Pilot Plant Experiments of Co-firing Various Levels of Cereal Co-product (CCP) with El-Cerrejon Coal

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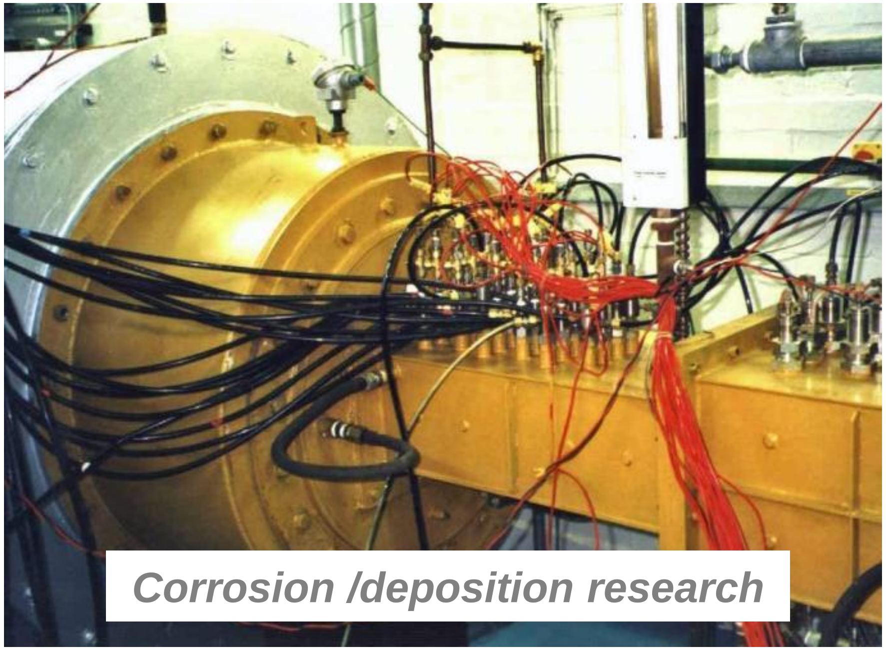
Cranfield University

- UK university
    - Two campus
    - £150 m / year
- Post-graduate students only
    - MSc, PhD, EngD, MBA
    - ~3000 full time students
    - 100+ countries
- Focused on
    - Science
    - Engineering
    - Management
    - Defence
- Research intensive

Centre for Energy and Resource Technology (CERT)

- Fuels
  - Biomass, wastes, coals, etc
- Energy processes
  - Combustion (fluidised bed/ pulverised fuels)
  - Gasification (updraft/ downdraft/ fluidised bed)
  - Gas cleaning
  - CO_2 capture
  - Oxy-firing
- Materials
  - Component focused
    - heat exchangers, gas turbines, etc
  - Damage development
    - deposition, fireside / hot corrosion, steam oxidation, etc
  - Modelling
    - mechanistic, life, risk, etc
- Resource
  - Life cycle engineering
  - Integrated pollution management
  - Landfill science
  - Anaerobic digestion

Combustion and deposition research



Corrosion /deposition research

Aims & Objectives

Co-firing of Cereal Co-product (CCP) mixed with El-Cerrejon Coal (0, 20,40,60, 80, 100 wt.%) in a $100KW_{th}$ pilot scale combustion rig

- Flue gas compositions (major and minor species)
- Deposit formation on air-cooled probes (simulating heat exchanger tubing)
- Thermodynamic modelling of gaseous and condensed species

Outline

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- Introduction
- Experimental
  - Pilot scale rig
  - Fuel compositions
- Results & Discussion
  - Gaseous emissions (Major species)
  - Gaseous emissions (Minor species)
  - Deposition flux
  - Deposit composition
  - Thermodynamic modelling
- Conclusions

Deposition on Superheater / Reheater Tubing

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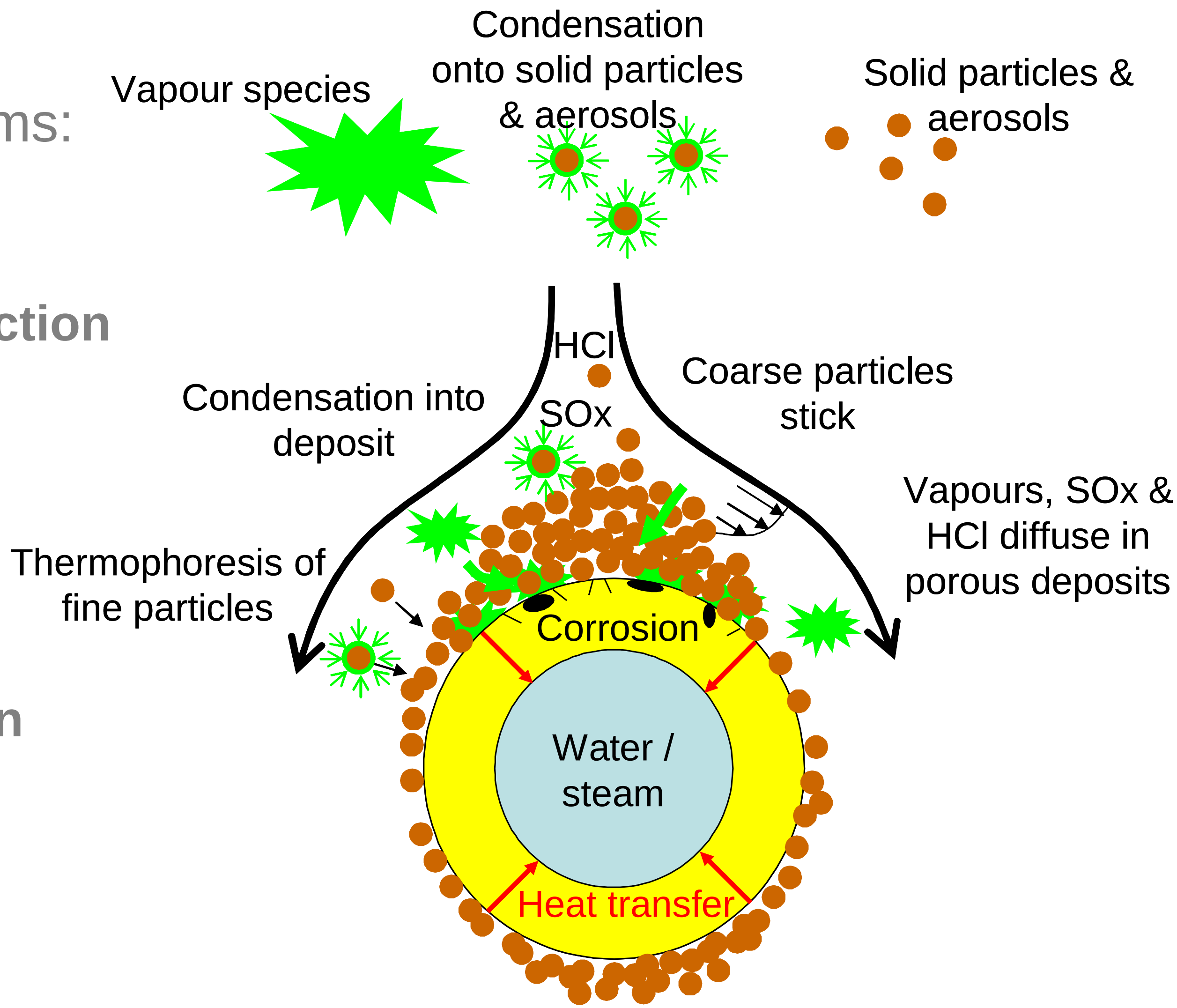
Deposition mechanisms:

Particles:

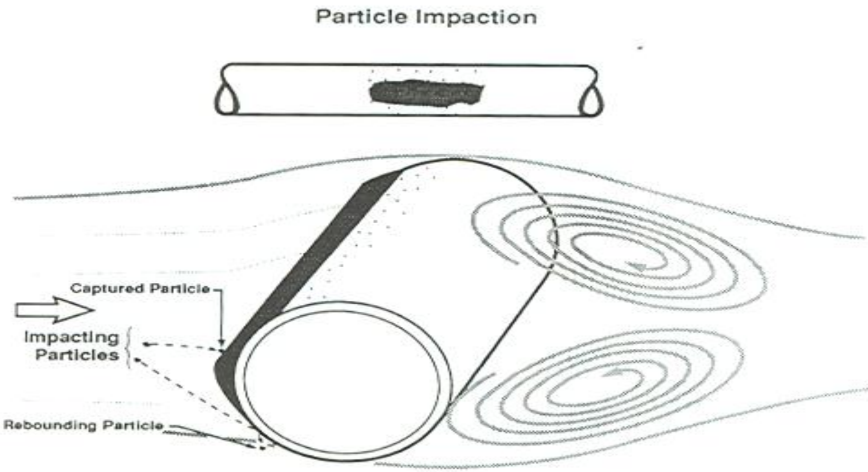
- **Direct inertial impaction**
- **Thermophoresis**
- **Eddy diffusion**
- **Brownian**

Vapour:

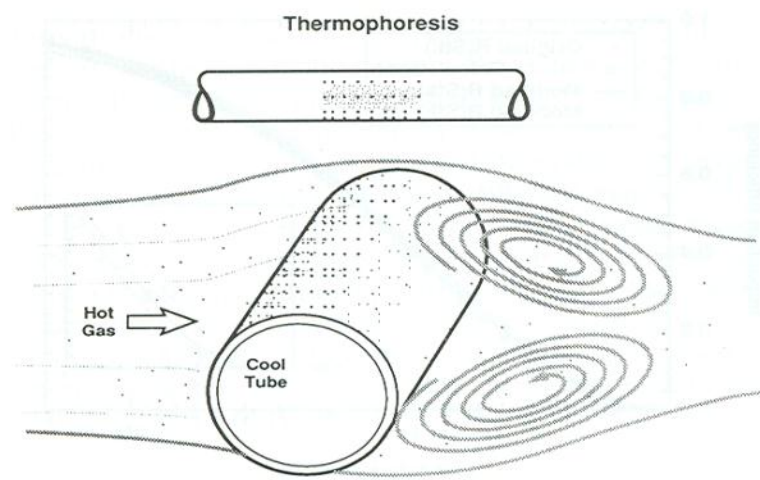
- **Direct condensation**
- **Condensation on particles**



Deposition Mechanisms: Direct Inertial Impaction & Thermophoresis



- **Large ash particles (≥10μm)**
- **Particle impact due to momentum of the particles**

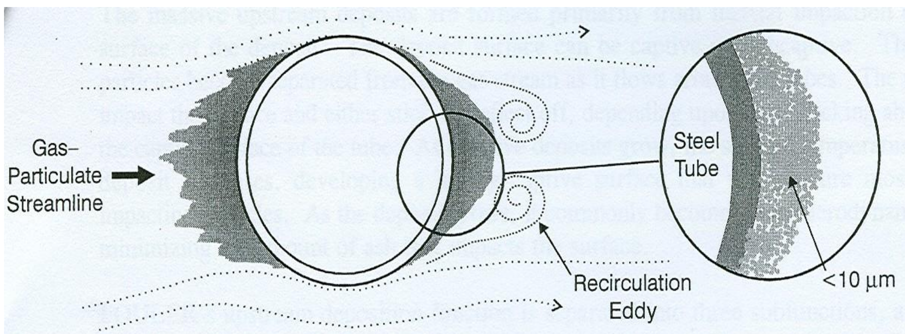


(Baxter and DeSollar, 1993)

- **Smaller particles (<10μm)**
- **Particle transport mechanism that relies on a strong local temperature gradient**

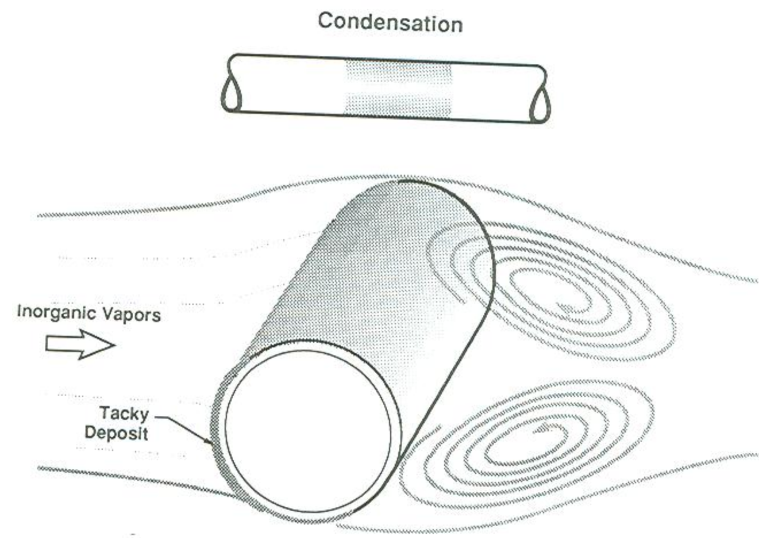
Deposition Mechanisms: Eddy Diffusion & Vapour Condensation

Eddy diffusion



Downstream deposition (Allan et al, 1996)

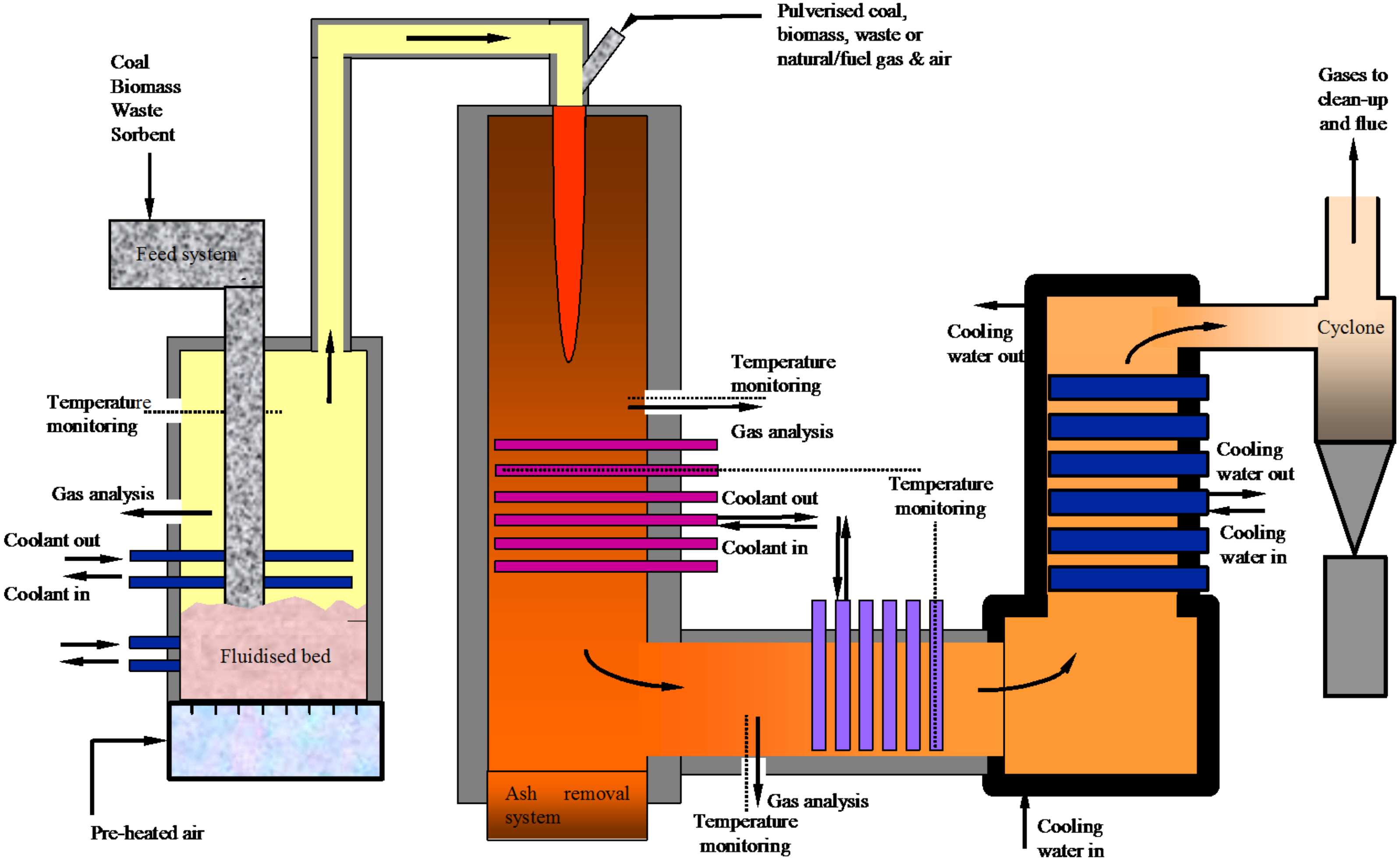
- **Very small particles**



(Baxter and DeSollar, 1993)

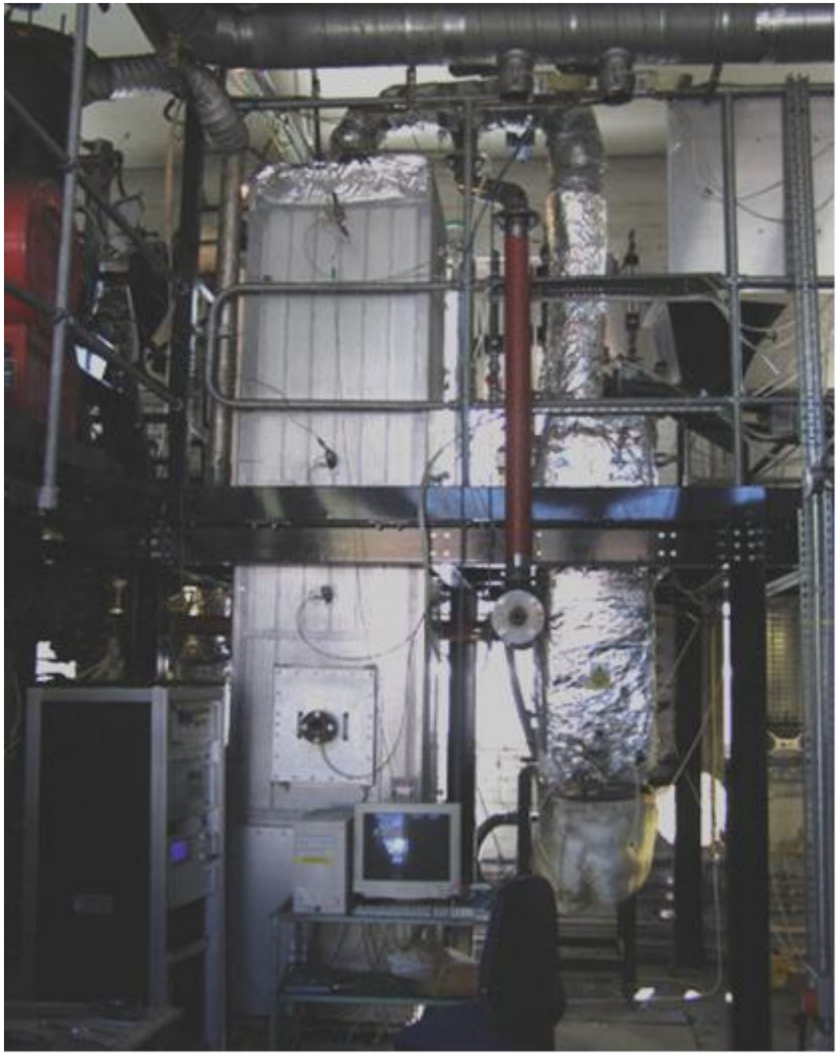
- **Inorganic vapours diffuse through the boundary layer and condense on cooler surfaces**

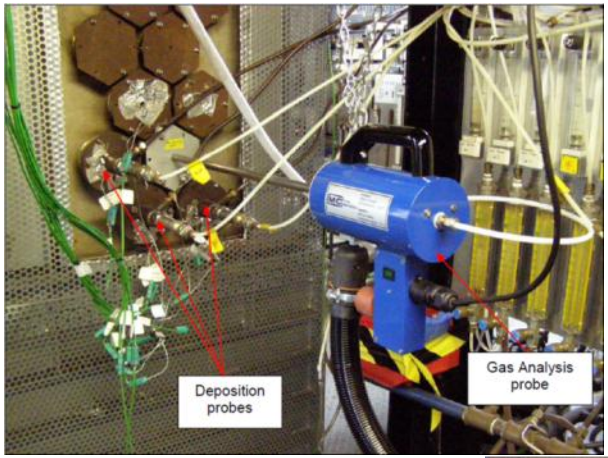
Pilot Scale Combustion Rig

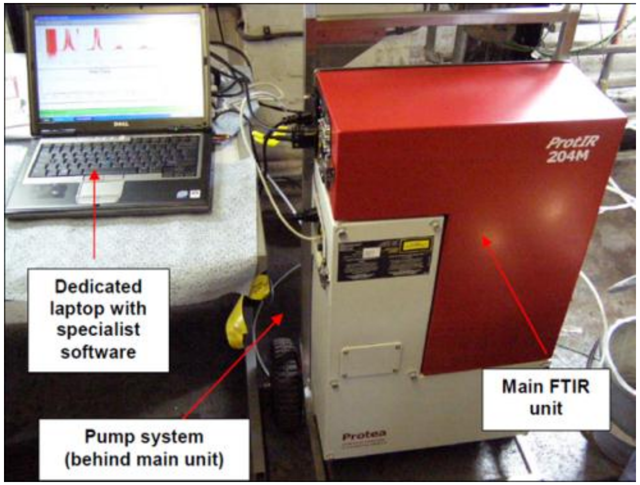


- 100 kW_{th} capacity pulverised fuel combustor
- Fuel feed rate 7-15 kg/h

Experimental Setup







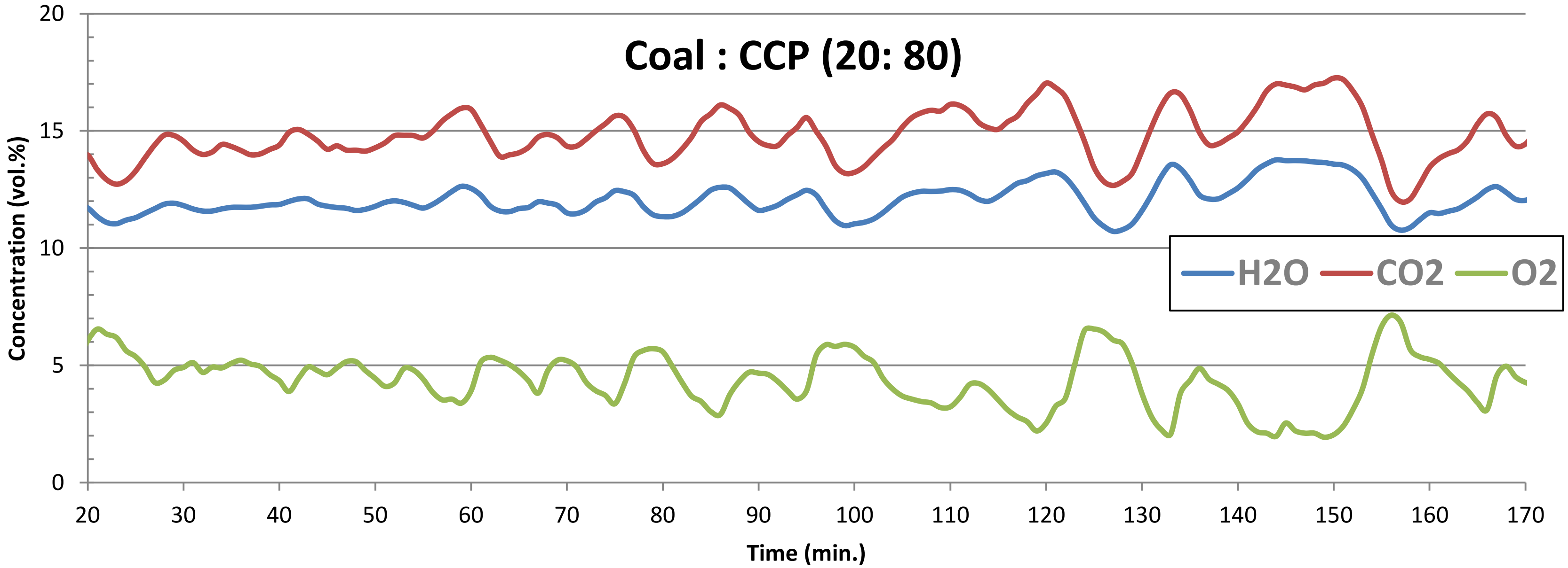
Fuel Compositions

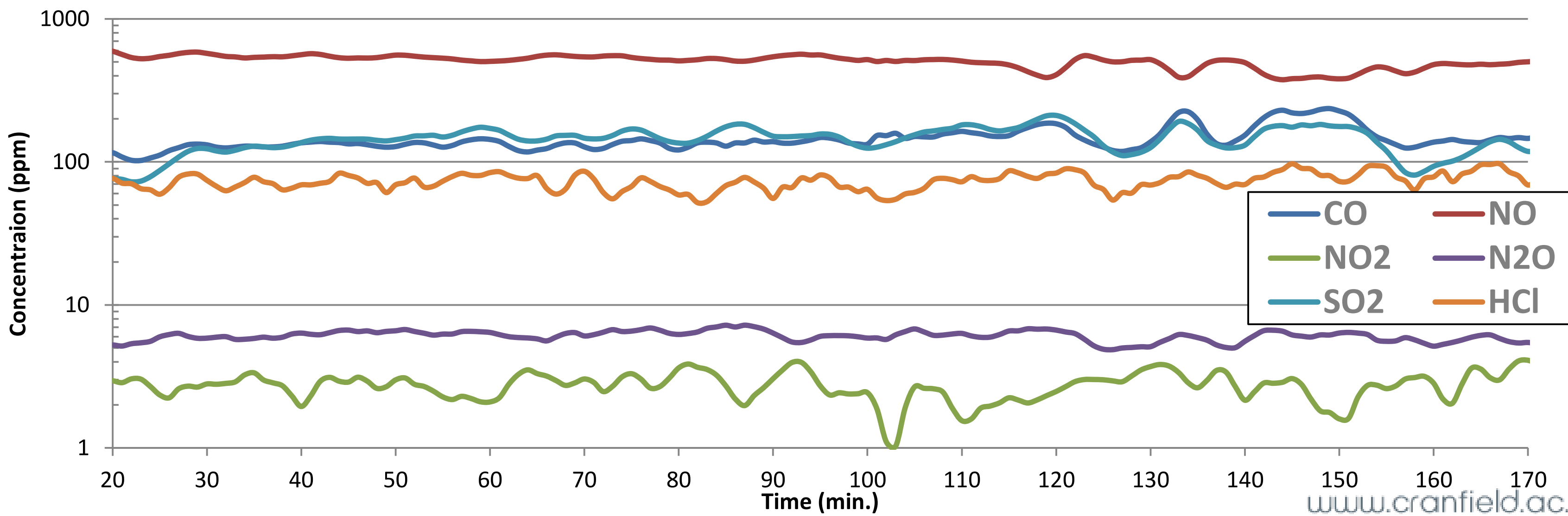
	El-Cerrejon Coal	CCP
Proximate analysis (% wt, AR)		
Moisture	5.80	8.10
Ash	8.60	4.20
Volatile matter	34.80	70.80
Calorific value (kJ/kg)		
Gross Calorific value	27850	17610
Net Calorific value	27122	16340
Ultimate analysis (% wt, AR)		
Carbon	69.20	43.30
Hydrogen	4.80	5.80
Nitrogen	1.42	2.70
Oxygen	9.98	35.57
Sulphur	0.58	0.16
Chlorine	0.02	0.17
Ash composition (% wt, of total ash)		
SiO_2	60.69	44.36
Al_2O_3	22.01	2.79
Fe_2O_3	7.43	2.47
TiO_2	0.92	0.12
CaO	2.27	7.78
MgO	2.90	3.96
Na_2O	1.06	0.36
K_2O	2.32	24.72
Mn_3O_4	0.06	0.10
P_2O_5	0.21	12.04
SO_3	-	-
BaO	0.11	0.05

Test Matrix

El-Cerrejon (wt.%)	CCP (wt.%)	Air-cooled probe surface temperature (ºC)
100	0	500, 600, 700
80	20	500, 600, 700
60	40	500, 600, 700
40	60	500, 600, 700
20	80	500, 600, 700
0	100	500, 600, 700

Online FTIR measurement





Gaseous Emissions (Major Species)

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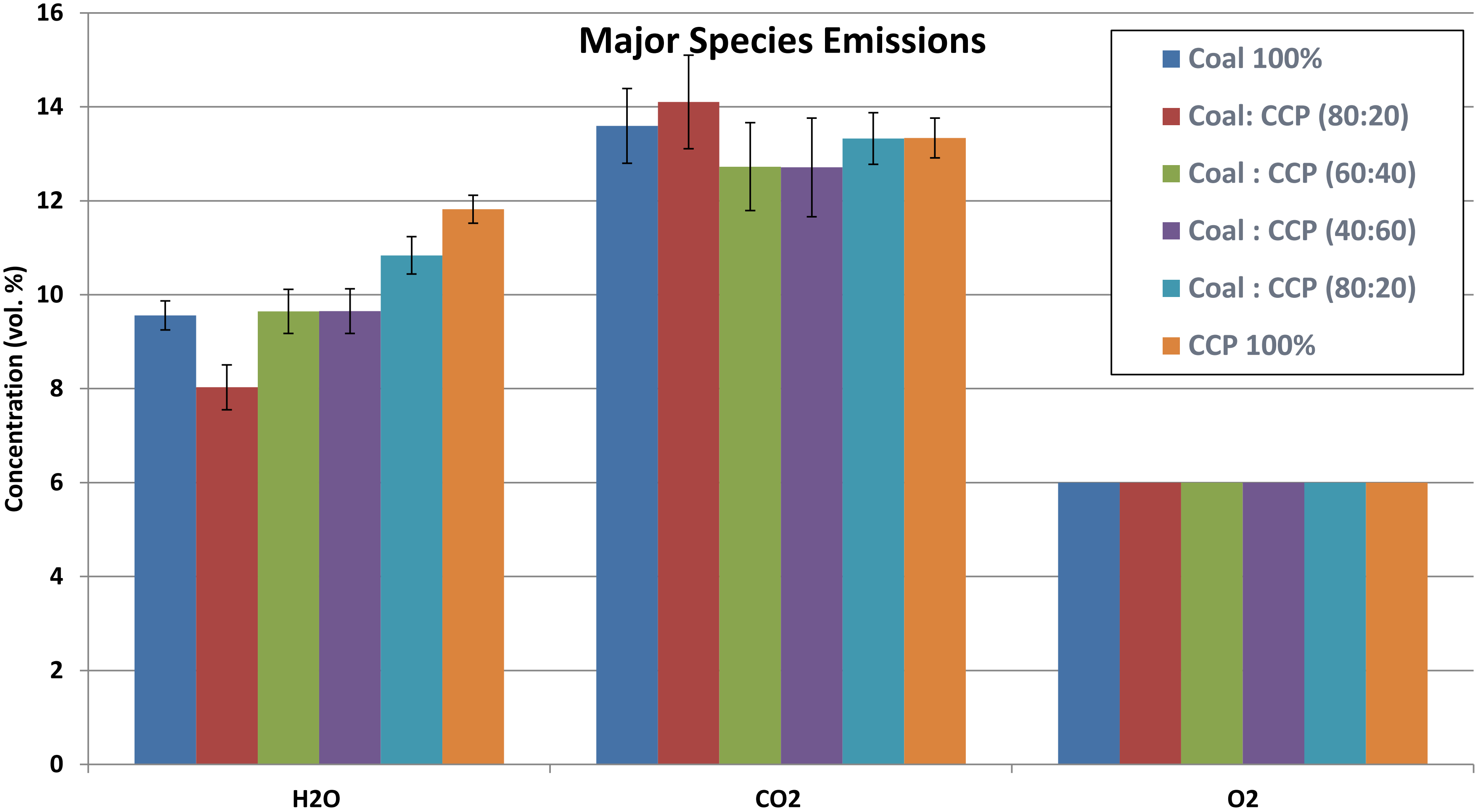
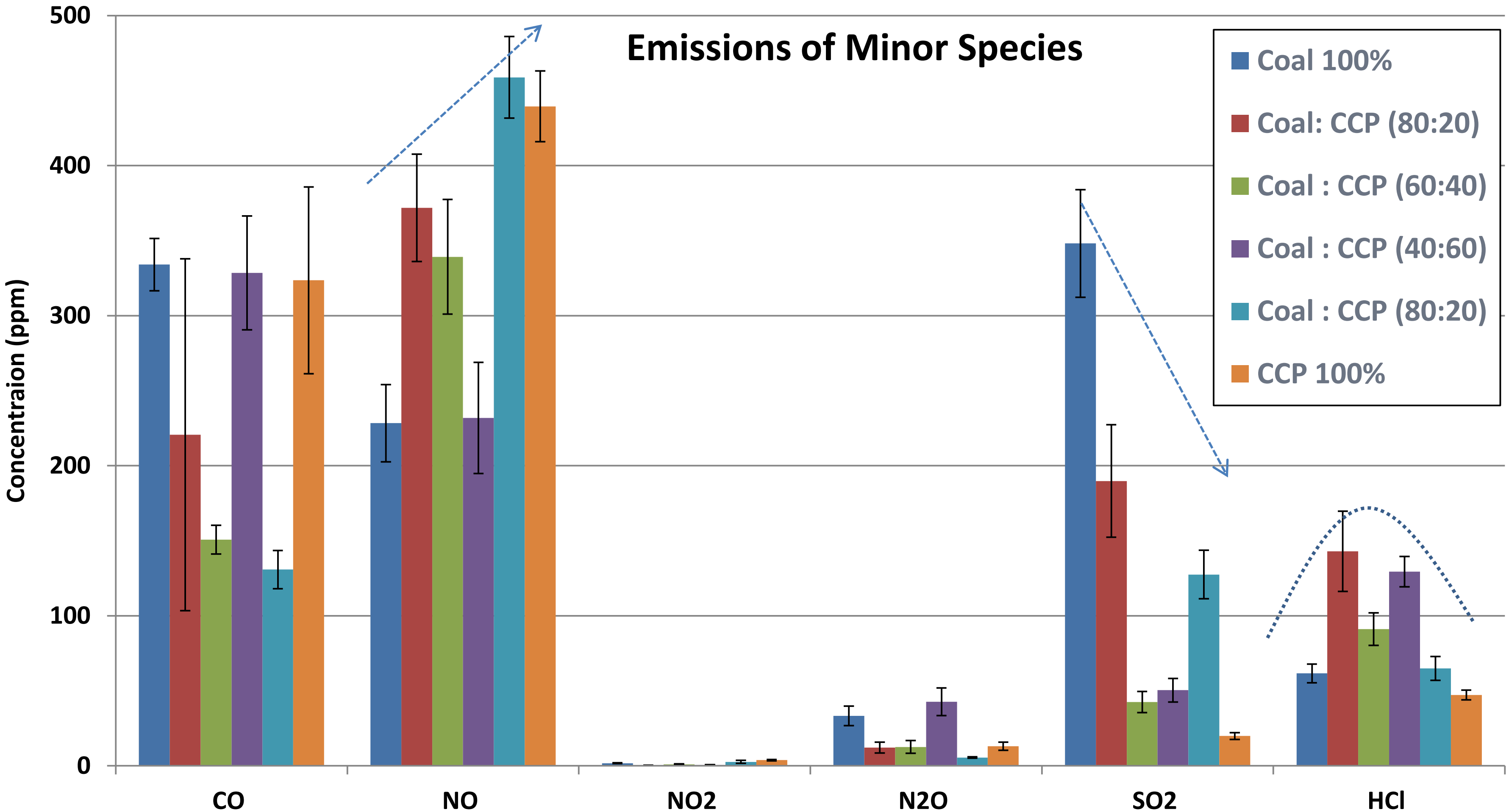


- All data normalised to 6 vol.% oxygen for ease of comparison

Gaseous Emissions (Minor Species)



- All data normalised to 6 vol.% oxygen for ease of comparison

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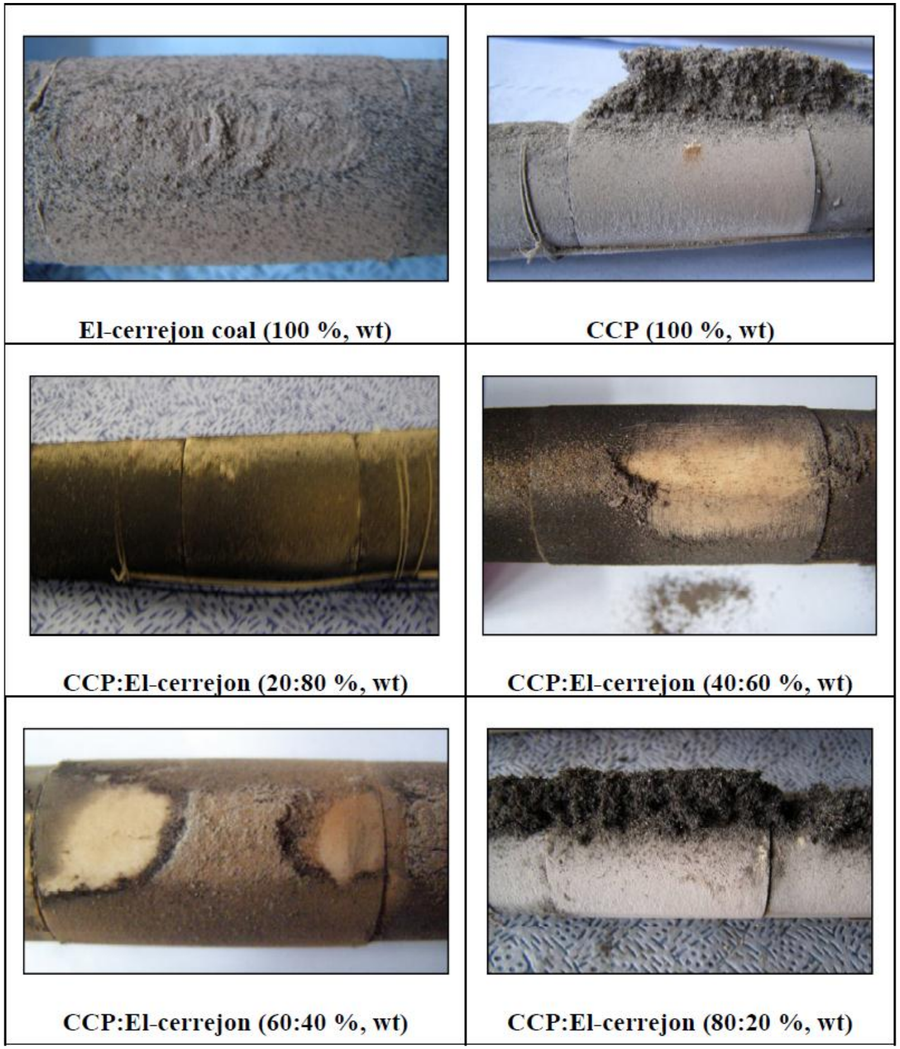
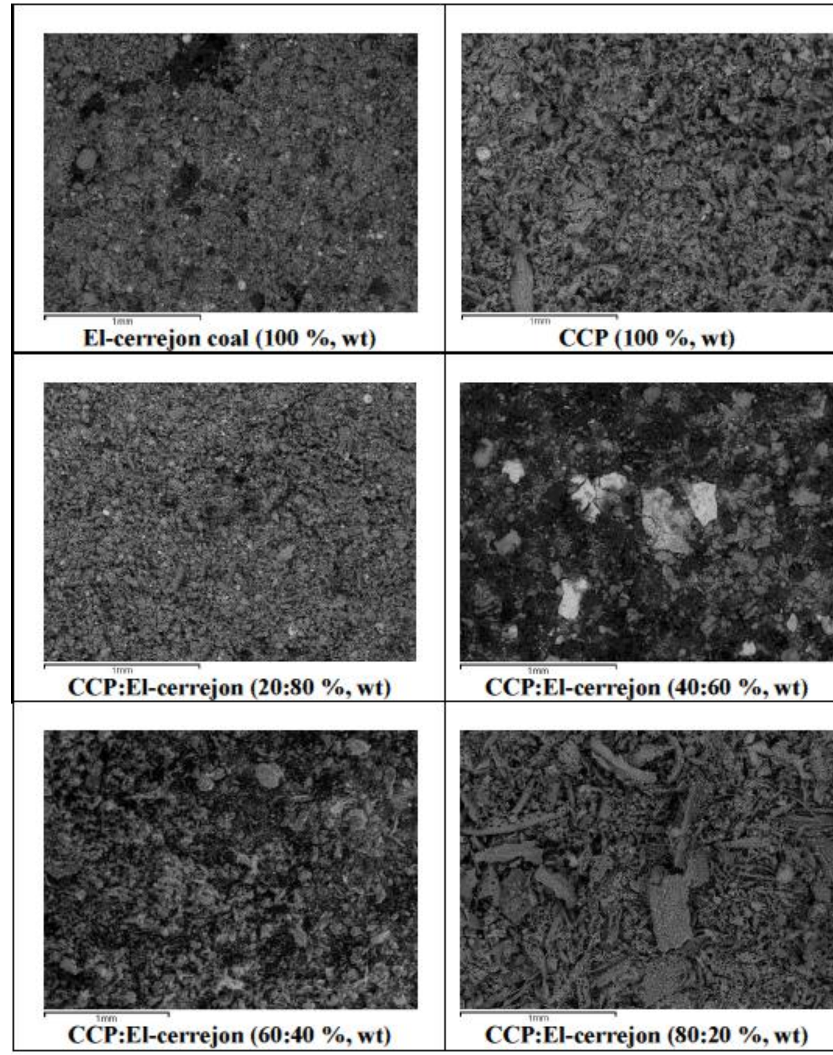
Deposition on Probes



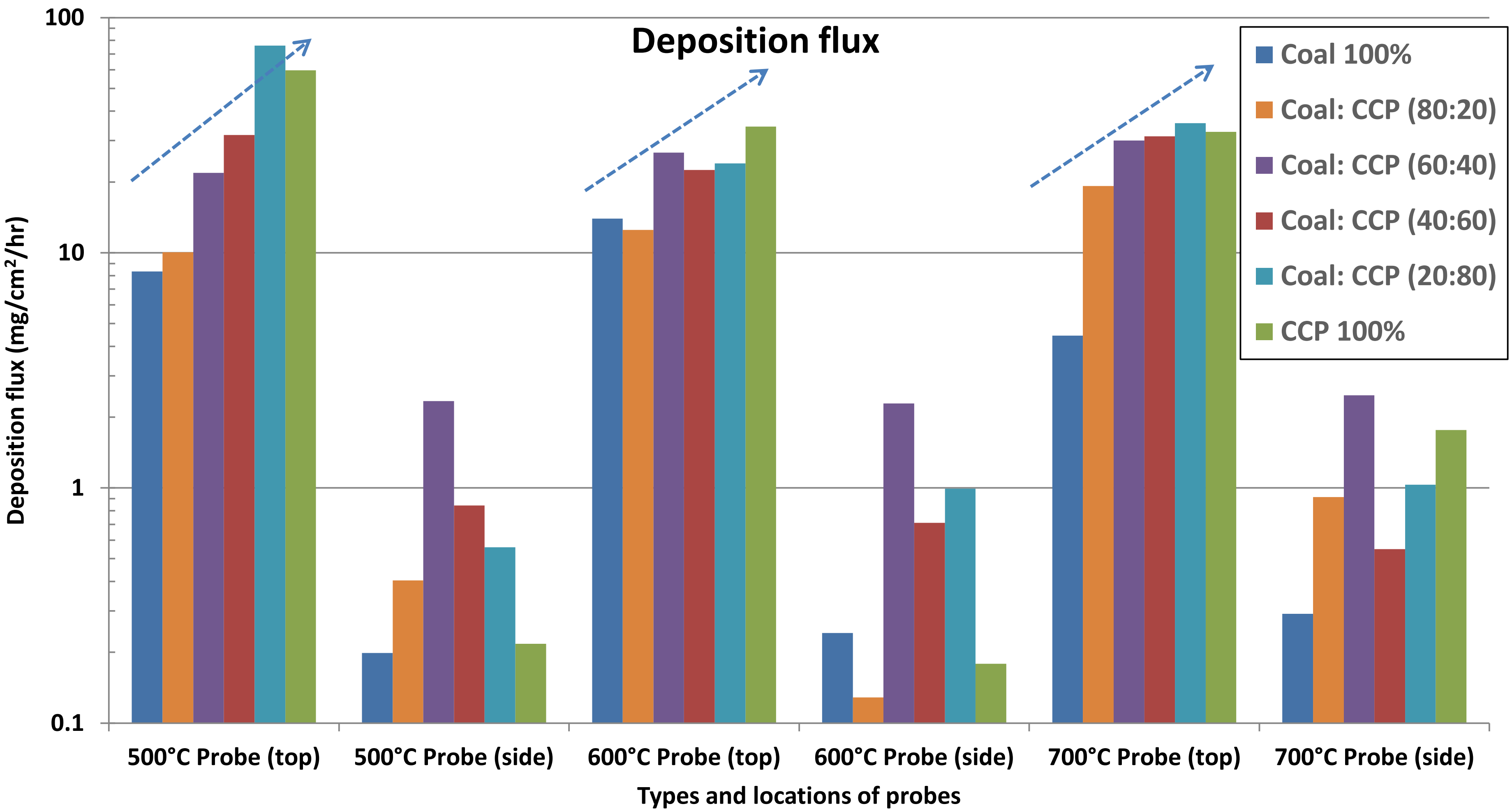
Digital images



SEM images

Deposition on 500ºC surface temperature probes

Deposition Flux



Elemental Concentration of Deposits (500°C probe)

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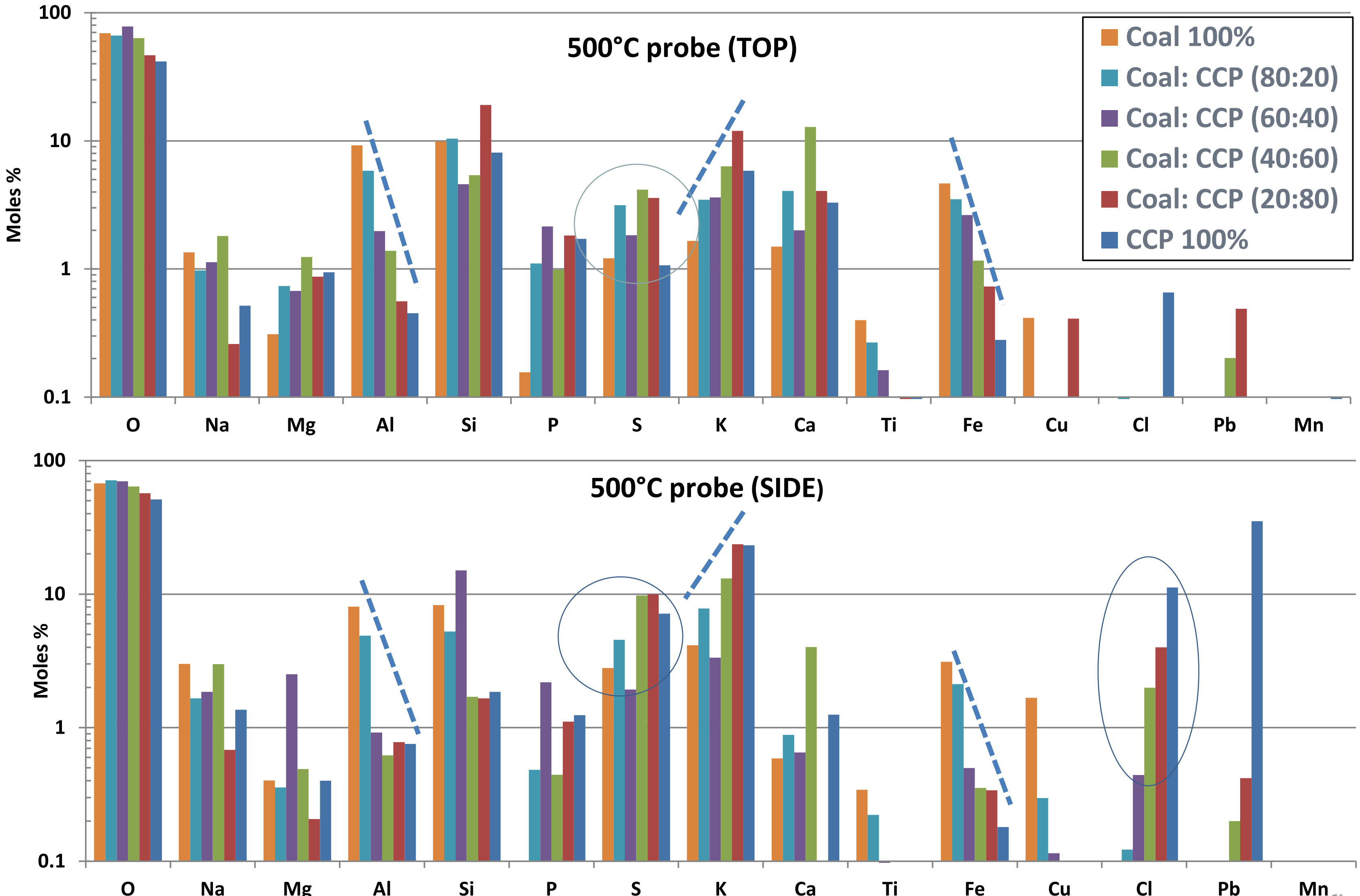
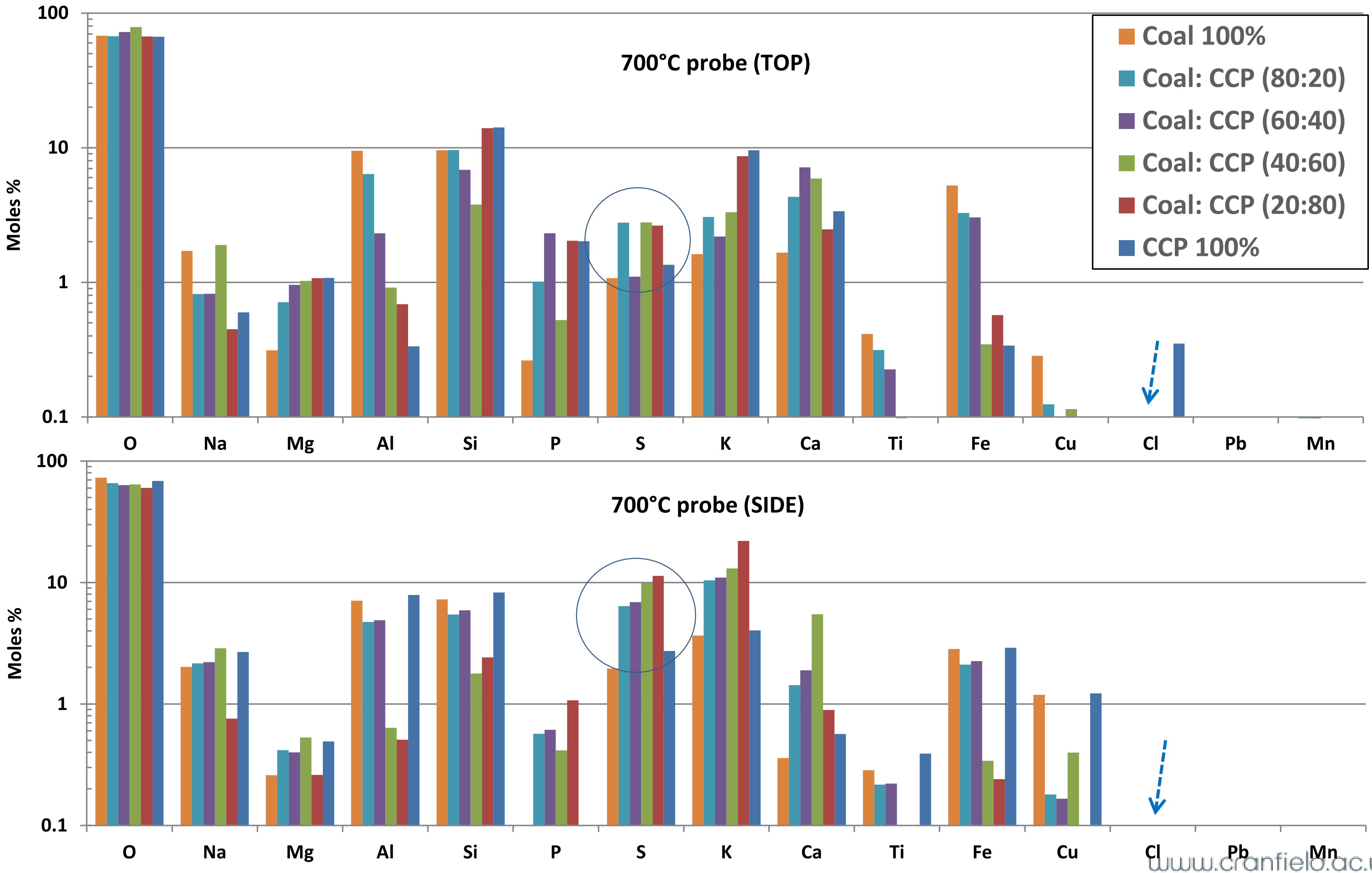
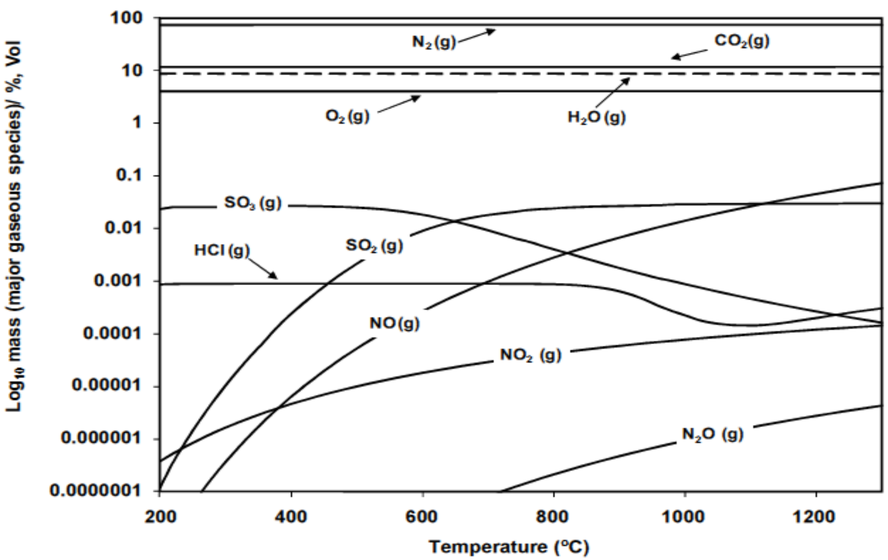


Elemental Concentration of Deposits (700°C probe)



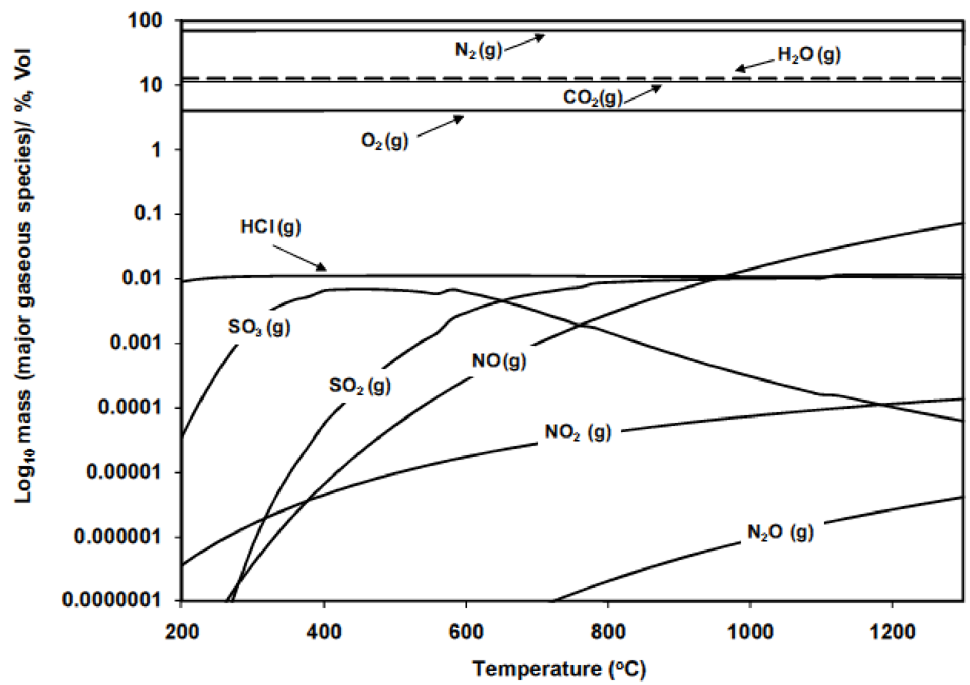
Thermodynamic Modelling (MTDATA) of Major Gaseous Species



100% El-Cerrejon Coal

- Modelling targeted at oxygen content of 4 vol.% in the combustion gas stream
- Consideration of 15 elements in modelling (excluding Al & Si)

100% CCP



- Trend of decreasing SO_2 and increasing H_2O with increasing co-firing of CCP
- Pilot plant data in agreement with modelling

Thermodynamic Modelling of Gaseous & Condensed Species

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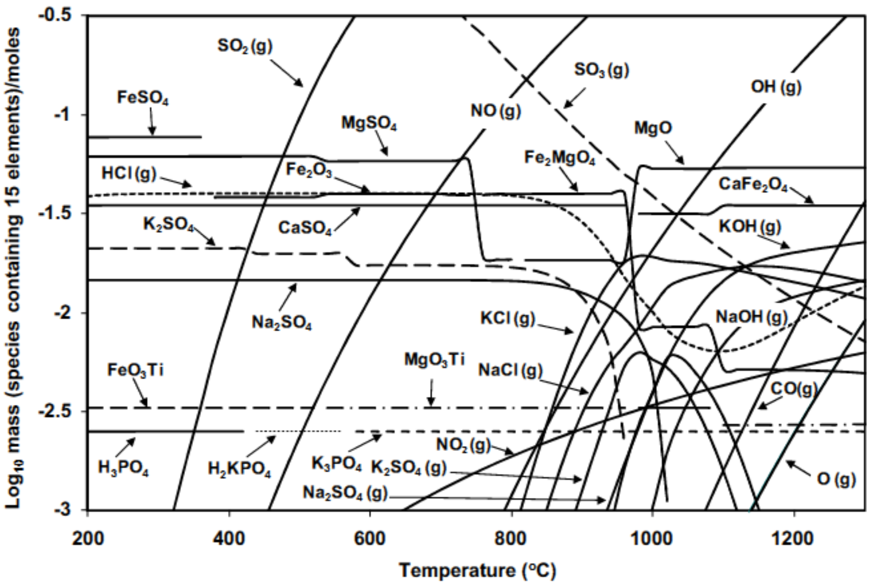
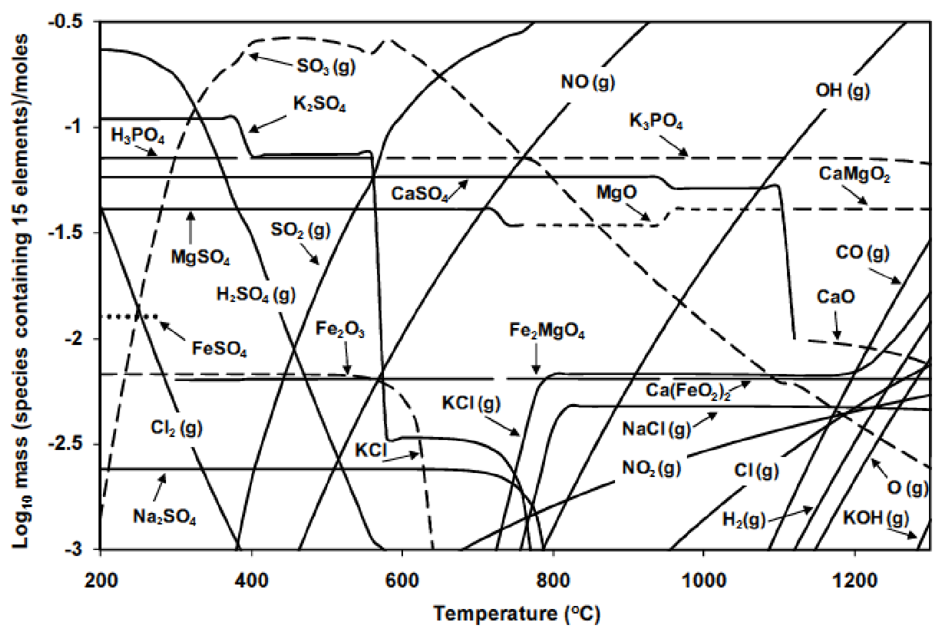


100% El-Cerrejon Coal

100% CCP



- Sulphates (K_2SO_4, $CaSO_4$, Na_2SO_4, $MgSO_4$, $FeSO_4$) in 100% coal
- Condensed Chloride (KCl) in 100% CCP (stable up to 680ºC)

Conclusions

- El-Cerrejon Coal was co-fired with CCP (0, 20, 60, 80, 100 wt.%) in a 100 KW_{th} pilot scale rig
- High combustion efficiencies achieved in all co-firing conditions (CO, CO_2)
- Increasing levels of co-firing CCP resulted in an increase in H_2O and NO_x, but resulted in a reduction of SO_2
- HCl emissions in all co-firing conditions were higher than coal or biomass alone
- Deposition flux increased with increasing levels of co-firing (on all three probes)
- Particle size in the deposit become coarser with increasing levels of co-firing

Conclusions (continued)

- Higher levels of S and K were detected on the side of the probes than the top indicating vapour phase condensation
- Cl was detected in all co-firing conditions only on the coolest probe (500ºC) which is in the form of KCl
- Thermodynamic modelling showed possible formation of KCl when CCP was fired and condensed sulphate species when coal was fired.
- Trends in thermodynamic modelling were validated by experimental findings.

Thank You

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