STUDY OF SOLID BIOMASS COMBUSTION MODELING USING OPENFOAM

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INTRODUCTION

To overcome the serious environmental problems of global warming and poor air quality, it is necessary to develop clean energy sources and reduce society's energy consumption. Due to this, studies have been carried out around the world in order to find and improve renewable energy sources that can replace the fossils ones, of which biomass is one of the most important. Over time, various processes have been developed for the transformation of biomass into energy of which combustion is the most used as it is the most suitable from the economic point of view. Nevertheless, there are still some problems in current biomass combustion furnaces, such as slagging, instability of heat load and low thermal efficiency. Computational models are a valuable tool to improve the performance of biomass combustion systems since through it the design and operating conditions of these systems can be improved without incurring the economic and environmental costs of the experimental studies. which has motivated the development of Computational fluid dynamics (CFD) models in recent decades. This is an issue that is still under development due to the complexity of the combustion process, which requires various sub-models for the thermo-chemical conversion of the biomass and sufficient computational resources for the simulation. OpenFoam is a powerful open-source engineering-tool, which has been successfully used in numerous applications, however, there are relatively few works that use it to simulate the combustion of solid biomass. In order to guide researchers interested in the use of OpenFoam for this type of applications, in this document a 2D simulation of combustion in a boiler fed with grape marc employing OpenFoam is reported, this is a simple model that predict CO and H_2O profiles of velocity and temperature over the freeboard.

METHODOLOGY

In this work, the combustion in a biomass boiler with dimensions: 8 m wide and 15 m high, used in a 12.5 MWel combined heat and power plant, was simulated. The system was already analyzed in the work of Cordiner et al. (Cordiner et al., 2014, 2016), but the novelty of our study lies in the simplicity of the model, which requires relatively few computational resources. A squared mesh with a grid size of approximately 20 was used, the computational grid was done with the blockMesh utility. The characteristics of the biomass used were also taken from the work of Cordiner et al. (Cordiner et al., 2014, 2016). On the other hand, the volatilization kinetic parameters were taken from the work of Fiori (Fiori et al., 2012).

The simulation was under the following main assumptions:

- The fuel (biomass) is supply to the combustion chamber following a predefined path.
- Solid particles are not moved by gas action (drag and gravity forces are neglected) but gas phase movement is affected by bed particles.
- The Equations of continuity, energy and momentum of the gas are solved taking in account chemical reactions and interactions with the solid phase.

An empirical 2D model implemented in OpenFoam was used, utilizing the coalChemistyFoam solver. To model the turbulence/chemistry interaction in the combustion process the k-ε model and the Partially Stirred Reactor (PaSR) combustion model were employed, in the latter, the computational cells are divided into two zones, one in which all reactions occur and the other in which no reactions occur so that the composition changes due to the mass exchange with the reaction zone. The governing equations used in the gas phase are presented below:

- Continuity equation:

$$\frac{\partial(\rho_g)}{\partial t} + \nabla \cdot (\rho_g \mathbf{U}_g) = S_m \quad (1)$$

- Energy transport equation:

$$\frac{\partial(\rho_g h)}{\partial t} + \frac{\partial(\rho_g K)}{\partial t} + \nabla \cdot (\rho_g \mathbf{U}_g h) + \nabla \cdot (\rho_g \mathbf{U}_g K) - \nabla \cdot \left(\alpha_{eff} \nabla(h)\right) = -\nabla p + \rho_g \mathbf{U}_g \cdot \mathrm{g} + S_{\mathbf{h}} \quad (2)$$

- Momentum equation:

$$\frac{\partial(\rho_g \mathbf{U}_g)}{\partial t} + \nabla \cdot (\rho_g \mathbf{U}_g \mathbf{U}_g) - \nabla \cdot (\tau_g) - \nabla \cdot (\rho_g \mathbf{R}_g) = -\nabla p + \rho_g \mathrm{g} + S_{\mathbf{U}} \quad (3)$$

- Species transport equation:

$$\frac{\partial(\rho_g \mathbf{Y}_i)}{\partial t} + \nabla \cdot (\rho_g \mathbf{U}_g \mathbf{Y}_i) - \nabla \cdot \left(D_{eff} \nabla(\rho_g \mathbf{Y}_i)\right) = S_{\mathbf{i}} \quad (4)$$

Where h is the enthalpy, S is the source terms, K is kinetic energy, Rg is Ronald stress term, Yi is the mass fraction of the species, and αeff and $Deff$ are the effective thermal and mass. The freeboard reaction mechanism used was proposed by Gómez et al. (Gómez et al., 2014), which consists of the reactions summarized in table 1. The system was simulated in a computational cluster of the “Universidad Industrial de Santander” , named GUANE, that consists in 16 ProLiant SL390s-G7 computing nodes such as shown in the work of García et al. (García Henao et al., 2015; UIS, s. f.).

Table 1. Combustion reactions (Gómez et al., 2014).

Homogeneous reactions	
R1	$C_6H_6 + \frac{9}{2}O_2 \rightarrow 6CO + 3H_2O$
R2	$CH_4 + \frac{3}{2}O_2 \rightarrow CO + 2H_2O$
R3	$H_2 + \frac{1}{2}O_2 \rightarrow H_2O$
R4	$CO + \frac{1}{2}O_2 \rightarrow CO_2$
R5	$H_2O + CO \rightarrow CO_2 + H_2$
R6	$CO_2 + H_2 \rightarrow H_2O + CO$

RESULTS

The furnace was simulated under steady state conditions, CO, H_2O and velocity fields obtained are reported in figure 1. The results are similar to those obtained by (Cordiner et al., 2016), who simulated the same type of boiler; Although this model does not simulate NOx emissions, its value is that it achieves good results in a simple way with low computational resources. The calculated temperature closer to the outlet section equal to 1300 K, which can be compared with the experimental one, that is equal to 1,270±15 K (Cordiner et al., 2016).

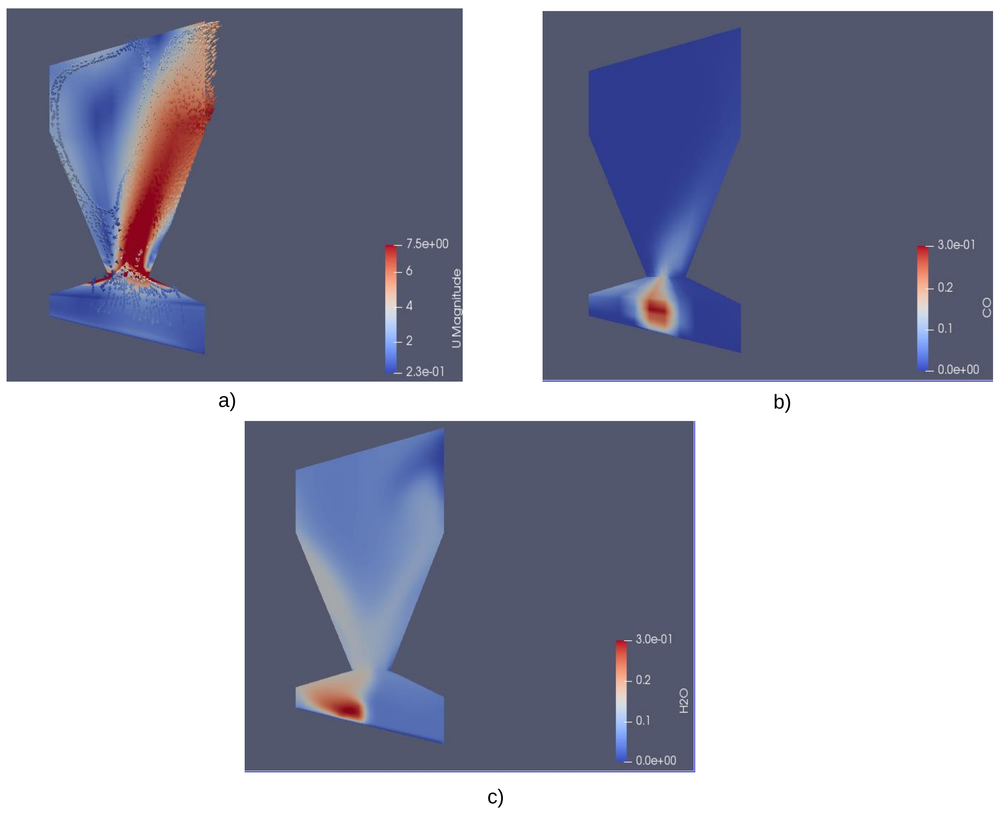

Figure 1. Simulation results. a) Velocity magnitude field [m/s]. b) CO mass fraction. c) H2O mass fraction.

CONCLUSIONS

A 2D model for biomass furnace is reported in this paper, the model represents the evolution during thermal decomposition in the combustion chamber with a relatively low computational cost. The model is capable of predicting the CO and H2O concentration and velocity, and temperature, profiles evolution over the freeboard. The results present an overall satisfactory behavior showing good agreement with literature data.

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