ETII
ENERGY TECHNOLOGY AND INNOVATION INITIATIVE

UNIVERSITY OF LEEDS

LES of a 250kW oxy-coal burner: an investigation into flame stability

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Introduction

Oxy-fuel combustion

- Can be retrofitted to existing power stations
- Thermochemical differences when N_2 is replaced with a CO_2 rich stream

Flame stability

- Affects heat transfer, pollutant emissions, burnout and performance
- Oscillation frequency can be used to characterise the flame

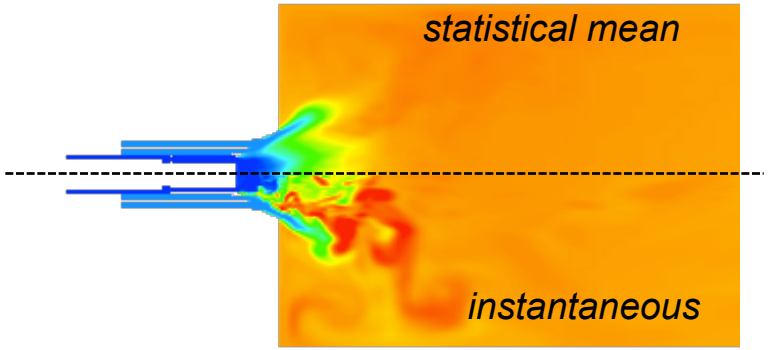
Computational Fluid Dynamics (CFD)

- CFD can provide insight into combustion problems
- Large eddy simulations (LES) can give details into the transient nature of a flame, important for analysing flame stability

Objectives

- Numerically assess flame stability in oxy-coal flames using LES
  - Animations
  - Oscillation frequency

- Examine the stability in a 250kWth Combustion Test Facility (CTF)
  - **Air-coal combustion**
  - **Oxy-coal 21% (Oxy21)**
  - **Oxy-coal 25% (Oxy25)**
  - **Oxy-coal 30% (Oxy30)**



250kW$_{th}$ Combustion Test Facility (CTF)

- Designed for solid-fuel combustion under air and oxy-fuel conditions
- Located at the PACT facilities in Yorkshire, UK
- Down-fired furnace, approximately 4m x 0.9m (I.D.)

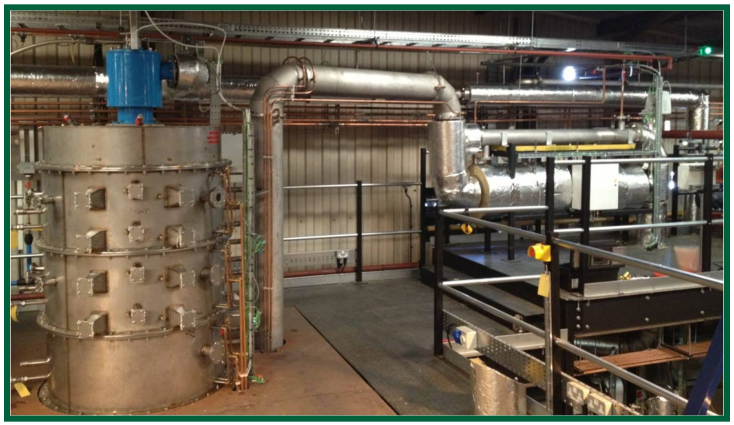
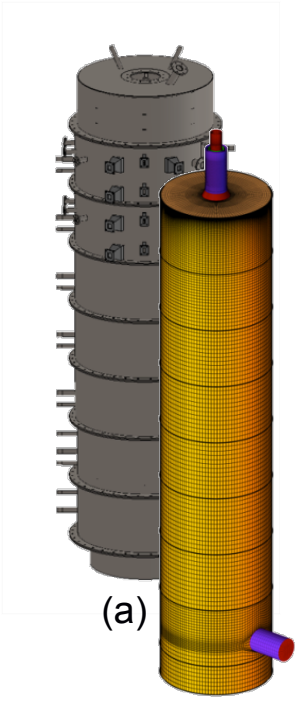


Figure: Image of the top section of the facility and burner



(a)

(b)

Figures: (a) CAD of furnace
(b) Full 3D mesh of the burner and furnace

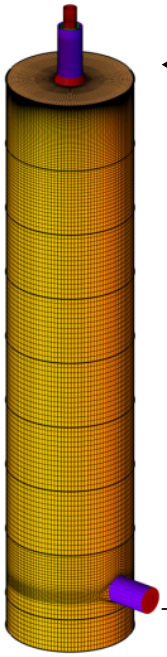
Numerical study: air and wet-recycle (CO_2 + H_2O)

O_2 mass flow rate (kg/s)

AIR	OXY21	OXY25	OXY30
2.24×10^{-2}	2.15×10^{-2}	2.11×10^{-2}	2.08×10^{-2}

Thermal input

ALL CASES
250kW$_{th}$



Recycle Ratio (%)

AIR	OXY21	OXY25	OXY30
-	77	73	67

Exit O_2 (dry)

ALL CASES
3% (vol.)

$$\text{RecycleRatio}\ (\%) = \frac{\text{Mass flow of recycle}}{\text{Mass flow of recycle + mass flow of products}}$$

Numerical study: air and wet-recycle (CO_2 + H_2O)

- Doosan Babcock low-NO_x burner, 250kW_{th}
- Coal carried through the **primary annulus**
- **Secondary** and **tertiary** swirled, preheated air

Oxygen concentration		AIR	OXY21	OXY25	OXY30
Primary	(mass %)	23.2	19.0	19.0	19.0
Secondary	(mass %)	23.2	19.0	23.6	29.5
Tertiary	(mass %)	23.2	19.0	23.6	29.5

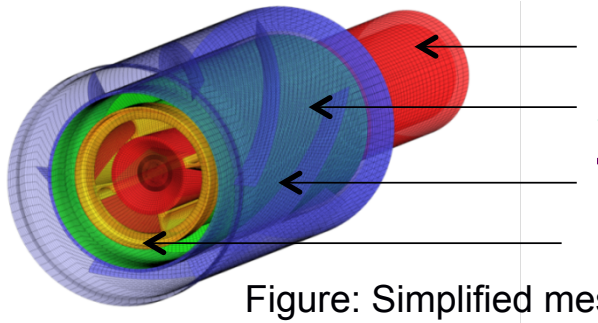


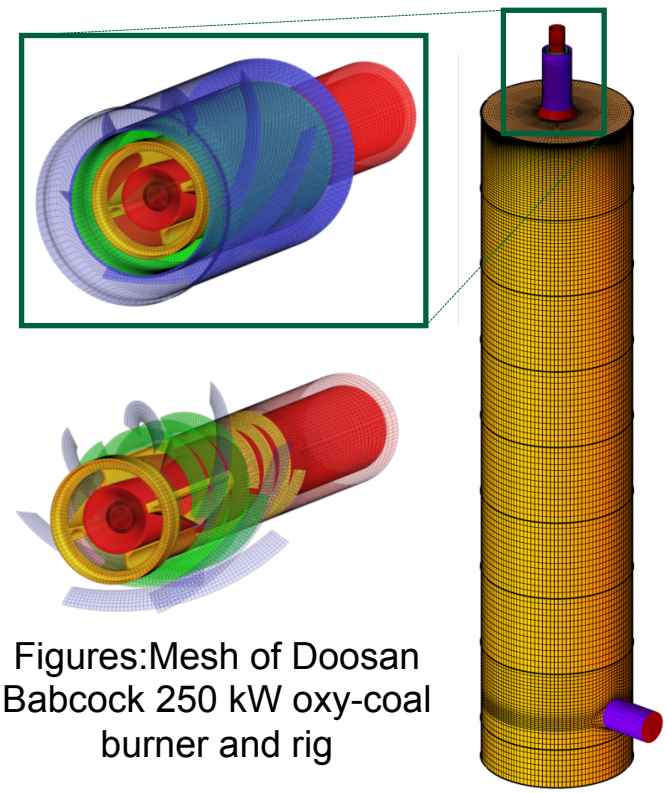
Figure: Simplified mesh of the burner

CFD approach: air and oxy-fuel cases

Commercial software: ANSYS FLUENT v14.0

Full 3D mesh: 3.0 million cells

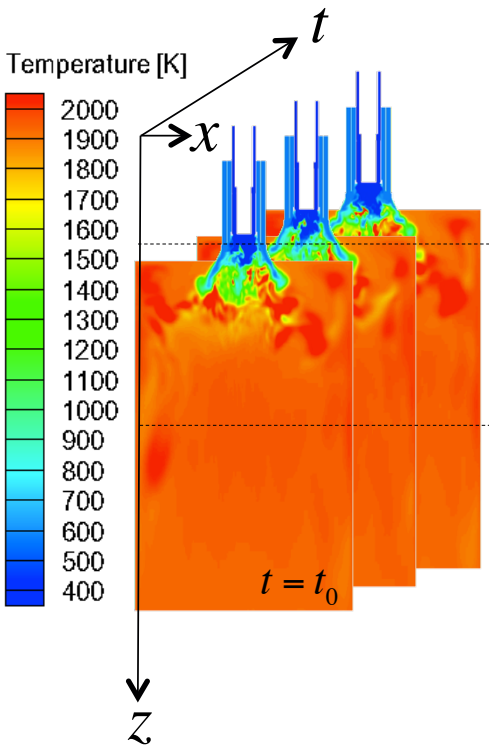
- High volatile bituminous coal: El-Cerrejon
- Turbulence: LES (WALE subgrid scale model)
- Radiation: WSGG model[1], Discrete Ordinates
- Turbulence chemistry interaction: eddy dissipation
- Two step global reaction for volatile combustion
- Devolatilisation: single rate (FG-DVC)
- Char combustion: intrinsic model
- Particles: Euler-Lagrange approach



Figures:Mesh of Doosan Babcock 250 kW oxy-coal burner and rig

[1] R. Johansson et. al., Combustion and Flame. 158:5, 893-901. 2011.

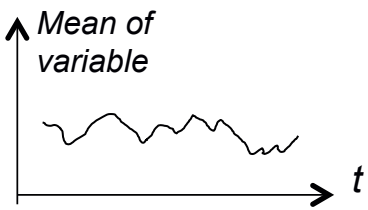
Oscillation frequency and instability



Cross section of a CFD variable, e.g. temperature distribution (K)

First section[1]

Region of interest



Average value at each timestep

Oscillation frequency F

$$F = \frac{\sum_{i=0}^{i-1} P_{xx}(f_i) \cdot f_i}{\sum_{i=0}^{i-1} P_{xx}(f_i)_i}$$

Instability I

$$I = \frac{\sigma}{\mu}$$

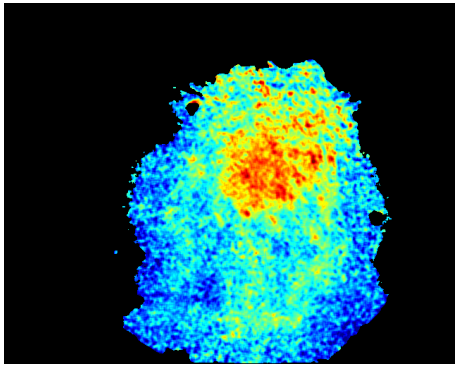
Evaluated from Power Spectral plot

[1] From burner exit to first section (z = 0.5m)

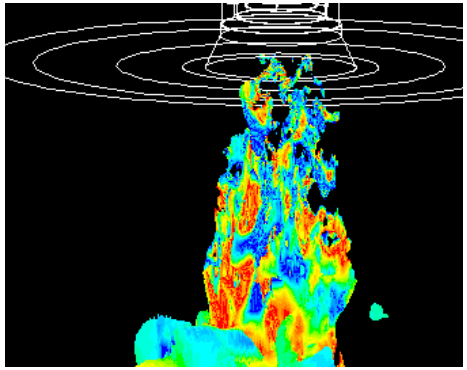
Benchmark: Oscillation frequency

- 200kW$_{th}$ air coal combustion
- 2D flame imaging by Kent University[1]

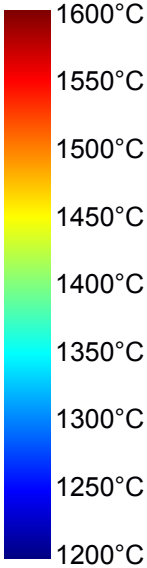
Oscillation frequency (Hz) exp	*Oscillation frequency LES (Hz) [First section]*
6-9	5.27

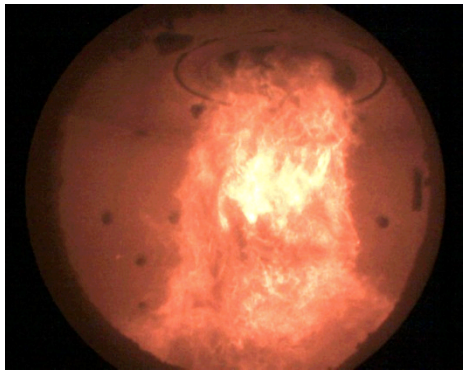


Instantaneous experimental temperature distribution

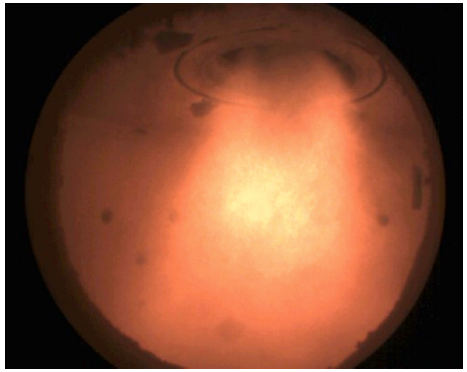


LES instantaneous temperature distribution





Instantaneous image



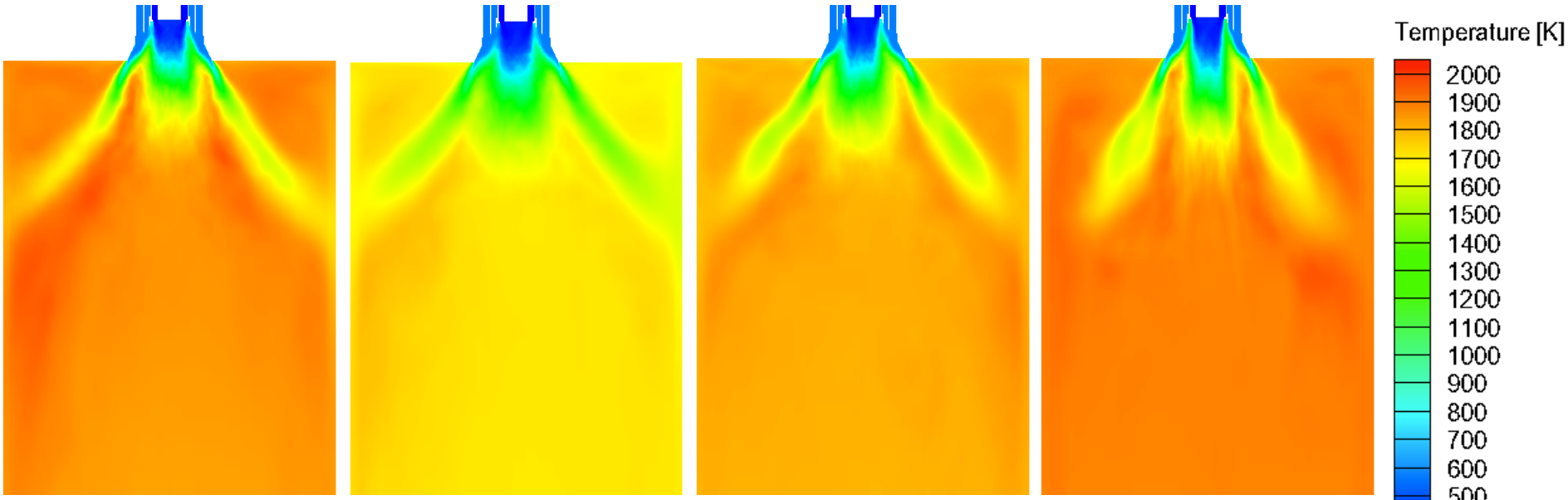
Time-average image

[1]Experimental Images and data courtesy of Kent University

Numerical predictions

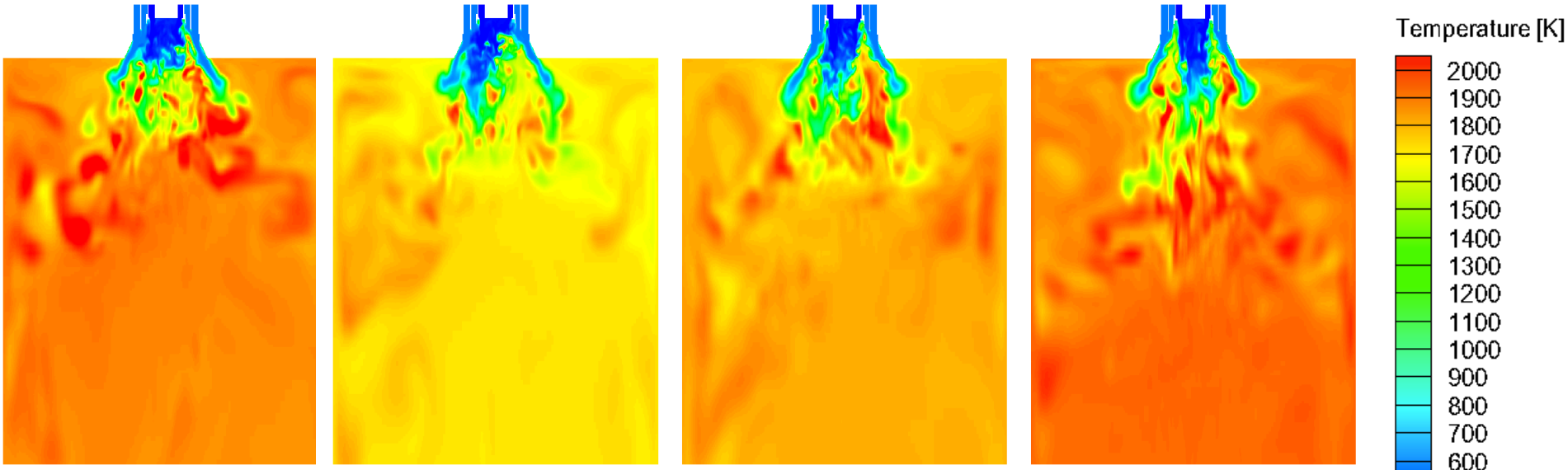
- **Air-coal combustion**
- **Oxy-coal 21% (Oxy21)**
- **Oxy-coal 25% (Oxy25)**
- **Oxy-coal 30% (Oxy30)**

Predicted mean temperature distribution



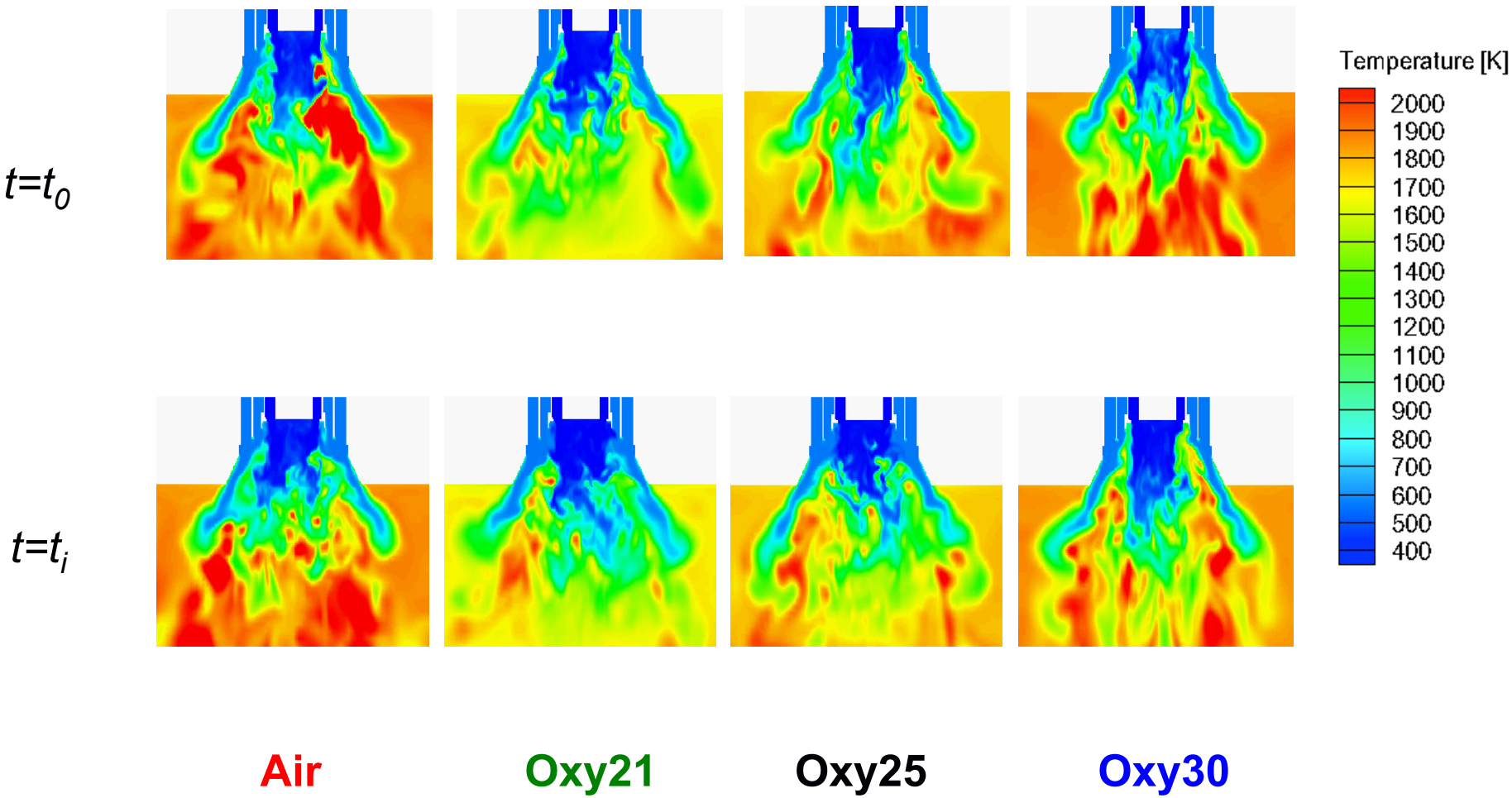
Air	Oxy21	Oxy25	Oxy30
Exit temperature [K]			
1356	1306	1350	1402

Predicted instantaneous temperature distribution

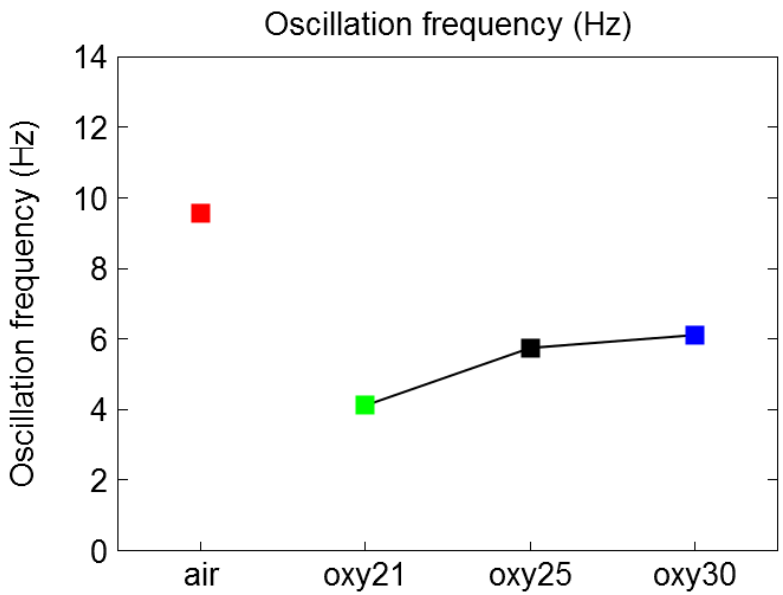


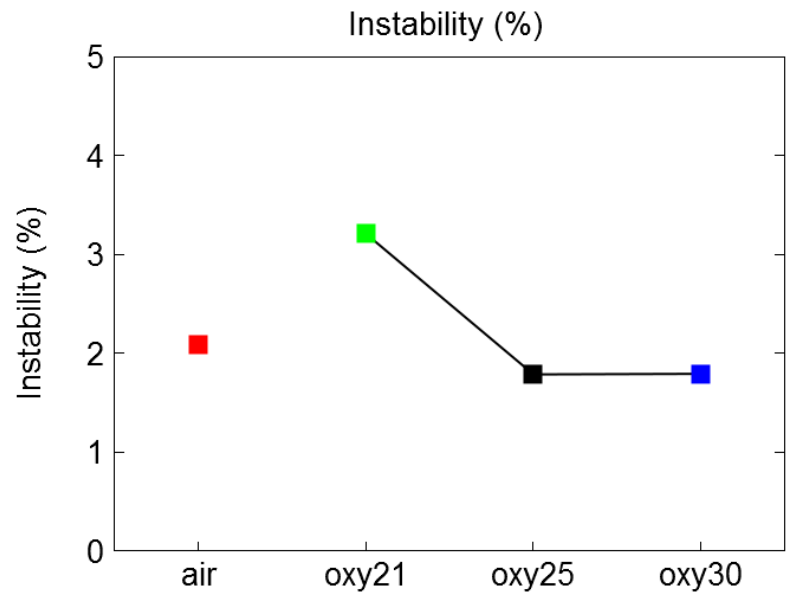
Air **Oxy21** **Oxy25** **Oxy30**

Predicted instantaneous temperature distribution



Predicted oscillation frequency





	Air	Oxy21	Oxy25	Oxy30
CIA (%)	**0.04**	**0.37**	**0.17**	**0.17**

Summary

Conclusions

- Flame stability was numerically examined in oxy-coal flames using LES
- Lower oscillation frequency in oxy-coal cases compared to air
- Oscillation frequency appears to decrease with higher recycle ratios
- The work presented demonstrates the potential importance of using measured data for validation of LES for coal combustion

Way forward

- 3D flame imaging data → Further validation and understanding of flicker

Acknowledgements

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