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ON THE PREDICTION OF FLAME STABILITY: ESTIMATION OF THE CHARACTERISTIC FLAME FREQUENCY UNDER AIR AND OXY-FUEL CONDITIONS

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Contents

Introduction

New technologies on combustion

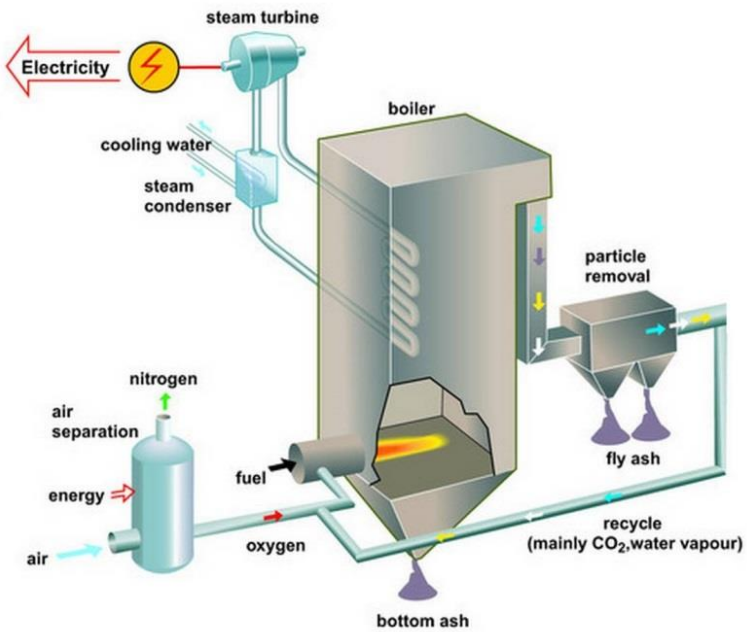
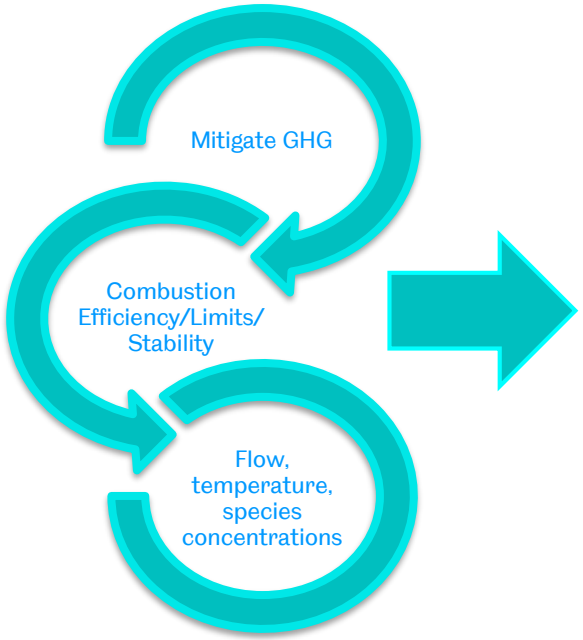


Image 1. Representation of a retrofitted oxy-fuel combustion power plant.



Computational Fluid Dynamics (CFD)

- Low NOx burners
- Oxy-fuel combustion
  - Coal
  - Biomass

Objectives

- Evaluate the oscillatory nature of the flame by LES simulations
  - Instantaneous values of different scalars
  - Image and data processing
- Obtain a trend for the flame dynamics under different oxy-fuel conditions
  - Air
  - Oxy – 21, 25, 30

Overview of the experimental facilities

Image 2 and 3. Picture and CAD representation of the 250 kW_{th} down-fired furnace at PACT facilities.

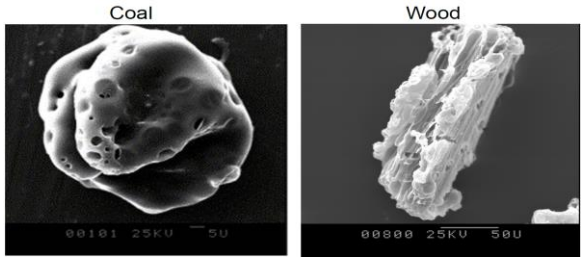


Image 5. Different solid fuel particles used at PACT facilities[1].

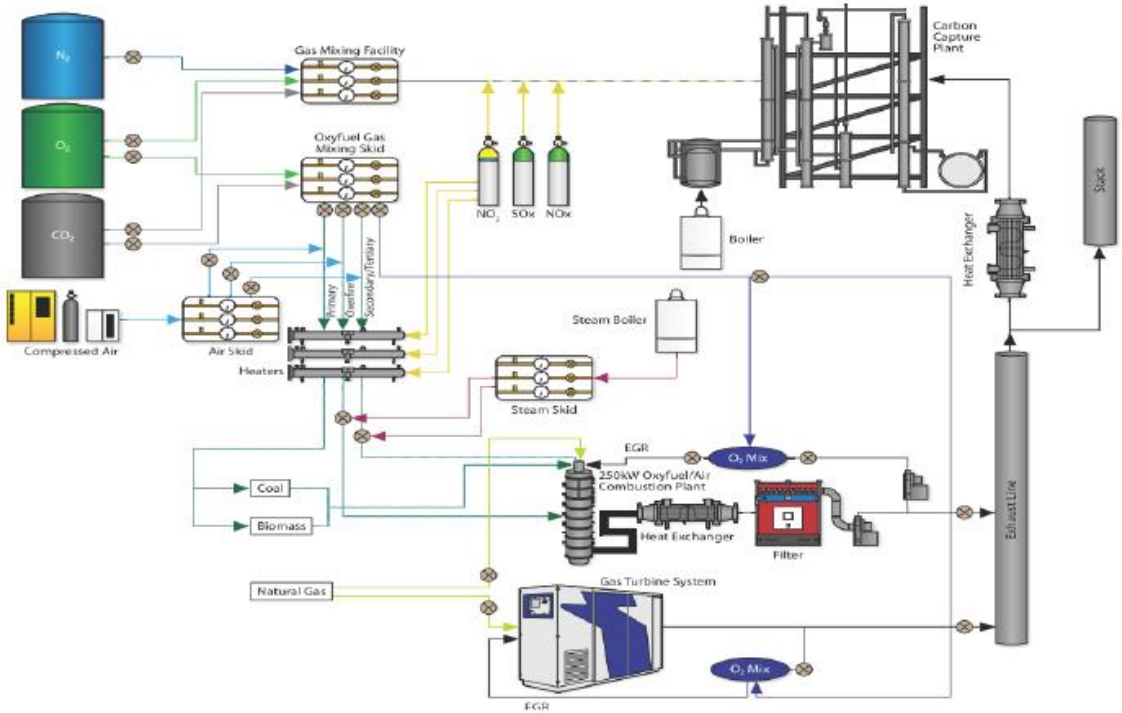
UKCCSRC Pilot-scale Advanced Capture Technology (PACT)

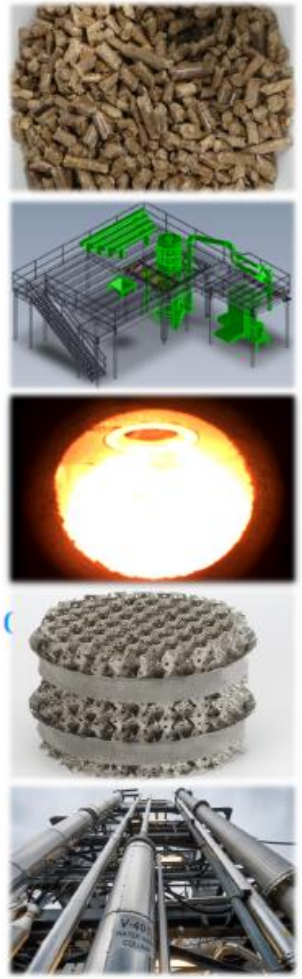
Location: South Yorkshire, UK.
Thermal input: 250 kW_{th}
Geometry: Down-fired furnace, refractory lined cylindrical shape, which is 4 m in height with a 0.9 m internal diameter
Burner: Scaled version of a commercially available Doosan Babcock third generation low-NOx burner

Overview of the experimental facilities

UKCCSRC PACT FACILITIES

PACT Pilot-Plant Tests





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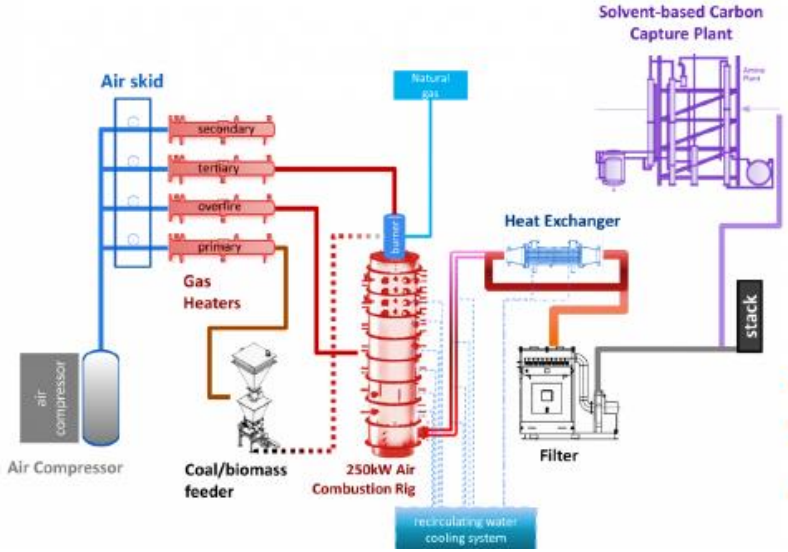
Overview of the experimental facilities

PACT Tests

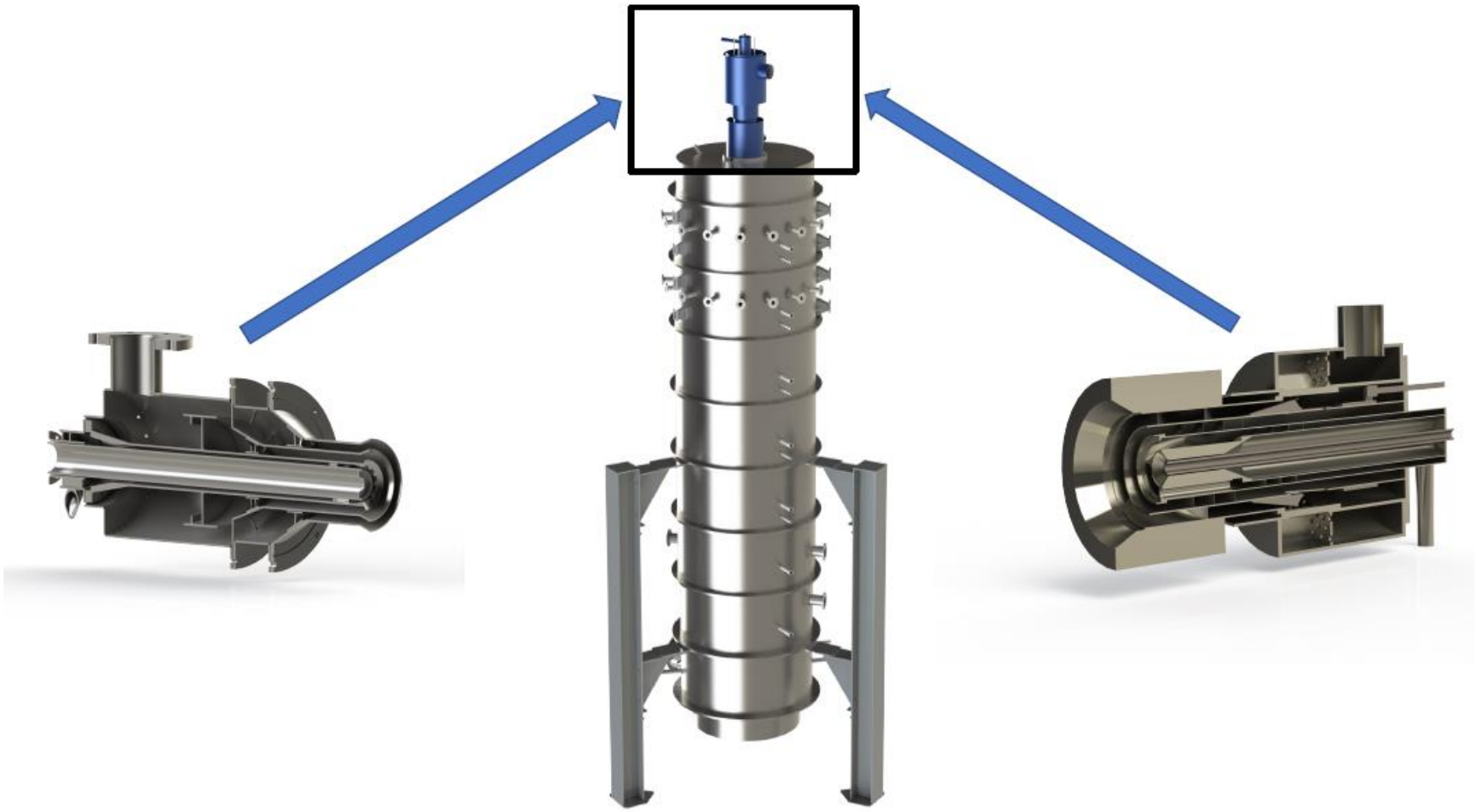
- 250 kW pulverised fuel combustion test facility, integrated with the solvent-based post-combustion capture plant



Coal firing baselines:
- El Cerrejon coal
- air-firing with post-combustion CCS
- oxy-coal tests

Biomass firing campaigns:
- white wood pellets
- air-firing with post-combustion CCS
- oxy-biomass tests

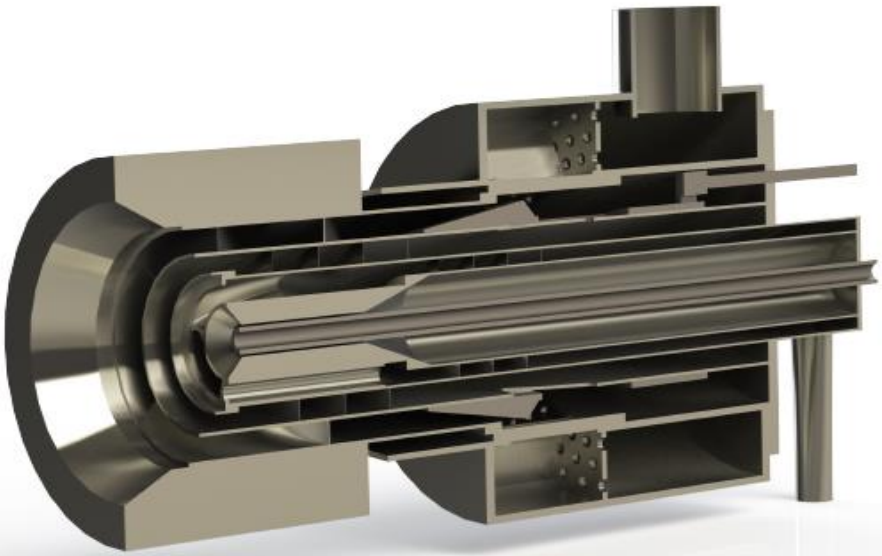
Overview of the experimental facilities



Overview of the experimental facilities

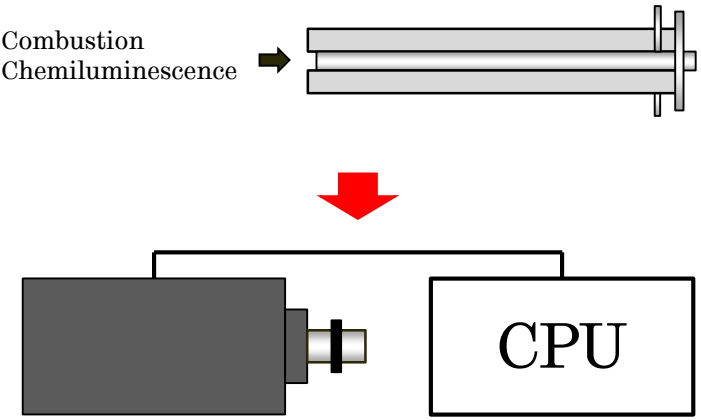
Coal and Biomass Burners

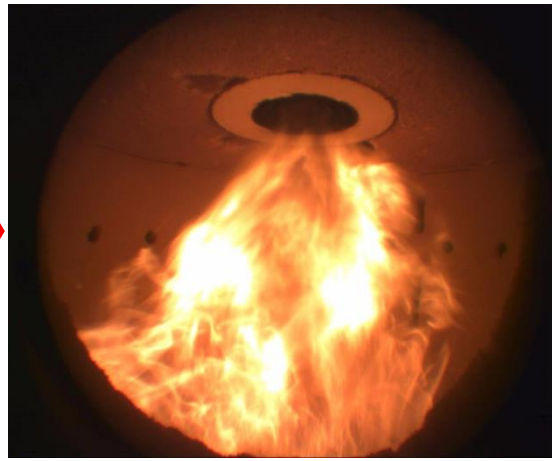
Flame stability, Combustion performance and Emission



Methodology

Experimental methodology





Camera array

Industrial CMOS RGB camera:

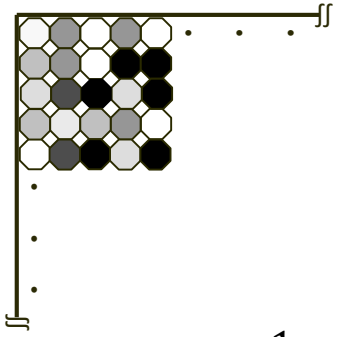
- 1280 × 1024 at 25 fps
- 320 × 256 at 265 fps

Original video

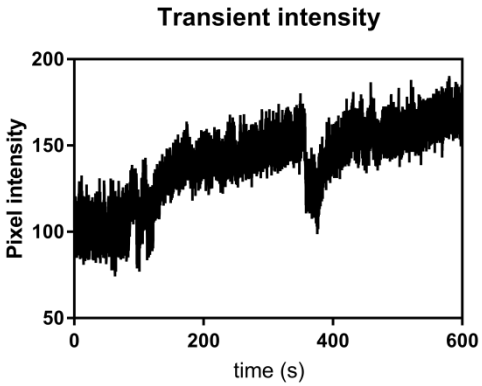
Video sectioning and frame recovery

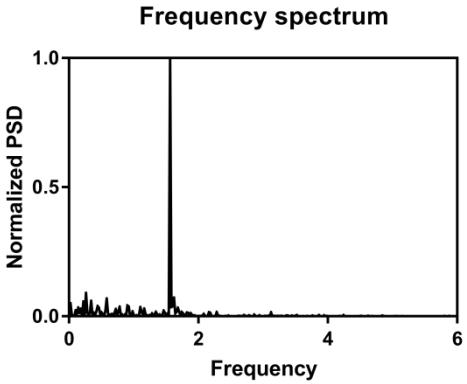
Methodology

Experimental methodology



$$I(t) = \sum_{i \in R_f} \sum_{j \in R_f} \frac{1}{|R_f|} A(i,j)$$





$$F = \frac{\sum_{n=1}^{N} [P_{xx}(f_n) \cdot (f_n)]}{\sum_{n=1}^{N} P_{xx}(f_n)}$$

Processed grayscale image

Overall intensity calculation

Transient intensity of the flame

Frequency spectrum construction

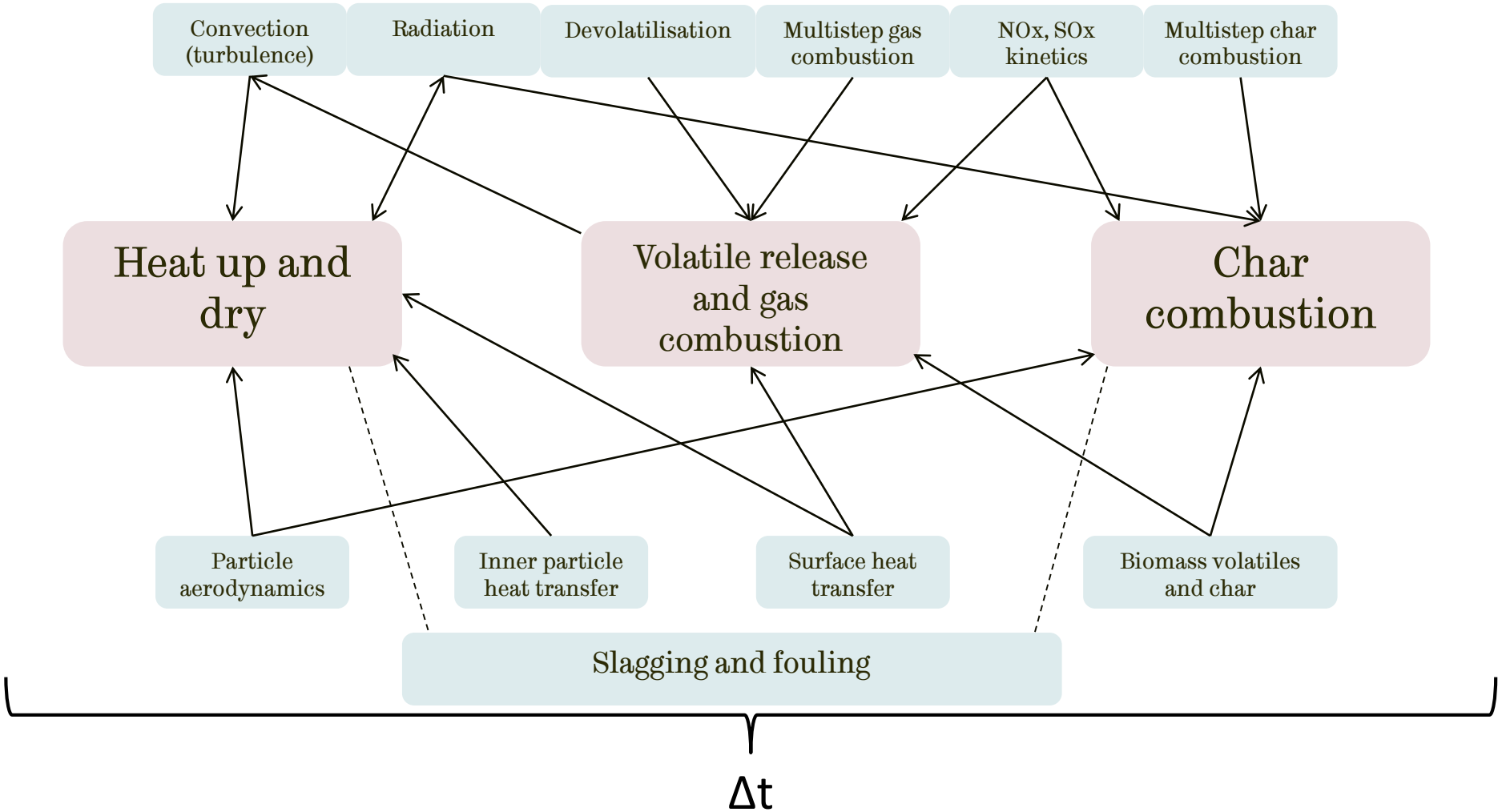
Methodology

Numerical methodology

Image 6. CAD representation and computational domain of the furnace.

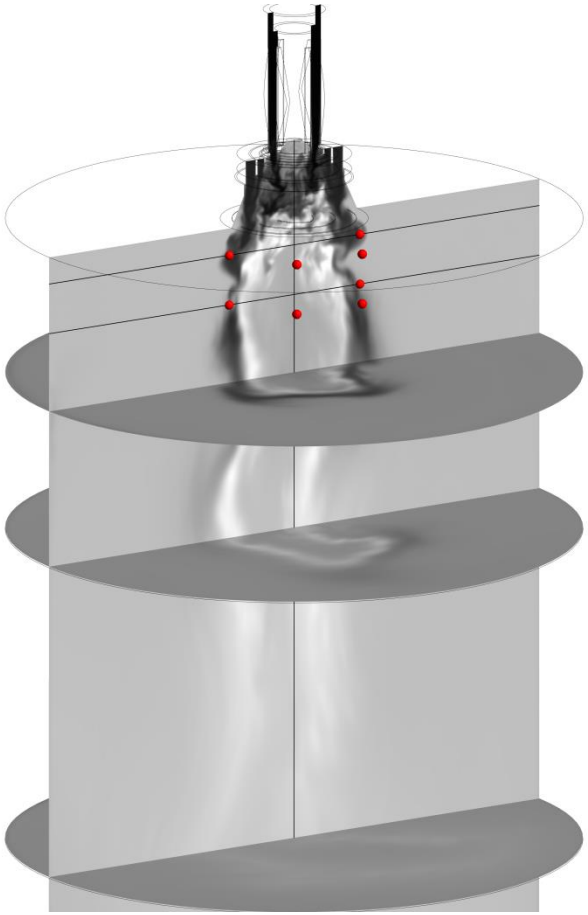
CFD approach	
Software :	ANSYS Fluent v17.2
3D mesh :	Roughly 5 million hexahedrons
Fuel :	'El Cerrejon' (high volatile bituminous coal)
Turbulence modelling :	Incompressible LES (WALE subgrid scale model, Werner-Wengle wall functions)
Turbulence – Chemistry interaction	Eddy dissipation model
Radiation	Weighted sum of gray gases, full spectrum correlated K model
Devolatilisation model	Single rate
Volatile combustion	Two-step global reaction
Char combustion	Intrinsic model
Particle treatment	Unsteady discrete phase model

Methodology



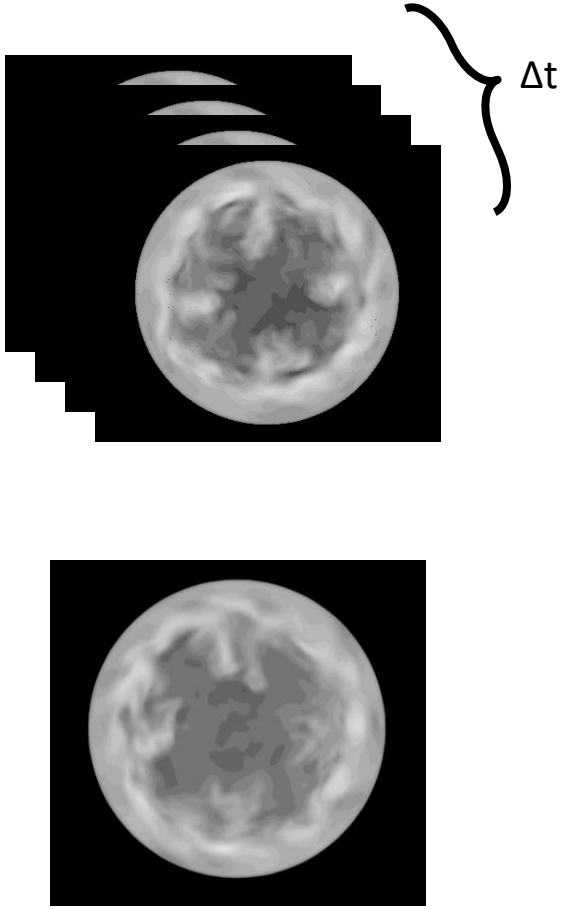
Methodology

Numerical methodology



Monitor points, lines and volumes are used in this study

Contour plots of heat of reaction

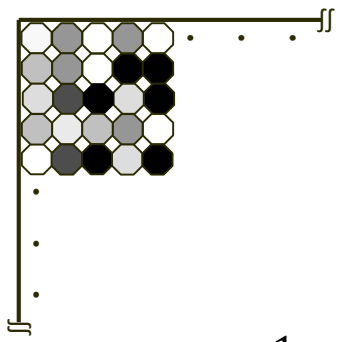


Contour plots of axial velocity

Methodology

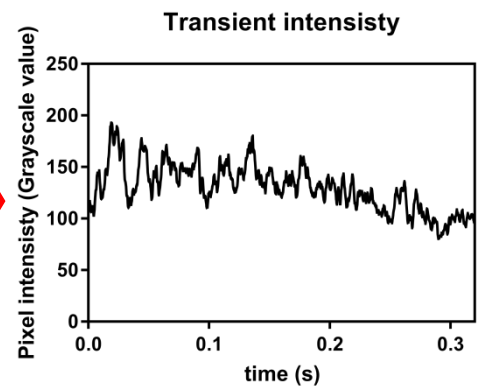
Numerical methodology

Grayscale contour of a scalar

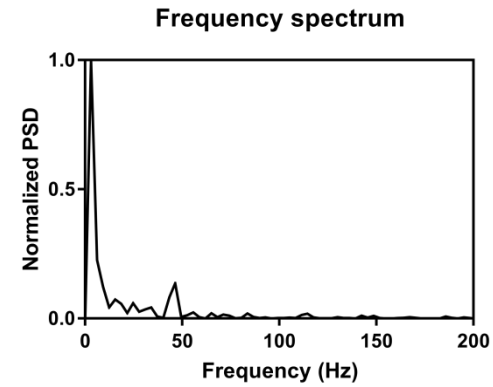


$$\mathrm{I}(t) = \sum_{i \in R_f} \sum_{j \in R_f} \frac{1}{|R_f|} A(i,j)$$

Overall intensity calculation



Transient intensity of the contour

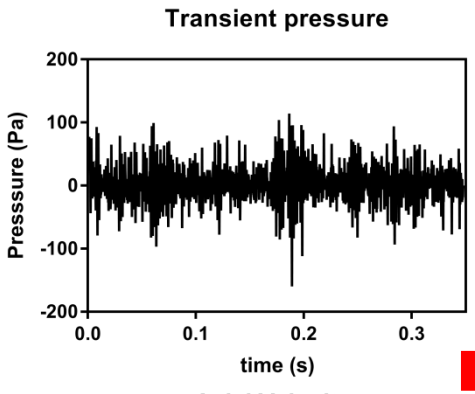


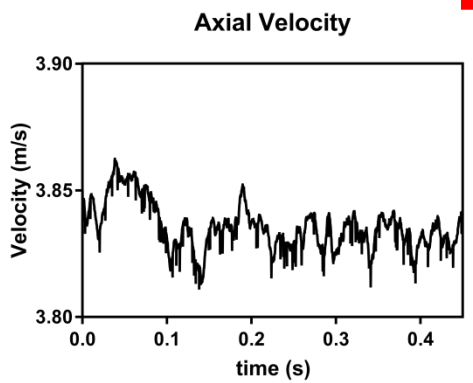
$$F = \frac{\sum_{n=1}^{N} [P_{xx}(f_n) \cdot (f_n)]}{\sum_{n=1}^{N} P_{xx}(f_n)}$$

Frequency spectrum construction

Methodology

Numerical methodology

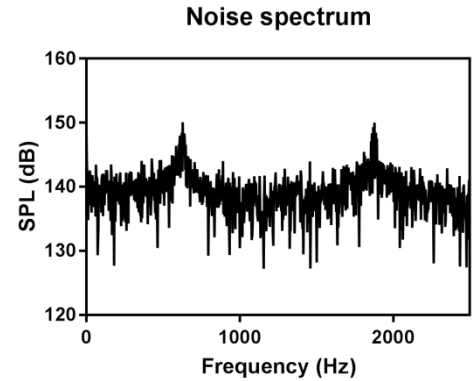




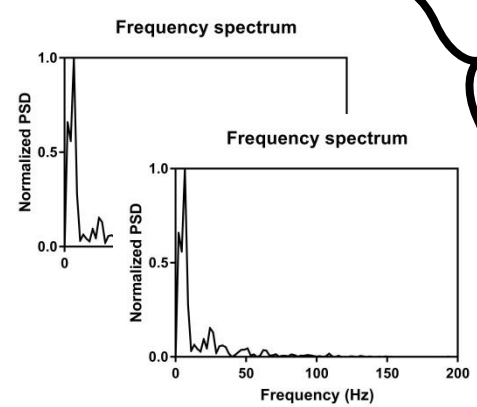
Transient scalar

$$F = \frac{\sum_{n=1}^{N}[P_{xx}(f_n)\cdot(f_n)]}{\sum_{n=1}^{N} P_{xx}(f_n)}$$

Frequency spectrum construction



Flame rumble



P1, P2, P3…

Turbulent coherent structures

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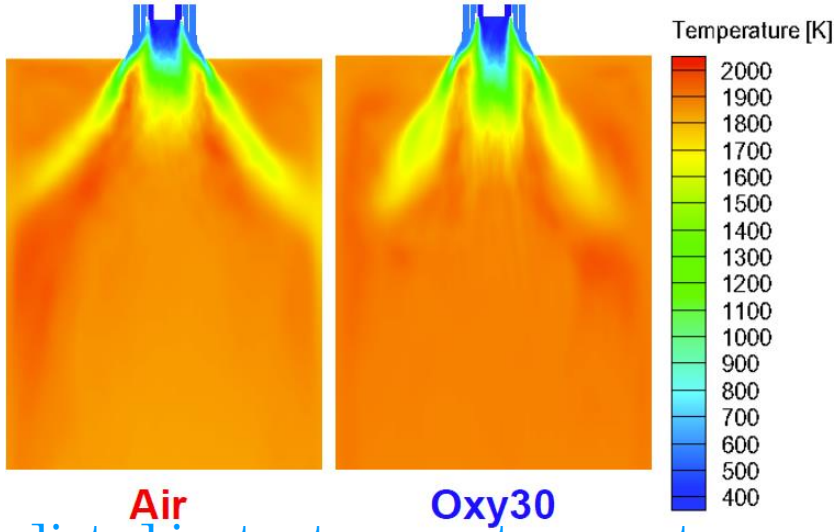
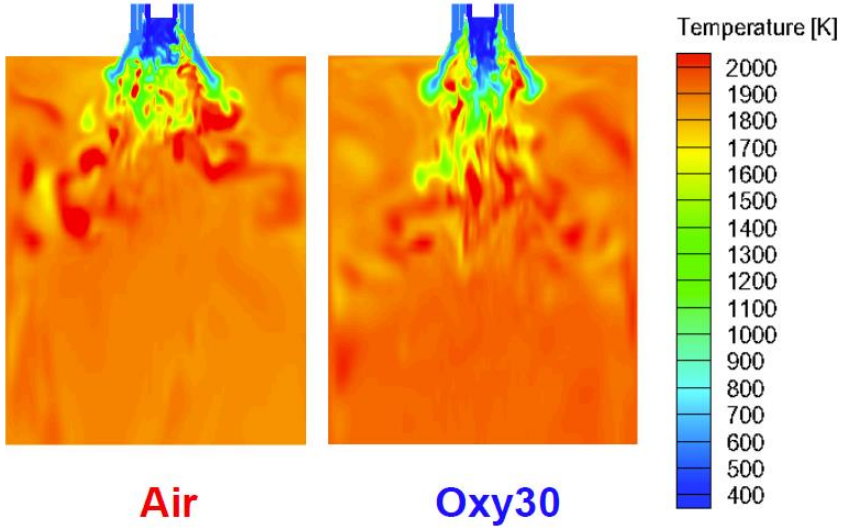
Results

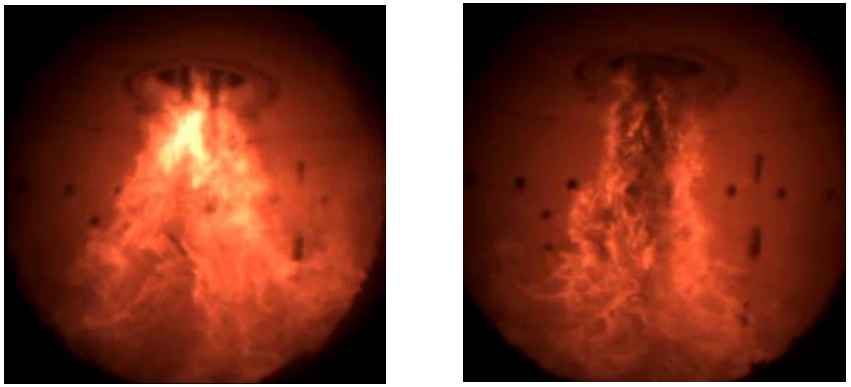
Predicted mean temperature distribution



Predicted instantaneous temperature distribution

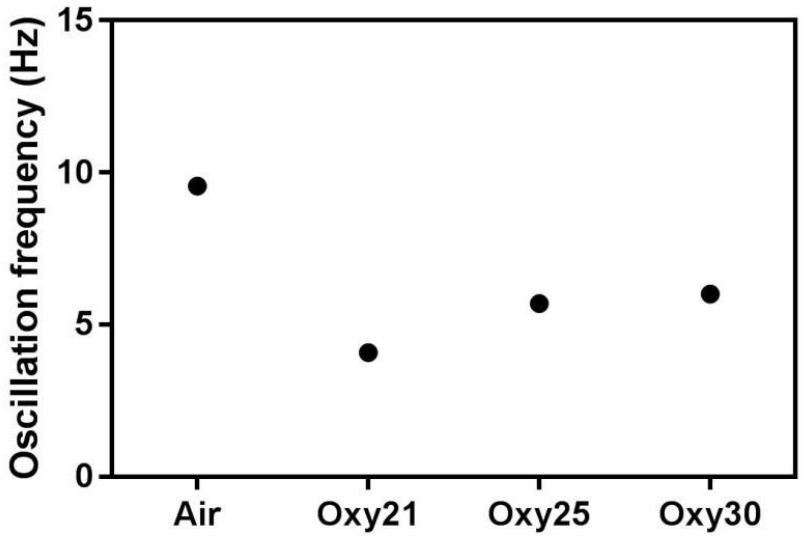


Experimental flame imaging

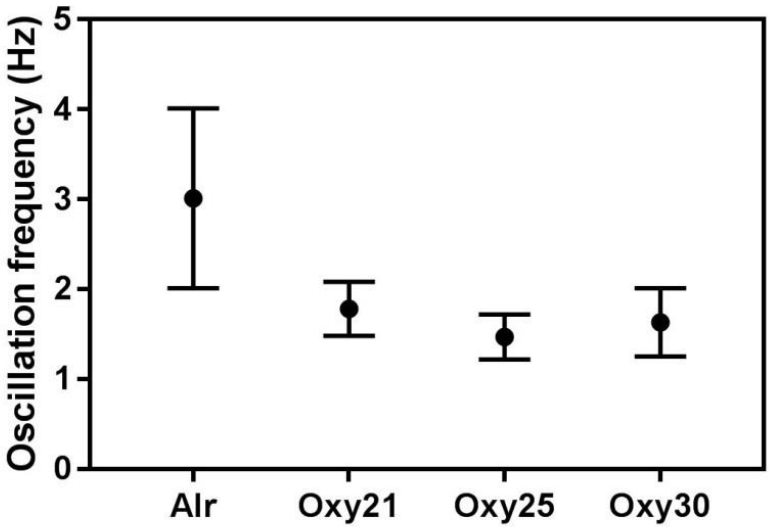


Air Oxy30

Results



Numerical estimation



Experimental estimation

Conclusions and ongoing work

Conclusions

- LES instantaneous results were successfully used to characterize the flame
- Oxy-fuel flames showed lower flicker frequencies in comparison to the air-fired case
- Obtained a trend for the flame dynamics under different oxy-fuel conditions

Ongoing and further work

- Evaluation of the turbulent coherent structures development in the furnace and their impact on the flame oscillation
- Development of the mathematical model for the propagation of pressure waves in confined spaces
- Assessment of flame stability for different fuels

Acknowledgements

The authors would like to acknowledge EPSRC for funding this work, Dr. Sandy Black from Doosan Babcock Ltd. and the Mexican Council for Science and Technology (CONACyT) for the scholarship granted.

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