Numerical modeling of multi-component viscous fuels combustion

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Introduction

The worldwide concern regarding global warming has increased the interest of using biomass as a renewable and CO_2 neutral source of energy. Pyrolysis oil (PO), as one of the most important product of biomass conversion, has the potential to be used as a fuel oil substitute in many applications for heat and electricity generation. However, pyrolysis oil properties and its behavior during combustion are considerably different from conventional fossil fuels. From a chemical point of view, PO contains large number of oxygenated compounds derived from the decomposition of biomass during thermal treatment. It has also considerable amount of water originated from both moisture content and the decomposition reactions. Water is homogeneously dissolved in the oil and cannot be eliminated with drying processes without losing volatile hydrocarbon compounds [1]. From the physical point of view, bio-oils are characterized by high viscosity and surface tension, low heating value and, due to multicomponent composition, a very wide boiling range [2]. Moreover, they are thermally unstable and when heated, undergo polymerization processes, leading to the formation of carbonaceous solid material (char) in the fuel supply line, at the nozzle tip and in the combustion chamber [1]. Van Rossum et al. [3] found that pyrolysis oil evaporation is always coupled with the formation of char.
Literature survey indicates that combustion behavior of pyrolysis oil is still unknown process. More investigations is required to understand PO spray formation, evaporation and combustion. Especially, the impact of char formation on the combustion characteristics, which has been not yet explored, needs detailed assessment. Knowledge and data about the specifics of the processes and phenomena which interact during combustion of PO will support efficiency increase and design of new generation of burners operating on this bio-fuel.
The objective of this work is to investigate pyrolysis oil combustion, taking into account mutual interactions between gaseous, liquid and solid fields. A numerical model that takes into account liquid fuel evaporation and gaseous and char combustion has been developed in OpenFOAM. The char is considered to be present in the fuel droplets and its oxidation is modeled after complete evaporation of liquid.

Modeling

A new numerical model for combustion of multicomponent and multiphase fuels has been implemented into the open source CFD package OpenFOAM with the Eulerian-Lagrangian formulation, where the gas phase is a continuous phase but each particle/droplet is tracked with a Lagrangian approach. A two way data exchange is applied between particles and gas phase which makes a strong coupling between Eulerian and Lagrangian domain. Each particle consist of two phases (liquid and solid), while it interacts with surrounding gas phase by heat, mass and momentum transfer. Due to small particle/droplet size and low Biot number, the intra-particle gradient of temperature and species is neglected. The coupling model describes the interaction between particles and environment through heat and mass transfer. Energy and mass are transferred from gas to particles and/or particles to gas phase as heat and mass source, respectively. A uniform droplet size of 50μm was applied.
Van Rossum et al. [3] observed that some amount of solid char is always produced during the evaporation of pyrolysis oil (8% - 30% on carbon basis). The amount of char formation is dependent on heating rate, where higher heating rates produce less char. However, the process of char formation inside the droplet is not well known. In this study, since the droplet size is relatively small, it has been assumed that there is constant amount of char in the particles, i.e. 10 wt.%. Phenol and water (25 wt.%, on liquid weight basis) are used as representative for pyrolysis oil.

Results

Figure 1 presents the species and temperature distribution in the burner as a result of spray combustion of pyrolysis oil. As can be seen in Fig. 1a and 1b, phenol and water in the particles evaporate and go to the gas phase, while char remains in the particle. The remaining char undergoes heterogeneous reaction with oxygen. High temperature and enhanced CO_2 concentration downstream in the domain indicate char combustion. Phenol in the gas phase reacts with O_2 and produces H_2O and CO_2. It is consumed totally before the char combustion is accomplished.

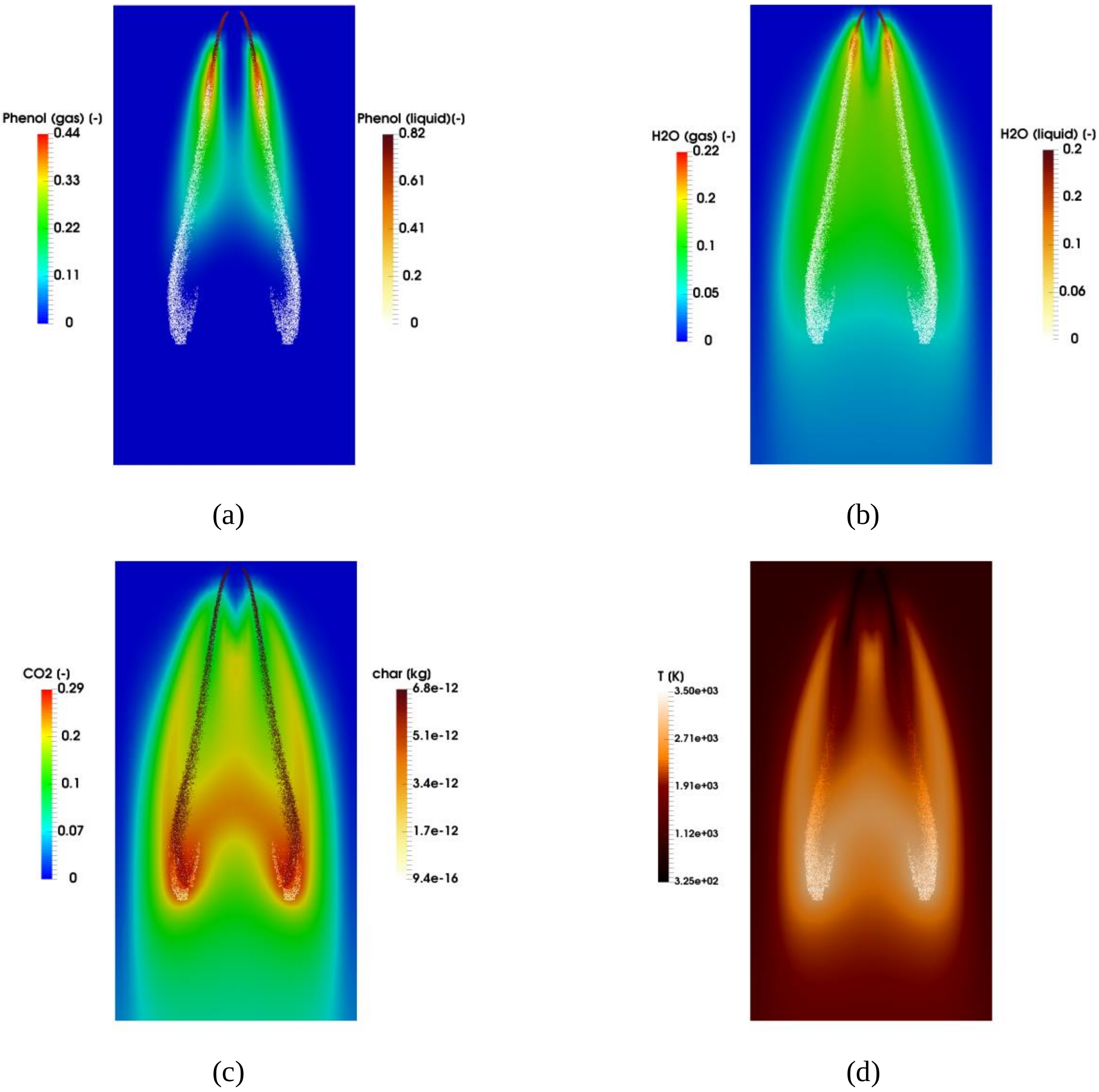

Figure1: Species and temperature distribution in spray combustion of phenol/water

Conclusions

The research presents combustion of renewable multicomponent fuel. As a representative for pyrolysis oil droplets, a phenol/water blend containing 10 wt% of solid char was used. Further char formation inside the droplets, due to heat flux from the hot combustion environment was neglected. An Eulerian-Lagrangian transient simulation was performed in OpenFOAM code to study the effect of multicomponent fuel combustion on flame behavior. It was observed that presence of char in the fuel influences combustion process significantly. Char combustion downstream of the primary combustion region may result in combustion chamber fouling, walls overheating and combustion device life time reduction.

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