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Numerical Simulation of the combustion on fixed bed of Volatile Organic Compounds Produced by Thermal Degradation of Biofuel Pellets Prepared from Olive Mill Solid Wastes

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***Abstract*— The main object in this paper is to study the combustion modeling of solid biofuels under fixed bed conditions. Samples on which the simulation will be realized are lignocellulosics biomasses which can really prepared from oleic industry by-products (olive stone) blended with pine sawdust under optimal mixtures as pellets or logs when experimental test will be conducted later. The simulation is investigated using the OpenFOAM CFD in a small –scale grate fired furnace. First of all we focused on the sub-models for the homogeneous gas phase reactions. After validation of our code based on literature by considering the same reactor geometry and the same experimental conditions, we attempt to replace the biofuels by our specific biofuels. The chemical combustion model is PaSR, and the turbulence model is the standard model which is widely used worldwide either in laboratory or in industry.**

***Keywords*— mathematical modeling, compressible gaz phase, turbulent flows, combustion process, reactor bed combustion, OpenFOAM.**

I. Introduction

Increased demands for energy sustainability in face of decreasing of biofuels production and concerns over global warming have led to a growing interest in sustainable and renewable sources of energy.

As a sustainable and renewable source of energy, biomass has a great potential in generating heat and power. It offers important advantages as a solid biofuel due to the high volatility and the high reactivity. It has also low density and low heating value (LHV), because of the higher oxygen and moisture content. Biomasses are primarily composed of C, H, and O elements, with a smaller amount of N, S, Cl, and metal and metal oxides. Several correlations between the heating value and ultimate or elemental analysis are proposed in the literature [1]. While in industry domain, the role of biomass still limited until now in heating development. Other wise, biomass schow soundly positive environmental properties resulting in net zero releases of carbon dioxides and very low sulphur content. Biomass resulting especially from agriculture residual, we are interrested in solid olive waste (SOW) in the world wide, 34 country such as Spain, Tunis, Algeria, Marock, and Italy ground more than twelve Million hectars olive, and produce more than 1.7 million Tonne of olive oil in 2016/2017 years. In practice, olives residues are underused for heating which contributes into the primary heat demand. For theses reasons, SOW can be integreted in reneweble enery domain, especially for its very-high heating capacity value.

Thermo-chemical technologies such as pyrolysis, gasification and combustion, are used for converting ligno-cellulosic biomass into heat or energy. Examples of such processes are production of biogas, in which degradation of logs or pellet biomass forms methane rich gases.

During the thermochemical conversion of a biomass particle, the dried portion of the particle, typically initiating from the surface, starts a thermal decomposition process known as devolatilization. If this process takes place in the absence of oxygen, it is referred to as pyrolysis. The pyrolysis products are lumped in three groups: gas, tar (volatile) and char [2], increasing the temperature is in favor of gas production.

Combustion process is the most advanced and mature technology of biomass thermal conversion, due to its ability to produce high quantities of carbonaceous aerosol (volatiles gas). It is, however a complex process involving heat and mass transfers, fluid dynamics, homogeneous as well as heterogeneous reactions.

Furnances as a heat producing system consist of gasification chamber and combustion chamber, various types of combustion methods exist, Within a fluidised bed furnance [3], a mixture of biomass fuel is fluidized in oxygen or air. The fixed bed furnance consist of two separate sub-domains in series in direction fluid flow; the decomposition process of

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solid fuel in the grate and the volatiles combustion in reactor region above the bed (free-board) [4]. Combustion process happen where the primary combustion air is fed below the grate, the volatiles components burn when secondary air is supplied, taking place in the reactors part (free board). Therefore, a detailed simulation of the complex thermo-physical phenomena happening inside the combustion reactors is needed to improve the understanding of the underlying physics of conversion of biomass to thermal energy in order to provide suggestions and solutions to improve the energy production system. CFD simulation of turbulent biomass gas-phase combustion employ turbulence-chemistry interaction, which reffer to calculate turbulent field characteristics and combustibles species properties, based on chemistry scheme relatif for species gas combustion process. Consequently, temperature prediction depend on turbulence approach, combustion model, as well as kinetic reactions mechanisms. The present model aims at characterizing compositions and quantities of the volatile gases leaving the surface of isothermal fuel in particular small- scale reactor which combine three differents inlet, one for fuel inlet, the other for air inlet in ambient temperature conditions.

II. Motivation of the Study

During the last decade the gaseous combustion in the free-room above the grate in a reciprocating grate furnace has been modelled with different CFD (computational fluid dynamics) tools, where the combustible gas leaving the bed is distributed along the grate based on the assumed combustion behaviour of the fuel bed. The main task of the work is to investigate combustion properties of volatiles components coming from olive stone.

The complexity of turbulent fuel flow in reactor geometry as in three-dimensional computational domain with fuel inlet supplied by two other different air inlets, need to use high mesh resolution required at regions with high temperature and species gradients. While, the computational cost escalated especially in finite Volume Discrete Ordinate Method (fvDOM) are implemented.

III. Methdology

The numerical modelling of the combustion was done using the same techniques and methodologies as during the validation process of the combustion model. For modelling turbulence, the gas phase combustion process in the free board is modelled using Favre averaged Navier-Stokes equations and these equations were approximated with Low-Reynold number $k-\varepsilon$ model for more accurate results [5] , where the gas is assumed to obey the incompressible ideal gas law, together with transport equations for enthalpy and mass fractions of different species.

The study of turbulence-combustion interaction was achieved through Partially Stirred Reactor (PaSR) model in OpenFOAM. Turbulence is transient for reactive fluid flow, while to attain quasi-steady state results to accompany with the steady state fixed-bed model neither DNS nor LES models suitable. Therefore, RANS approach represent a simplified model, available as an application solver in OpenFOAM called reactingFoam.

Volatile combustion reactions were modelled using global mechanisms with two steps for oxidation of fuel, developed by Jones-Lindstedt (JL); JL mechanism [6]. In adition, near-wall modelling approach is used as boundary conditions to investigate fuel combustion without heating lost. The validity is assessed in first case through comparisons with experimental data of turbulent flames.

A. Boundary Conditions

Temperature of the bed and composition of the gas leaving the fuel are used as boundary conditions. Therfore to ensure combustion in gas phase equivalent temperature above the grate is assumed first. The mass flow rate of gas fuel and air provided on the basis of the suggested values and experimental measurements reported in [7].

The thermo-chemical degradation of biomass allows the production of volatiles gas or “biogas”, consisting mainly of carbon monoxide (CO), hydrogen (H2), carbon dioxide (CO2), water vapor (H2O), methane (CH4), nitrogen (N2), some hydrocarbons in very low quantity and contaminants, such as carbon particles, tar and ash [8,9]. The specific compositions depends upon the fuel source and processing technique. These substantial variations in composition and heating value are among the largest barriers toward their usage.

In the study we compare two different biomass ; char composed especially from CH4, CO2, CO, H2O, N2, O2, C6H6. And solid olive waste with main volatiles; CH4, CO2, H2, CO, O2, N2 [10]. Table1 schow the different gas composition for the different biomass, with the same inlet boundary conditions.

TABLE1 COMPOSTION OF VOLATILE GAS

Mass Fraction									
		C6H6	**CH4**	**H2O**	**CO2**	**CO**	**H2**	**O2**	**N2**
char	Primary	0.1305	0.0297	0.109	0.264	0.015	-	0.0194	0.4324
	Secondary	-	-	-	-	-	-	0.233	0.767
	Tertiary	-	-	-	-	-	-	0.233	0.767
Solid olive waste	Primary	-	0.205	0.0	0.141	0.3148	0.2947	0.008	0.0365
	Secondary	-	-	-	-	-	-	0.233	0.767
	Tertiary	-	-	-	-	-	-	0.233	0.767

B. Generation and meshing the free board geometry

The numerical study was carried in a mall scale reactor system (free-board) operating in a nominal capacity of 8-11 kW, that has been custom-designed for the systematic investigation of fuel combustion. The reactor is a cylindrical combustor with a diameter of 0.2 m and 0.8 m of length. In bottom part placed cirular surface with 0.132 m in diameter act as a grate, in which placed 16 hole of 0.3 m of diameter, the fuel mass flow rate injected into the bed is 0.52e-3kg/s, which represent 3.125% of opening area for half of the geometry. Secondary and tertiary air are supplied in freeboard region, respectively with 0.59e-3kg/s and 0.945e-3kg/s mass flow rate. The hole present symmetrical distribution around the center line reactor. Meshing the full reactor is time consuming due to the complexity of the geometry, for symmetric conditions, simulation have been taken in the half of the gemetry. All airflow inlets are supplied at standard ambient conditions (i.e., 300,15 K and 100 kPa).. The effluent gas coming out of the bed and the wall temperatures were measured to be 1373.15 and 873.15 K, respectively. The full reactor geometry is illustrate in Figure 1, prepared using «Salome» software, then converted into OpenFOAM, Further detail of the geometry can be found in reference [7].

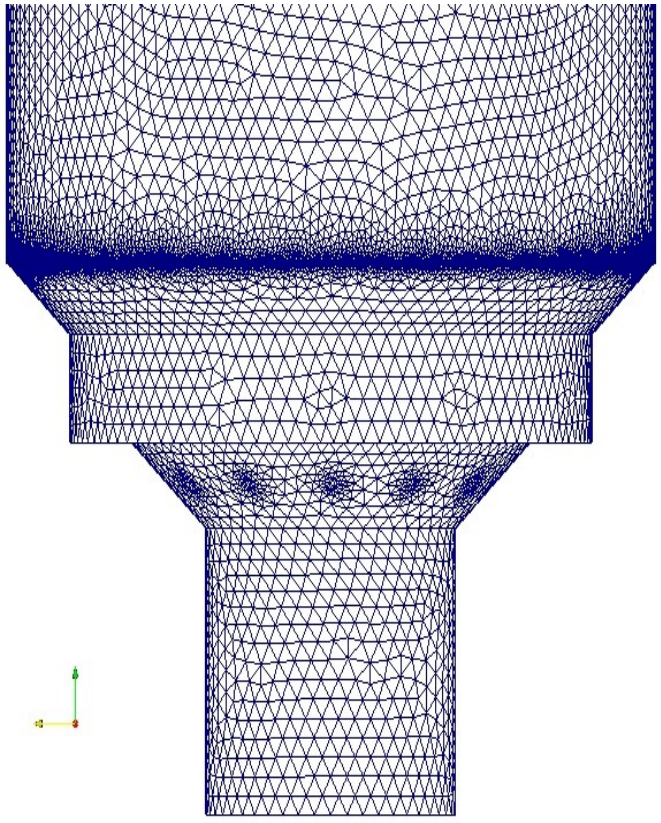

Fig. 1 Meshed gasifier geometry and customized mesh at air inlets

IV. Results and Analysis of Biomass Combustion Simulation in Free Board:

In this study some literature data on the pyrolysis characteristics of olive stone are used for combustion simulation under oxygen atmosphere in small reactor-scale were structured and analyzed, constituting a guide to the conversion behavior of volatiles gas within the temperature range of 300–2300° K.
Figure 2 The results reported hear are a comparaison of temperature prediction according to char and Olive Stone (sow) biofuels , species is presented in this section.

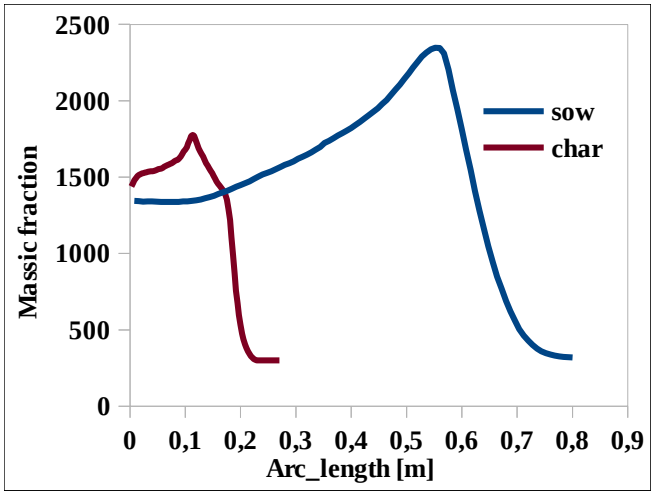

Fig. 2 Temperature profiles along the centerline of the furnace

Figure 3 and Figure 4 is qualitatif validation and verification of reactif fluid flow of char in ref [11], compared to the experiments based on the boundary condition listed below.
A high temperature zone with a peak flame temperature about 1775 °K is simulated, a result of the fast mixing rate of the combustible volatile and the air. With such turbulence inflow, the temperature profile, the CO, CO 2 , and O 2 profiles are in fairly good agreement with the experimental data.
Figure 5-6 present species profiles evolution in SOW at the reaction zone. Then, the numerical simulation of gas coming from solid olive stone schow a maximum temperature of 2347 °K, which provide an expecting high heating value of solid olive waste.

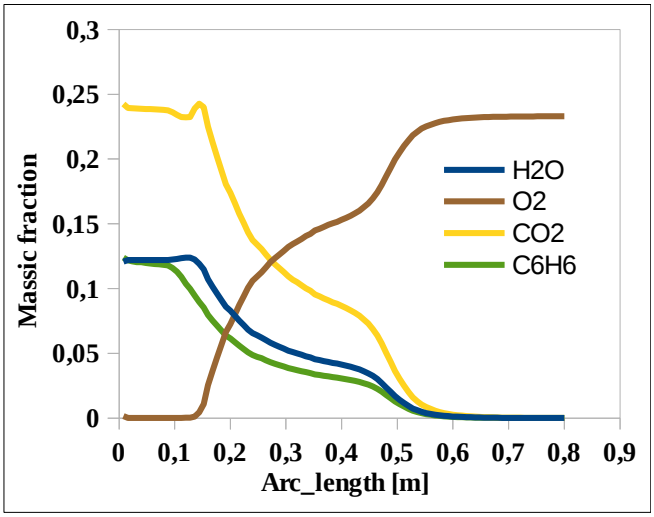

Fig. 3 Profiles of C6H6, CO2, O2 and H2O massic fractions along the centerline of the furnace

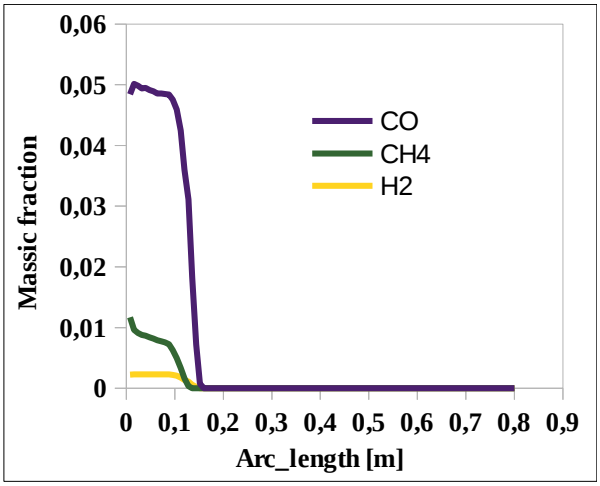

Fig. 4 Profiles of H2, CH4 and CO massic fractions along the centerline of the furnace

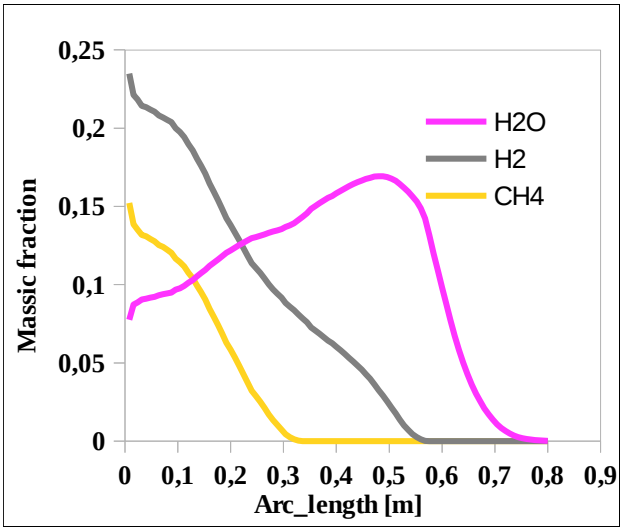

Fig. 5 Profiles of CH4, H2O and H2 massic fractions along the centerline of the furnace

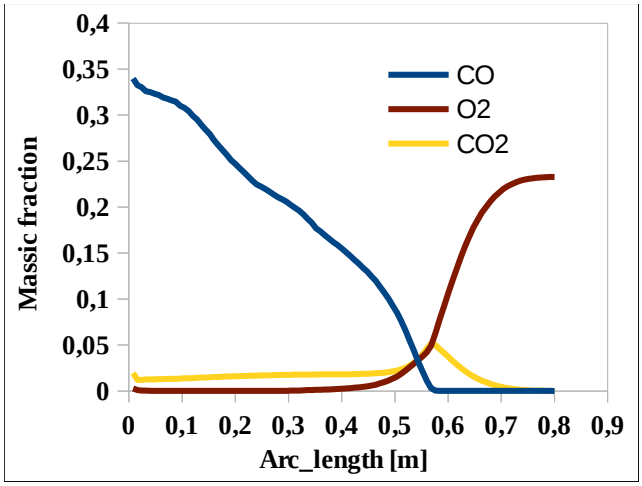

Fig. 6 Profiles of CO2, CO and O2 massic fractions along the centerline of the furnace

V. Conclusions

A 3D CFD model was used to describe the combustion of olive stone in a fixed bed furnance using OpenFOAM. Turbulence is taken into account by the two-equation k-epsilon closure. The chemical reactions are modelled using global mechanisms with two steps for oxidation of fuel, developed by Jones-Lindstedt (JL).

Reproducing the experimental results using OpenFOAM as a first step show qualitative agreement between the numerical simulation and the experimental results. The numerical simulation proved the capability of CFD model to predict reactive fuel flow in a complex geometry. The concentrationof chemical species and temperature distribution in the free-board was analysed and the effect of combustion reaction showed temperature increase up to 2347 °K at the

combustion zone, proving the high heating value of volatile gas of SOW in fixed bed furnance.

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