POLYTECH.MONS

Thermal Engineering & Combustion Laboratory (FPMs)
Thermodynamics Laboratory (ULg)

Feasibility study of the diluted combustion in a semi-industrial boiler at low temperatures

SUBTASKS 2.1 H & 2.1 I

WORK IN PROGRESS

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Contents

1. Introduction

- New combustion technology ➔ diluted combustion : high process thermal efficiency and low pollutant emissions.
- Technology mainly used in high temperature process furnaces ➔ lower NO_X emissions
- High level of dilution of the reactants with flue gases before combustion reaction occurs ➔ slower reaction in a much larger volume than in classical combustion
- Lower local heat release ➔ temperature field more homogeneous
- No peak values responsible of high thermal NO_X formation
- Interest in increase furnace temperature uniformity at low temperatures (less affected by NOX emission level restriction)

1. Introduction

• In this work, the application of the principles of diluted combustion is considered in the combustion chamber of a semi-industrial boiler, which differs from a furnace mainly in geometrical and thermal confinement.

• Safe diluted combustion conditions request that the reactant mixture temperature remains above its self-ignition level (for methane-air 1100 K) everywhere in the furnace.

• In the case of a boiler, the combustion chamber is generally water-cooled, and the very high wall heat losses are therefore not compatible with the self-ignition temperature requirement.

➔ Feasibility study of the diluted combustion in a semi-industrial boiler at low temperatures (without preheating the combustion air)

2. Boiler

• Test bench = Viessmann Paromat-Triplex boiler (Thermodynamics Laboratory ULg) : nominal output power ±370kW

Heat exchanger

Combustion chamber

Fuel-oil burner

(Ph. Ngendakumana)

2. Boiler

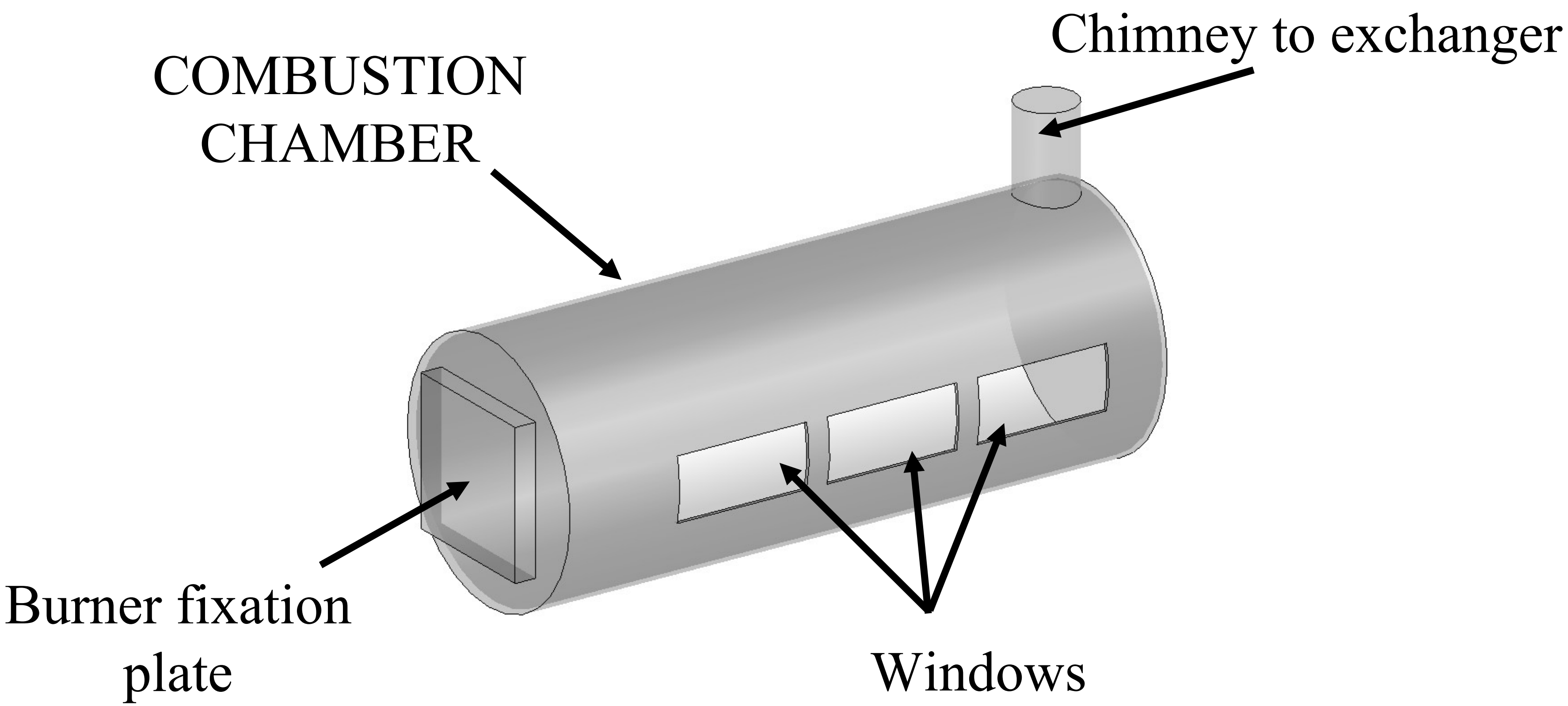
• In this work, diluted combustion is performed by using direct injection of the reactants into the combustion chamber of a boiler. A jet burner is first used for preheating the combustion chamber with classical combustion. When the mixture self-ignition temperature is reached, combustion air and gas are then injected separately into the combustion chamber.

- Central injection for the air
- Gas injection (choice of the position)

Combustion chamber (water-cooled)

2. Boiler

- Boiler = combustion chamber (water-cooled) + exchanger



2. Boiler

- The chosen solution is the use of a natural gas jet burner in place of the fuel-oil burner to heat up the combustion chamber.

- To start the system, the jet burner will be used in a classical flame combustion mode, in order to heat up the combustion chamber above the mixture self-ignition temperature level.

- When the temperature is high enough, we pass gradually from a classical combustion operation to a diluted combustion mode, by using the jet burner as the air injector and adding a second separated injector for the gas.

- The position of the gas injector has to be optimized to get enough dilution of the reactants before they meet in the combustion chamber.

2. Boiler

• To approximate dilution ➔ calculation of the free jet entrainment ratio (Ricou and Spalding formula) :

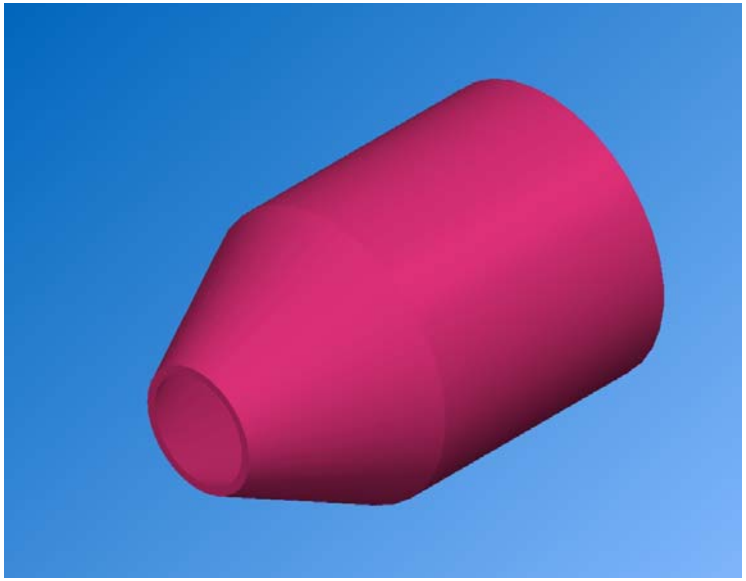
$$\frac{\dot{M}_{tot}}{\dot{M}_0}=\frac{\dot{M}_0+\dot{M}_e}{\dot{M}_0}=1+K_V=0{,}32\left(\rho_e/\rho_0\right)^{0{,}5}x/d$$

differences in temperature and composition between the jet and the fluid entrained

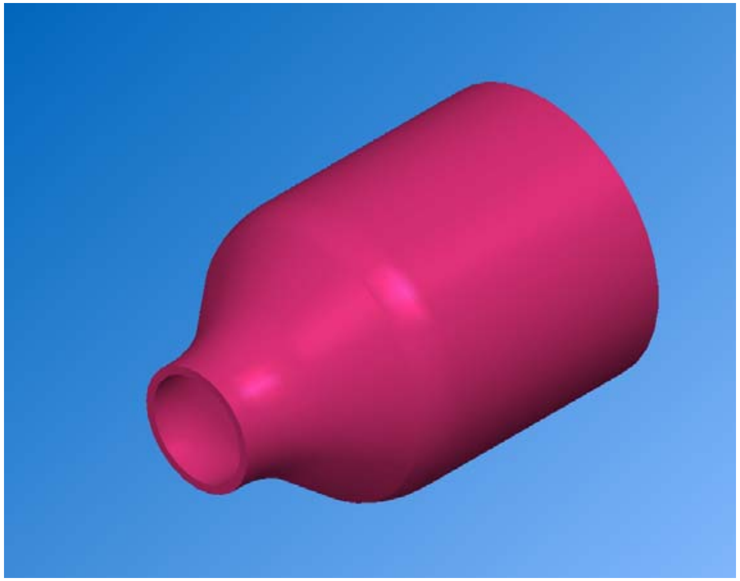
Where M_0= jet mass flow
M_e= mass flow entrained by the jet
d= injector nozzle diameter
x= jet length

3. Burner selection

- Four natural gas jet burners with appropriate firing rate (±400kW) have been pre-selected
- Flame velocity of 150 m/s
- Difference = the quarl shape : conical or streamlined



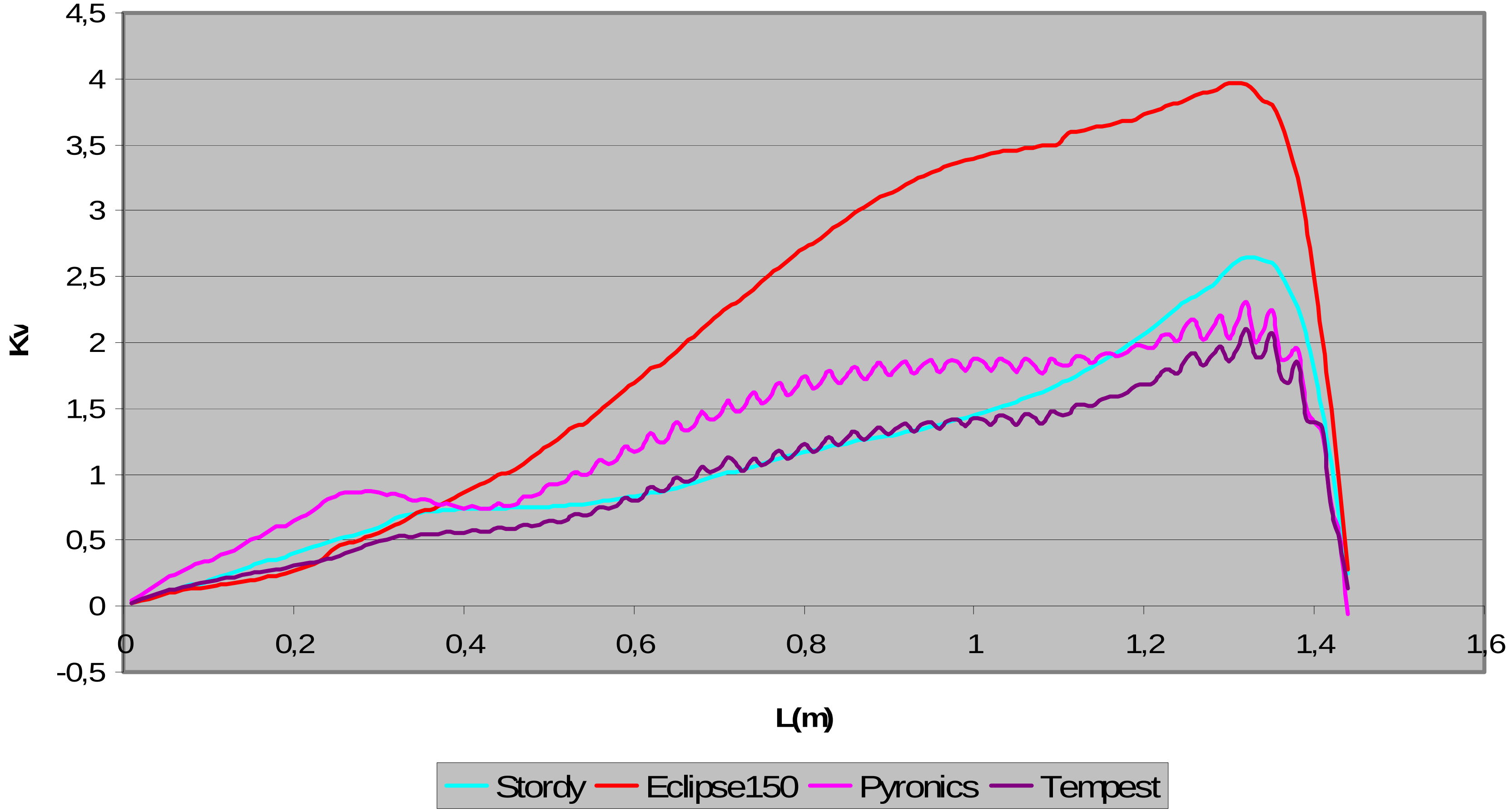
Eclipse (Thermjet)



Stordy, Pyronics, NA (Tempest)

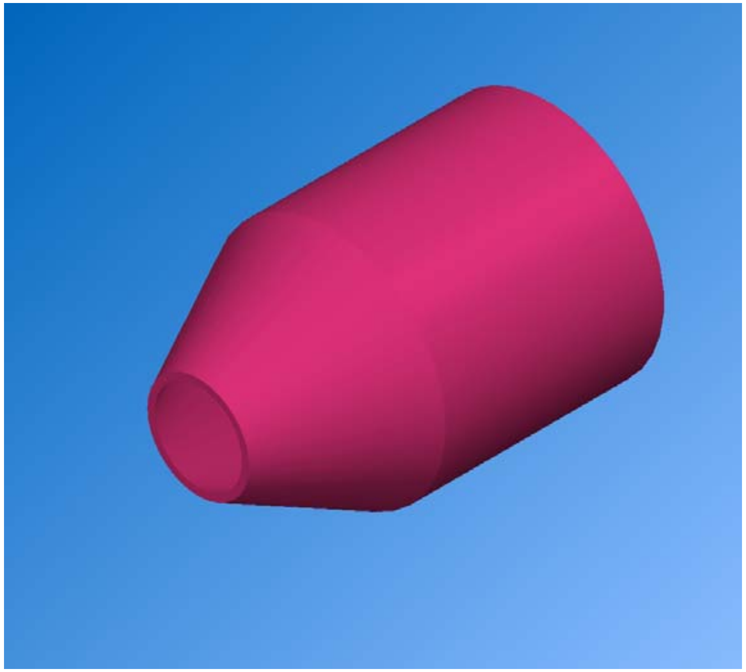
3. Burner selection

- Kv : flue gases injection in the combustion chamber



3. Burner selection

• Higher Kv for Eclipse Thermjet burner because of the conical shape of the quarl



• High Kv favourable to diluted combustion ➔ Thermjet 150 (440 kW)

➔ Numerical study for validating our choice

4. Numerical study

• Combustion chamber + burner modelled by 450000 hexahedral cells grid

• The jet burner is only figured by its quarl in the model of the combustion chamber

The boundary conditions have been defined as follows :

• For the air and gas inlets, purely axial mass flow and temperatures have been imposed.

• Outflow conditions have been imposed at the chimney.

• For the walls, a global heat transfer coefficient has been calculated from the heat balance measured in the fuel-oil operation in order to get a rough estimate of the boiler heat losses.

4. Numerical study

Standard models implemented in FLUENT are used:

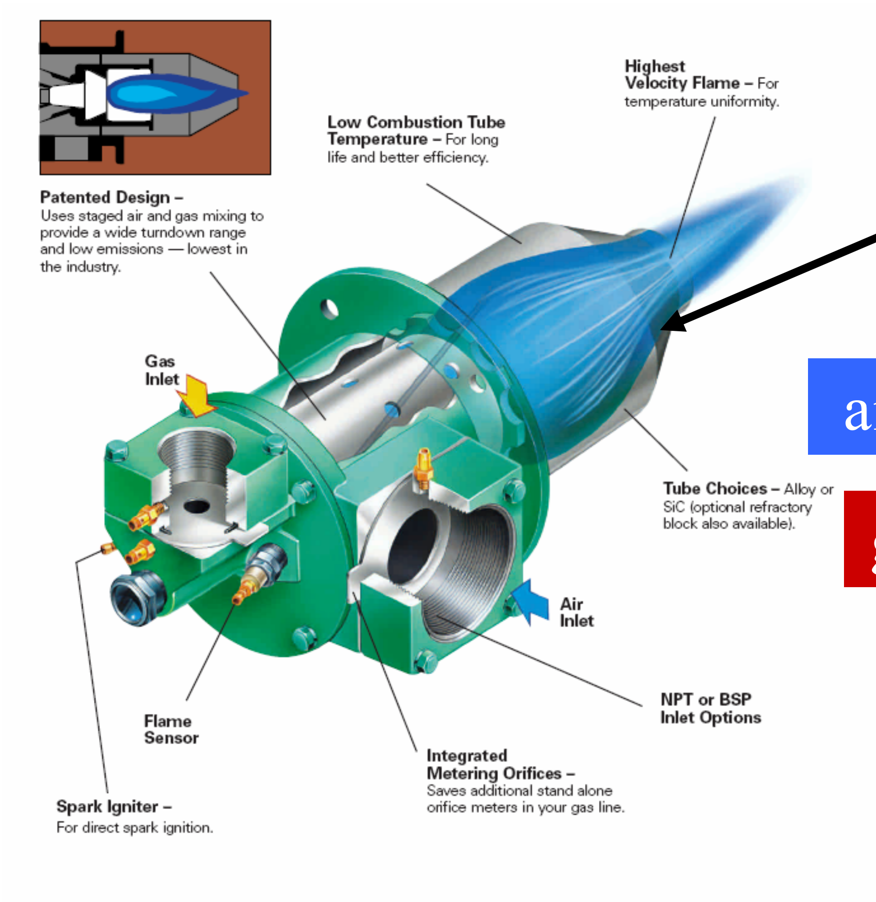
- Turbulence is modelled using standard *k-ε* model, with standard wall functions.

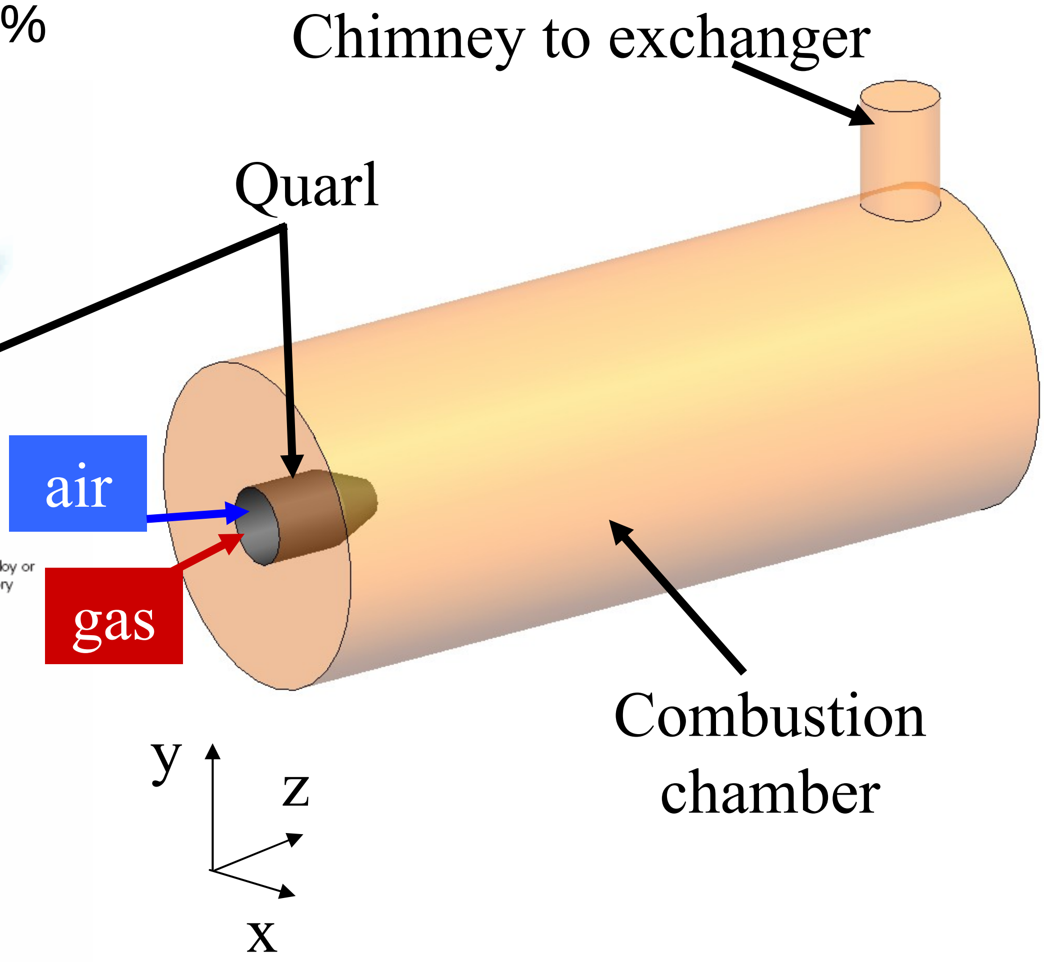
- Radiative heat transfer is modelled with the discrete ordinates approach where absorption coefficient is computed with the weighted sum of gray gases assumption.

- A transport equations is solved for each species involved in the combustion reaction mechanism. Fluent proposes several models which differ by the way they compute the average reaction rate. We use the “Eddy-Dissipation Model” which assumes that the reaction rates are fully controlled by turbulent mixing parameters.

4. Numerical study

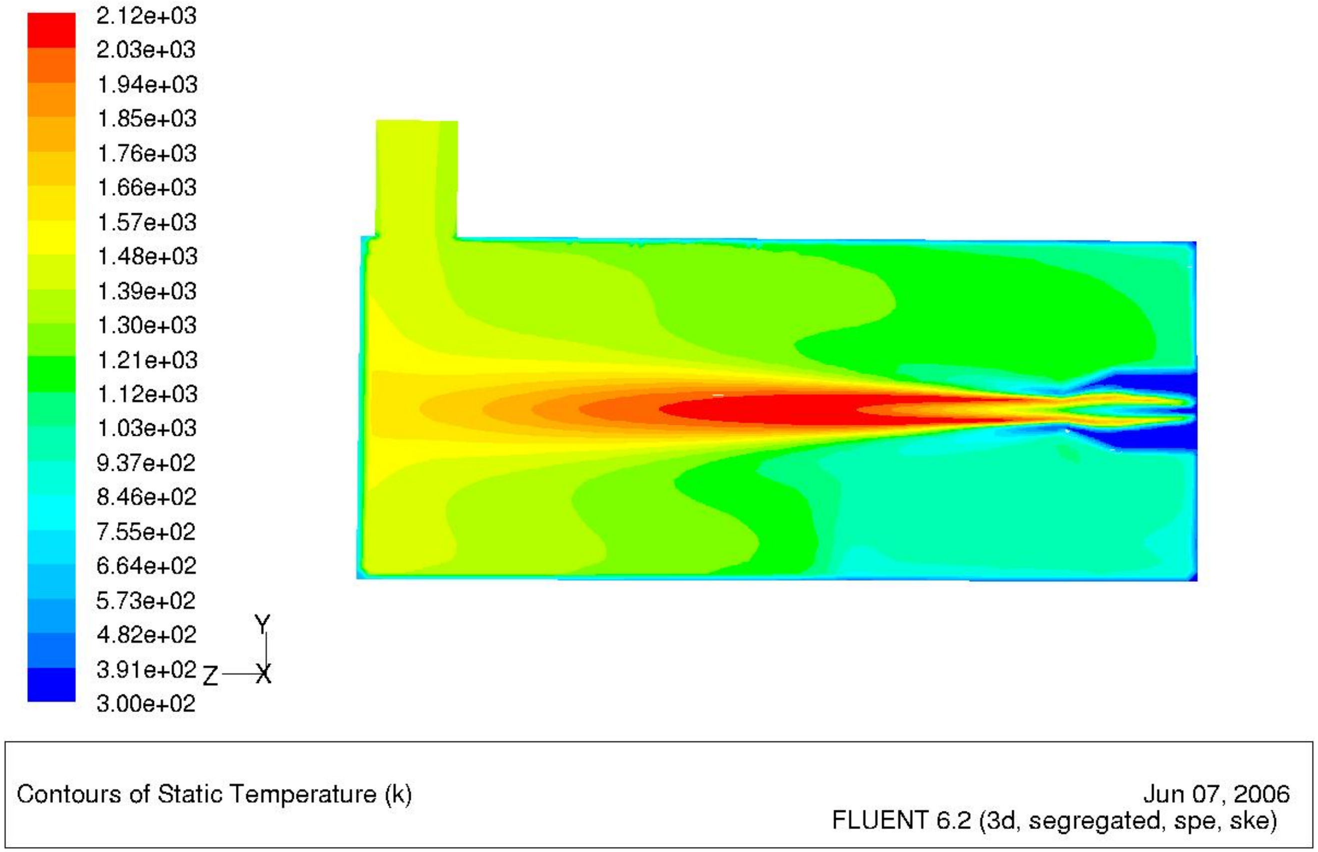
- classical combustion operation with an excess air of 15 %





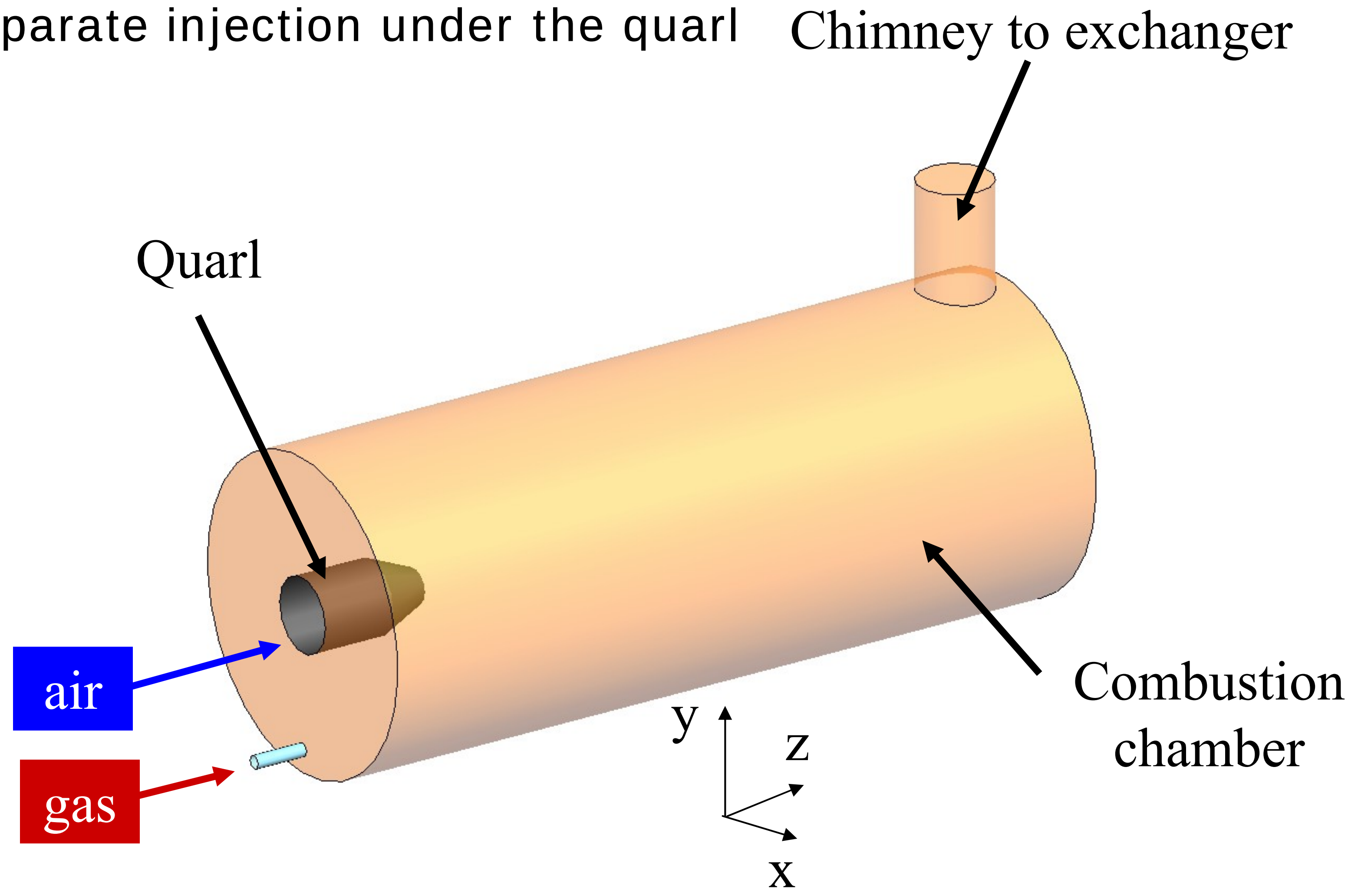
4. Numerical study

- Classical combustion working : heating up combustion chamber



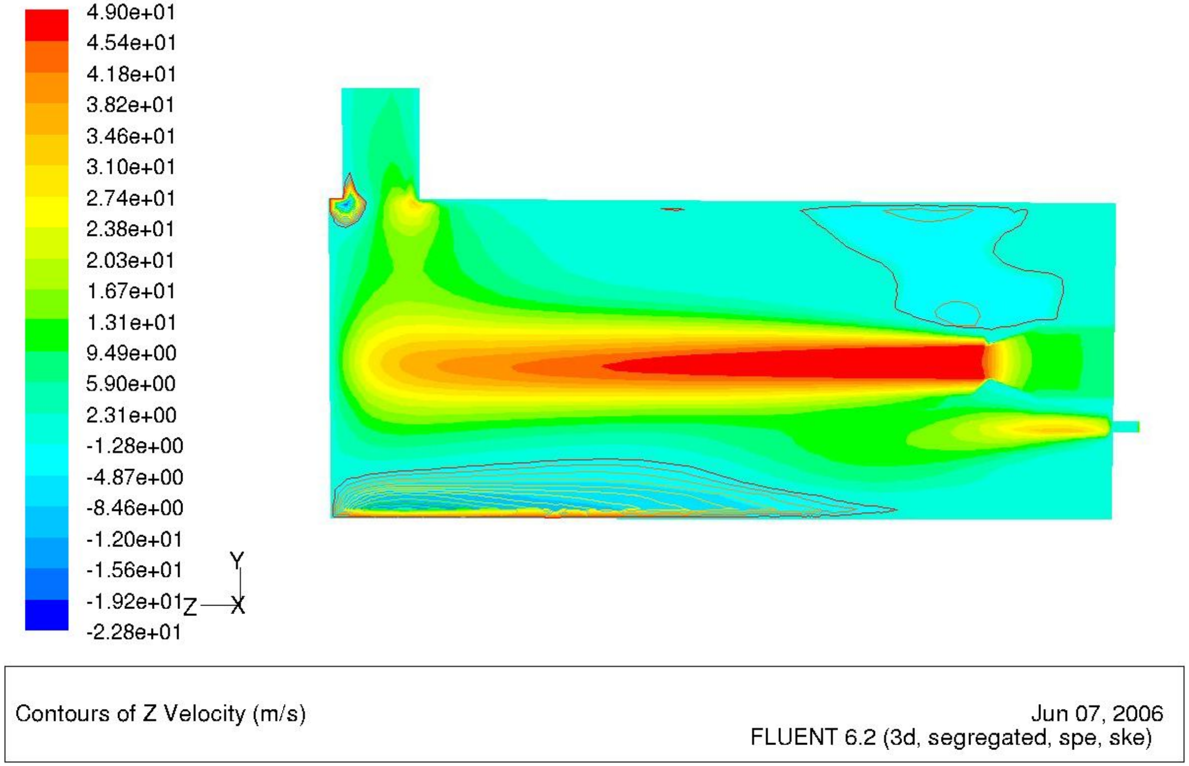
4. Numerical study

- Separate injection under the quarl

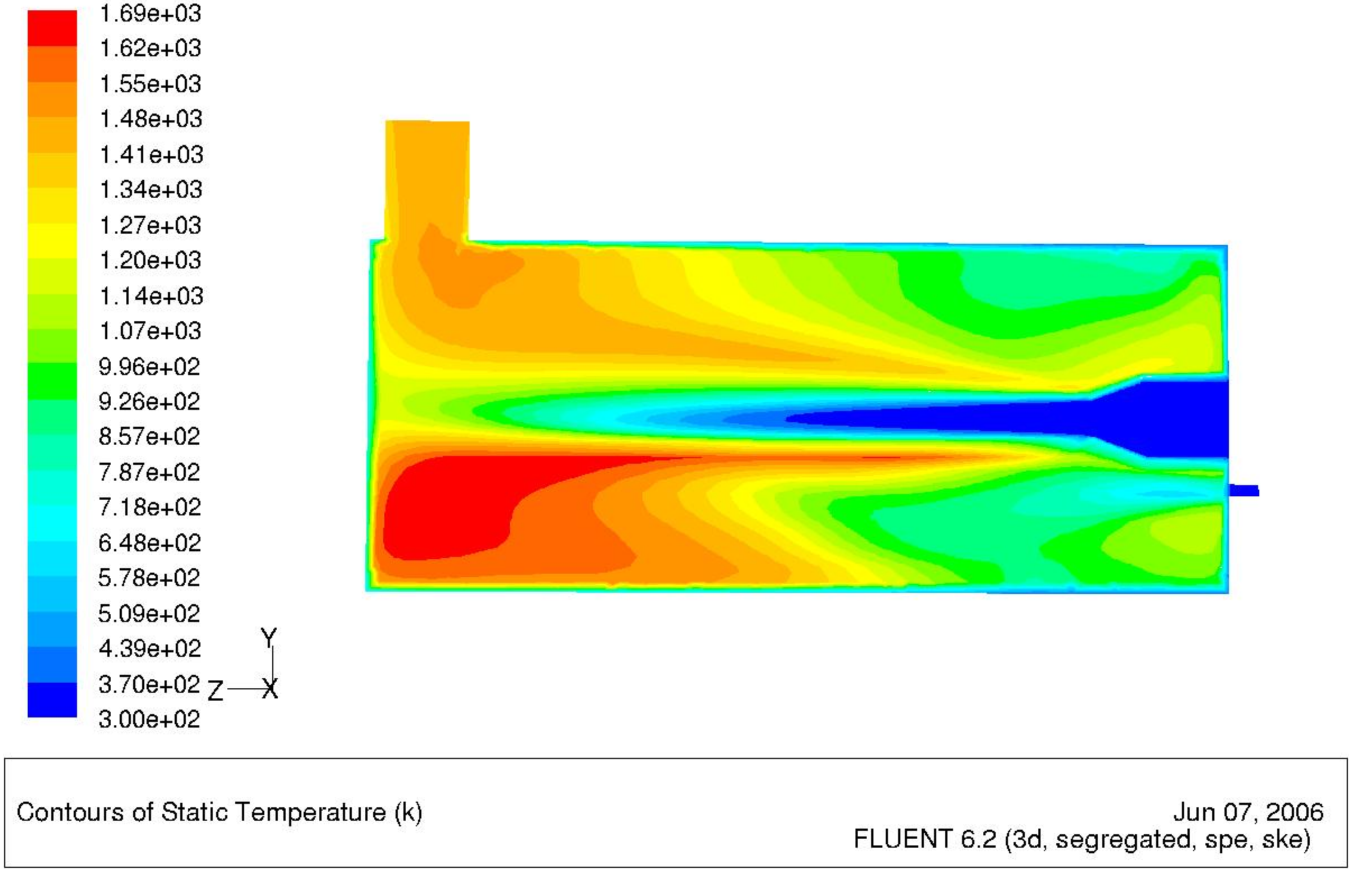


4. Numerical study

- Velocity nozzle exit : 150 m/s ➔ 40 m/s
- L/d too low ➔ entrainment rate too low



4. Numerical study



➔ New solution : replace the burner for a flow amelioration in the combustion chamber by increasing L/d (reducing d)

4. Numerical study

New solution :

• Use of Thermjet 100 burner (293 kW) ➔ nozzle quarl diameter reduction

• The use of a smaller burner capacity leads to change the switching procedure between classical and diluted combustion boiler operation.

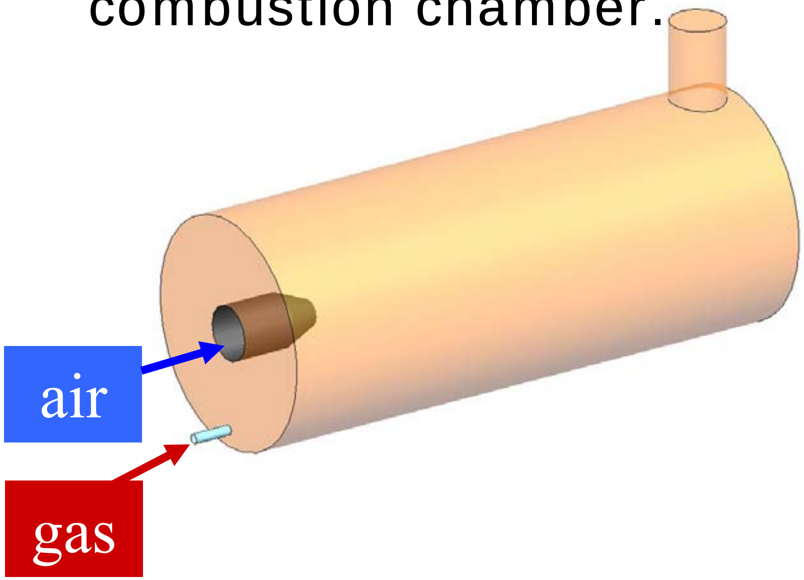
• The 293 kW jet burner will be used in a classical flame mode at the boiler starting, to increase the temperature in the combustion chamber.

• Then, additional air, necessary to reach the nominal air flow rate for a 440 kW burner operation (15% excess air) is injected in the burner quarl and the corresponding complementary gas (to reach 440 kW) is added through the separate injector.

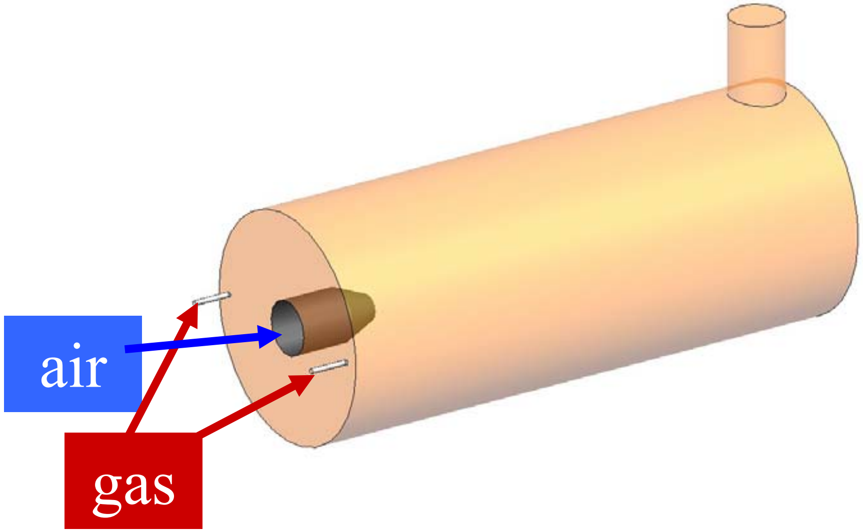
• When the combustion chamber reaches the mixture self-ignition temperature limit, the gas flow rate of the Thermjet is gradually reduced down to zero while the complementary gas is increased until getting the total 440 kW firing rate through the separate injector.

4. Numerical study

• The position of the gas injection has to be determined for getting enough dilution of the reactants when they meet in the combustion chamber.



1st solution :
direct injection under the quarl



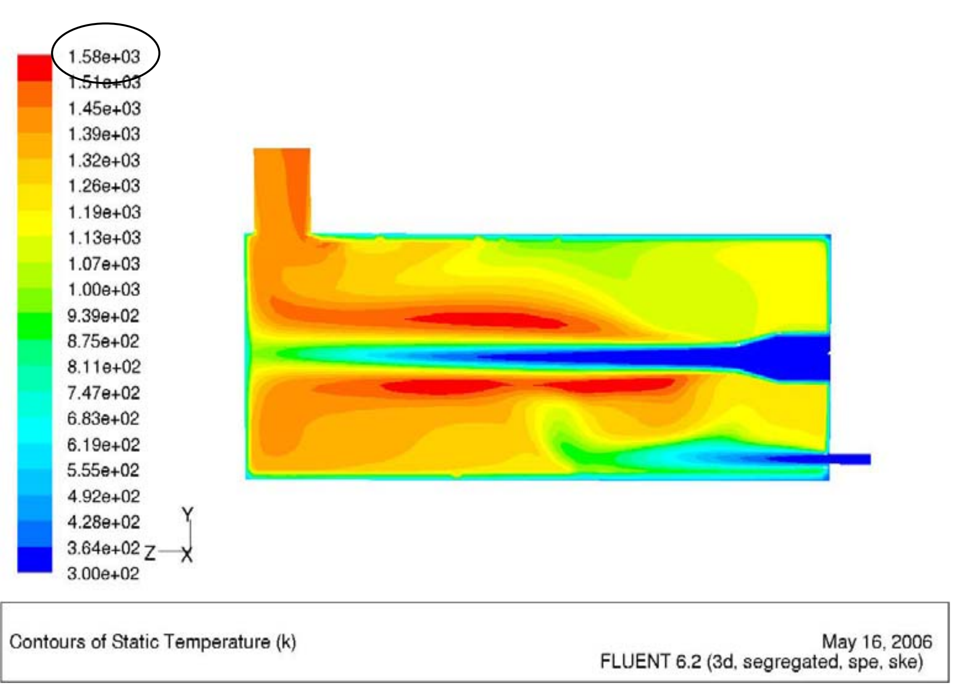
2nd solution :
direct injection at the left and at the right of the quarl

4. Numerical study

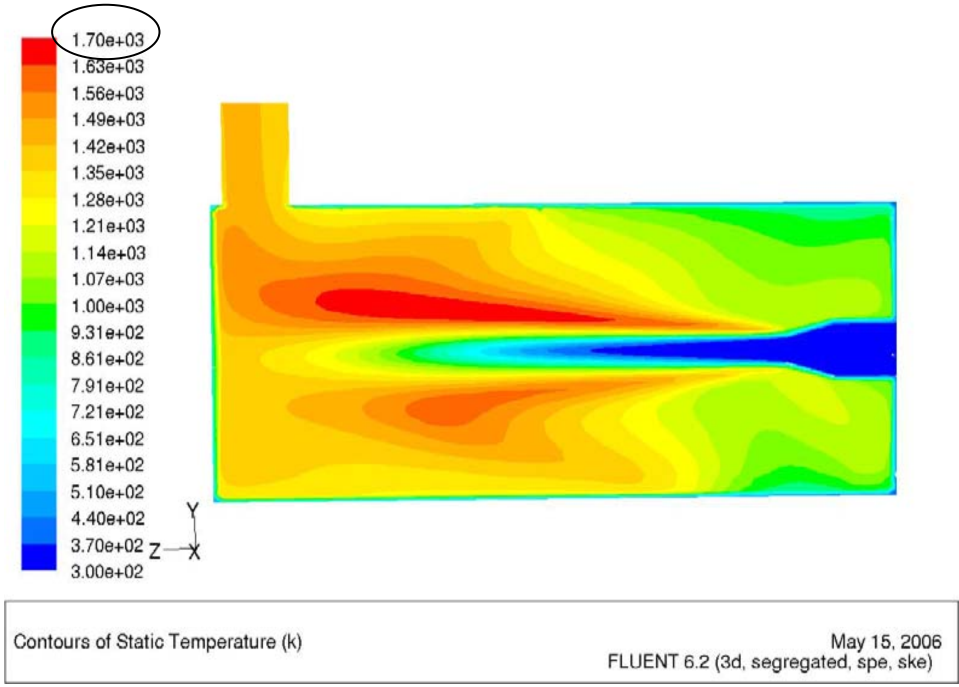
The direct injection under the quarl gives better numerical results for the temperature field in the combustion chamber

➔ Direct injection under the quarl chosen

➔ The quarl can be moved back (L increased)



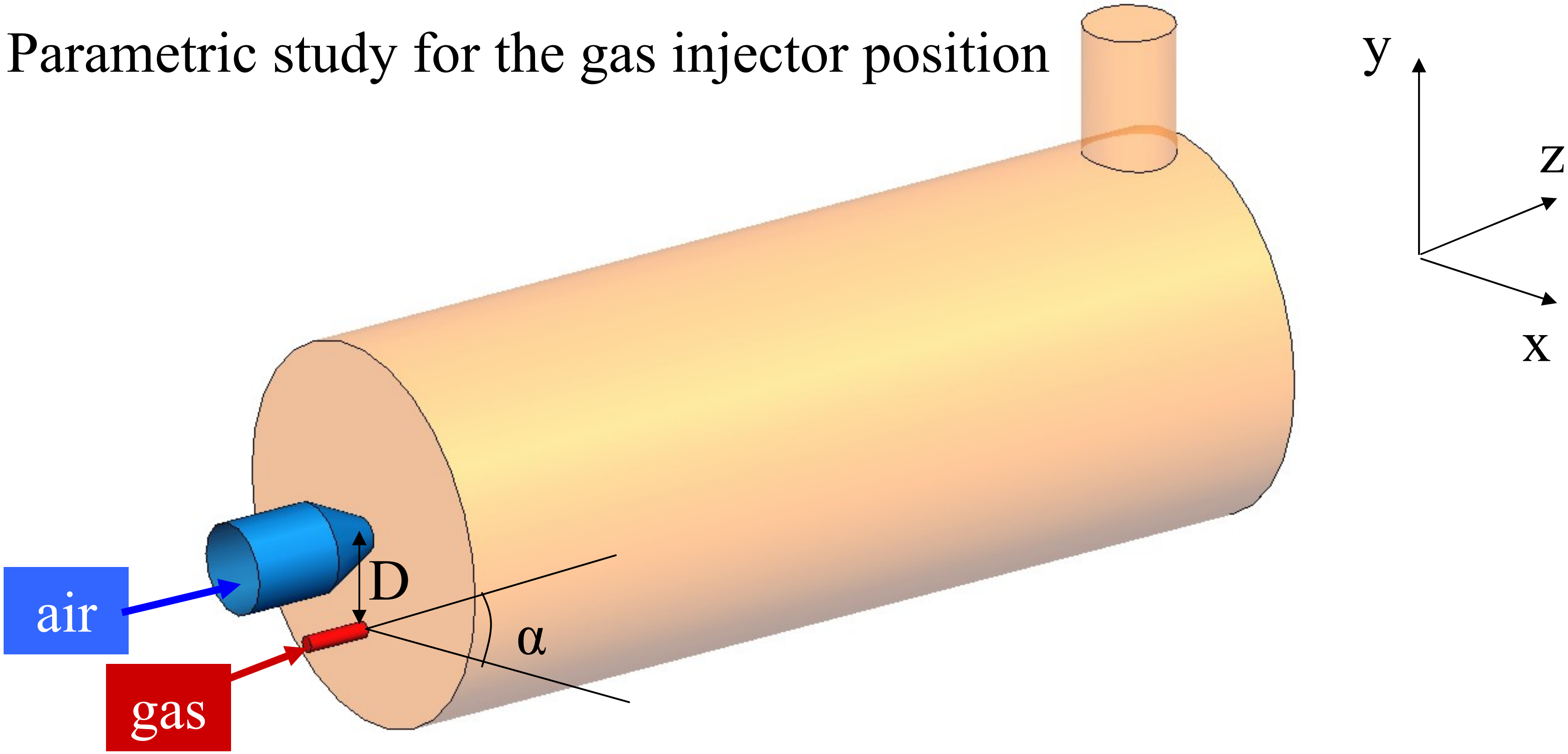
1st solution



2nd solution

4. Numerical study

Parametric study for the gas injector position

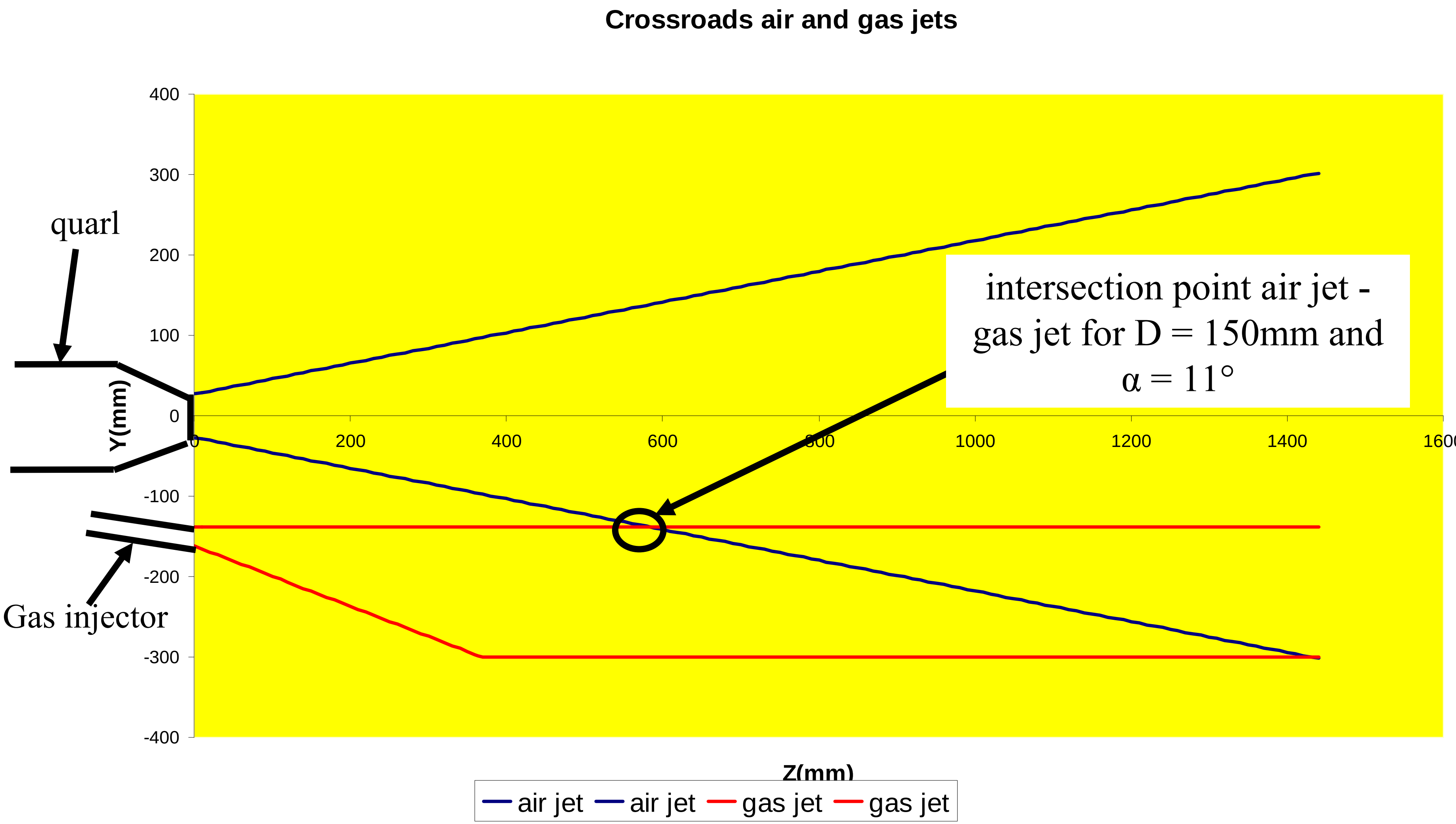


2 parameters for the direct injection :

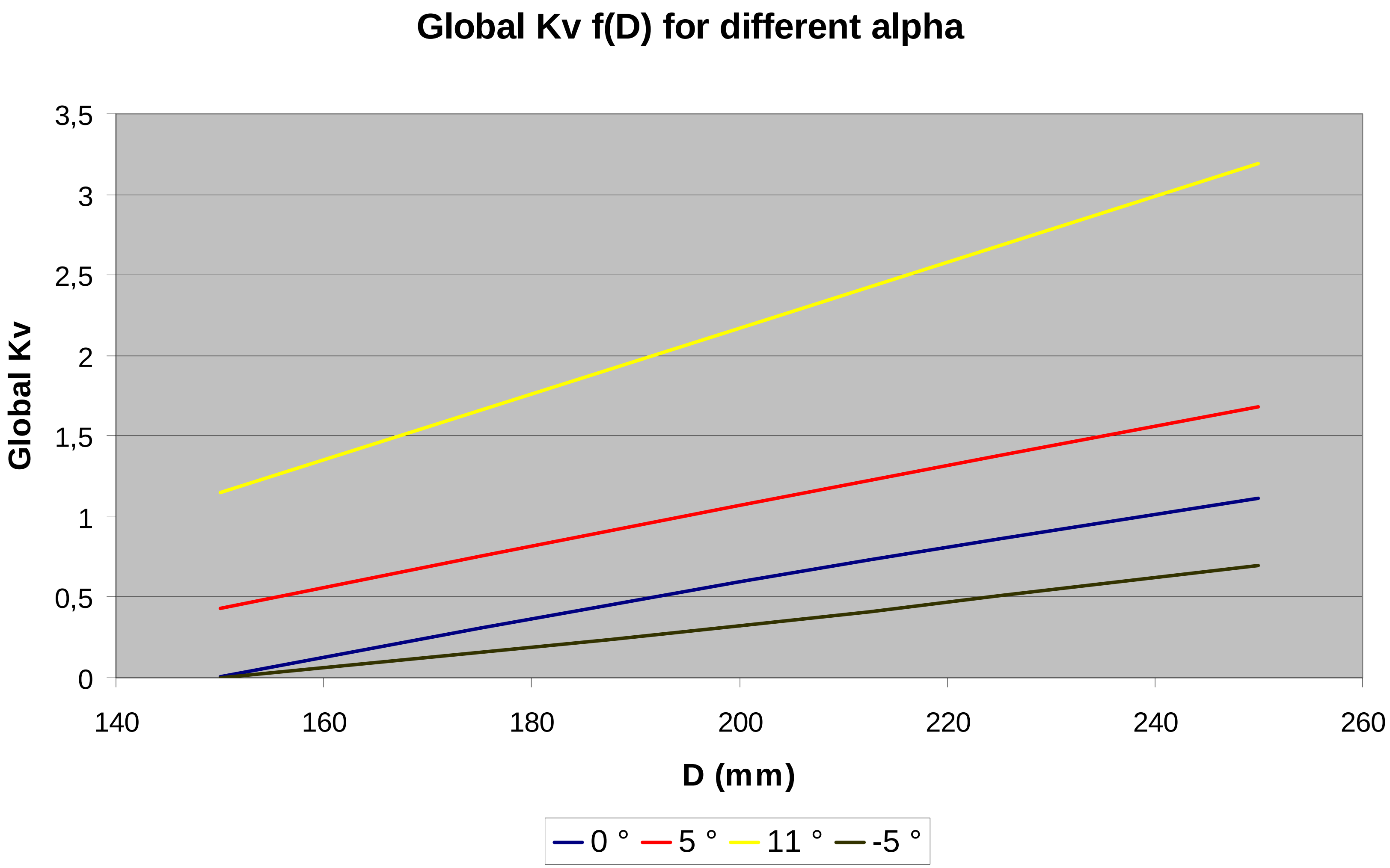
➔ Distance D

➔ Angle α

4. Numerical study



4. Numerical study



5. Conclusions

Done

• A preliminary CFD study has been performed, to select a standard jet burner from the current market, able to generate sufficient internal recirculation for reactants dilution in the boiler.

• A first parametric study has been performed to determine the optimum location and injection angle of a secondary gas injector to maximize the dilution of the air and gas jets before they meet.

Following of the work

• An experimental characterization of the selected material will be performed to validate numerical results.

• In the meantime, the dependence of the present numerical results to the parameters of the turbulence and combustion models is examined.

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THANK YOU FOR YOUR ATTENTION