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

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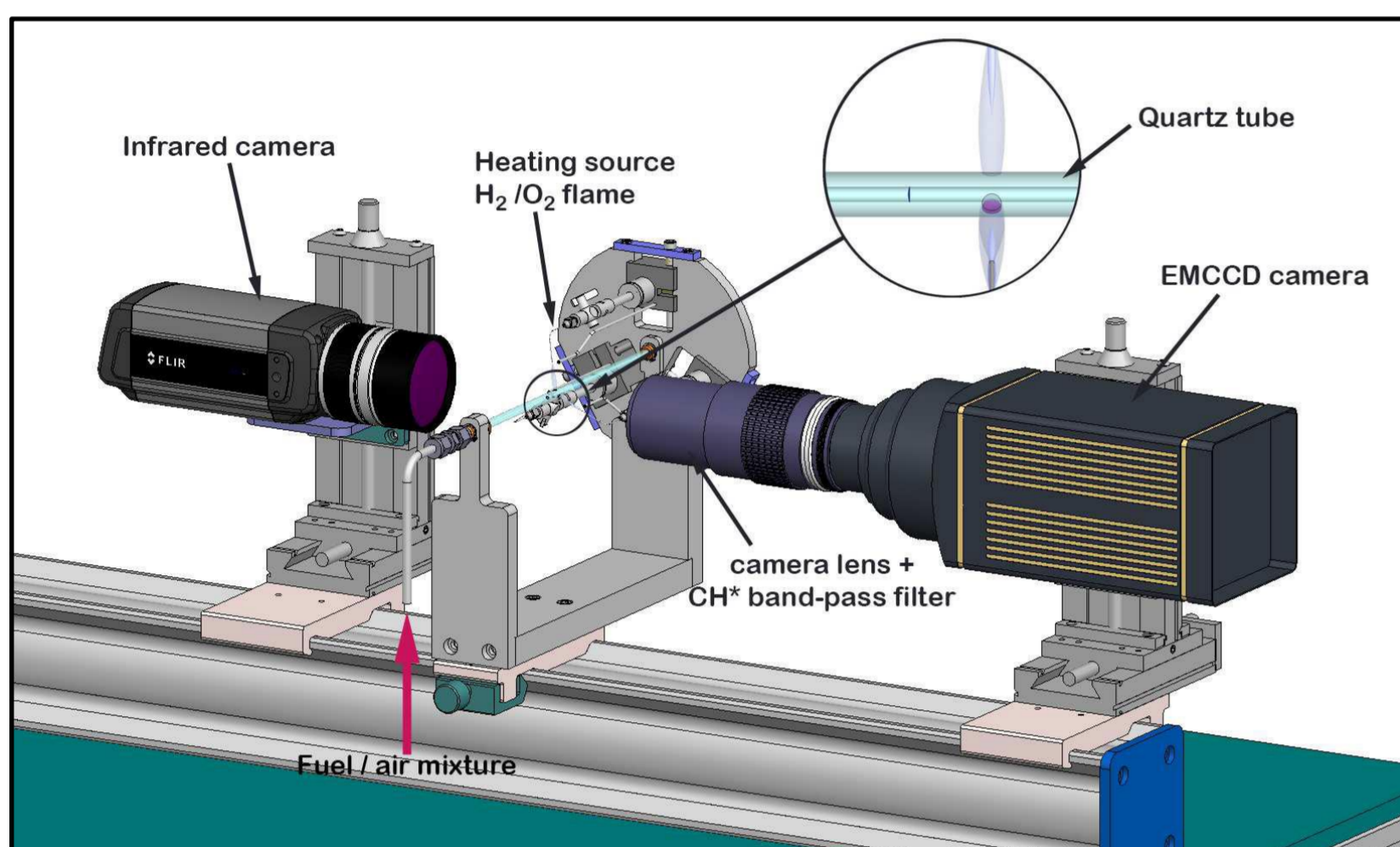
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1. Goal of the study

- 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 CH₄/O₂ 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.
- CH₄/diluent mixture is supplied in a 1.85 mm internal diameter reactor. (Quenching distance of CH₄/air is 2.50 mm)



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

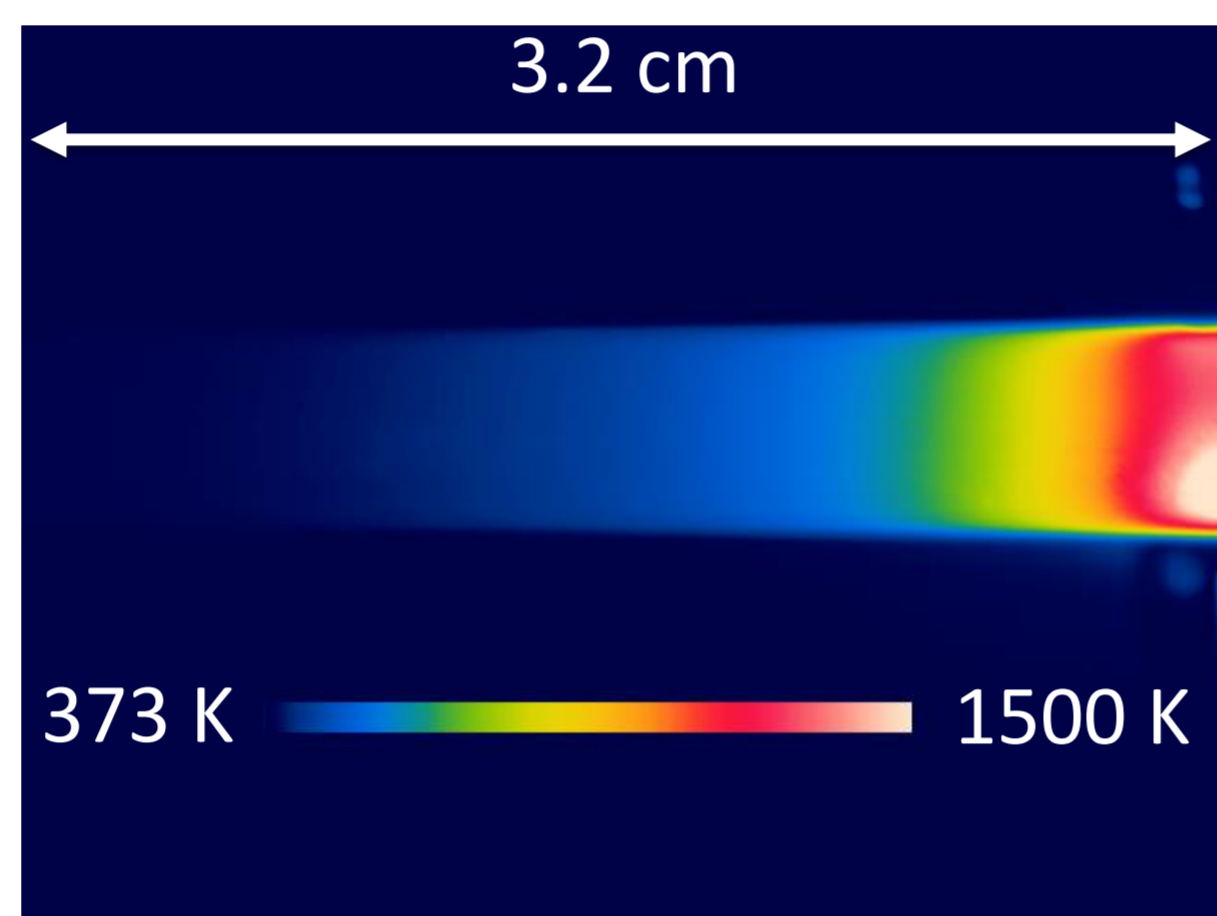
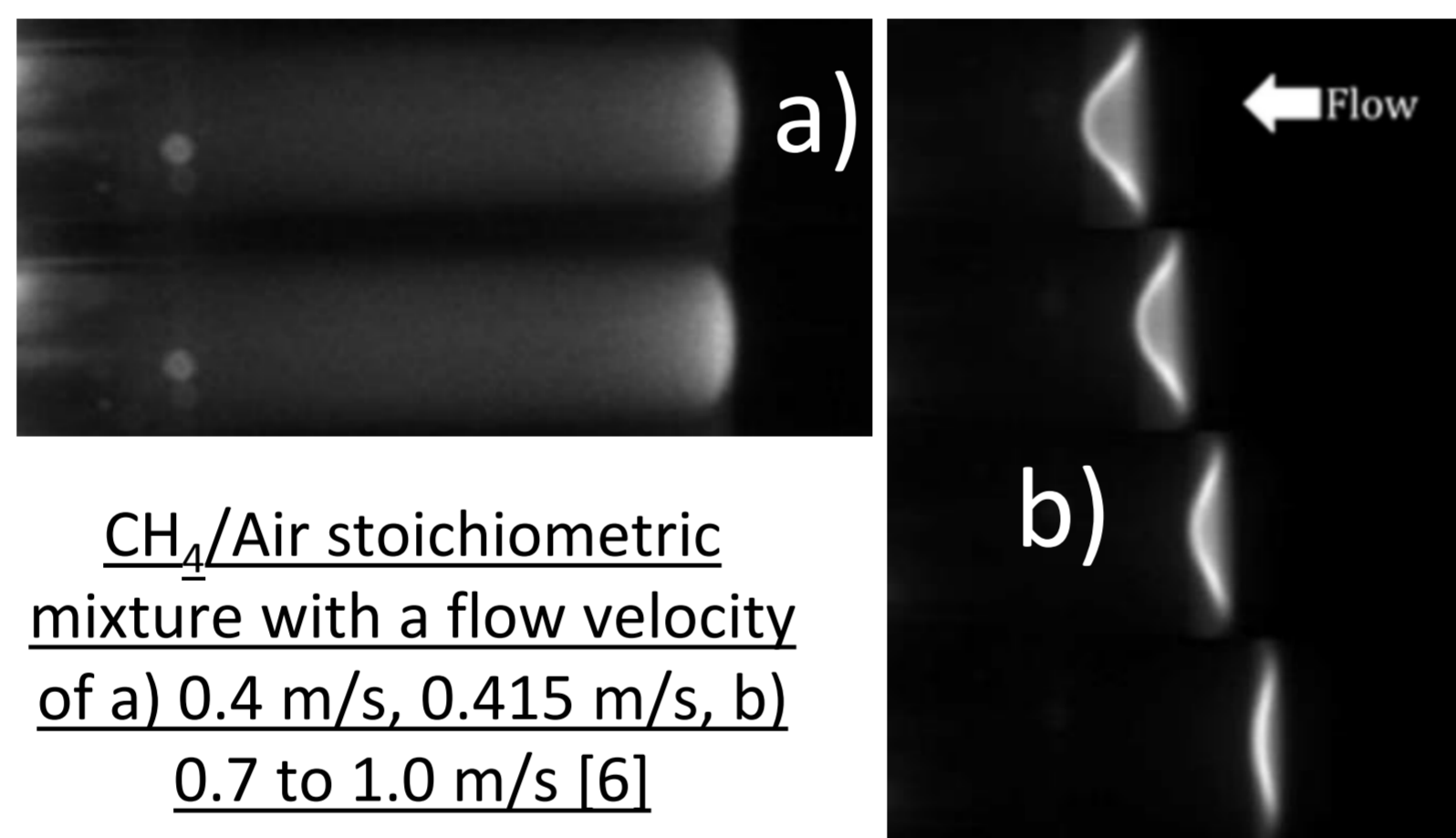


Image from FLIR camera of the external temperature for a stoichiometric mixture of CH₄/air, a flow velocity of 0.7 m/s, in a 1.85 mm internal diameter tube

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.



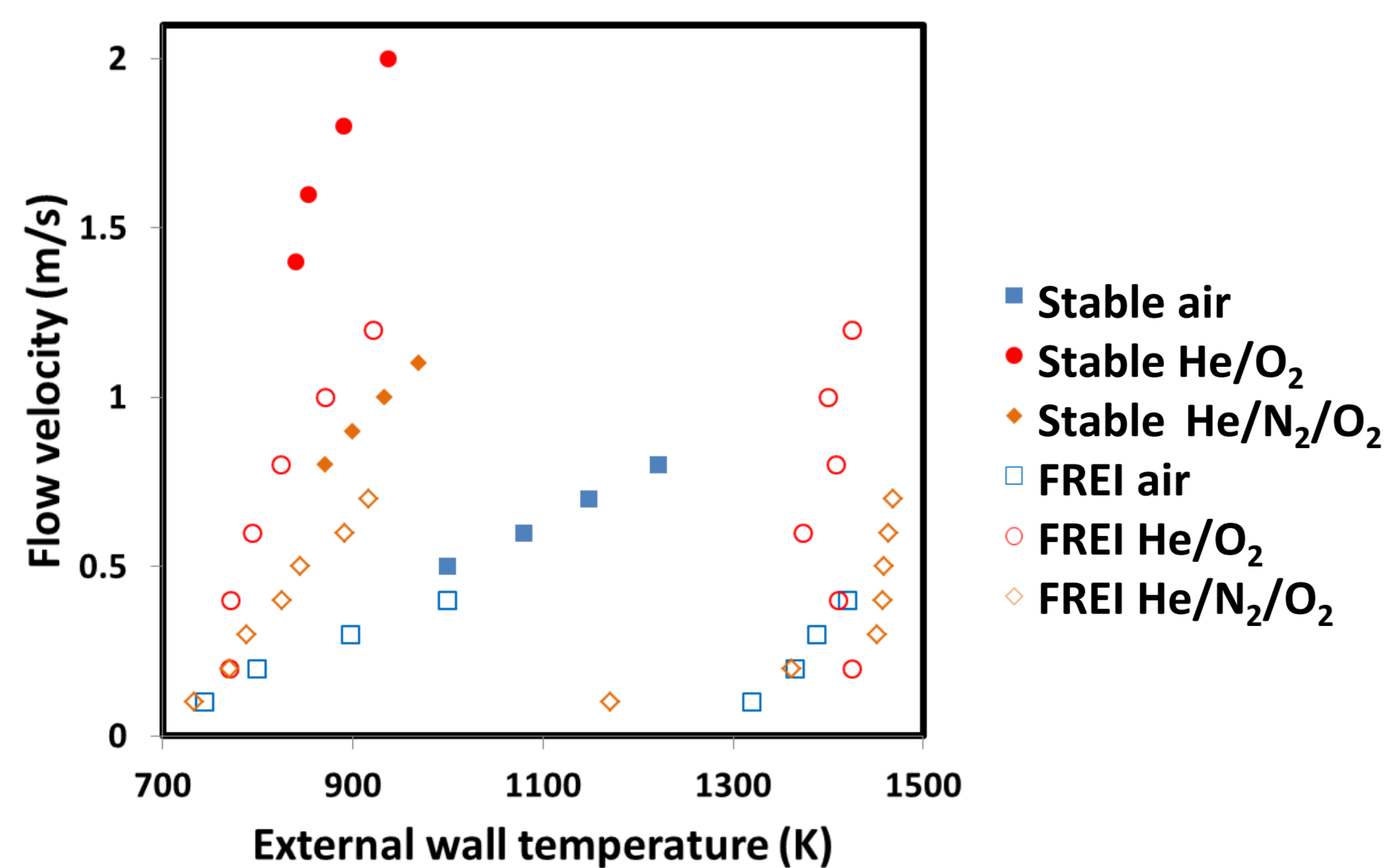
4. Experimental and numerical results

Diluent	O ₂	He	N ₂
Air	20%	0%	80%
He/N ₂ /O ₂	21.18%	39.20%	39.62%
He/O ₂	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 ₂ /O ₂	61	2367
He/O ₂	119	2519

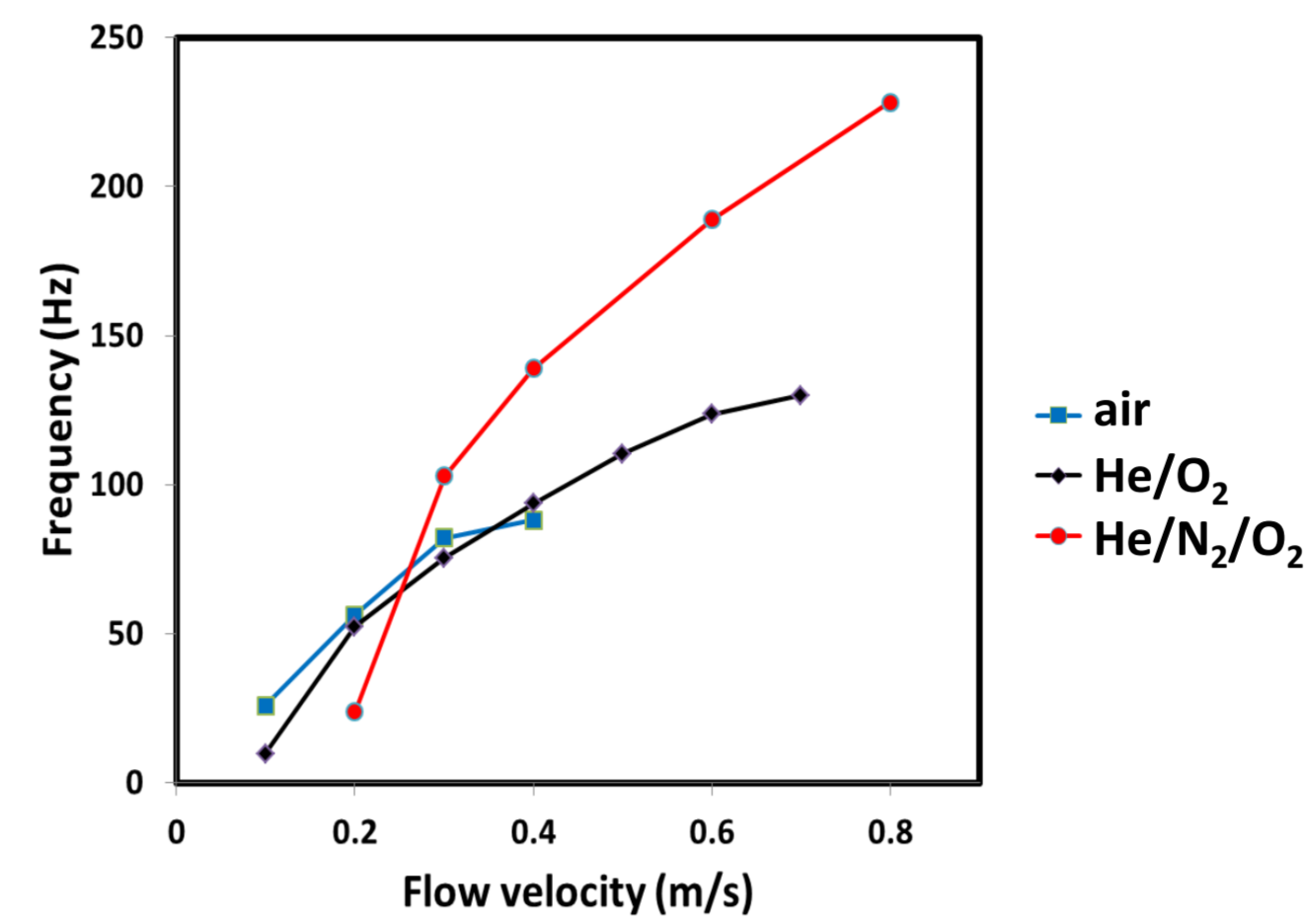
Laminar burning velocity and adiabatic flame temperature of a stoichiometric mixture CH₄/diluent



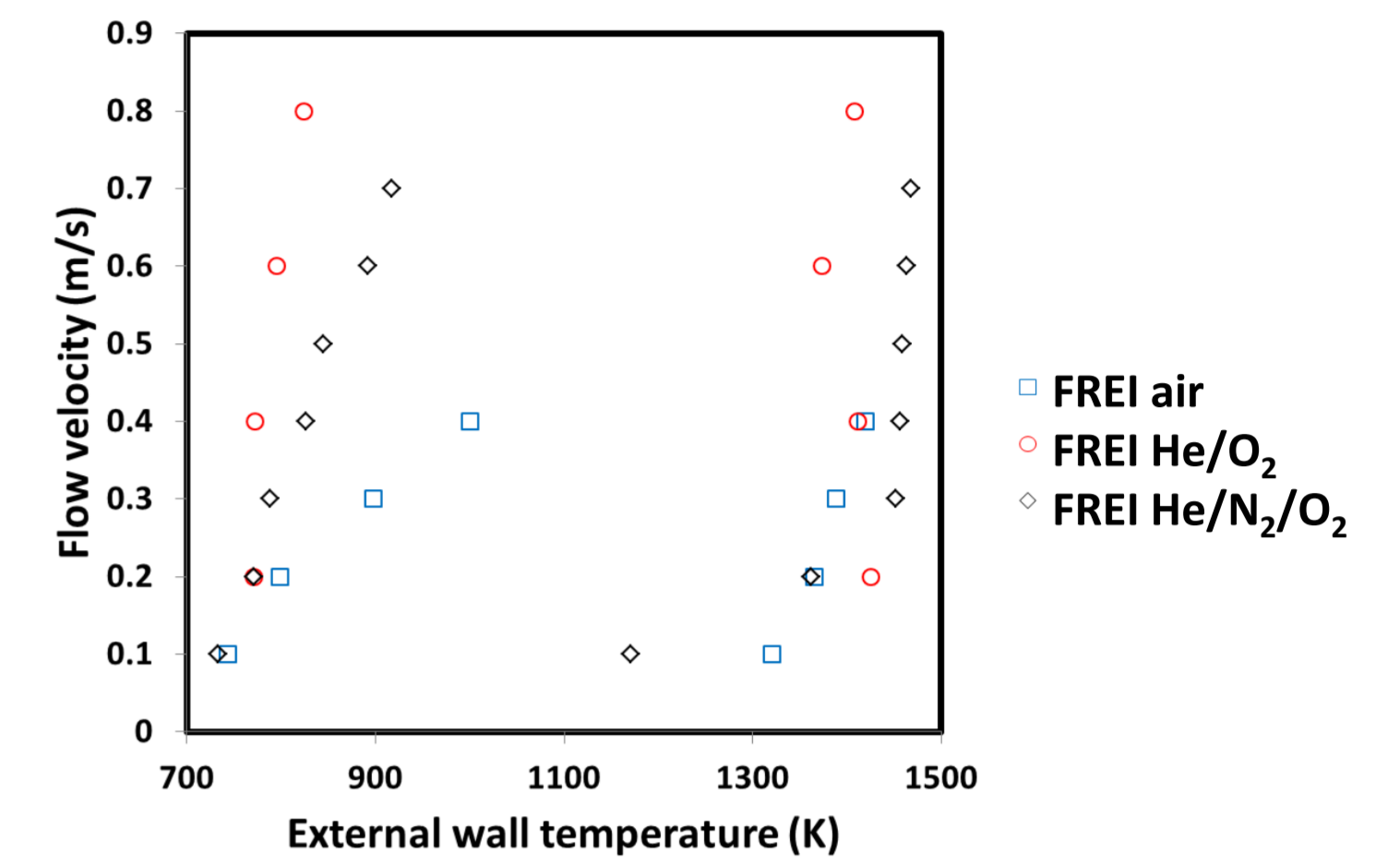
Flame position defined at the wall temperature as a function of the mixture flow velocity

4.1. FREI

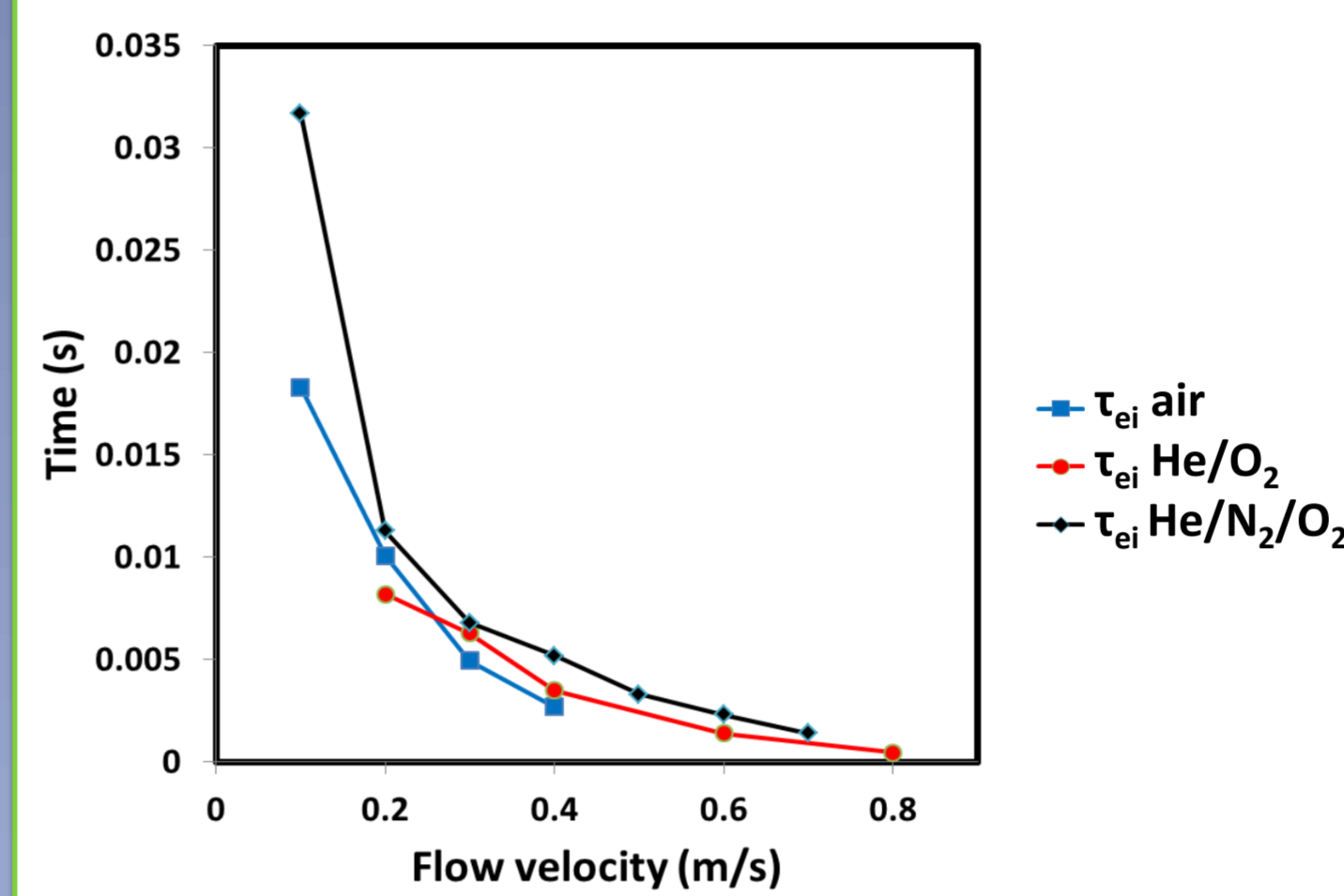
- For a given fuel/oxydant mixture: when the flow velocity increases → frequency increases.
- For a given flow velocity: when the flame propagation speed of a mixture A is bigger than a mixture B → τ_{ie} in A is smaller than in B.



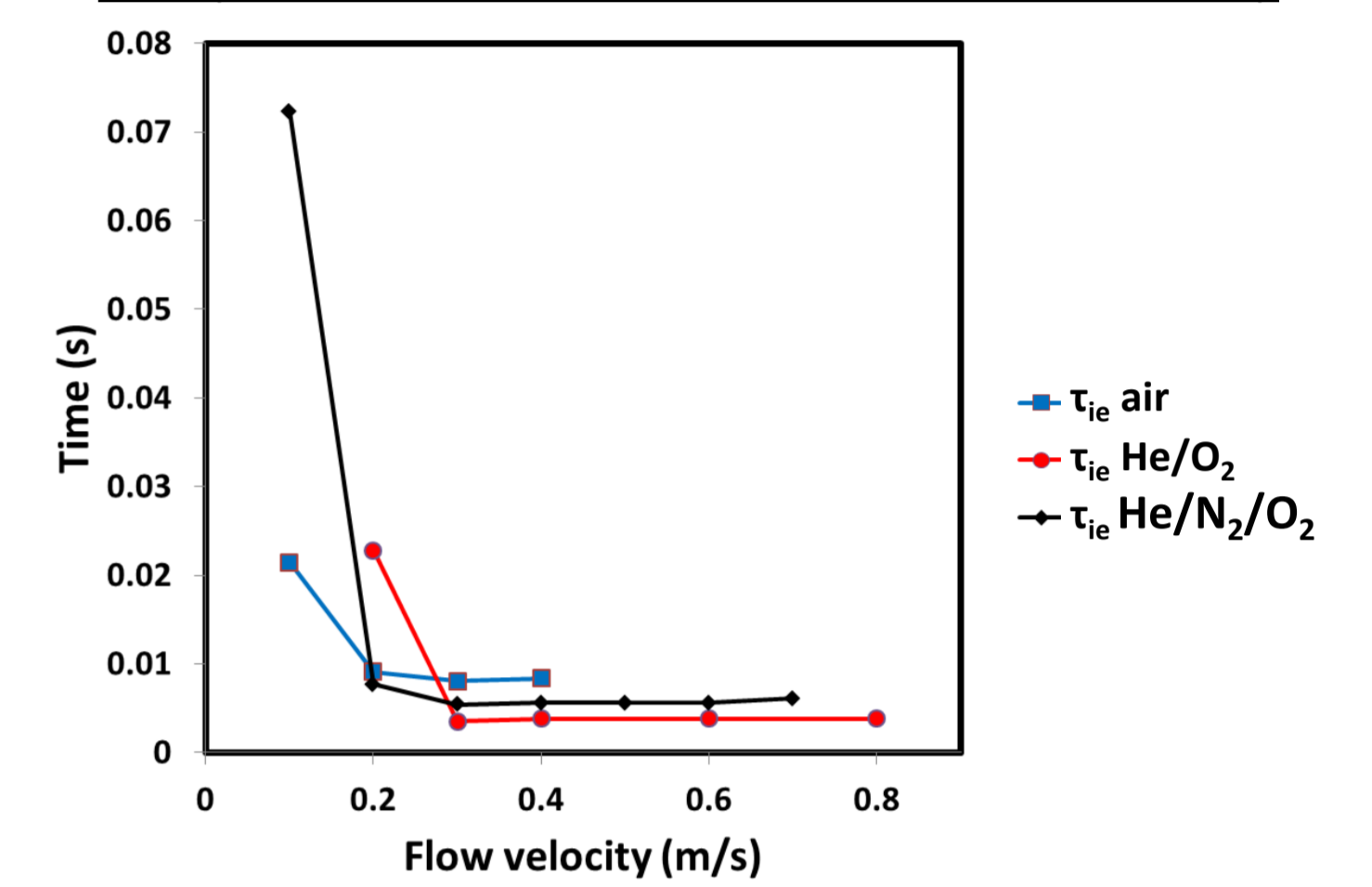
Frequency of FREI variation as a function of inlet velocity



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



Time between Extinction and Ignition



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

Geometry/ Meshing:

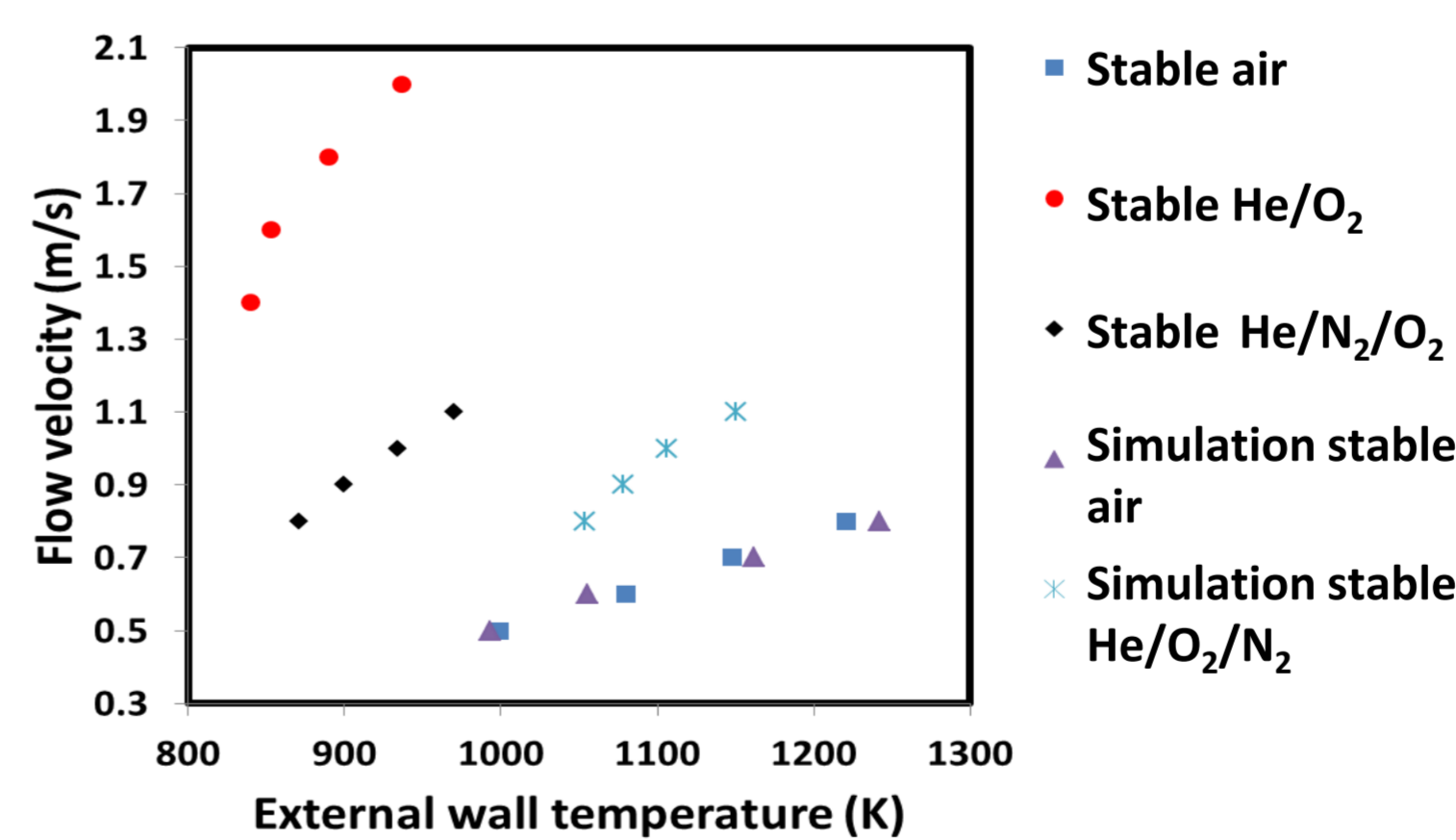
- A 2D-axisymmetric geometry
- Total length of 10 cm, inner diameter of 0.925 mm, external diameter of 3.0 mm
- Quadrilateral elements
- 25 elements to mesh the inner radius, 20 elements for the wall. A constant size mesh of 33 μ m where the temperature is the highest, and a progressively bigger size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

Boundary conditions:

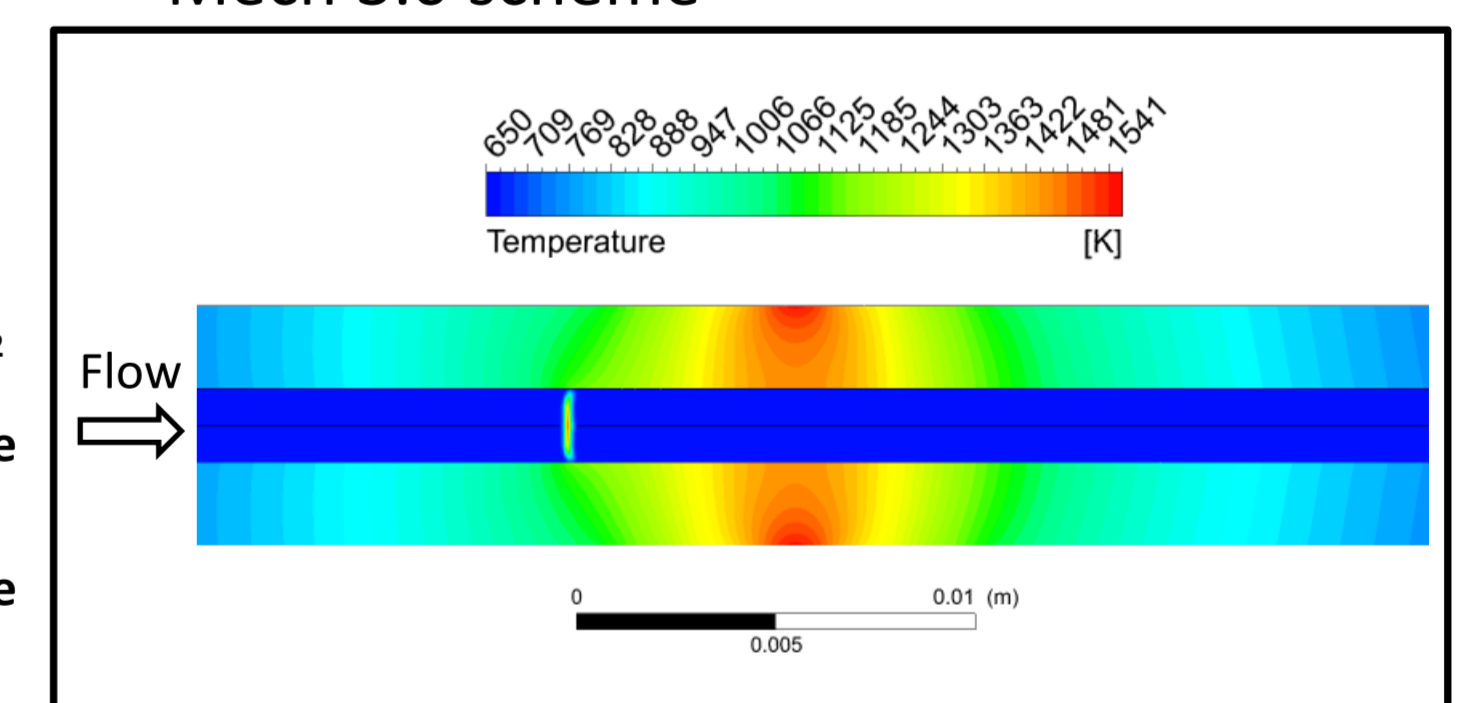
- Experimental external wall temperature is averaged and used as boundary condition
- A velocity inlet boundary condition is applied on the left part of the geometry, and a pressure outlet boundary condition (1 atm) on the right part

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 CH₄/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

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[1] A. C. Fernandez-Pello, "Micropower generation using combustion: Issues and approaches," *Proceedings of the Combustion Institute*, vol. 29, no. 1, pp. 883–899, Jan. 2002.
 [2] K. H. Lee and O. C. Kwon, "Studies on a heat-recirculating microemitter for a micro thermophotovoltaic system," *Combustion and Flame*, vol. 153, no. 1, pp. 161–172, Apr. 2008.
 [3] P. Galie, B. Xu, and Y. Ju, "Kinetic Enhancement of Mesoscale Combustion by Using a Novel Nested Doll Combustor," 2007.
 [4] T. A. Wierzbicki, I. C. Lee, and A. K. Gupta, "Rh assisted catalytic oxidation of jet fuel surrogates in a meso-scale combustor," *Applied Energy*, vol. 145, pp. 1–7, May 2015.
 [5] A. Di Stazio, "Caractérisation expérimentale de la dynamique de la combustion à micro-échelle," Thesis, Orléans, 2016.