Thermal Engineering & Combustion Laboratory

WORK IN PROGRESS

Development of stability diagrams of flame in diluted combustion
Task 2.1I

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OUTLINE

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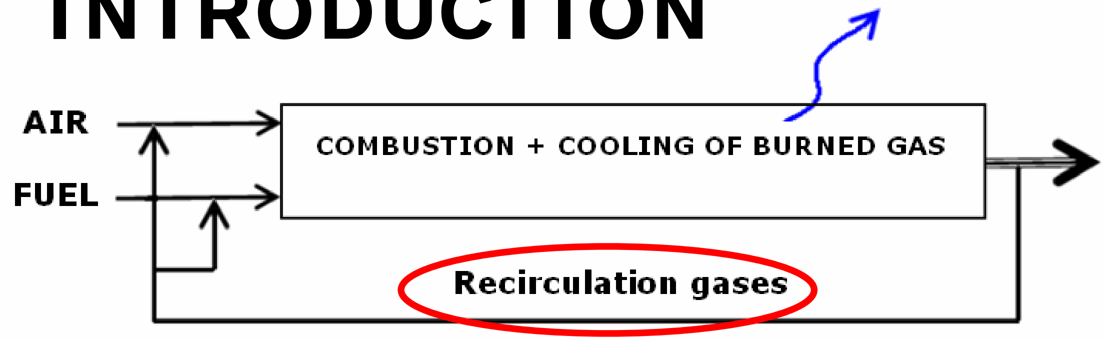
- Design of experimental apparatus
- Conclusions and perspectives

INTRODUCTION



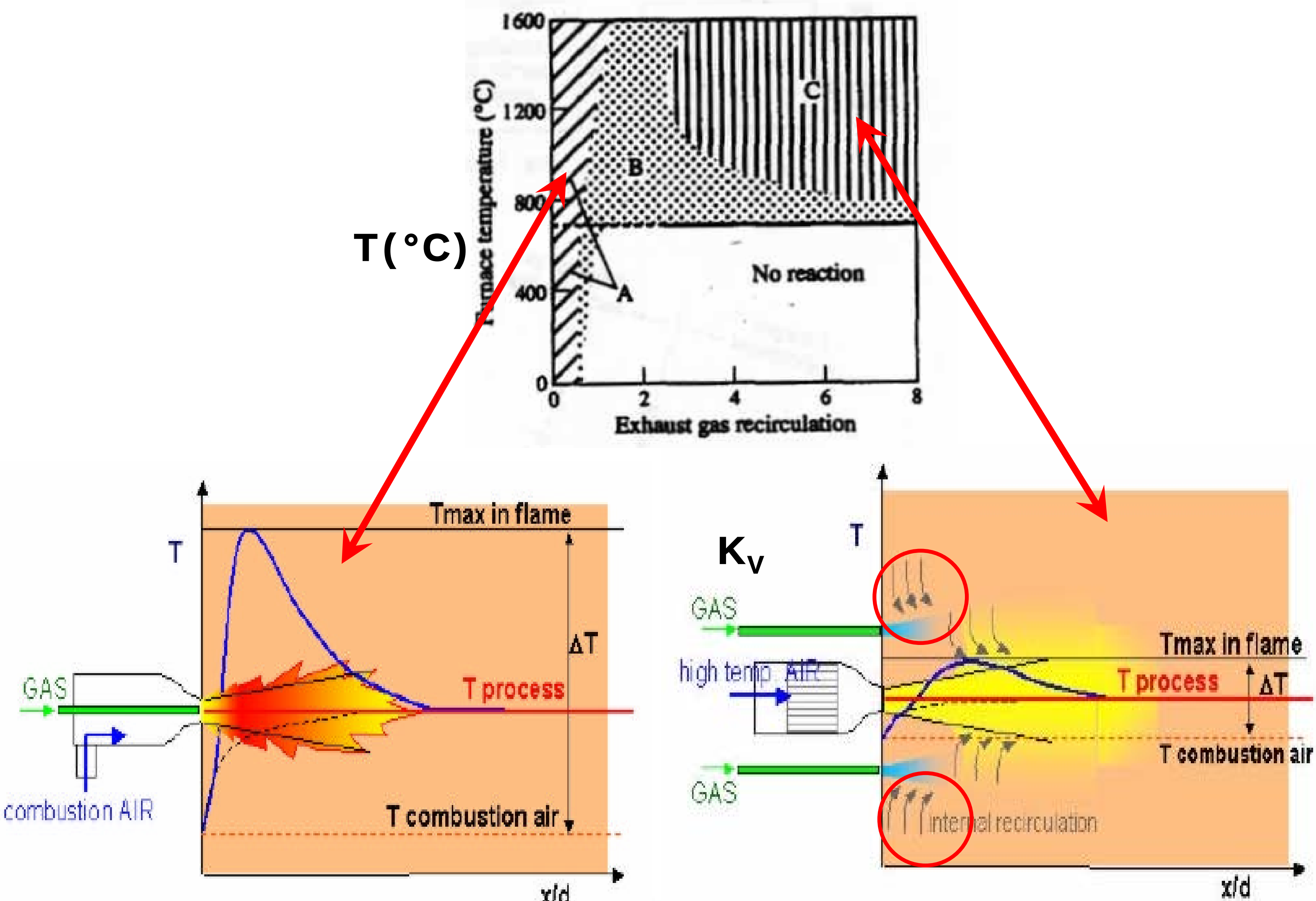
$$K_V = \frac{\dot{M}_{recirculation\ \ gas}}{\dot{M}_{fuel} + \dot{M}_{Air}}$$

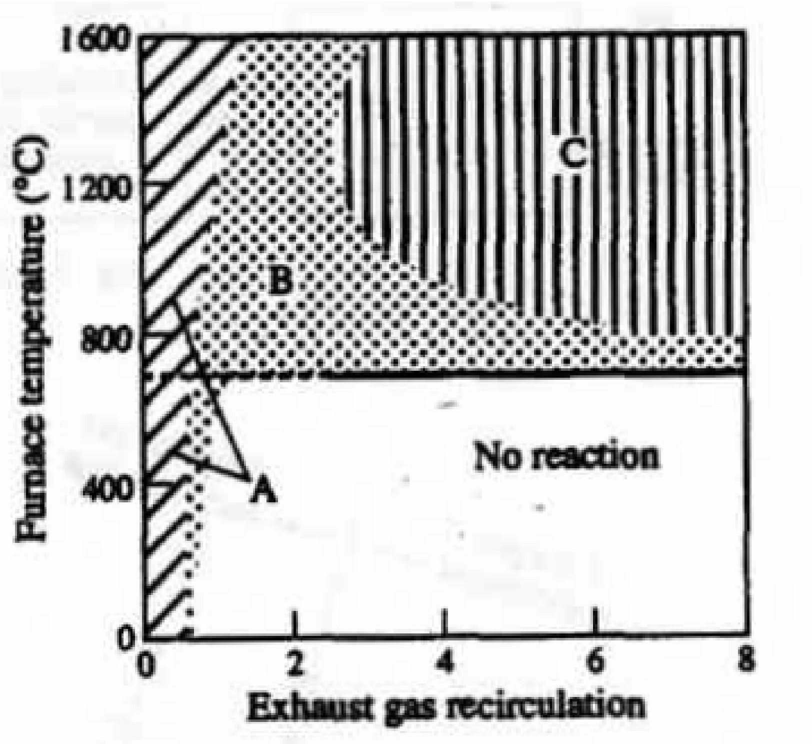
Diluted combustion has been acknowledge as one of the most effective combustion technologies to meet both the targets of high process efficiency and low pollutant emissions.

2 fundamental requirements :

- The process temperature must be above the mixture autoignition temperature

- The recirculation ratio (**K_v**) (i.e., the ratio between the recirculation gases mass and the incoming mixture mass) must be higher than a threshold


1600
1200
800
400
0
Furnace temperature (°C)
C
B
A
No reaction
0
2
4
6
8
Exhaust gas recirculation
T(°C)
K_V
T
Tmax in flame
ΔT
GAS
T process
combustion AIR
T combustion air
x/d
T
GAS
high temp. AIR
Tmax in flame
T process
ΔT
T combustion air
GAS
internal recirculation
x/d



- Diagrams are often built for the couple methane-air or propane-air

Lack of information with other gases blends, namely gases containing CO and H2.

- The temperature to be considered in the diagrams is not always clearly defined

OBJECTIVE

→ Develop a methodology for building stability diagrams in diluted combustion for various **fuel/oxidiser** couples

→ Design an experimental apparatus

→ for various mixtures of gaseous fuels

→ for various combustion regime (especially in diluted combustion)

→ for a range of operating conditions

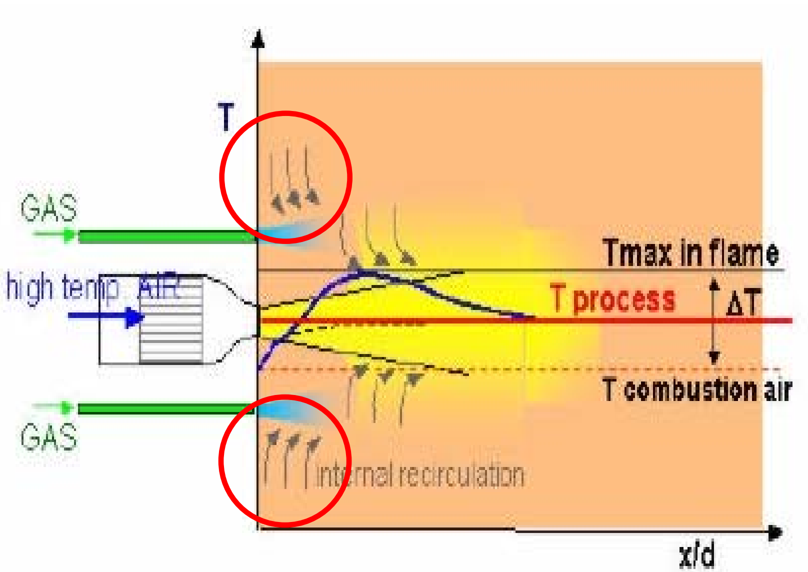
DESIGN OF EXPERIMENTAL APPARATUS

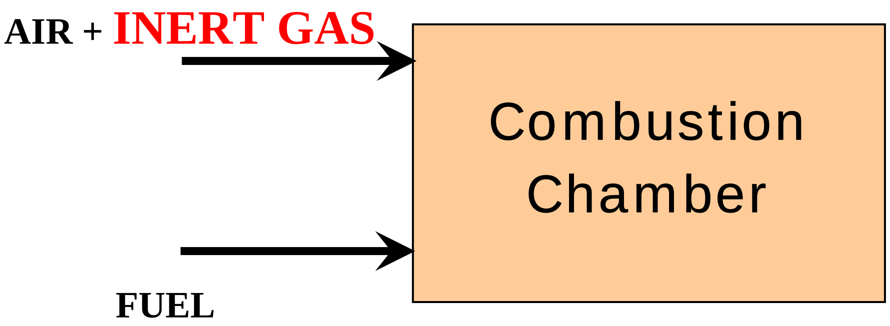
The experimental setup must satisfy very specific constraints:

- allow a very broad range of recirculation ratio as well as a perfect control of the composition of incoming mixture

- provide a thermically controllable environment, while allowing an optical access to visualize the combustion zone

- the installation must be able to fire different couples of fuel/oxidizer.

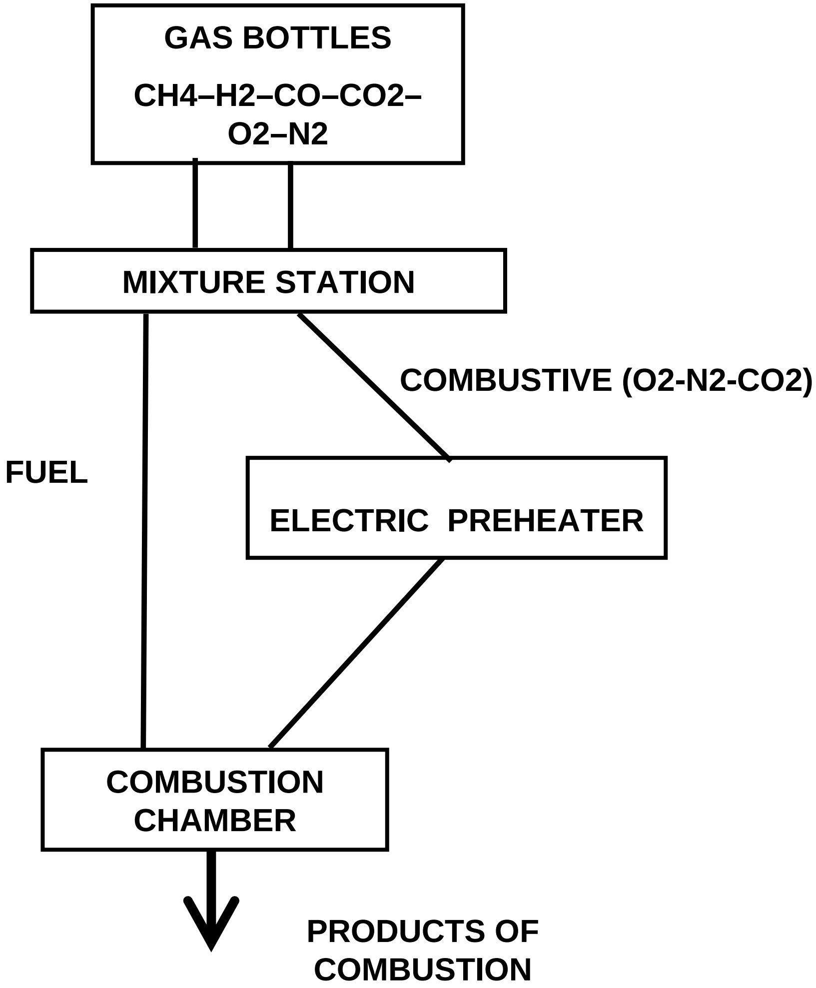




In practice, the dilution is obtained aerodynamically by internal recirculation in the combustion chamber

Difficult to regulate the rate of recirculation K_V (1→8)

The recirculation will be figured, in the new experimental setup, by vitiating the combustion air by inert gases (N_2, CO_2) at high temperature



Gases proportions (CH_4, H_2, CO, CO_2, O_2 and N_2) are chosen to imitate representative mixtures of combustion gases with low calorific value, like :

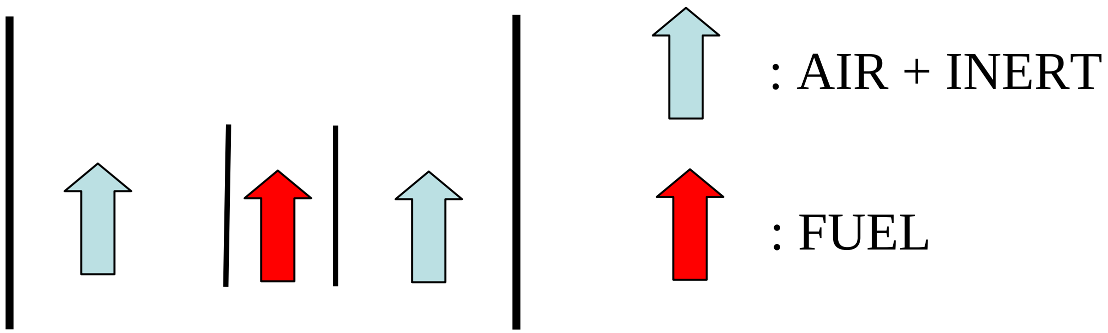
- blast furnace gas,
- coke oven gas (COG)
- or gasification of biomass gas,

under various conditions of dilution.

• Configuration of the flow

The coflow configuration is chosen because it is closer to an industrial burner geometry and it also allows easier observation of the phenomena suitable for diluted combustion (expansion of the reaction zone).

Fuel is injected in the axis of the annular vitiated air co-flow.

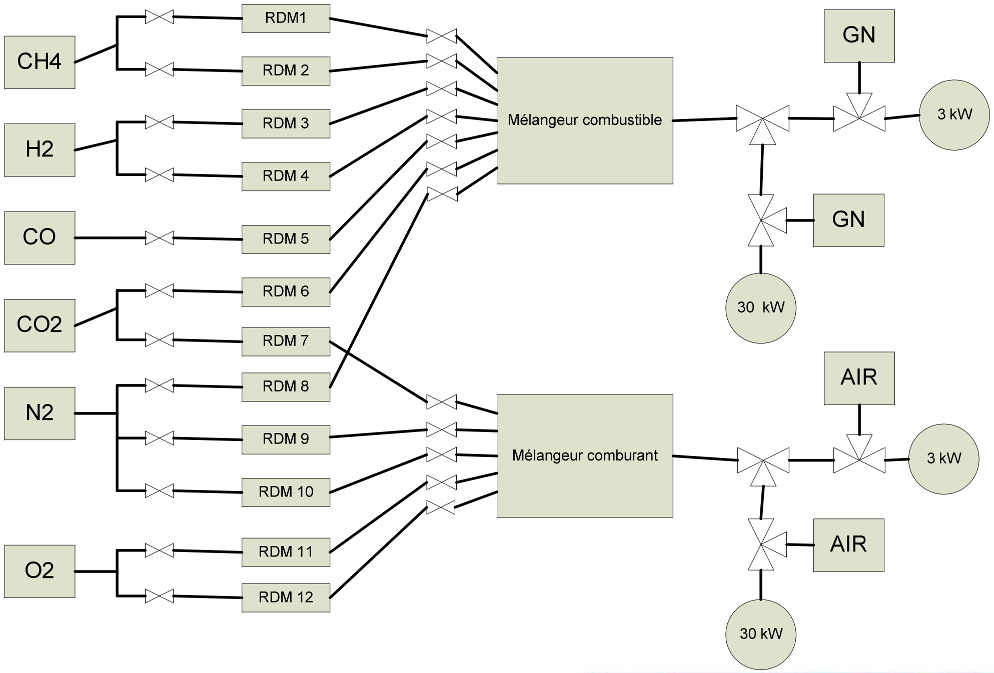


• Mixing Station

The fuel components are mixed to obtain the desired fuel composition

The vitiated air composition is also imposed in the mixing station

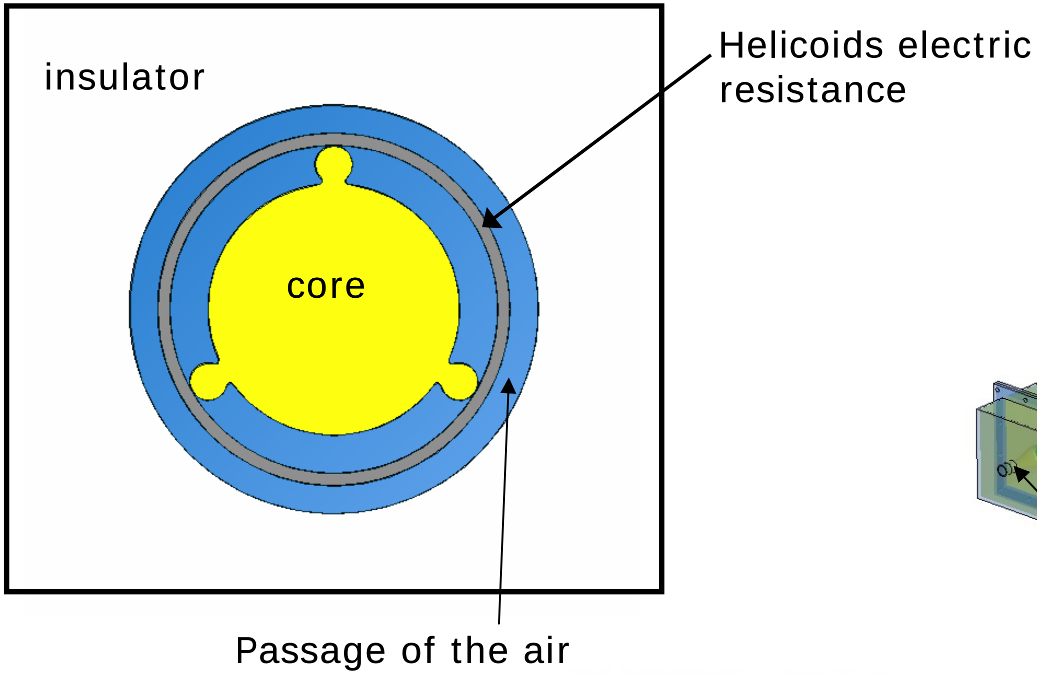
This station is equipped with mass flow controllers and valves to control the various flows under operation.

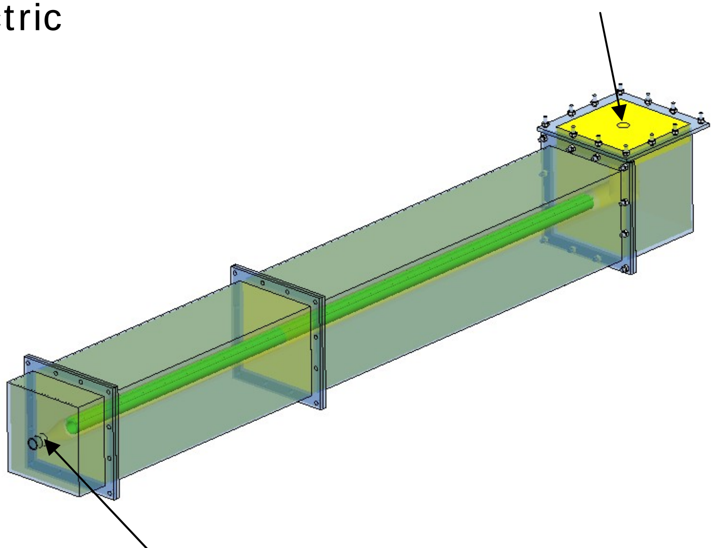


- Electric preheater

$$K_V = \frac{\dot{M}_{gaz\ inerte}}{\dot{M}_{Combustible} + \dot{M}_{Air}}$$

Aims :
- Preheat oxidizer (vitiated air) 20°C →1100°C
- for a wide range of flow rates (Kv : 0 → 8)

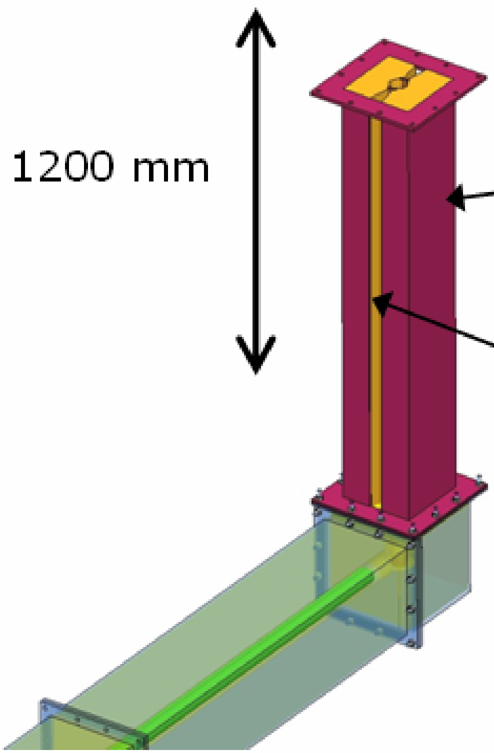


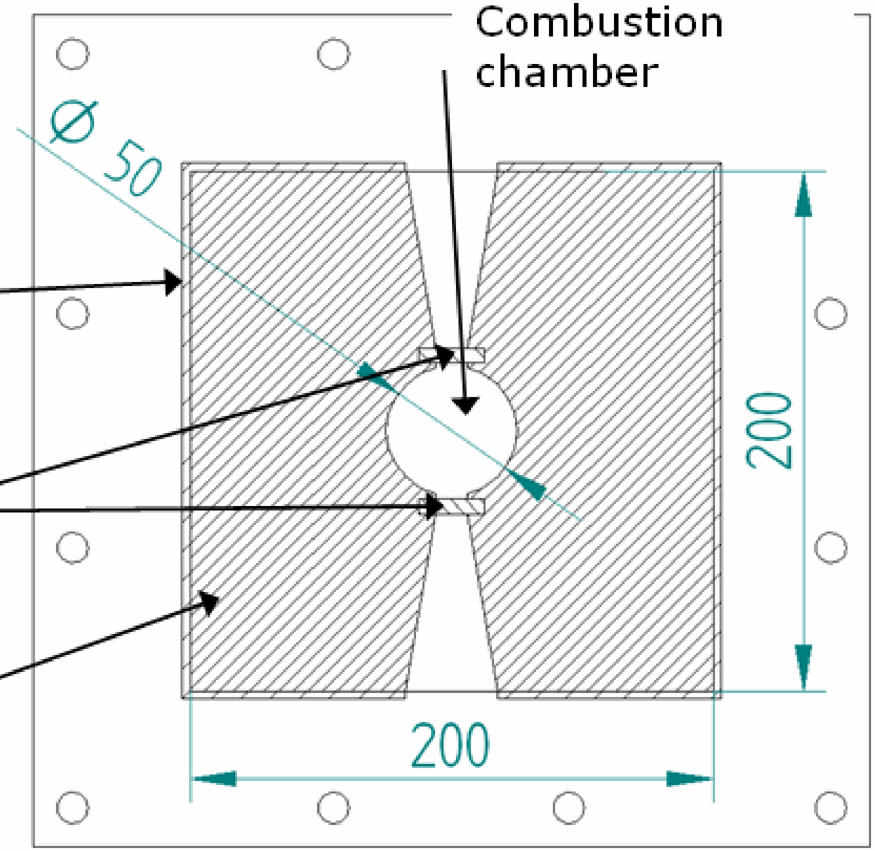


- Combustion chamber

The chamber has to provide

- a perfectly controlled thermal environment
- to allow optical access in order to visualize the reaction zone.





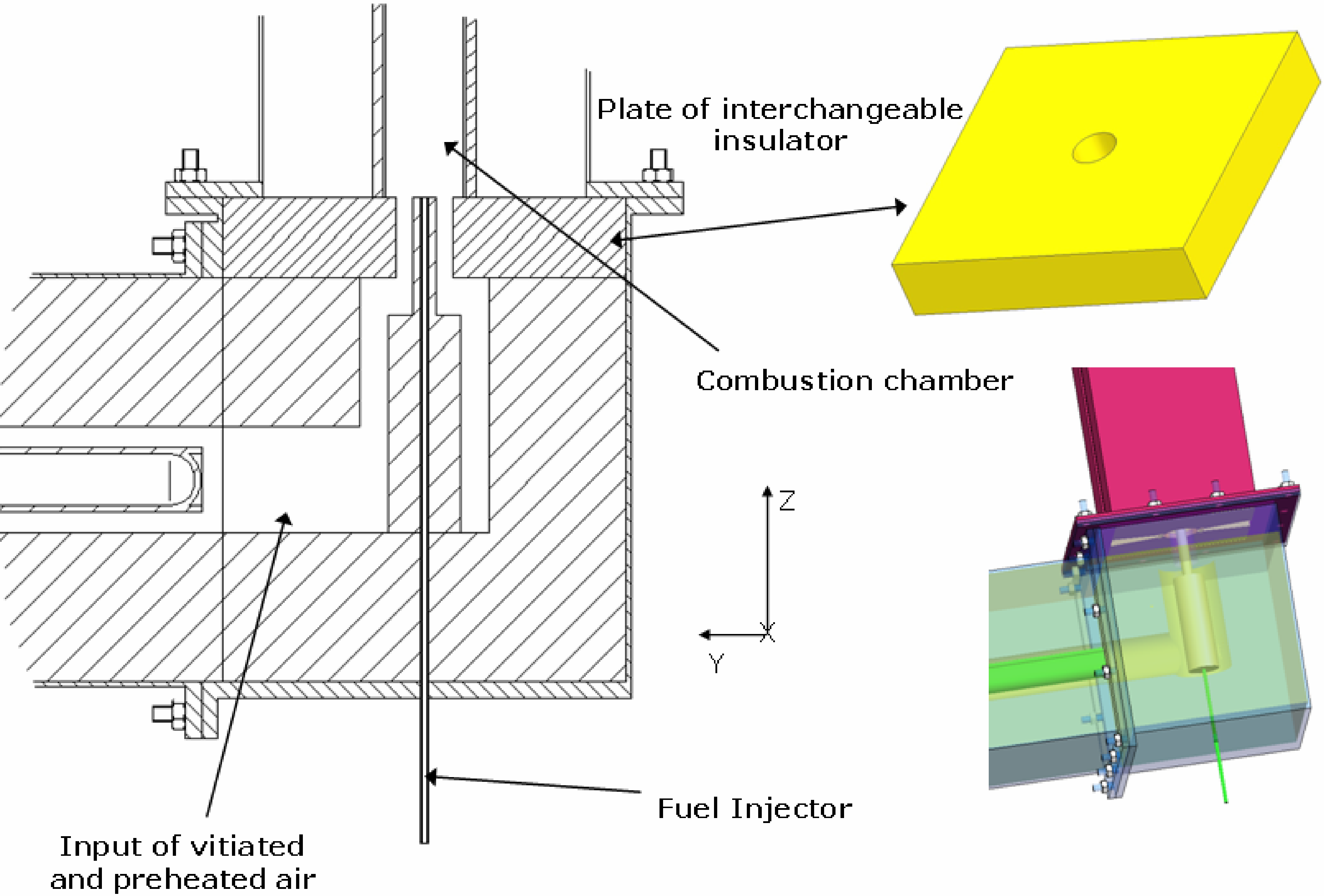


Plate of interchangeable insulator
Combustion chamber
Z
Y
Fuel Injector
Input of vitiated and preheated air

- Numerical study

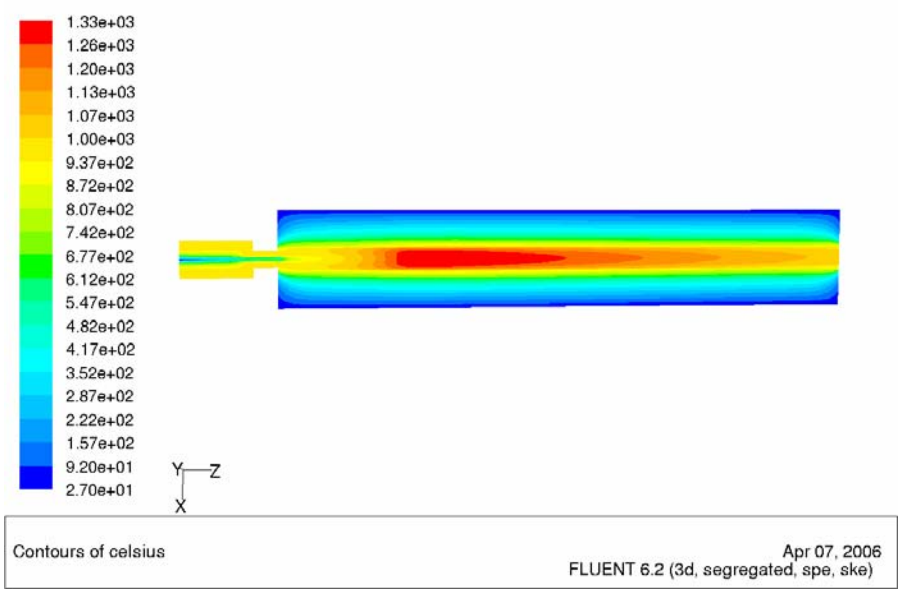
FIRST STEP

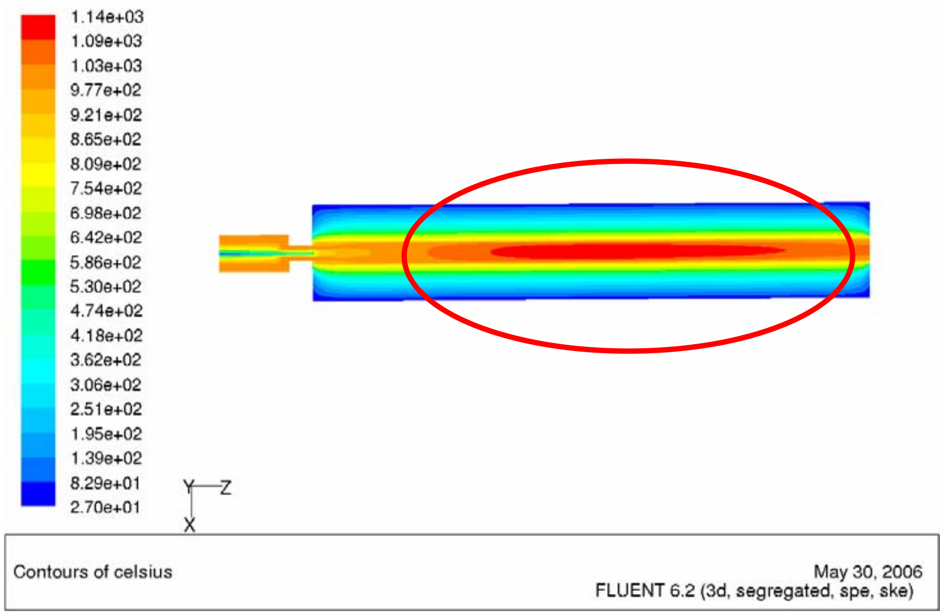
CFD modelling of combustion in this chamber has been realized with the Fluent ® code to optimize the geometry.

Effect of oxidizer temperature and dilution on the location and size of the reaction zone in methane combustion has been examined.

The parameters of these first numerical simulations are as follows:

- Combustion model : Eddy Dissipation/Finite Rate
- Fuel : CH_4
- Firing rate : 3 kW
- Combustion Mechanism : 1 step
- Oxidizer: Air - diluter : N_2
- Recirculation ratio: Kv = 0-2- 4- 6- 8.
- Air temperature : 800°C, 1000°C





Temperature field

(air temperature =1000°C ; $K_v = 4$)

Temperature field

(air temperature =1000°C ; $K_v = 6$)

SECOND STEP

The numerical model parameters (composition of fuel and oxidizer diluter, combustion model and mechanism) have been varied to check their effect on the reaction zone shape.

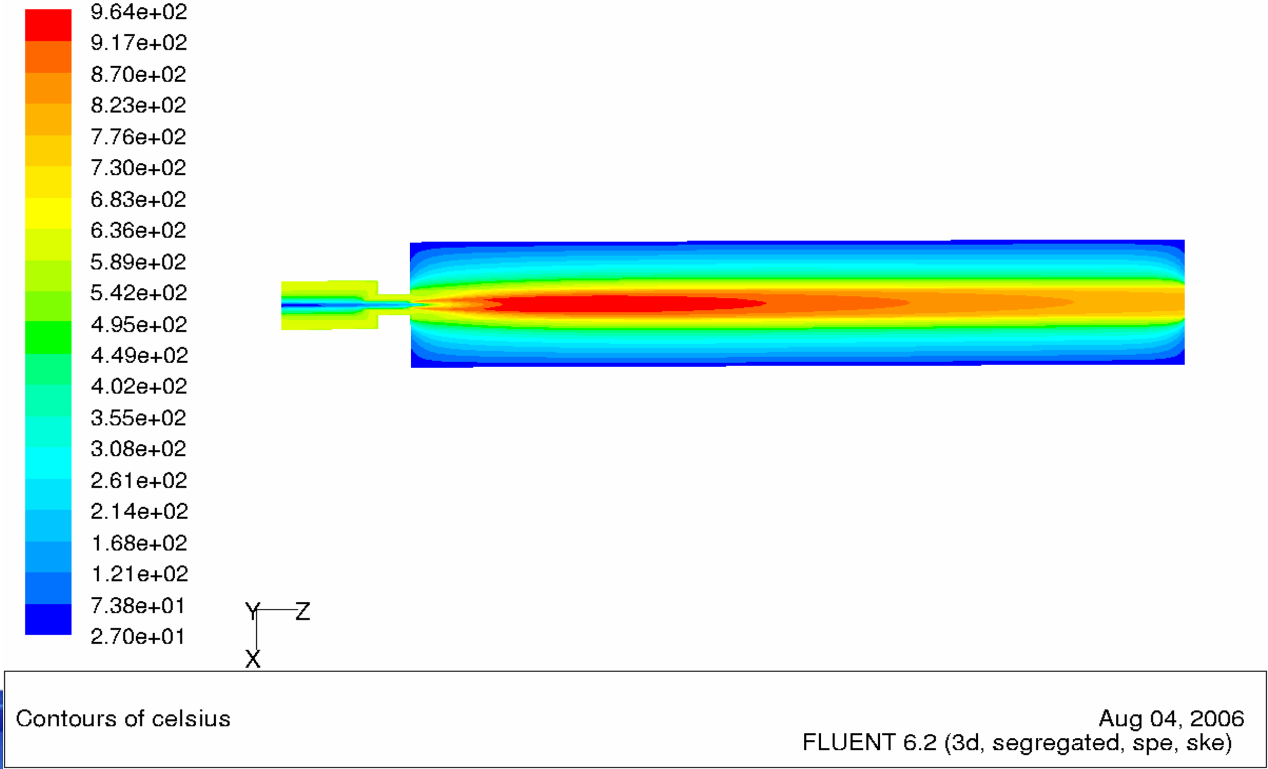
This second part of the numerical study is under development.

Up to now, simulations have been performed for two different fuel blends (mixture 1: 90% H2 and 10% CO – mixture 2: 10% H2 and 90% CO), with a simple 1-step mechanism for each species in the fuel:

$$CO + \frac{1}{2} O_2 \rightarrow CO_2$$
$$H_2 + \frac{1}{2} O_2 \rightarrow H_2O$$

Temperature field

- Mixture 1
- air temperature =600°C
- Kv = 6



Conclusions and perspectives

• The preliminary design computations and CFD study reported here have allowed determining the geometry of a low thermal input furnace to be used in building stability diagrams of combustion of various fuel blends in a range of temperature and dilution conditions.

• The various items of the experimental device are currently under construction. Within a few weeks, a first experimental campaign will begin with tests of combustion of methane in air, with nitrogen as diluter; characterization of combustion of CO/H2 blends will follow.

• Simultaneously, the CFD modelling will be carried on with studying the influence of the combustion model parameters and mechanism on the results, for various fuel and oxidizer composition.

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RÉGION WALLONNE

THANKS FOR YOUR ATTENTION