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# A model of the dynamics of a fluidized bed combustor burning biomass

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**Abstract**

A dynamical model of an atmospheric, bubbling, fluidized bed combustor of biomass is presented. The model, based on one previously developed for the steady combustion of high-volatile solids, accounts for the fragmentation and attrition of fuel particles, the segregation and postcombustion of volatile matter above the bed, as well as thermal feedback from the splashing region to the bed. The model was used to assess how the dynamic behavior of the combustor varies with some of the operating parameters. To this end, a bifurcation analysis was first used to study the influence of selected parameters on the number and quality of steady state solutions. Moreover, direct integration of the governing equations provided a simulation of the dynamic behavior of the combustor after perturbing the parameters. Results of the bifurcation analysis indicated that extinction may take place through limit point bifurcations when varying the moisture content of the biomass and the flow rates of feed or air. Dynamic simulations showed that the bed temperature changes slowly when a stepwise change is imposed on one of the parameters. Either a new steady state or extinction eventually results, depending on the stepwise change. While relaxation of the bed temperature occurs rather slowly, the dynamics of the splashing region and of the freeboard are much faster, due to the shorter time-scales associated with homogeneous oxidation reactions. The relaxation time of the bed is determined by the heat capacity of the fluidized solids and by the fraction of the heat released recycling to the bed as thermal feedback.


*Keywords:* Model; Fluidized bed; Biomass

## 1. Introduction

Fluidized bed combustion (FBC) is a viable technology for a variety of solid fuels, including coal, low-grade or "difficult" fuels, waste-derived or biomass fuels, alone or in combination with each other. In particular, biomass fuels provide an increasingly

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**Nomenclature**

| | | |
|---|---|---|
| $A$ | Cross-sectional area of the bed | $m^2$ |
| $c_x$ | Specific heat of species $x$ | kJ/(kg K) |
| $C_x^y$ | Molar concentration of component $x$ in section $y$ | $kmol/m^3$ |
| $d_x$ | Average diameter of particles belonging to phase $x$ | m |
| $F_0$ | Fuel feed mass flow rate | kg/s |
| $F_{0x}$ | Fuel feed mass flow rate into phase $x$ | kg/s |
| $F_S$ | Mass flux of ejected inert particles at the bed surface | $kg/(s\,m^2)$ |
| $G$ | Fines generation rate due to coarse particles fragmentation | kg/s |
| $h_x$ | Height of section $x$ | m |
| $h_{c,x}$ | Particle heat transfer coefficient in section $x$ | $kW/(K\,m^2)$ |
| $h_{mf}$ | Height of the bed at minimum fluidization conditions | m |
| $H$ | Moisture content in fresh feed | |
| $\Delta H_x$ | Heat of combustion of species $x$ | kJ/kg or kJ/kmol |
| $k_{x,y}$ | Combustion kinetic coefficient of component $x$ in section $y$ | $s^{-1}$ |
| $k_{el}$ | Fines elutriation constant | $s^{-1}$ |
| $k_d$ | Devolatilization constant | $s^{-1}$ |
| $K_{be}$ | Mass transfer coefficient between dense phase and bubbles | $s^{-1}$ |
| $M_x$ | Molecular weight of component $x$ | kg/kmol |
| $Q_{air}$ | Air inlet flow rate | $N\,m^3/s$ |
| $t$ | time | s |
| $T_x$ | Temperature of phase $x$ | K |
| $u_T$ | Coefficient in Eq. (3) | |
| $U_x$ | Velocity of phase $x$ | m/s |
| $US$ | Heat transfer coefficient bed-walls | kW/K |
| $W_{x,y}$ | Mass of phase $x$ in zone $y$ | kg |
| $x_y$ | Mass fraction of component $y$ | |
| $z$ | Axial coordinate | m |

*Greek symbols*

| | | |
|---|---|---|
| $\varepsilon_{bub}$ | Bed volume fraction occupied by bubbles | |
| $\varepsilon_{eff}$ | Char particles effective emissivity | |
| $\varepsilon_{mf}$ | Bed voidage at minimum fluidization condition | |
| $\eta$ | Combustion efficiency | |
| $\lambda_{vap}$ | Water latent heat of vaporization | kJ/kg |
| $\rho_x$ | Density of phase $x$ | $kg/m^3$ |
| $\rho_{gas,y}$ | Gas density in section $y$ | $kg/m^3$ |
| $\sigma$ | Stefan Boltzman constant | $kW/(m^2\,K^4)$ |
| $\tau_S$ | Inert particles residence time in splashing region | s |
| $\phi_{xy}$ | global view factor related to region $x$ and $y$ | |
| $\chi$ | Total exposed surface area of ejected inert particles per unit bed cross-section | |
| $\Omega$ | Integral defined in Eq. (6) | $kmol/m^2$ |

*Subscripts and superscripts*

| | |
|---|---|
| C | Coarse char particles |
| F | Fine char particles |
| S | Inert particles |
| V | Volatile matter |
| bed | Bed |
| bub | Bubbles |
| dev | Devolatilization |
| fb | Freeboard |
| fc | Fixed carbon |
| gas | Gas phase |
| mf | Minimum fluidization |
| p | Inert particles |
| ref | Reference |
| sp | Splashing region |
| tot | Total |
| vap | Vaporization |
| water | Water |
| wall | Bed walls |
| 0 | Inlet |

attractive primary energy source, due to their intrinsically renewable nature and potentially limited generation of pollutants. Biomass usually contains negligible sulfur, low nitrogen and heavy metals, and is considered neutral with respect to greenhouse gases. FBC of biomass fuels has been extensively investigated recently [1–8]. As far as the fate of combustibles is concerned, it has been recognized that two important features characterize the combustion of a biomass fuel, making it different from the combustion of a coal or other low-volatile solid fuels:

1. Homogeneous combustion of volatile matter accounts for a large contribution to the overall heat release. This emphasizes the importance of mixing and segregation in the bed and of the actual location of where the volatile matter burns. In fact, the heat release profile in a combustor significantly affects its design and operation.
2. The loosely connected structures of the chars left after devolatilization makes their attrition important. This feature, together with the large intrinsic combustion reactivity of biomass chars,