Ponferrada - Spain
9th-13th September 2013

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Co-Firing Performance of a Retrofitted Oxy-Combustor: Experimental and Simulation Study

Centre for Energy and Resource Technology
Cranfield University

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Background and Scope

Study the oxy-combustion process to understand the possible compensation in the heat transfer by co-firing blends of coal and biomass

- *Experimental trials in a retrofitted 100 kWth Oxy-combustor*
- *Design of a rate-based simulation model which will be used as a tool to select future test parameters*

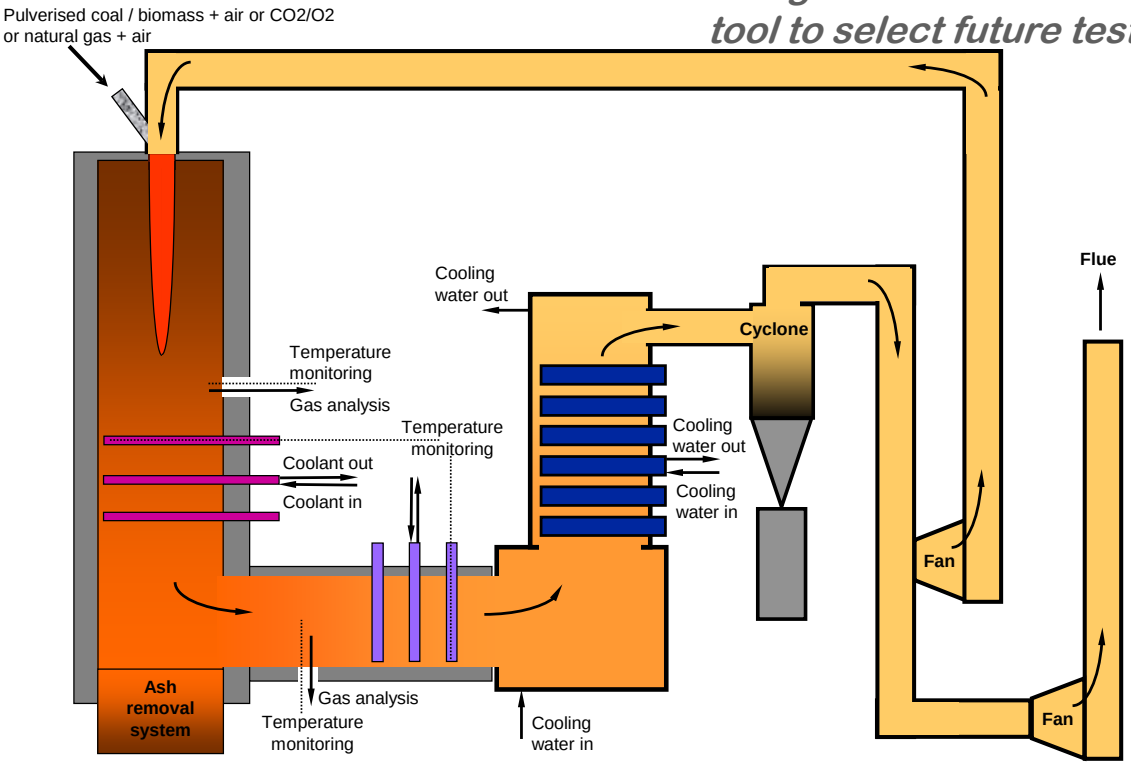
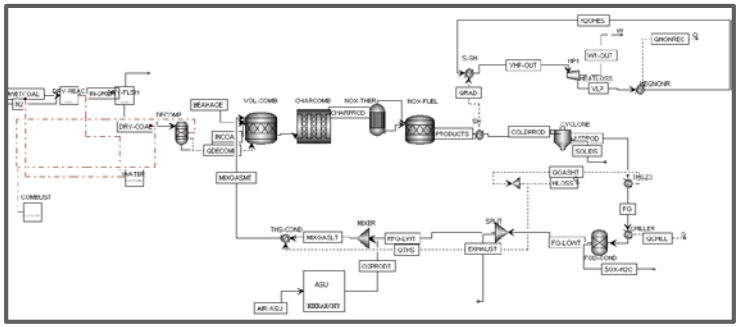


Diagram of 100kWth Multi-fuel Oxy-Combustor at CERT



Simulation of Oxy-Combustion process using Aspen Plus

Retrofitting Process
INITIAL MODIFICATIONS

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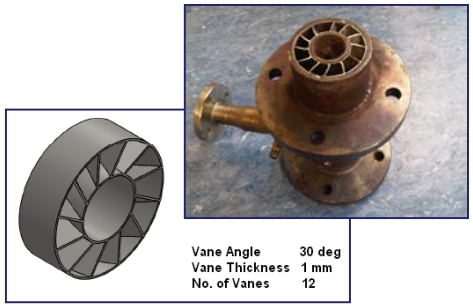
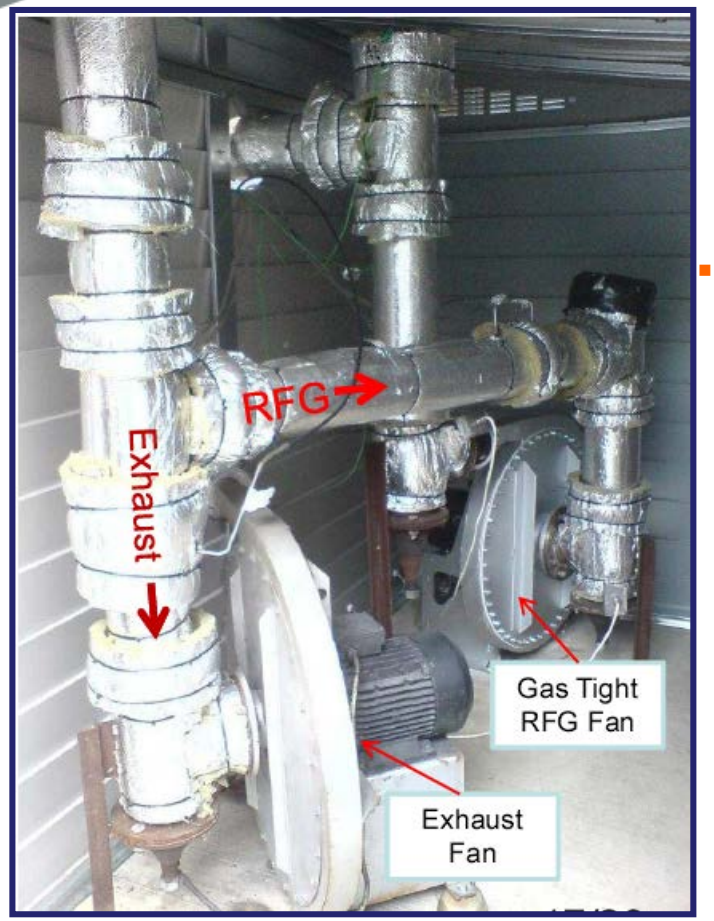
- Swirler of the Burner



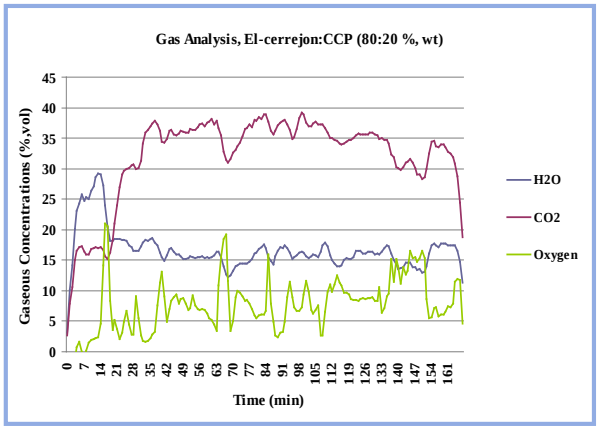


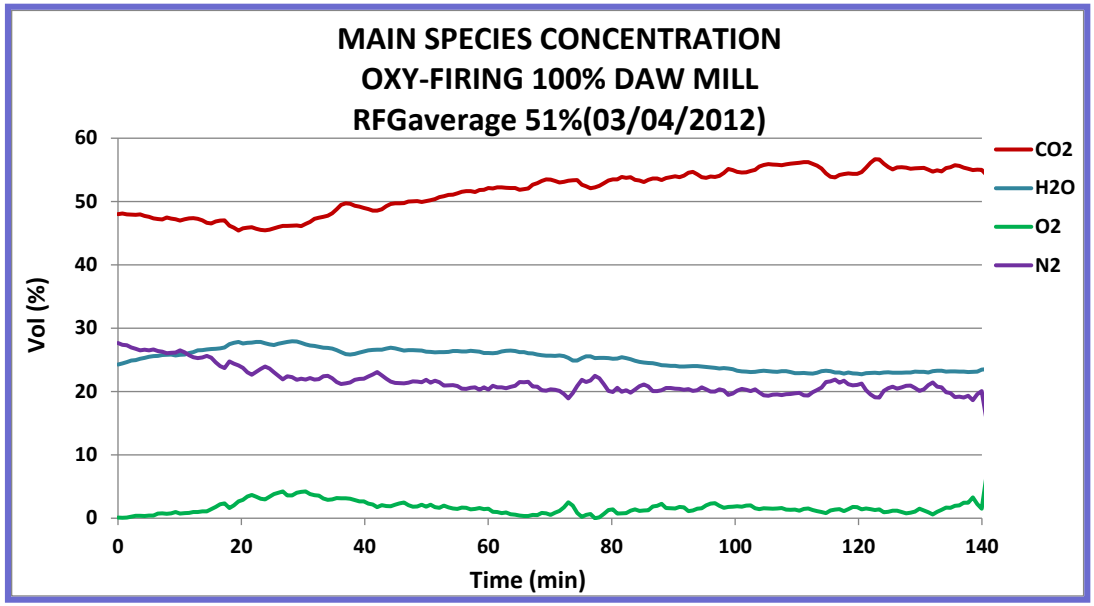
- RFG System
  - ✓ Gas tight fans
  - ✓ Thermal conditioning of the RFG

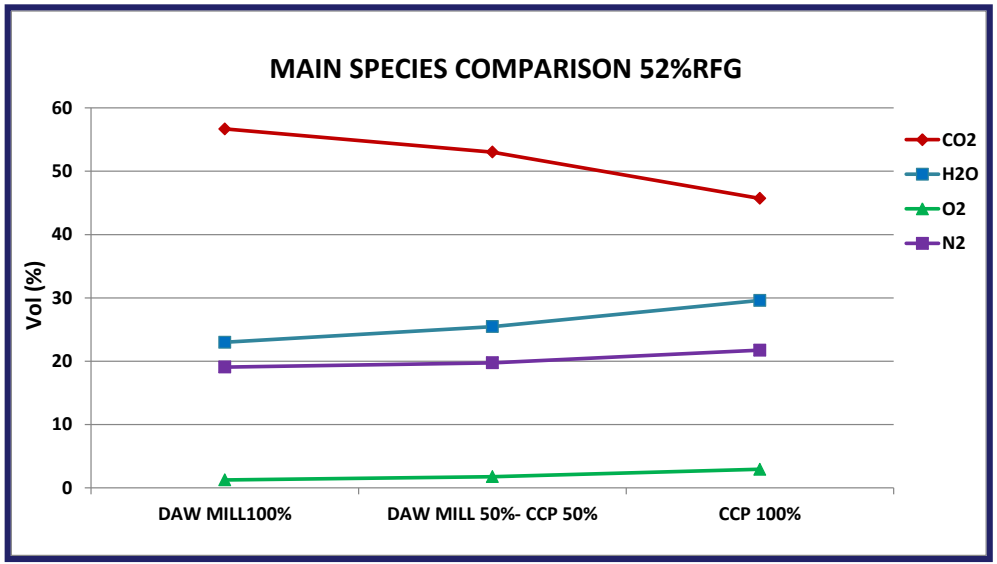
- New Fuel Feeder

Retrofitting Process

EXPERIMENTAL RESULTS PREVIOUS STAGES







- Maximum CO_2 when burning coal
  56.7 % wet basis
  74 % dry basis
- The water vapour concentration increases with the percentage of CCP in fuel
  H_2O ~ 23-30 %
- Oxygen in excess too low (30% fed)
  O_2~ 1.5% (v/v)

Stable operation

Retrofitting Process
LATEST MODIFICATIONS

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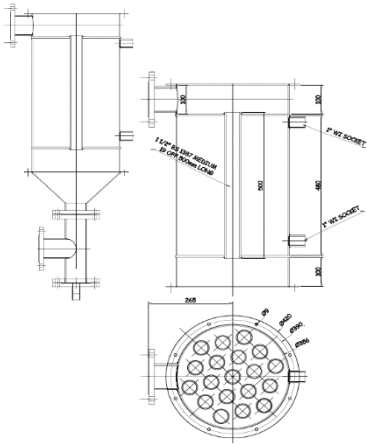
CONDENSER



Technichal detail of condenser

Condenser

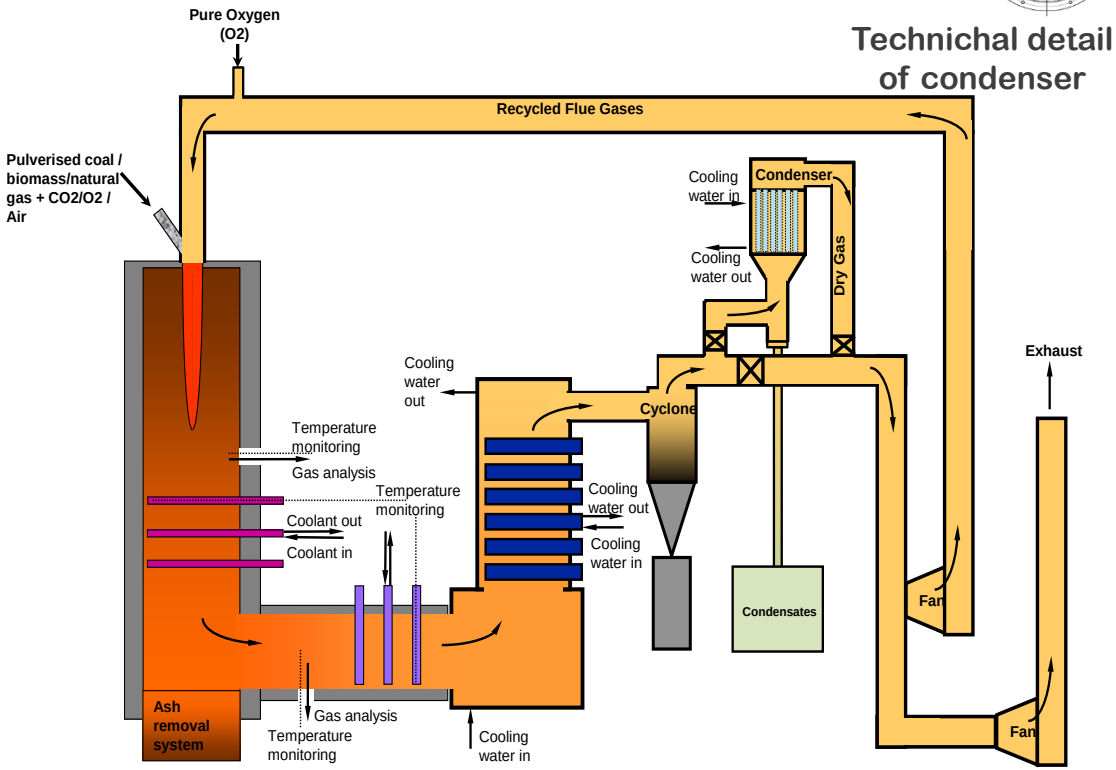


Diagram of 100kWth Oxy-Combustor with Condenser

Retrofitting Process
LATEST MODIFICATIONS

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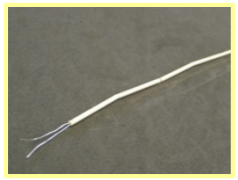
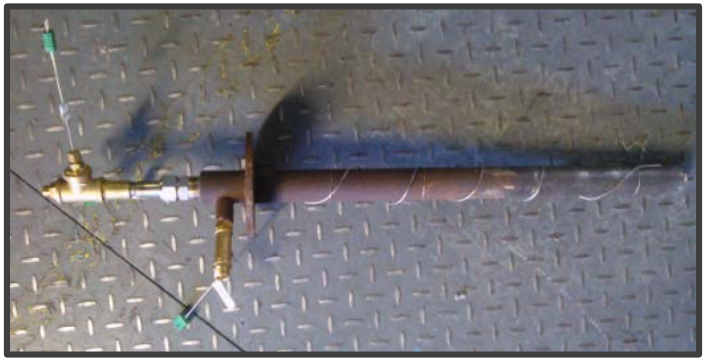


Type R thermocouple with ceramic beading

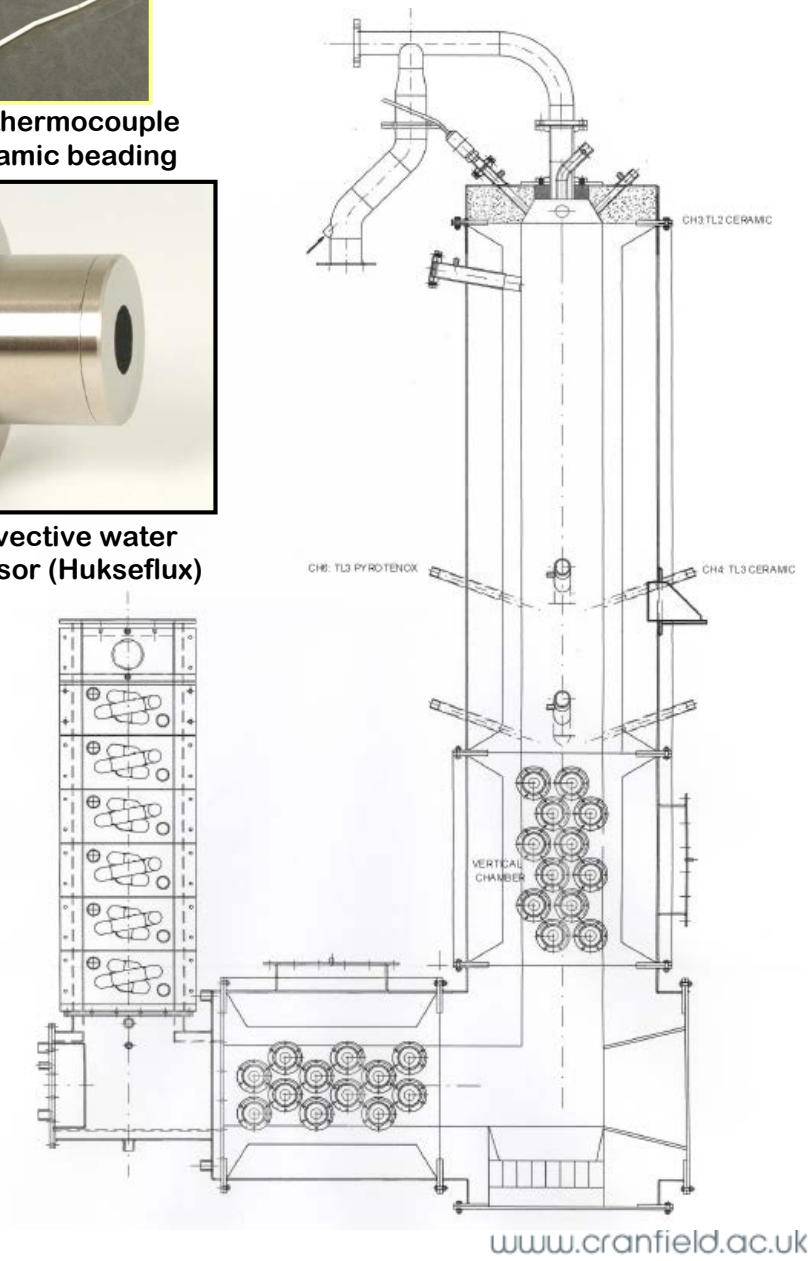
HIGH T
AND
HEAT TRANSFER FLUX

Radiative and convective water cooled heat flux sensor (Hukseflux)

Engineered heat flux sensor (Hukseflux)



In-house air-cooled probe for convective heat flux measurement



Retrofitting Process
LATEST MODIFICATIONS

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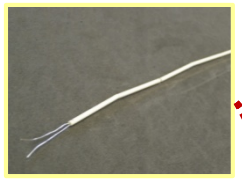

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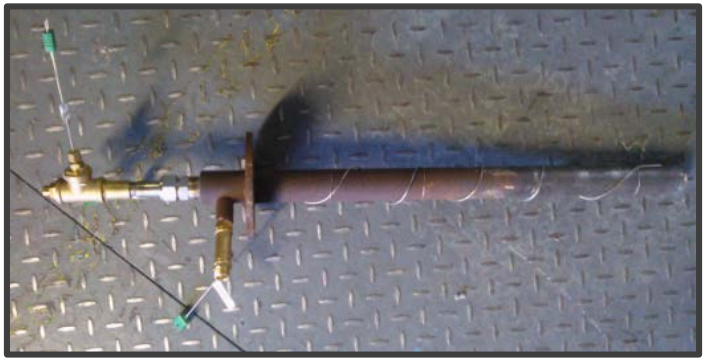

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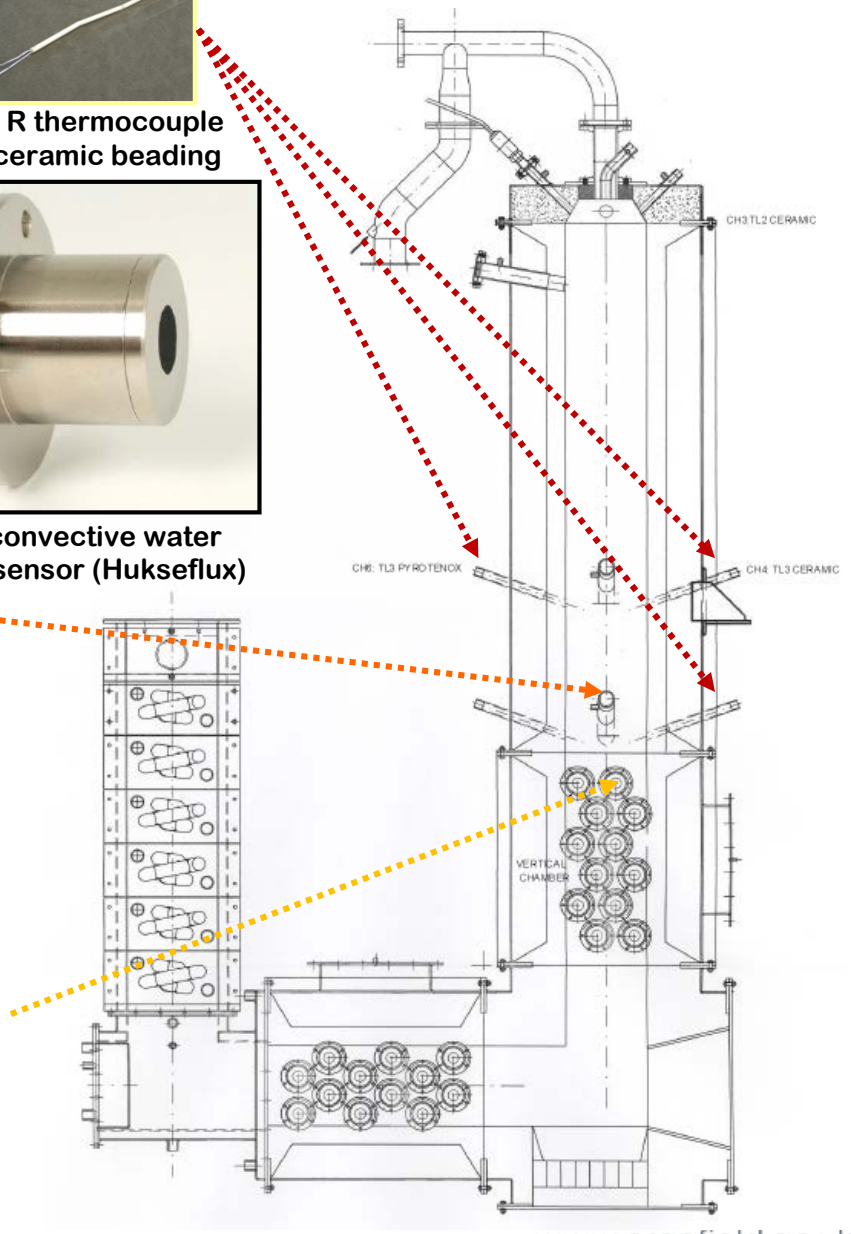

Retrofitting Process
LATEST MODIFICATIONS

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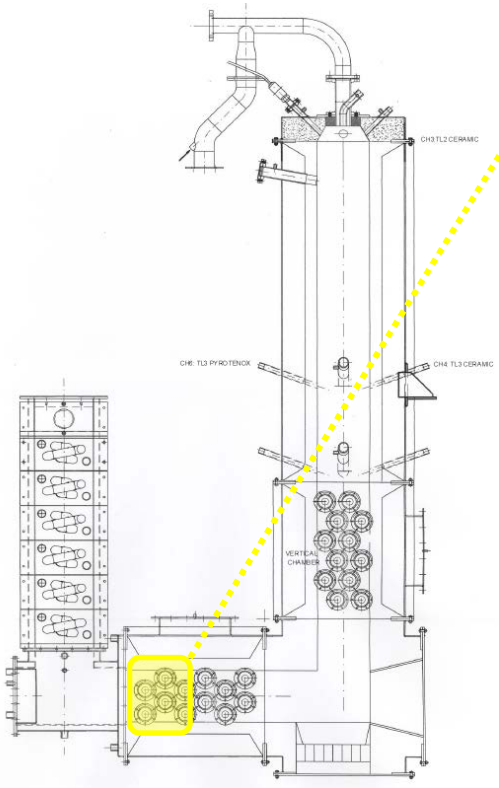
SO_3 MEASUREMENT
Controlled Condensation Method (EPA Method 8A)



Location of the sampling point

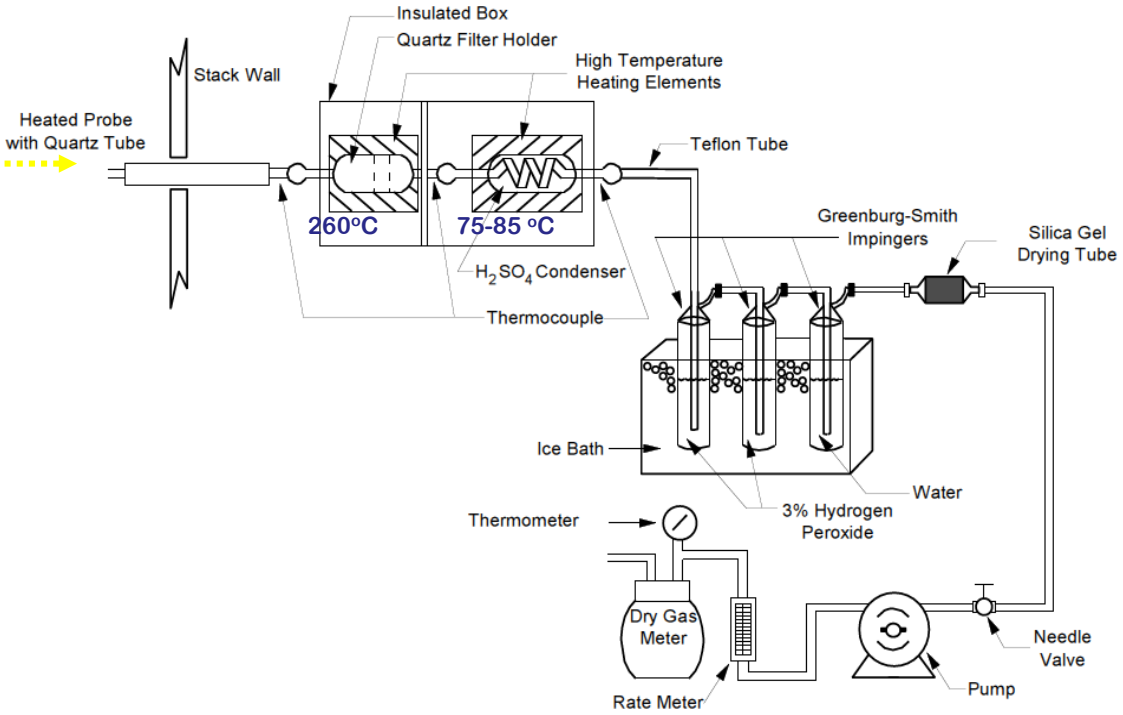


Diagram for SOx sampling train proposed in EPA Method 8A

Sampling train is currently being manufactured

Retrofitting Process
LATEST MODIFICATIONS

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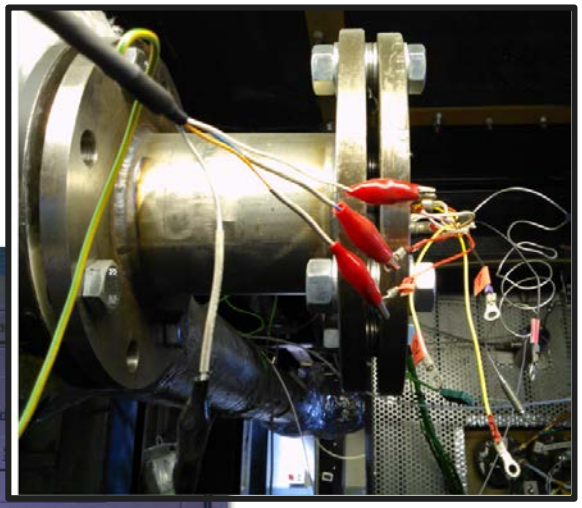
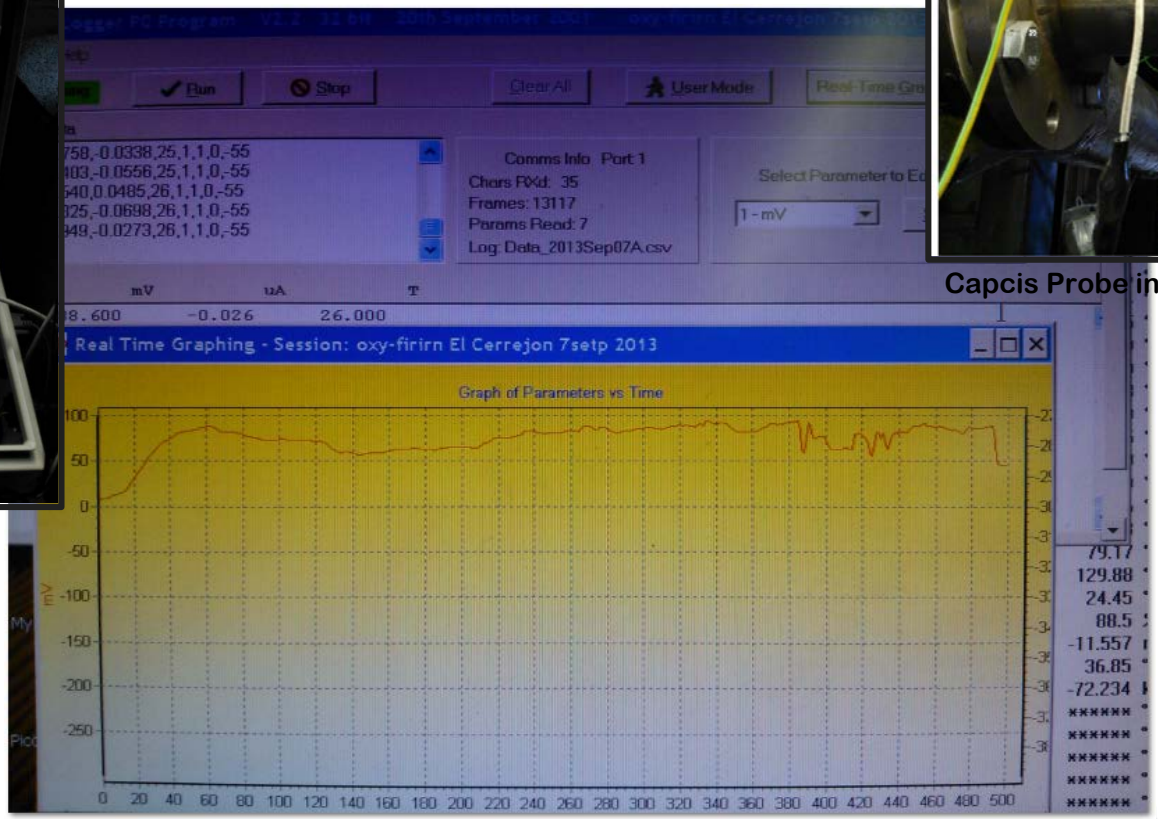
ACID DEW POINT MEASUREMENT

Capcis Box



Capcis Probe installed in Recirculation line



Data acquisition system

Retrofitting Process
LATEST MODIFICATIONS

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UNEXPECTED CHANGES

Retrofitting Process
LATEST MODIFICATIONS

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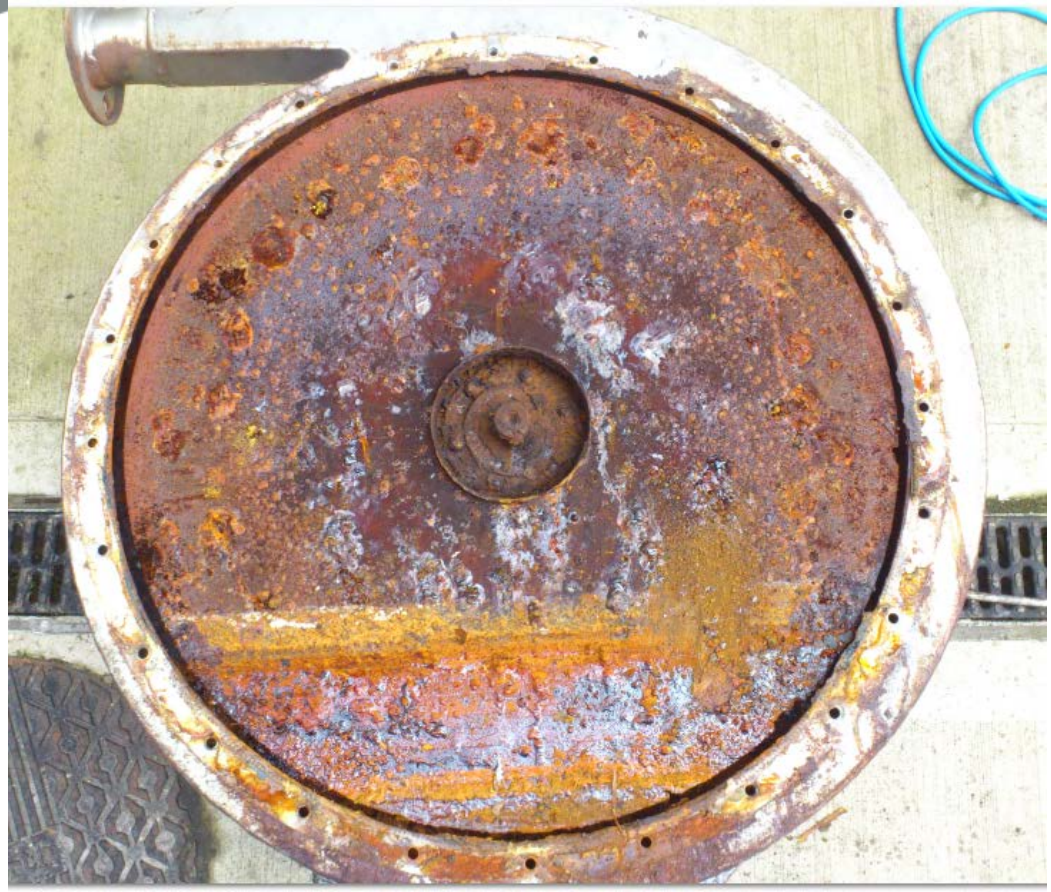
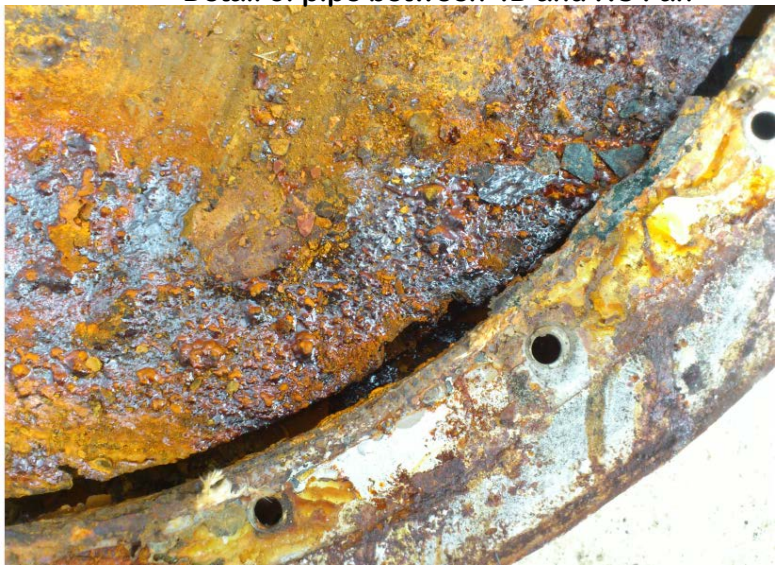
FANS CORROSION

Detail of pipe between ID and RC Fan



ID Fan



Detail of impeller of ID Fan

Retrofitting Process
LATEST MODIFICATIONS

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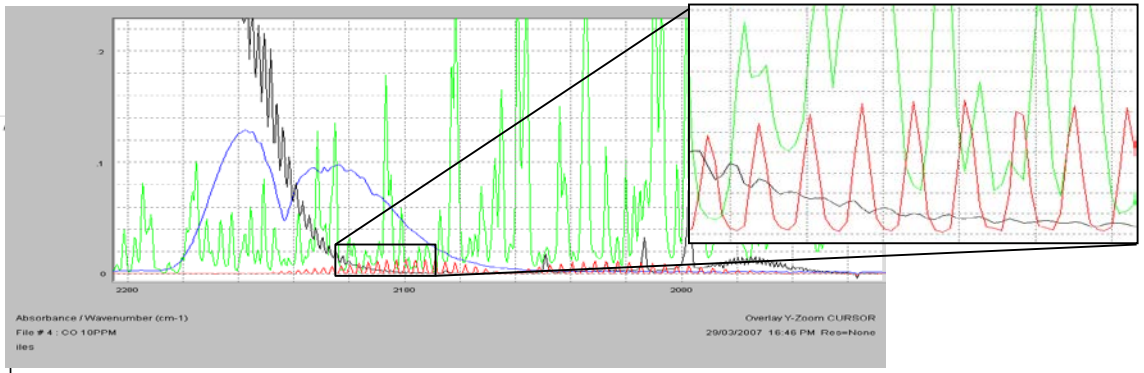
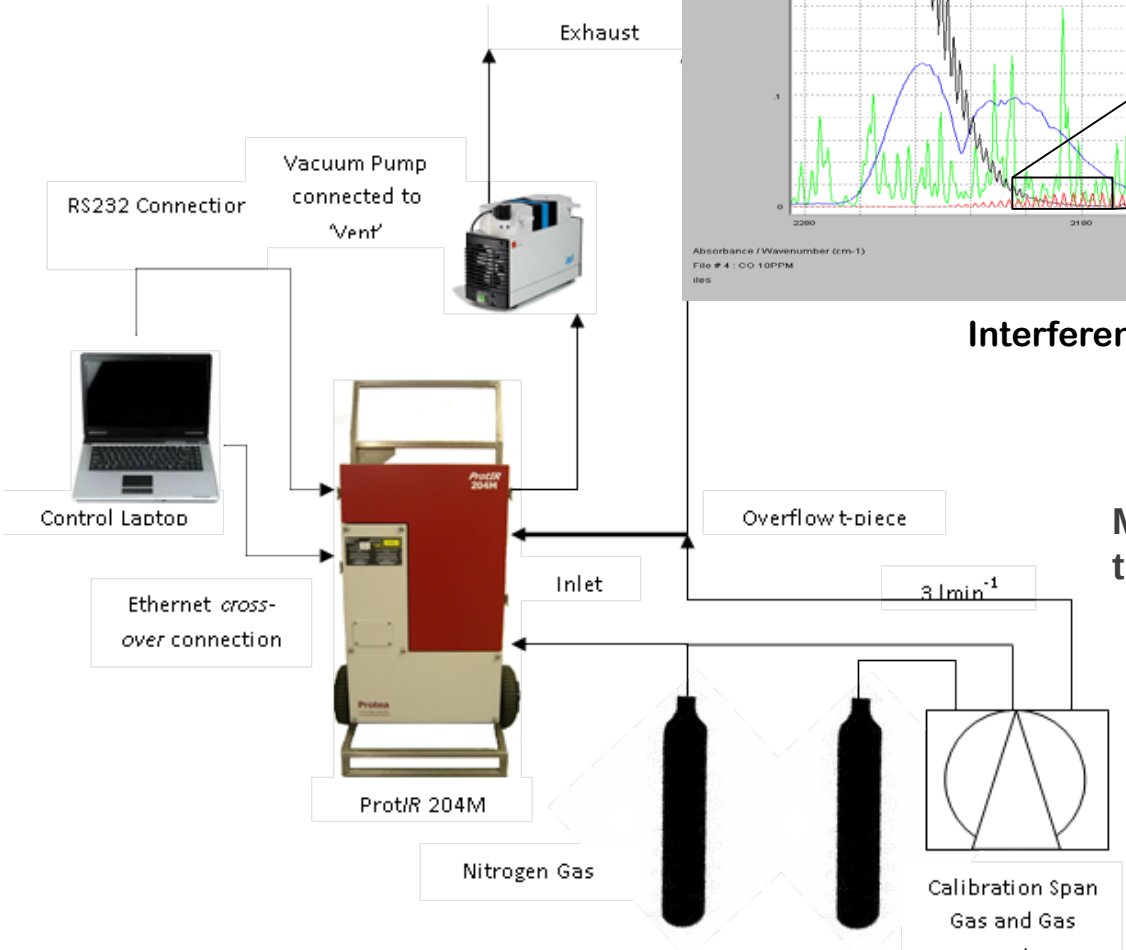
NEW MODEL to use FTIR after the CONDENSER



Interference with CO_2 and water



Maximum concentrations measured with the Conventional Combustion Method:

CO_2	60 % wet basis
H_2O	40 %

Experimental Test
INPUTS

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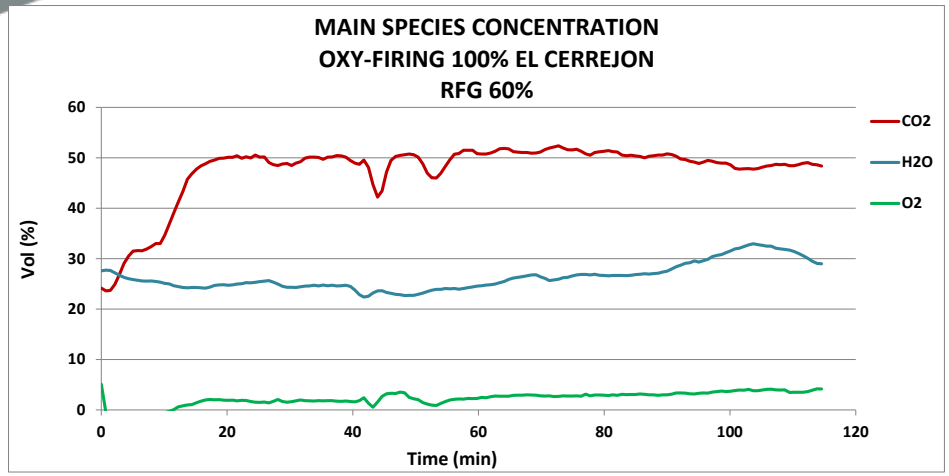
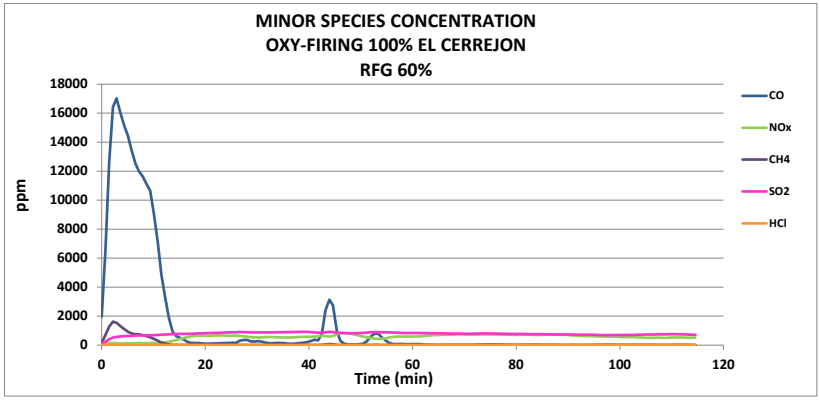
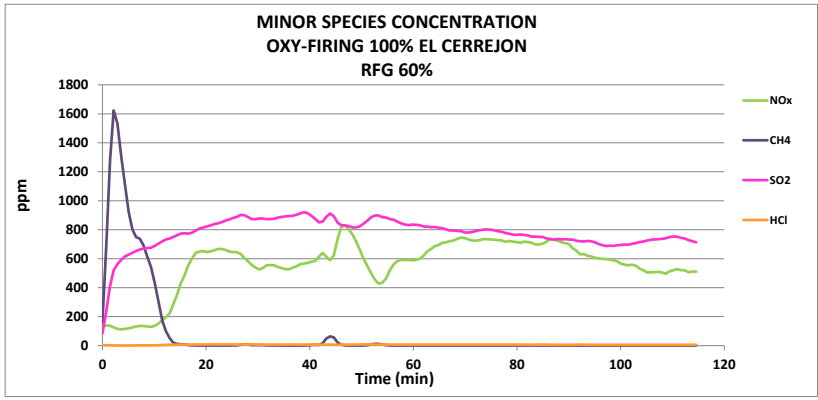
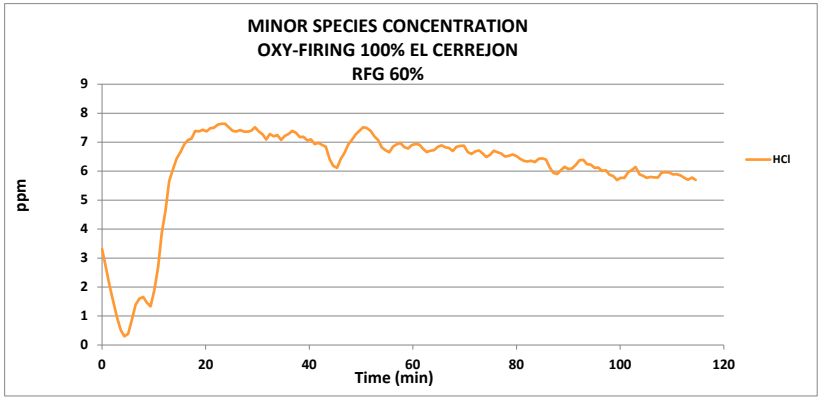
- Type of fuel: El Cerrejon Coal 13.5kg/h
- Percentage of Recycled Flue Gas :60-65%
- Types of Recycled Flue Gas
  - Wet- Hot Recirculation (After Particle Removal): First stage of test
  - Dry – Cool Recirculation (After Particle, Condenser); Second Stage
- Oxygen Injection
  - Primary O_2 (Fuel carrier draught): Not Used
  - Secondary $O_{2:}$; 35-40% in gas fed

Experimental Test
RESULTS
Gas Composition









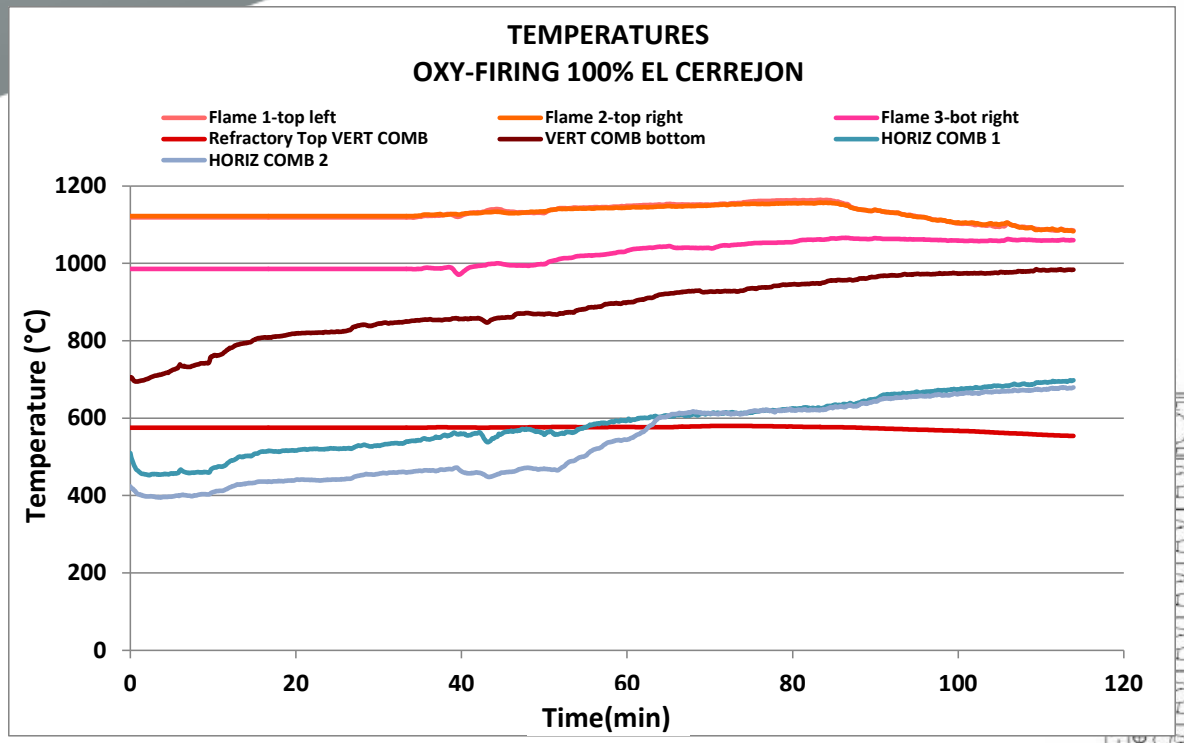
- Maximum CO_2 : 53 % wet basis [71 % (d. b.)]
- H_2O ~ 26% (v/v)
- O_2~ 2.8% (v/v)
- Average values minor species

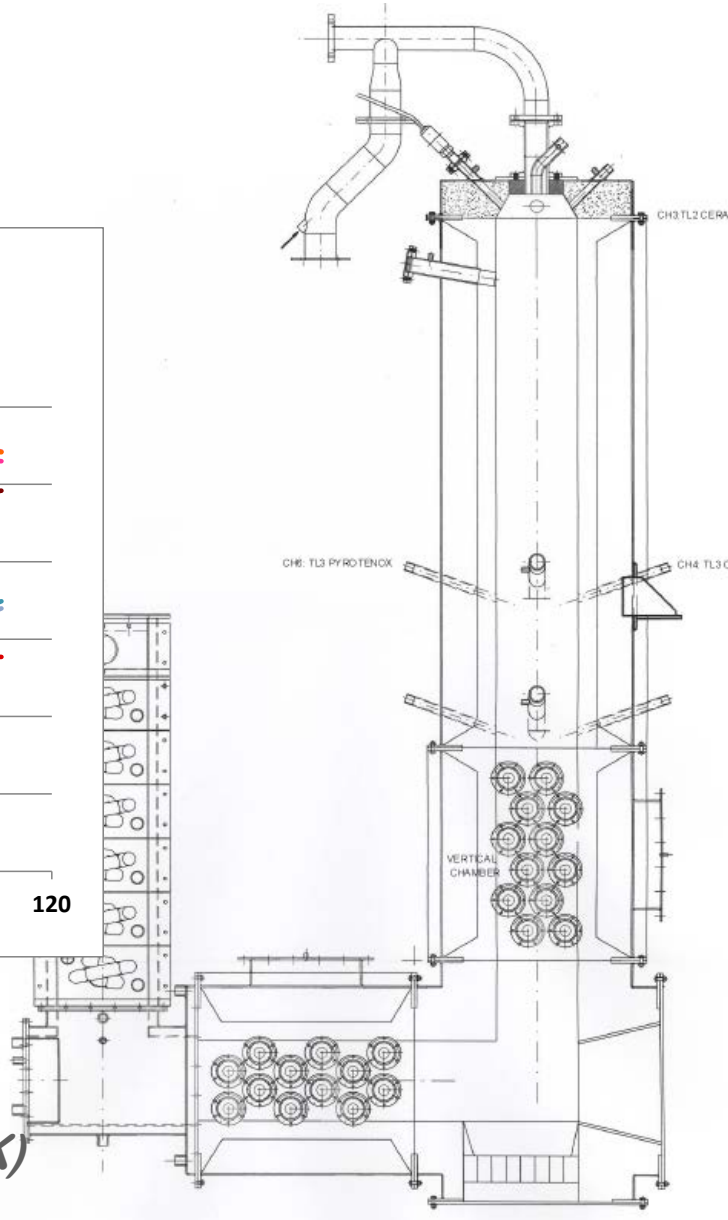
SO_2	770ppm
NOx	560ppm
CO	1400ppm
HCl	6ppm

Experimental Test

RESULTS

Temperatures



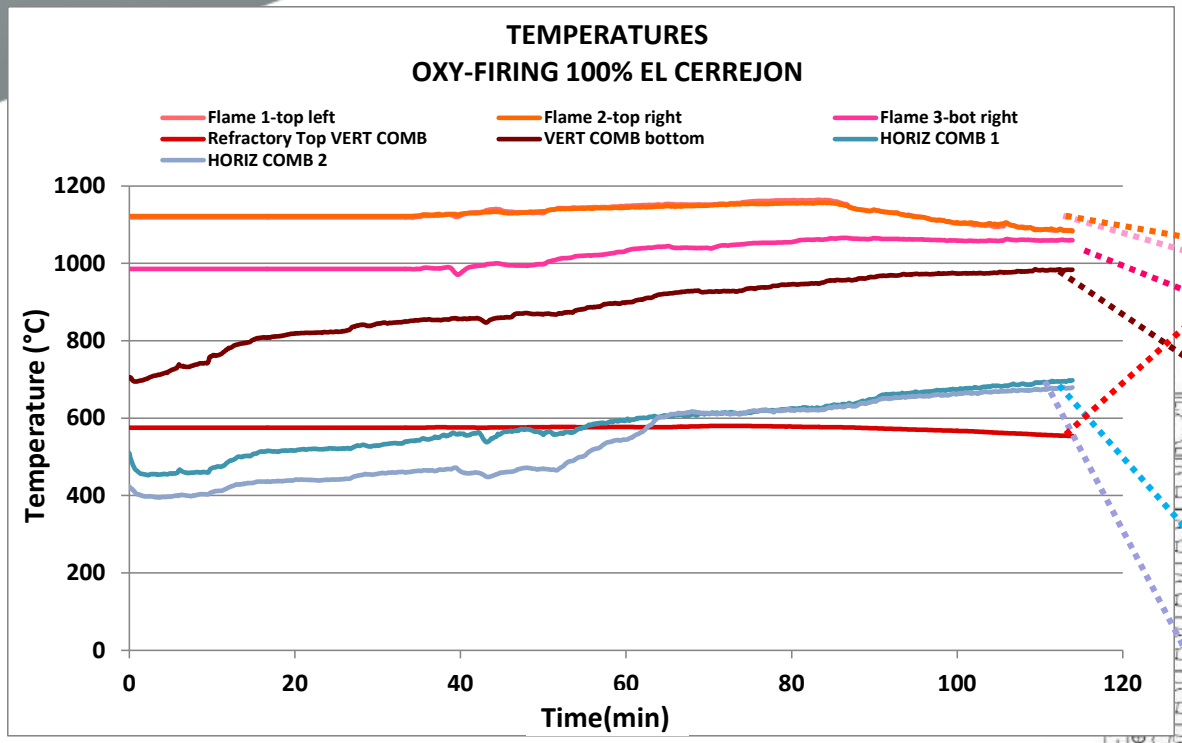


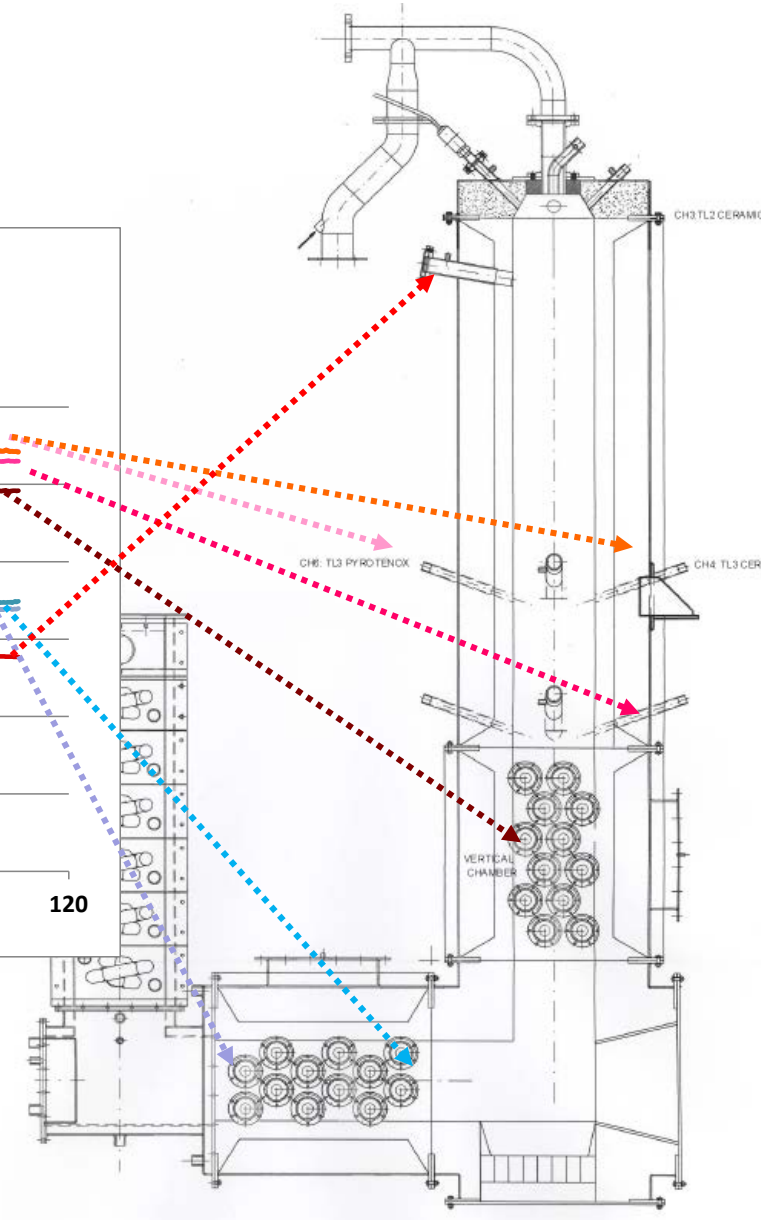
Maximum temperature reached was1165ºC (1440K)

Experimental Test

RESULTS

Temperatures





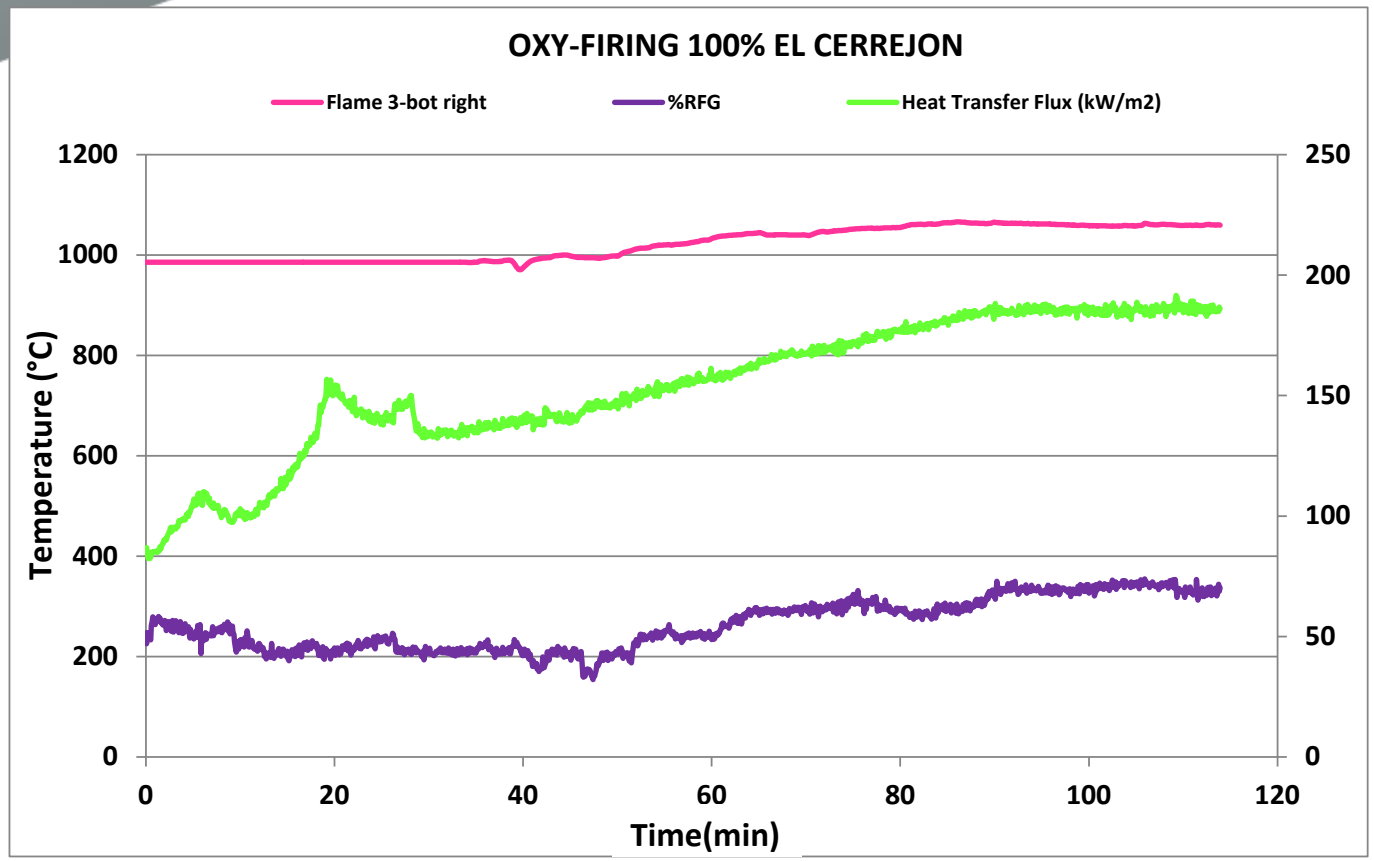
Maximum temperature reached 1440K

Experimental Test

RESULTS

Heat flux

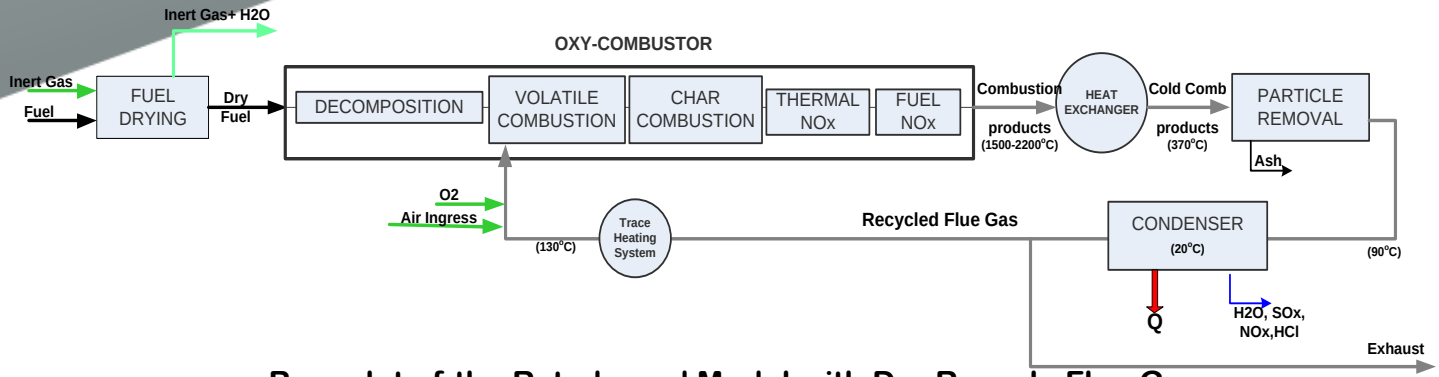
%RFG



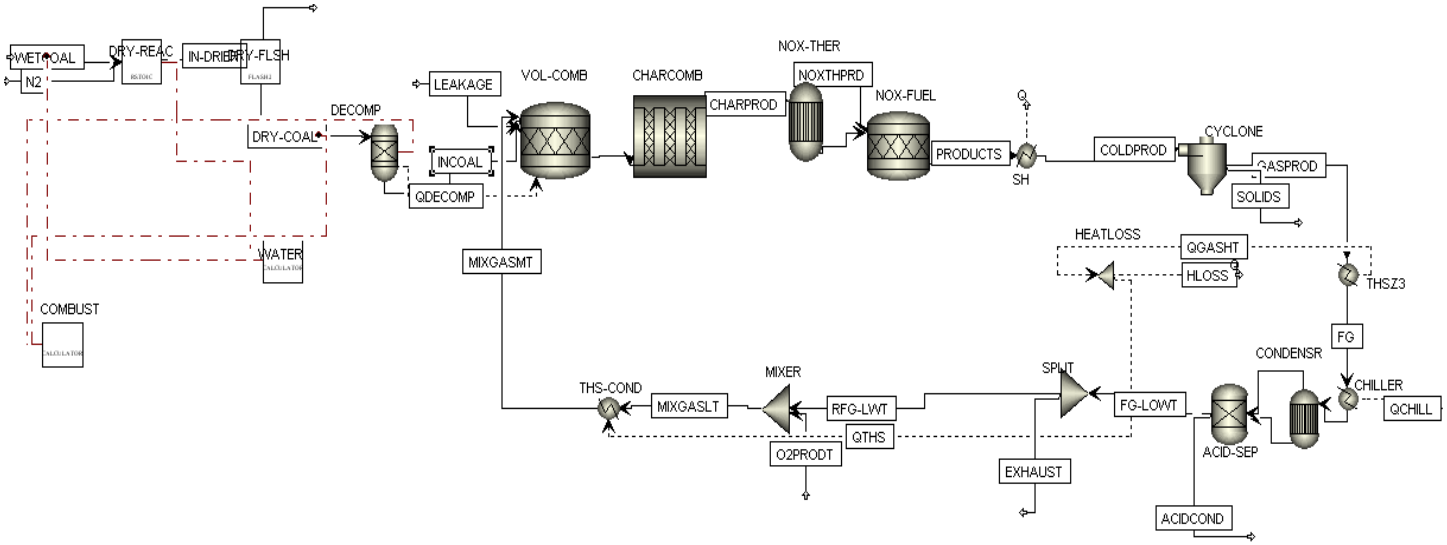
- **RFG**
  - Max 74%
  - Av 61%
- **Heat flux (Hukseflux sensor)**
  - Max 192 kW/m^2
  - Av 155 kW/m^2

Simulations using Aspen Plus®

DRY RFG



Box- plot of the Rate-based Model with Dry Recycle Flue Gas



Interface of the rate-based model with dry RFG in Aspen Plus

Experimental .vs. Simulation Test

COMPARISON

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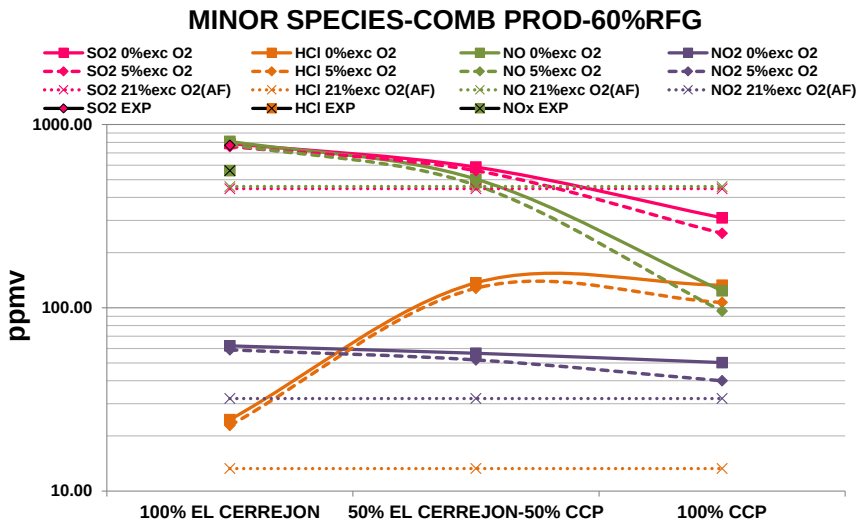

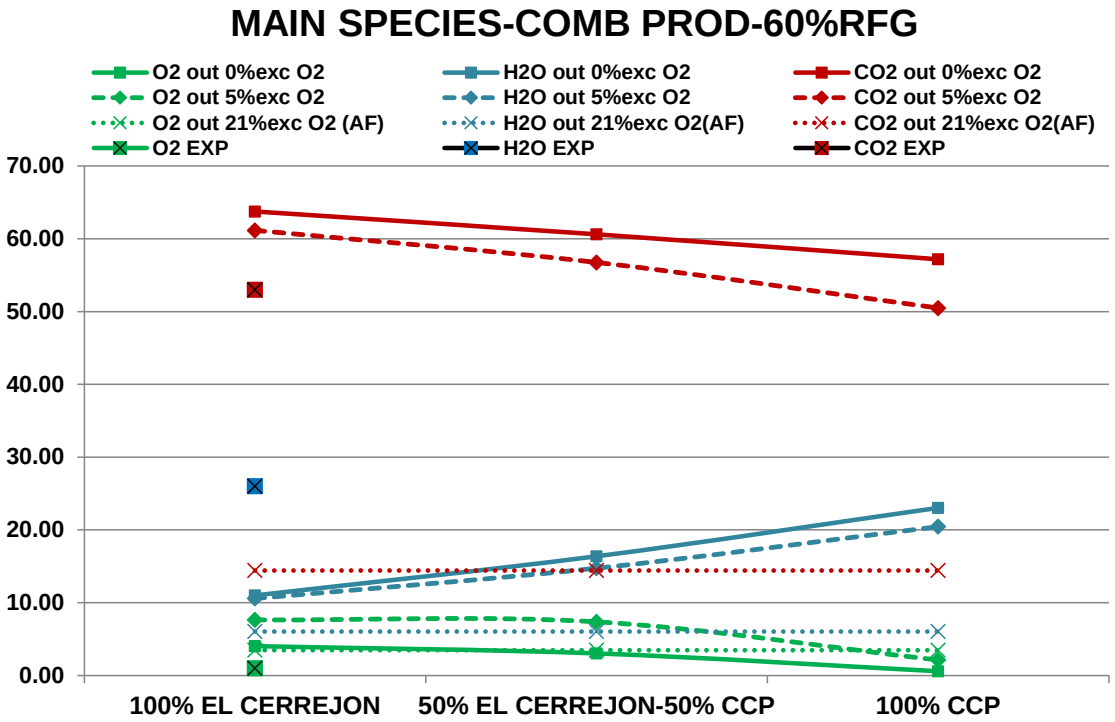

Values for WET RFG (simulations)

CO_2	*51 % wet basis*
H_2O	*21.4 %*
SO_2	*1600 ppm*
NOx	*1600 ppm*
HCl	*9ppm*

Summary

- Modifications performed to the oxycombustor in different phases

- Experimental results showed for each phase
  - Substantial Increase in the amount of flue gas recirculated
  - Oxygen fed up to 40%
  - Condenser used for first time
  - A few difficulties during operation with the new configuration have been identified and work will be done to solve them

- Kinetic Simulation Model has been developed
  - Acceptable agreement in comparison with wet RFG results for main species
  - More work required in comparison with dry RFG results *(Still not clear if it is due to not optimal operation of the rig or inaccurate results of the model)*

- Starting new set of tests applying Dry RFG and new measurements (SO_3, Acid Dew Point, Heat flux…) for which a noticeable increase in CO_2 in the exhaust is expected thanks to the condenser

Acknowledgements

Support of UK Engineering and Physical Sciences Research Council (EPSRC) and EON to the Oxy-Cap UK consortium

Special gratitude to the team of technicians at CERT for their help

CC3

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9th-13th September 2013

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Thanks for your attention

Any questions?

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Fuel Composition

	Daw Mill Coal	El-cerrejon Coal
Proximate analysis (% wt, AR)		
Moisture	4.60	5.80
Ash	4.20	8.60
Volatile matter	31.30	34.80
Calorific value (kJ/kg)		
Gross Calorific value	25260	27850
Net Calorific value	24107	27122
Ultimate analysis (% wt, AR)		
Carbon	74.15	69.20
Hydrogen	4.38	4.80
Nitrogen	1.17	1.42
Oxygen	10.49	9.98
Sulphur	1.28	0.58
Chlorine	0.20	0.02
Ash composition (% wt, of total ash)		
SiO_2	36.80	60.69
Al_2O_3	23.90	22.01
Fe_2O_3	11.20	7.43
TiO_2	1.10	0.92
CaO	12.00	2.27
MgO	2.50	2.90
Na_2O	1.50	1.06
K_2O	0.50	2.32
Mn_3O_4	0.40	0.06
P_2O_5	-	0.21
SO_3	-	-
BaO	-	0.11

Simulations using Aspen Plus®

STAGES

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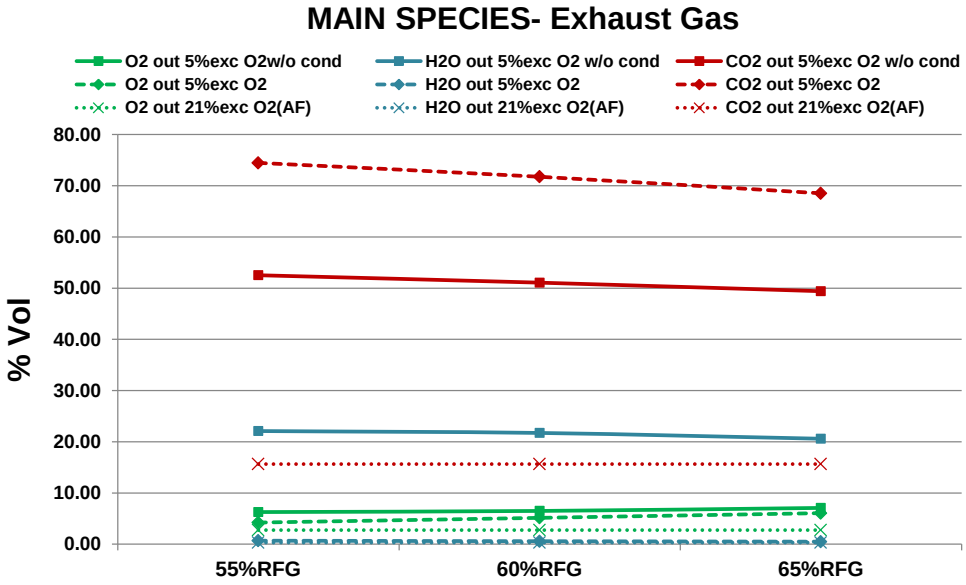
KINETIC MODEL

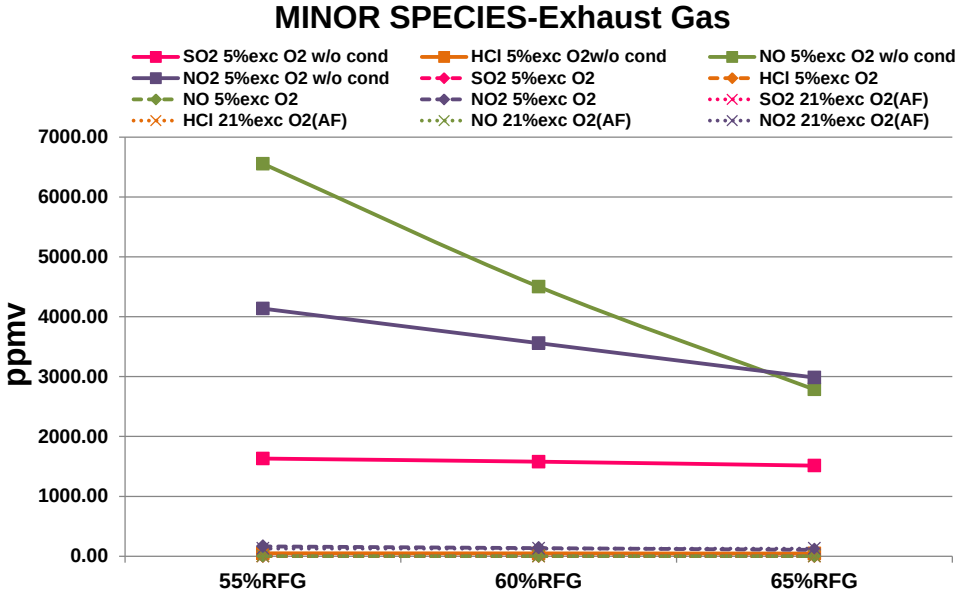
	STAGE 1 Air-firing case	STAGE 2 Oxy-firing case with wet recirculation, heat loss and air leakage	STAGE 3 Oxy-firing case with partial condensation in RFG, heat loss and air leakage	STAGE 4 Oxy-firing case with dry recirculation, heat loss, air leakage	STAGE 5 Air-firing case with power generation unit	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} (ºC)	--	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

- ✓ Establish reference cases (Stages 1 and 5)
- ✓ Validation of the model by applying similar conditions to experiments (Stage 3)
- ✓ Simulations with condenser implemented to include dry RFG (Stage 4)
- ✓ Simulation of the entire system including ASU and steam turbine (Stage 6)

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