Effects of Particle Shape and Size on Biomass Combustion

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Introduction

Biomass particles commonly have aspect ratios of 3 to 5 (sometimes up to 12) and irregular geometric forms. Such particles cannot be adequately described using spherical approximations for mass and heat transfer during pyrolysis and oxidation processes. Furthermore, many combustion processes are controlled by surface area effects. Spheres have the lowest surface-area-to-volume ratio of any geometric shape, making them particularly poor choices as approximations for fuels with widely varying shapes.

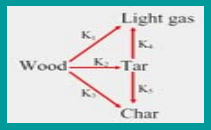
Objectives

The objectives of this project is to develop experimental and modeling description of non-spherical particle combustion and to apply it to descriptions of biomass-fired boilers. A biomass combustion database for particles of varying shapes and sizes will be established upon a high-tech entrained flow reactor; a comprehensive biomass particle combustion model will be developed, which can predict both the pyrolysis and oxidation behaviors of biomass particles of any shape and size.

Model Development

- **Kinetics Scheme:**

Two-step model



Chemical Percolation Devolatilization (CPD)

- Being capable of describing different genre biomass
- Focuses on bridges between rings and their length, energy and statistical breaking
- Includes rings' weights, chemistry, energy, and vapor pressure
- Function of biomass type, heating rate, temperature and pressure
- The model is under development; preliminary results obtained

- **1-D intra-particle transport equations during pyrolysis**

Species conversion in gas phase

$$\frac{\partial}{\partial t}\varepsilon\rho_g Y_i + \frac{1}{r^n}\frac{\partial}{\partial r}(r^n \varepsilon\rho_g Y_i U) = \frac{1}{r^n}\frac{\partial}{\partial r}(r^n \varepsilon D_i \rho_g \frac{\partial Y_i}{\partial r}) + S_i$$

i = tar, light gas, vapor, or inert gas;

S = source term from chemical reactions

Gas phase continuity equation

$$\frac{\partial}{\partial t}\varepsilon\rho_g + \frac{1}{r^n}\frac{\partial}{\partial r}(r^n \varepsilon\rho_g U) = S_g$$

$$S_g = S_1 + S_2 - S_5 + S_6 - S_7$$

Energy equation

$$\frac{\partial}{\partial t}\left[\left(\rho_B \hat{H}_B + \rho_C \hat{H}_C + \rho_M \hat{H}_M\right) + \varepsilon\rho_g\left(Y_G \hat{H}_G + Y_I \hat{H}_I + Y_T \hat{H}_T + Y_V \hat{H}_V\right)\right]$$
$$+ \frac{1}{r^n}\frac{\partial}{\partial r}\left[r^n \varepsilon\rho_g U\left(Y_G \hat{H}_G + Y_T \hat{H}_T + Y_I \hat{H}_I + Y_V \hat{H}_V\right)\right] = \frac{1}{r^n}\frac{\partial}{\partial r}(r^n k_{eff}\frac{\partial T}{\partial r})$$

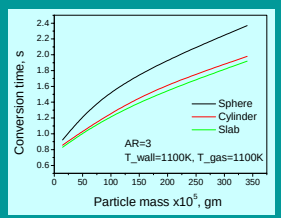
where $\hat{H} = \hat{H}^0_{i,f} + \int_{T^0}^{T} Cp_i\, dT$

Momentum equation

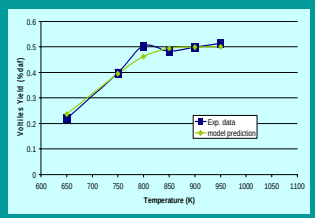
$$u = -\frac{K}{\mu}\frac{\partial P}{\partial r}; \quad P = \frac{\rho RT}{M_w}$$

Species conversion in solid phase

$$\frac{\partial \rho_B}{\partial t} = -(k_1 + k_2 + k_3)\rho_B;$$
$$\frac{\partial \rho_C}{\partial t} = k_3\rho_B + k_5\rho_T;$$
$$\frac{\partial \rho_M}{\partial t} = -k_6\rho_M + k_7\rho_V;$$



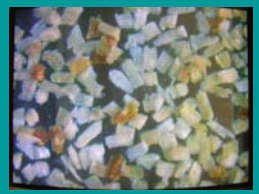
1-D model prediction of sawdust



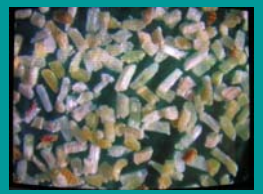
CPD model prediction of Black liquor

Experimental data collection

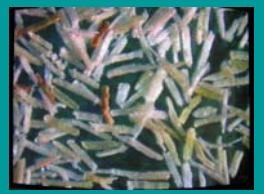
- **Samples:** Sawdust particles with different shapes and similar volumes were prepared.



flake-like: $V=1.69\times10^{-11}m^3$ $V=1.68\times10^{-11}m^3$ $S=4.91\times10^{-7}m^2$ AR=1.3 AR=6.1



prolate-like: $V=1.74\times10^{-11}m^3$ $S=3.44\times10^{-7}m^2$ AR=1.6

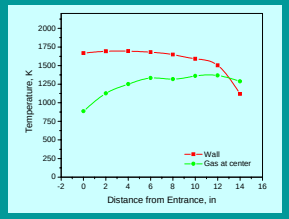


cylinder-like: $S=4.79\times10^{-7}m^2$

- **Equipment**

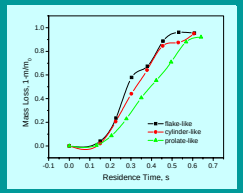
Pyrolysis experiments of the above sawdust particles were conducted on an entrained flow reactor, as is shown at the right.

- **Experimental data and model predictions**

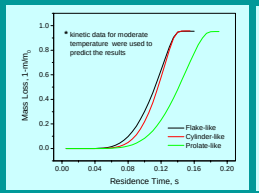


Reactor temperature profile

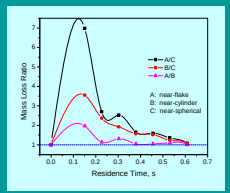
Entrained flow reactor



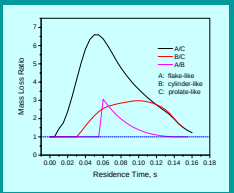
Mass loss data



Mass loss predictions



Mass loss ratio data



Mass loss ratio predictions

Conclusions

- A biomass pyrolysis model has been developed, which is capable of describing particles of varying shapes and sizes.
- The near-spherical particle losses mass more slowly than the other two shapes.
- Kinetic data at high temperature are needed for the two-step model.

Acknowledgement

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