Effects of Particle Shape and Size on Biomass Reactivity

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Outline

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- Objectives
- Model development
- Data collection
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- Future work
- Acknowledgement

Introduction

- Biomass particle shape and size
  - Irregular shapes (aspect ratios 2-15)
  - Poorly approximated by spheres
- Biomass particle surface area
  - Surface area/volume essential to heat, mass, and momentum transfer
  - Sphere is extreme case (lowest surface area to volume ratio of all shapes)

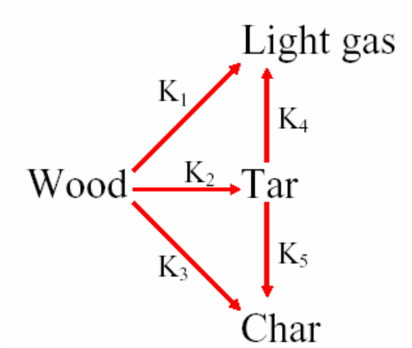
Objectives

- **Establish a biomass combustion database for particles with different shapes and sizes**
  - Collecting experimental data at different operating conditions (mass loss, particle surface temperature, particle volume, surface area, and shape as functions of residence time).
- **Develop a comprehensive biomass particle combustion model**
  - This model should be capable of simulating combustion behaviors of biomass particles with any shape and size.

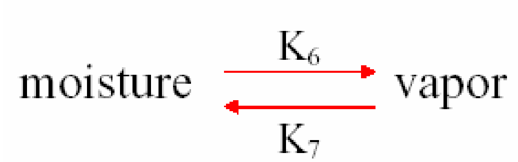
Model Development

- **Major assumptions**
  - Heat, mass, and momentum transfer exist in particle
  - Temperature gradients same for solid and gas phase;
  - Particle shrinkage neglected (for now).
- **Pyrolysis kinetic scheme**

    Two-step model



(Colomba 1996)



(Bryden 2003)

Model Development

- **Intra-particle transport equations**

continuity equation

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

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

species mass conversion

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

$i =$ tar, light gas, water vap, or inert gas

momentum equation

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

solid phase species conversion

$$\frac{\partial \rho_B}{\partial t} = -(k_1 + k_2 + k_3)\rho_B;$$

$$\frac{\partial \rho_C}{\partial t} = k_3\rho_B + k_5\rho_T;$$

$$\frac{\partial \rho_M}{\partial t} = -k_6\rho_M + k_7\rho_V;$$

energy equation

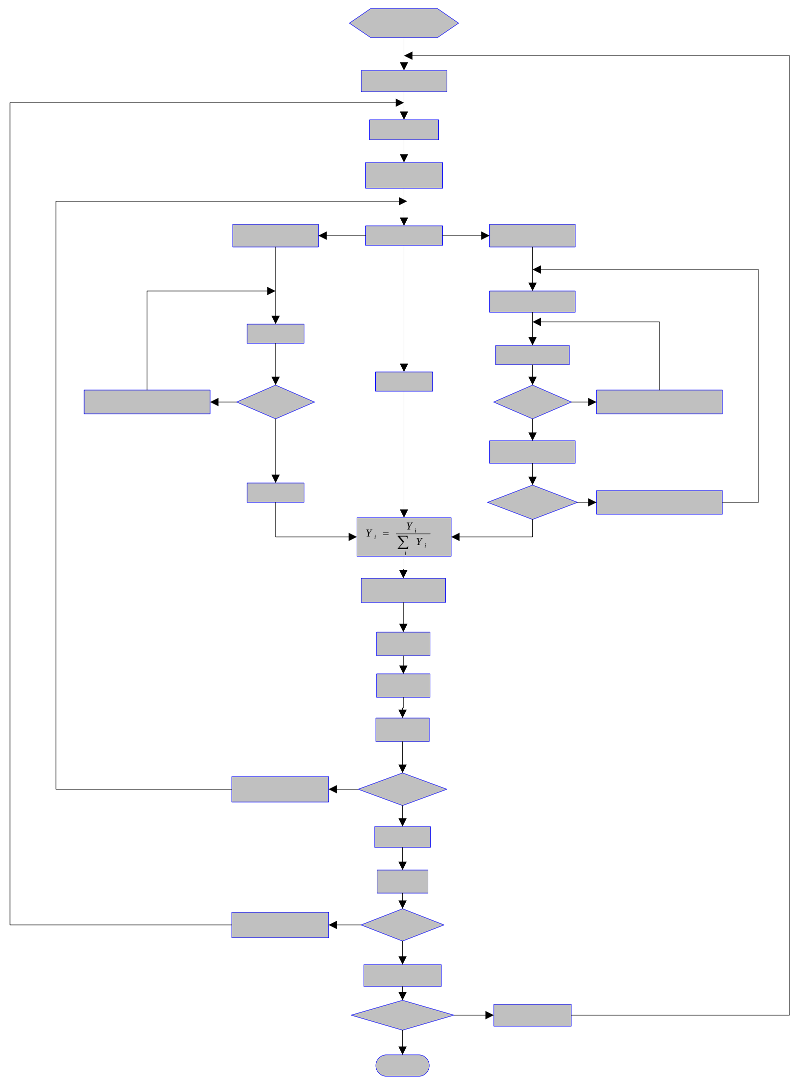
$$\frac{\partial}{\partial t}\left[\left(\rho_B \hat{H}_B + \rho_C \hat{H}_C + \rho_M \hat{H}_M\right) + \varepsilon\rho_g\left(Y_G \hat{H}_G + Y_I \hat{H}_I + Y_T \hat{H}_T + Y_V \hat{H}_V\right)\right]$$

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

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

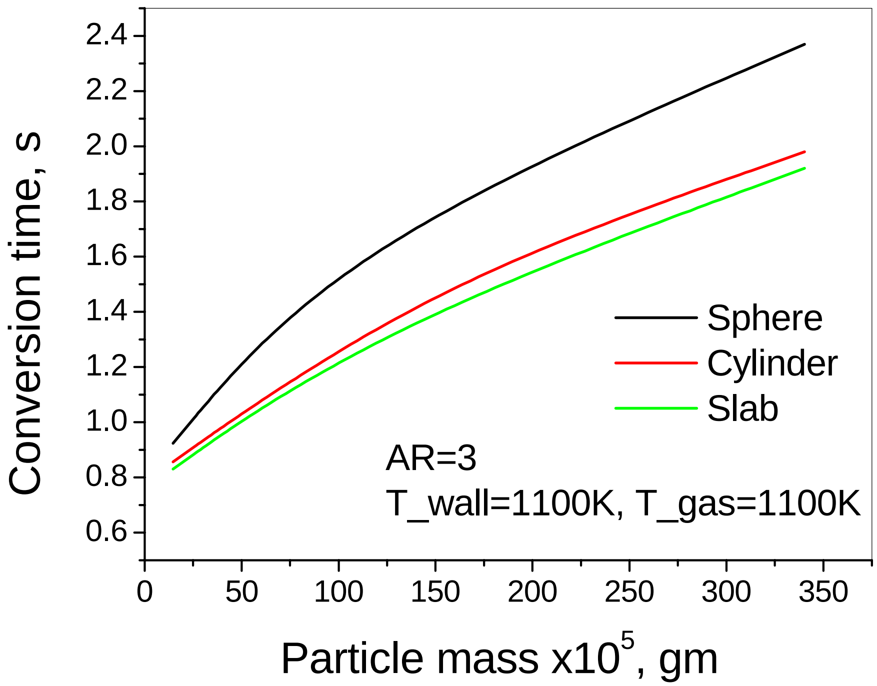
Model Development

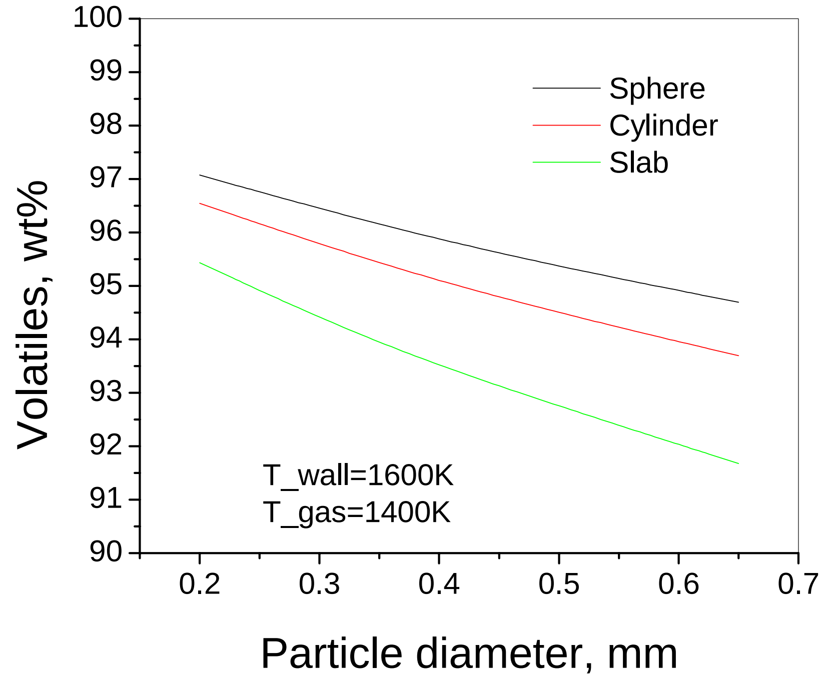
- **Model solution**
  - Control volume method
  - Hybrid scheme
  - SIMPLE algorithm



Model Predictions

Conversion time and volatile yield predictions





Conversion time comparison

(same volume)

Volatile yield comparison

(same diameter)

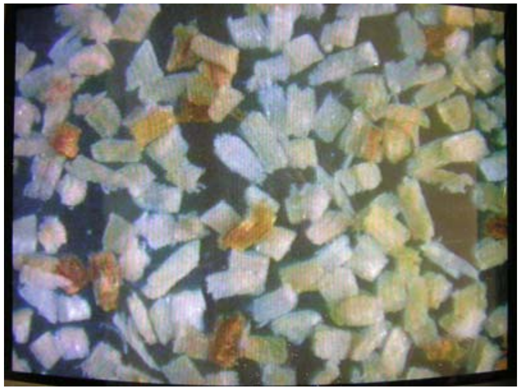
Higher aspect ratios lead to more significant difference

Data Collection

- **Sample preparation**
  - 1st: Sawdust separated using sieves
  - 2nd: particles aerodynamically classified;
  - 3rd: different aspect ratios were separated by sieves

Data Collection

flake-like

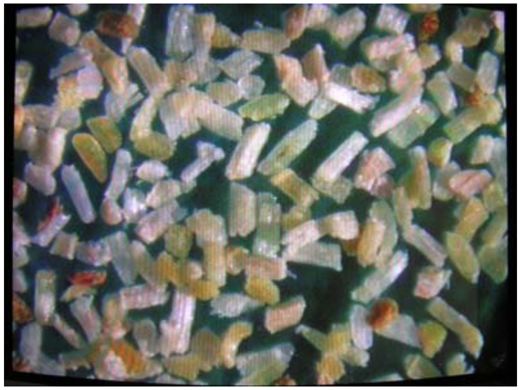


V=1.69x10^{-11}m^3

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

AR=1.3

prolate-like

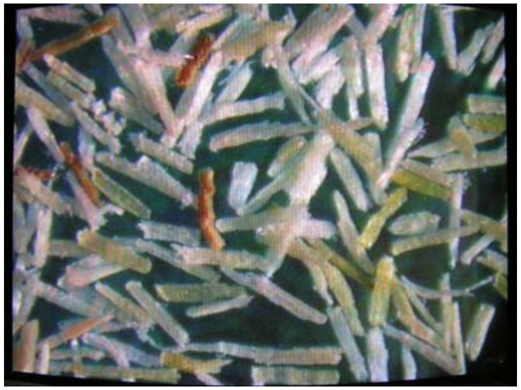


V=1.74x10^{-11}m^3

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

AR=1.6

cylinder-like



V=1.68x10^{-11}m^{-3}

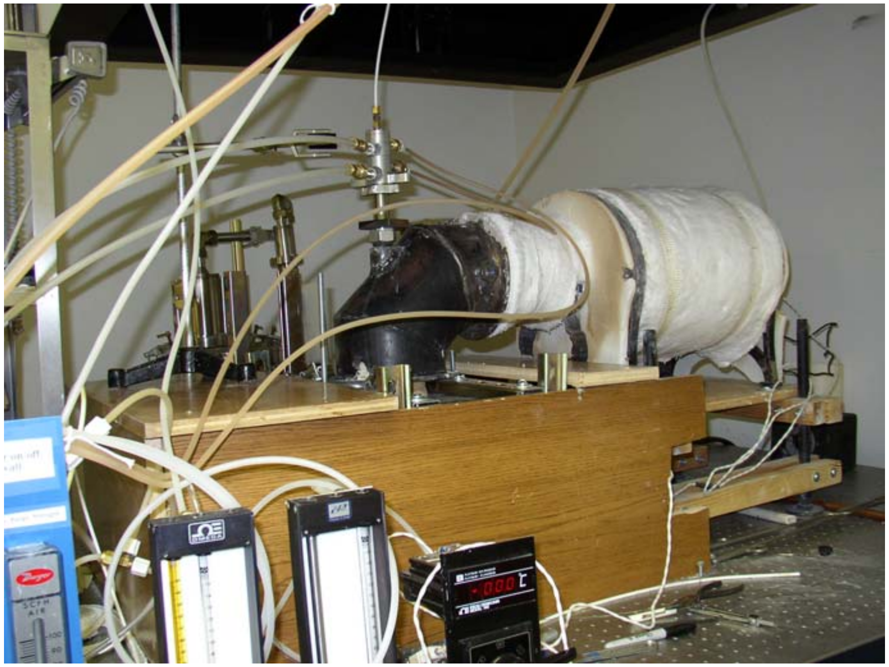
S=4.79x10^{-7}m^2

AR=6.1

Volume and surface area measured by a 3D particle shape reconstruction code developed at BYU

Data Collection

- **Equipment**



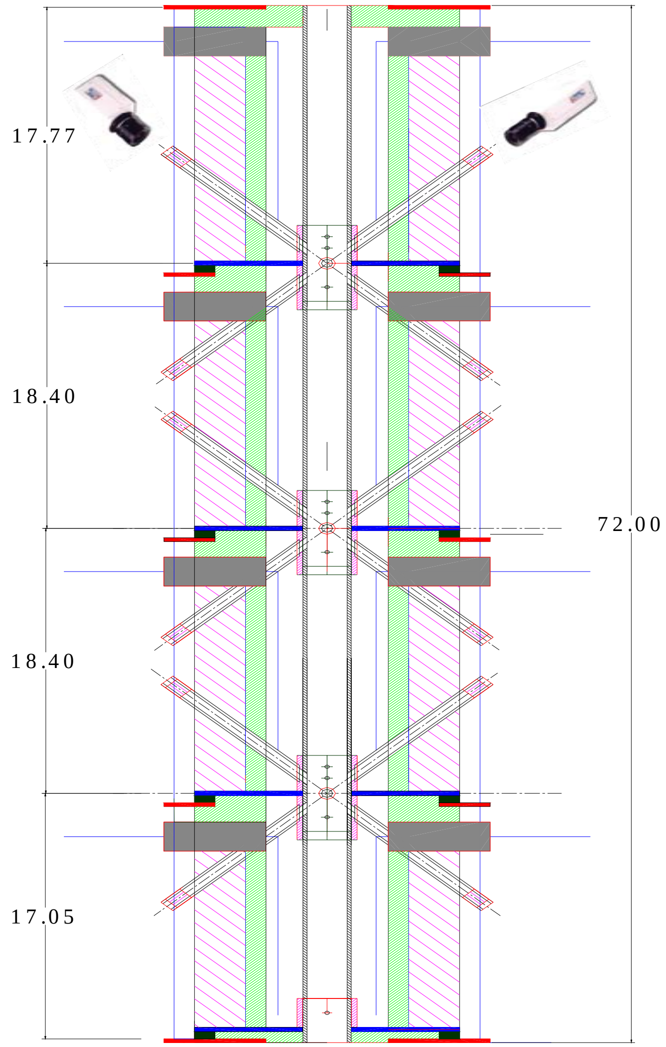
Current entrained flow reactor

Capabilities:

- residence time: 0.6 s
- wall temperature: up to 1650 K
- char collected by cyclone separator

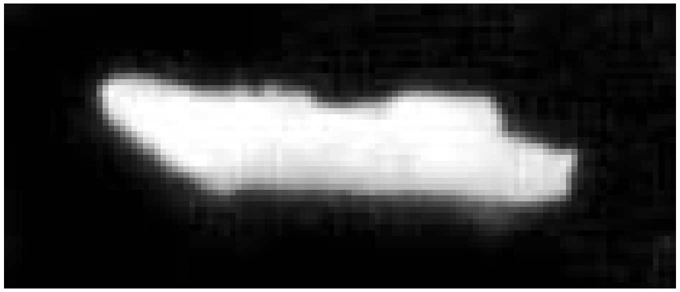
Data Collection

- **Equipment**
  - **Optical access**
  - **Imaging system**
  - **Simultaneous measurement of particle temperature, shape, and size as functions of residence time.**
  - **Up to 3 seconds residence time**
  - **Temperature separately controlled (up to 1650 K)**



New reactor under construction

Data Collection



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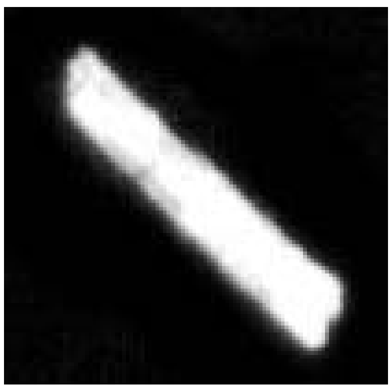

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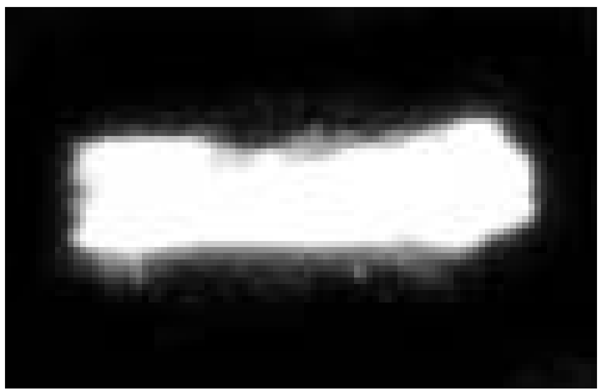

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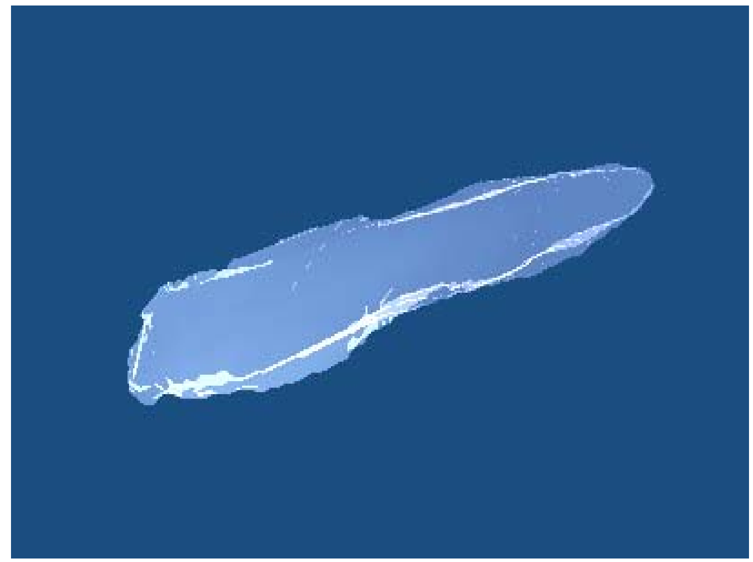
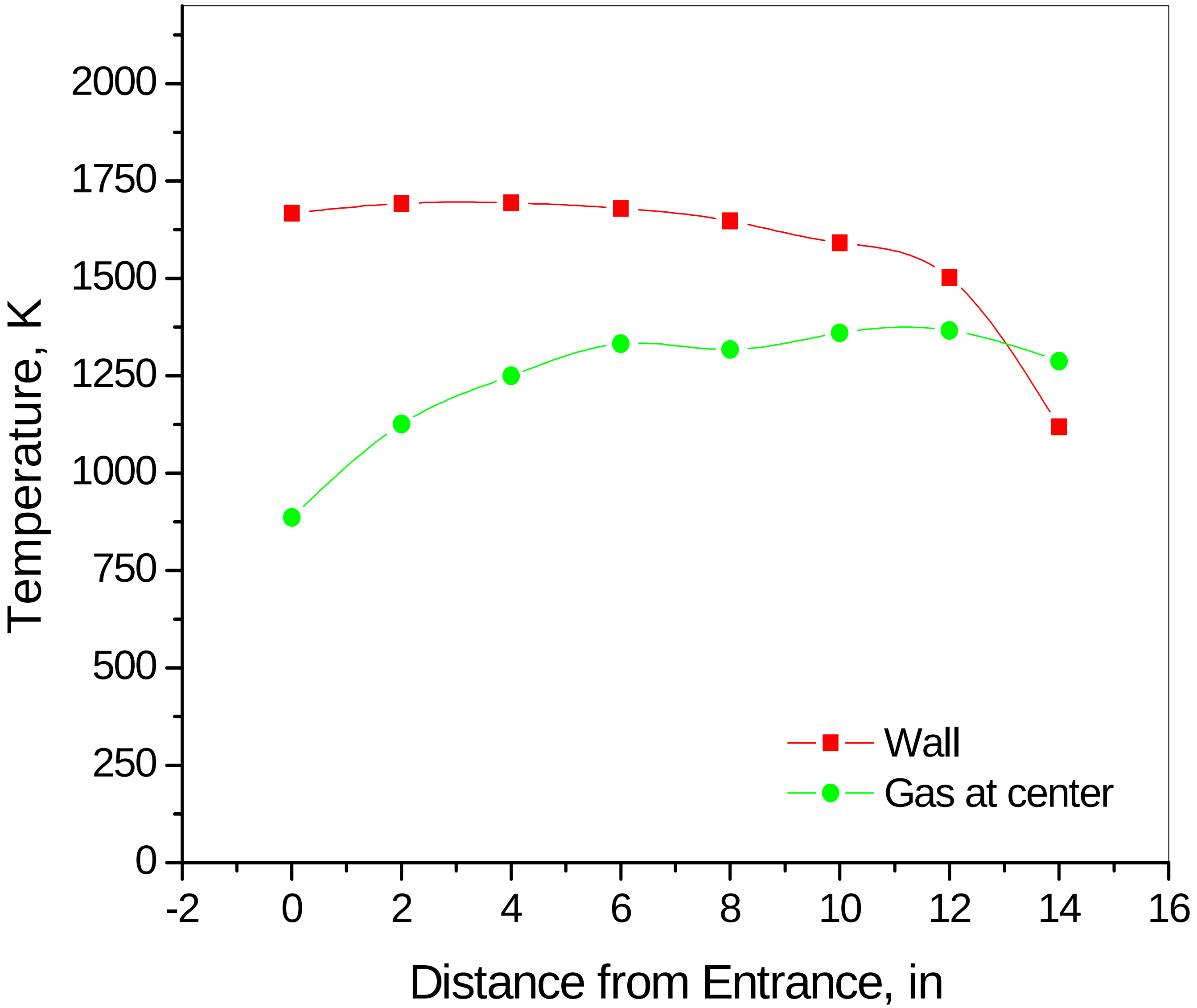


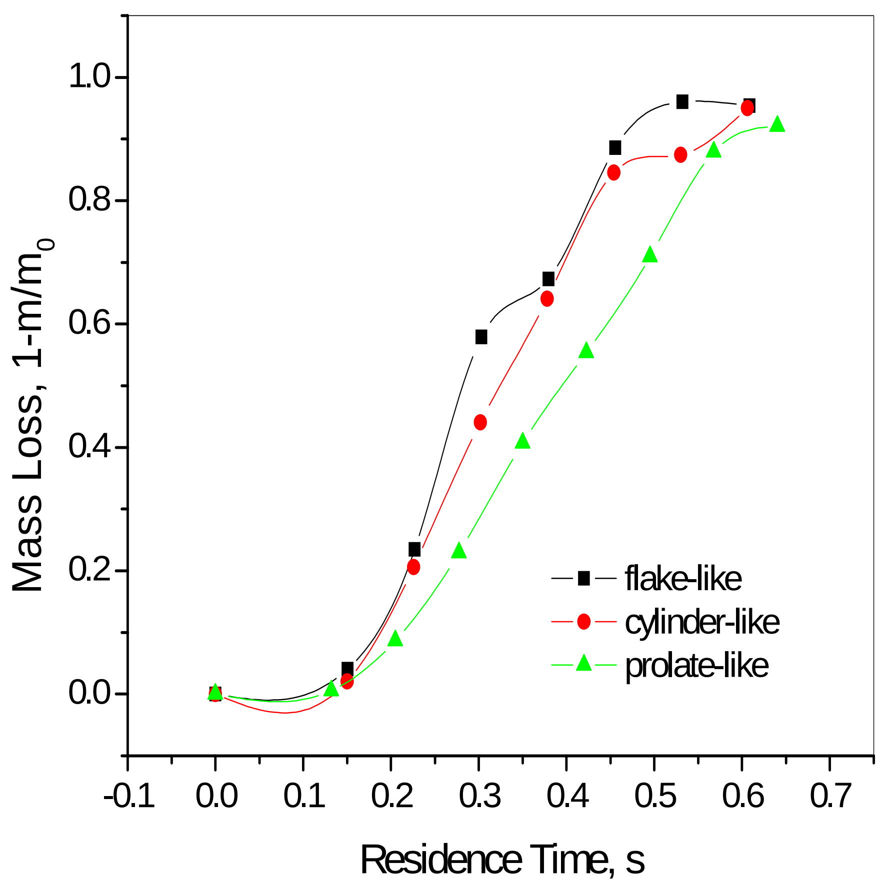
Reconstructed 3D shape

Particle temperature -------- multi-color-band method

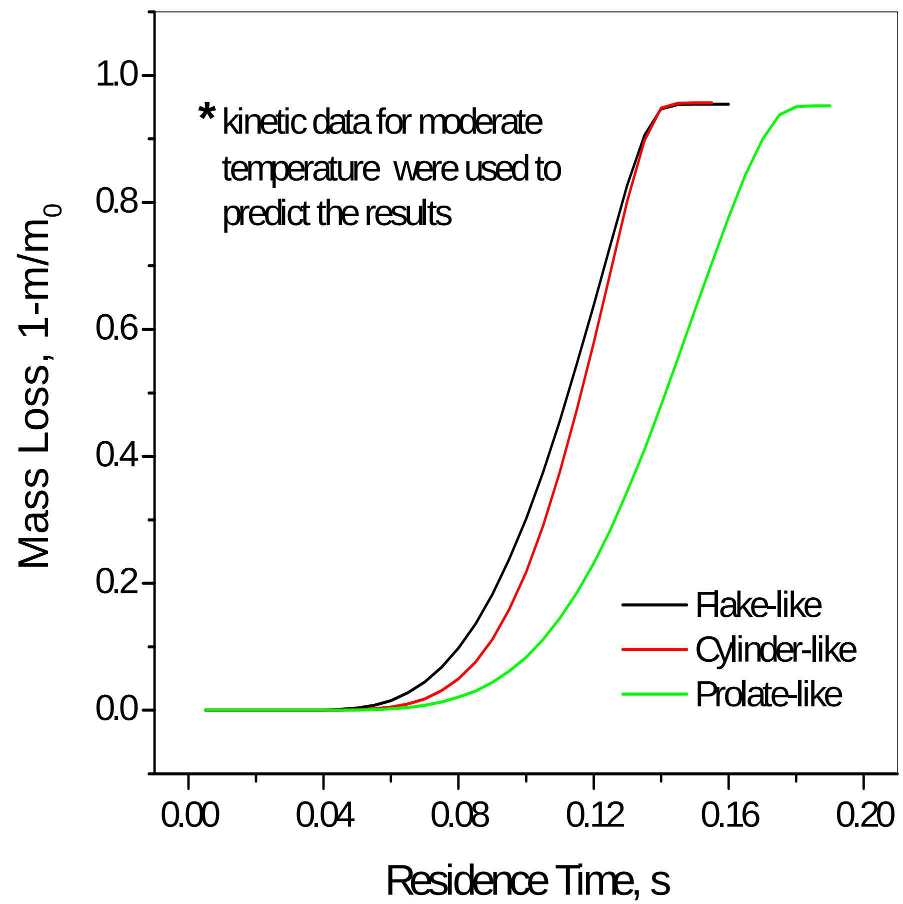
Data Collection



Data Collection



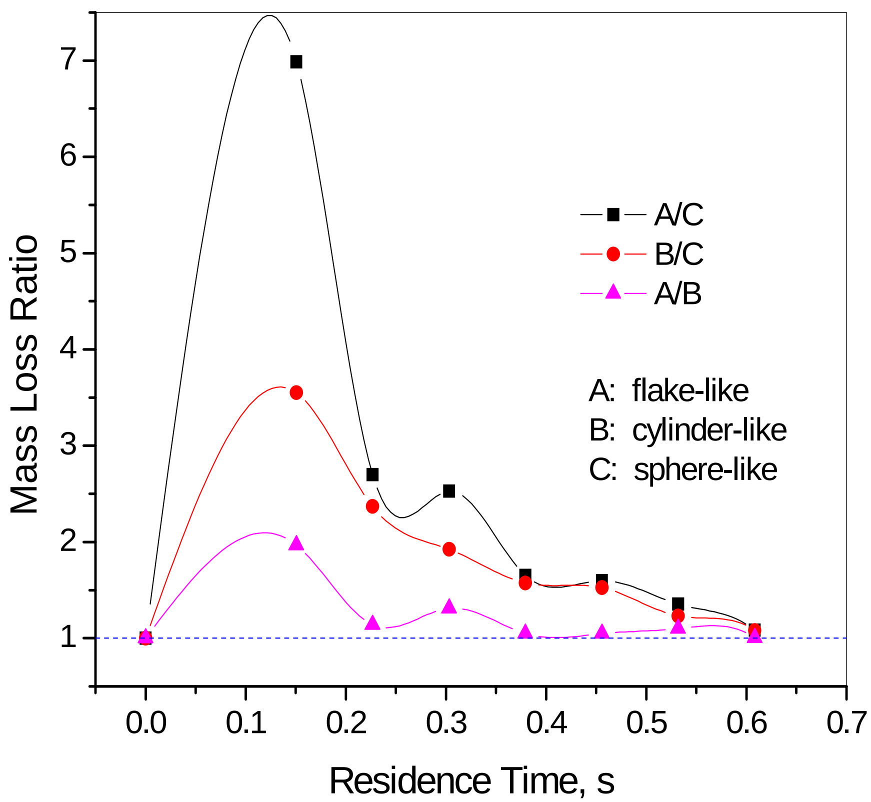
Experimental Data

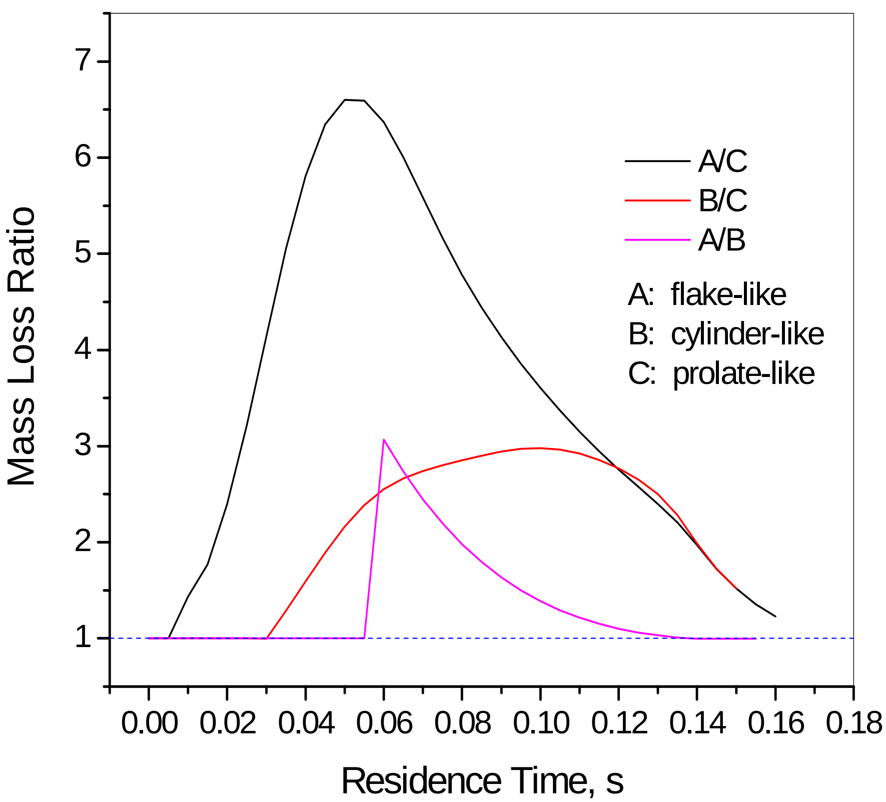


Model Predictions

- Different time scale due to fast kinetic parameters;
- Another project is going on at BYU to obtained kinetic data at high temperature

Data Collection



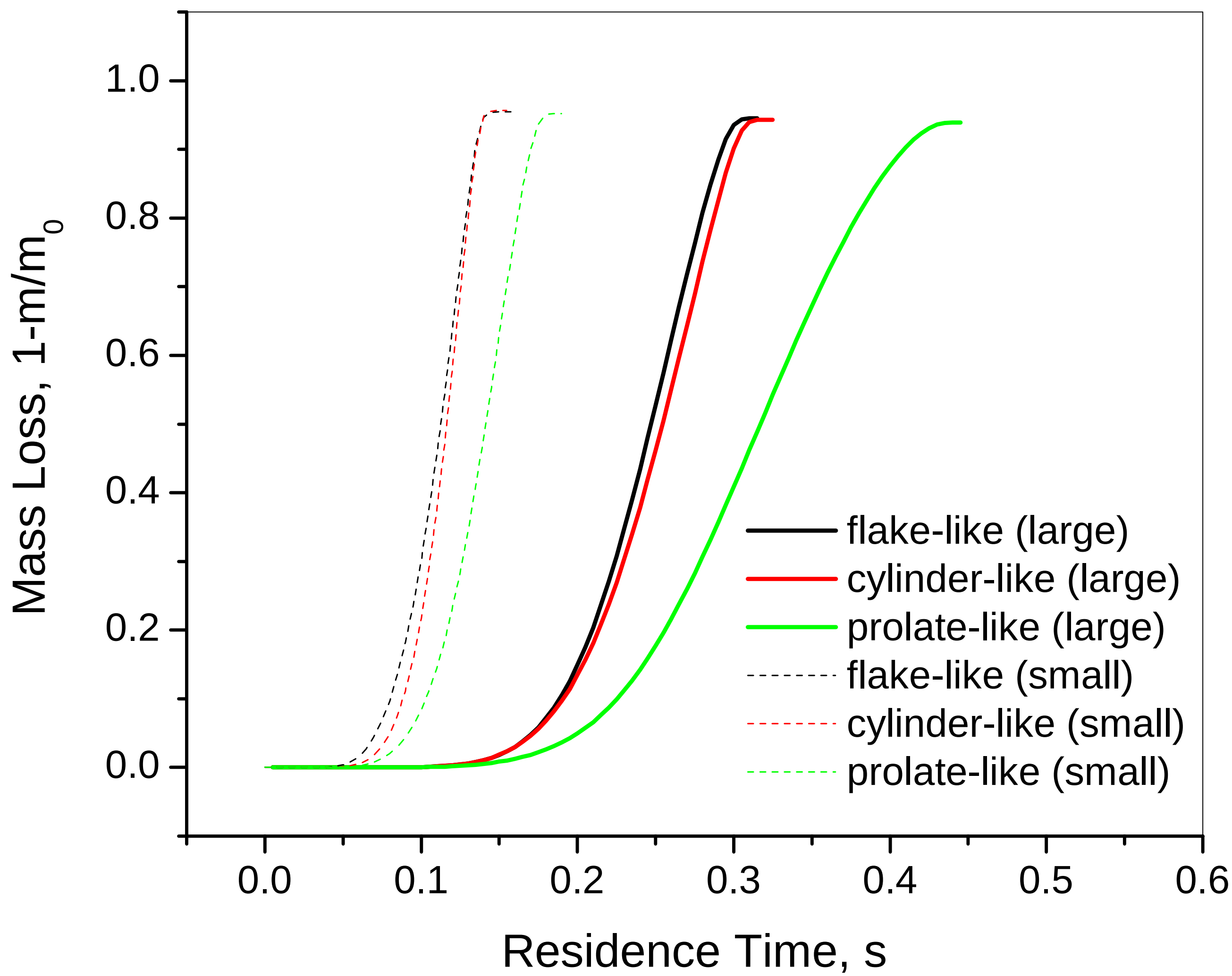


Mass loss ratio of different shapes

Model predictions

* Different time scale due to fast kinetic parameters

Data Collection



Comparison of mass loss with ten times volume change

Conclusions

- A biomass particle model has been developed;
- Near spherical biomass particle was found to lose mass most slowly during pyrolysis, consistent with theory;
- Particle shape and size affect both conversion time and product yield distribution during pyrolysis, also consistent with model;
- Shape effects impact particle reactions in substantial ways when particles are large (> 300 μm equivalent diameter).

Future Work

- Biomass particle oxidation model will be added to the current model;
- Particle surface temperature, volume, surface area, shape, and size will be measured as functions of residence time on the new entrained flow reactor.

Acknowledgement

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