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SIMULATION OF BIOMASS COMBUSTION IN CFBS

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ABSTRACT
In this study, a 2D model for a CFB biomass combustor has been developed which integrates and simultaneously predicts the hydrodynamics, heat transfer and combustion aspects. Combustor hydrodynamic is modeled taking into account previous work. Simulation model calculates the axial and radial distribution of voidage, velocity, particle size distribution, pressure drop, gas emissions and temperature at each time interval for gas and solid phase both for bottom and upper zones. The model results are compared with and validated against experimental data both for small-size and industrial-size biomass combustors which uses different types of biomass fuels given in the literature. As a result of sensitivity analysis, it is observed that: major portion of the combustion will take place in the upper zone, the air staging could improve combustion, for industrial-size CFB biomass combustors and the decrease of NO_x *adversely results in high CO emissions as air ratio decreases.*
Keywords: combustion, biomass, CFB, modeling, pollutant emissions

1. INTRODUCTION
Mathematical modeling of CFB biomass combustion could improve both their design and operation, reduce any associated problems and facilitate the implantation of this technology. A good understanding of the combustion and pollutant generating processes in the combustor can greatly avoid costly upsets. Presently, there is a focus on developing models of CFB for burning biomass and waste material. The objectives of these models are to be able to predict the behavior with respect to the combustion efficiency, fouling problems and pollutant emissions performance of different fuels or mixtures in commercial scale fluidized bed combustors. Several review articles summarized the latest development in biomass combustion [5-7].

Although several different types of models [5-7] have been developed for CFB biomass combustion systems, modeling CFB biomass combustion is still at developing stage. From this point of view, in this study, a comprehensive 2D model capable of describing the CFB biomass combustion phenomenon has been developed which integrates and simultaneously predicts the hydrodynamics, heat transfer and combustion aspects. Combustor hydrodynamic is modeled taking into account previous work [8]. Simulation model calculates the axial and radial distribution of voidage, velocity, particle size distribution, pressure drop, gas emissions and temperature at each time interval for gas and solid phase both for bottom and upper zones. The model results are compared with and validated against experimental data given in the literature [9, 10]. Ranges of experimental data used in comparisons are as follows: bed diameter from 0.1-1.6 m, bed height from 13.5-15.5 m, and mean particle diameter from 2-4 mm. In the experiments, three different types of biomass fuels are used (peat, wood and wood chips). A sensitivity analysis is carried out using the model to examine the effect of different operational parameters such as air ratio (AR) on the overall CO and NO_x emissions from the biomass combustor.

2. MODEL DESCRIPTION

2.1. Hydrodynamic model

The model addressed in this paper uses particle based approach which considers two-dimensional motion of single particles through fluids. According to the axial solid volume concentration profile, the riser is axially divided into the bottom zone and the upper zone. In the present model, bottom zone in turbulent fluidization regime is modeled as two-phase flow which is subdivided into a solid-free bubble phase and a solid-laden emulsion phase. A single-phase back-flow cell model is used to represent the solid mixing in the bottom zone. A two phase model is used for gas phase material balance. In the upper zone core-annulus solids flow structure is established. Particles move upward in the core and downward in the annulus. Hydrodynamic model takes into account the axial and radial distribution of voidage and velocity, for gas and solid phase, pressure drop for gas phase and solids volume fraction and particle size distribution for solid phase. Further details on the hydrodynamic model are given elsewhere [8].

2.2. Kinetic Model

Kinetic information for the reactions is supplied by the reaction kinetic sub-model, which contains description of devolatilization and char combustion, and emission formation and destruction respectively.

Biomass generally has a lower heating value than coal and this is due to its higher moisture and volatile matter (VM) content. High moisture content of biomass is one of the predominant factors in affecting the energy output and combustion performance. The energy from the VM is higher for biomass fuel when compared to those from coal [1]. In the model, volatiles are entering the combustor with the fed biomass particles. It is assumed that the volatiles are released along the riser at a rate proportional to the solid mixing rate. The degree of devolatilization and its rate increase with increasing temperature. The following correlations are used in the model [11]:

$$[CO] = 120.72 - 0.1183T + \left(5.0\times10^{-5}\right)T^2 \quad (1)$$

$$[CO_2] = 140.51 - 0.1991T + \left(7.0\times10^{-5}\right)T^2 \quad (2)$$

$$[H_2] = -74.44 + 0.1467T - \left(5.0\times10^{-5}\right)T^2 \quad (3)$$

$$[CH_4] = -49.345 + 0.1026T - \left(4.0\times10^{-5}\right)T^2 \quad (4)$$

$$[C_mH_n] = -37.401 + 0.068T - \left(3.0\times10^{-5}\right)T^2 \quad (5)$$

where [CO], [CO_2], [H_2], [CH_4] and [C_mH_n] are the volume percentages of CO, CO_2, H_2, CH_4 and C_mH_n in the volatiles, respectively; T is the bed temperature in K. C_mH_n is considered as C_2H_6 in the model.

Twenty-five global homogeneous and heterogeneous reactions which are given in literature [12], are included in the reaction network for the modeling of NO emissions from biomass-fired CFBs. Due to lack of systematic studies of biomass-related reactions, several reaction rates in the model are based on coal combustion results. However, if possible, they have been replaced or corrected according to the limited available literature data obtained from biomass-related reactions. In the model, global reaction scheme for HCN (and CNO) is selected from Desroches-Ducarne et al. [13]. Reaction between NO_x and char is the most important reaction which influences NO_x emissions. The scheme for the oxidation of char-N to NO and N_2O is based on Goel et al. [14]. The details of kinetic model are given in the literature [12].

3. RESULTS AND DISCUSSION

The validity of developed model is proved via comparing the simulation results with three different sizes biomass fuel-fired CFB combustors published in the literature [9, 10]. In these comparisons, the same input variables are used in the tests as the simulation program input. The effects of operational parameters on CO and NO_x emissions such as air ratio are also investigated by developed model and are also validated with published experimental data in the literature [10]. The measurement conditions of experimental data used for the comparison are shown in Table 1. The experiments are performed in an industrial-size combustor at Chalmers University of Technology (CTH) and in a bench-scale facility at the Technical University Hamburg-Harburg (TUHH). The proximate and ultimate analyses of these fuels are given in Table 2. Gas samples are collected from the centerline of the combustion chamber of CTH. Since the extension of the gas-sampling probe inside the combustion chamber of TUHH reaches over the whole diameter, the concentration values inside the TUHH riser are roughly cross-sectional averages, whereas in the CTH combustion chamber only local concentration measurements are made [9, 10].

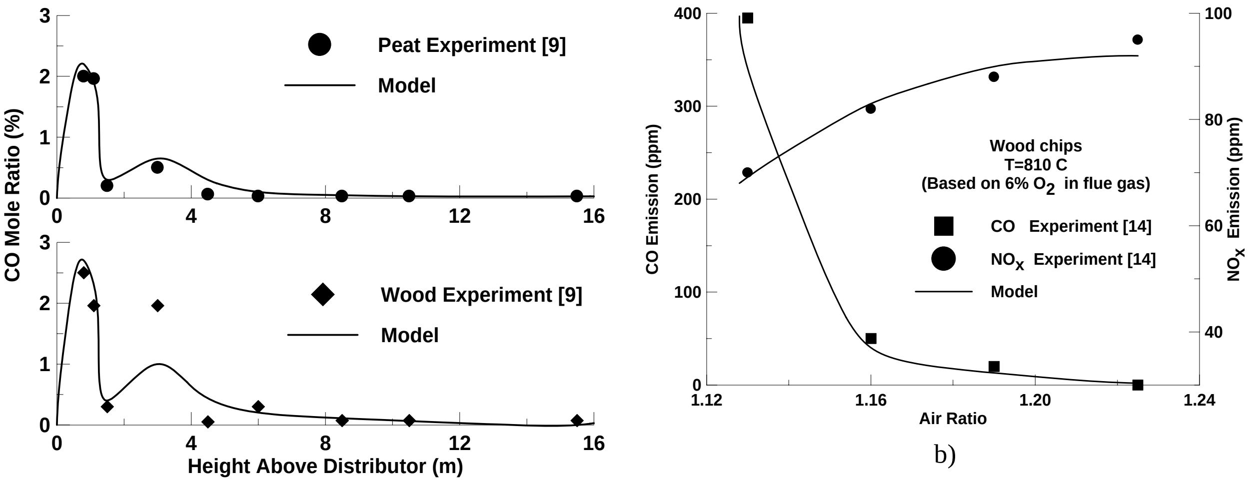

Figure 1. Comparison of a) axial CO concentration profiles with Knöbig et al. [9]'s data for the fuels of peat and wood; in the combustor of TUHH, b) axial CO and NO_x concentration profiles versus air ratio with Lyngfelt and Leckner [10]'s data for the fuels of wood chips in the combustor of CTH.

Fig.1a shows the predicted profile of CO concentration and measured profile of CO concentration by Knöbig et al. [9]'s experiments carried out both for small-size combustor along the riser. The lowest O_2 concentrations are found in both combustors below the secondary-air injection during the combustion [12]. This is caused by the reducing conditions in the bottom zone yielding high values of CO concentration (Fig.1a). Additionally, because of hydrodynamic behavior of CFB combustor, turbulent fluidization in the bottom zone does not allow all carbon monoxide to be reduced to CO_2 and causes high values of CO concentration. The small-size combustor has their maximum CO values for the two fuels in the bottom zone. CO concentrations rapidly reduce due to both dilution and oxidation. The comparison shows that the model correctly predicted the trends of the measured CO concentration profiles.

Table 1. Operating parameters of the experimental data referred to in this study.

Operating parameters	Knöbig et al. [9]		Lyngfelt and Leckner [10]
	TUHH (small-size)	CTH 12 MW	12 MW
Bed diameter (m)	0.1	1.6 m x 1.6 m	
Bed height (m)	15.5	13.5	
Bed temperature (°C)	850	850	
Superficial velocity (m/s)	7	6	
Biomass fuel	Peat/Wood	Peat/Wood	Wood chips
Particle size (mm)	2/4	2/4	4

Table 2. Proximate and ultimate analysis of biomass fuels.

	Peat	Wood	Wood chips
Proximate analysis			
Moisture (wt%)	37.0	10.1	40.8
Ash (wt%)	6.8	0.9	0.5
Vol. Mat. (wt%)	69.8	78.0	82.0
Fixed carbon (wt%)	30.2	22.0	22.0
Ultimate analysis			
Carbon (wt%, dry)	57.1	50.70	50.60
Hydrogen (wt%, dry)	6.3	5.90	6.30
Sulphur (wt%, dry)	0.8	0.04	0.04
Nitrogen (wt%, dry)	23.0	0.20	0.14
Oxygen (wt%, dry)	33.5	43.10	43.00

Fig.1b shows the effect of air ratio on the emissions of CO and NO_x for industrial-size combustor [10]. The emissions based on 6% O_2 in the flue gas are plotted with respect to air ratio (60% primary air and 40% secondary air introduced at a height of 2.2 m) for industrial-size CFB in Fig.1b. The CO emissions increase to very high levels at low air ratios. For industrial-size CFB biomass combustors, the decrease of NO_x adversely results in high CO emissions as air ratio decreases. As can be seen from the Fig.1b, the model predictions match the experimental data satisfactorily in the riser for industrial-size combustor.

4. CONCLUSION

In this study, a 2D model for a CFB biomass combustor has been developed which integrates and simultaneously predicts the hydrodynamics, heat transfer and combustion aspects. Simulation model calculates the axial and radial distribution of voidage, velocity, particle size distribution, pressure drop, gas emissions and temperature at each time interval for gas and solid phase both for bottom and upper zones. The model results are compared with and validated against experimental data both for small-size and industrial-size biomass combustors which uses different types of biomass fuels given in the literature [9, 10]. As a result of this analysis, it is observed that: for industrial-size CFB biomass combustors, the decrease of NO_x adversely results in high CO emissions as air ratio decreases.

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