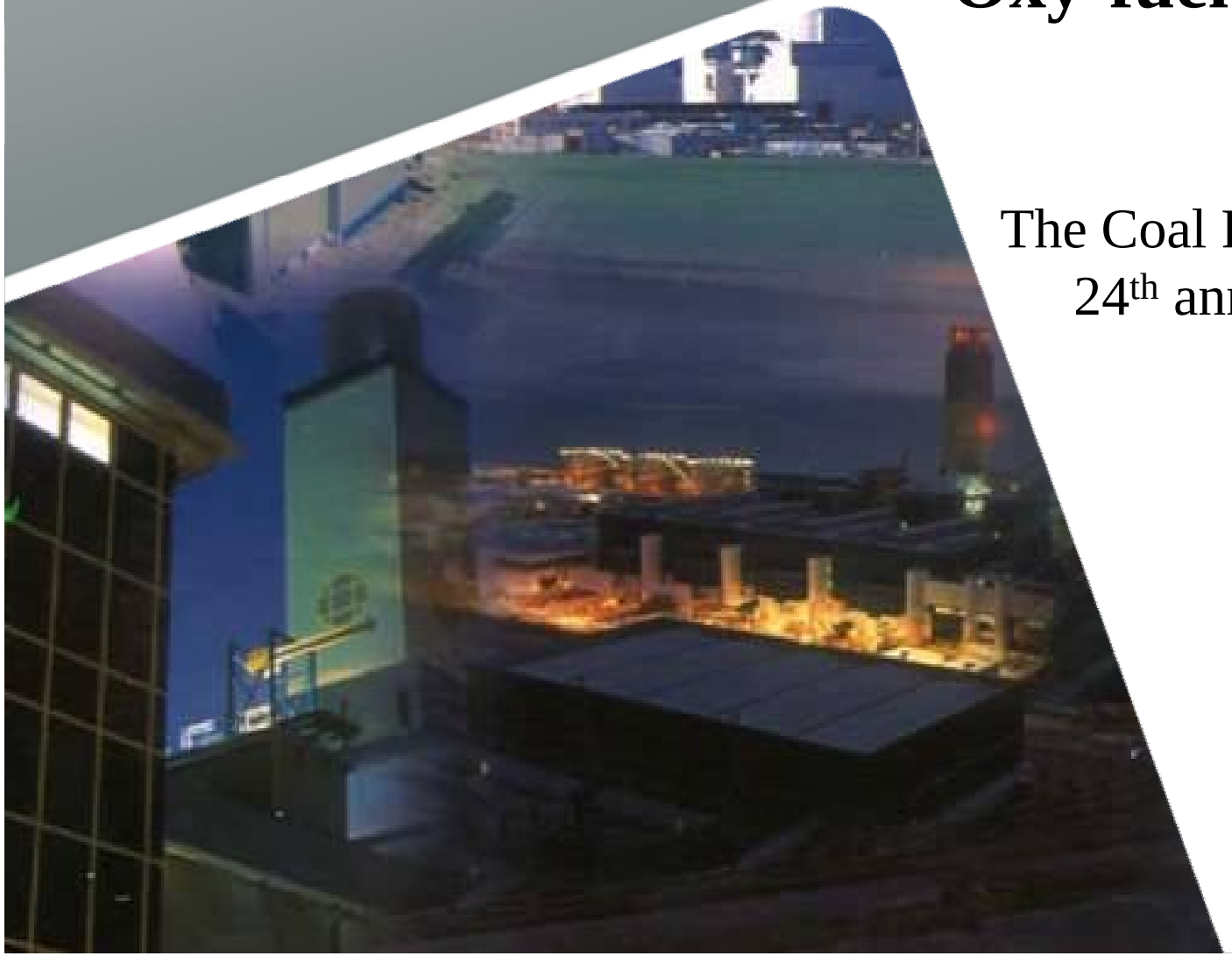
Centre for Energy and Resource Technology

Cranfield UNIVERSITY

Process Conditions in Oxy-fuel Combustion



The Coal Research Forum
24th annual meeting

Nelia Jurado
Hamid G Darabkhani
John E Oakey

Cranfield University

10th April 2013

http://www.cranfield.ac.uk

Multi- Fuel Combustion Rig at CERT: MAIN FEATURES

Cranfield UNIVERSITY

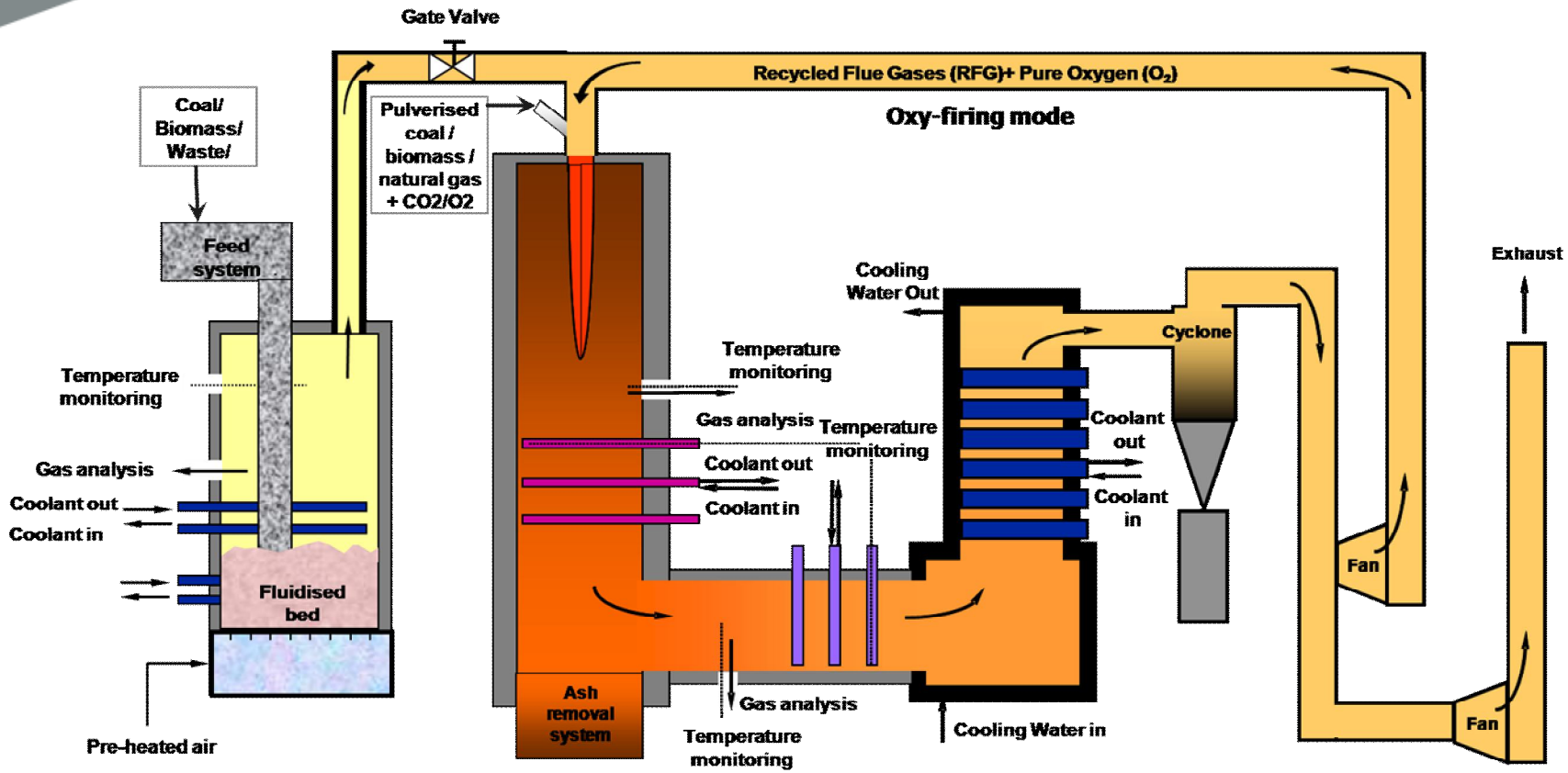


Diagram of 150kWth Multi-fuel Combustor at CERT

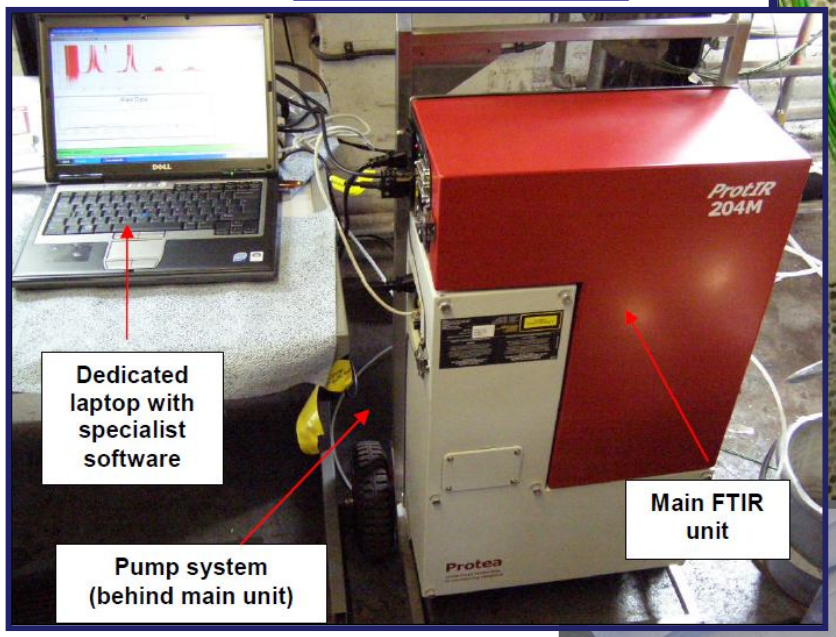
Operational Conditions

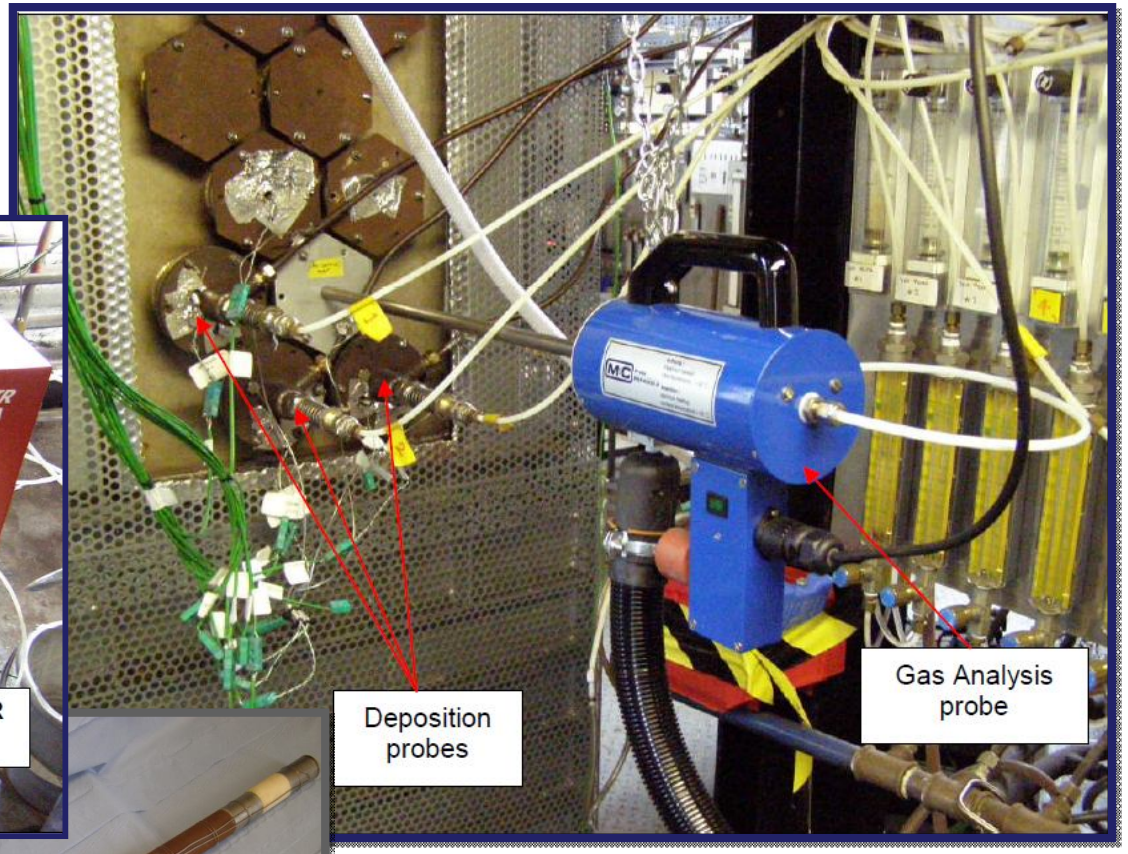
- **Type of fuel:**
  - **Coal (Daw Mill) 100% (w/w)**
  - **Biomass (Cereal Co-Product) 100% (w/w)**
  - **Blends of Parent Fuels 50% Daw Mill-50% CCP**
- **Recycled flue gas: 52%(v/v)**
- **Oxygen flow rate:**
  - **Primary stream (Fuel carrier) <21%(v/v)**
  - **Secondary stream <28%(v/v)**
- **Flue gas conditioning: Particle removal**
- **Pressure: Below atmospheric but as close as possible to it (minimise air ingress)**

Gas Analyser and Deposition probes

Cranfield UNIVERSITY

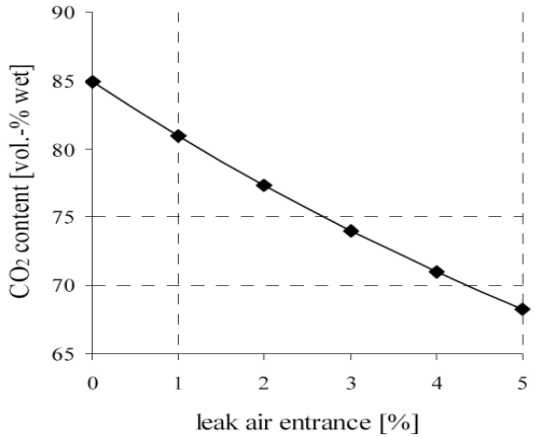
Protea Unit (ProtIR)



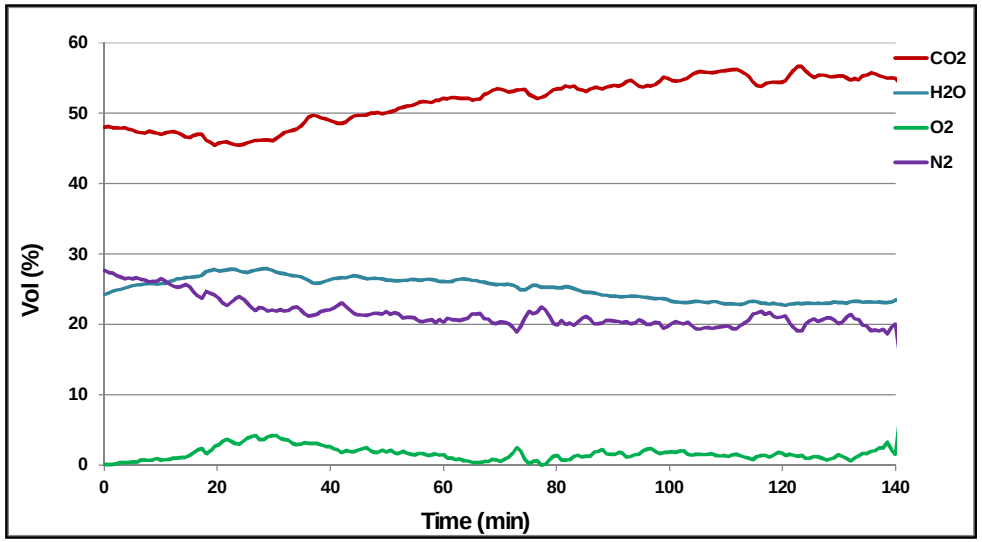


A fully assembled deposit capture probe including the 'K' type thermocouples connection plugs

Experimental Results:
GAS COMPOSITION
Daw Mill 100%



Data taken from Steinmetz *et al.*, (2011)



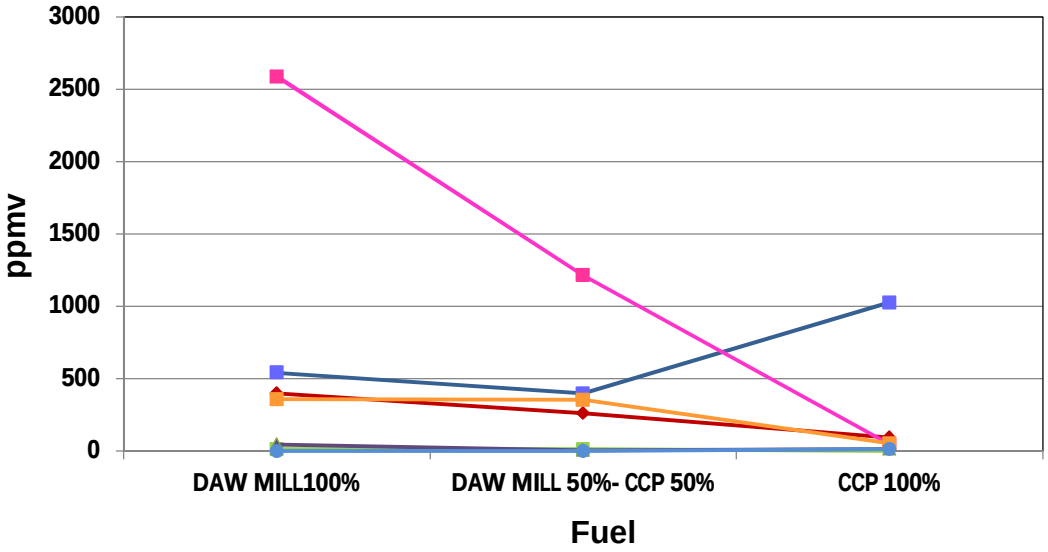
	CERT (100% Coal)		Steinmetz *et al.*, (2011)		Haykiri-Acma *et al.*,(2010)		Zhang *et al.*, (2011)	
	Wet basis	Dry basis	Wet basis (10% air ingress)	Dry basis	Wet basis	Dry basis	Wet basis	Dry basis
CO_2 (%)	56.7	74	62.4	--	55-65	96	68	90
H_2O (%)	23	--	4.2	--	--	--	20	--
O_2 (%)	2	--	3	--	--	--	--	--
N_2 (%)	22	--	29.1	--	--	--	--	--

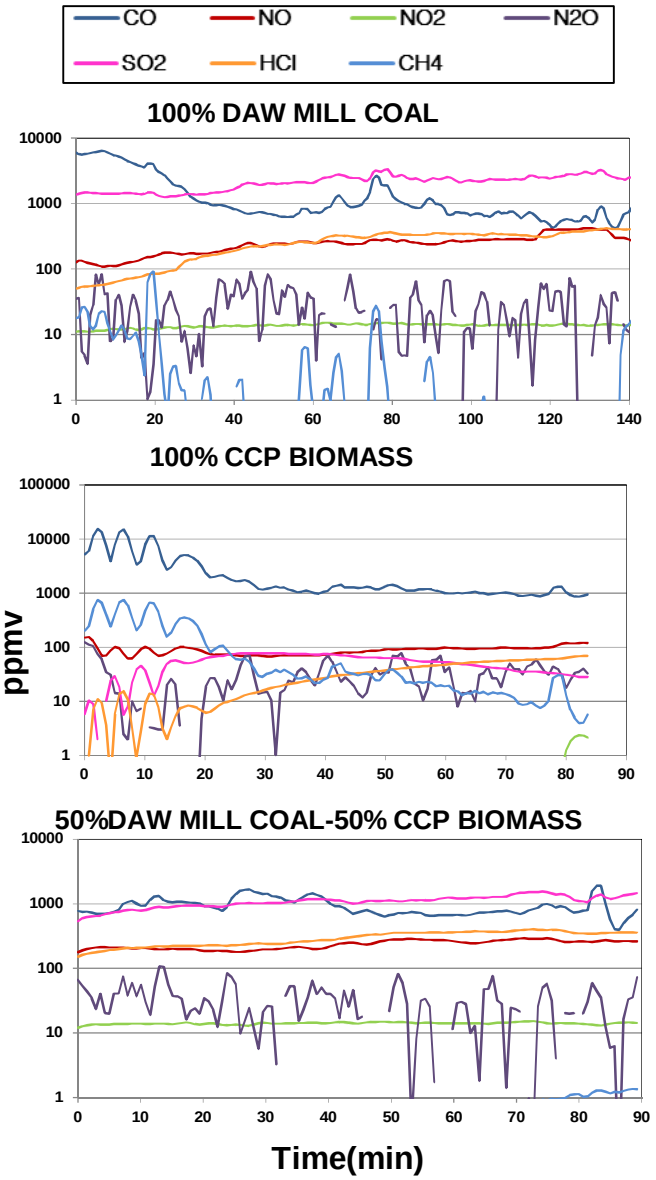
Avoid AIR INGRESS through:
- ✓**Resealing combustor**
- ✓**Do maintenance of RFG fan**

Experimental Results:
GAS COMPOSITION COMPARISON
Minor Species

- **SO_2 decreases with more CCP into the fuel mixture**
  Possible reasons:
  - ✓ SO_2 → SO_3
  - ✓ More S is retained in ash deposits
  - ✓ Bad performance of FTIR analyser (High H_2O and CH_4)

- **CO higher for CCP case → Possible reason: Not enough O_2 fed**
- **HCl and NO: decrease with CCP content**
- **NO_2 and N_2O: no variation with type of fuel**

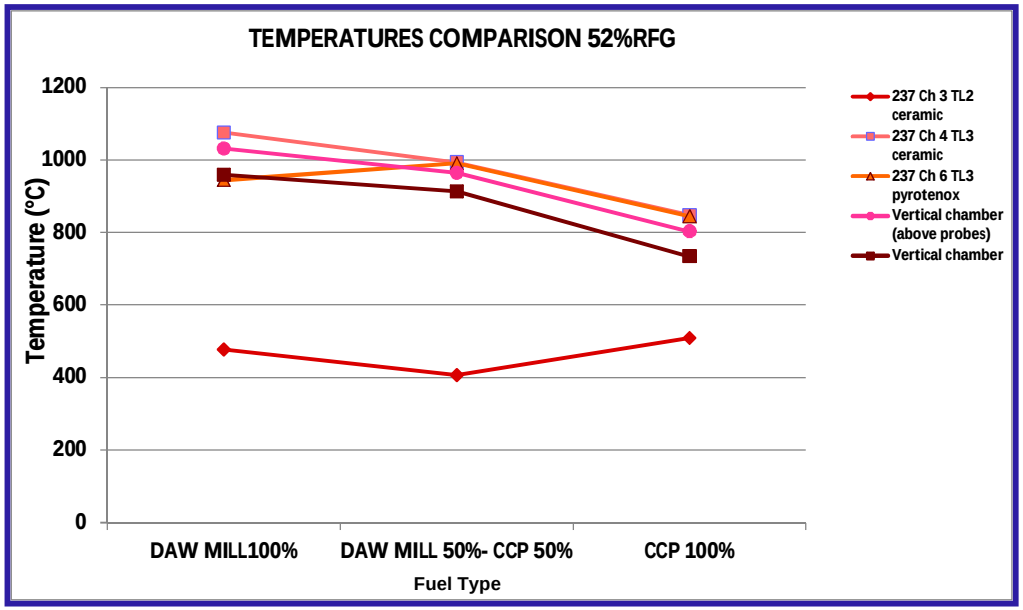


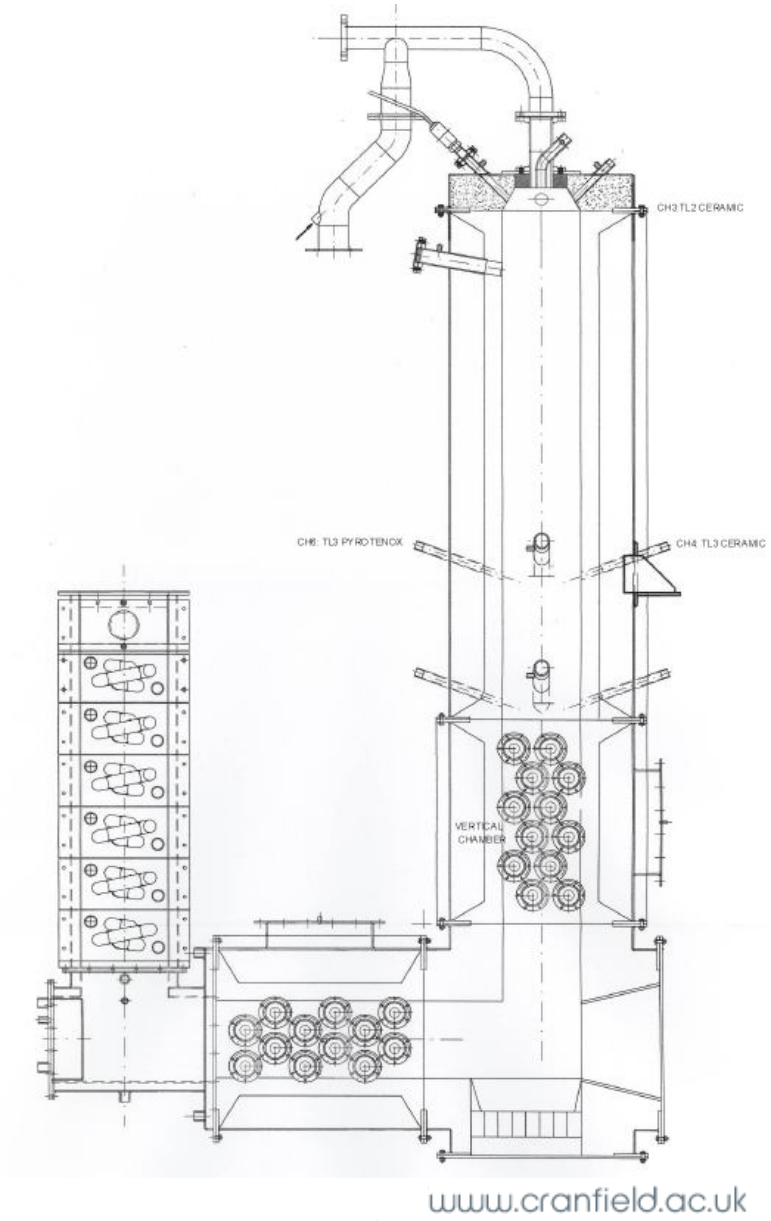


Experimental Results:
TEMPERATURES COMPARISON

Maximum Temperatures

- ✓Daw Mill 100% : 1100ºC
- ✓Daw Mill 50% - CCP 50% : 993ºC
- ✓CCP 100%: 848ºC





Experimental Results:
ASH DEPOSITS COMPARISON

Cranfield UNIVERSITY

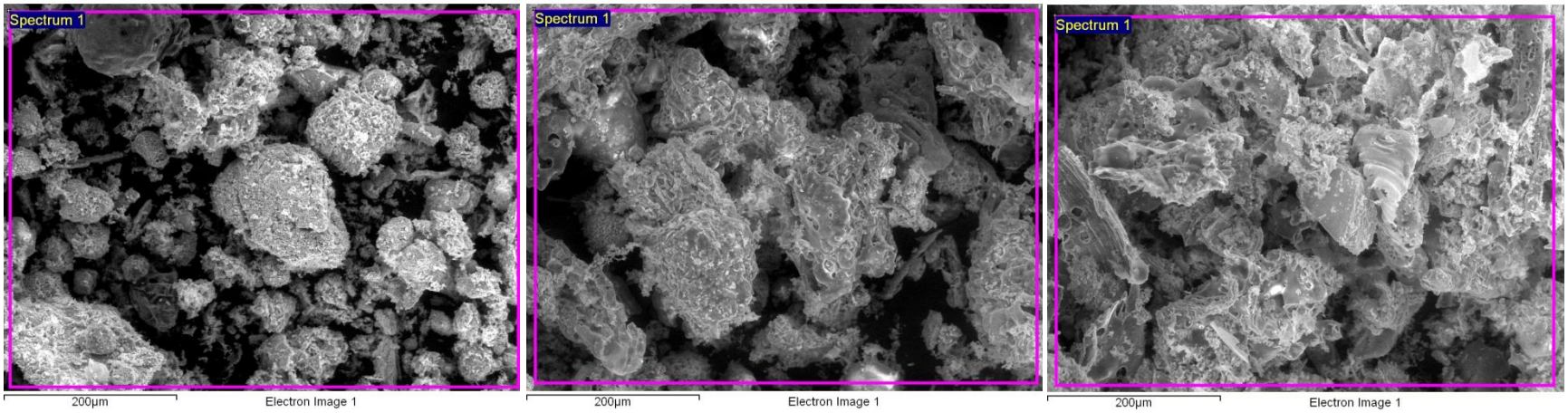
Ash Deposit Probe Daw Mill 50%-CCP 50%

- **More fibrous and porous texture of the deposits generated by 100%CCP**
- **Larger size of deposits particles from 100%CCP**

Ash Deposit Probe CCP 100%
100% CCP BIOMASS

100% DAW MILL COAL

50%DAW MILL COAL-50% CCP BIOMASS



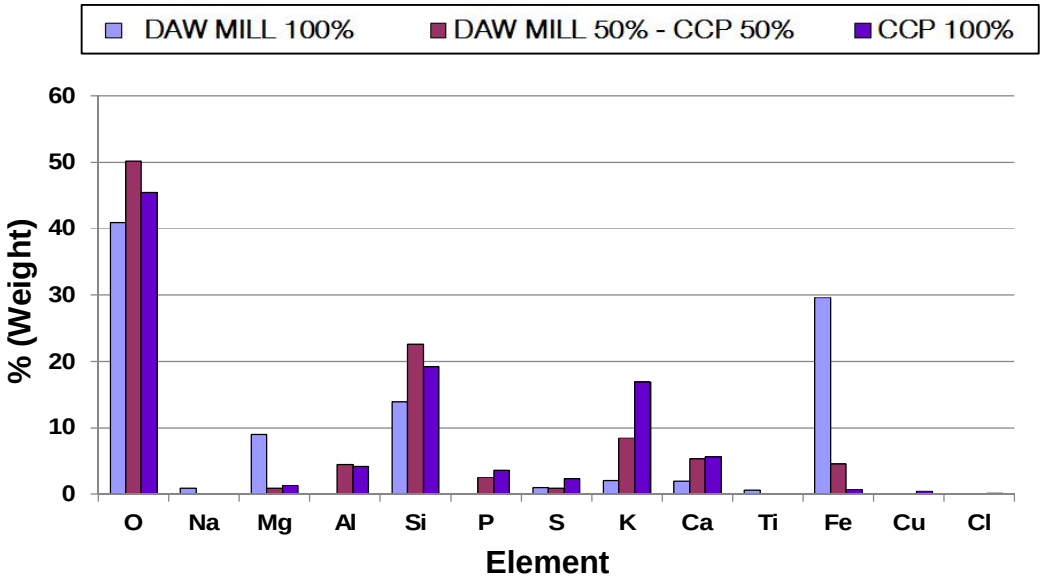
SEM images of the top deposits

Experimental Results:
ASH DEPOSITS COMPARISON

- S: higher retention in deposits in 100% CCP case
- K: higher content in the 100% CCP case

K_2SO_4 FORMATION

Corrosion Problems **associated with the use of biomass**



	SiO2	Al2O3	Fe2O3	TiO2	CaO	MgO	Na2O	K2O	Mn3O4	P2O5	SO3	BaO
DAW MILL	36.8	23.9	11.2	1.1	12	2.5	1.5	0.5	0.4	-	-	-
CCP	44.36	2.79	2.47	0.12	7.78	3.96	0.36	24.72	0.1	12.04	-	0.05

Previous ash Previous ash analysis supplied by EON

Next modifications

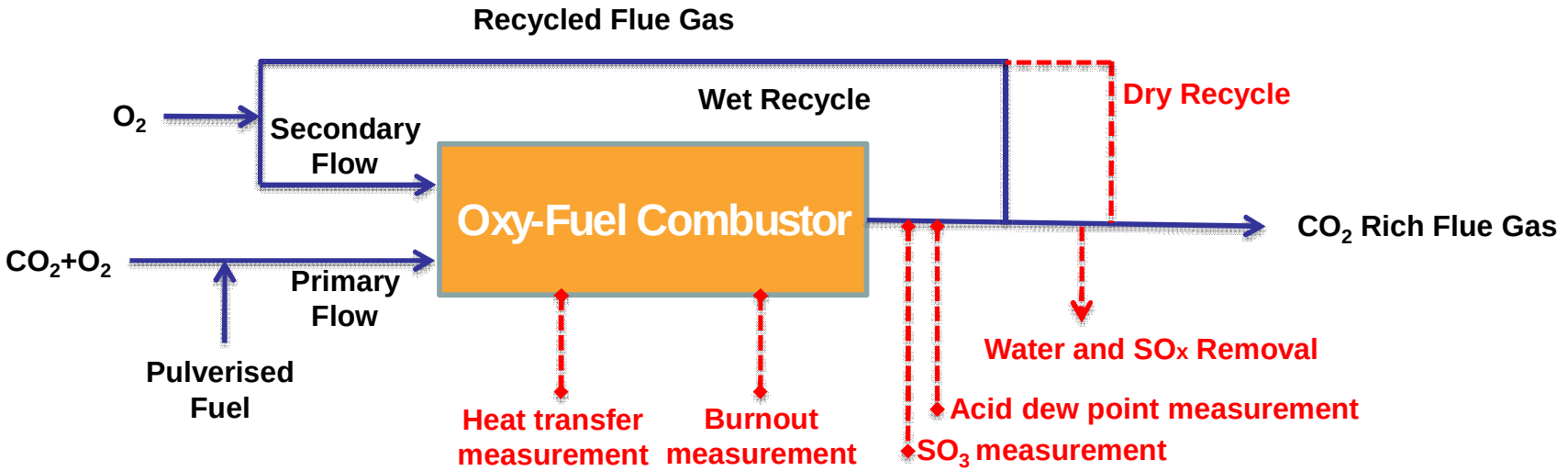
Cranfield UNIVERSITY

New measurements:

- ✓Acid dew point (CAPCIS Probe)
- ✓SO_3 (Controlled Condensation Method)
- ✓Heat transfer
- ✓Percentage of burnout

New flue gas conditioning:

- ✓Water and SOx removal



Flow diagram of the Cranfield oxy-fuel pulverised fuel fired combustor
(red: on-going modifications)

Multi- Fuel Combustion Rig at CERT: Condenser Installatio

Cranfield UNIVERSITY

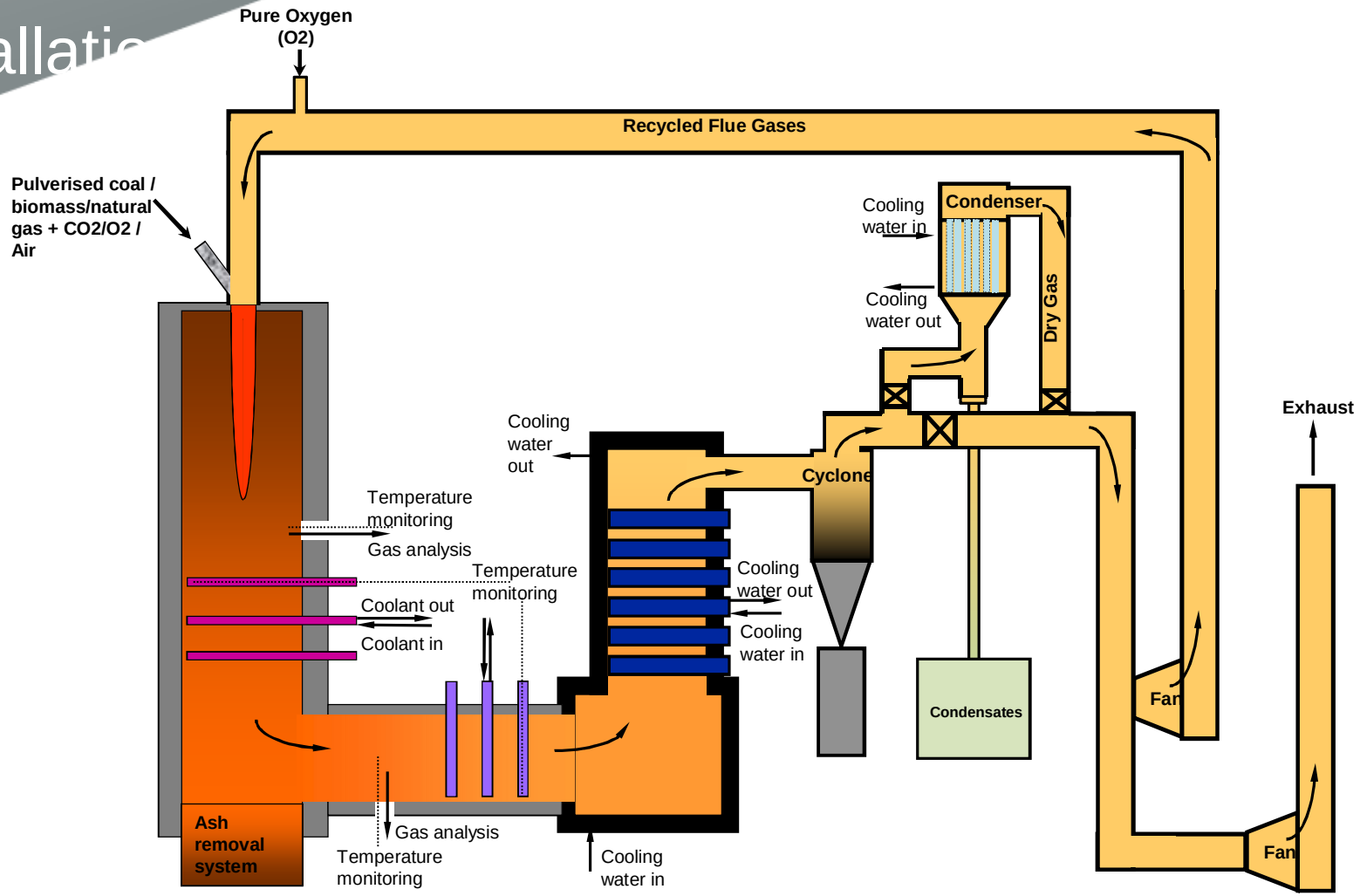


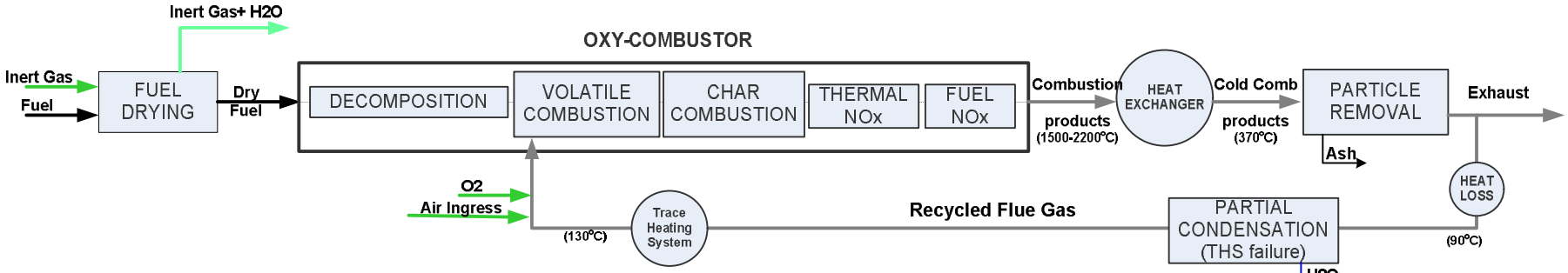
Diagram of 100kWth Oxy-Combustor with Condenser

Simulations using Aspen Plus®

Cranfield UNIVERSITY

KINETIC MODEL

	STAGE 1 Air-firing case	STAGE 2 Oxy-firing case with wet recirculation, heat loss and air leakage	STAGE 3 Oxy-firing case with partial condensation in RFG, heat loss and air leakage	STAGE 4 Oxy-firing case with dry recirculation, heat loss, air leakage	STAGE 5 Air-firing case with power generation unit	STAGE 6 Oxy-firing case with dry recirculation, heat loss, air leakage, ASU and power generation unit
AIR/ OXY-FIRING	Air -firing	Oxy -firing	Oxy -firing	Oxy -firing	Air -firing	Oxy -firing
RFG (%)	--	55, 60, 65, 70	55, 60, 65, 70	55, 60, 65	--	55, 60, 65
O_2 Exc (%) (v/v)	21	0,5,10	0,5	0,5	21	0,5
T_{RFG} (°C)	--	130	75,90	130	--	130-200
Air Leakage (% of Total Gas fed)	--	1.7	0, 2, 10, 18	10	--	10
Fuel	Coal	Coal (El Cerrejon, Daw Mill), Biomass(Cereal Co-Product, Miscanthus), blends of coal and biomass (75/25; 50/50; 25/75)	Daw Mill coal, Cereal Co-Product biomass, blends of coal and biomass (75/25; 50/50; 25/75)	El Cerrejon coal, Cereal Co-Product biomass, blends of coal and biomass (75/25; 50/50; 25/75)	Coal	El Cerrejon coal, Cereal Co-Product biomass, blends of coal and biomass (75/25; 50/50; 25/75)
RFG Purification	Particle removal	Particle removal	Particle removal	Particle removal, acid species and water vapour condensation	Particle removal, acid species and water vapour condensation	Particle removal, acid species and water vapour condensation

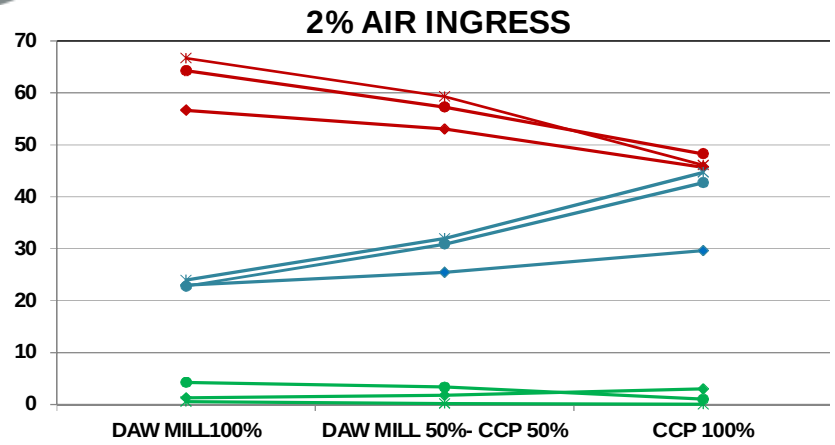


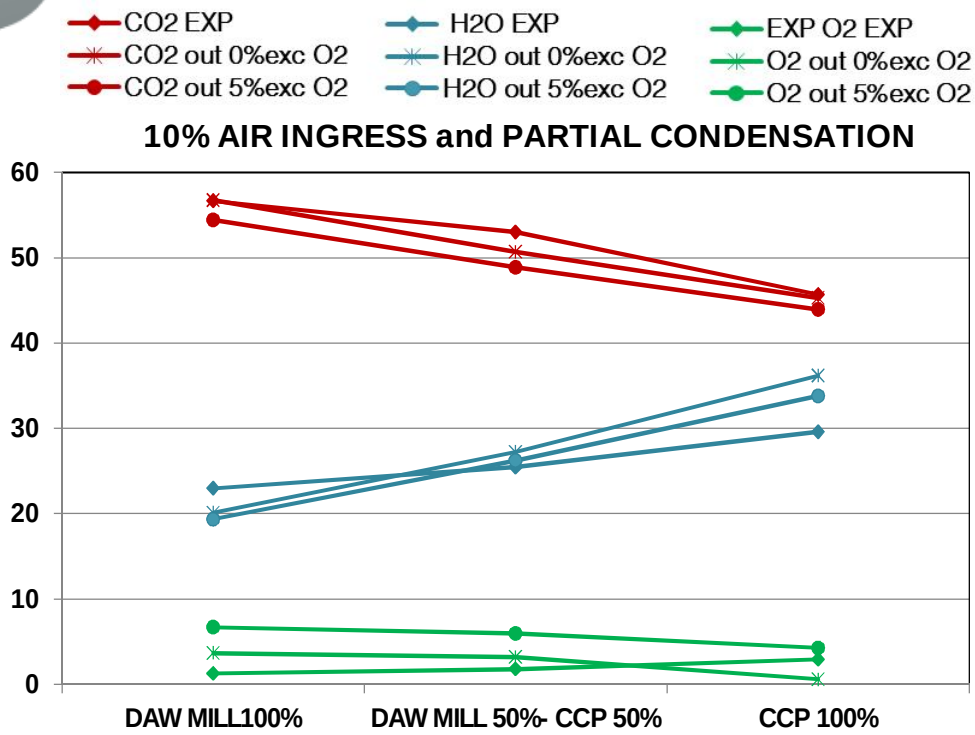
Box- plot of the Rate-based Model (Stage 3)

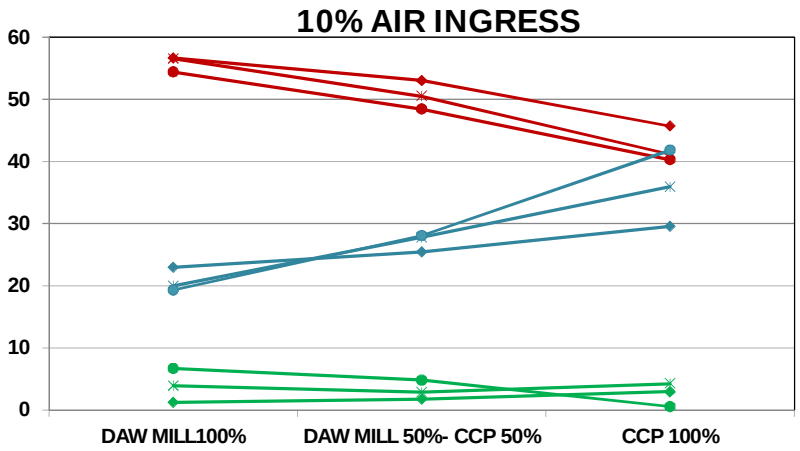
Simulations using Aspen Plus®:

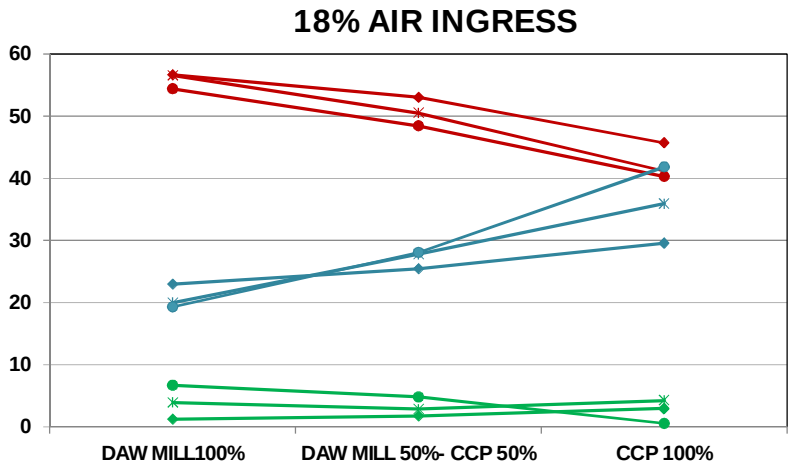
AIR INGRESS COMPARISON

Cranfield UNIVERSITY

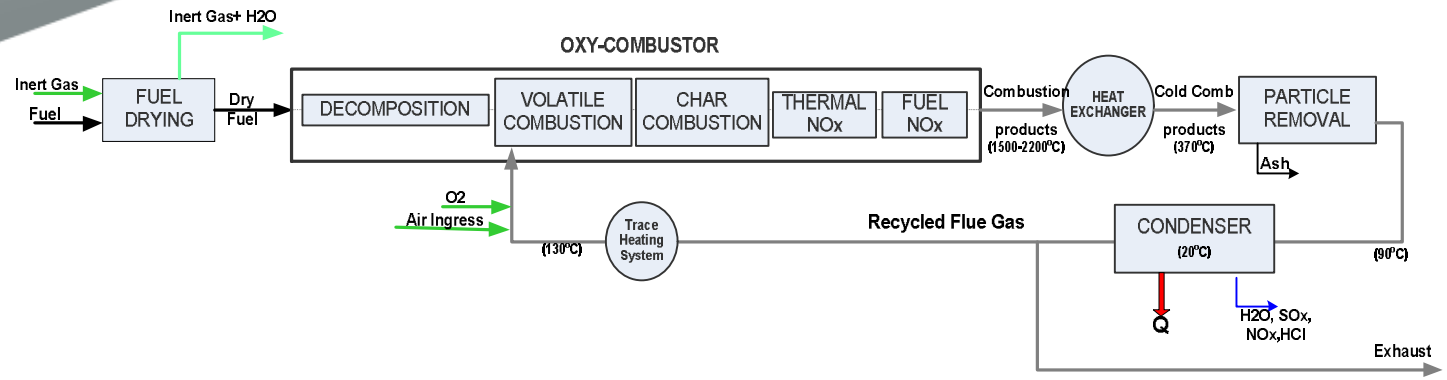




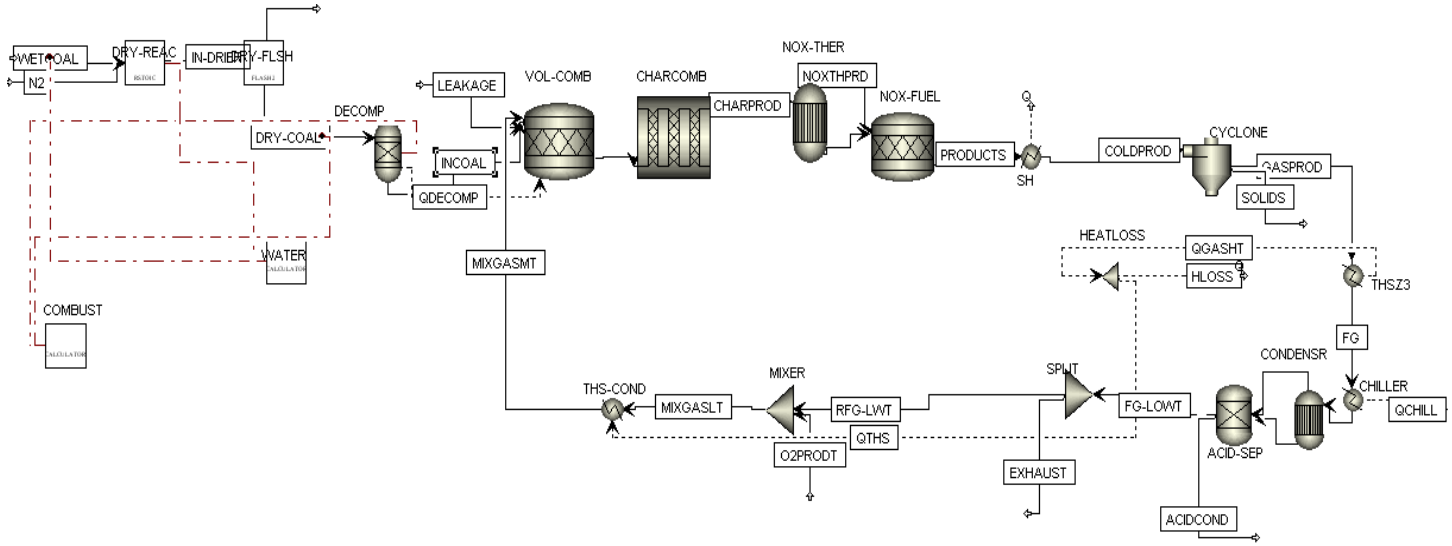




Simulations using Aspen Plus®:
DRY RECYCLE FLUE GAS



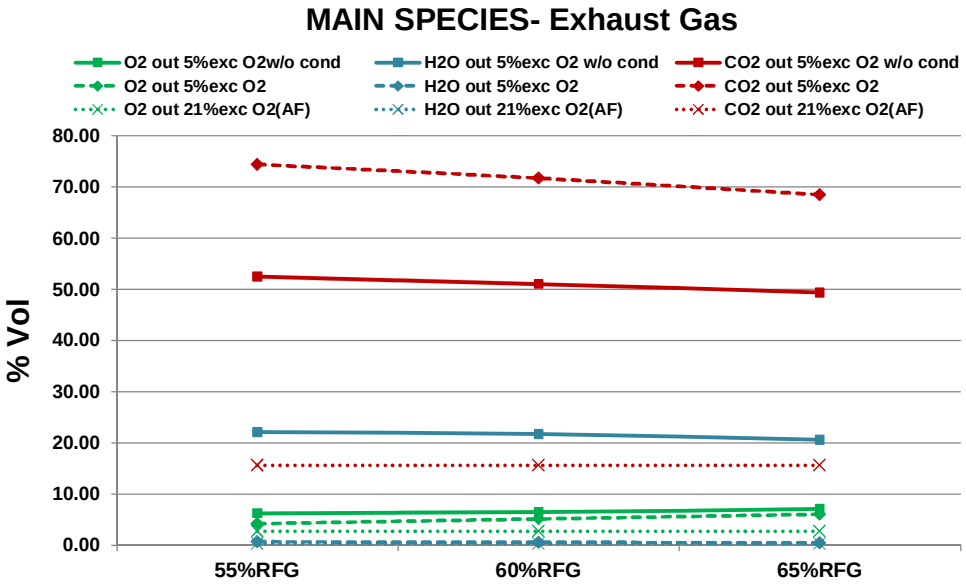
Box- plot of the Rate-based Model with Dry Recycle Flue Gas (Stage 4)

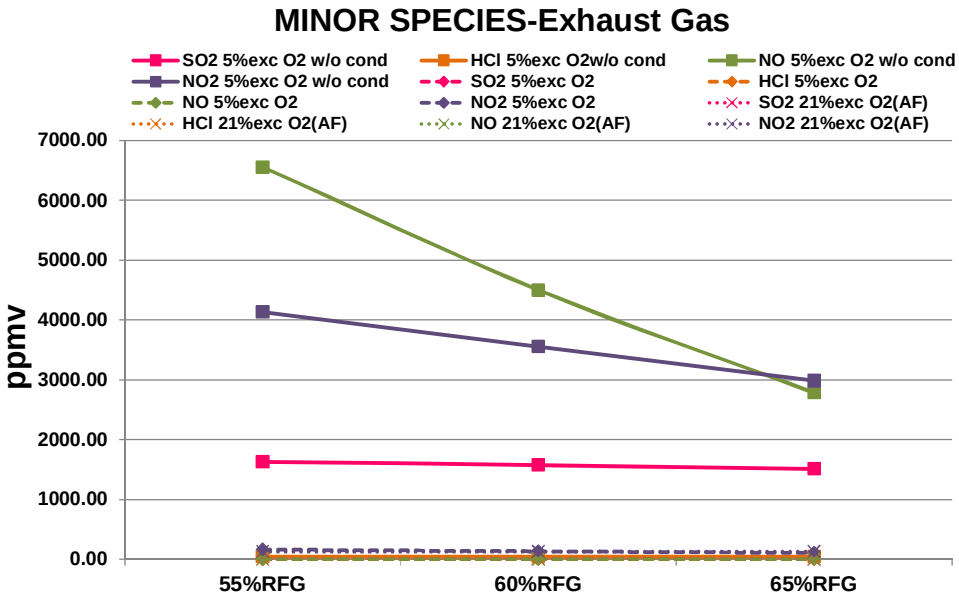


Interface of the rate-based model with dry RFG in Aspen Plus (Stage 4)

Simulations:
DRY RECYCLE FLUE GAS EFFECT ON THE EXHAUST

- CO_2 increases 20% (v/v) as consequence of implementation of the condenser
- H_2O decreases at the same proportion to the increase of CO_2





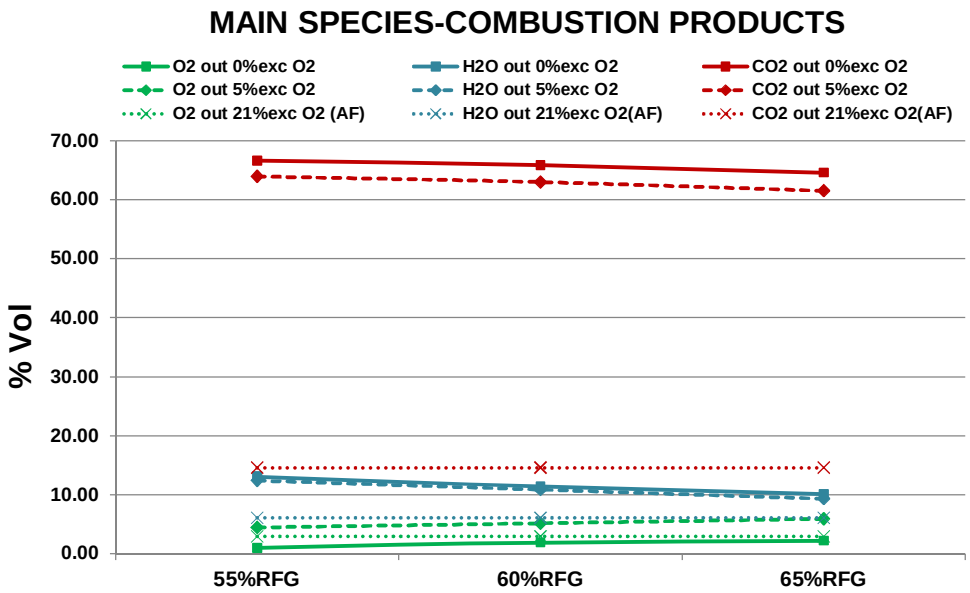
- All minor species drop to near zero content in the exhaust gas, in the cases where the condenser was used
- There is a decrease of NO and NO_2 levels, at higher % RFG, due to dilution
- Not good prediction for HCl, NO and NO_2
- Condensates composition:

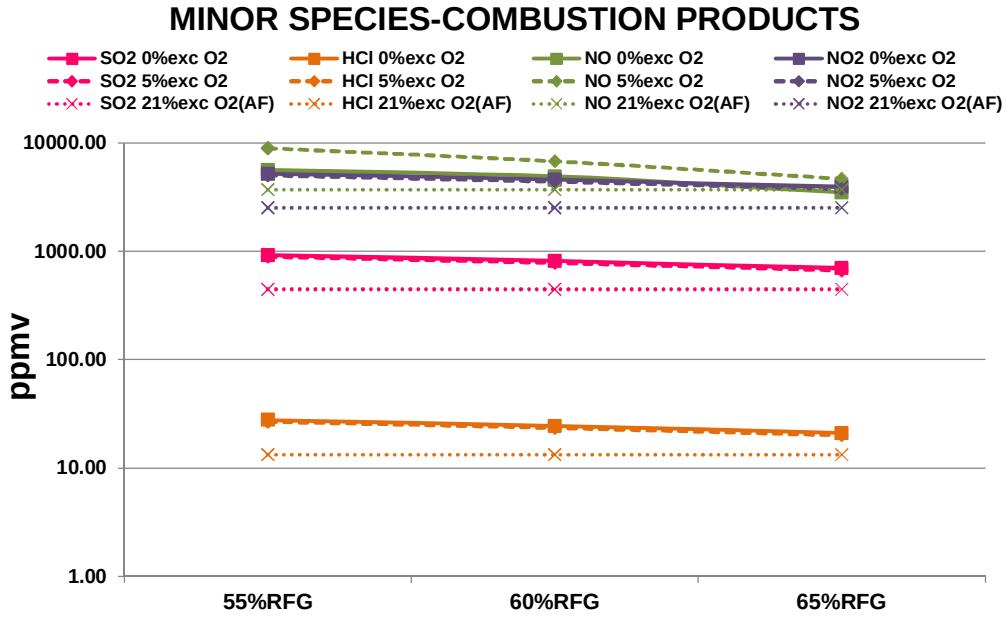
	H_2O (% v/v)	H_2SO_4 (% v/v)	HNO_3 (% v/v)	HCl (% v/v)
OXY-FIRING 60% RFG 0% O_2 exc	90.96	0.72	8.29	0.02
OXY-FIRING 60% RFG 5% O_2 exc	89.13	0.71	10.13	0.02
AIR-FIRING	89.18	0.73	10.05	0.02

Simulations:
DRY RECYCLE FLUE GAS EFFECT ON THE COMBUSTION PRODUCTS

Cranfield UNIVERSITY

- Max. CO_2 at the exit of oxy-combustor 66.6%(v/v) versus 14.6 % (v/v) reached for air-firing
- No significant changes in H_2O content at different % RFG, between 10 and 12.5% (v/v)





- Comparison with air-firing:
  - ✓ SO_2 : 900 vs 450 ppmv
  - ✓ HCl: 24 vs 13 ppmv
  - ✓ NO: 8000 vs 3500 ppmv
  - ✓ NO_2 : 5000 vs 2500 ppmv

In general, oxy-firing doubles minor species concentration versus air-firing cases

- Minimal effect on the minor species when changing the % RFG and the excess of O_2 fed (exemption NO content)

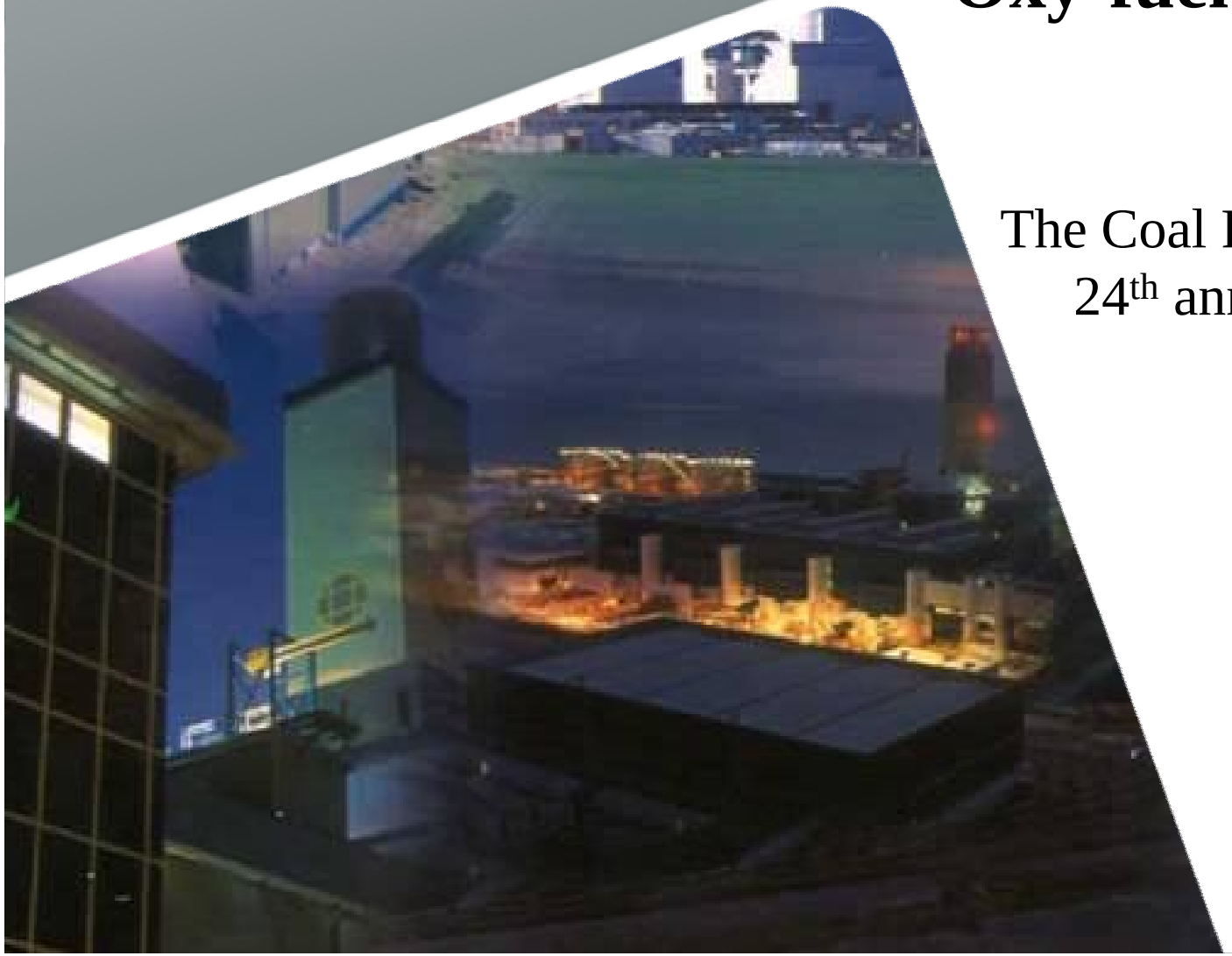
Summary

- **Experimental results showed are in the range proposed by other researchers. Max. concentration of CO_2 reached in experiments: 56.7%(v/v) (Wet basis)**
- **The air ingress has been deduced to be of 10% of the total flue gas fed to the combustor**
- **Ash deposits analysis has shown their high corrosion potential in the 100% CCP case due to K_2SO_4 formation**
- **On-going modifications of the rig have been presented:**
  - **Water and SOx condenser**
  - **New measurements (Acid dew point, SO_3, heat transfer, % burnout)**
- **Kinetic Simulation Model has been developed with acceptable accordance with experimental results**
- **Simulation model including equipment for CO_2 purification predicts remarkable increase of the $\%CO_2$ contents**

Centre for Energy and Resource Technology

Cranfield UNIVERSITY

Process Conditions in Oxy-fuel Combustion



The Coal Research Forum
24th annual meeting

Nelia Jurado
Hamid G Darabkhani
John E Oakey

Cranfield University

10th April 2013

http://www.cranfield.ac.uk