NUMERICAL SIMULATION OF THE IMPACT OF THE FEEDING PROCESS IN THE COMBUSTION OF BIOMASS BOILERS

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Abstract

This work presents a transient model for the simulation of biomass combustion in a fixed bed boiler fed through particle drop. The method combines the classical CFD techniques to simulate the gas phase with a set of Eulerian variables defined to model the solid phase and Lagrangian trajectories which model the particle drop. Several submodels are implemented to simulate the numerous processes that occur during the combustion of the solid phase. These submodels include the thermal conversion of biomass, heat and mass transfer, particle shrinkage and bed compaction as well as the interaction of the DPM (Discrete Phase Model) trajectories and the bed variables. The predictions are contrasted with experimental tests with reasonably good results that show an overall good behavior of the models. The simulation helps to understand the heat transfer inside the boiler and the instability of the emissions measurements. Once the model has been validated, it has been embedded into ANSYS-Fluent by means of a Graphical User Interface so that other researchers can employ this model to study other systems or to test other submodels.

Keywords: Biomass; CFD simulation; combustion; boiler

1. INTRODUCTION

The study of biomass combustion is currently receiving increased interest due to the effects of greenhouse gas emissions and the lack of fossil fuel resources in certain countries. Understanding biomass behaviour in the combustion process is a key factor in designing and improving combustion systems such as boilers, burners and furnaces. CFD techniques have become efficient tools in the search for a better understanding of biomass thermal conversion phenomena. However, CFD commercial codes still require extensive development regarding the combustion and/or gasification of solid fuels, particularly those that involve the thermal conversion of solid biomass.

Most published CFD models of biomass combustion systems are based on compact domains where the combustion of the packed bed occurs through either a zero- or one-dimensional approach [5-11]. Yang et al. [6] employed a higher level of discretisation that modelled a two-dimensional packed bed of thermally thick particles. Most of these works focused on species prediction with temperatures in a steady state; however, a few cases solved the transient evolution of the combustion system. Collazo et al. [7] simulated a three-dimensional burner in which the biomass particles were considered to be in a continuously solid phase. The same Eulerian solid-phase approach was used by Gómez et al. [8] to simulate an experimental burner by developing a specific set of equations to engage the bed in a CFD Discrete Ordinates Model (DOM) to study the radiative exchange among particles, gases and surroundings.

Several authors [1–3, 9] used the top of the bed as a gas inlet to the furnace where the by-products of the solid fuel combustion were introduced. These products introduce the mass, energy and species that were previously calculated by the bed's submodels. This methodology is commonly employed to couple a 0-D or 1-D model to a CFD gaseous domain; for instance, Eskilsson et al. [10] used experimental measurements to select the composition and properties of the gas leaving the bed. However, several authors simulated the packed bed region as a porous zone and introduced the combustion products as volumetric sources [4, 11]. A further advancement introduced these mass, energy and species sources through user-defined functions (UDFs) that allowed them to be dependent on the embedded models, thereby accounting for local conditions when calculating the behaviour of each specific point of the packed bed.

The work applies a transient three-dimensional model to the simulation of an actual biomass domestic boiler with different feeding methods. The solid phase is modelled using Eulerian variables that are defined and calculated through transport equations that model the thermal conversion of the solid particles. A feeding model was introduced in this work and coupled with the bed consumption and

adapted to the boiler geometry. This method uses Lagrangian trajectories to account for the particles drop and transform the trajectories in Eulerian variables when the particles reach the bed. Experimental tests are used to contrast the response of the boiler to different fuel feeding conditions.

Once the model has been validated, it has been embedded into ANSYS-Fluent by means of a Graphical User Interface so that other researchers can employ this model to study other systems or to test other submodels. The model will be soon available at the URL gte.uvigo.es as a beta release for further testing.

THE EXPERIMENTAL BOILER

The experimental boiler simulated is a commercial 27 kW pellet boiler. The fuel bed of this boiler is located in a metallic box with several holes at its floor and at the lateral walls to allow the air to cross the bed. The fuel is dropped on the bed from a fuel store through a feeding channel. The air inlet is a tube that drives the air to a semi closed space placed under the bed which makes the air to enter in the bed distributed among the numerous holes in the floor of the bed box. The flame is expected to be located over the bed box and the hot gases released from the fuel exchange heat with the tubes and the boiler walls which are cooled by water. Those exhausted gases are driven out from the boiler through an escape tube which is also cooled by water. In front of the flame region there is a frontal door that allows the visibility of the flame and part of the bed. This door has an important effect to the boiler behavior since it is the main inlet of air infiltrations.

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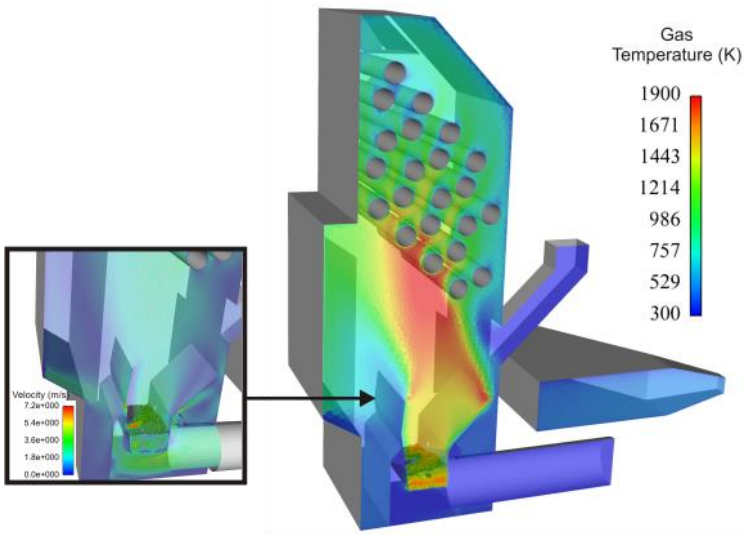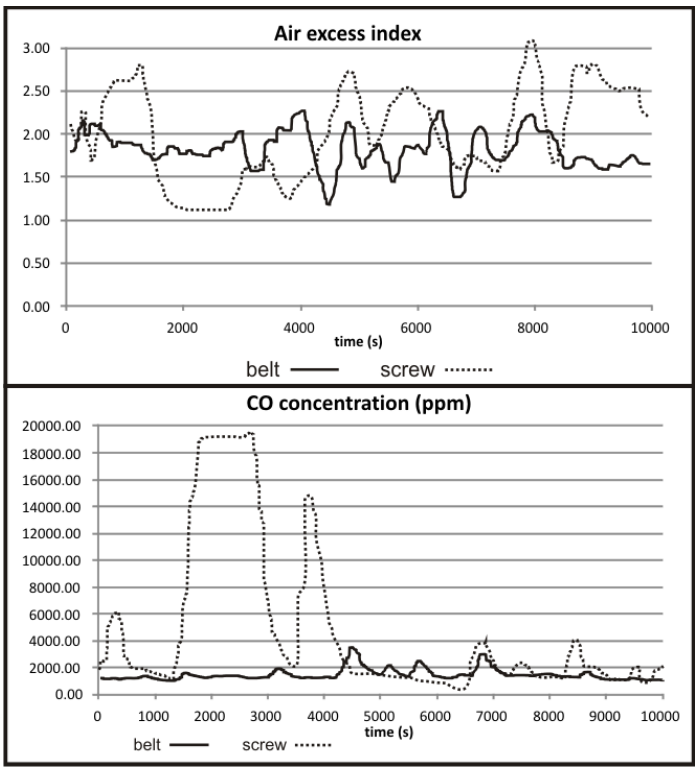
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