Evaluation of a cyclone biomass devolatilization chamber design using discrete particle model

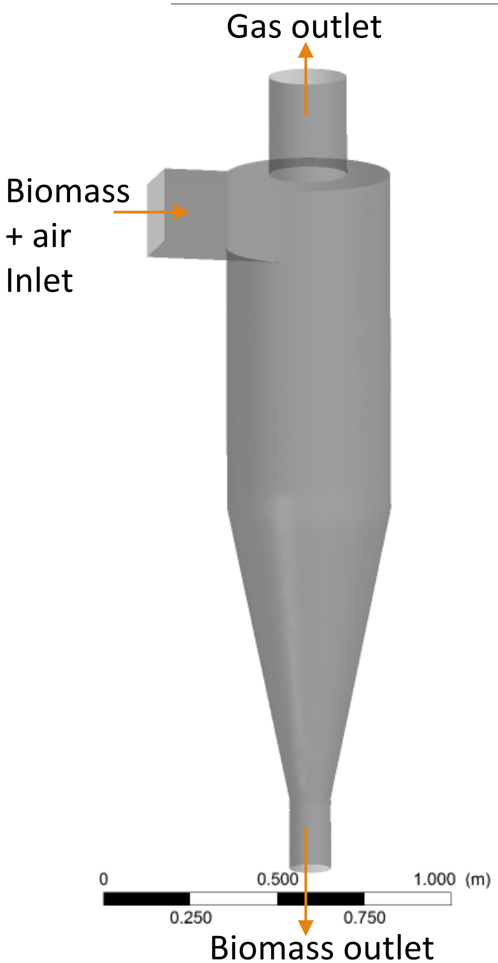
YAN YAN

MAY 16, 2018

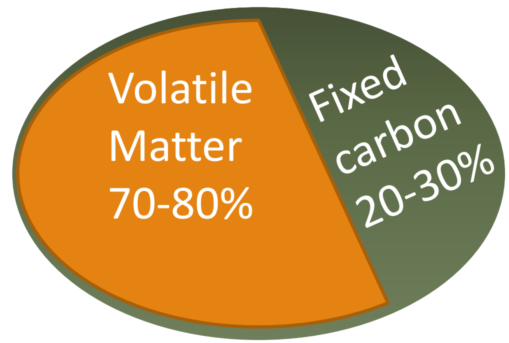
Introduction

- CYCLONE BIOMASS PYROLYSIS CHAMBER
- THEORY OF DPM

Cyclone biomass devolatilization chamber



A dry, ash-free biomass particle

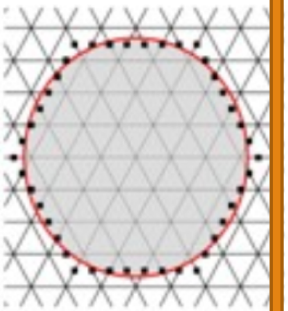


- Biomass devolatilizatoin:

$$biomass \xrightarrow{heat} H_2 + CO_2 + CO + CH_4 + tar + char$$

- Devolatilization temperature range: 500 K – 1000 K

Lattice Boltzmann Methods (LBM)



Fluid-particle interaction

Discrete Particle Model (DPM)

Particle-particle interaction

Level of interphase or intraphase interaction	Volume fraction of particles (V%)
One-way coupling • Particles have no effect on the flow	V% < 10 $^{-6}$
Two-way coupling • **Particles exchange momentum, mass and energy with flow**	**10 $^{-6}$ < V% < 10 $^{-2}$** **(FLUENT DPM)**
Four-way coupling • Particle-particle interaction, e.g. collusion • Particle-flow interaction	10 $^{-2}$ < V% (MFIX, FLUENT DDPM)

10^{-5} m — 10^{-2} m — 10^{-1} m — 10^{-0} m — 10^{1} m

Lower complexity/cost
Larger scale phenomena

Multiphase flow modeling approaches

Bates, R. 2014.

Discrete particle model

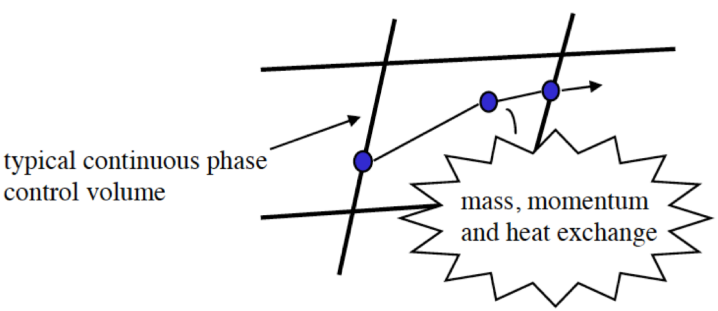
- Fluid flow equation (RANS): $$\frac{\partial}{\partial t}(\rho\vec{v})+\rho(\vec{v}\cdot\nabla)\vec{v}=-\nabla p+\nabla\cdot\tau+\nabla\cdot\tau_t+\vec{F}.$$
- Discrete particle equation:

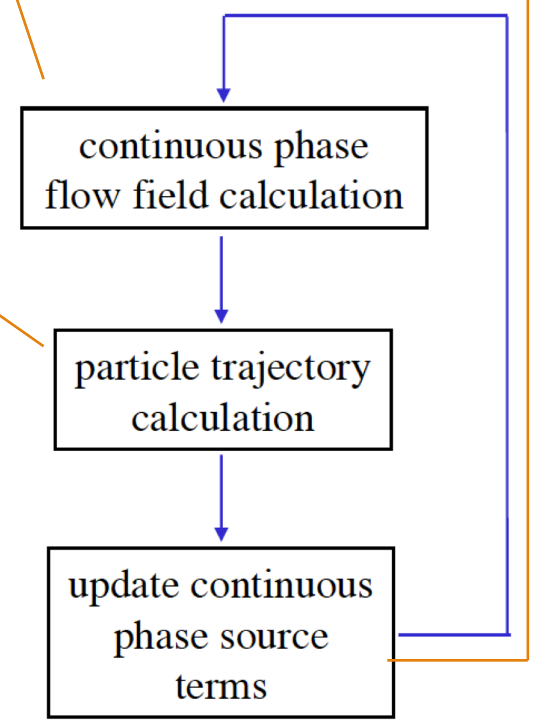
$$\frac{du_i^p}{dt}=F_D\left(u_i-u_i^p\right)+g_i(\rho_p-\rho)/\rho_p+F_i/\rho_p$$

drag force is a function of the relative velocity

Gravity force

Additional forces:
- Pressure gradient
- Thermophoretic
- Rotating reference frame
- Brownian motion
- Saffman lift
- Other (user defined)



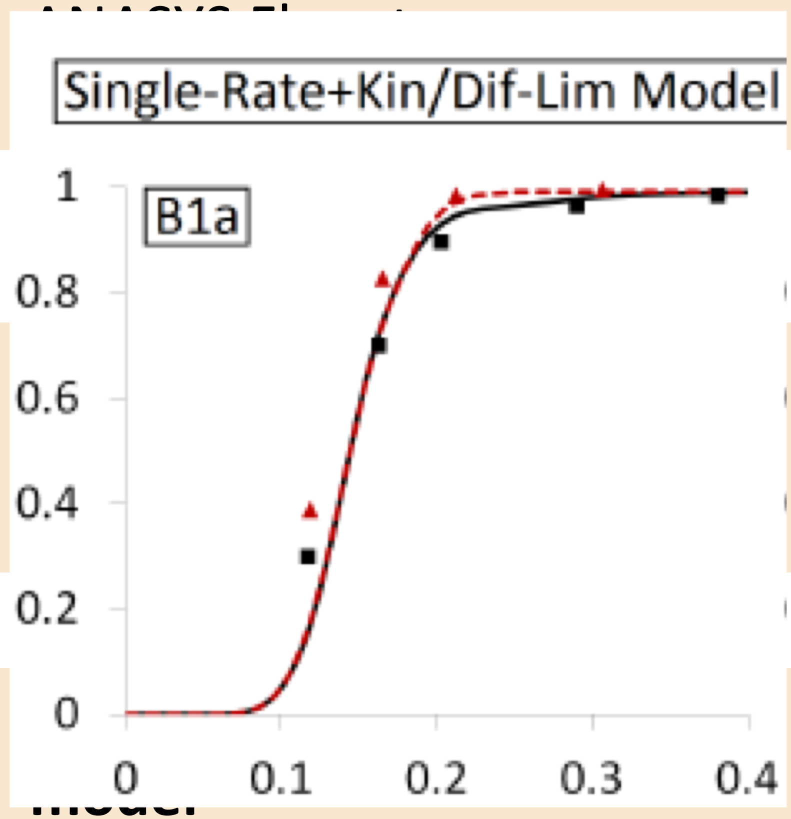


Method

-SIMULATION DETAILS AND SUBMODELS

Simulation details

Particle model	Discrete particle model
Solver	
Turbulence Model	
Species model	
Devolatilization Model	
Combustion Model	
Radiation Model	**Discrete Ordinates (DO)**

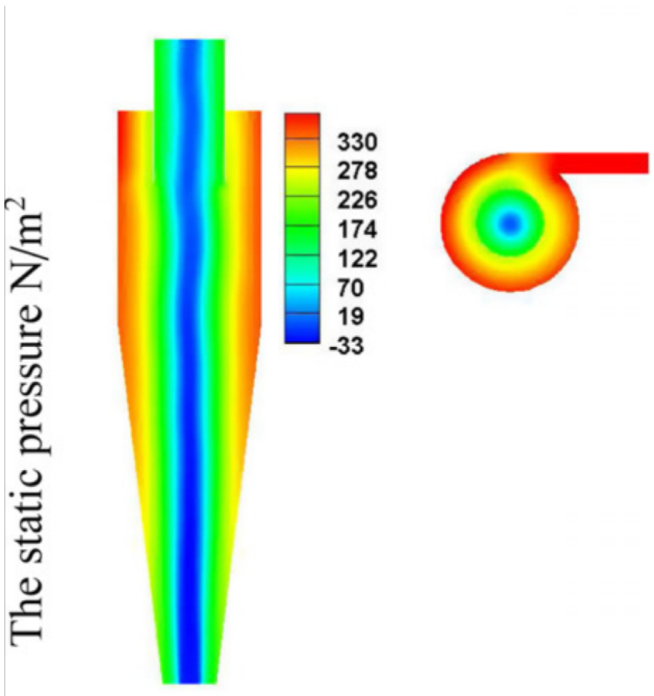


Niemela, N. 2016

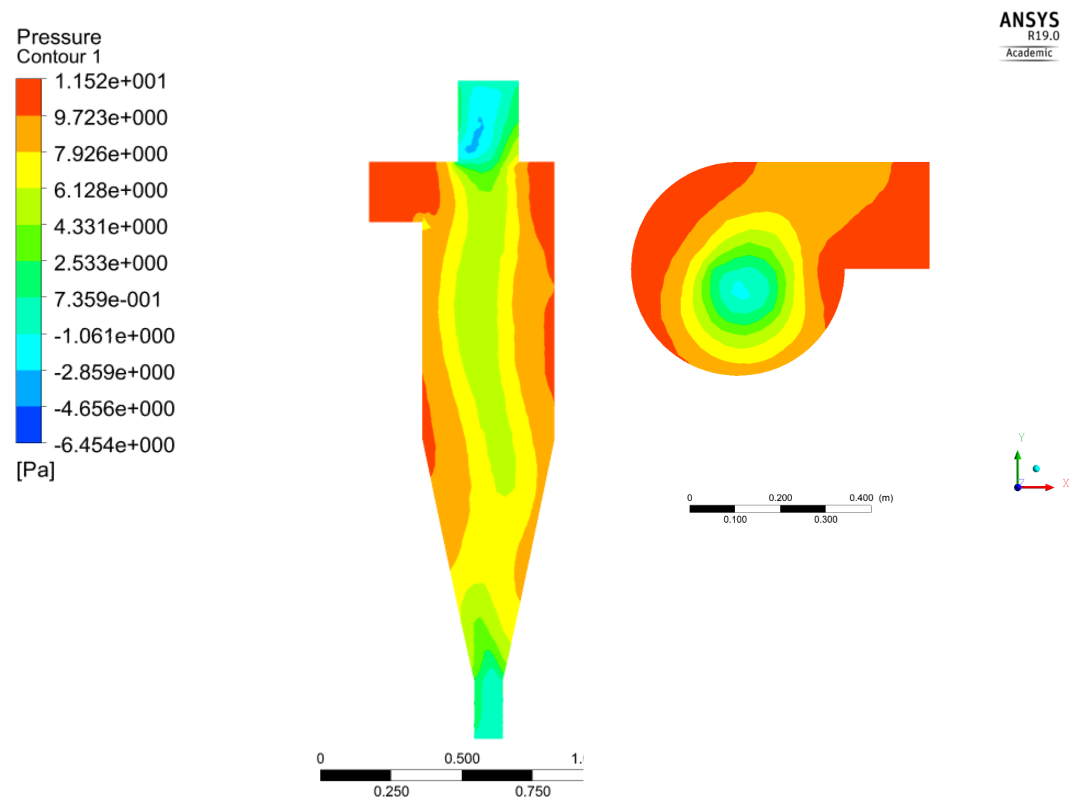
Results

- REACTOR PRESSURE FIELD
- REACTOR TEMPERATURE FIELD
- RESULTS OF PARTICLES OF TWO DIFFERENT SIZES

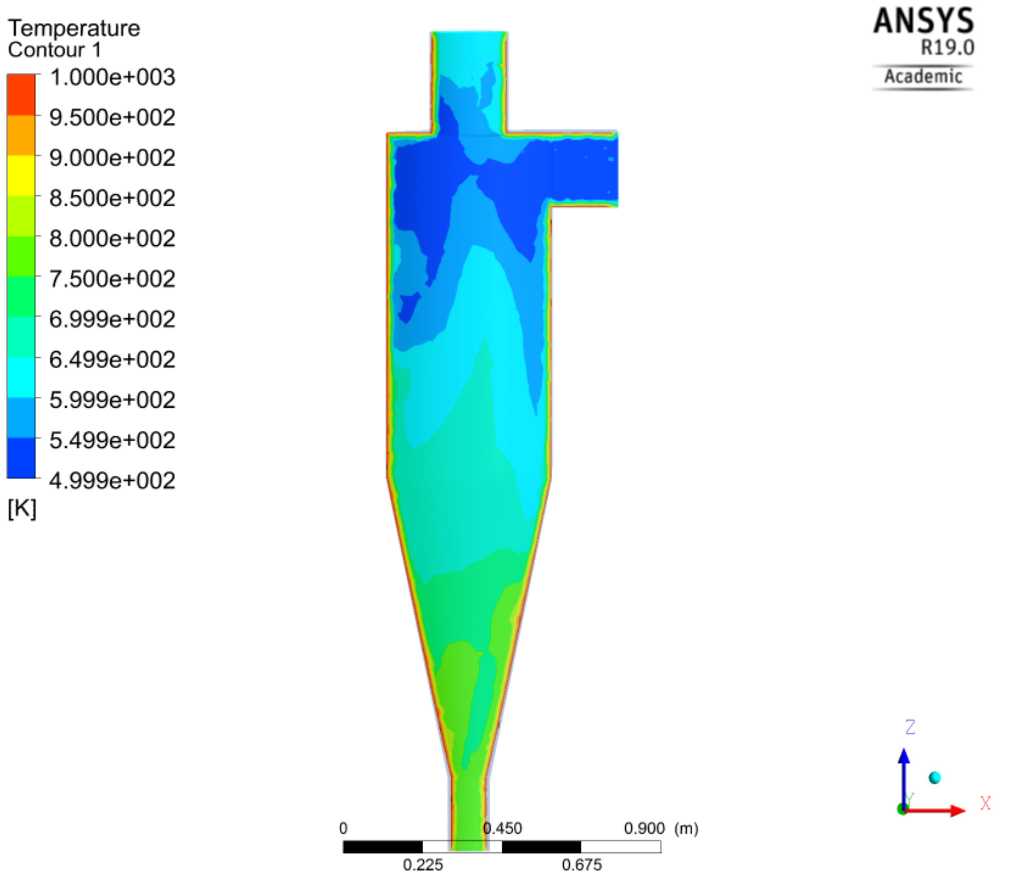
Reactor pressure field



K. Elsayed, C. Lacor, 2011

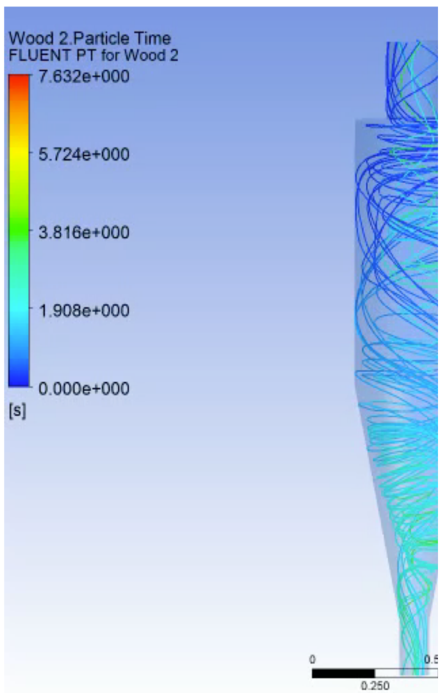


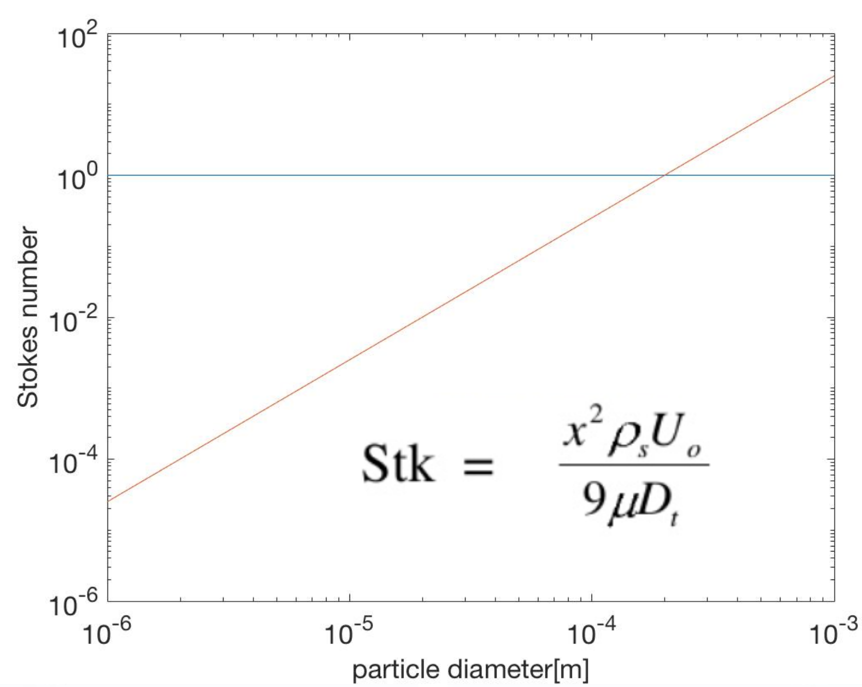
Reactor temperature field



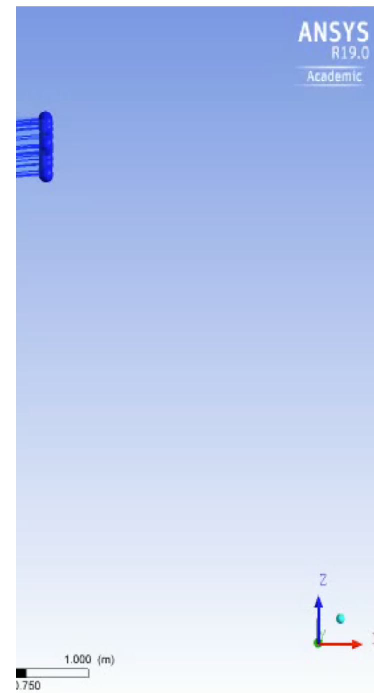
Trajectories and residence time of wood particles of different sizes

PARTICLE DIAMETER: 1E-06 M



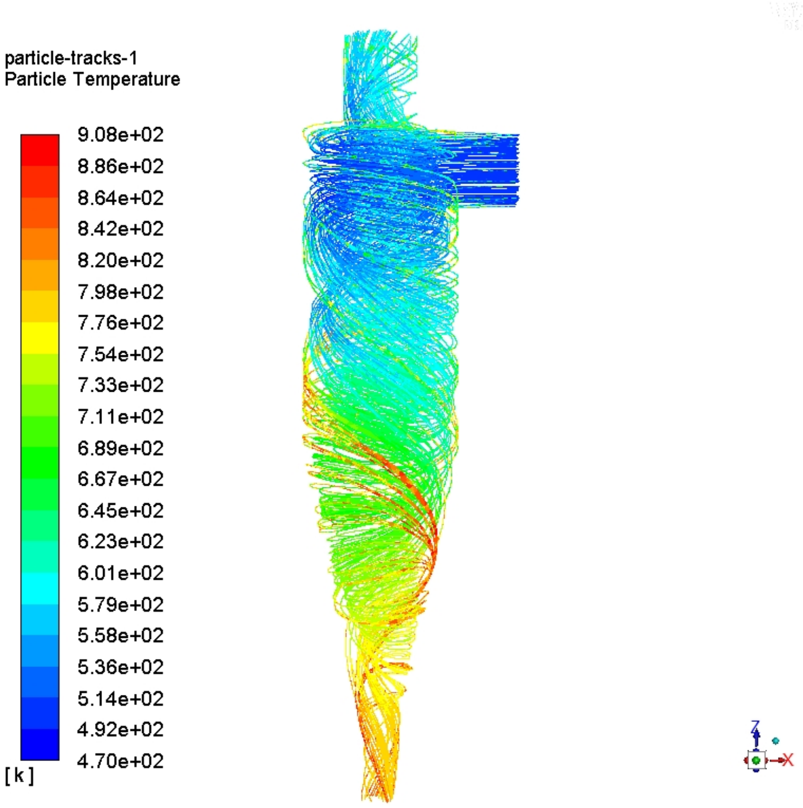


PARTICLE DIAMETER: 1E-03 M

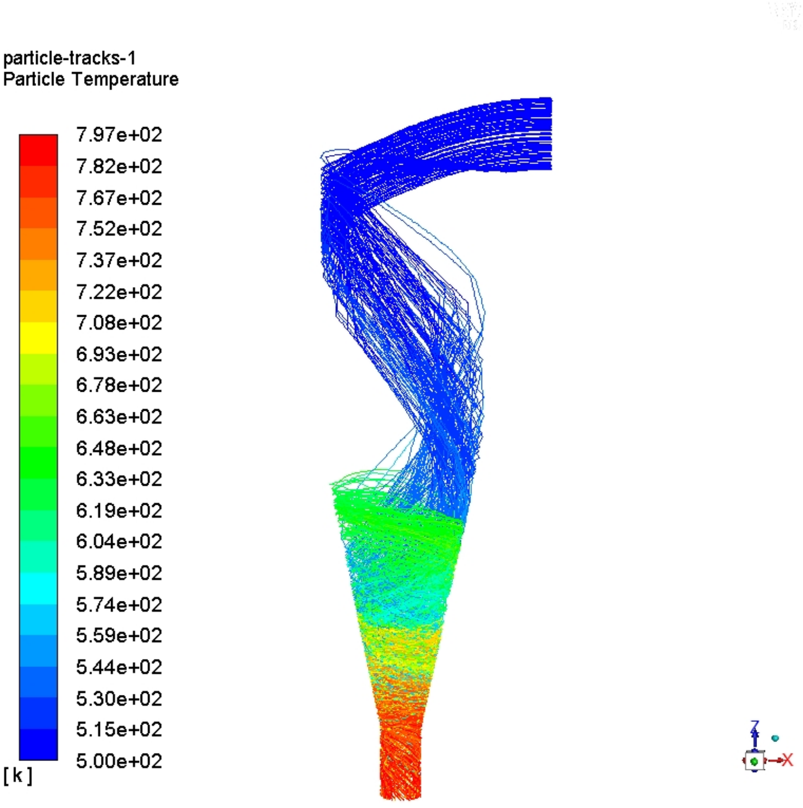


Particle temperature

PARTICLE DIAMETER: 1E-06 M

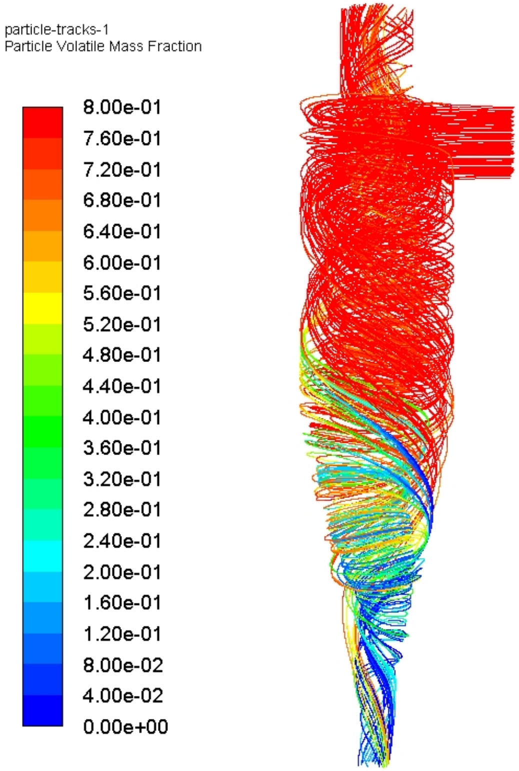


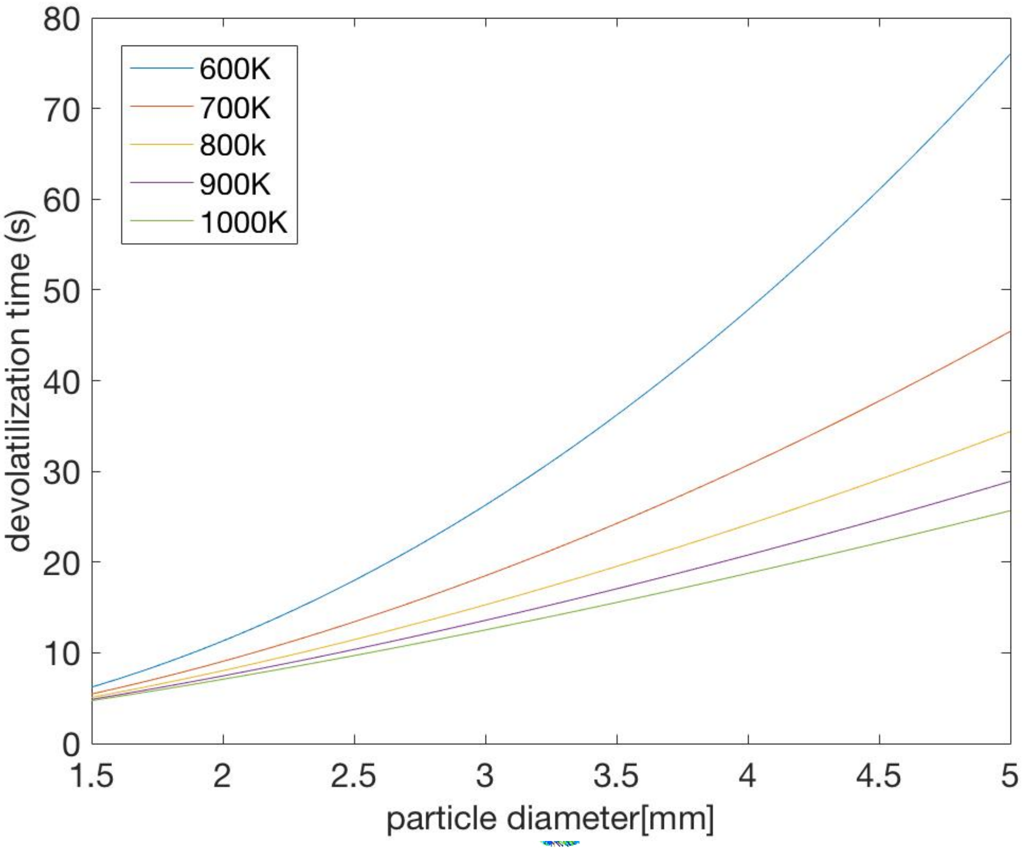
PARTICLE DIAMETER: 1E-03 M



Particle volatile mass fraction

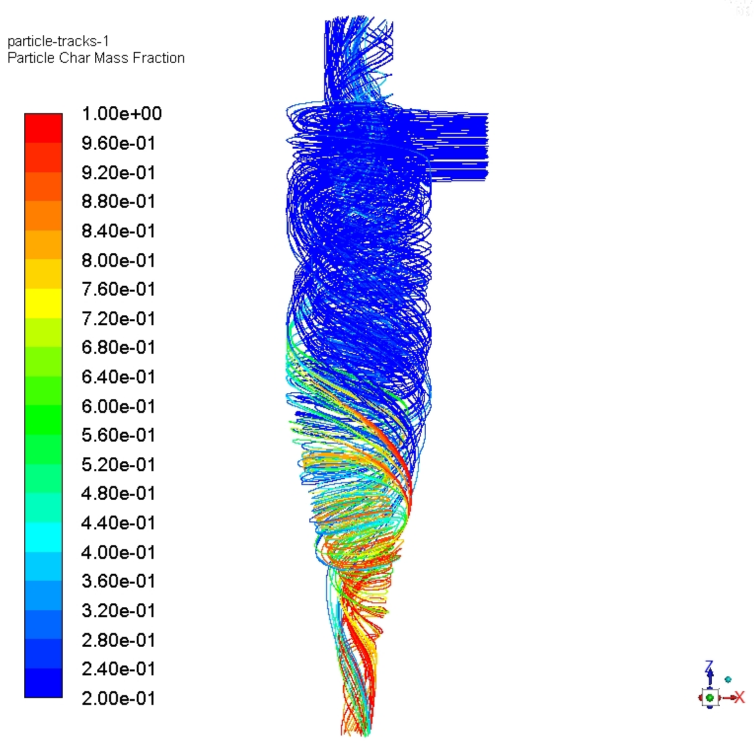
PARTICLE DIAMETER: 1E-



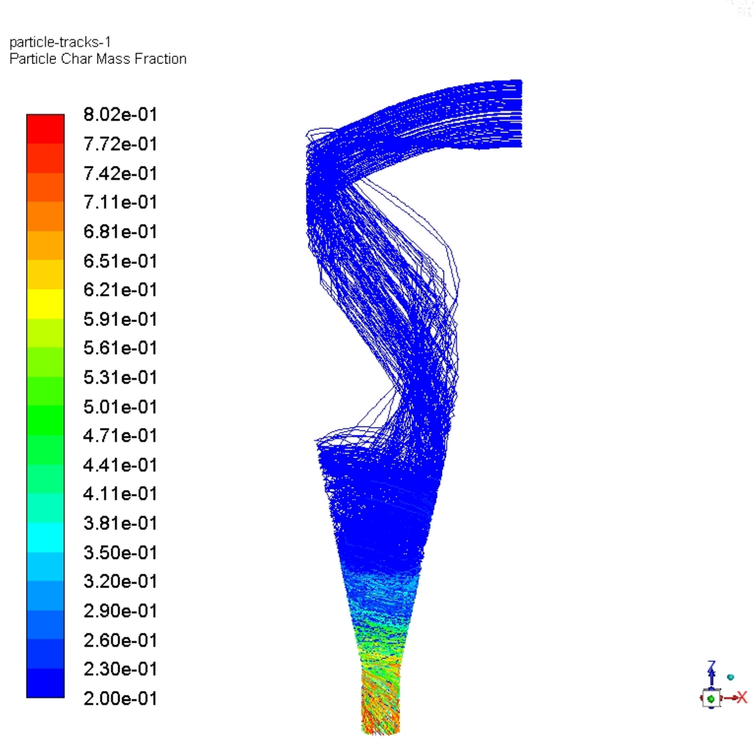


Produced char mass fraction

PARTICLE DIAMETER: 1E-06 M



PARTICLE DIAMETER: 1E-03 M



Conclusion & next step

Discrete particle model

- Allows the examination of states of fluid phase and particle phase at the same time;
- But has limitation of volume fraction of the particle (has to be less than 10%), so multiphase flow model can be used in the future

Cyclone pyrolysis reactor

- Millimeter scale particles can't follow the swirl flow very well thus don't have a good contact with the heated surface, thus have a worse conversion efficiency than micron level biomass
- Cyclone reactor is a good fast pyrolysis reactor for pulverized biomass, but not a ideal reactor when slow pyrolysis reaction of bigger biomass particles is desired

Thank you!

Q&A

Appendix i. Calculation of particle trajectory

Integrate this equation over time can give you the velocity of particle at each point of the trajectory

$$\frac{du_p}{dt} = F_D(u - u_p) + \frac{g_x(\rho_p - \rho)}{\rho_p} + F_x$$

The trajectory itself is predicted by

$$\frac{dx}{dt} = u_p$$

Assuming the term containing the body force remains constant over each small time interval, and linearizing any other forces, the velocity equation can be simplified to

$$\frac{du_p}{dt} = \frac{1}{\tau_p}(u - u_p)$$

For turbulent flow, FLUENT uses either stochastic particle tracking or particle cloud tracking to model the dispersion of particles

Appendix ii. Coupling between discrete and continuous phases

Momentum, heat and mass exchange

The momentum, heat and mass transfer from the continuous phase to the discrete phase is computed in FLUENT by examining the change in momentum, thermal energy and mass of a particle as it passes through each control volume in the FLUENT model. This momentum change is computed as

$$F = \sum \left(\frac{18 \mu C_D \mathrm{Re}}{\rho_p d_p^2 24} (u_p - u) + F_{\mathrm{other}} \right) \dot{m}_p \Delta t$$

$$Q = \left[\frac{\bar{m}_p}{m_{p,0}} c_p \Delta T_p + \frac{\Delta m_p}{m_{p,0}} \left(-h_{\mathrm{fg}} + h_{\mathrm{pyrol}} + \int_{T_{\mathrm{ref}}}^{T_p} c_{p,i} dT \right) \right] \dot{m}_{p,0}$$

$$M = \frac{\Delta m_p}{m_{p,0}} \; \dot{m}_{p,0}$$