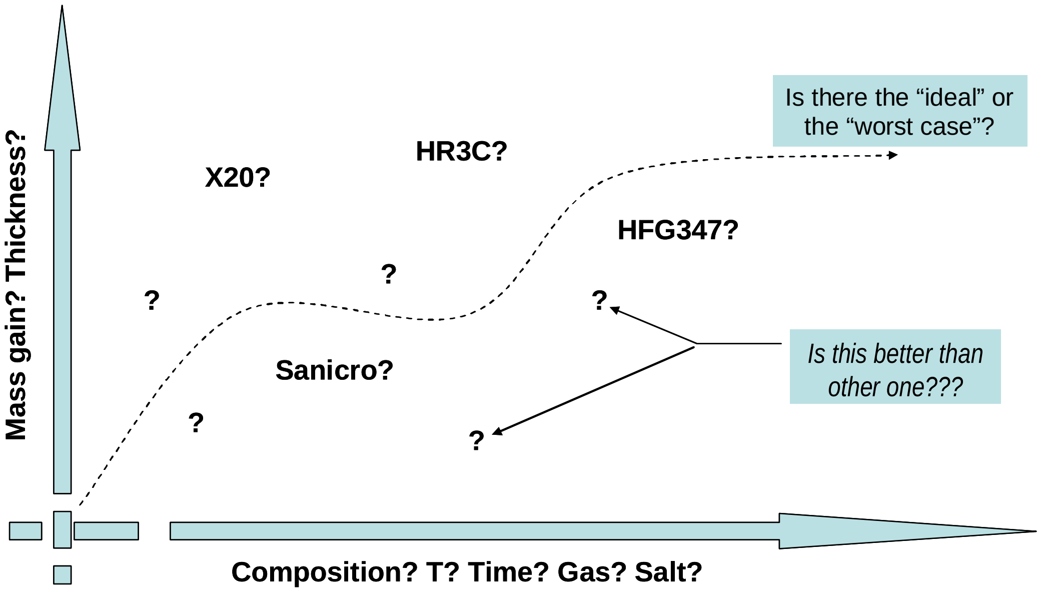


Figure 5. The estimation of trends and X-correlations of obtained test results and test conditions.

Table 5. Factors affecting weight change and oxide thickness based on RSA analyses.

Factors	**For weight changes**	**For oxide thickness**
Most important: better alloy composition	Cr/ECr, ENi/Ni (-), C, V (+)	ECr, ENi, Mo, Al, Co (-), C (+)
Most important: salt/gas composition	Salt: N/A Gas: no effect	Salt: KCl (++), Pb/$ZnCl_2$ (+?) Gas: O_2(+), H_2O, CO_2(-)
"Best" candidates (min gain, thickness & alloying)	347HFG, Sanicro25, HR3C	347HFG, HR3C

2.2 On-line corrosion monitoring system

The on-line corrosion probe was successfully implemented. The probe was based on Linear Polarisation Resistance (LPR) –technique, which is the most commonly used electrochemical method applied to online corrosion monitoring The first step was to evaluate the performance of the probe in laboratory under gas atmosphere with conductive deposits, which are prerequisite for the LPR-measurement to function. LPR monitoring involves measurement of the polarization resistance of a corroding electrode using small amplitude DC polarisation of the electrodes. Measured corrosion rate is proportional to the corrosion current. The obtained results are semi-quantitative, and the calibration is done with wall thickness and/or weight loss measurements of sample rings located in the tip of the probe. Figure 6 shows the probe at different stages of the laboratory experiment.

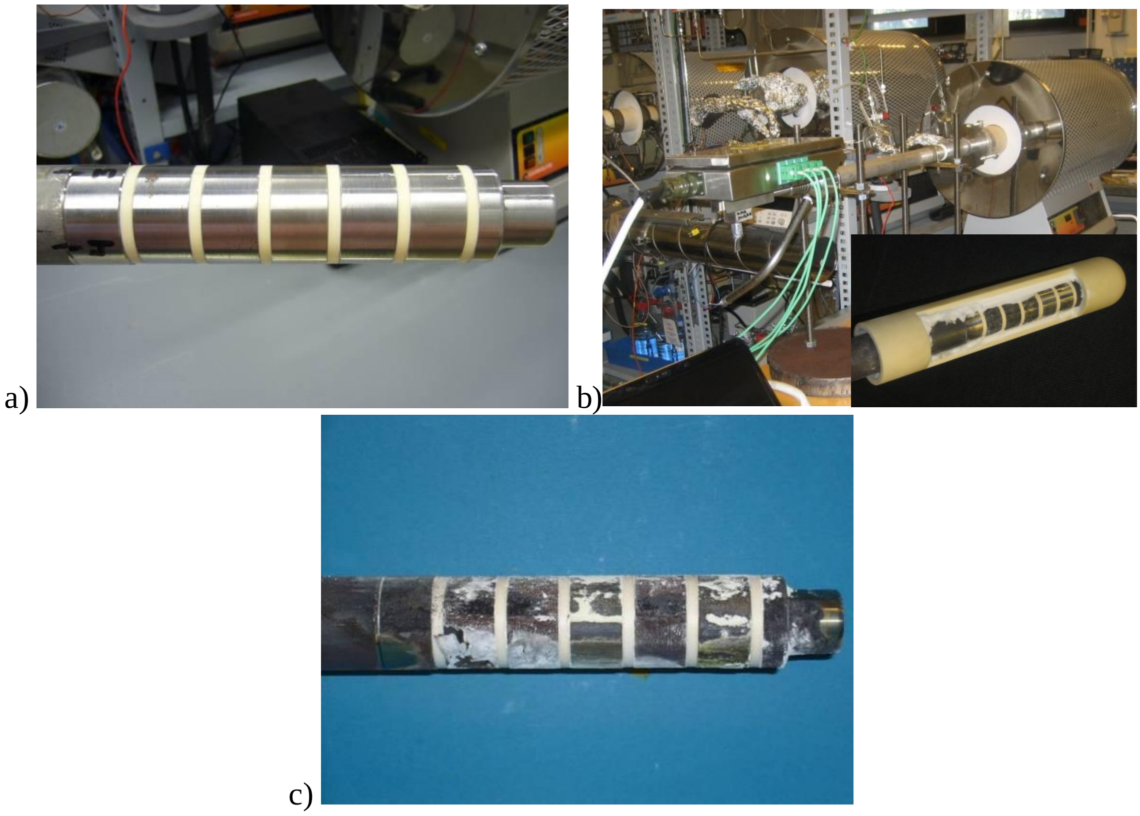
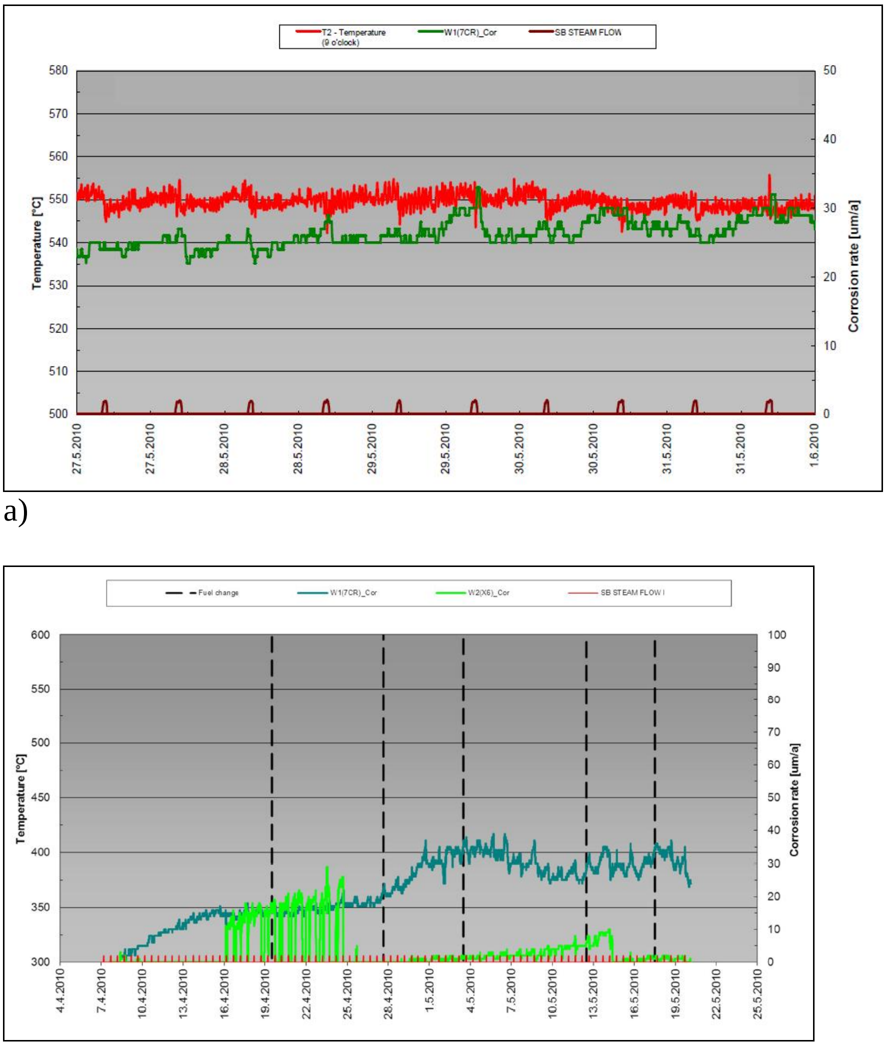


Figure 6. Implementation of the probe for laboratory scale experiment. Probe a) before test, b) connected to the furnace, c) after the test.

After the laboratory trials a measurement campaign in Tartu CHP-plant (thermal capacity of 77 MWth with steam values of 28.5 kg/115 bar/525°C) together with Fortum was carried out. The aim of the plant measurements was to evaluate commercial electrochemical probe, and to define what is the corrosivity of the different woodchips and milled peat fuel mixtures. The ferritic steel 7CrMoVTiB10-10 (W.Nr. 1.7378, ASME T24) and austenitic stainless steel X6CrNiNbN25-20 (W.Nr. 1.4952, ASME SA-213 310HCbN), which both are commonly used materials in superheaters, were selected for test materials for the probe test. The duration of campaign was 84 days (2016 hours during time period of 07.04.-30.6.2010) and it proved the usability of electrochemical corrosion probe in monitoring of the effects of operational conditions, e.g. fuel quality changes and soot blowing, on deposit formation and thus corrosion behaviour of superheater tubes

Examples from probe measurements are shown in Figure 7. Soot blowing effectively removes deposits and decrease corrosion rate (Fig. 7a). The burned good quality woodchips and peat were not corrosive and changes in their mixtures did not have any marked effect on the corrosion behavior of examined super heater materials (fig. 7b).



a)

b)

Figure 7. Examples from probe measurements: a) Effects of sootblowing and b) effects of fuel changes.

This action generated the additional co-operation between VTT, Fortum and Tartu power plant after the end of HICOR project.

2.3 Thermodynamic and CFD modelling

Modelling was applied to predict the limiting flue gas and material temperatures in boiler components, supported by extended databases for the applied thermodynamic modelling tools. This activity was divided into two main parts, thermodynamic equilibrium and computational fluid dynamic (CFD) modelling. The emphasis of the thermodynamic modelling in the project was on alkali, sulphur and calcium systems, for calcium the focus was on sulphate and carbonate equilibrium. The temperature range of interest was 500-700°C. FactSage© and HSC Chemistry® tools were used for phase diagrams and database development.

CFD-based thermodynamical modelling tool for the ash deposit was created during the project. CFD program FLUENT©, with mesh generating program Gambit©, was used for calculating the flue gases flow field and temperatures for whole calculation domain. Based on calculated temperatures thermodynamical equilibrium was calculated for the system and for this thermochemical programming library ChemApp© was used. To visualize the ChemApp's results FLUENT's user define functions (UDFs) ability were utilized. Flue gas and ash deposit temperatures, along with concentration of flue gas components were used in equilibrium calculations to estimate chemistry of the deposit. Thermodynamic calculations and CFD modelling indicated that ash deposits formed from air and oxyfuel combustion flue gases are very similar. Figure 8 shows as an example of modelling results. From all CFD modelling cases could be seen, that alkali chloride concentration increase toward tube's surface. Ash deposits formed from air and oxyfuel combustion flue gases are very similar Detailed descriptions of modelling work are shown in the separate reports [4].

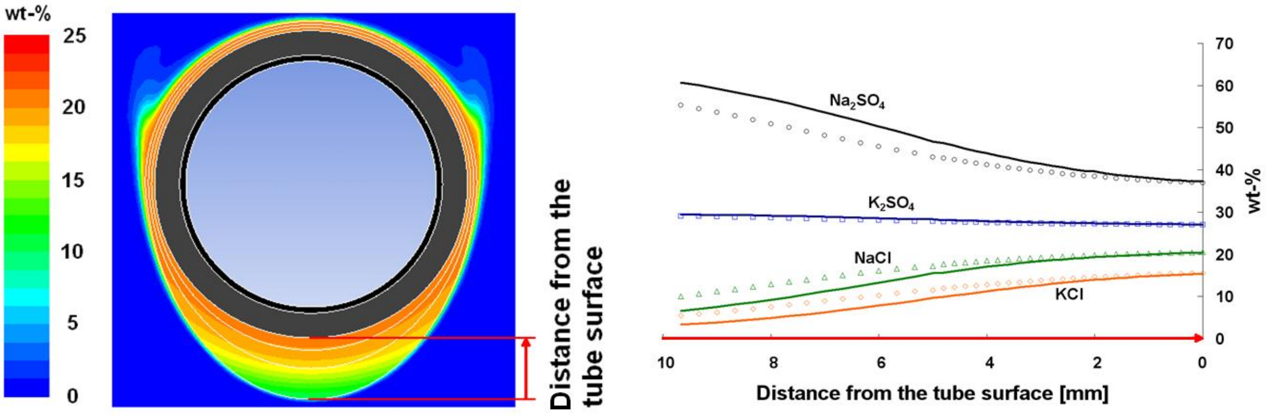


Figure 8. Deposit composition on the tube according to thermodynamical modelling.

3 Publications

Five international conference papers and one workshop presentation have been written based on the project results:

- Corrosion 2010, NACE (14.-18.3.2010): “Fireside corrosion of superheater materials in oxyfuel combustion”, P.Pohjanne, S. Yli-Olli, P. Auerkari, S. Tuurna, P Jauhiainen, E. Turunen, T. Varis, K. Ruusuvuori, M. Mäkipää
- BALTICA VIII (18.-20.5.2010): “Oxyfuel combustion: Oxidation performance of steels in simulated oxyfuel conditions”, S. Tuurna, P. Pohjanne, S. Yli-Olli, T. Kinnunen, P. Jauhiainen
- First International Conference on Materials for Energy (ENMAT2010) 4.-8.7.2010: “Corrosion behaviour of fireside materials under oxyfuel conditions”, S. Tuurna, P. Pohjanne, T. Kinnunen, P. Jauhiainen (poster, extended abstract)
- 9th Liege Conference on Materials for Advanced Power Engineering (27.-29.9.2010): “Oxidation performance of high temperature materials under oxyfuel conditions”, S. Tuurna, P. Pohjanne, S. Yli-Olli, T. Kinnunen
- IEAGHG Special Worksop on SO_2/SO_3/Hg/Corrosion Issue under Oxyfuel Combustion Conditions, 25.-26.1.2011 London: “Corrosion performance of boiler materials under CaCO3-CaSO4 deposit” (oral presentation), S. Tuurna, P. Pohjanne, E. Coda Zabetta
- EUROCORR 2011, 4.-8.9.2011, Stockholm” Performance of superheater materials in simulated oxy-fuel combustion conditions”, D. Bankiewicz, S. Tuurna, P. Yrjas, P. Pohjanne

4 Conclusions

Cost efficient performance of alloys for the heat transfer elements is crucial for economy, efficiency and long service life of advanced future boilers. This is particularly the case in combustion of corrosive renewable biomass or waste-based fuels in air or oxygen to reduce CO_2 emissions in the emerging sustainable energy systems. Materials will set the limits to the cost, performance and attainable efficiency of such systems. To support optimal materials selection, the HICOR project aimed at improving understanding of materials performance and corrosion mechanisms affecting boilers in biomass, co-firing and oxy-firing conditions.

An extensive test program under selected atmospheres has been carried out at the Åbo Akademi University and VTT. The results can be utilised in overhauls, retrofits and planning of future energy production with high efficiency and near zero emission. Exposure tests provide the background information for the material selection, especially for oxyfuel combustion, where the construction of demo plant (Ciuden) is starting in near future and material questions are, at least partly, still open.

The implementation of on-line corrosion probe was successful and using this probe, the measurement campaign in Tartu CHP-plant together with Fortum was carried out. The in-service experience with the on-line corrosion probe has provided added confidence to the technology amongst the utility owners and boiler suppliers. The co-operation with on-line corrosion monitoring has been continued between VTT, Fortum and Tartu power plant after the end of HICOR project.

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References

1. D. Bankiewicz & P. Yrjas, Hicor Final report. Åbo Akademi University, May 2011. 18 p.
2. S. Tuurna, P. Pohjanne, P. Auerkari, Performance of superheater materials in simulated oxyfuel combustion. VTT-R-02456-11, May 2011. 37 p.
3. http://www.metaanalysis.com/index.html (6.6.2011)
4. K. Penttilä, H. Sommarström, K. Vänskä, M. Hämäläinen, M. Gasik. Modelling Report for HICOR, June 2011

Appendix 1: Test matrix for exposure testing

Application	Gas	Temp [°C]	Salt [wt-%]	Material	Time [h]
Waste/Bio firing	air	500	90KCl-5ZnCl$_2$-PbCl$_2$	10Cr(EU) 10Cr(UA) X20 347HFG 347HFG(CN)	168
		570	90KCl-5ZnCl$_2$-PbCl$_2$	10Cr(EU) 10Cr(UA) X20 347HFG 347HFG(CN)	168
		600	90KCl-5ZnCl$_2$-PbCl$_2$	10Cr(EU) 10Cr(UA) X20 347HFG 347HFG(CN)	168
Co-firing	air	570	KCl	10Cr(EU) 10Cr(UA) X20 347HFG 347HFG(CN)	168
		600	KCl	10Cr(EU) HR3C Sanicro 25 347HFG 347HFG(CN)	168
		650		HR3C Sanicro 25 347HFG A263 A617	168
		570	85CaO-14CaSO$_4$-KCl	10Cr(EU) 10Cr(UA) X20 347HFG 347HFG(CN)	168
		600	85CaO-14CaSO$_4$-KCl	10Cr(EU) HR3C Sanicro 25 347HFG 347HFG(CN)	168
		650	85CaO-14CaSO$_4$-KCl	HR3C Sanicro 25 347HFG A263 A617	168
Oxy-fuel firing	CO$_2$ 60% - H$_2$O 30% - O$_2$ 4% - N$_2$	600	85CaCO$_3$-CaSO$_4$	10Cr(EU) HR3C Sanicro 25	168

				347HFG 347HFG(CN)	
		650	$85CaCO_3$-$CaSO_4$	HR3C Sanicro 25 347HFG A263 A617	168
		650		HR3C Sanicro 25 347HFG A263 A617	168
	CO_2 60% - H_2O 10% - O_2 4% - N_2	650	$85CaCO_3$-$CaSO_4$	HR3C Sanicro 25 347HFG A263 A617	168
		650		HR3C Sanicro 25 347HFG A263 A617	168
	CO_2 60% - O_2 4% - N_2	650	$85CaCO_3$-$CaSO_4$	HR3C Sanicro 25 347HFG A263 A617	168
		650		HR3C Sanicro 25 347HFG A263 A617	168
	CO_2 15% - O_2 4% - N_2	650	$85CaCO_3$-$CaSO_4$	HR3C Sanicro 25 347HFG A263 A617	168
		650		HR3C Sanicro 25 347HFG A263 A617	168
Air-firing (ref for oxy)	CO_2 15% - H_2O 8%- O_2 3%-N_2	600		X20 X20 347HFG(CN) 347HFG(CN) 347HFG 347HFG HR3C HR3C Sanicro 25 Sanicro 25	1000
Oxy-fuel firing	CO_2 60% - H_2O 30% - O_2 4% - Ar	600		X20 X20 347HFG(CN)	1000

			347HFG(CN) 347HFG 347HFG HR3C HR3C Sanicro 25 Sanicro 25	
Air-firing (ref for oxy)	CO_2 15% - H_2O 8%- O_2 3%-N_2	650	X20 X20 347HFG 347HFG HR3C HR3C A263 A263 A617 A617 Sanicro 25 Sanicro 25	168
		650	X20 X20 347HFG 347HFG HR3C HR3C A263 A263 A617 A617 Sanicro 25 Sanicro 25	500
		650	X20 X20 347HFG(CN) 347HFG(CN) 347HFG 347HFG HR3C HR3C A263 A263 A617 A617 Sanicro 25 Sanicro 25	1000
Oxy-fuel firing	CO_2 60% - H_2O 30% - O_2 4% - Ar	650	X20 X20 347HFG 347HFG HR3C HR3C A263 A263 A617 A617 Sanicro 25	168

			Sanicro 25	
	650		X20	500
			X20	
			347HFG	
			347HFG	
			HR3C	
			HR3C	
			A263	
			A263	
			A617	
			A617	
			Sanicro 25	
			Sanicro 25	
	650		X20	1000
			X20	
			347HFG(CN)	
			347HFG(CN)	
			347HFG	
			347HFG	
			HR3C	
			HR3C	
			A263	
			A263	
			A617	
			A617	
			Sanicro 25	
			Sanicro 25	
	650	85$CaCO_3$-$CaSO_4$	X20	500
			X20	
			347HFG(CN)	
			347HFG(CN)	
			347HFG	
			347HFG	
			HR3C	
			HR3C	
			A263	
			A263	
			A617	
			A617	
			Sanicro 25	
			Sanicro 25	
	650	85$CaCO_3$-$CaSO_4$	X20	1000
			347HFG	
			HR3C	
			A263	
			Sanicro 25	