SMARTCATs Final Report

Assembling and testing of a flameless burner

1. Details of STSM

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Length of stay:
07/12/2015 to 11/12/2015

2. Objective

The STSM is set in the framework of my PhD project entitled "Fuel flexibility for smart energy carriers in novel combustion system" under the supervision of prof. Parente at ULB (Université Libre de Bruxelles). It main focuses on numerical and experimental analysis of different energy carriers in novel combustion system, such as flameless combustion, to assure flexibility and low pollutant emissions.
The short term mission at WS, under the supervision of Mr. Cresci, aims to contribute to the assemblage and testing of a 20 kW self-recuperative flameless burner, which has been manufactured on behalf of ULB and it was moved there at the end of December 2015.

3. Timeline and activities

Monday 07/12//2015: Visit of WS company, visual inspection of the combustion chamber, discussion about operating principles and technical details.

Tuesday 08/12/2015: Assembling of the missing parts (air cooling, primary air, thermocouples, exhaust gases line).

Wednesday 09/12/2015: Test of the combustion chamber in Flame and Flameless mode at different powers.

Thursday 10/12/2015: Test with different cooling air mass flows. Disassembling of the plant.

Friday 11/12/2015: Disassembling completed and discussion about numerical modeling of MILD combustion.

4. Plant

The plant consists of a burner and a combustion chamber (Figure 1). The overall dimensions are **3.2** x **1.3** x **1.3** m.

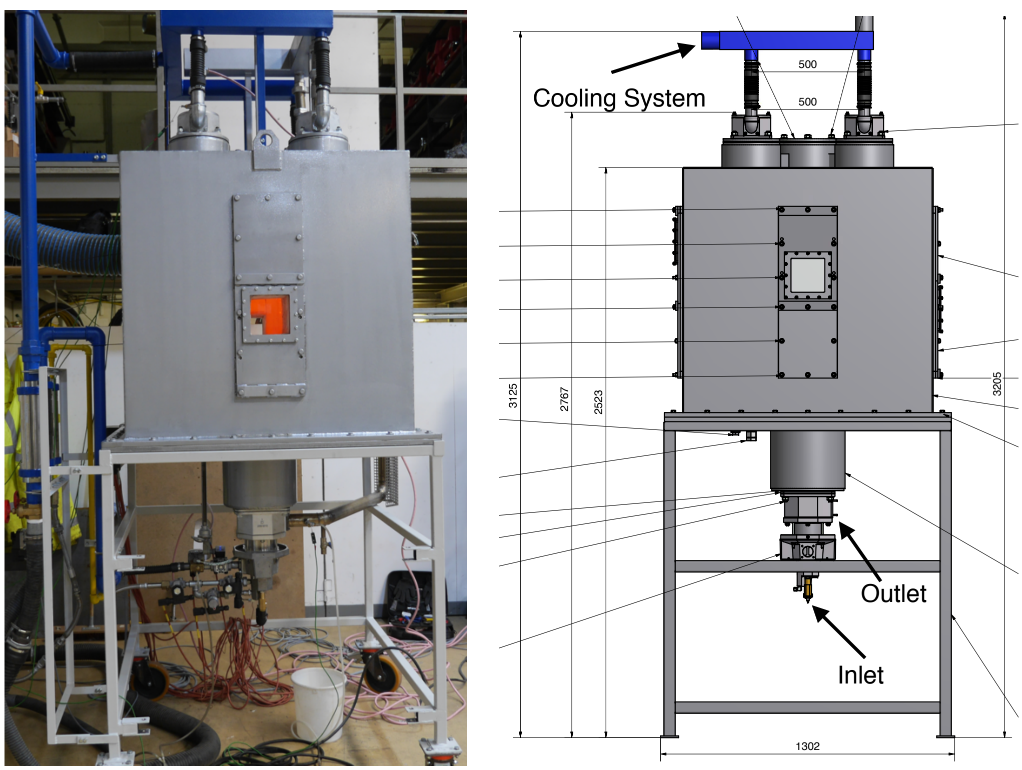

Figure 1 Burner and combustion chamber

The burner is a 20 kW nominal power flameless unit with integrated metallic finned heat exchanger to extract energy from the hot gases and to pre-heat the combustion air. Differently from other set-ups, it has industrial features allowing tests varying the fuel and

air velocity, the air excess, the injection geometry and the fuel blends (methane, biogas, coke oven gas (COG) and syngas).
Both the inlet (air and gas) and the outlet (hot gases) are placed in the bottom part of the burner (Figure 1), therefore after being burnt the combustion products cross the entire length of the burner and provide energy to warm up the inlet air.
A set of four adjustable cooling systems (Figure 2) allows operating the combustion chamber at different working conditions. Indeed, the cooling air flows through four fixed-length pipes (ϕ=80mm, h=600mm), while the flow rate can be regulated.

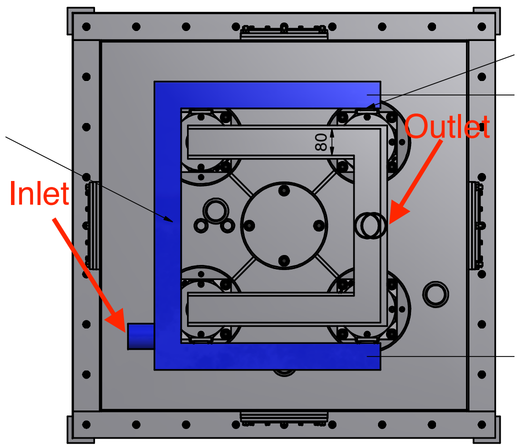

Figure 2 Detail of the cooling system

The combustion chamber (Figure 3) is thermally insulated (20 cm ceramic fiber) to limit the heat losses, while the flue gas recirculation, needed for flameless combustion, is achieved through aerodynamic recirculation.

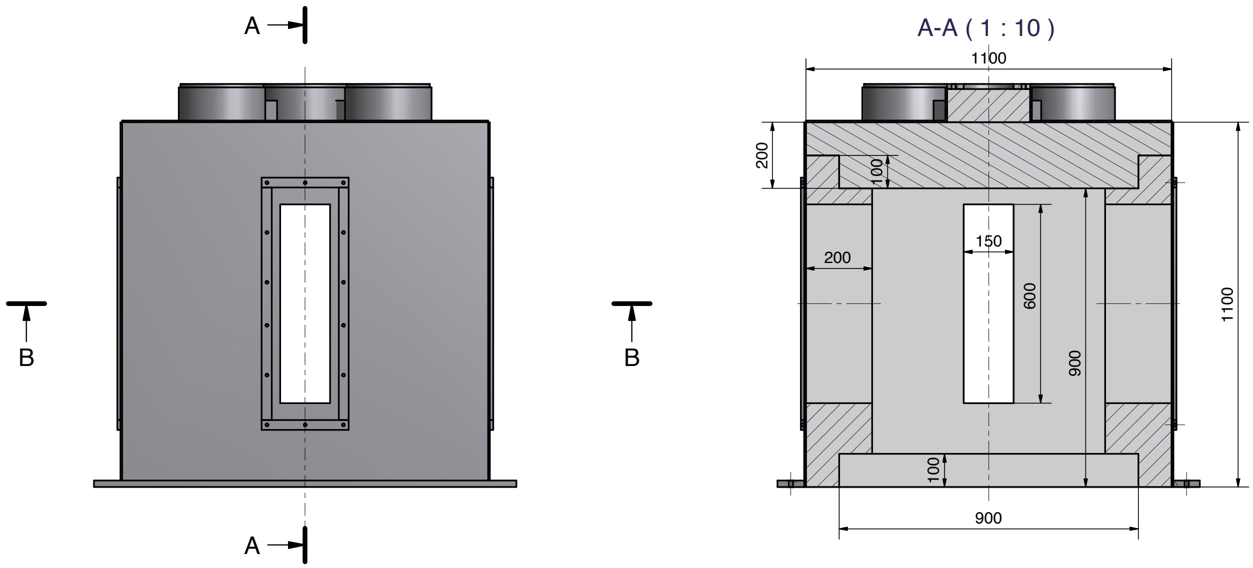

Figure 3 Detail of the combustion chamber

On each side of the chamber, there is a slot (15x60 cm) for measurements. It can be equipped with a quartz window (15x15 cm) which allows optical access to the chamber for further LDV, LIF, OH* measurements or it can be closed allowing thermocouples access to measure the wall temperature profiles. In the first case, the window can be fixed in the upper or in the lower side of the slot, allowing a complete access to the reactive zone.

The injection configuration is depicted in Figure 4. The air channel is co-axial with the hot gases exit, while for the fuel line there is a difference of working between flame and flameless mode. Using the former, the fuel comes out through a series of holes within a pre-chamber placed inside the burner, resulting in a partially premixed flame, therefore part of the reactions happens inside and part outside it. After having reached a temperature higher than the self-ignition temperature of the fuel/air mixture (in literature [1] a value of 850°C is often reported accounting for a certain safety margin) and thanks to the internal recirculation of burnt gases, flameless combustion can be reached. Therefore, the fuel comes out from the central nozzle and the combustion reaction happens entirely inside the combustion chamber.

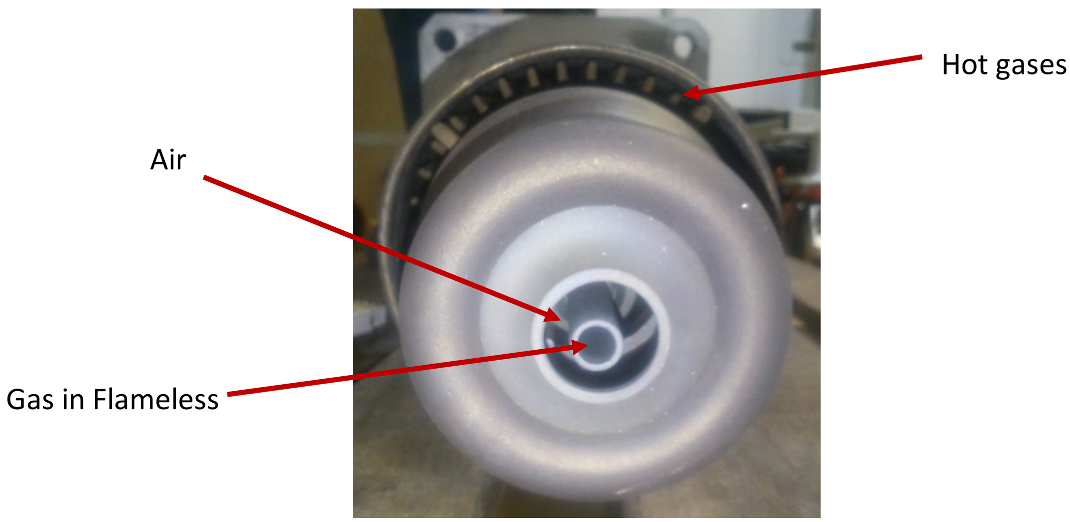

Figure 4 Injection configuration

5. Tests

Once having assembled the plant, different tests have been carried out including a pre-heating in flame mode and the switch in flameless mode after reaching a temperature above the self-ignition temperature. For these purposes only natural gas (NG) has been used because of the convenience and the economic saving of having a NG network. Further tests with different fuel blends will take place during my PhD.
Figure 5 shows the flame mode (left) at the beginning of the test (cold chamber) and the flameless mode (right). Both pictures have been taken with the window positioned in the upper side of the slot.

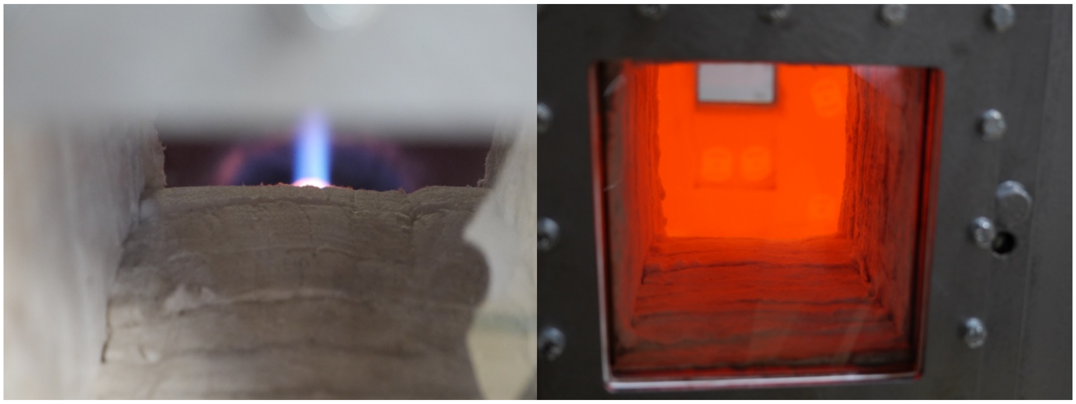

Figure 5 Flame and Flameless Combustion

In particular, different set-point temperatures (temperature of the combustion chamber in the upper part), in the range 900-970 °C, have been tested and a steady-state has been correctly reached. Furthermore, also the air cooling flow rate values have been investigated in order to limit the cooling air-outlet temperature and to maintain the set-point within the expected range, as simulating an industrial load inside the combustion chamber.

Several parameters have been detected during testing, such as the four cooling air-outlet exit temperatures, the wall temperatures in three positions on one side of the combustion chamber, the temperature and composition (NO_x) of the exhaust gases. In particular, Figures 6-7 provide a particular of the evolution of these fields on time.

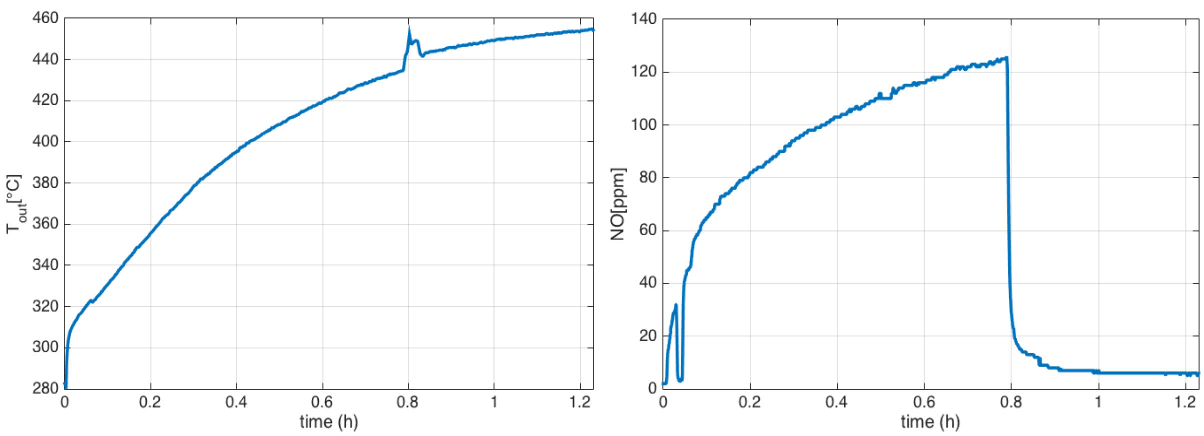

Figure 6 Time evolution of exhaust gases temperature and NOx concentration. The sudden drop of NOx concentration is associated to the switch from flame to flameless operation.

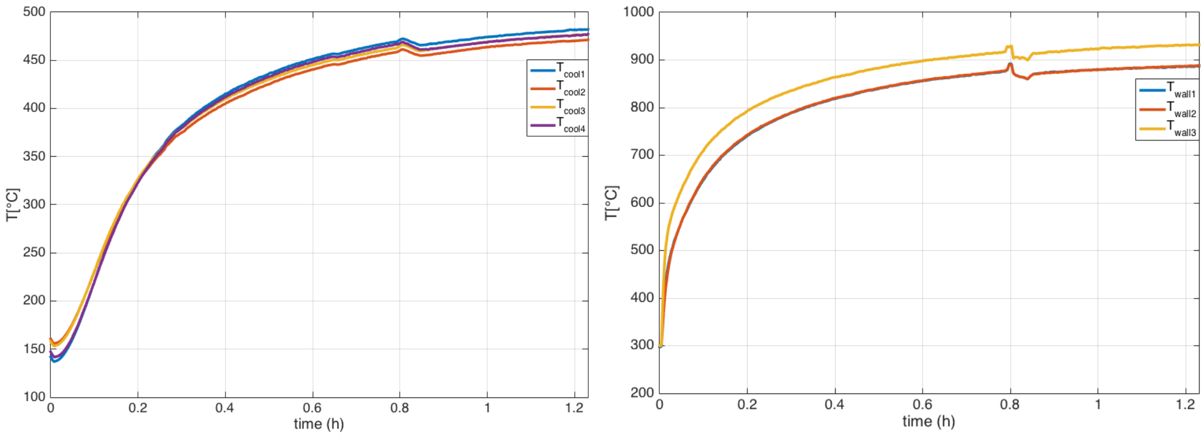

Figure 7 Time evolution of the four cooling air-outlet temperatures and wall temperatures. They maintain a quasi constant value after switching to flameless operation.

The plant switched well to flameless combustion (t~0.8 h) after reaching the self-ignition temperature, indeed the flame "disappeared" and the NO_x level decreased by two orders of magnitude reaching values of some ppm (Figure 6). The exhaust gases temperature is still increasing because the furnace set-point has not reached yet. Moreover, in this regime the wall temperature profiles remain almost constant and the four cooling pipes provide almost the same temperatures, showing the good design of the system.

In Table 1, some numerical values of the main parameters obtained in flameless mode are available.

Table 1 Test parameters

Q_{air} (Nm3/h)	29.5
Q_{fuel} (Nm3/h)	2.45
Q_{cool} (Nm3/h)	80
Power (kW)	24.5
T_{gas} (°C)	455
T_{cool_out} (°C)	490
T_{set_point} (°C)	900
$\%O_2$ @Hot gases	3.3
NO_x (ppm)	6
CO (ppm)	0

6. Conclusion

During my stay in WS, I have contributed to the assembling and testing of a 20 kW combustion chamber. After becoming familiar with the experimental apparatus, different parameters were investigated, such as thermal powers, air cooling flow rates, set-point temperatures. The tests were successfully carried out and the plant was able correctly to

switch between flame to flameless mode over the self-ignition temperature of the fuel, as highlighted by very low NOx emissions.
Based on the current experience, I really appreciated the opportunities that this STSM gave me to collaborate with such a company leader in the world of burner development and manufacturing. Indeed, it was also a way to learn useful practical aspects for the successive tests during my PhD and to understand more in details how industrial plants mounting flameless burner work.
Moreover, considering that the burners development is frequently based on CFD analysis, during the STSM an open discussion and exchange about combustion modelling was carried out.

7. References

[1] A. Milani. MILD combustion techniques applied to regenerative firing in industrial furnaces. In: The Second International Seminar on High Temperature Combustion, 17-18 January, Stockholm.