Engineering

EMWG Conference : Materials Challenges in Biomass Combustion

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Energy from Biomass

- Direct Firing of solid fuel:
  - as collected/harvested and dried, or
  - semi-processed, e.g. as pellets or some other more handleable form
- As a liquid or gas from:
  - pyrolysis
  - gasification
  - anaerobic digestion/fermentation

Energy from Biomass

- Direct Firing of solid fuel:
  - as collected/harvested and dried, or
  - semi-processed, e.g. as pellets or some other more handleable form

Because it is closer to my area of expertise.

(but their will be similar market opportunities and research priorities for the other technologies)

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MatUK SRA - BIOMASS FOR ENERGY PRODUCTION

The MatUK Strategic Research Agenda (SRA) for Energy Materials, launched by the Energy Materials Working Group of MatUK in December 2007, identified the utilization of biomass for energy production as one of the key low carbon technology alternatives to fossil fuels.

In the SRA, biomass firing was identified as being of high priority, because of:

- the modest technological risk involved, and
- the ready availability of waste biomass in many countries.

MatUK SRA - UK Strengths

- The UK has a growing industry in small scale bioenergy systems.
- Europe is some way ahead, particularly where large quantities of biomass are available, e.g. Finland forestry waste or where government pressures / initiatives have encouraged early development (e.g. Denmark).
- The UK has established strengths in the manufacture of heat exchangers and gas turbines.
- Major UK energy companies are strongly represented in the global market for bioenergy systems.
- The UK has considerable strength in biomass energy technology research - through support from EPSRC and Government – there are strong links between manufacturers, end users, technology support consultancies, universities and Research and Technology Organisations.

CO_2 Reduction

E.ON has set ambitious targets to reduce its specific CO_2 emissions by 50% from 1990 levels by 2030

"E.ON believes the development of biomass-fired renewable energy plants, together with other forms of renewable developments, is vital to help achieve the Government's carbon dioxide (CO_2) reduction targets as well as providing security of energy supply."

Waste Wood

A report on behalf of Defra, entitled 'Carbon Balances and Energy Impacts of the Management of UK Wastes' (March 2007) confirmed that waste wood is one of a number of materials that offer significant opportunity for greenhouse gas and fossil energy savings over the period 2005-2031. This is in part based on the greenhouse gas impact (particularly of methane generation) of sending material to landfill.

The report estimated that:

- 7.5M tonnes of waste wood arises annually in the UK, of which:
  - 6M tonnes (80%) is landfilled
  - 1.2M tonnes (16%) is re-used and recycled,
  - 0.3M tonnes (4%) is used for energy recovery

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Steven's Croft

FBC 535°C/165Bar – Commissioned 2008

Every year, the largest biomass plant in Scotland will:

- **generate enough electricity to power the equivalent of 70,000 homes,**
- **burn over 480,000 tonnes of renewable fuel,**
- **displace up to 140,000 tonnes of greenhouse gases.**

The planned fuel is a blend of:

- **60% sawmill co-products and small round wood**
- **20% short rotation coppice (willow)**
- **20% recycled fibre (from wood product manufacture)**

Initially, the fuel will be a mixture derived from forestry co-products such as sawdust from local saw mills.

Within four years, around 90,000 tonnes a year will come from willow harvested by local farmers

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Opportunities for UK plc

Blackburn Meadows

In July 2008 E.ON received planning approval from Sheffield City Council to build a £60M biomass-fired power station at Blackburn Meadows in Sheffield.

25MW - Construction is expected to start early in 2009, with the first power being produced in 2011.

Blackburn Meadows will:

- provide enough power for around 40,000 homes
- burn a combination of recycled wood, forestry residue and specially grown crops such as willow and elephant grass.
- displace the emission of around 80,000 tonnes of carbon dioxide every year.

E.ON are also looking at opportunities to supply heat to neighbouring commercial and industrial establishments, further boosting the project's green status and efficiency.

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Portbury Dock

In August 2008, E.ON issued a Scoping Statement to North Somerset Council, the Department for Business, Enterprise and Regulatory Reform (BERR) and other interested parties outlining its plans to build a renewable energy plant at Portbury Dock, Bristol. E.ON hope to submit a full planning application to BERR in the middle of next year.

If consent is given, construction is expected to start in 2010, with the first power being produced in 2013 and full operation would be reached in 2014.

Portbury Dock - Outlines

Likely to be a fluidised bed boiler which will:

- produce around 150MW of electricity from biomass,
- provide the needs of around 250,000 homes,
- require a fuel supply of approximately 1.2M tonnes per year,
- displace the emission of around 0.5M tonnes of CO_2 annually.

The principal biomass fuel to be burnt will be woodchip, sourced from sustainable supplies.

It is also intended to be able to supply heat, as hot water or steam, or a combination of both, to neighbouring industrial establishments.

Port Talbot Renewable Energy Plant - Prenergy Power Ltd.

Prenergy is seeking to develop a renewable energy plant within a disused area of the port of Port Talbot, (South Wales) which will supply enough renewable energy to supply around 587,000 average homes, equivalent to roughly one in two Welsh homes. The plant is currently under construction and is claimed to be the largest biomass facility in the world. It will:

- become operational in early 2010,
- be a 350 MW, single, Circulating Fluidised Bed (CFB) boiler designed to achieve an efficiency of around 36%,
- operate for 8,000 hours each year (equating to around 90% of the year),
- burn around 2.5M to 3M tonnes of clean wood chip fuel per year.

Wood chip fuel will be transported from "sustainable forests located in the U.S., Canada, Eastern Europe, and South America." and be delivered to the Renewable Energy Plant by sea (or potentially in the future by rail)

Helius Energy

Two sizes of biomass-fired, renewable, electricity generation plants:

- large plants of 50-65MWe,
- smaller scale, GreenSwitch™ 5-8MWe plants,

both based around conventional direct combustion in high-pressure steam raising boilers, a steam turbine and an electricity generator.

Will also provide a source of steam and hot water, if required.

Initially, up to three 65MWe plants and up to three 5MWe plants in the UK.

Helius Energy Alpha Ltd - Stallingborough

The Company's flagship 65MWe biomass-fired power plant in Stallingborough, North East Lincolnshire received consent under Section 36 of the Electricity Act earlier this year.

- feedstocks will predominantly be sourced from timber residues and the co-products of cereals and oil.
- will be capable of burning a variety of fuels
- aiming for a plant availability of 90% or higher.

Trade sale to RWE Innogy on 26 September 2008. (The two companies will work together to implement this project.)

RWE Innogy and Helius Energy plan to develop additional biomass projects together in the UK.

Helius Energy – GreenSwitch™ Projects

Modular 5-8 MWe plants located where sustainable and renewable feedstocks are readily available, such as breweries and distilleries,

will:

- generate onsite electricity and export any surplus to the local electricity network,
- provide potential customers with an environmentally sustainable and economic method of utilising processing by-products.

Rothes Distillers (CoRD) has lodged a planning application with Moray Council for a 7.2MWe CHP scheme.

Subject to planning approval and commercial agreement, construction is expected to begin in the first half of 2009.

The MatUK SRA argues that:

- Whilst highly efficient energy conversion from waste has not been a priority in the past, it is becoming of much more importance where biomass is purchased as an energy crop.
- Even the most advanced straw burning plant in Sweden returns a conversion efficiency of only around 29%.
- This is because severe fouling and corrosion problems, experienced as a result of high contamination levels in many biomass fuels, limits the maximum steam conditions of such plant to 540°C and 92bar pressure, compared with current targets for coal-fired plant of 650°C/300bar.
- Even under such reduced steam conditions, boilers firing 100% forest-derived fuels reportably need to replace conventional superheater tubes every 4 years.

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Boiler Tube Failure in UK Straw Burning Plant

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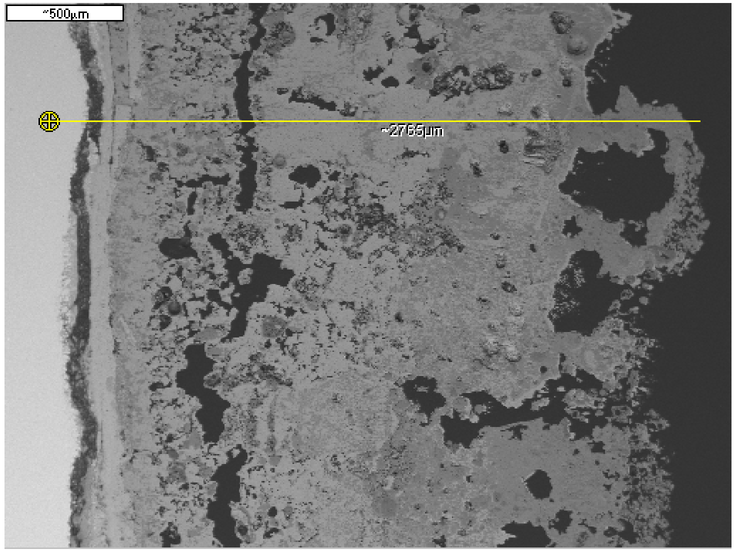

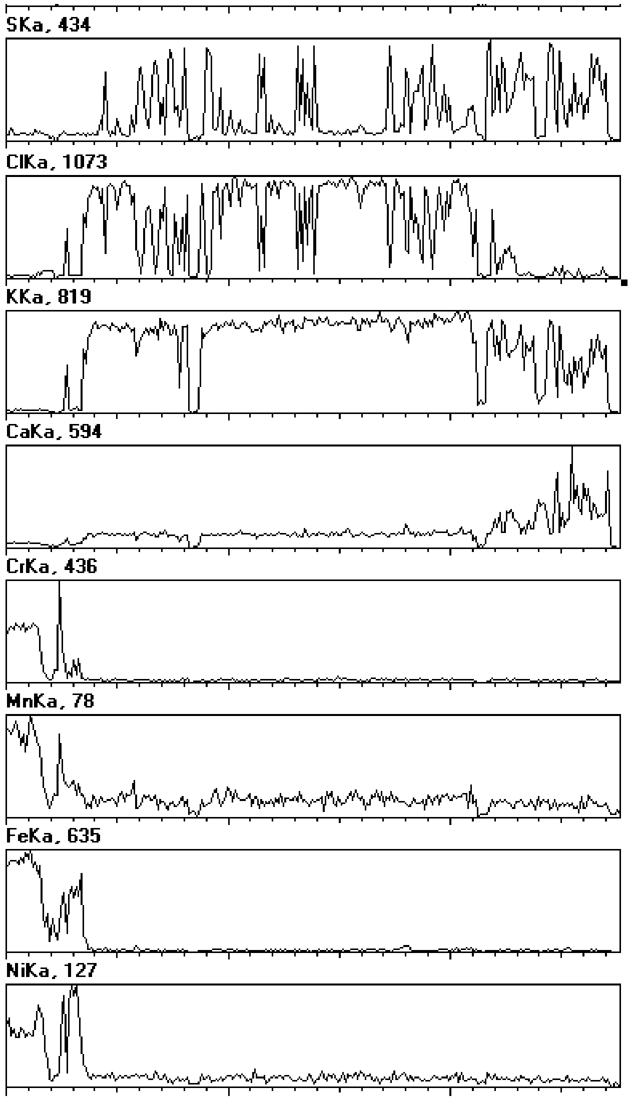

UK straw-fired power station,
began operating in September 2000,
primarily fires straw at a rate of 200kt/y,
38MW, 520°C and 90 bar.

After 40,000 hours, a final superheater tube leak occurred in the pendant outlet leg, close to the roof of the boiler.

Type 347H steel 30.0mm OD X 5.6mm wall

Recommendations for consideration:

- replace with like-for-like TP347H material and operate as before: a further set of replacements will likely be required after another 5 years operation,
- replace with like-for-like TP347H material, but reduce the final steam temperature by 10°C: increasing the anticipated tube life from approximately 43,000 hours to 130,000 hours,
- apply costly, high alloy, weld overlay coatings,
- limit the chlorine and alkali metal contents in the fuel burnt by blending with other low alkali metal and chloride containing fuel,
- use fuel additives containing calcium / phosphorus and sulphur which can be effective in combating superheater corrosion,
- Determine the operating temperature range for the final superheater tubing: redesigning the stage to reduce large temperature differences may be beneficial.

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IN625 Weld Overlay

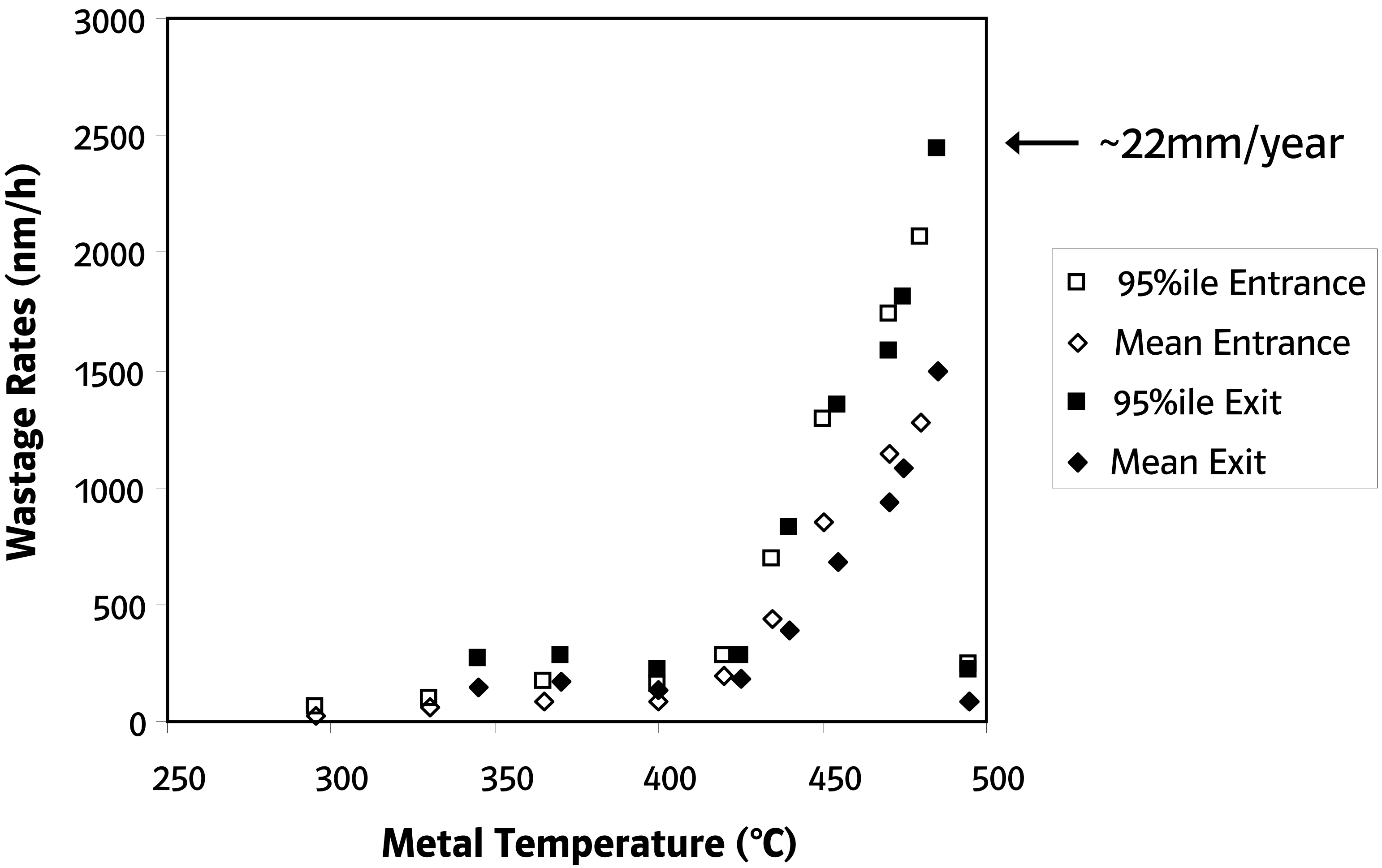
A Biomass-fired plant burning MBM has a history of severe fireside corrosion in its second and final stage superheater tubing, despite relatively modest final steam temperatures of approximately 475°C.

The corrosion damage was associated with the combustion of meat and bone meal + catering waste.

Superheater corrosion probes were installed in the boiler to examine the corrosion mechanisms, the influence of metal temperature and the likely performance of IN625 weld-overlay tube.

During the exposure the boiler operated with a typical fuel composition comprising MBM with variable chlorine contents due to the inclusion of differing proportions of catering waste.

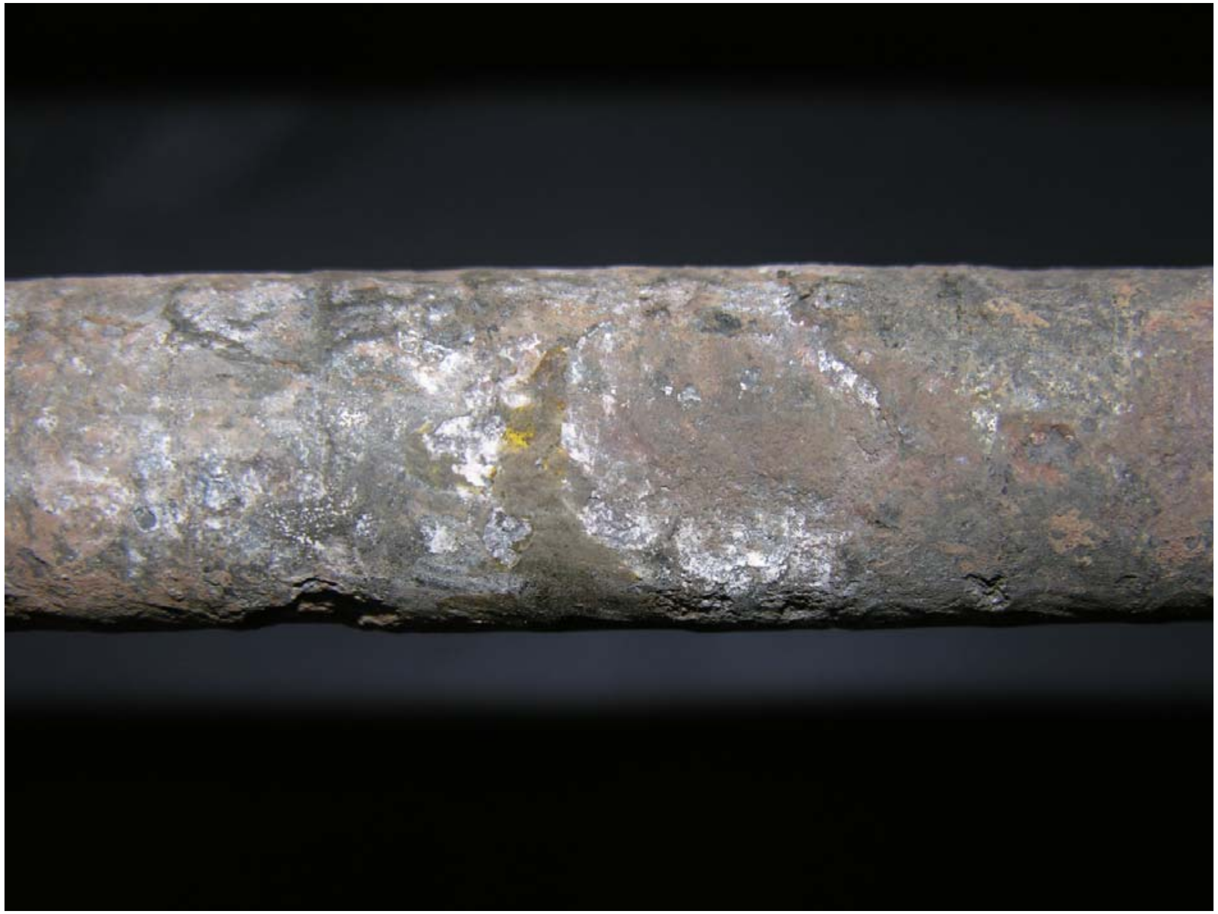
Corrosion Rates Under MBM-Firing



IN625 Weld Overlay

Weld Overlay

After 12 months, superheater corrosion of variable depths of attack - ranging from essentially no metal loss, to near penetration of the weld overlay.



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Conclusions & Recommendations

- corrosion continues as a result of the deposition of highly aggressive chloride from the combustion environment, leading to pitting and interdendritic attack,
- the tubes had operated at "normal" metal temperatures <450°C,
- IN625 wastage rates approaching 300nm.h^{-1} were substantially greater than those rates predicted by the corrosion probe exposures,
- the fuel diet was probably significantly more aggressive than during the corrosion probe exposures,
- the previously predicted tube lives in excess of 28,000 hours are unlikely to be realised.
- Possible Remedies
- consider a reduction in steam, and metal temperatures in this stage,
- fuel blending to reduce peak chlorine concentrations, or the use of additives.

MatUK Strategy for Biomass for Energy –Research Priorities

The MatUK SRA identifies the major materials challenges facing biomass in energy processes and, therefore, the R&D priorities as:

- improved alloys and coatings for evaporator and superheater tubing in heat exchangers and hot gas paths of gas turbines/gas engines,
- Improved life prediction modelling for heat exchangers to optimize maintenance and repair procedures,
- monitoring of corrosion/contaminants to provide early warning of problems, and
- improved repair/refurbishment procedures for heat exchangers and gas turbine parts.

Fireside Corrosion Under Biomass - Qualitative

- Higher chlorine – lower sulphur levels favour the formation of chlorides over sulphates.
- Higher potassium levels, particularly the readily available potassium in biomass, combines with chlorine to form low melting point compounds during combustion.
- These lower melting point compounds react with otherwise protective oxide scales to form low melting point eutectics which cause rapid corrosion.
- Lower ash contents provide less dilution of any deposits formed on component surfaces.

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Fuel Analyses

	STRAW	Green Woodchip	S R C	RECYCLED FIBRE	MDF	UK COAL	IMP'D COAL
Moisture, % Total	9.2	44.0	40.7	21.3	8.6	7.0	7.0
Ash, %ar	5.5	0.2	0.9	0.7	0.3	9.0	9.0
Volatile Matter, %ar	67.9	46.8	48.4	66.4	74.3	34.0	34.8
CV, kJ/kg ar Gross	17430	11365	11780	15932	18268	27840	27850
Net	15760	9609	10075	14439	16935	26700	26700
Sulphur, %ar	0.13	0.01	0.09	0.03	0.01	1.42	0.62
Chlorine, %ar	0.46	0.01	0.01	0.06	0.01	0.20	0.02
Volatile Matter, %DAF	79.6	27.56	28.47	38.51	43.22	40.5	41.4
CV, kJ/kg DAF Gross	20434	20367	20171	20426	20053	33143	33155
Ash SiO_2	48.96	19.11	5.10	23.13	7.68	49.18	60.69
Al_2O_3	0.45	4.24	0.91	4.47	2.59	26.78	22.01
Fe_2O_3	0.57	2.32	0.60	4.39	1.26	9.11	7.43
CaO	10.66	40.55	66.95	46.89	47.43	7.79	2.27
MgO	2.46	7.58	5.49	4.27	7.96	2.11	2.90
K_2O	32.18	15.82	12.28	5.39	20.25	2.07	2.32
Na_2O	0.81	1.01	0.54	2.87	4.18	0.97	1.06
P_2O_5	3.14	4.82	7.66	0.99	5.26	0.35	0.21

UK Work on Fireside Corrosion under Coal-Firing

In the 1970's and 80's, the CEGB was faced with similar issues on coal-fired plant and embarked upon extensive studies to understand and quantify the nature of furnace wall and superheater/reheater fireside corrosion to:

- Identify and quantify the important parameters, e.g.
  - Combustion
  - Fuel
  - Temperature
  - Material
- Identify and put in place preventative measures

Fireside Corrosion under Coal

Chemical Species Implicated in Furnace Wall and/or SHTR/RHTR Fireside Corrosion:

- Chlorine
- Sulphur
- Sodium
- Potassium

Biomass can contain Higher Percentages of Chlorine and free Potassium than Coal.

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General Characteristics of FWC under Coal

Excessive FW wastage on UK Coal-Fired plant characterised by:

- **localised nature,**
- **confinement to the burner belt zone,**
- **zones of persistent attack coincide with detection of low pO_2 & high CO (>0.5%) - H_2S only found where pCO>3%,**
- **significant quantities of uncombusted material in recovered solids.**

Furnace Wall Corrosion

Empirical equation from plant data:

$$R = 1380.Cl - 290$$

R	= Corrosion Rate ($nm.h^{-1}$)
Cl	= Coal Chlorine (wt%)

No terms for S, K, Na, O_2, CO, Temperature, Heat Flux

Superheater/Reheater Corrosion

Empirical equation from plant data:

$$R = K.L.B.(Cl - a).(T_m - b)^c.(T_g - d)^e$$

R	= Corrosion Rate ($nm.h^{-1}$)
K,a,b,c,d,e	= Empirically Derived Constants
Cl	= Coal Chlorine (wt%)
T_m	= Surface Metal Temperature
T_g	= Gas Temperature
L	= Positional Factor
B	= Material Factor

No terms for S, K, Na, O_2, CO

Difficulties in Quantifying Fireside Corrosion

Despite extensive laboratory and boiler studies, the quantitative understanding of the thermochemical processes involved was limited by difficulties in:

- replicating complex boiler environments in the laboratory,
- controlling individual parameters during plant studies,
- the absence of proven on-line monitoring techniques which can relate real time corrosion rates to transient combustion conditions

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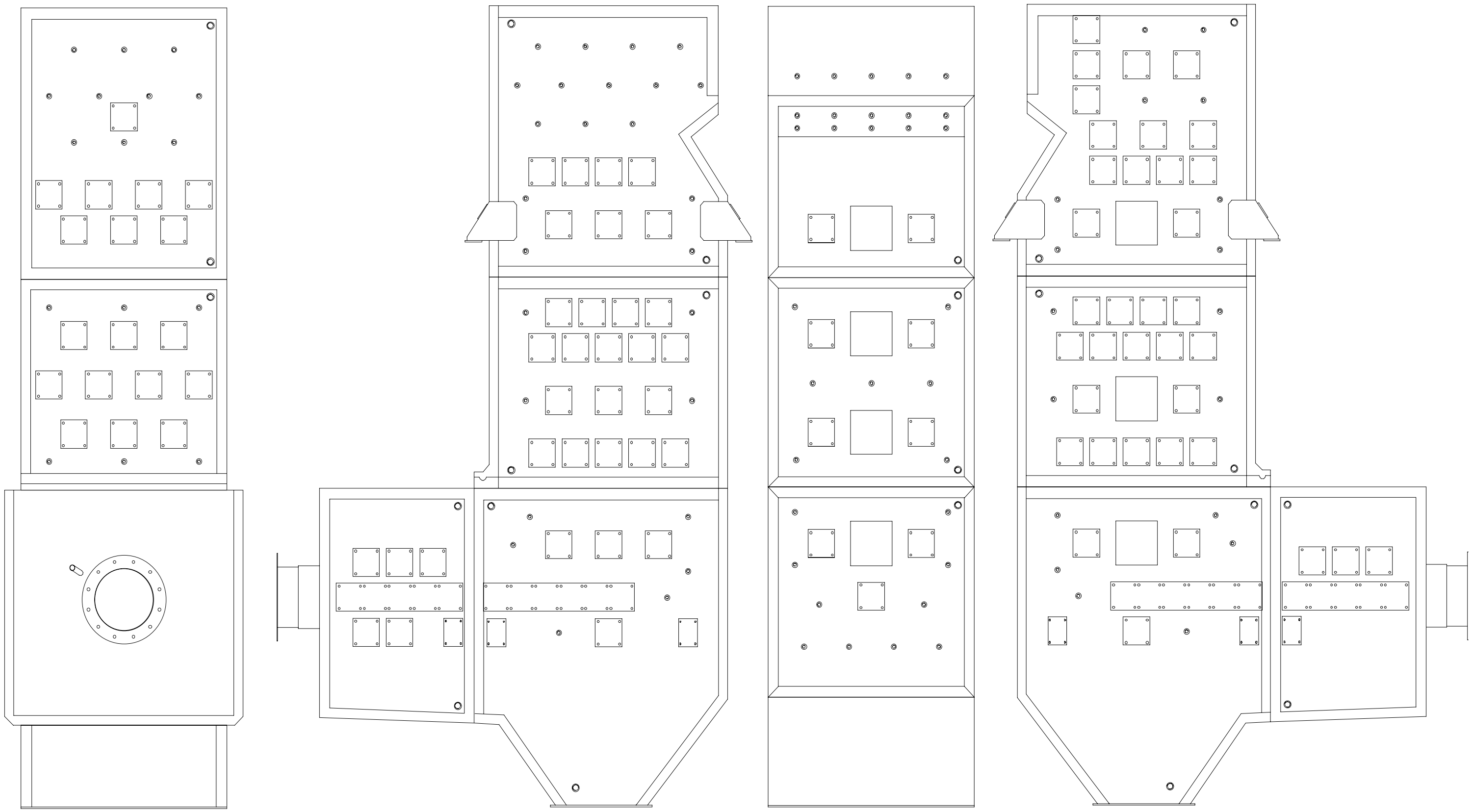
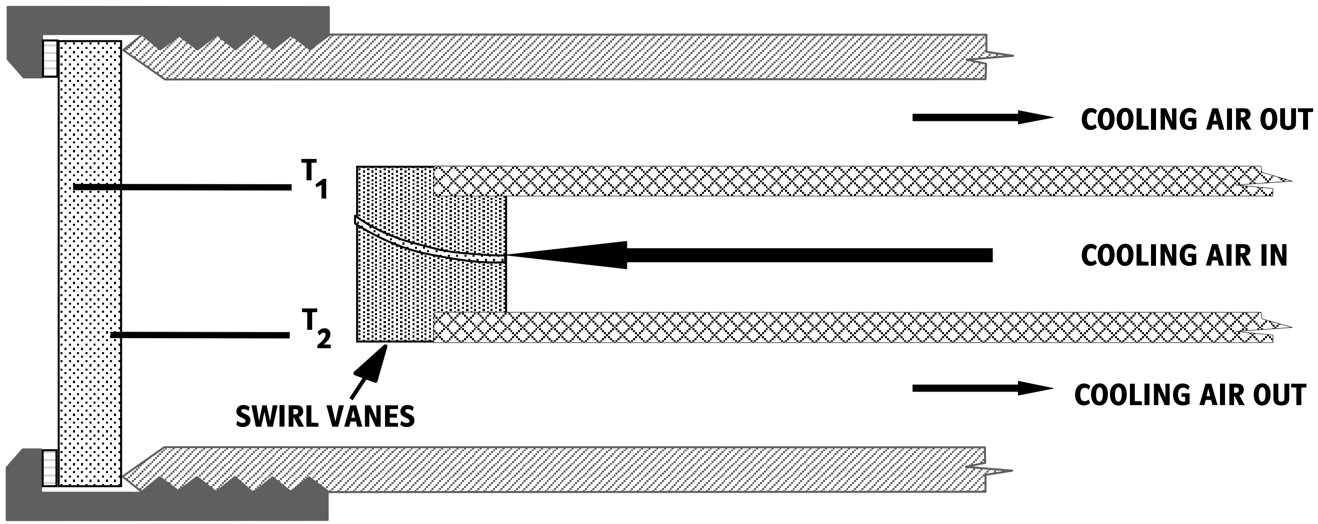
Combustion Test Facility



FRONT (BURNER) WALL RHS WALL REAR WALL LHS WALL

Air-Cooled Precision Metrology Corrosion Probe



T_1 THERMOCOUPLE 1

T_2 THERMOCOUPLE 2

PROBE BODY (Carbon Steel)

END CAP

COMPRESSED AIR TUBE

PLAIN CARBON STEEL CORROSION COUPON

NICKEL PLATE

Overall Equation for FWC under Coal-Firing

$$MetalLoss(\mu m) = 6\times10^5\left[(t_o \times Kp_o)^{0.5} + (t_r \times Kp_r)^{0.5}\right] + \left[\frac{t_r \times ACR}{10^3}\right]$$

$$Kp_o = A\times\varepsilon^{-\left(\frac{Q_o}{RT}\right)} \qquad Kp_r = B\times(\%CO)^n \times\varepsilon^{-\left(\frac{Q_r}{RT}\right)}$$

$$ACR = \left[(C\times\%Cl)\times(HF)^m \times\varepsilon^{-\left(\frac{Q_{Cl}}{RT}\right)}\right] - d$$

T_o	= time under oxidising conditions	Tr	= time under reducing conditions
%Cl	= percentage of Cl in coal burnt	%CO	= CO content of flue gas
HF	= Heat Flux ($kW.m^{-2}$)	Q	= Activation Energy
R	= Gas Constant	T	= Temperature (K)

Still No S, K, Na terms

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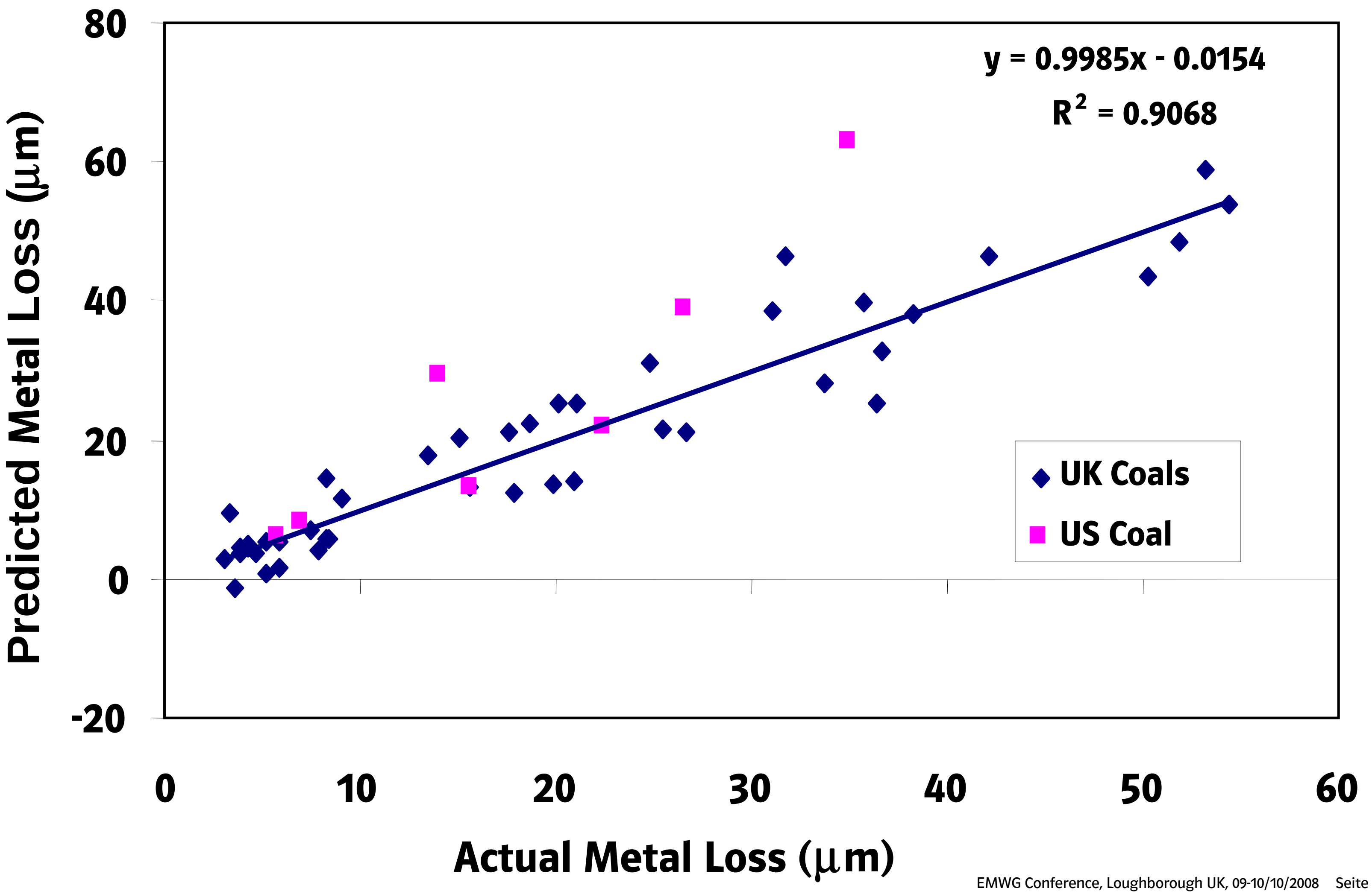
Overall Equation for FWC under Coal-Firing



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Furnace Wall Corrosion Trials - Straw and Waste Wood

Firing with straw (with and without Additive) and Hardwood (without Additive) showed:

- oxidising conditions were the most aggressive, probably as a result of the formation of alkali chlorides and sulphates,
- fuels with high chlorine and alkali metal contents were found to be the most aggressive.
- blending corrosive and less corrosive fuels, combined with using an Additive, was effective in modifying slag formation and significantly reduced corrosion, although their individual effects could not be discerned from the completed test programme,
- where Additive was added to the fuel, increased fouling with un-burnt fuel was observed in the furnace section.

Superheater Corrosion Trials - Straw and Waste Wood

Firing with straw (with and without Additive) and Hardwood (without Additive) resulted in:

- severe localised and internal attack for high alloy austenitic materials, without the formation of a protective corrosion scale,
- chlorine induced subsurface chromium depletion in the high alloy austenitic samples,
- no improvement in corrosion performance was gained by using even higher alloyed austenitic stainless steels, such as AC66, over that of Eshette1250 and TP347HFG.
- the nickel based IN625 weld overlay offered the best corrosion resistance when exposed to the most severe corrosive environment.

Coating of External Surfaces

Coatings may be required to protect against the fireside environment, because:

- increasing temperatures and increasingly aggressive fuels increase the risk of serious damage from fireside corrosion,
- increasing alloying element content to improve corrosion performance can be detrimental to mechanical properties and/or weldability,
- alloys resistant to fireside corrosion are not always compatible with waterside or steamside environments.

Current R&D – Corrosion Modelling

Modelling Fireside Corrosion of Heat Exchanger Materials in Advanced Energy Systems - Jan 2007 to Jan 2010

£1.8m Project, with 50% Support from the Technology Strategy Board (TSB) of UK Government, under the Materials Modelling Call - Autumn 2005

To develop validated boiler tube corrosion rate models in the complex and aggressive combustion-derived environments associated with advanced coal-fired power plants for low carbon energy generation.

Partners:

Cranfield University
Doosan Babcock
E.ON
National Physical Laboratory
RWE npower

Current R&D - Coatings

Advanced Surface Protection to Enable Carbon abatement Technologies (ASPECT) - Sept 2008 to Sept 2011

£2.5M Project, with 50% support from the Technology Strategy Board (TSB) of UK Government, under the Materials for Energy Call – Autumn 2007

To develop coatings and application techniques for the protection of both the fireside and steamside surfaces for oxy-fuel combustion of coal and the co-firing of biomass in ultra-supercritical boilers.

Partners:

Cranfield University
E.ON
National Physical Laboratory
Sulzer Metco
Doosan Babcock Engineering Limited
Monitor Coatings
RWE npower