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Sensors and Instrumentation Systems for Oxy-Coal Combustion Diagnosis

-- Updates for the EPSRC-EON OxyCAP Project in Kent

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Outline

- Background
- 3-D flame imaging system
- 2-D flame imaging system
- Trials on the PACT 250kW$_{th}$ PF rig at Beighton
- Concluding remarks

Introduction

- **Project Partners**
  - **UK Institutions**: Leeds, Kent, Nottingham, Cranfield, Cambridge, Imperial and Edinburgh
  - **Chinese Institutions**: Zhejiang University, South China University of Technology
  - **Industry**: E.ON, EPRI of Guangdong Power Grid Corporation

EPSRC Engineering and Physical Sciences Research Council

UKCCSRC PACT FACILITIES

e·on

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Background

- Oxy-coal combustion is a promising technology that utilizes highly concentrated oxygen and recycled flue gas instead of air in a combustor. The key advantages are,
  - it could deliver environmental benefits while providing power from an abundant energy source.
  - it could reduce NOx emission and enhance the combustion efficiency in addition to the recovery of CO_2 from exhaust gas.
  - it can easily be adapted at both new and existing coal-fired power plants.
- Advanced techniques are required to provide reliable, non-intrusive and online monitoring of oxy-flames.
- 3-D/2-D visualisation and characterisation techniques are desired for fully revealing the dynamic nature of oxy-flames.
- This presentation presents an overview of recent developments in the 3-D/2-D flame imaging techniques carried out at Kent.

3-D Flame Imaging System

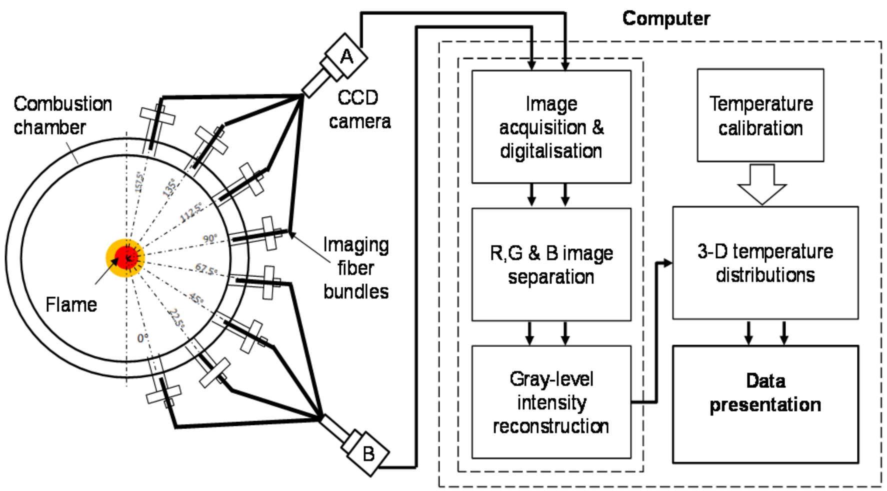
Technical challenges in 3-D imaging

In view of the nature of the flame in a practical furnace, the development of a 3-D flame imaging technique faces a number of technical challenges,

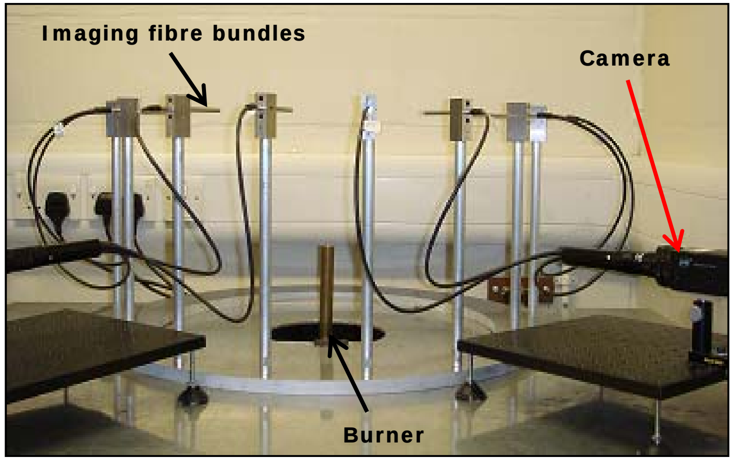
- Suitable system hardware platform for a large-scale installation.
- The number of image projections available for the reconstruction.
- Improved accuracy of the reconstruction.
- Computer algorithms for the characterisation of burner flames including flame stability, and identification of the internal flame structure and flame front movement.

3-D Flame Imaging System

- The 3-D flame imaging system has 8 imaging fibre bundles, each having 30k individual optical fibres with a 92° objective lens.
- Four of the eight fibre bundles are joined onto a single eyepiece, forming four identical images into the same camera.
- A tomographic algorithm which combines the Logical Filtered Back-Projection and Simultaneous Algebraic Reconstruction Technique is utilized for the 3-D grey-level reconstruction of flame sections.

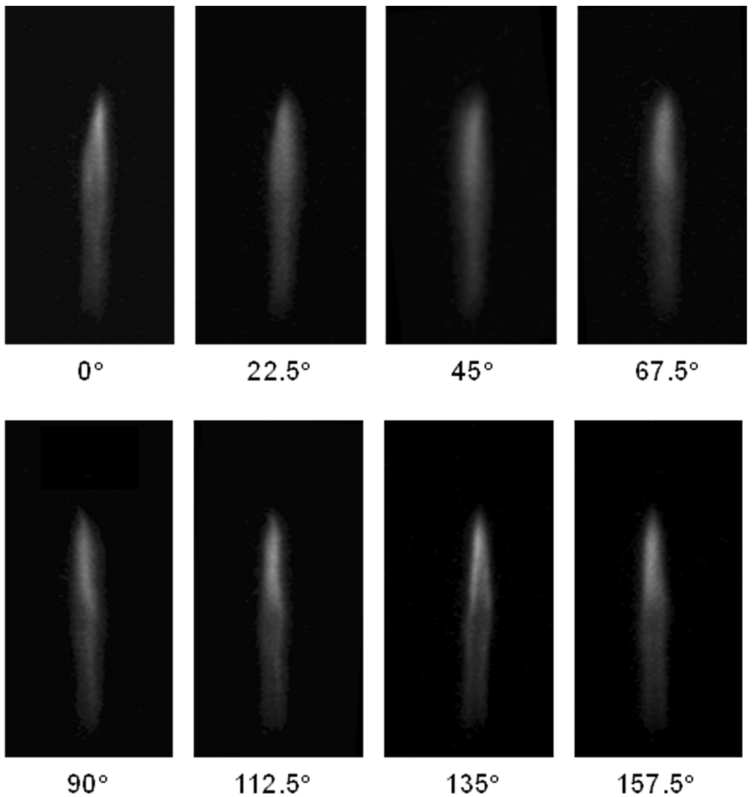


Schematic of the 3-D imaging system

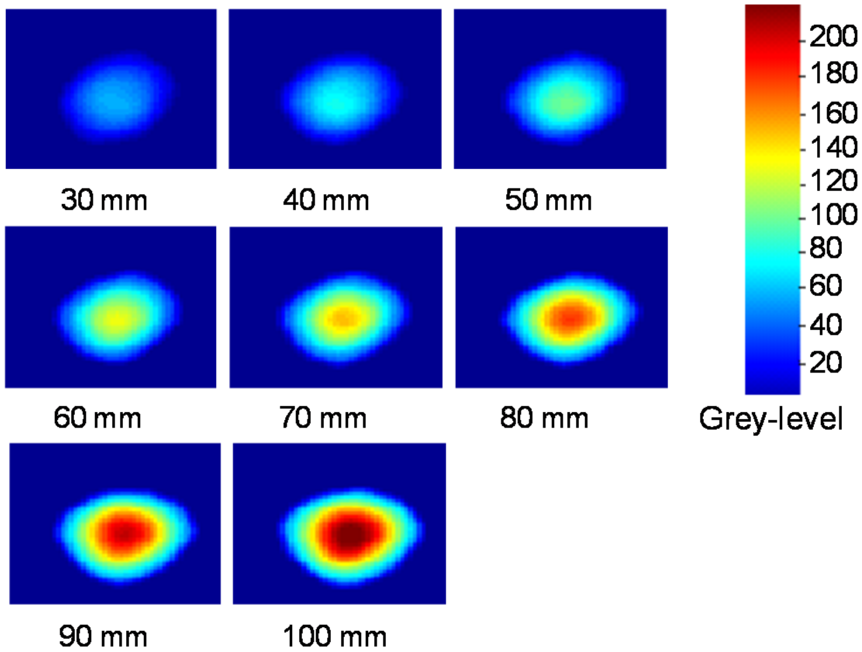


Overview of the 3-D imaging system

Grey-level Reconstruction



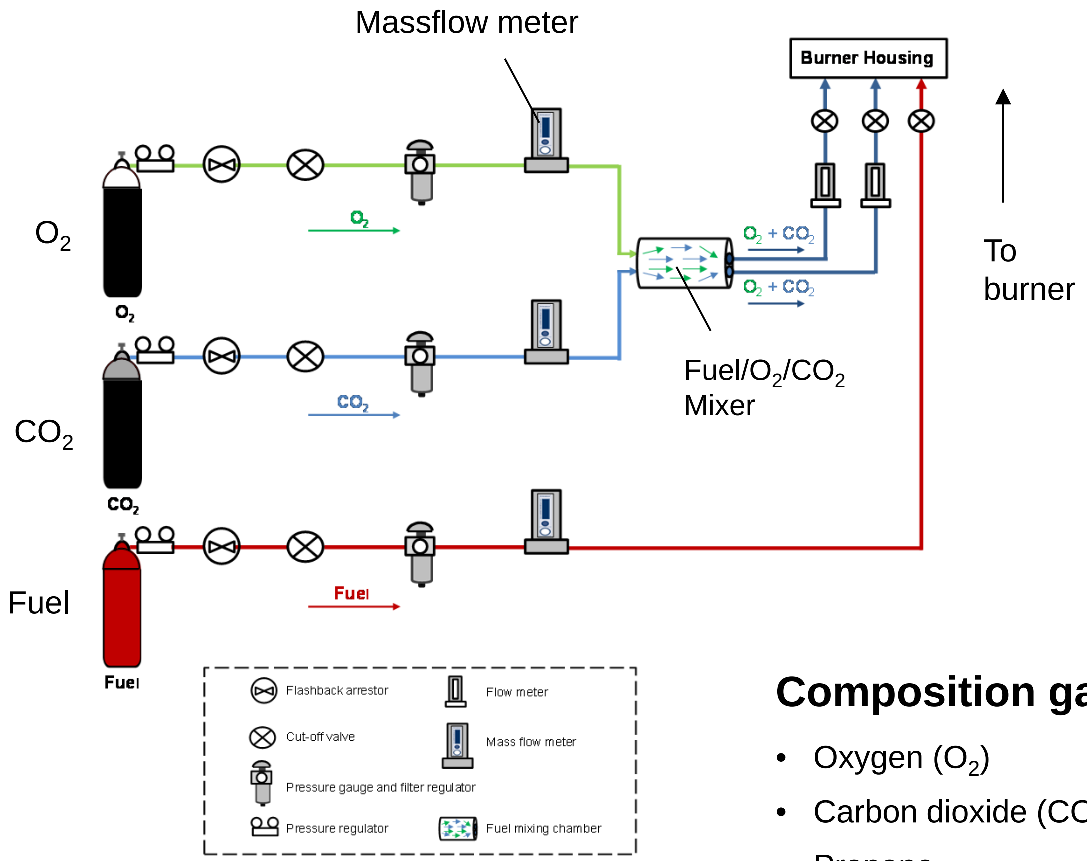
2-D flame images captured by the imaging system



Grey-level reconstruction of cross-sections of a laminar diffusion flame

Experiments on Lab-scale Oxy-gas Flames

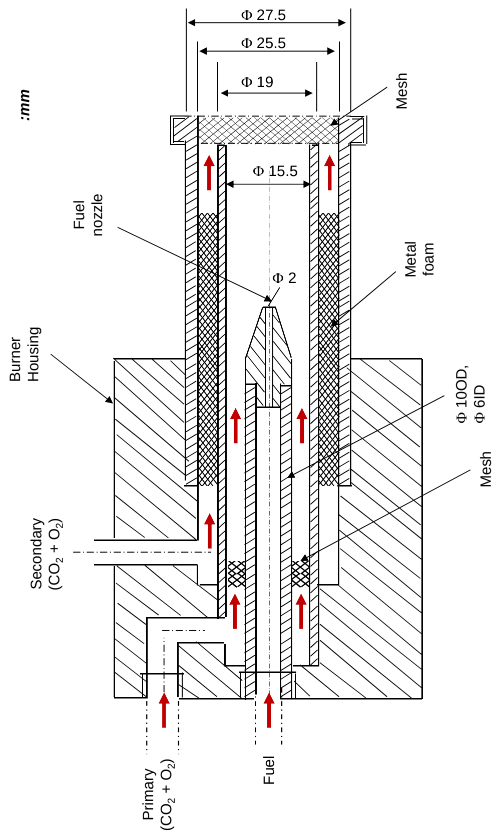
- Experiments have been carried out on a small-scale oxy-gas burner rig to monitoring the oxy-gas flames using the 3-D flame imaging system.



Schematic of experimental set-up

Composition gases

- Oxygen (O_2)
- Carbon dioxide (CO_2)
- Propane
- Air



Oxy-gas burner

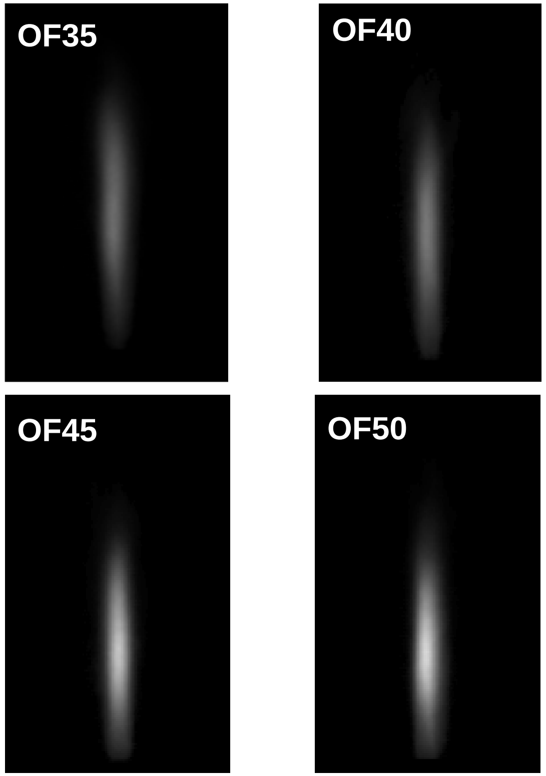
Experiments on Lab-scale Oxy-gas Flames

- Four oxy-fuel conditions (i.e.,**OF35**, **OF40**, **OF45** and **OF50**) under a fixed fuel flow rate were investigated.

Test conditions

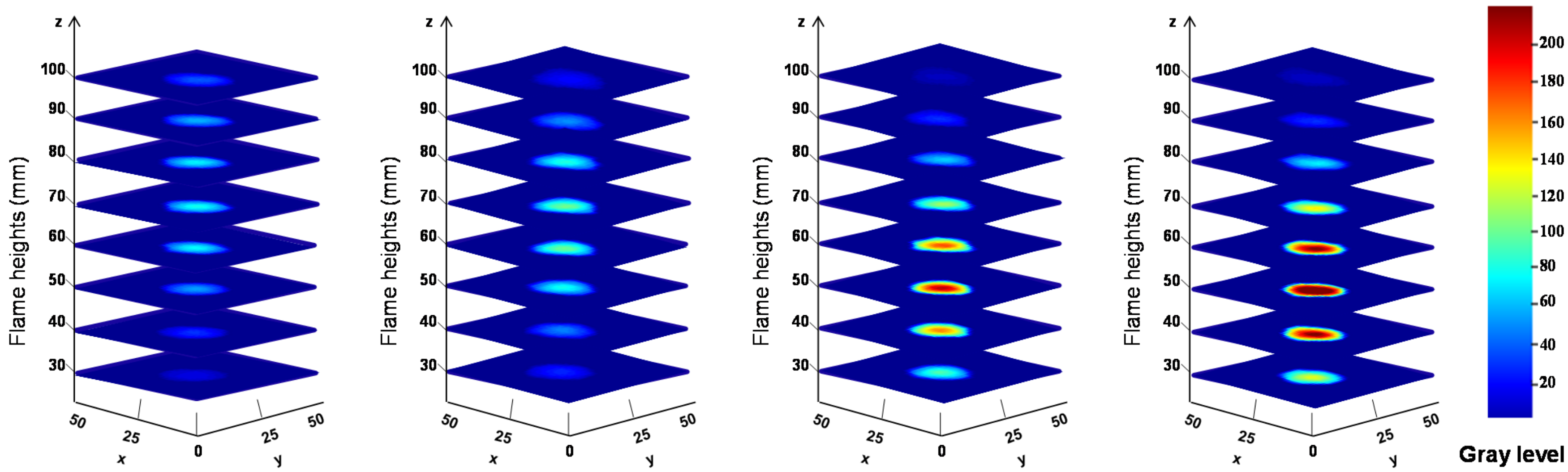
Properties			Value	
Fuel: Propane (C_3H_8)			0.014 g/s	
Oxygen (O_2)			0.064 g/s	
Primary supply (O_2 +CO_2)			15% of total gas composition	
Secondary supply (O_2 +CO_2)			85% of total gas composition	
Relative stoichiometric oxygen-fuel ratio			1.25	
Supply error (%)			< ± 1.5	
Tests	**Volume (%)**		**Mass (%)**	
	O_2	CO_2	O_2	CO_2
OF35	35	65	28.14	71.86
OF40	40	60	32.65	67.35
OF45	45	55	37.31	62.69
OF50	50	50	42.11	57.89

Averaged images of the oxy-gas flame



Grey-level Distribution of Oxy-gas Flame

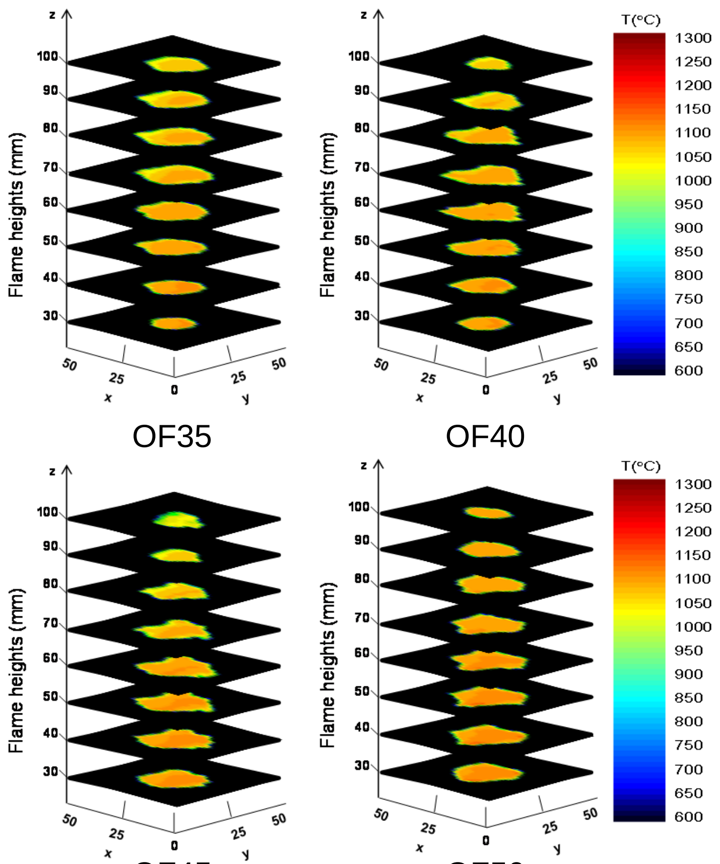
The grey-level distributions of oxy-gas flames were reconstructed at different heights from the burner outlet.



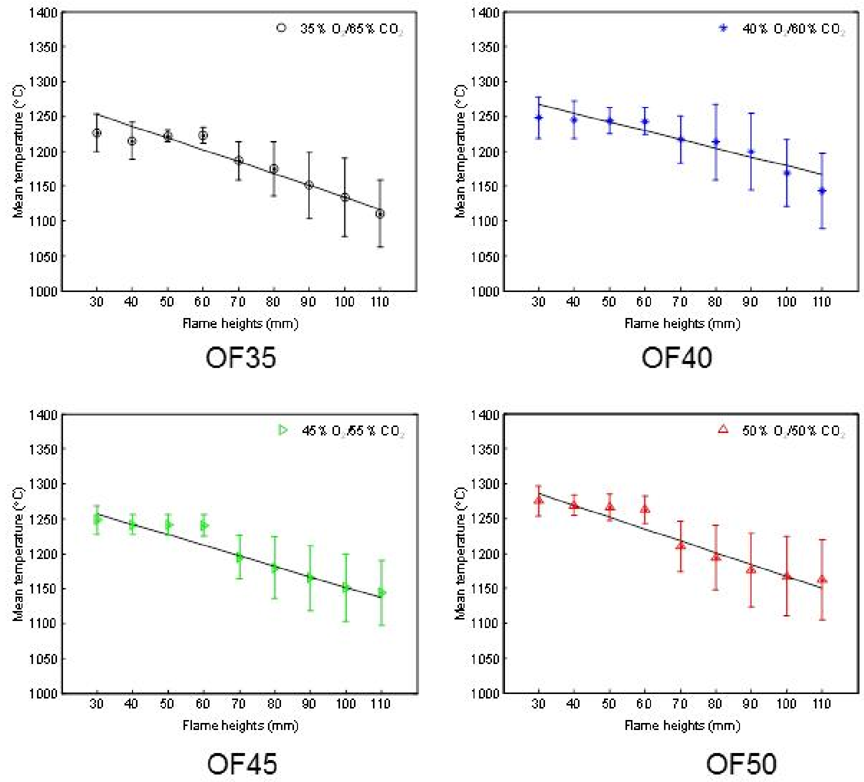
OF35 OF40 OF45 OF50

Remarks: It is observed that the grey-level luminosity of OF50 flame is much higher than that of OF35, OF40 and OF45 flames, particularly in the root region of the flame. This is due to that the higher concentration of CO_2 reduces the luminous radiation of the flame whilst the higher concentration of O_2 increase band radiation of the flame.

Temperature Measurement



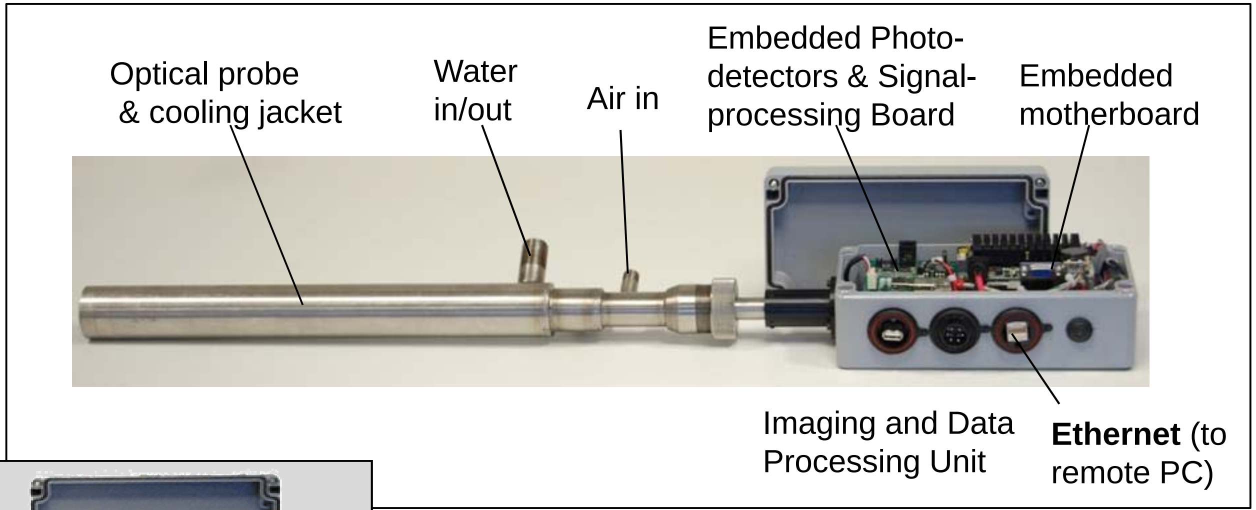
Reconstructed temperature distributions at different heights from the burner outlet.

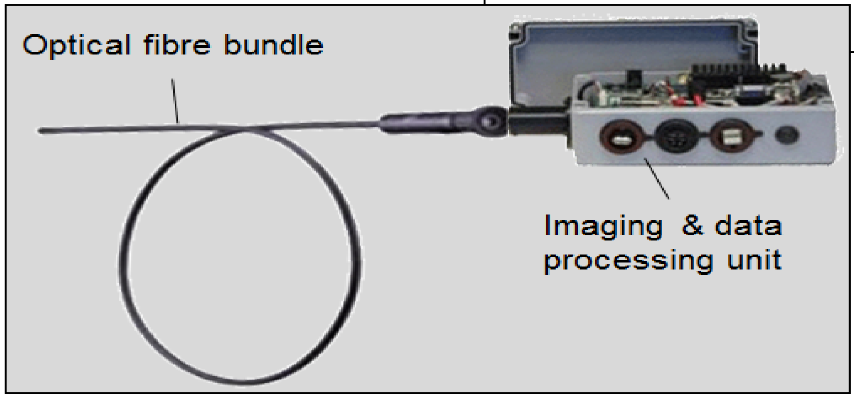


Measured mean temperature at different heights from the burner outlet.

2-D Flame Imaging System

- A 2-D flame imaging system was also used for flame temperature and oscillation frequency measurements.



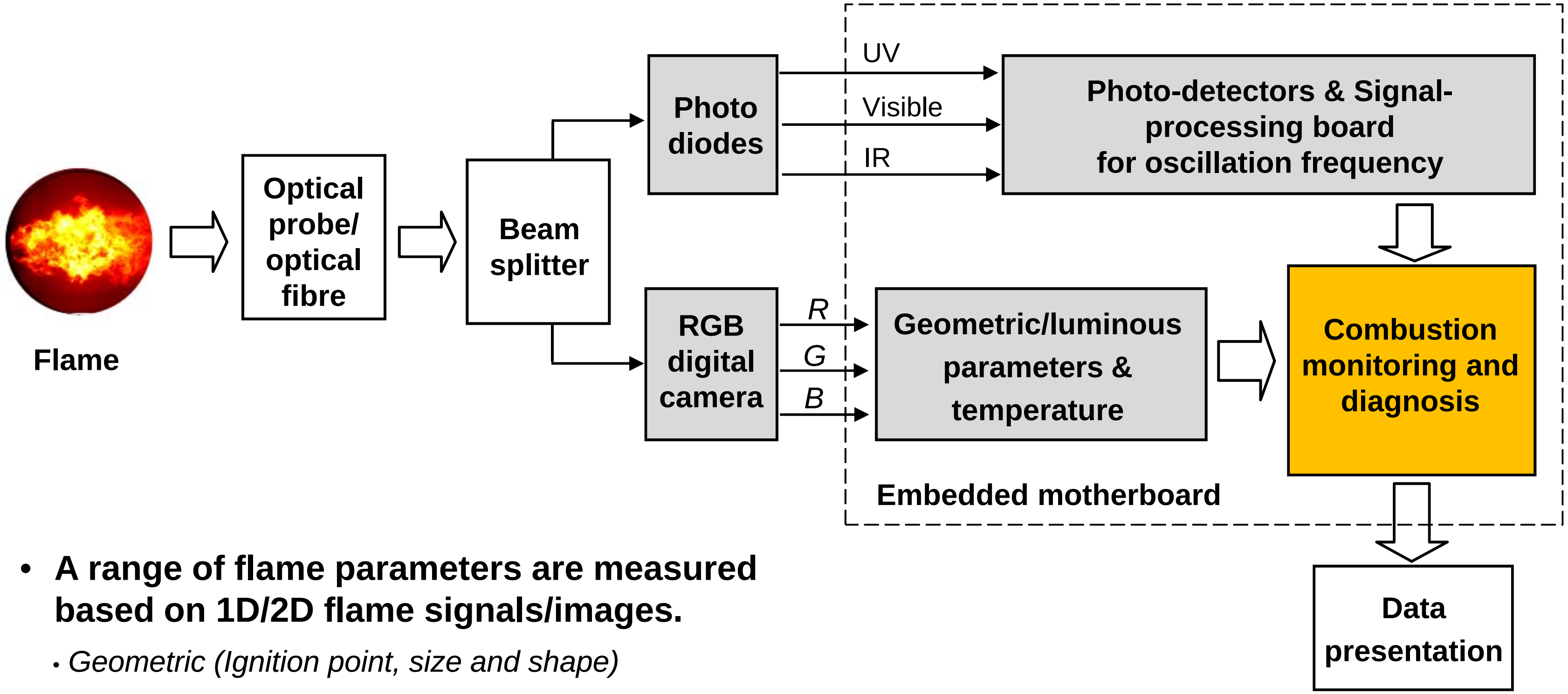


Industrial requirements are met:

- Robust
- Compact
- Fast response
- Acceptable cost

2-D Flame Imaging System

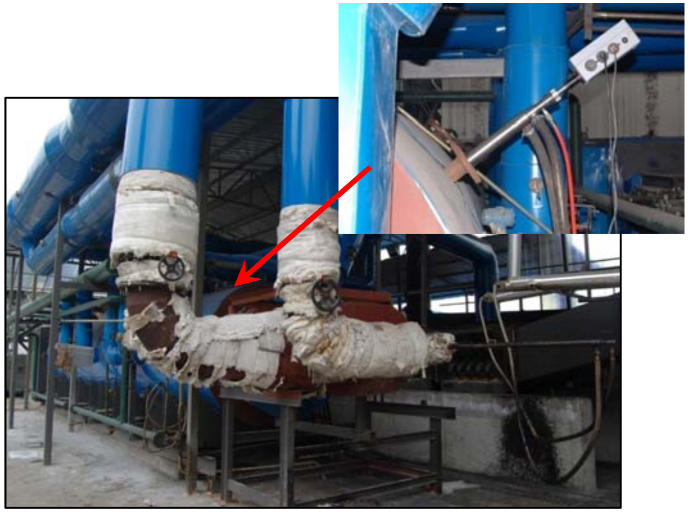
- **System strategy**



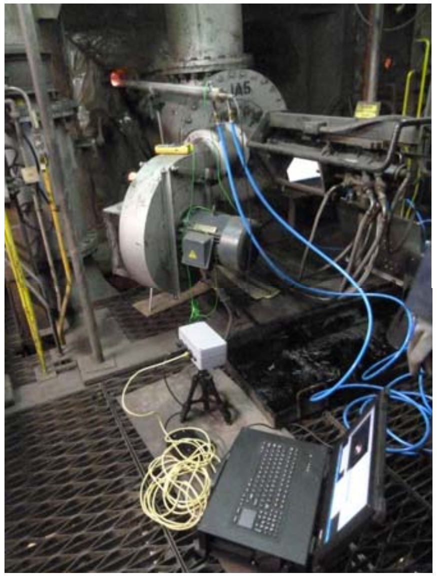
- **A range of flame parameters are measured based on 1D/2D flame signals/images.**
  - *Geometric (Ignition point, size and shape)*
  - *Luminous (brightness, non-uniformity)*
  - *Oscillation frequency*
  - *Temperature distribution*
- **The flame stability is assessed through statistical analysis of the characteristic parameters obtained.**

Field Trials

- The 2-D system has been tested on
  - a $9MW_{th}$ heavy-oil-fired CTF at Zhejiang University, Hangzhou, China,
  - a $660MW_e$ coal/biomass-fired boiler at a power station in UK, and
  - a $660MW_e$ heavy-oil-fired boiler at a power plant in Saudi Arabia.



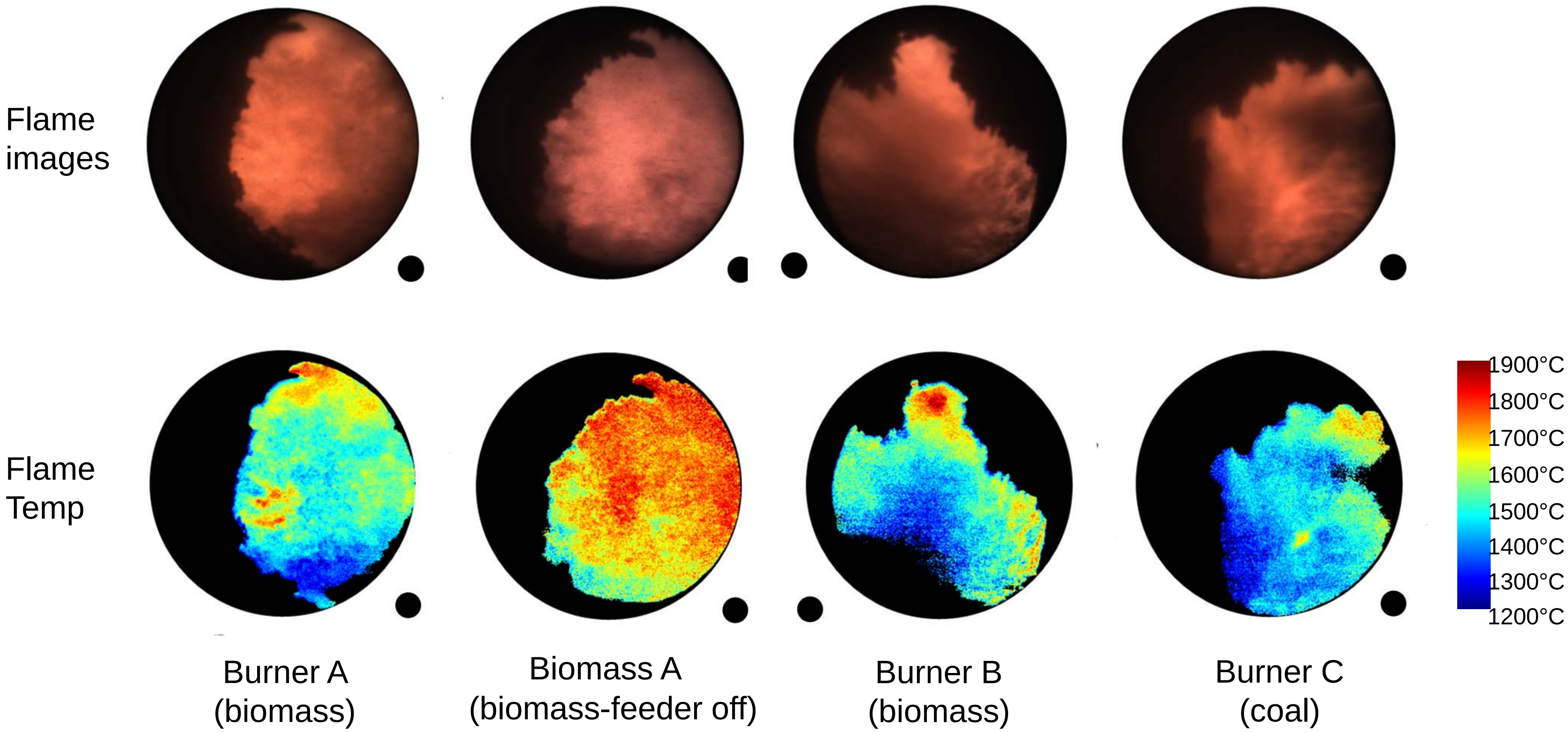
$9MW_{th}$ CTF at Zhejiang University



A power station in UK

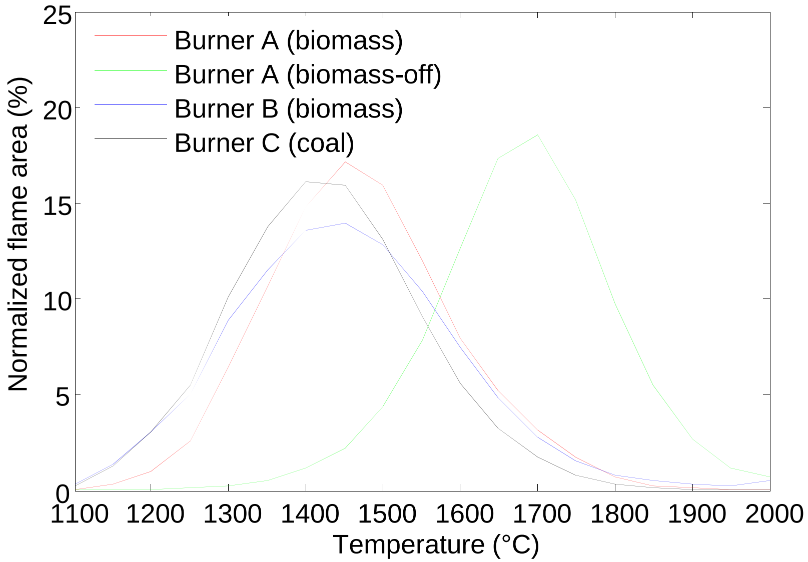
A power station in Saudi Arabia

Flame Images and Temperature Distribution on a 660MW$_e$ Biomass/Coal-Fired Boiler

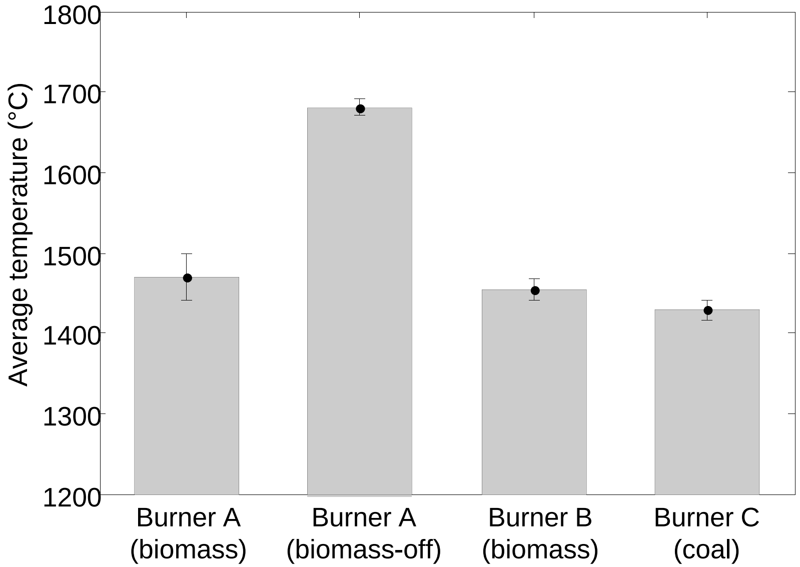


Note: ● - Centre of the burner

Flame Temperature on a 660MW$_e$ Biomass/Coal-Fired Boiler



Temperature histogram



Average temperature

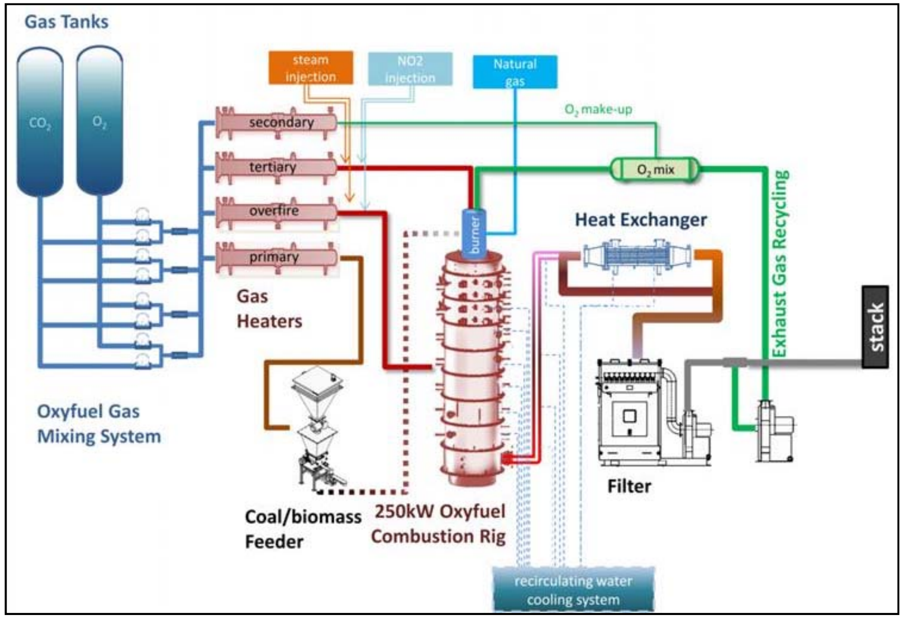
Remarks:

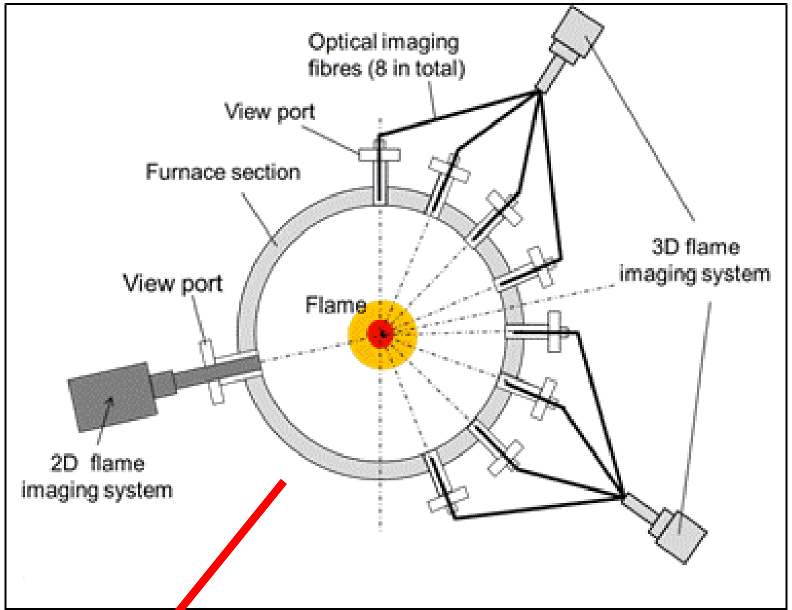
- Increased standard deviations of the flame temperature and luminous region were found under all the biomass conditions, indicating greater instability of the biomass flames.

Test on the PACT 250kW$_{th}$ PF Rig at Beighton

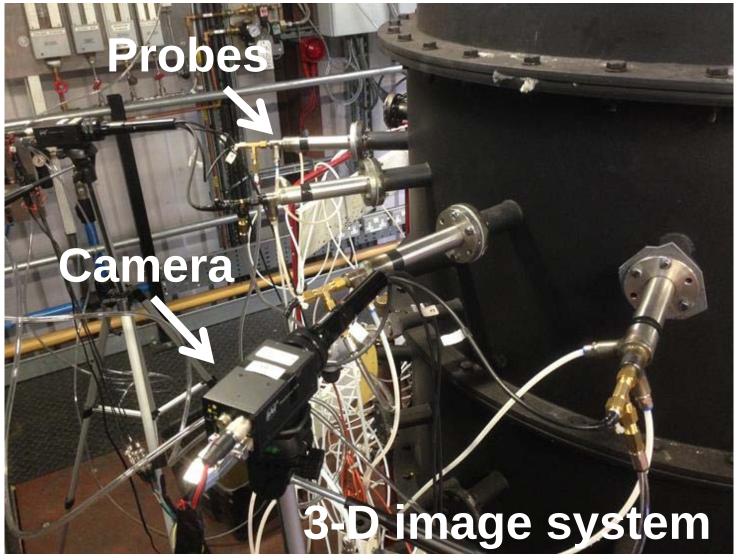
- The 2-D and 3-D systems have recently been tested on the PACT 250kW$_{th}$ PF rig at Beighton with the University of Leeds.
- Due to the limitation of the fibre length, only four of eight probes of the 3-D system were used.
- A variety of air-coal firing conditions were created, including variations in primary air, setting of the secondary air (SA) and tertiary air (TA) splitter.

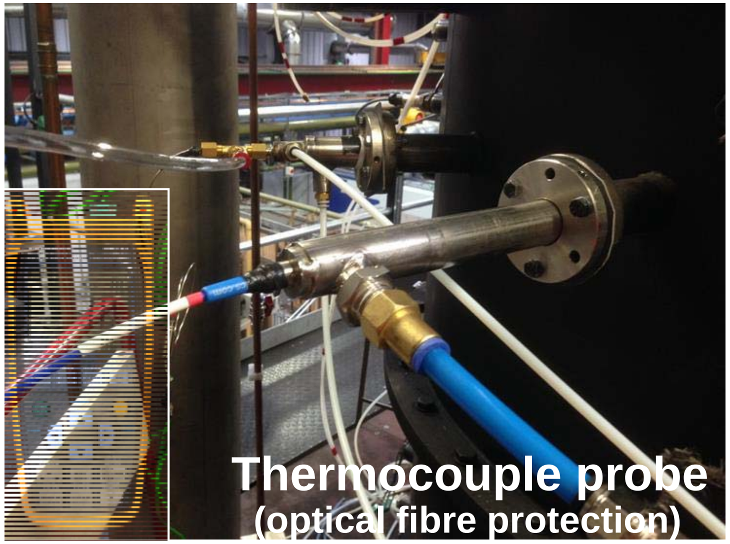
Test on the PACT 250kW$_{th}$ PF Rig at Beighton



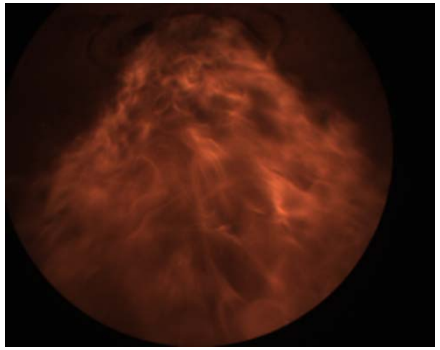


Test on the PACT 250kW$_{th}$ PF Rig at Beighton





Flame Images for Different SA-TA Splitter Settings (2-D System)



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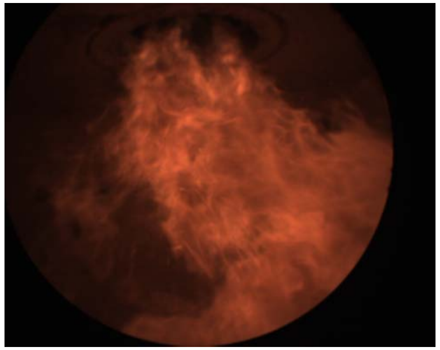
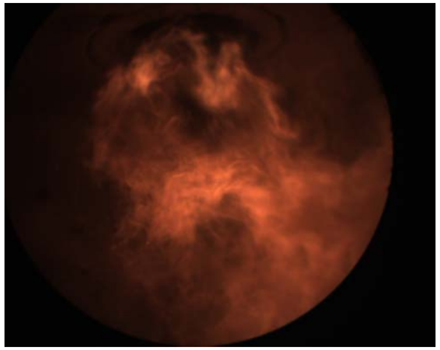


1



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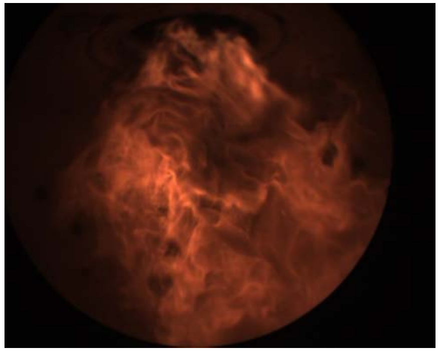

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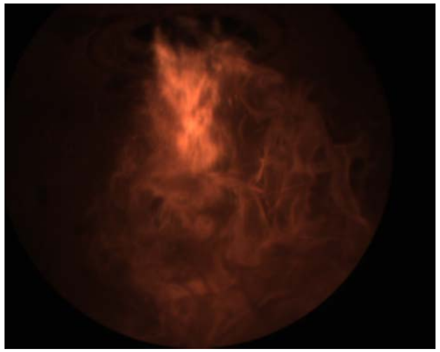

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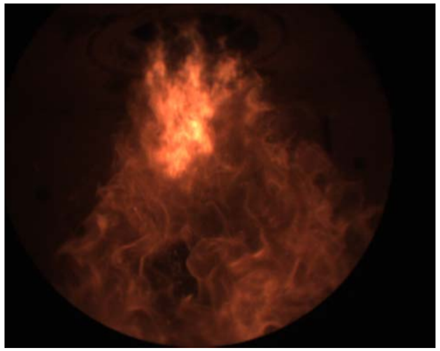

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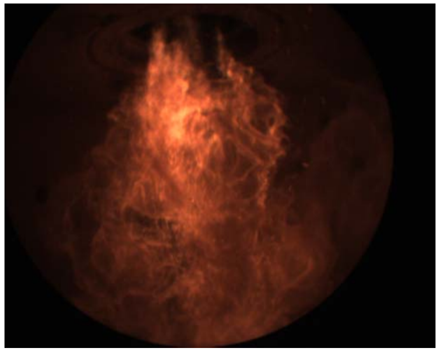

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Note: PA: 20%

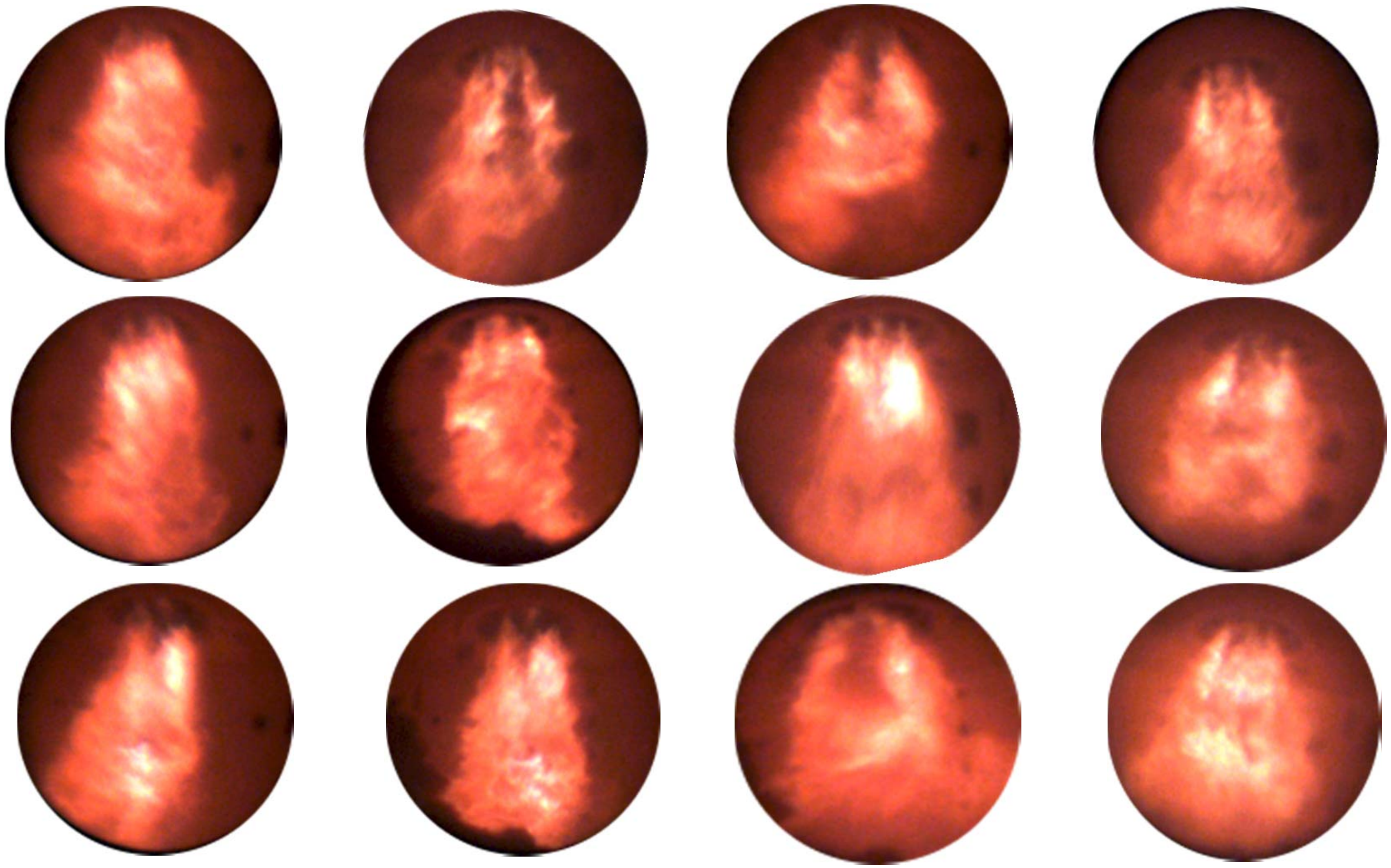
Flame Images from the 3-D System

PA

18%

20%

22%

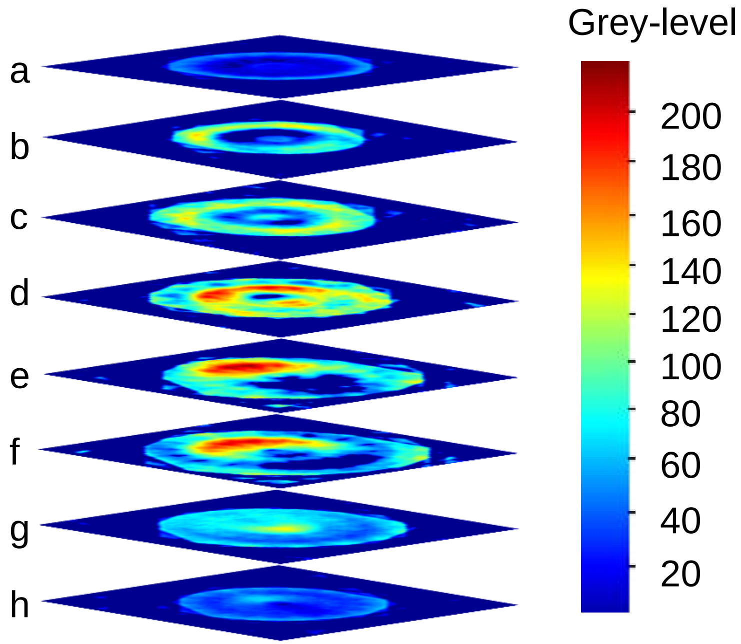


Probe 1 Probe 2 Probe 3 Probe 4

Note: 260KW$_{th}$, *SA-to-TA splitter setting: 3*

3-D Grey-level Reconstruction

2-D flame image



Grey-level reconstruction of flame cross-sections

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Concluding Remarks

- 3-D/2-D flame imaging systems have been developed for the visualisation and characterisation of air- and oxy-coal flames, including flame temperature, emissivity and soot distribution measurements.
- The systems have been tested on various combustion test rigs under different air-firing and oxyfuel-firing conditions in the UK and China.
- Recent tests have been conducted on the PACT 250kW$_{th}$ PF rig at Beighton for different air-firing conditions.
- Oxy-coal tests on the PACT 250kW$_{th}$ PF rig at Beighton have been arranged with the University of Leeds.
- Further oxy-gas testes will be conducted at the Gas Turbine Research Centre at Cardiff University.
- It is envisioned that a combination of the data from measurement systems and CFD modelling results will lead to an in-depth understanding, and subsequent optimisation of oxy-fuel combustion.