Effects of Particle Shape and Size on Biomass & Black Liquor Reactivity

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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.

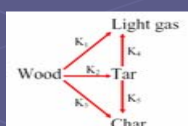
Objectives

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 devolatilization model



Bound water evaporation

$$moisture \overset{K_6}{\underset{K_7}{\Leftrightarrow}} vapor$$

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

Species conversion in gas phase

$$\frac{\partial}{\partial t}\varepsilon\rho_g Y_i + \frac{1}{r^n}\frac{\partial}{\partial r}(r^n \varepsilon\rho_g Y_i u) = \frac{1}{r^n}\frac{\partial}{\partial r}\left(r^n \varepsilon D_{eff,i}\rho_g \frac{\partial Y_i}{\partial r}\right) + S_i$$

where $i = T$ for tar, G for light gas, V for water vapor, and I for inert gas

Gas phase continuity equation

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

$$S_g = K_1\rho_B + K_2\rho_B - \varepsilon K_5\rho_T + K_6\rho_M - \varepsilon K_7\rho_g Y_V u$$

Energy equation

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

$$\hat{H}_i = \hat{H}^0_{i,f} + \int_{T_0}^{T} Cp_i dT$$

Momentum equation

$$u = -\frac{\eta}{\mu}\frac{\partial P}{\partial r} \qquad P = \frac{\rho_g R_g T}{M_W}$$

Species conversion in solid phase

$$\frac{\partial\rho_B}{\partial t} = -(K_1 + K_2 + K_3)\rho_B$$

$$\frac{\partial\rho_C}{\partial t} = K_3\rho_B + \varepsilon K_5\rho_T$$

$$\frac{\partial\rho_M}{\partial t} = -K_6\rho_M + \varepsilon K_7\rho_g Y_V u$$

- **Solution Procedure**

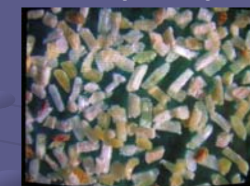
The mass conversion equations of biomass, char, and moister are solved using fourth-order Runge-Kutta method. Control volume (finite volume) method is applied to solve the gas species mass conservation equations and energy conservation equations. A power-law scheme and the SIMPLE algorithm are used to accelerate the convergence of the solution procedure.

Experimental Procedure

- **Samples:** Sawdust particles with different shapes and similar volumes, characterized using a 3D particle shape reconstruction code developed at the particle combustion lab at Brigham Young University.

flake-like: V=1.69x10^{-11}m^3

S=4.91x10^{-7}m^2 AR=1.3



prolate-like: V=1.74x10^{-11}m^3

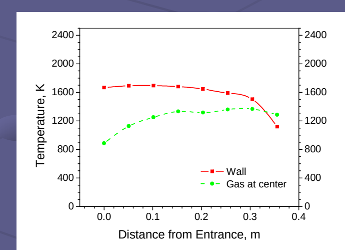
S=3.44x10^{-7}m^2 AR=1.6

cylinder-like: V=1.68x10^{-11}m^{-3}

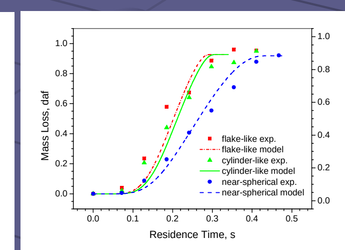
S=4.79x10^{-7}m^2 AR=6.1

- **Procedure:** Pyrolysis experiments of the above sawdust particles were conducted on an entrained flow reactor, particle mass loss data were collected as function of residence time.

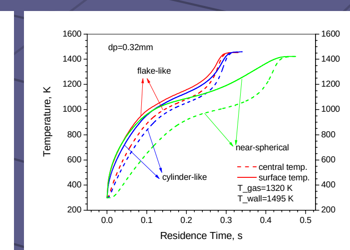
Results



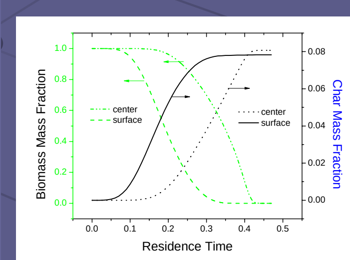
Reactor temperature



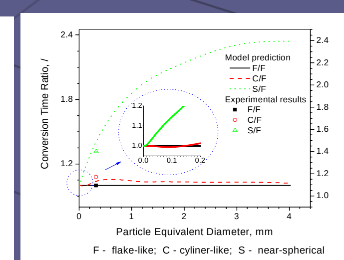
Mass loss history



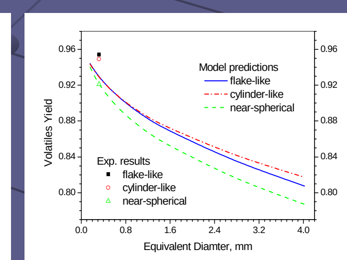
Particle temperature history



Composition



Conversion time



Volatile yields

Conclusions

•A biomass pyrolysis model has been developed, which is capable of describing particles of varying shapes and sizes.

•Both experimental and theoretical investigations indicate the impact particle shape and size have on overall particle reactivity. The near-spherical particle losses mass more slowly than the other two shapes.

Acknowledgement

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