Università degli Studi di Firenze
Dipartimento di Ingegneria Industriale - DIEF

Associazione Sezione Italiana del Combustion Institute ASICI

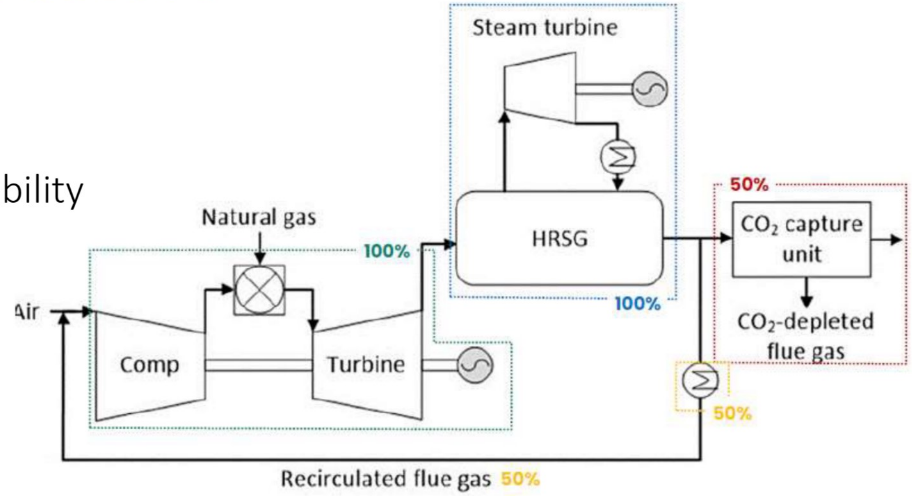
Experimental characterization of an industrial burner operated with simulated EGR

Florence, 30/05/2023

S. Galeotti[1]*, A. Picchi[1], R. Becchi[1], R. Meloni[2], G. Babazzi[2], C. Romano[2], A. Andreini[1]
[1] Department of Industrial Engineering, University of Florence, Italy
[2] Baker Hughes, Via F. Matteucci 2, 50127, Florence, Italy
*sofia.galeotti@unifi.it

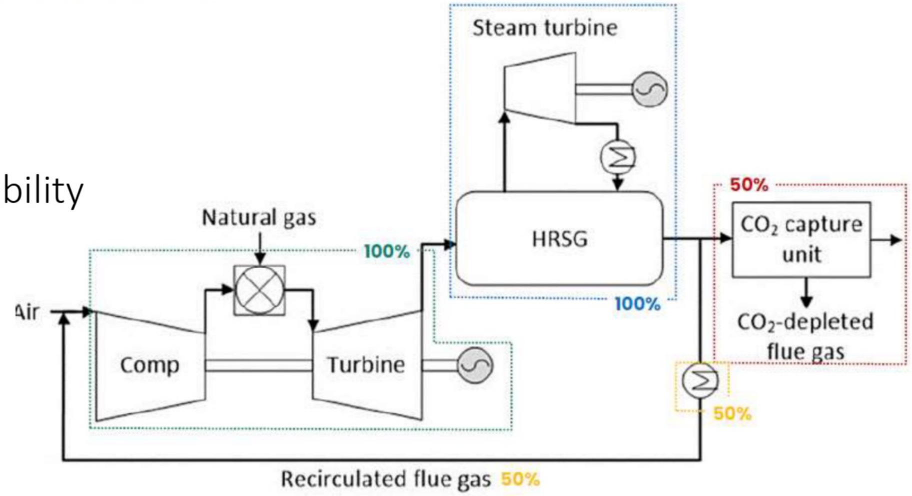
Introduction: EGR in gas turbine combustors

- Exhaust Gas Recirculation (EGR) in gas turbine involves plant complications and high costs
  - Decrease in inlet oxygen is challenging in terms of combustion stability
  - CO and UHC emission increase
- EGR becomes convenient when gas turbines power plants are coupled with CO_2 capture and sequestration processes



Introduction: EGR in gas turbine combustors

- Exhaust Gas Recirculation (EGR) in gas turbine involves plant complications and high costs
  - Decrease in inlet oxygen is challenging in terms of combustion stability
  - CO and UHC emission increase
- EGR becomes convenient when gas turbines power plants are coupled with CO_2 capture and sequestration processes



TRANSITION

Funded by the European Union

fuTure hydRogen Assisted gas turbiNeS for effective carbon capTure IntegratiON

Main objective: Pave the way for the carbon-neutral energy generation from natural gas-fired power plants using GT

→Efficient coupling of gas turbine generators with CO_2 capture and sequestration (CCS) processes:

→EGR to increase CO_2 content in exhaust in order to maximize CCS efficiency

→Need to extend EGR operations capabilities of GT units

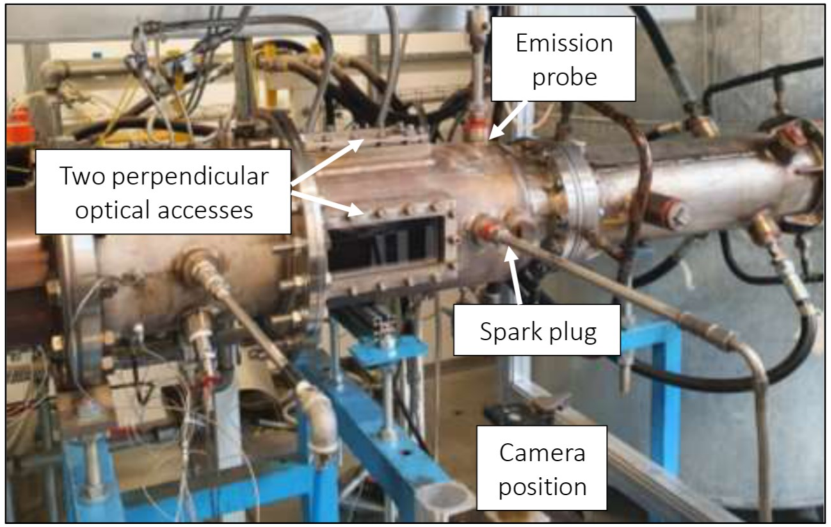
Aim of the work:
Experimental characterization of baseline DLN burner in simulated EGR conditions

Experimental campaign at ambient pressure with industrial burner fuelled with natural gas

- Emission measurements: NO_x and CO
- OH* chemiluminescence
- Thermoacoustic instabilities

EGR is simulated with CO_2 addition in the combustion airflow

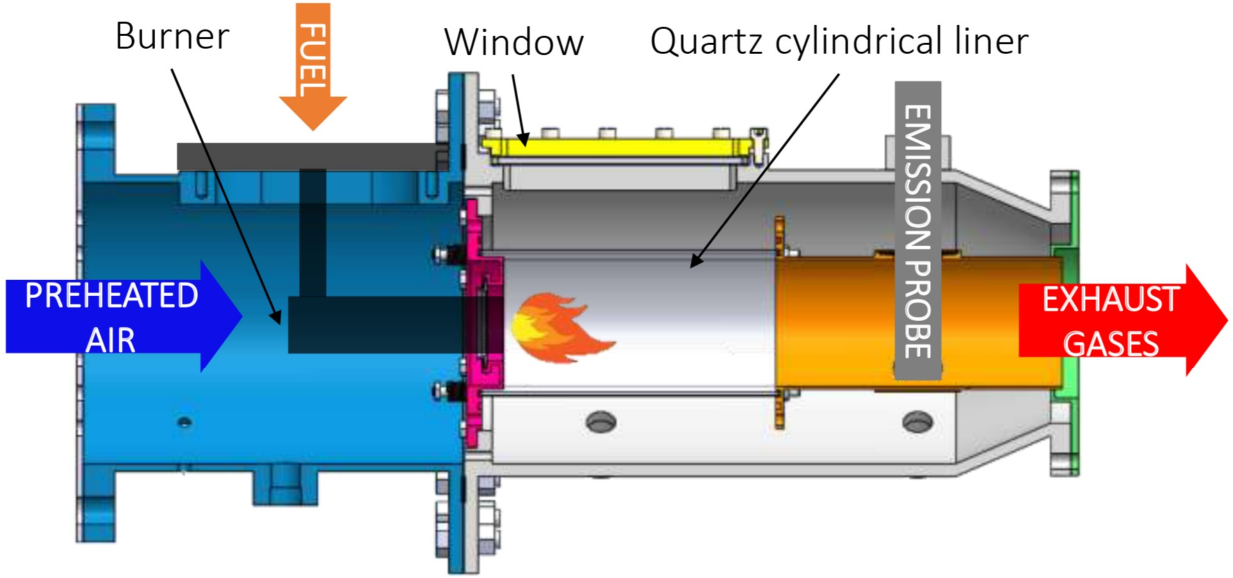
Experimental data will be used to validate CFD models to optimize the burner geometry and expand the EGR operability range



Test rig and burner

Optical reactive test rig:

- Single cup configuration (1:1 scale)
- Quartz tubular liner
- Effusion cooled dome
- Double optical access to the flame
- Emission probe
- Spark ignition



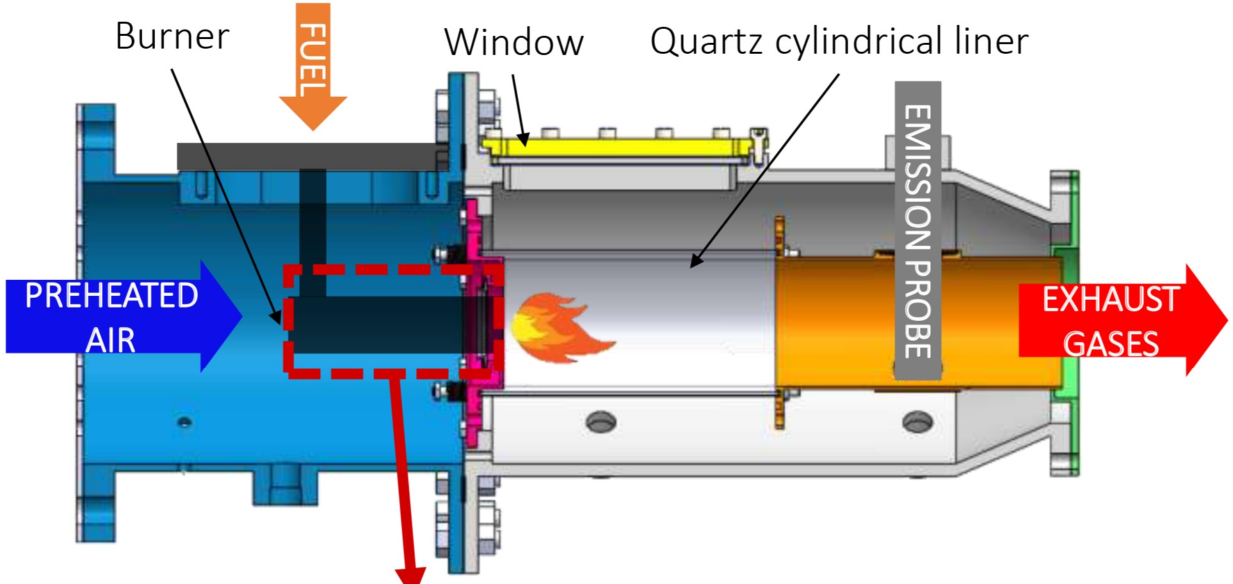
Test rig and burner

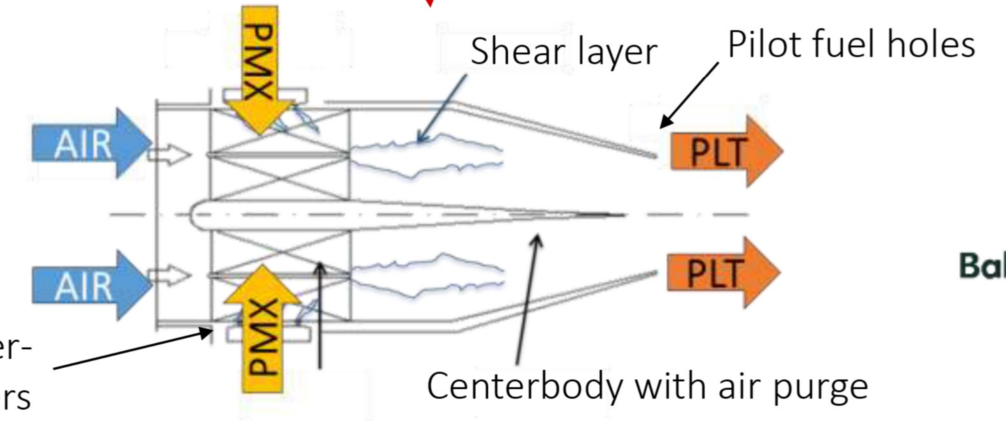
Optical reactive test rig:

- Single cup configuration (1:1 scale)
- Quartz tubular liner
- Effusion cooled dome
- Double optical access to the flame
- Emission probe
- Spark ignition

DLN baseline burner

- Double counter-rotating swirlers
- 2 fuel lines
  - Pilot line (PLT)
  - Premix line (PMX)

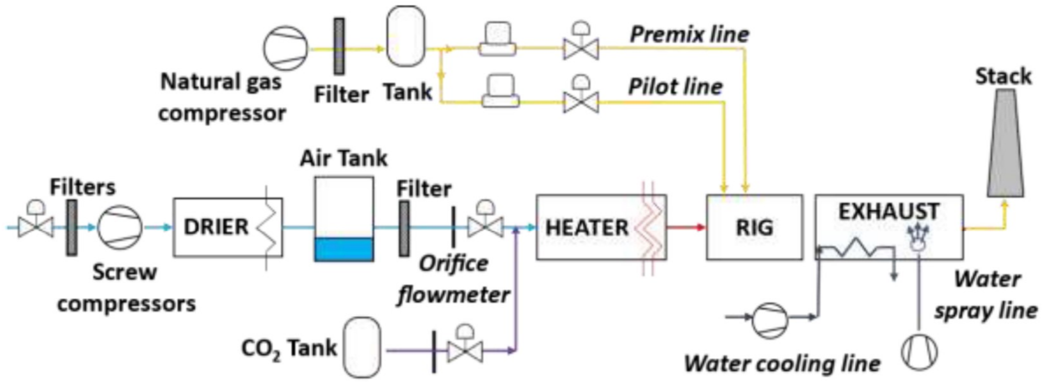




Baker Hughes

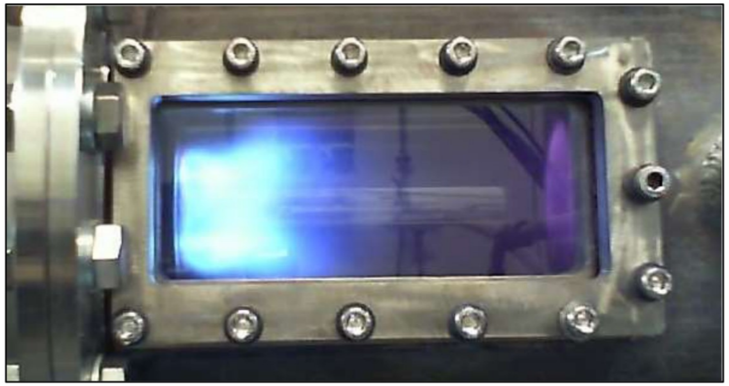
Operating conditions: reactive tests

- Atmospheric pressure
- Fuel: natural gas (from domestic line)
  - Fuel composition analysed at BH after each test
- Inlet temperature T_{inlet}=300°C
- Burner pressure drop ΔP/P=4.2%

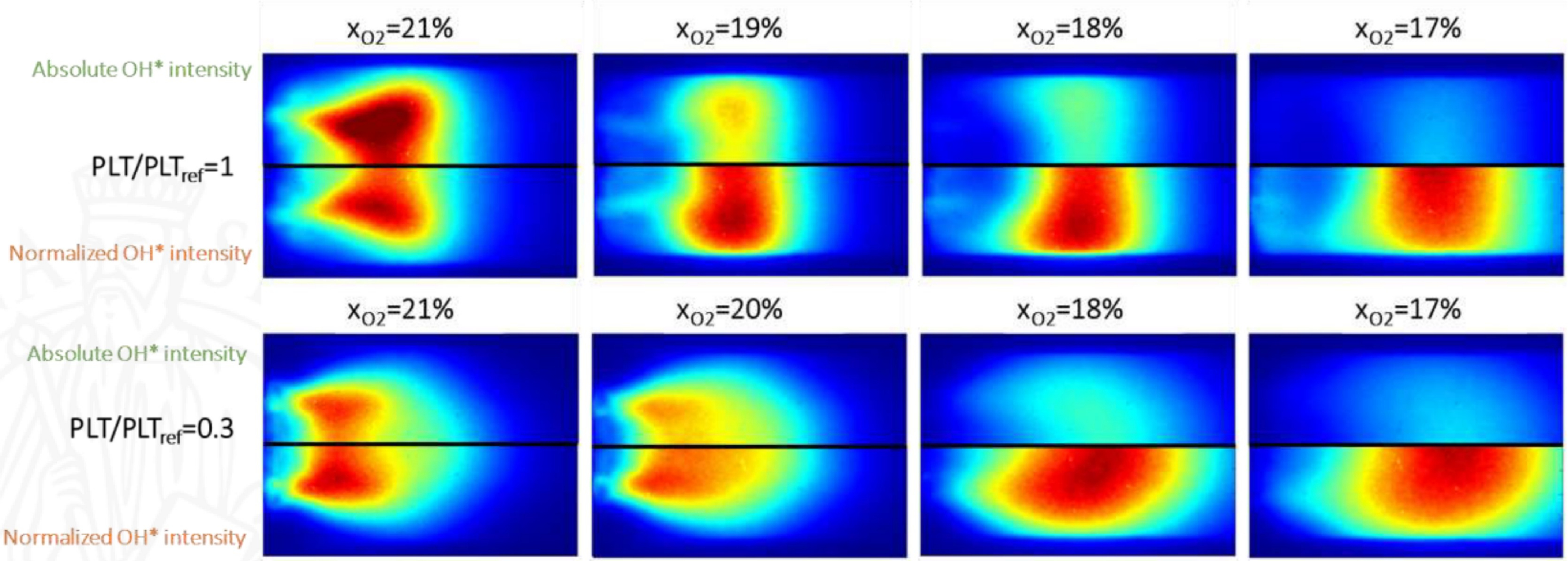


Investigated parameters:

- Different fuel splits (PLT%)
- Two different sets of operating conditions
  - Combustion with standard air (x_{O2}=21%)
  - Combustion with **CO_2 vitiated air (simulated EGR)**
    - **EGR condition is defined by inlet oxygen mole fraction x_{O2} and adiabatic flame temperature**



Results: OH* chemiluminescence



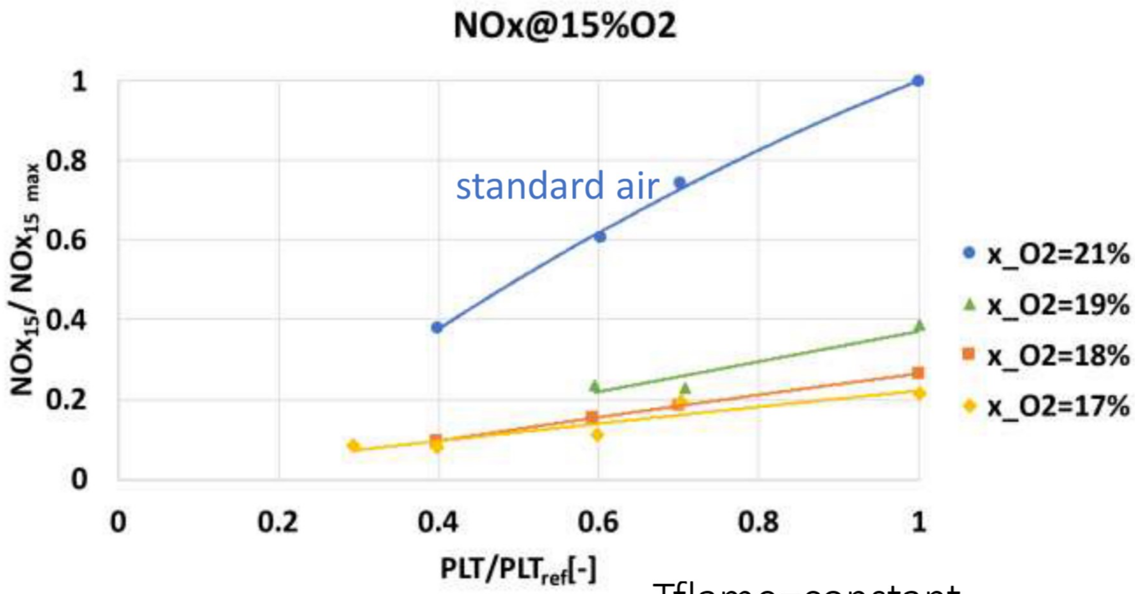
Test are performed at Tflame=constant

Time-averaged images acquired with HS Phantom camera and HAMAMATSU image intensifier

Emission measurements: effect of CO_2 addition and fuel split

NO_x

- NO_x emission with standard air decrease with lower pilot fuel fraction
- **CO_2 addition strongly decrease NO_x emissions**
- Further increase in CO_2 dilution has limited effect
- CO_2 addition lowers the effect of fuel split



Tflame=constant

Correction with CO2 vitiated air to take into account oxygen depletion

$$NO_{x\,15} = NO_{x\,dry} \cdot \frac{0.2095 - 0.15}{2 - 0.2095} \frac{2 - x_{O2\,inlet}}{x_{O2\,inlet} - x_{O2\,dry}}$$

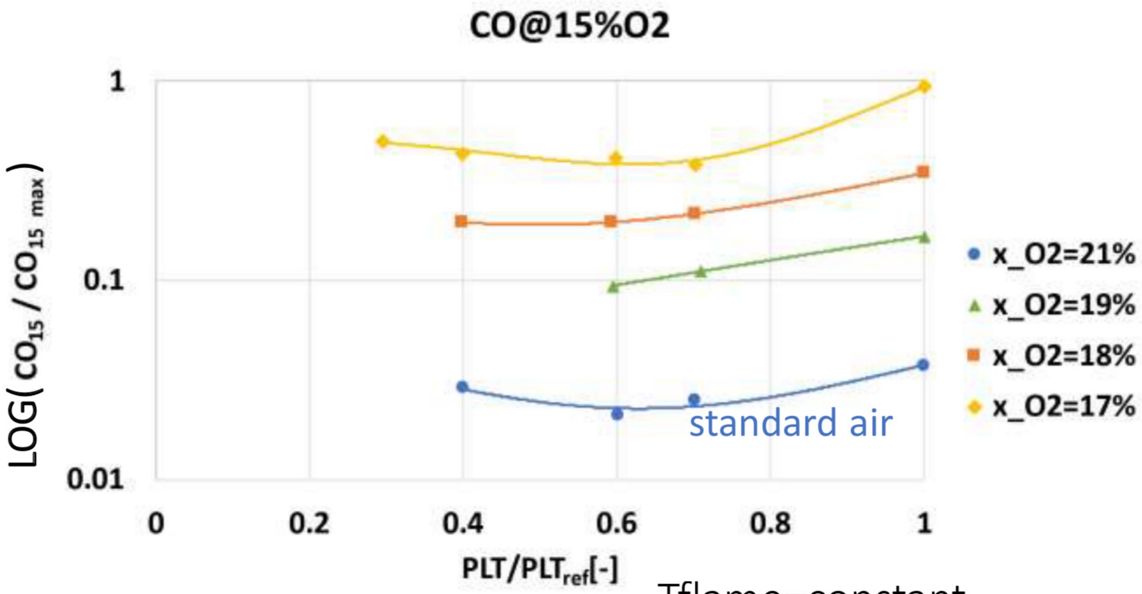
Emission measurements: effect of CO_2 addition and fuel split

NO_x

- NO_x emission with standard air decrease with lower pilot fuel fraction
- CO_2 addition strongly decrease NO_x emissions
- Further increase in CO_2 dilution has limited effect
- CO_2 addition lowers the effect of fuel split

CO

- **CO emission strongly increase with CO_2 addition**
- Lower dependency on fuel split, CO_2 addition does not change trend



Tflame=constant

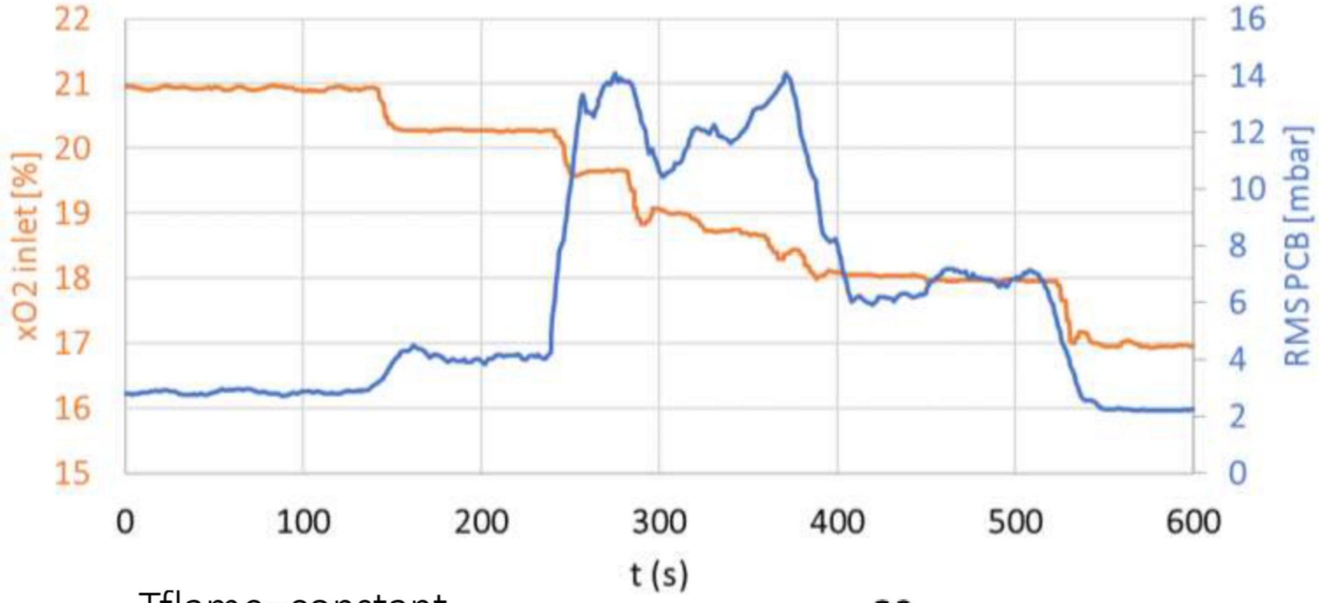
Correction with CO2 vitiated air to take into account oxygen depletion

$$CO_{15} = CO_{dry} \cdot \frac{0.2095 - 0.15}{2 - 0.2095} \frac{2 - x_{O2\ inlet}}{x_{O2\ inlet} - x_{O2\ dry}}$$

Thermoacoustic instabilities triggered by CO_2 addition

- Pressure oscillations arise with CO_2 addition
- Amplitude increases with CO_2 fraction in the oxidizer, reaches a maximum, and eventually decreases

Oxygen inlet content vs amplitude of pressure oscillations

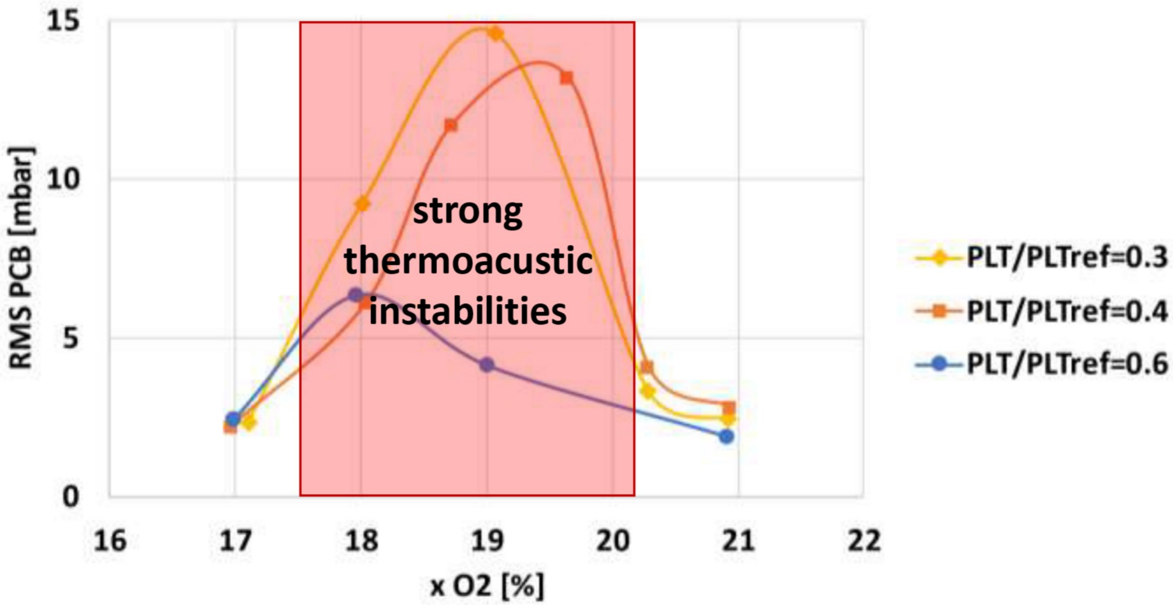


Tflame=constant

$PLT/PLT_{ref}=0.4$

Thermoacoustic instabilities triggered by CO_2 addition

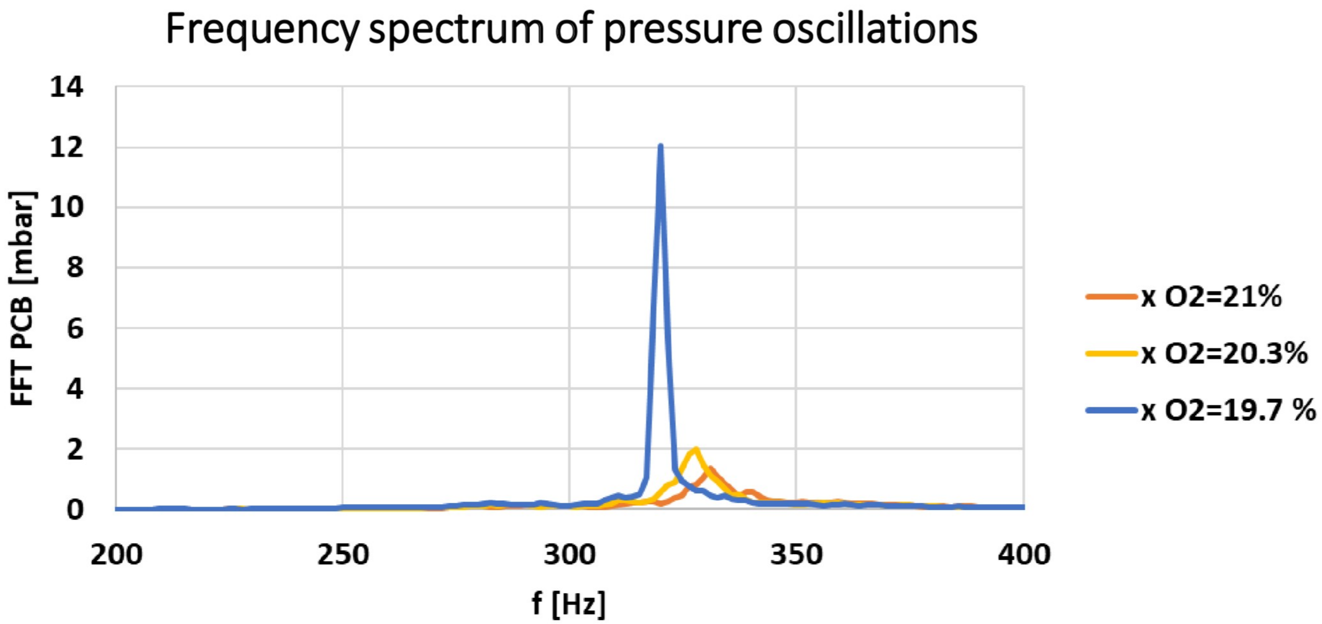
- Pressure oscillations arise with CO_2 addition
- Amplitude increases with CO_2 fraction in the oxidizer, reaches a maximum, and eventually decreases
- Same behavior observed with all fuel splits
- Amplitude increases with lower pilot fuel fraction



Tflame=constant

Thermoacoustic instabilities triggered by CO_2 addition

- Pressure oscillations arise with CO_2 addition
- Amplitude increases with CO_2 fraction in the oxidizer, reaches a maximum, and eventually decreases
- Same behavior observed with all fuel splits
- Amplitude increases with lower pilot fuel fraction
- Frequency lowers with higher CO_2 fraction in the oxidizer



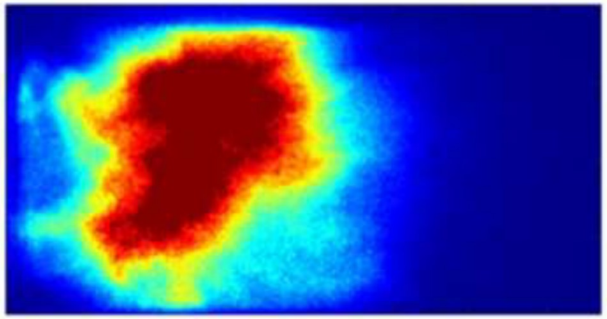
Tflame=constant

$PLT/PLT_{ref}=0.4$

Thermoacoustic instabilities triggered by CO_2 addition

- Pressure oscillations arise with CO_2 addition
- Amplitude increases with CO_2 fraction in the oxidizer, reaches a maximum, and eventually decreases
- Same behavior observed with all fuel splits
- Amplitude increases with lower pilot fuel fraction
- Frequency lowers with higher CO_2 fraction in the oxidizer
- OH* chemiluminescence shows intense longitudinal fluctuations of the flame

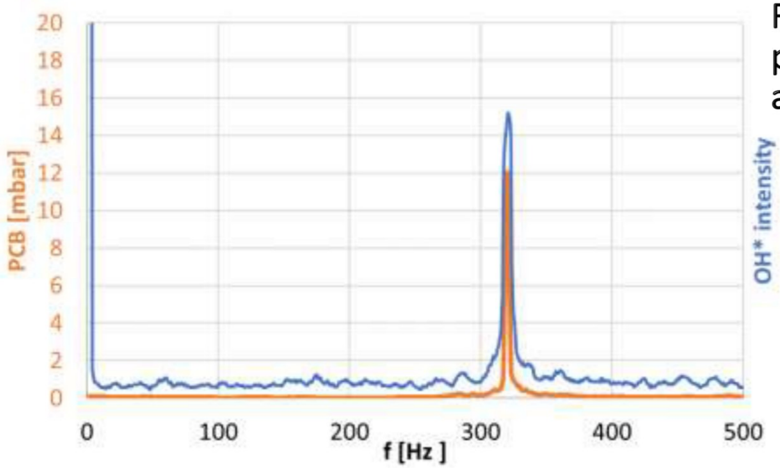
OH* chemiluminescence



PLT/PLT_{ref}=0.4

X_{O2}=19.7%

Acquired at 1000 Hz



Frequency spectrum of pressure oscillations and averaged OH* intensity

Conclusions

Experimental characterization of an industrial burner operated with simulated EGR

- Flame topology studied with OH* chemiluminescence:
  - OH* intensity strongly diminishes with CO_2 addition and reaction becomes widespread
- Emission measurements
  - CO levels significantly increase with CO_2 dilution
  - Nox emissions descrease with CO_2 dilution and lower fuel pilot fraction
- Outbreak of thermoacoustic instabilities with CO_2 vitiated air limits the burner EGR operating window
- Experimental data will support the validation of CFD models to optimize the burner geometry for EGR operation

Acknoledgments

Funded by the European Union

This project has received funding from the European Union's Horizon Europe research and Innovation program under Grant Agreement No 101069665

UNIVERSITÀ DEGLI STUDI FIRENZE

DIEF Dipartimento di Ingegneria Industriale

Associazione Sezione Italiana del Combustion Institute ASICI

Università degli Studi di Firenze
Dipartimento di Ingegneria Industriale - DIEF

Baker Hughes

Experimental characterization of an industrial burner operated with simulated EGR

Thank you for the attention!

S. Galeotti[1]*, A. Picchi[1], R. Becchi[1], R. Meloni[2], G. Babazzi[2], C. Romano[2], A. Andreini[1]

[1] Department of Industrial Engineering, University of Florence, Italy

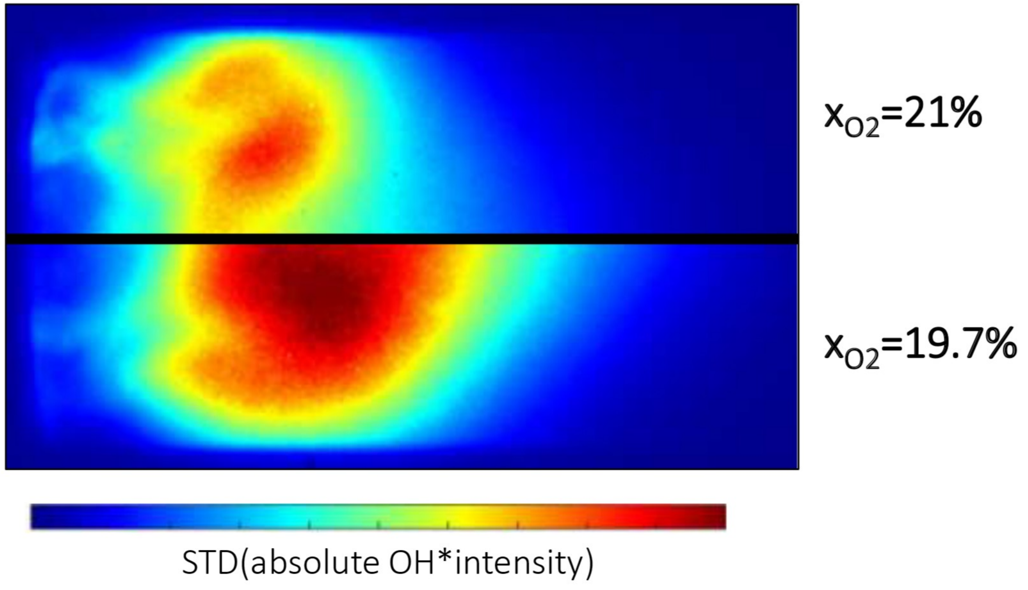
[2] Baker Hughes, Via F. Matteucci 2, 50127, Florence, Italy

*sofia.galeotti@unifi.it

Thermoacoustic instabilities triggered by CO_2 addition

- Pressure oscillations arise with CO_2 addition
- Amplitude increases with CO_2 fraction in the oxidizer, reaches a maximum, and eventually decreases
- Same behavior observed with all fuel splits
- Amplitude increases with lower pilot fuel fraction
- Frequency lowers with higher CO_2 fraction in the oxidizer
- OH* chemiluminescence shows intense longitudinal fluctuations of the flame

Standard deviation of OH* intensity



Tflame=constant

PLT/PLT_{ref}=0.4