Model Development for Lignocellulosic Biofuels

Amir Ahmadi, Amanda Fisher, Alex Toth, Helen Vo

Mentor: *Dr. Ralph C. Smith*, Graduate Assistant: *Lucus Van Blaircum*

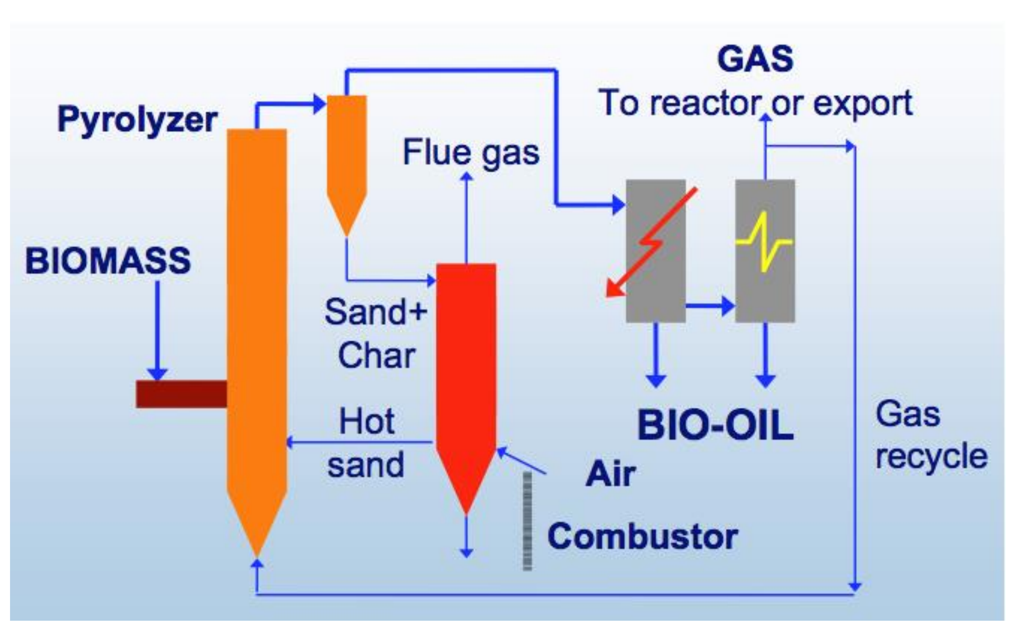
North Carolina State University, Funded by NSF

2nd Generation Biofuels:

- Potential for energy efficiency
- Higher yields of bio-oil
- Uses agricultural waste, not food

Production Process:

- Utilizes circulating fluidized beds and fast pyrolysis

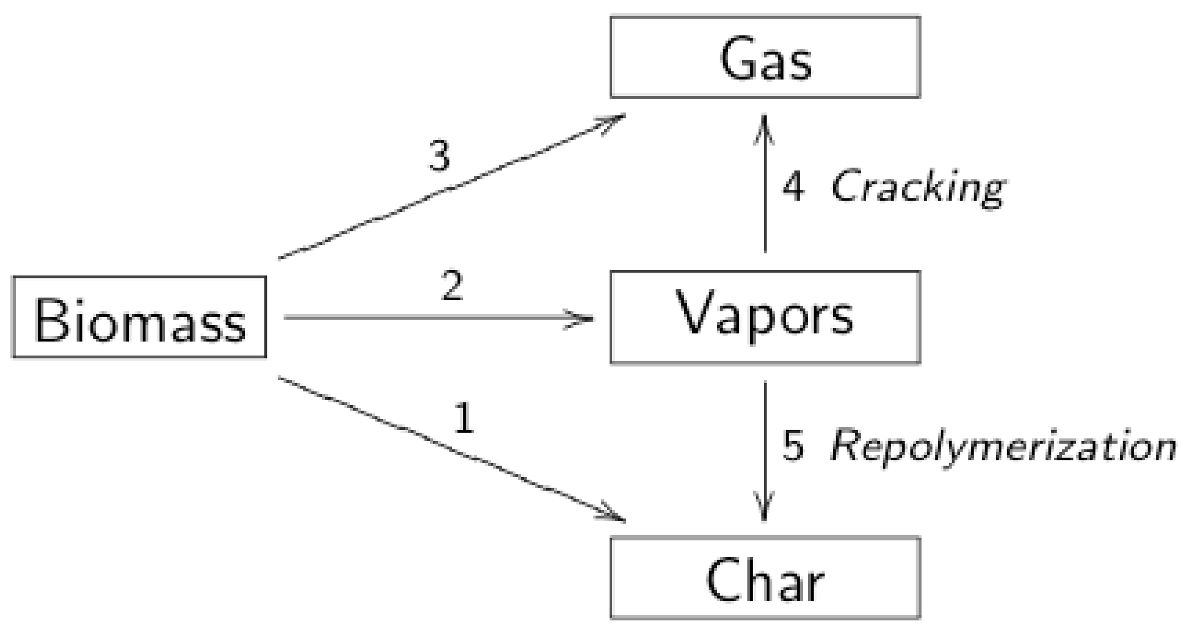


Focus:

Model the composition of bio-oil through process parameters and biomass characteristics[1]

Assumptions:

- Spherical wood particles with uniform characteristics
- Constant volume
- Particle gaseous volume fraction calculated by trapezoidal rule
- Two-second particle residence time



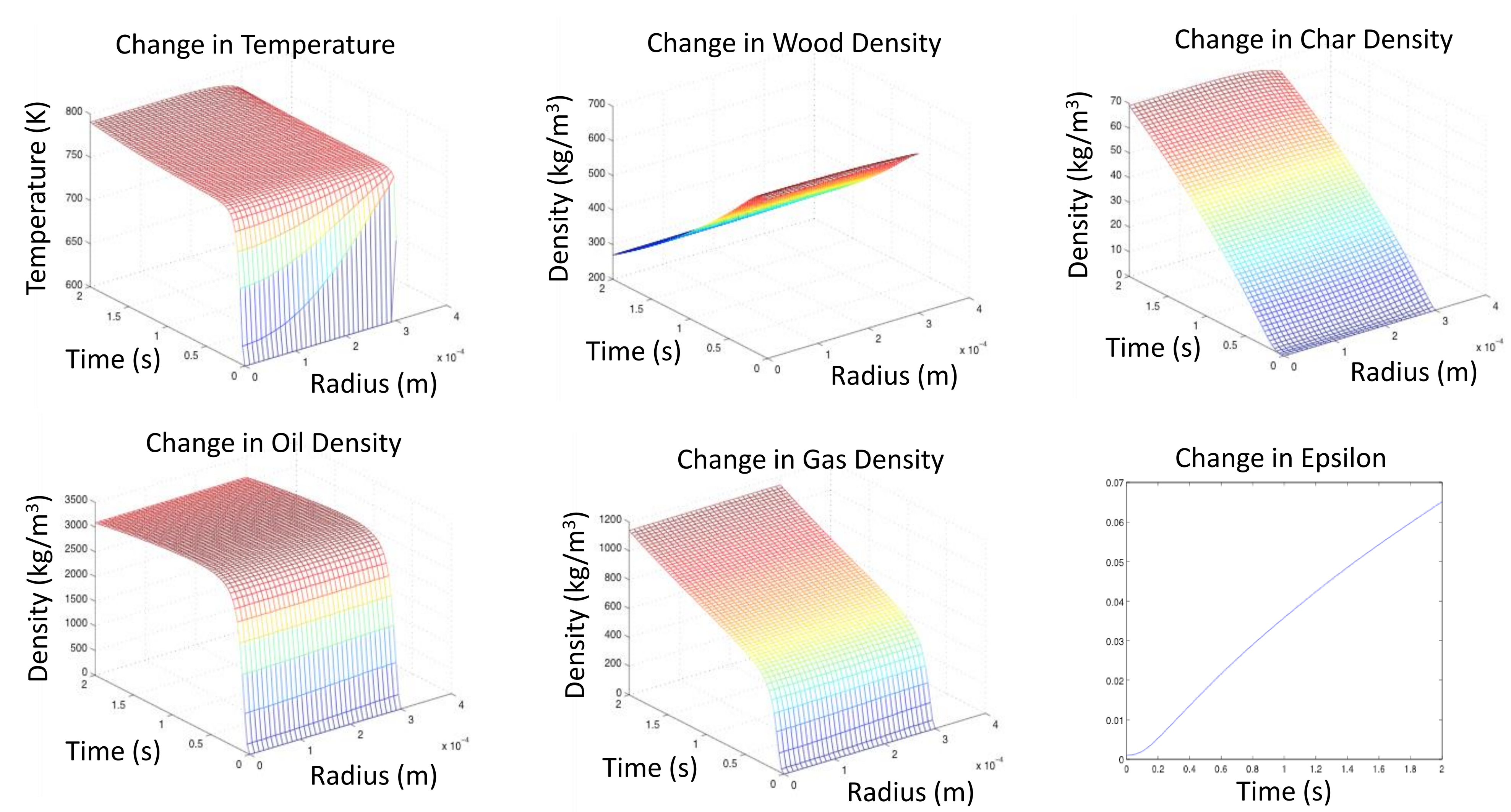
Nomenclature	
C	heat capacity, J/(kg K)
D	Diffusivity, m^2/s
H	volume enthalpy, J/m^3
k	reaction rate coefficient, s^{-1}
Q	reaction heat rate per volume, J/(m^3/s)
T	reaction temperature, K
u	flow velocity, m/s
V	volume, m^3
ε	gaseous volume fraction of particle
λ	thermal conductivity, W/(m K)
ρ	density, kg/m^3
τ	time, s
Subscripts	
g	gas
o	bio-oil
p	pressure, Pa
w	wood

Key Equations:

$\frac{DH}{D\tau} = C_p\nabla(\lambda\nabla T) + \sum_{i=1}^{5} Q_i - \frac{H}{V}\frac{\partial V}{\partial \tau}$	Enthalpy Balance
$\frac{\partial[(1-\varepsilon)\rho_w V]}{\partial \tau} = -(k_1+k_2+k_3)(1-\varepsilon)\rho_w V$	Wood Mass Balance
$\frac{\partial[(1-\varepsilon)\rho_c V]}{\partial \tau} = k_1(1-\varepsilon)\rho_w V + k_5\varepsilon\rho_o V$	Char Mass Balance
$\frac{\partial(\varepsilon\rho_o)}{\partial \tau} = D\varepsilon\nabla^2\rho_o - \varepsilon\nabla\rho_o\cdot u + k_2(1-\varepsilon)\rho_w - (k_4+k_5)\varepsilon\rho_o - \frac{\varepsilon\rho_o}{V}\frac{\partial V}{\partial \tau}$	Oil Component Diffusion

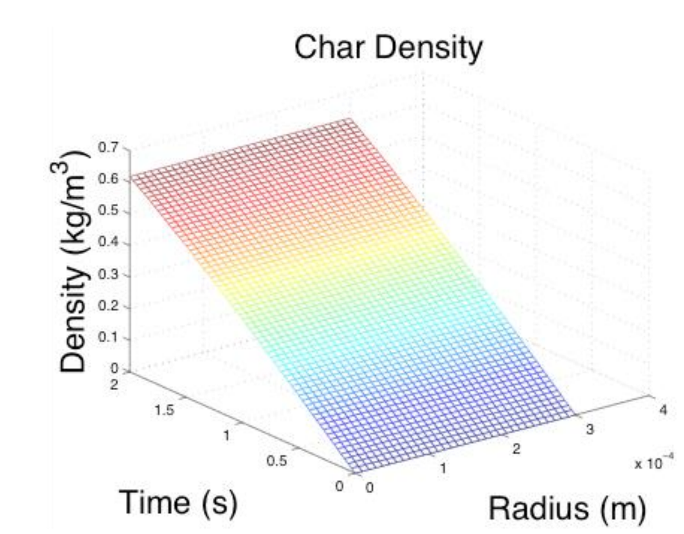
Results:

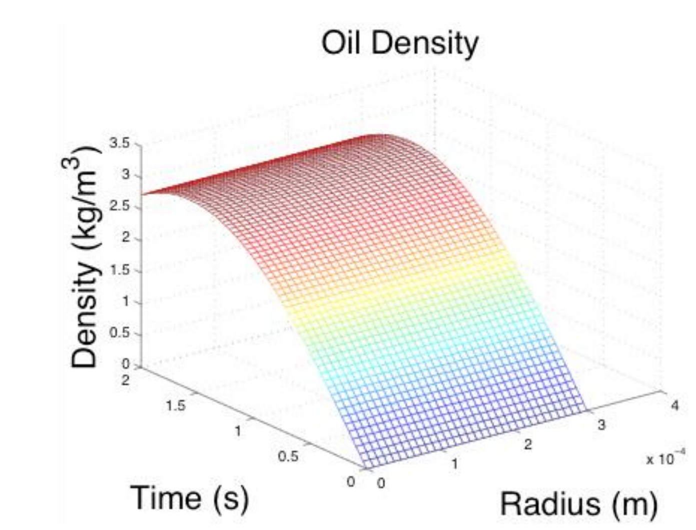
During fast pyrolysis, densities of products increase rapidly as wood density decreases, which models expected physical reactions



Verifications:

- MatLab ODE solvers: ODE15s, ODE45
- Parametric study of reactor temperature
- Poor matrix conditioning
- Method of Manufactured Solutions





$$\rho_c = \sin(\frac{\tau}{3})e^{\frac{-\tau}{3}} \qquad \rho_o = 3\,\sin(\tau)$$

$$\rho_w = \rho_{w_0} \qquad \rho_g = 4\,\sin(\frac{\tau}{2})$$

$$T = 500\text{K}$$

Conclusions:

- *Sensitivity analysis*—Arrhenius constants, activation energy, reactor temperature, and initial wood density are most important parameters
- Initial physical analysis is promising
- *Further work*: more stable solver, integration of volume and particle gaseous volume fraction into the model

Reference:

[1]Luo, Z., Wang, S., Cen, K. "A model of wood flash pyrolysis in fluidized bed reactor," *Renewable Energy*, vol. 30, pp. 377-392, 2005.