STSM Report

Ignition and early stage combustion of single biomass particles: comparison between experiments and numerical predictions

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1. Purpose of the STSM

The purpose of this STSM is to compare predictions obtained with an advanced biomass conversion model with experimental measurements of particle ignition and early stage combustion. The experimental database was developed at Instituto Superior Técnico, where the ignition behaviour of single biomass particles was characterized through high-speed cinematography of single particles entrained in a laminar flow of combustion products, for a broad range of industrial relevant operating conditions. Furthermore, ignition and combustions mode, volatile flame diameter and time-span are post-processed from the images collected. As for the kinetic model, it covers the following three main processes during biomass conversion: (1) Pyrolysis reactions of the coal particles. (2) Secondary gas phase reactions of the released gases. To this purpose a detailed gas phase mechanism is used; (3) Heterogeneous gas phase reactions of the residual char. For this STSM, the focus was given to processes (1) and (2). The single particle heating, initial pyrolysis and ignition were modeled adopting a multiphase CFD code. The effect of particle anisotropy and pyrolysis reactions on particle density and porosity are also considered. The model allows the inclusion of the detailed chemistry of the solid and the homogeneous kinetics inside the pores and in the surrounding environment. The model is then able to reproduce the ignition characteristics, individuating the controlling steps and the sensitivity to the operating conditions, but it also allows to predict the released gas and tar species, their ignition, oxidation and the pollutant formation, like nitrogen and sulphur oxides.

2. Description of the work carried out during the STSM

2.1 Introduction

Biomass can play a major role in accomplishing the European Union's (EU) renewable targets for both heat and electricity while contributing to energy security. In addition, biomass combustion is one of the few forms of dispatchable renewable power generation; having a key-role in electrical grid stability through the back up of other forms of intermittent and non-synchronous renewable generation. Co-firing of coal with biomass arises as an alternative that allows the use of biomass fuels in existing power plants, thus making it an attractive technology. Biomass is a highly reactive fuel and has a high volatile matter content, resulting in lower ignition temperatures for coal-biomass blends than for pure coal [1], helping with flame stability. Additionally, emissions of SO_2 and NO_x are typically reduced [2]. Despite some successful long-term demonstrations [3], there are still many open questions on the combustion process, particularly in the area of particle ignition behavior.

The biomass supply for power production has to grow proportionally and, due to environmental reasons, not all the technically available biomass from forests and fields can be removed. The majority of the growth potential lies in making use of agricultural and forest residues and in energy crops planted on idle or released cropland. However, the extreme variability in the composition of biomass, as opposed to that of coal, poses technical challenges to boiler designers and operators. The design and retrofitting of boilers that can burn a variety of biomass relies on a detailed knowledge of the combustion process. The understanding of the involved processes is fundamental to the development of numerical tools that can assist with the development of efficient, low-pollution biomass burners.

2.2 Experimental work

Figure 1 shows a schematic of the experimental setup used. Briefly, it consists of a biomass feeding unit, a McKenna flat flame burner, a gas feeding system and an image acquisition system. This setup is described in detail in [4].

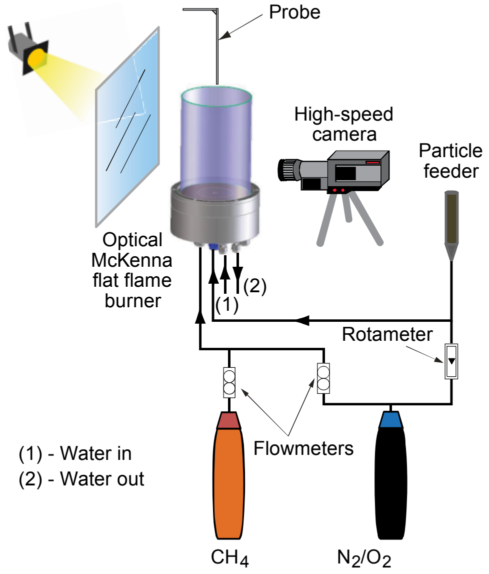

Figure 1. Schematic of the experimental setup.

In the experiments, the fuel and oxidizer flow rates and burner thermal input were varied to yield different operating conditions. Firstly, the equivalence ratio was kept constant, while the thermal input was varied to establish five conditions with different mean temperatures in the ignition zone, T1-T5. Subsequently, the fuel and oxidizer flow rates were varied to yield three different equivalence ratios and, hence, different oxygen concentrations for the same temperature, O1-O3. Throughout the tests the transport air flow rate was kept constant and at the lowest flow rate that ensured particle feeding.

In the current work, one of the tested conditions was selected as a benchmark to test and verify the model, specifically condition O2, the parameters of which are shown in table 1.

Table 1. Operating conditions.

Parameter	O2
Thermal input [kW]	1.1
Equivalence ratio ϕ [-]	0.71
O_2 concentration [dry vol. %]	5.1
Gas temperature [K]	1680

2.3 Numerical study

The numeric work was carried in two steps. Firstly, the flat flame of the Mckenna burner was modeled disregarding the solid fuel. The main objective of this simulation was to generate the transient boundary conditions for the following step. In a second stage, a resolved multi-region simulation of the particle and its surrounding was considered.

In the flat flame simulation a wedge shaped domain was considered above the burner, with a radius of 0.035 m, which corresponded to the radius of the reactor, and a height of 0.06 m. The mesh of this simulation, shown in Fig. 2 (on the left), was refined closer to the reactor where most of the reactions occur. In the resolved simulation, a wedge region of 0.001 m upstream and 0.002 m downstream of the particle and with a radius of 0.002 m was considered. The mesh of this case can be seen in Fig. 2 (on the right), and was more refined in the vicinity of the particle.

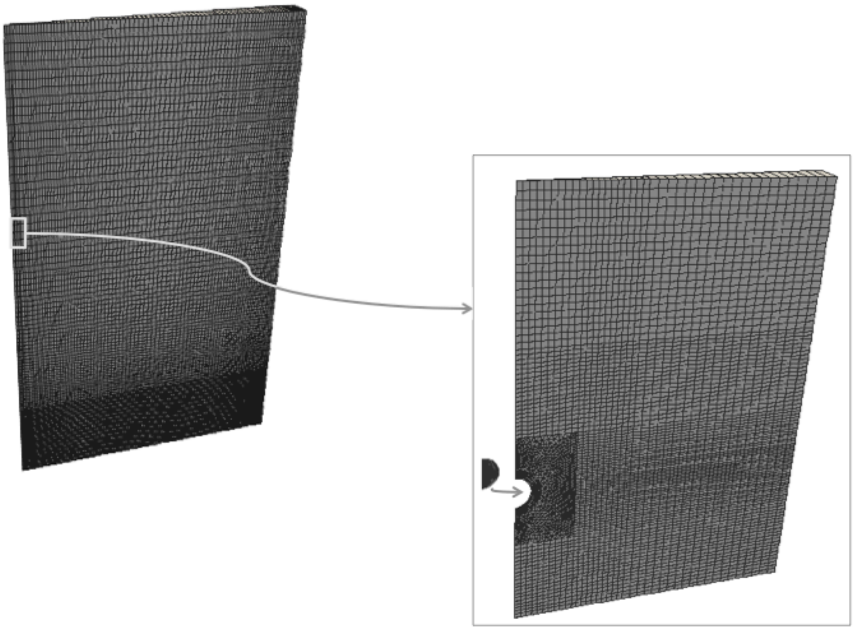

Figure 2. Mesh of the flat flame simulation on the left, and on the right, mesh of the resolved simulation around the particle.

3. Description of the main results obtained

3.1 Flat flame simulation

As mentioned above, the first step was to model the flat flame and the environment above the burner. Figure 3 shows the results of temperature and main species measured, against the respective experimental data. As seen in Fig. 3 the flat flame was successfully modeled with only minor differences when compared to the experimental measurements.

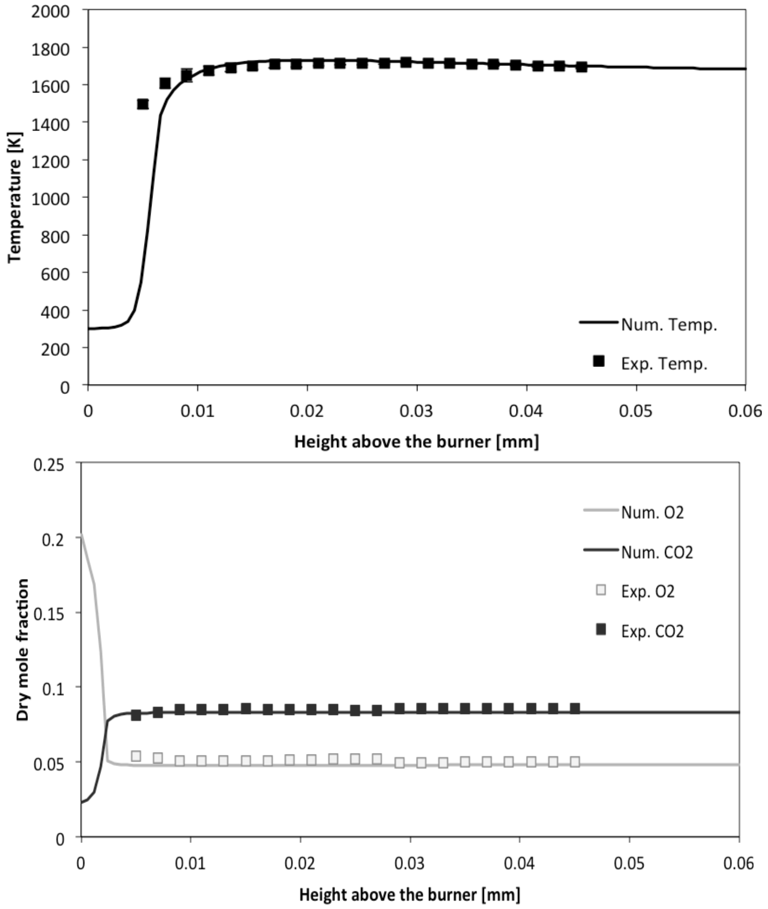

Figure 3. Temperature and gas species above the burner: the symbols represent the experimental data, and the lines the numeric results.

The results from this simulation were used to generate the transient boundary conditions for the resolved multi-region simulation around the particle.

3.2 Resolved simulation

The results of the resolved simulation are still being processed. The objective, however, is to compare not only ignition delay times but also the development of the volatile cloud flame around the particle obtained numerically with the experimental measurements.

4. Future collaboration with host institution

Given the extensive experience of the CRECK modeling research group in modeling reacting flows, and the wide experience of the combustion research group of Instituto

Superior Técnico in experimental work, I believe there is a high potential for further collaboration in the future.

5. Foreseen publications/articles resulting or to result from the STSM

Regarding the work done, and being developed at the moment there is a plan to present the results through the publication of a paper in the international scientific journal.

Acknowledgements

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6. References

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