IEAGHG Oxyfuel Workshop: Impact of Oxyfuel Operation on Emissions and Ash Properties Based on E.ON's 1MW CTF

Rembrandt Hotel, London

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E.ON New Build & Technology

Contents

Acknowledgements

Project partners – UK Technology Strategy Board (TSB), Doosan Power Systems, Uni. Of Leeds and IEAGHG (thanks Stanley)

E.ON team – Robin Irons, Colin Davis, Dave Miller, Keith Gregson, Will Quick, Susan Weatherstone, Chris Onions…….

The oxyfuel community

Introduction to E.ON New Build & Technology

- Mission is to add value to the E.ON group via operational support, by supporting the new build program and in the future by research, development and innovation.
- ~1100 employees +
- 2 main office locations
- History (Owners – CEGB, Powergen and E.ON. Recent names – PT, EEN, ENT)

Technology Centre,
Nottingham,

United Kingdom

←

Humboldt-Forum
Gelsenkirchen, Germany

→

What does ENT do?

- Outage & Maintenance
- Materials & Engineering
- Pressure Parts
- Power Plant Chemistry
- Turbines
- Power Engineering Services
- Electrical Engineering
- Networks
- Fuel Sciences
- Emission Monitoring
- Pollution Abatement
- Plant Performance
- Flexible Operation
- Life Extension
- Biomass Fuels
- Gas Turbine Optimisation
- Steam Turbine Performance
- Business Modelling
- Stimulator Training Systems
- New Build Optimisation
- Nuclear Development
- Risk Management
- Plant Status Review
- Maintenance Strategy
- Due Diligence
- Owner's Engineer
- Quality Assurance
- Sustainable Energy
- Technology Development
- Project Management
- New Technologies
- Emission Modelling
- CCS

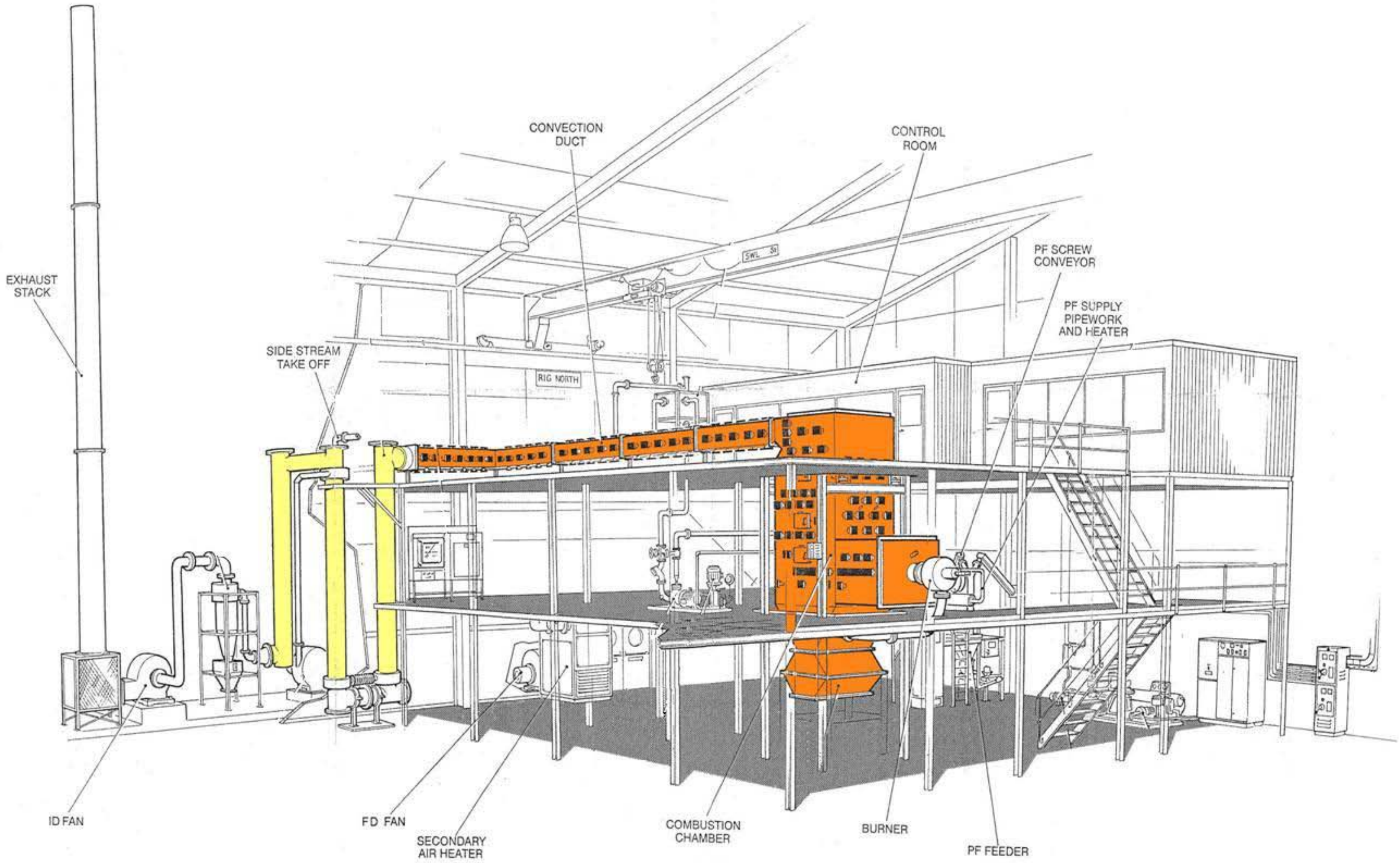
E.ON’s 1MWth Combustion Test Facility (CTF)

- Design and Planning in 1980’s with commissioning in early 1990’s
- Located at Ratcliffe on soar, Nottingham, England
- Time-temperature scaled to simulate full scale plant from burner to stack
- Fuel flexible - Coal, biomass, oil, orimulsion, gas, others
- Full combustion staging; overfire air, reburn
- Highly instrumented and controllable
- Other capabilities added such as TOMERED
- Graduated update to oxyfuel capability with FGR from 2006
- 100’s data points auto logged (X, T, P, F…)

- Used to study fuel quality effects on combustion, emissions, slagging, fouling and corrosion. Research in LN combustion, atomisers, combustion additives, trace emissions, instrumentation, oxyfuel combustion, biomass co-firing….

E.ON UK’s 1 MWth Combustion Test Facility (CTF)

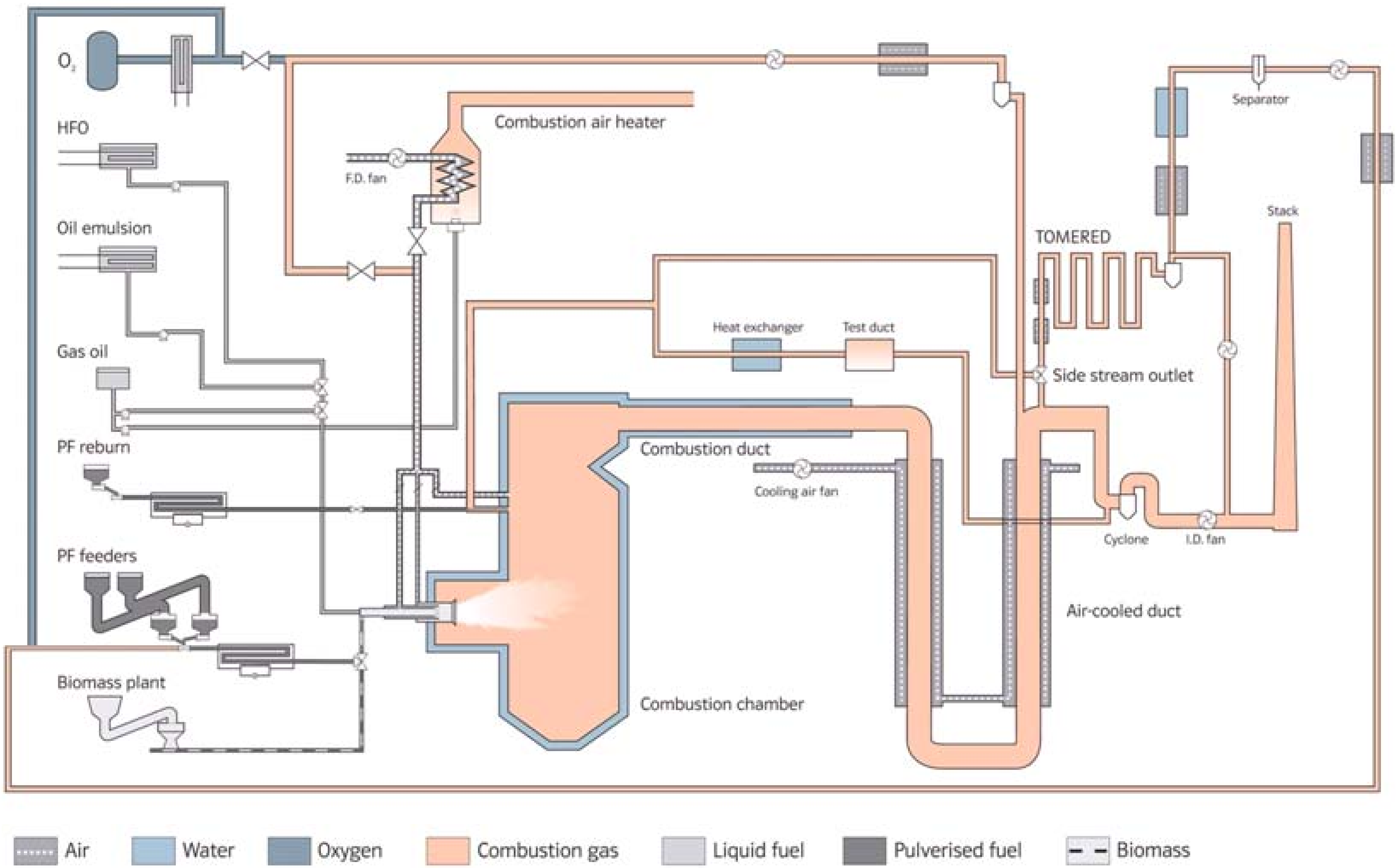
Original Schematic Depicting Physical Layout



CTF operating parameters

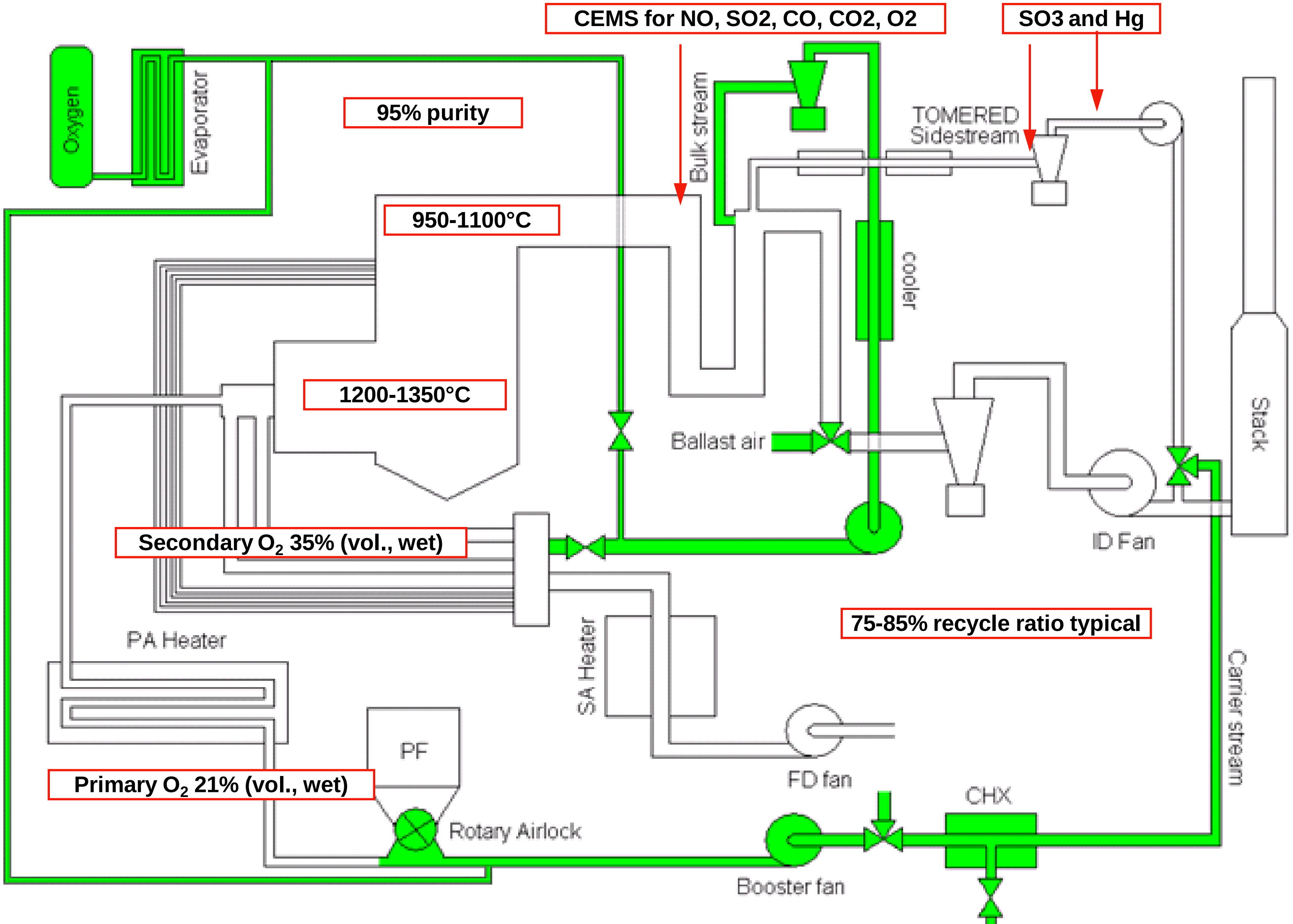
Thermal input	**1 MW_{th} (0.8 – 1.2MW_{th})**
Furnace	**Horizontally fired, refractory lined, water cooled, balanced draft**
Dimensions	**1m x 1m x 3m**
Burner	**Scaled MBEL Mk III Low-NO_X**
Windbox temp.	**300 to 330°C**
Primary air temp.	**80°C (70 to 90°C)**
Tertiary : secondary	**3.5:1 (1:1 to 7:1)**
Overfire air	**15% (0 to 25%)**
Flue gas cleanup	**High efficiency cyclone**

CTF Layout


O2
HFO
Oil emulsion
Gas oil
PF reburn
PF feeders
Biomass plant
F.D. fan
Combustion air heater
Heat exchanger
Test duct
Combustion duct
Cooling air fan
Combustion chamber
TOMERED
Separator
Stack
Side stream outlet
Cyclone
I.D. fan
Air-cooled duct
Air
Water
Oxygen
Combustion gas
Liquid fuel
Pulverised fuel
Biomass

CTF in reality

CTF Layout (highlighting oxyfuel)



Project

- Project included a 2 day corrosion test, 1 day Hg/SO3 test and a 1 day NOx/LOI parametric test repeated on 2 coals
- Following results are from the Hg/SO3 test firing Williamson coal

As received

	Sample 1	Sample 2
Moisture (%)	5.6	5.7
Ash (%)	8.4	8.7
S (%)	1.66	1.65
Cl (%)	0.34	0.32
CV (kj/kg)	29010	28870

		Sample 1	Sample 2
Al2O3	%w/w	20.5	20.1
BaO	%w/w	0.05	0.05
CaO	%w/w	5.18	4.86
Fe2O3	%w/w	15.9	15.1
K2O	%w/w	2.41	2.41
MgO	%w/w	1.14	1.12
Mn3O4	%w/w	0.06	0.06
Na2O	%w/w	0.68	0.64
P2O5	%w/w	0.1	0.1
SiO2	%w/w	50	49.1
SO3*	%w/w	4.78	4.32
TiO2	%w/w	1.05	1.03
Hg	mg/kg	0.07	0.08
Br	mg/kg	5.83	9.45

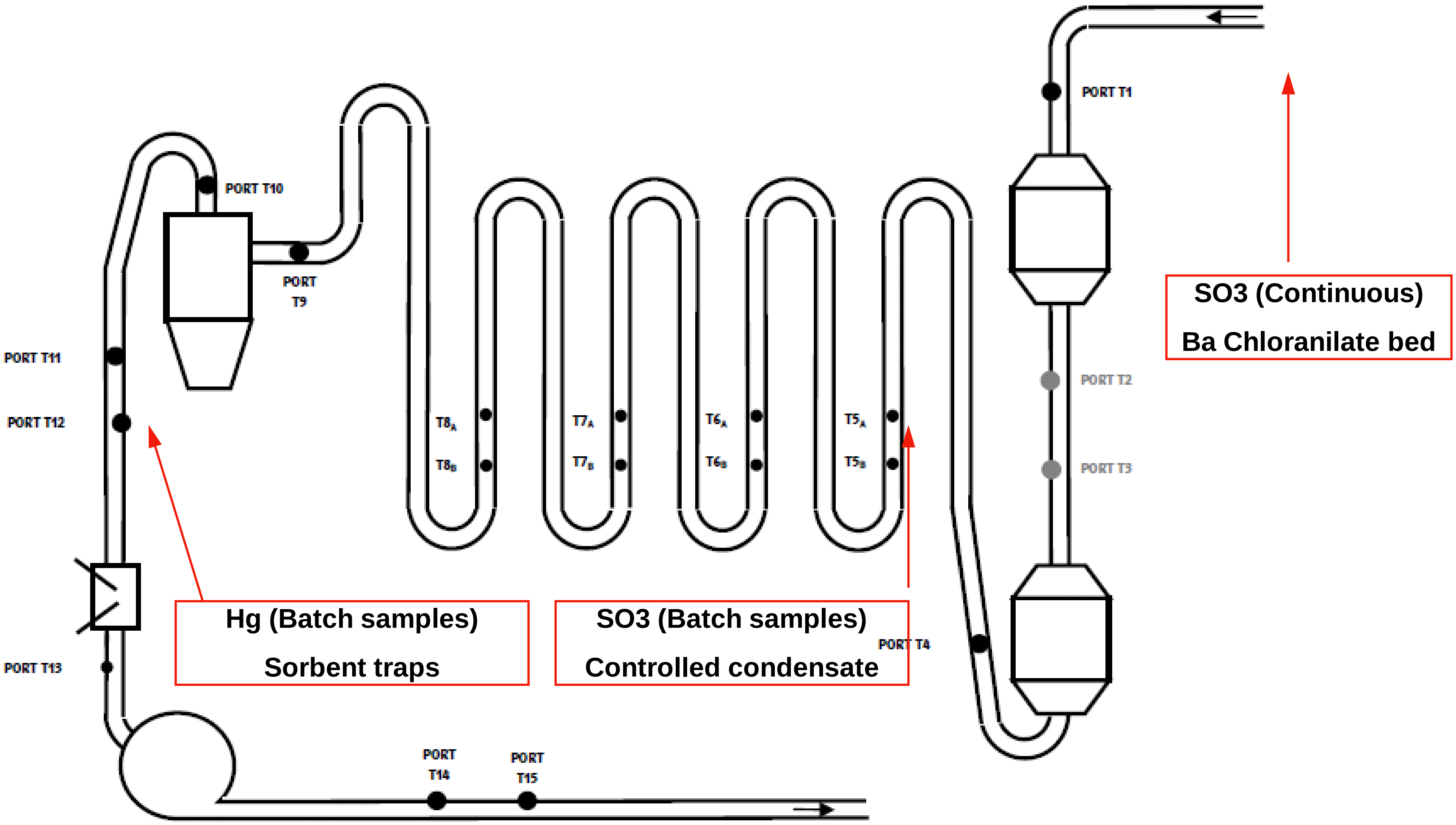
Testing plan

- Test run measured gaseous mercury and SO3 along with flyash and LOI samples taken.

- 3 test conditions
  - Air baseline with back end oxygen of 2% vol. dry
  - Oxyfuel condition 1 with back end oxygen of 2% vol. dry
  - Oxyfuel condition 2 with back end oxygen of 4% vol. dry

- Operating conditions
  - 15% OFA
  - 3.5-1 tertiary-secondary ratio
  - Primary enrichment of 21% oxygen and 35% for secondary

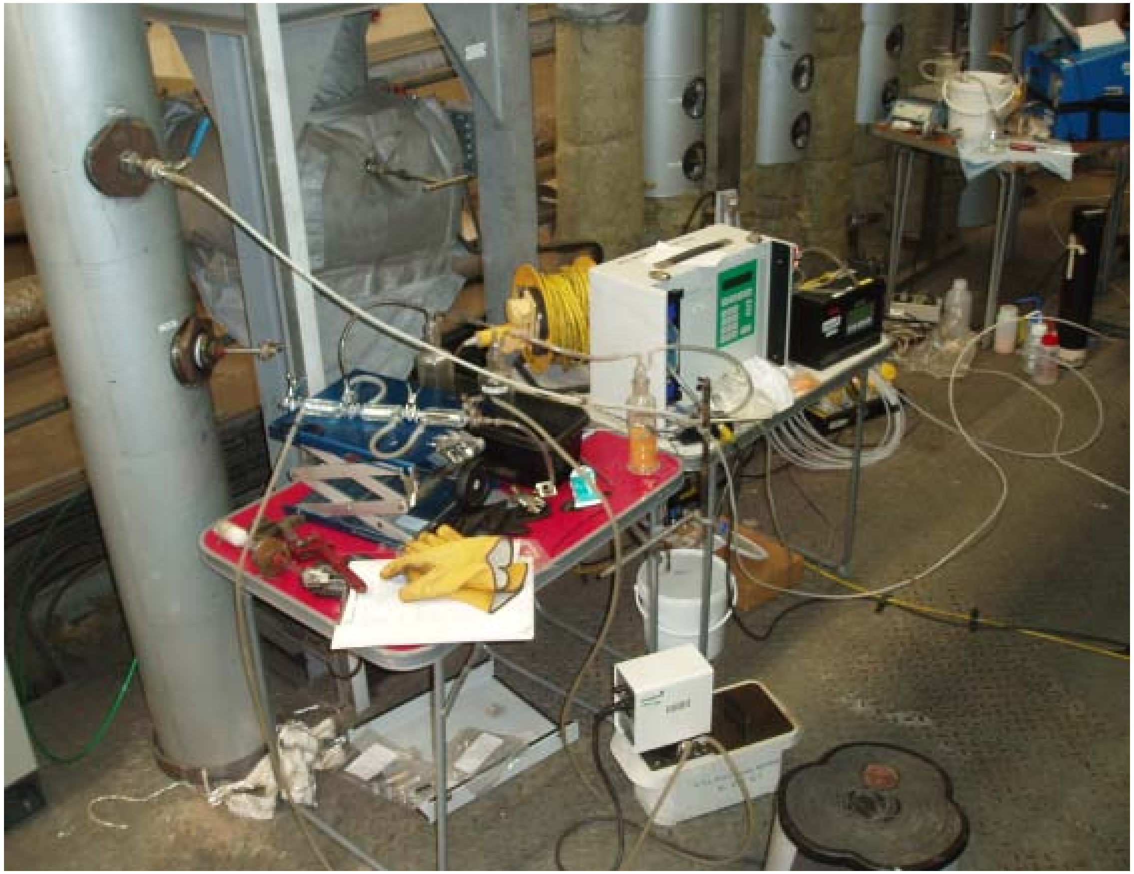
TOMERED Loop for SO3 and Hg



Hg measurements

- Used E.ON developed method, practised in the field on fuel/air combustion power plants for ~10+ yrs on E.ON & Non E.ON sites
- First trial on oxyfuel combustion plant
- Sorbent traps to capture oxidised and elemental mercury
- Activated carbon bed to capture elemental and resin for oxidised
- Each bed is hand held in size and made from glass
- Beds located in a water bath to prevent moisture condensation
- For each condition traps are exposed to flue gas for 1hr and then repeat sample conducted

Hg measurements



Hg numbers

		Oxidised	Elemental	Wool	Glass	Total
		(ug/Nm3, dry, 6% O2)				
Air	Test 1	*0.054*	*0.054*	0.009	0.043	0.116
Air	Repeat	0.094	*0.047*	0.023	0.012	0.165
Oxy 1	Test 1	0.145	*0.048*	0.047	0.008	0.240
Oxy 1	Repeat	0.388	0.086	0.006	0.005	0.481
Oxy 2	Test 1	18.245	0.068	0.119	0.008	18.433
Oxy 2	Repeat	18.815	*0.058*	0.190	0.071	19.063

NB: Oxidised and Elemental values around 0.05 ~ detection limit

- Very little to no elemental mercury detected
- Very little to no gaseous phase mercury detected in air firing or during first oxyfuel test
- Large spike in oxidised mercury at the second oxyfuel condition (back end oxygen of 4%)

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- Oxy O2 •
  LOI • Hg_p • SO3p •
- • Hg_p matches with • Hg_g
- Logical trends

		Target back end oxygen (% vol. dry)	Actual back end oxygen (% vol. dry)	Cyclone ash Hg (mg/kg)	Cyclone ash LOI (%)	Cyclone ash SO3 (%)	Measurement point temperature (oC)
Air	Test 1	2	2.12	0.07	5.60	1.19	124
Air	Repeat	2	2.05				124
Oxy 1	Test 1	2	2.29	0.27	3.55	1.55	126
Oxy 1	Repeat	2	1.81				126
Oxy 2	Test 1	4	3.71	0.05	1.59	1.81	127
Oxy 2	Repeat	4	4.14				127

- High Oxy 1 Hg_p ?
  - must treat trends with caution

NB: Ash taken from main cyclone for air firing and bulk stream cyclone for oxyfuel

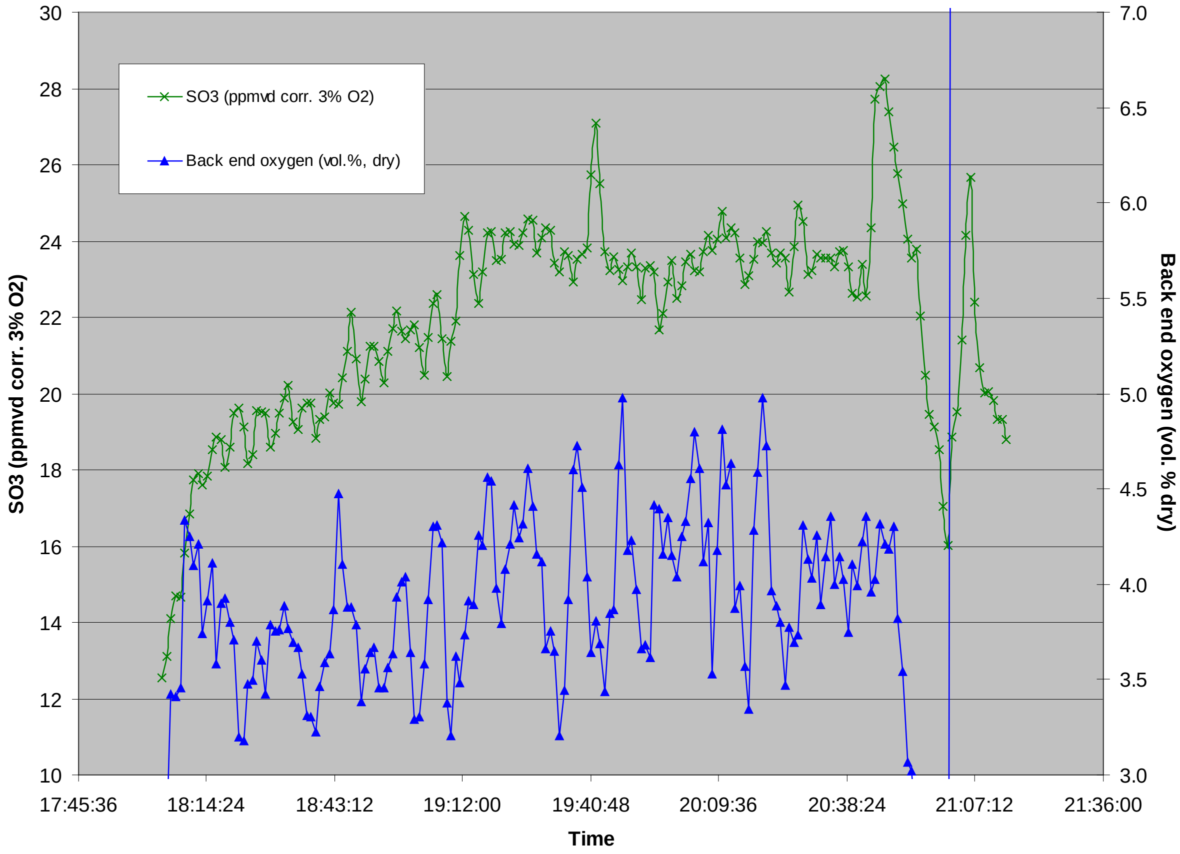
SO3 measurement

- Severn Science kit
  - Equipment developed by CEGB prior 1980's
  - SO_3 reacts with isopropanol to form sulphate ions
  - This solution is passed through a porous bed of barium chloranilate
  - Ensuing reaction releases light which is measured by a photometer
  - Ran continuously for the final condition (oxy with 4% back end oxygen)

- Controlled condensate kit
  - Equipment developed by E.ON for SO_3 measurements in the field on fuel/air combustion plant
  - Consists of filter wool followed by glass tubing to capture SO_3 which is sat in a water bath to prevent moisture condensation
  - Samples sent to laboratory for titration
  - Ran in batch mode with 3 samples taken at each condition

SO3 numbers

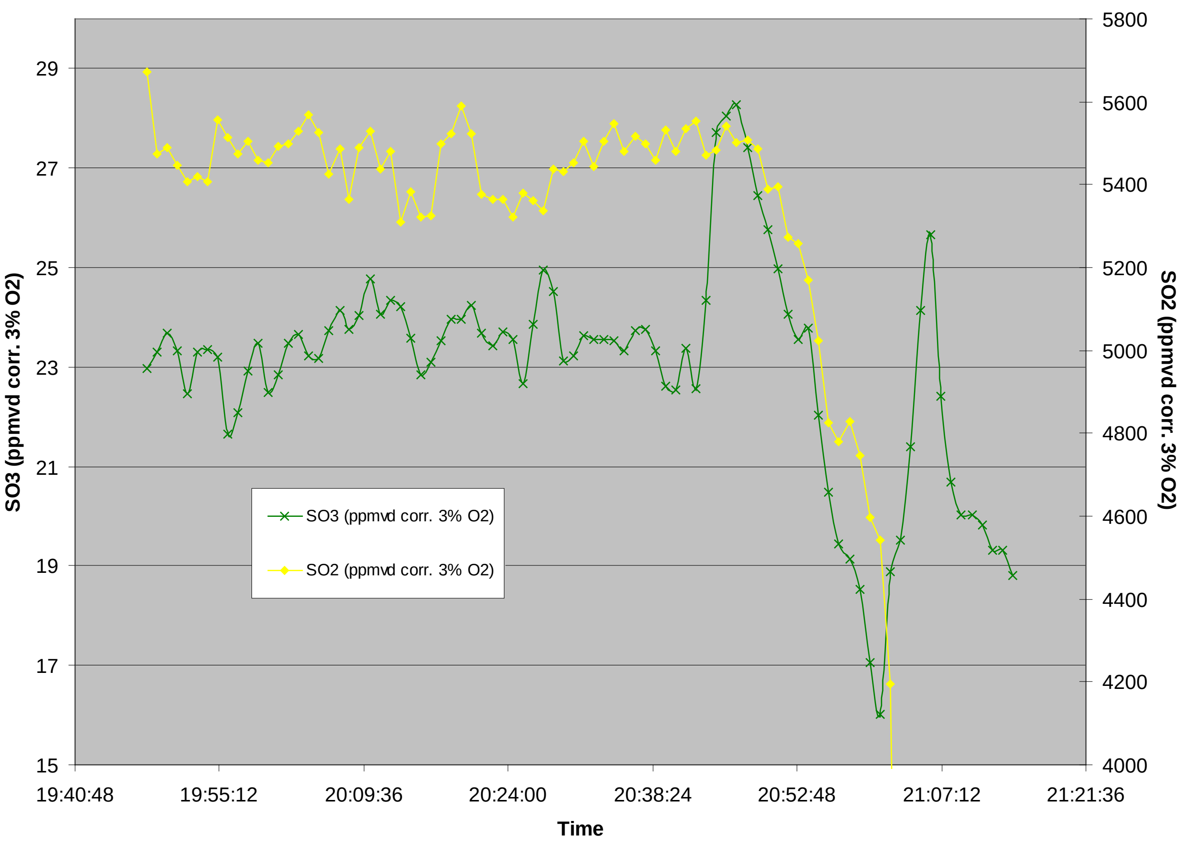
- Severn Science kit ran for last oxyfuel condition (back end 4%)



- Temp. ~430oC
- SO3 trends closely to O2.
- SO3 range ~18-28ppmvd c.
- SO3 average ~22.5ppmvd c.
- • O2 = • SO3g = • SO3p
- SO2 interference?

SO3 numbers

- Severn Science kit ran for last oxyfuel condition (back end 4%)



- SO3 trends closely to SO2.
- SO2 range ~5300-5671ppmvdc.
- SO2 average ~5470ppmvdc.
- SO2-SO3 conversion = ~0.41%

SO3 numbers

- Controlled condensate
  - Local temperature ~140-150oC
  - Pump malfunction during Oxy 2

	SO3 (ppmvd corr. 3% O2)	SO2 (ppmvd corr. 3% O2)	SO2-SO3 conversion (%)
Air	3.11	1306	0.24
Oxy 1	23.33	4975	0.47
Oxy 2	5.12	NA	NA

SO2 increase ~3.8

Similar to SS determined conversion of 0.41%

- Operational difficulties with port removal causing air ingress vs using old dust laden filter wool which absorbed SO3 resulting in lower readings

Ash analysis – Major components -XRF

		Air	Oxy 2%	Oxy 4%
Al2O3	%w/w	21.4	21.3	22.1
BaO	%w/w	0.06	0.06	0.06
CaO	%w/w	4.37	3.97	4.13
Fe2O3	%w/w	12.2	11.5	11.5
K2O	%w/w	2.48	2.62	2.72
MgO	%w/w	1.06	1.11	1.16
Mn3O4	%w/w	0.05	0.05	0.05
Na2O	%w/w	0.69	0.68	0.72
P2O5	%w/w	0.07	0.09	0.1
SiO2	%w/w	51.6	50.5	52.1
SO3	%w/w	1.19	1.55	1.81
TiO2	%w/w	1.17	1.21	1.25
CaCO3	%w/w dry	0.22	0.09	0.09
Total	%w/w	96.56	94.73	97.79

>5-10% variation typical

P2O5 → ~30%

SO3 → 30-40%

Ash analysis – Trace components

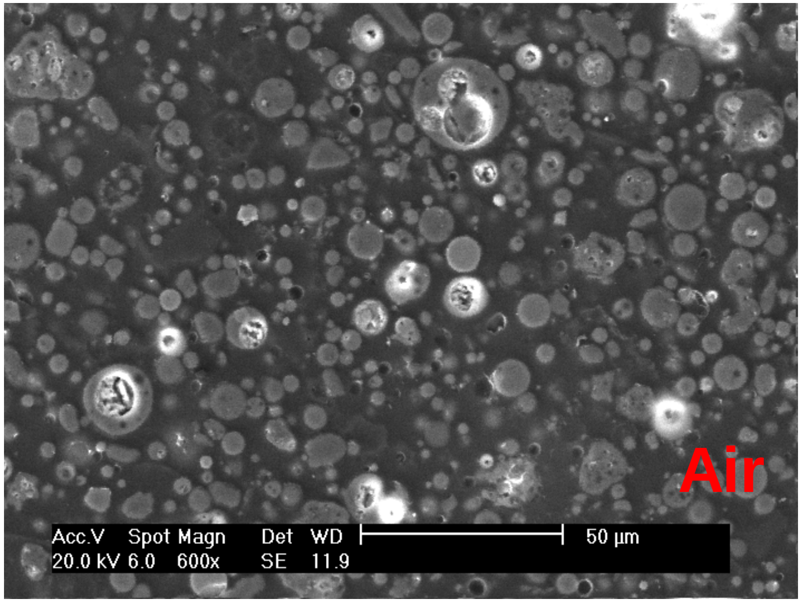
- Large increase in a number of trace elements with oxy compared to air (>20%)
- Particularly As, Mo and Cd
- Consistent with deposit found on coupon samples in convective section

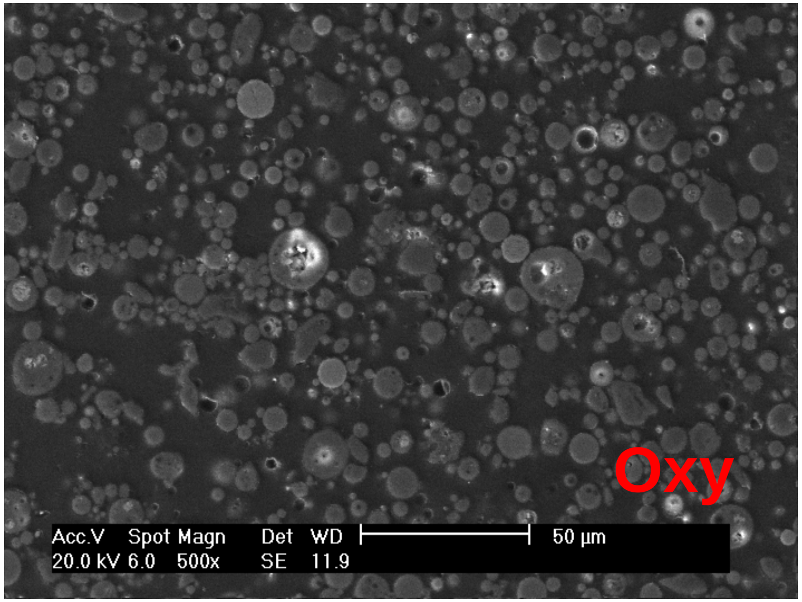
		Air	Oxy 2%	Oxy 4%
As	mg/kg	57.8	102	105
Sb	mg/kg	6.29	8.05	8.58
Se	mg/kg	<1	2.88	<1
Cr	mg/kg	182	253	223
Cu	mg/kg	81.5	106	110
Mo	mg/kg	26.7	51.4	48.6
Ni	mg/kg	206	257	238
V	mg/kg	220	267	271
Zn	mg/kg	400	494	491
Hg	mg/kg	0.07	0.27	0.05
LOI	%	5.6	3.55	1.59
Cd	mg/kg	1.34	2.1	1.81
Pb	mg/kg	121	157	151

% diff. from air to oxy	
76.5	81.7
28.0	36.4
39.0	22.5
30.1	35.0
92.5	82.0
24.8	15.5
21.4	23.2
23.5	22.8
285.7	-28.6
-36.6	-71.6
56.7	35.1
29.8	24.8

Ash analysis – SEM

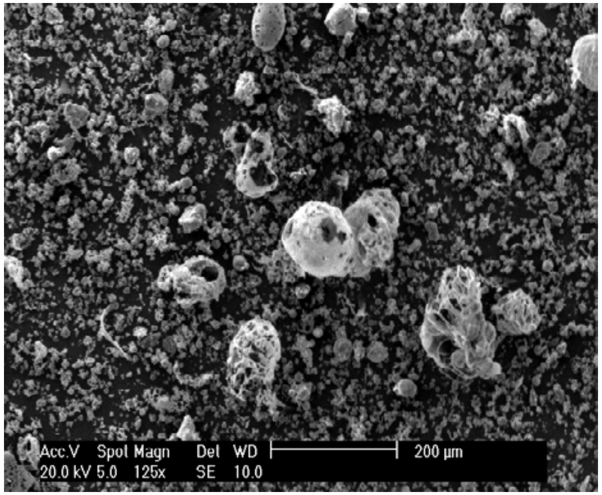
- Similar shapes and sizes (NB: superheater temp ±60oC)

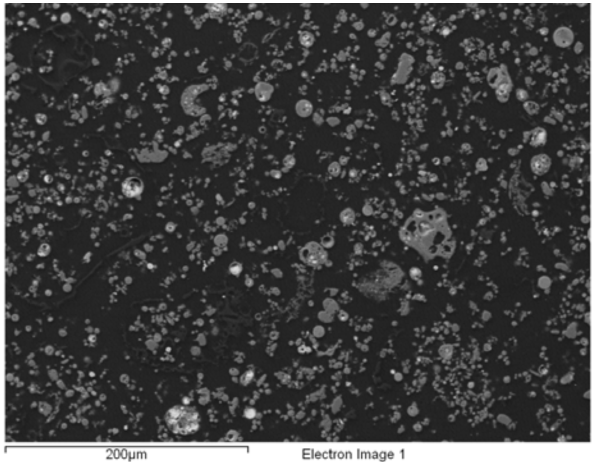




- Previous testing with no primary enrichment and lower furnace top temperatures compared to air (~100-200oC) did show some differences

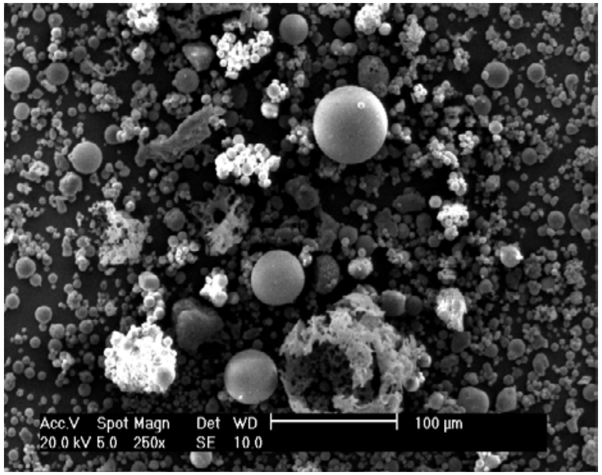
Ash analysis – SEM (previous project)

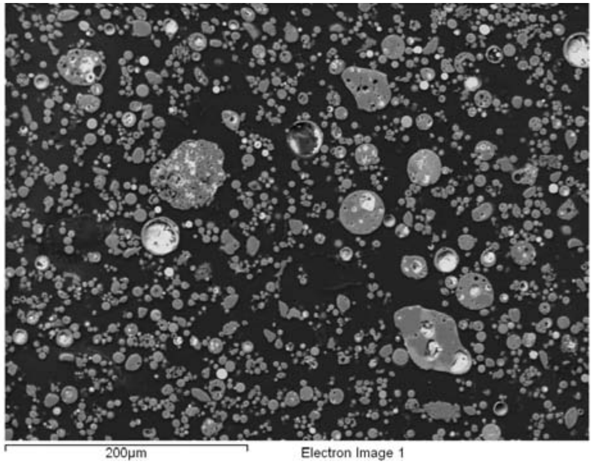




Air

Oxy has slightly larger and more spherical ash





Oxy

Summary

- Hg, SO3 and ash evaluated on air and 2 oxyfuel conditions
- No gaseous phase Hg found with air firing or oxyfuel (2% oxygen) corresponding with high ash phase Hg
- Peak in oxidised Hg detected on oxyfuel (4% oxygen) corresponding with decreased Hg in ash (lower LOI and increased SO3 in ash)
- SO2-SO3 conversion appears to be increased for oxyfuel (caution - based on limited data set)
- Difficulties measuring SO3 include ash build up interference and air ingress during filter switch over
- Main ash components show little variation from air to oxyfuel with the exception of sulphur
- Trace metals appear considerably more concentrated in oxyfuel ash

Close

- Evaluation and analysis of test run on second coal to follow this year
- Corrosion work and findings reported later today
- Thanks for listening
- Questions?
- Further questions? Feel free to contact me.
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