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# Experimental and numerical studies of the influence of diluent on characteristic micro-scale combustion flame behaviour

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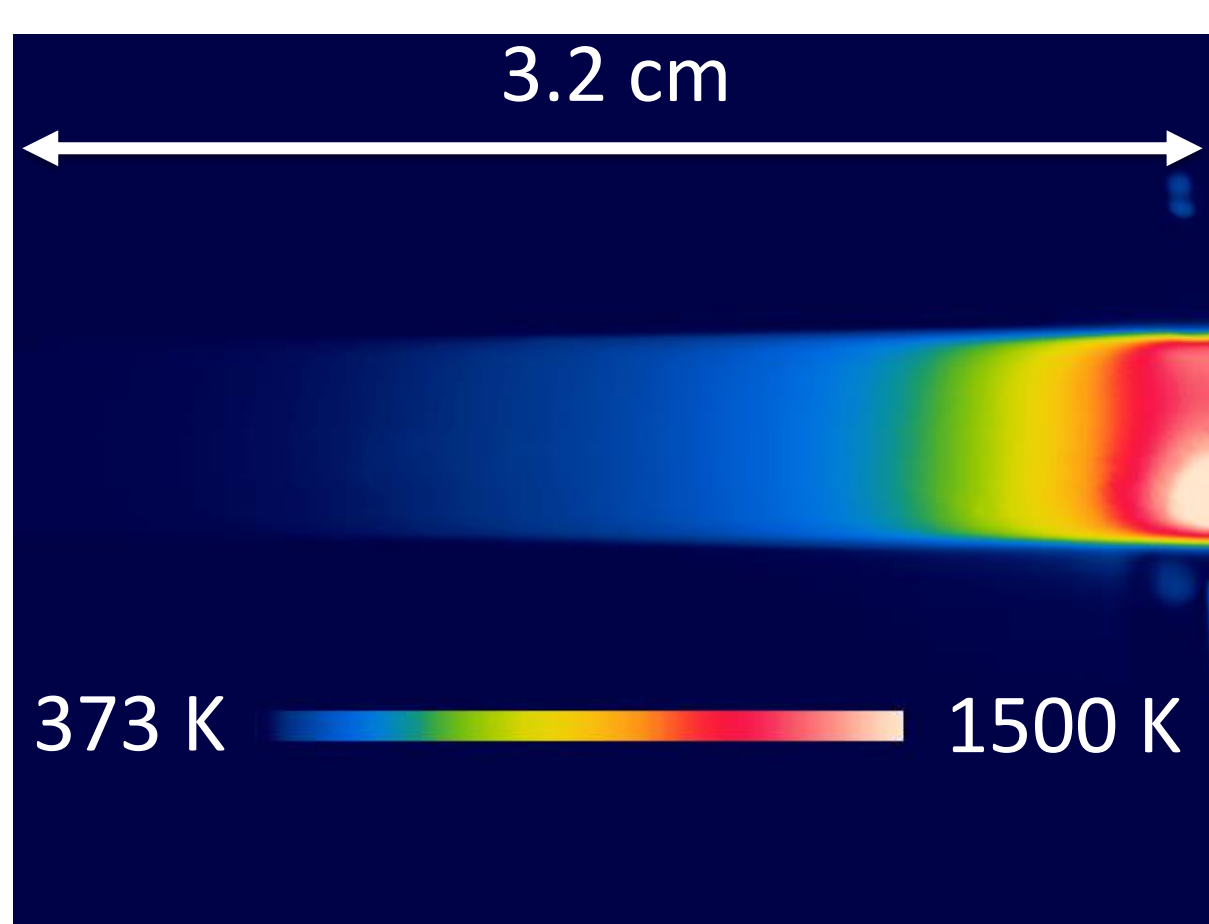
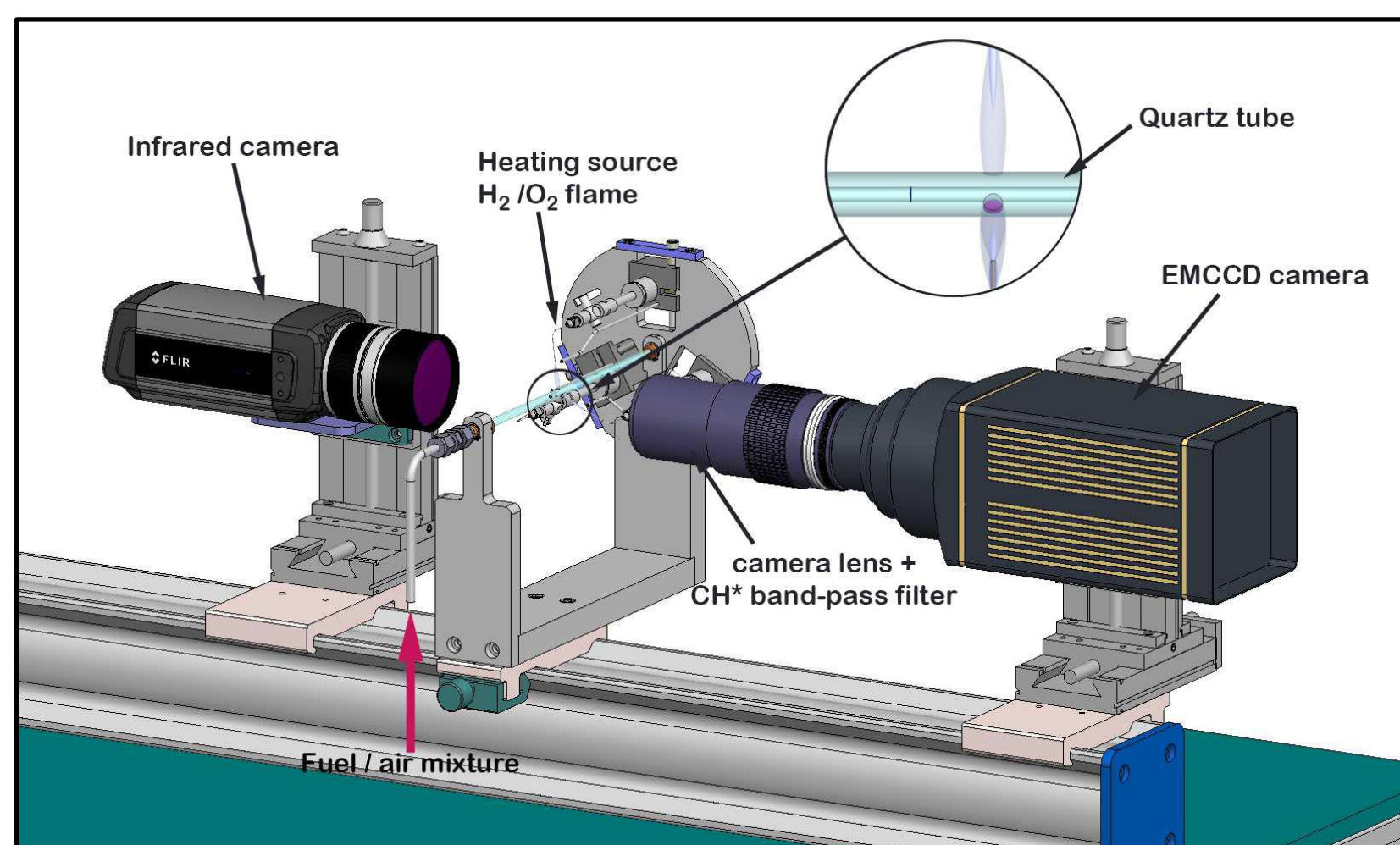
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## 1. Goal of the study

- Growing need to improve knowledge in the field of small-scale combustion and take advantage of high energy density of fuel [1] in different applications such as portable power device [2], micro-satellite thrusters [3], heat sources [4].
- Previous studies have been done with fuel/air mixtures. Combustion of a CH<sub>4</sub>/O<sub>2</sub> mixture with different diluents can improve the understanding of flame behaviour in micro-scale reactor by changing physical properties of the environment. Hence, be able to point out physico-chemical properties that play an important role in micro-scale combustion.

## 2. Experimental set-up

- Cylindrical quartz tube heated by 3 hydrogen/oxygen blowtorches.
- The temperature profile on the outer side is measured by an infrared camera A655sc.
- A spectroscopy EMCCD camera ProEM 1600 with a CH\* band-pass filter (20BPF1\_430) is used to detect the flame positions.
- CH<sub>4</sub>/diluent mixture is supplied in a 1.85 mm internal diameter reactor. (Quenching distance of CH<sub>4</sub>/air is 2.50 mm)

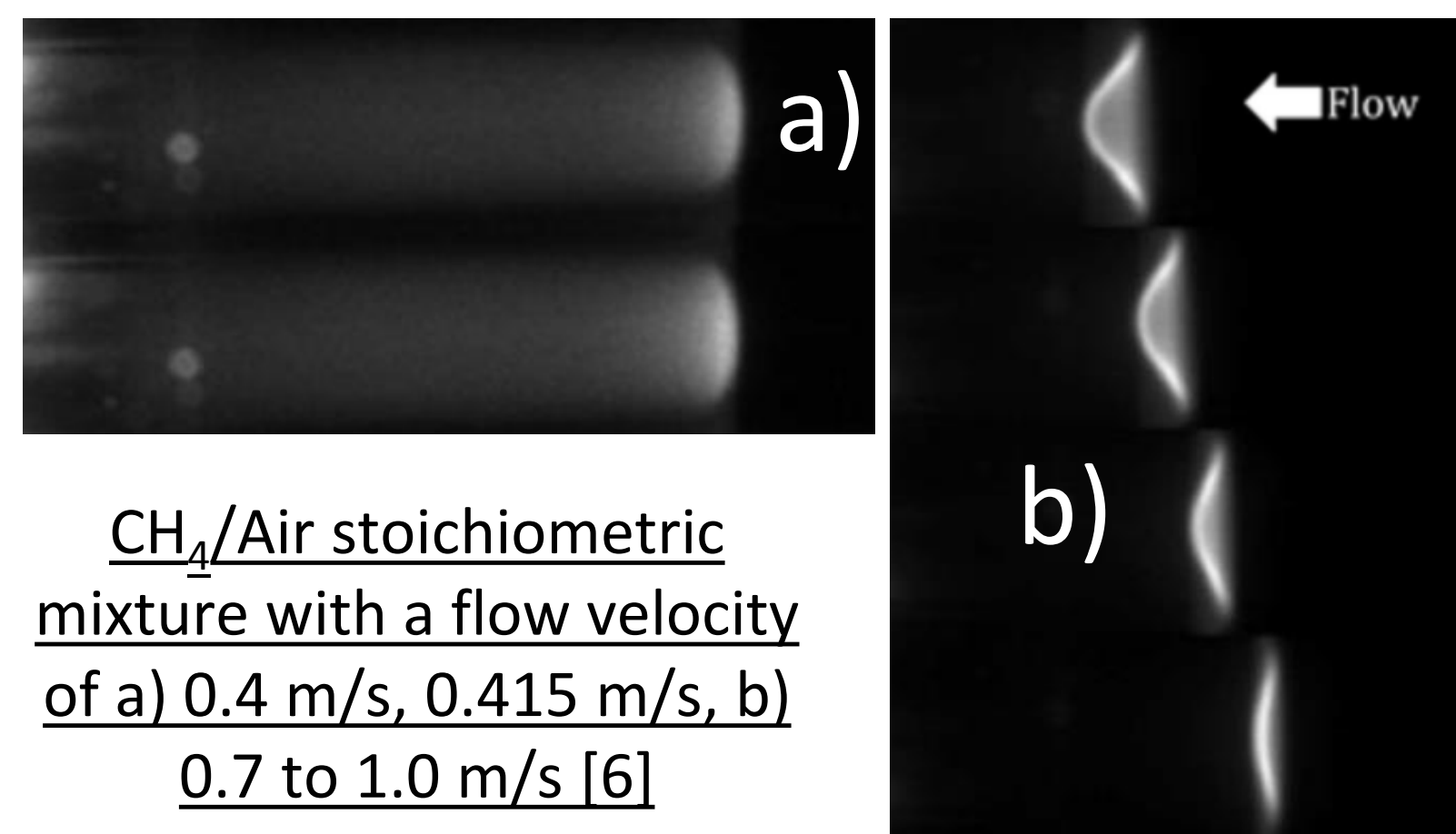


Schematic of the data acquisition system and micro-reactor [6]

Image from FLIR camera of the external temperature for a stoichiometric mixture of CH<sub>4</sub>/air, a flow velocity of 0.7 m/s, in a 1.85 mm internal diameter tube

## 3. Different flame behaviour

- a) **FREI** (Flame with Repetitive Extinction and Ignition): the ignition occurs downstream in high temperature region and extinction occurs upstream in low temperature region.
- b) **Stable flame**: flames with no relative motion with the reactor wall.



CH<sub>4</sub>/Air stoichiometric mixture with a flow velocity of a) 0.4 m/s, 0.415 m/s, b) 0.7 to 1.0 m/s [6]

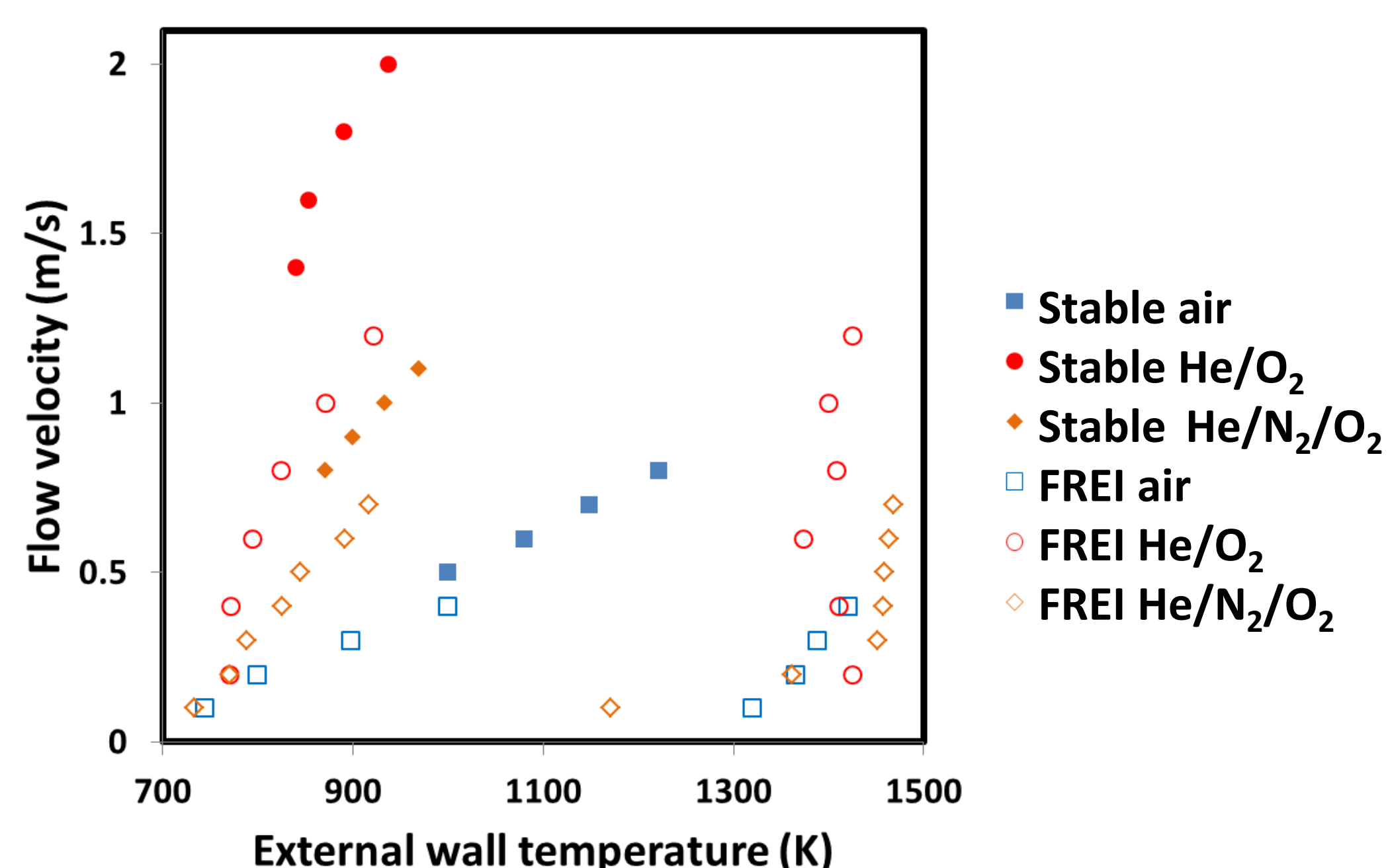
## 4. Experimental and numerical results

Diluent	O <sub>2</sub>	He	N <sub>2</sub>
Air	20%	0%	80%
He/N <sub>2</sub> /O <sub>2</sub>	21.18%	39.20%	39.62%
He/O <sub>2</sub>	21.68%	78.32%	0%

Compositions of diluents used in this study in molar fraction

Diluent	Laminar burning velocity (cm/s)	Adiabatic flame temperature (K)
Air	30	2221
He/N <sub>2</sub> /O <sub>2</sub>	61	2367
He/O <sub>2</sub>	119	2519

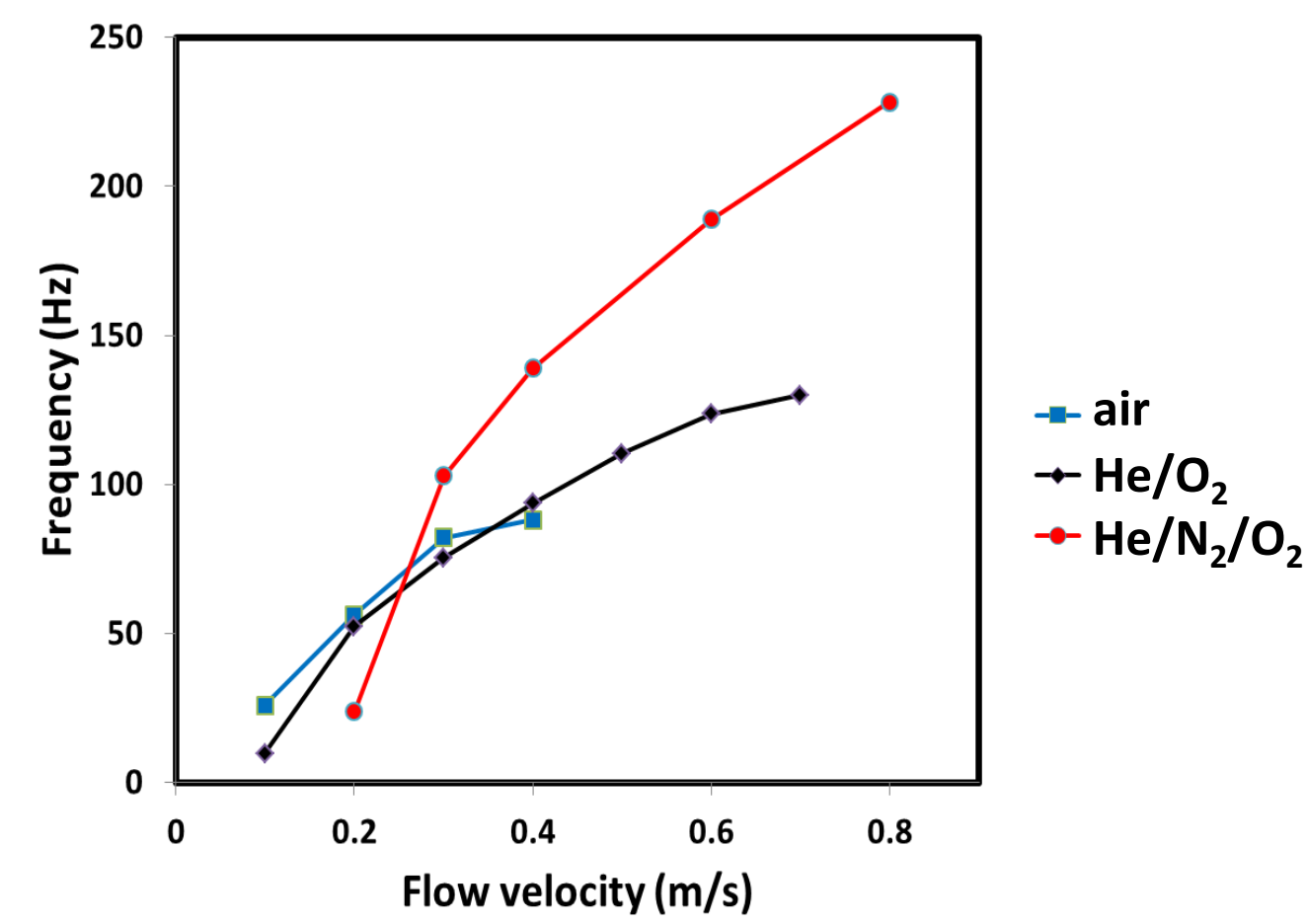
Laminar burning velocity and adiabatic flame temperature of a stoichiometric mixture CH<sub>4</sub>/diluent



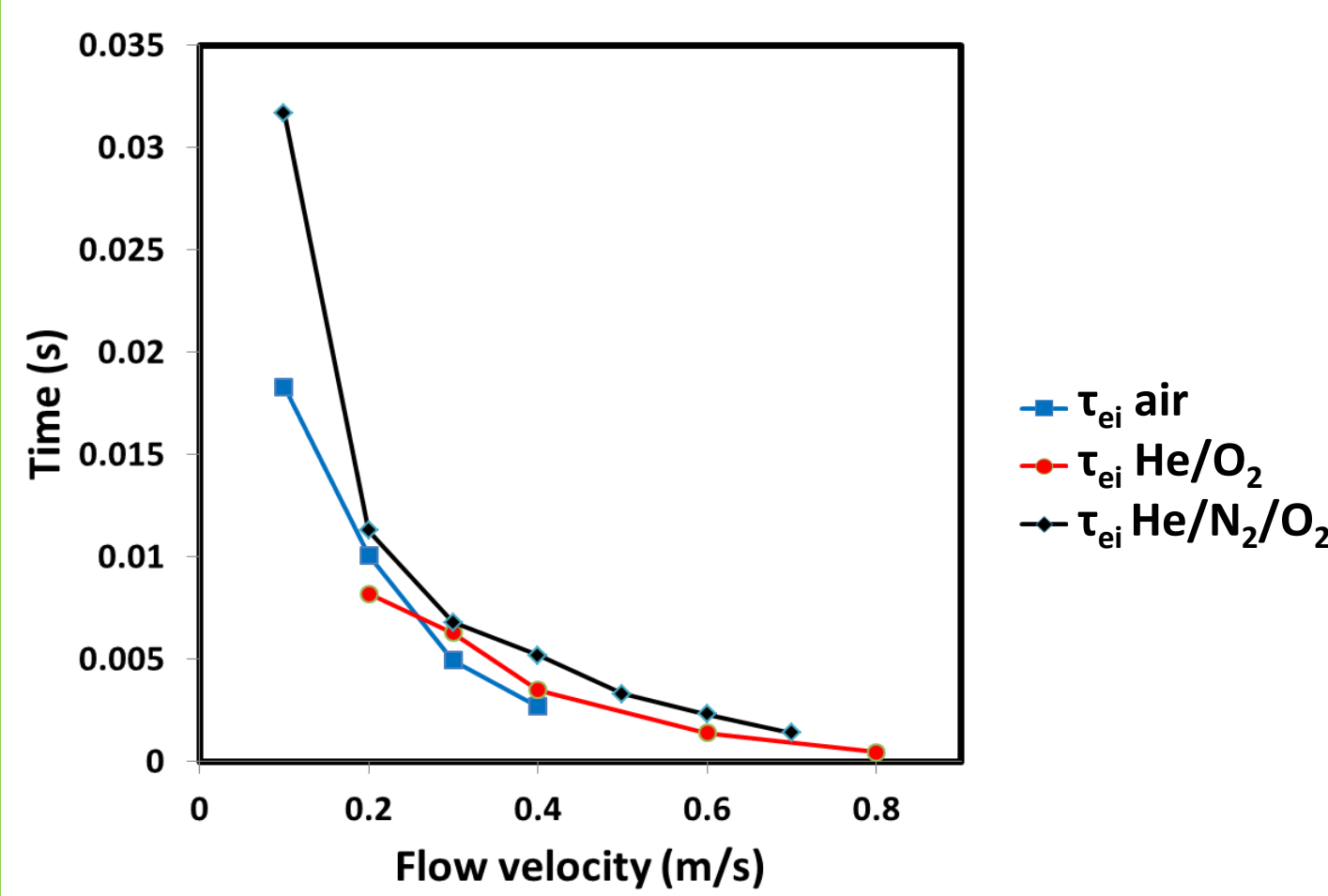
Flame position defined at the wall temperature as a function of the mixture flow velocity

## 4.1. FREI

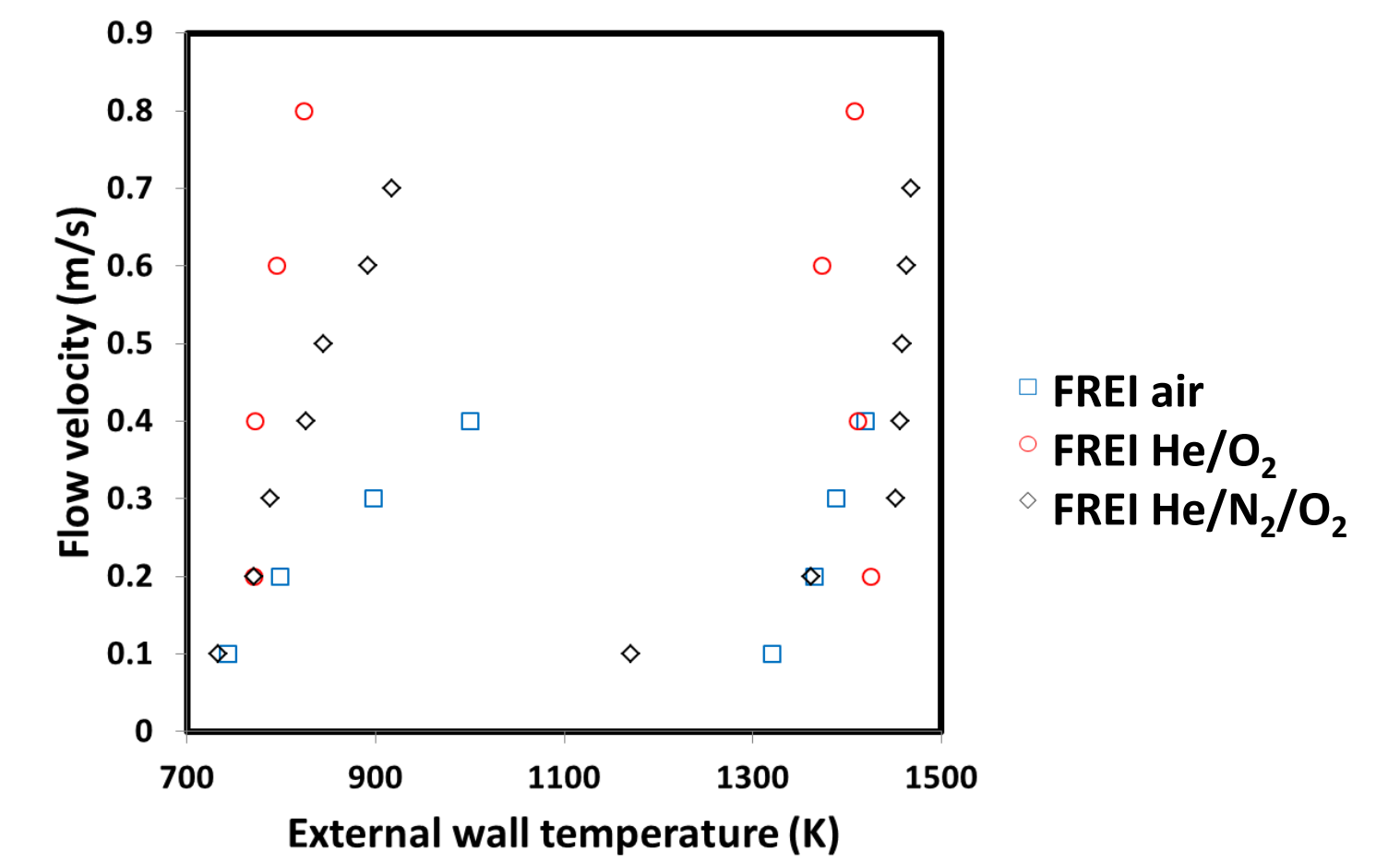
- For a given fuel/oxydant mixture: when the flow velocity increases → frequency increases.
- For a given flow velocity: when the flame propagation speed of a mixture A is bigger than a mixture B →  $\tau_{ie}$  in A is smaller than in B.



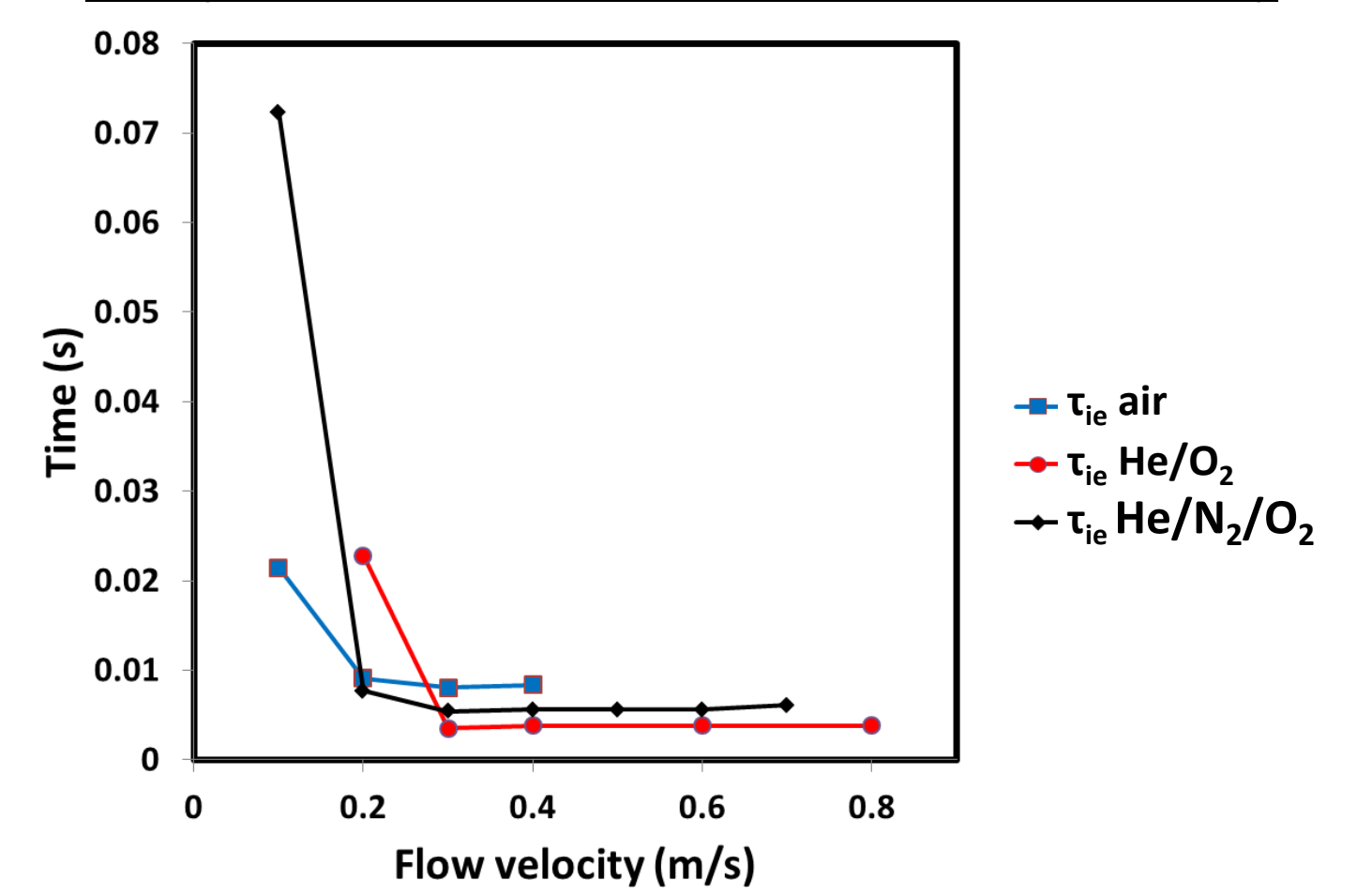
Frequency of FREI variation as a function of inlet velocity



Time between Extinction and Ignition



Flame position defined as the external wall temperature as a function of flow velocity



Time between Ignition and Extinction

## 4.2. Stable flame

### Solution methods and solvers

- Steady state simulation
- The Stiff Chemistry Solver of ANSYS Fluent is used to solve the reactive flow
- PISO method for velocity-pressure coupling is used to solve the discretized form of the Navier-Stokes system
- A second order upwind spatial discretization is used and a least squares cell-based method for the evaluation of gradients

### Boundary conditions:

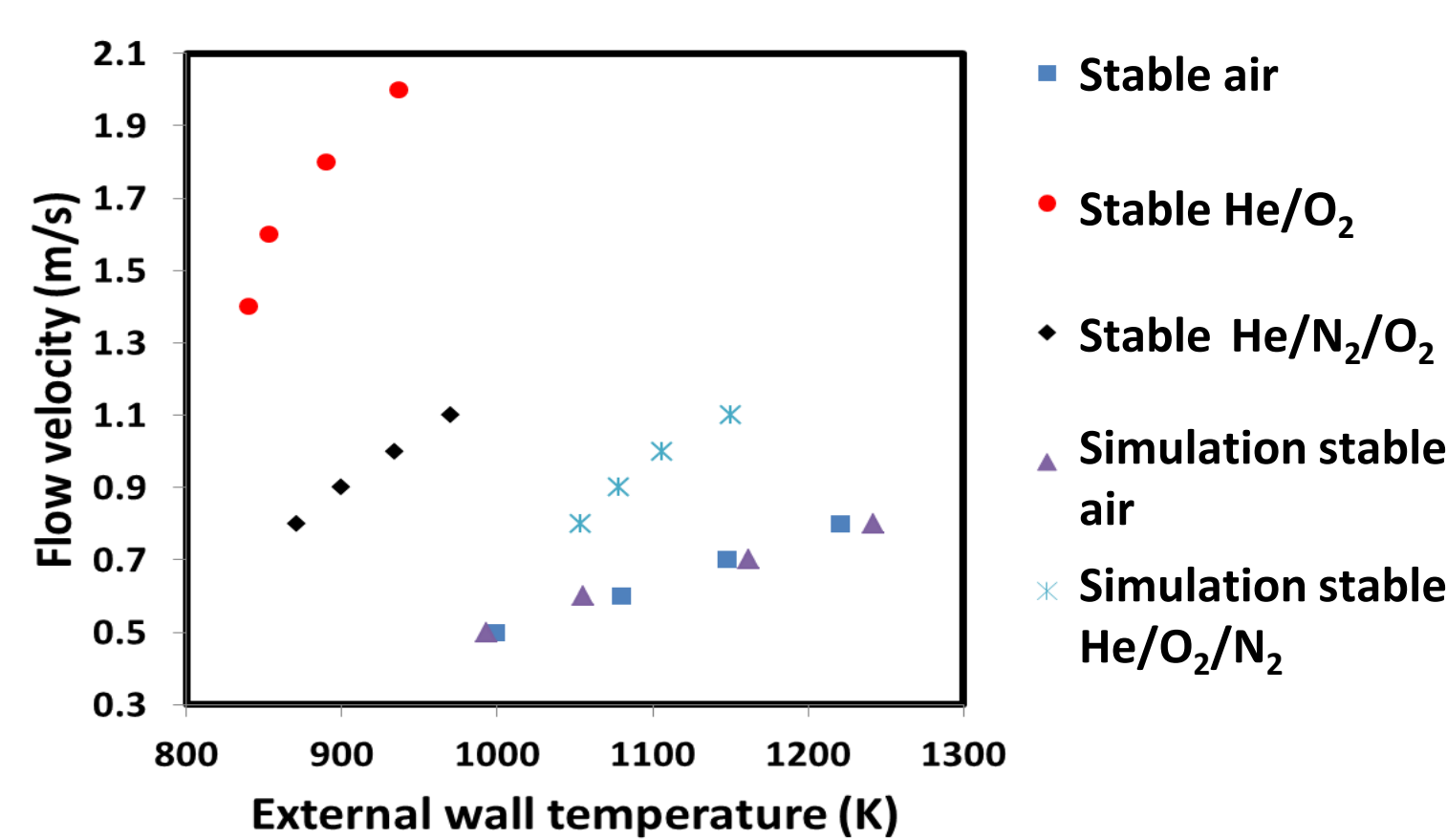
- Experimental external wall temperature is averaged and used as boundary condition
- A velocity inlet boundary condition is applied on the left part of the geometry, and a pressure outlet boundary condition (1 atm) on the right part

### Geometry/ Meshing:

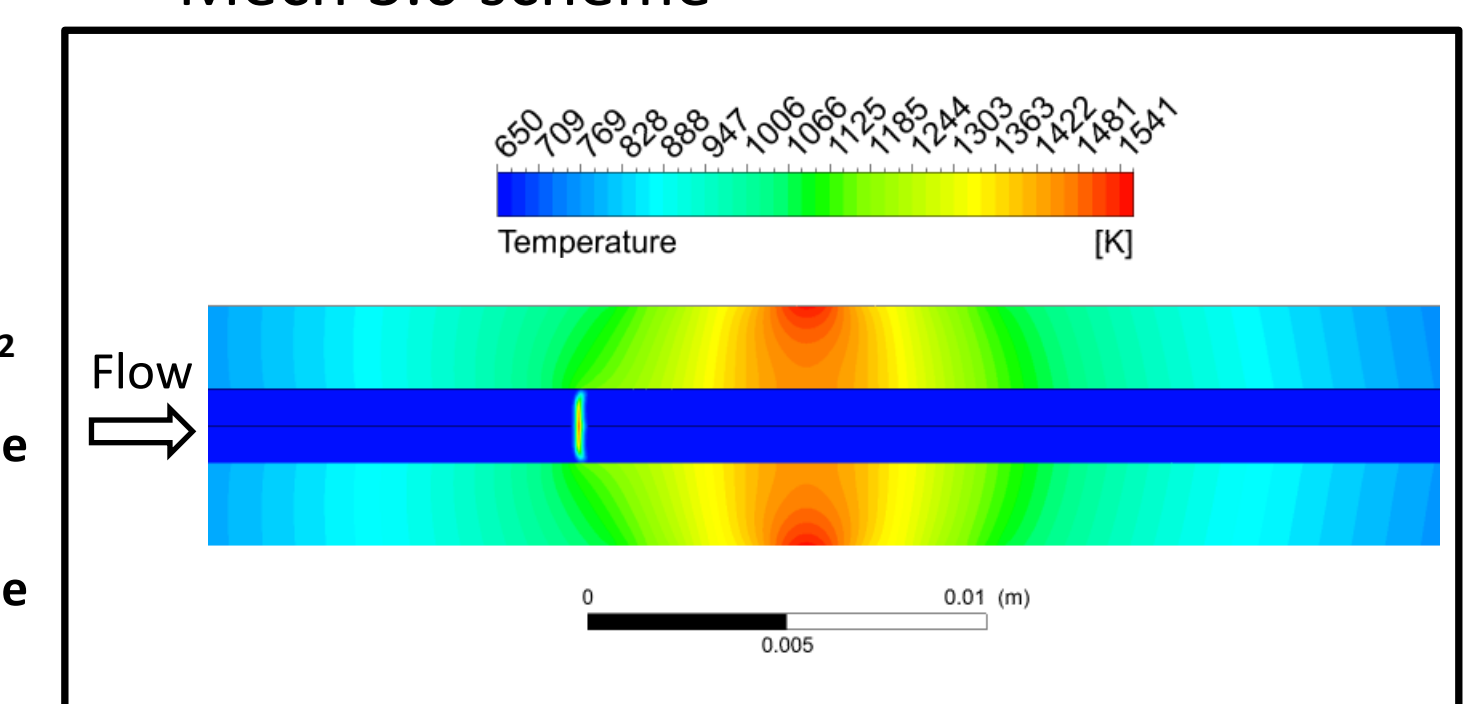
- A 2D-axisymmetric geometry
- Total length of 10 cm, inner diameter of 0.925 mm, external diameter of 3.0 mm
- Quadrilateral elements
- 25 elements to mesh the inner radius, 20 elements for the wall. A constant size mesh of 33 μm where the temperature is the highest, and a progressively bigger size toward the coldest region → 22500 elements for all the domain

### Models:

- A laminar viscous model
- The effect of enthalpy transport due to species diffusion in the energy equation
- Ideal gas
- Chemical, transport and thermodynamics properties are computed with the GRI-Mech 3.0 scheme



Stable flame position defined at the external wall temperature as a function of the mixture flow velocity



Wall temperature and flame front visualisation (CH\* molar fraction) of the simulation of a CH<sub>4</sub>/air mixture with an inlet velocity of 0.6 m/s

- For a given fuel/oxydant mixture: flow velocity increases → the flame front goes toward colder wall reactor region
- For a given flow velocity: when the adiabatic flame temperature of a mixture A is bigger than a mixture B → the front flame is located to colder wall reactor region.

## 5. Conclusions

- All characteristic flame behaviours are conserved with different diluents studied
- The increase in He molar fraction in diluent →
  - FREI velocity domains increases
  - Extinction is located to colder wall region
  - Stable flame is located to colder wall region
- Flame/wall thermal interaction clearly identified experimentally with stable flames but not numerically

## Acknowledgements

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