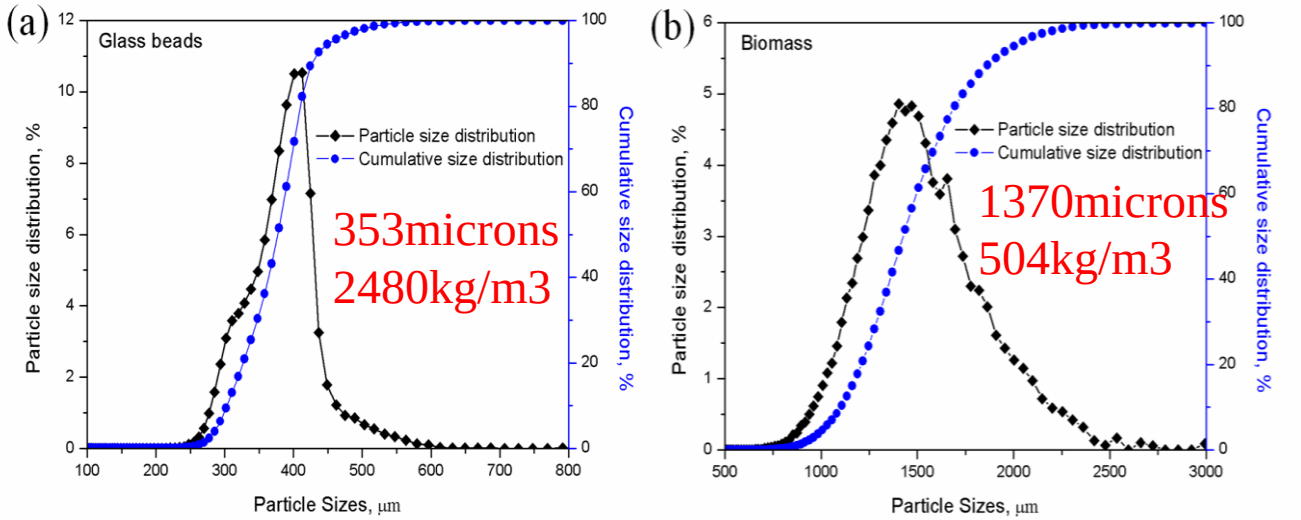
Hybrid drag model for the simulation of biomass fast pyrolysis

Solutions for Today | Options for Tomorrow

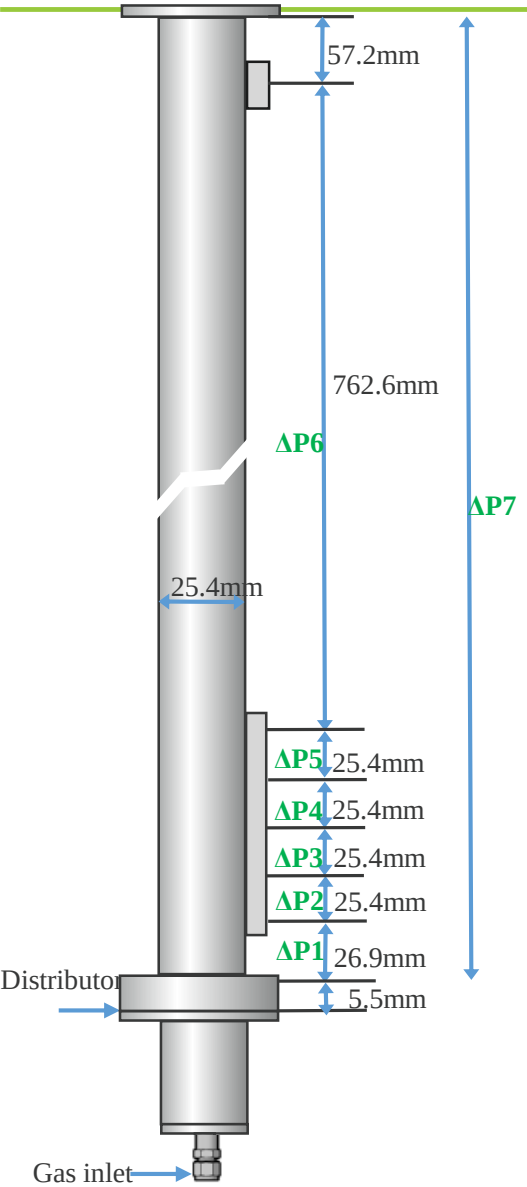
Research 1: Glass beads (Geldart B) + large pine white wood (Geldart B)

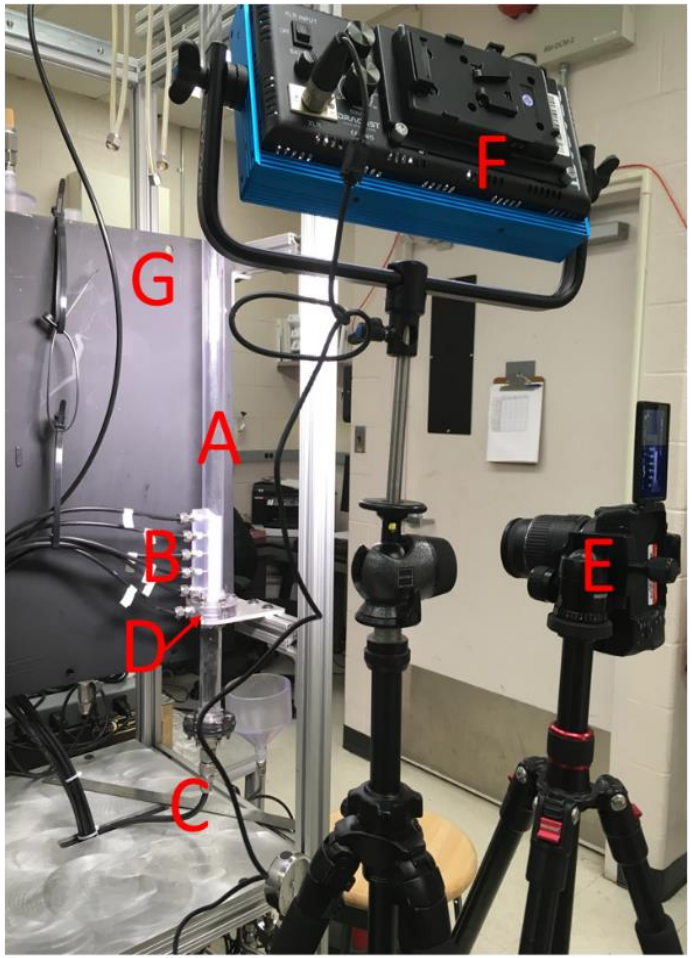
- Size and shape: Sympatec QICPIC particle analyzer
- Density: AccuPyc 1330 Helium Pycnometer, water displacement method



- Both biomass and glass beads particle are sieved to narrow the particle size distribution.

Research 1: Experiment setup





A - Fluidized bed

B - Differential pressure sensors

C - Gas Inlet

D - Distributor

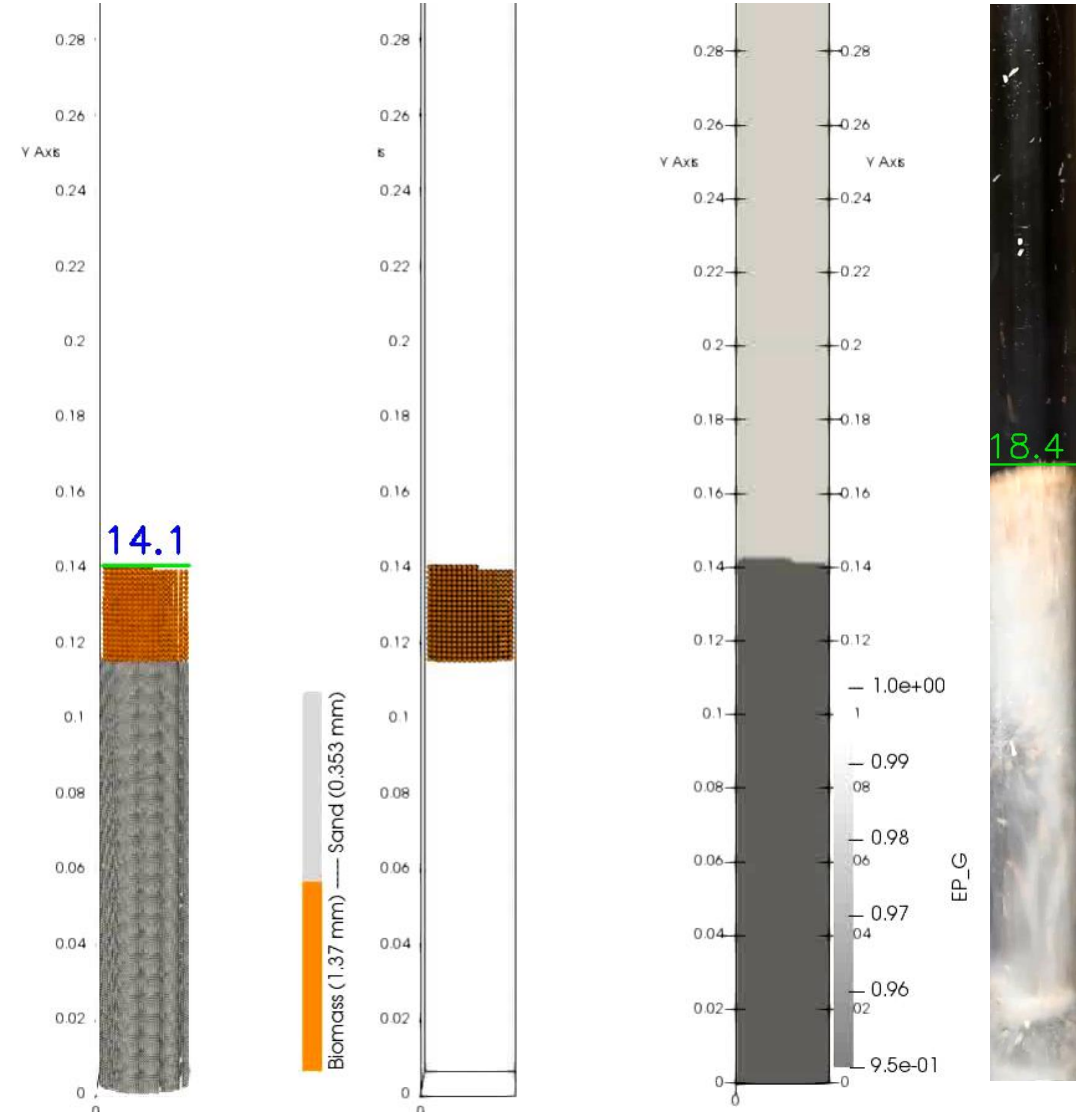
E - High-speed camera

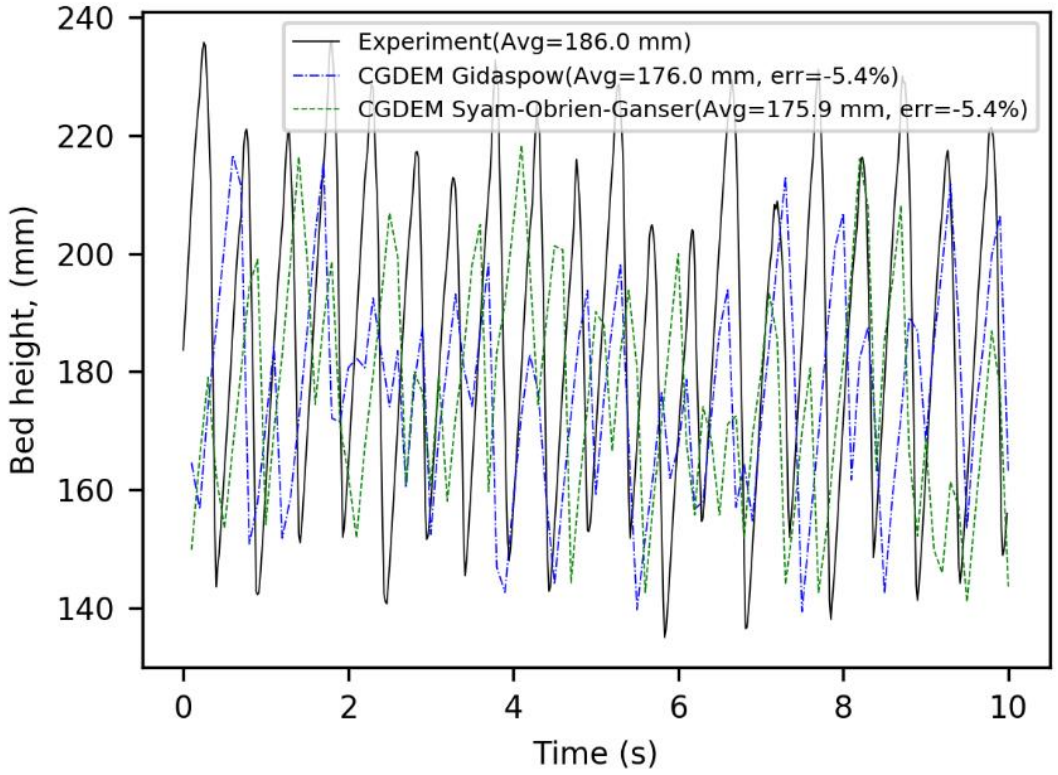
F - LED light

G - Black board

- A new 1 inch fluidized bed was build
- Bubbling and slugging fluidization regime
- Seven pressure drops were measured (100Hz)
- Expansion bed height were measured (60Hz)

Research 1 : Bed Height (3Umf, 4.0wt% biomass)

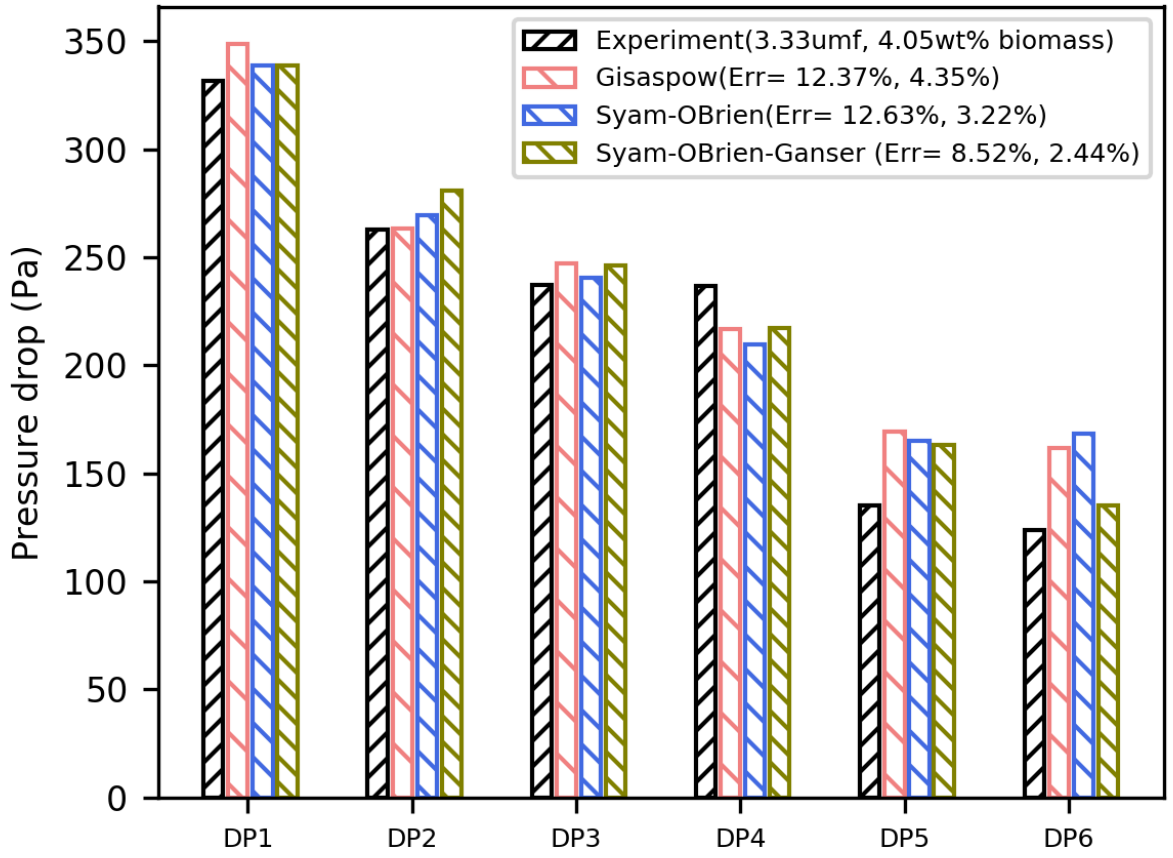




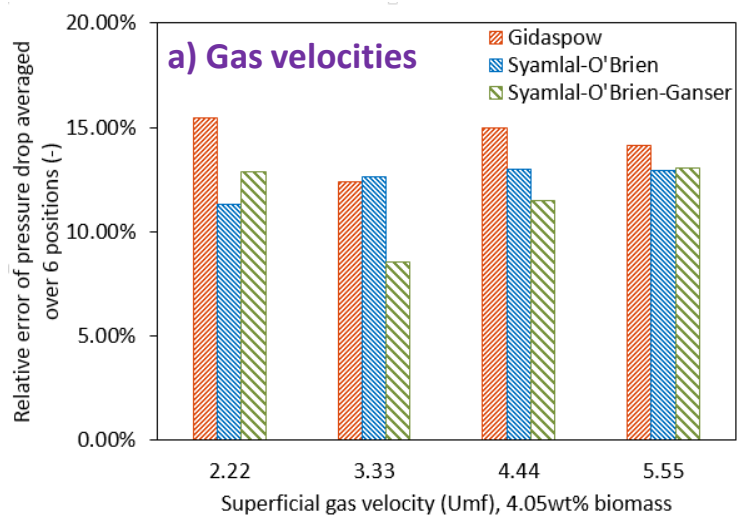
Both of the tested drag models predict reasonable results.

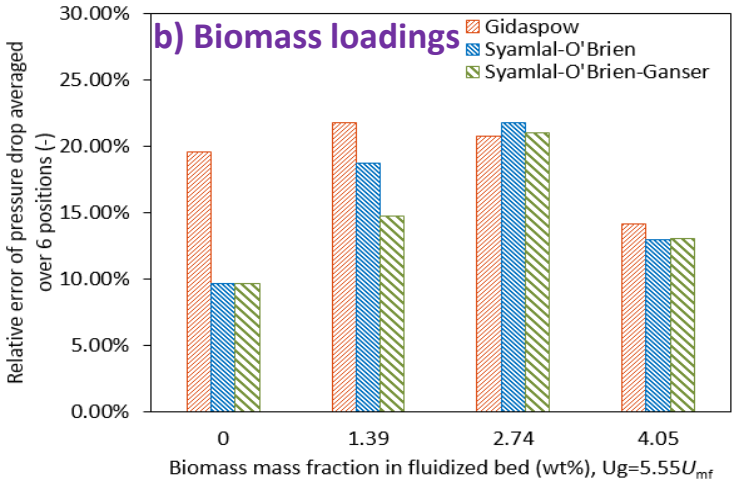
- **Gidaspow (5.4%)**
- **Syamlal-O'Brien -Ganser (5.4%)**

Research 1 : Axial pressure drops (6 locations, 4 gas velocities, 4 biomass loadings)



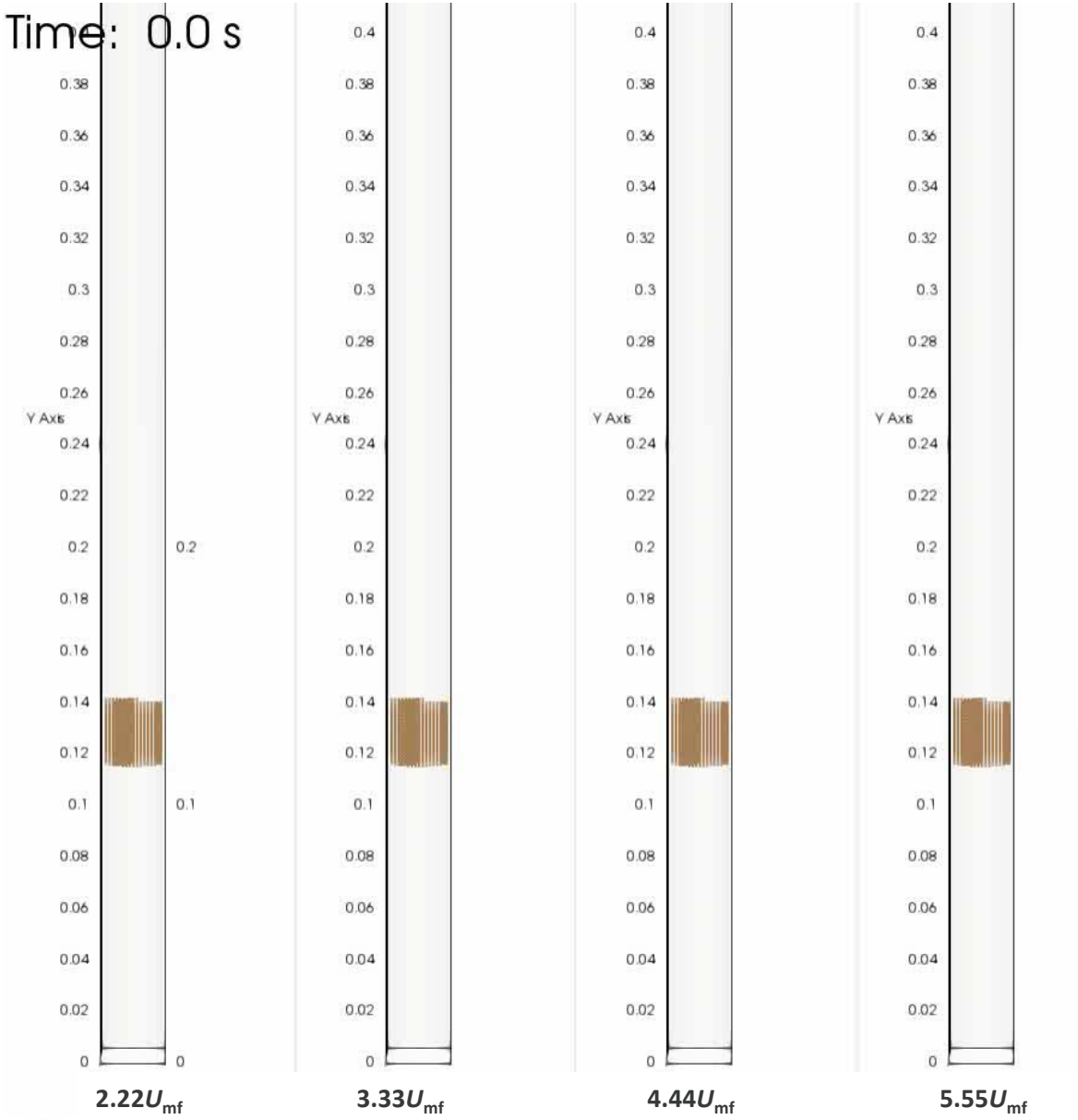
$$Err = \frac{1}{6}\sum_{i=1}^{6}\frac{\left(\Delta P^{i}_{\text{simulation}} - \Delta P^{i}_{\text{experiment}}\right)}{\Delta P^{i}_{\text{experiment}}}$$

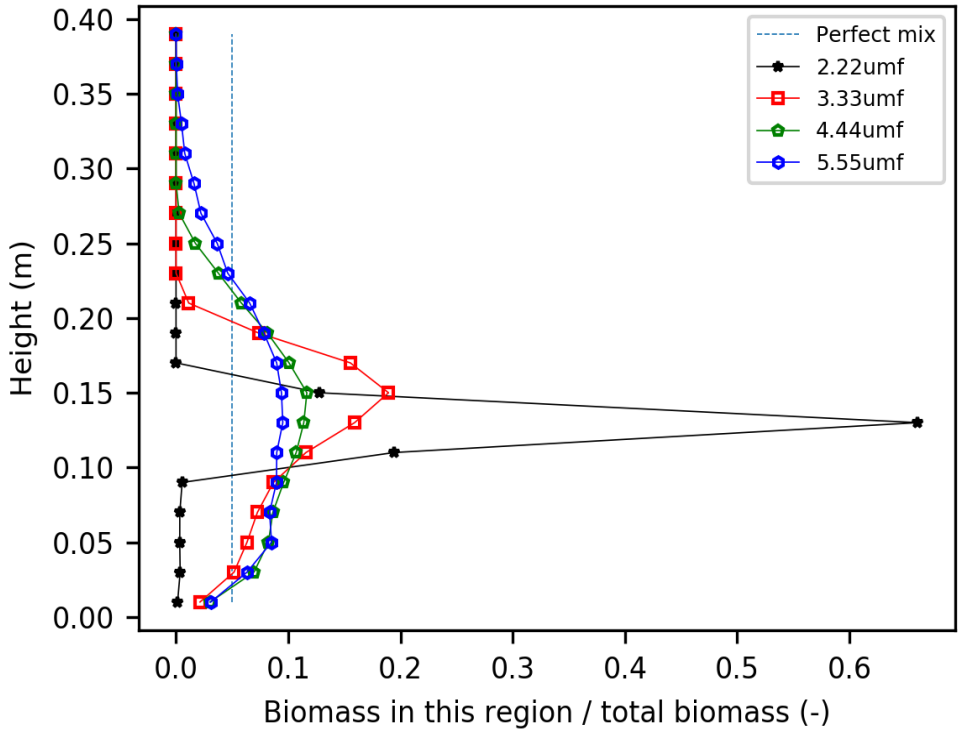




The new Hybrid Syamlal-O'Brien-Ganser drag model has the smallest error.

Research 1 : Mixing of Biomass under different velocity

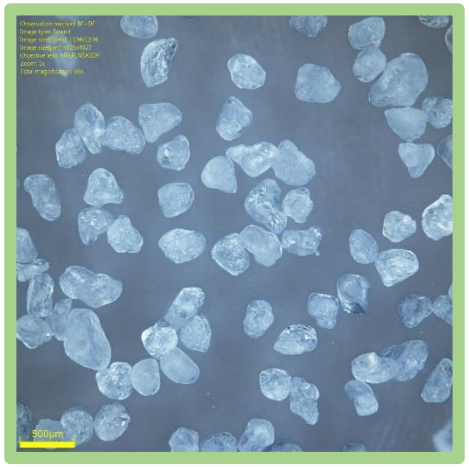


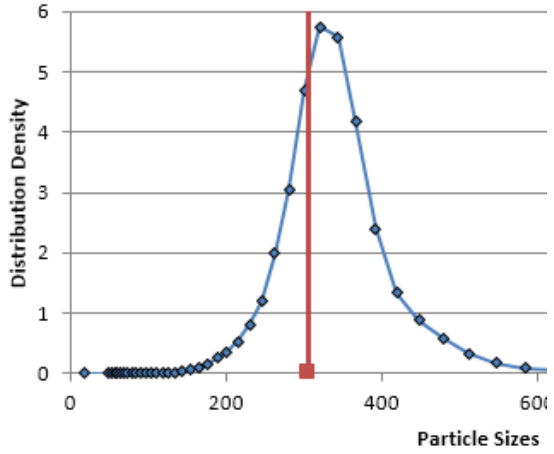


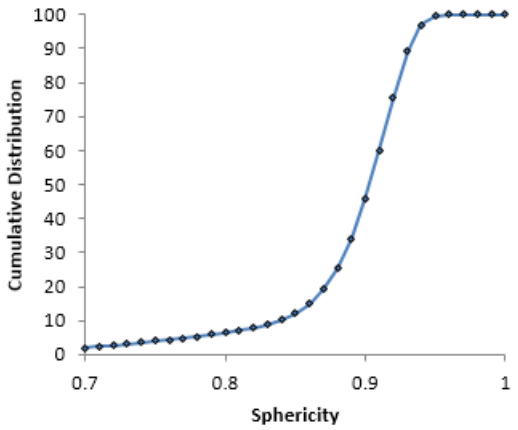
The dash line is the perfect mixing line when the biomass particles are uniformly distributed in the fluidized bed from 0 to 0.4 m. It is obvious that the distribution line is moving toward the perfect mixing line as the increase of superficial velocity. To achieve a good mixing, the superficial velocity should be larger than about 4.44 Umf.

Research 2: Black Rock Sands (Geldart B) + Small Loblolly Pine & Midrange Ash Tree (Geldart A)

Black Rock
W-430 Sand

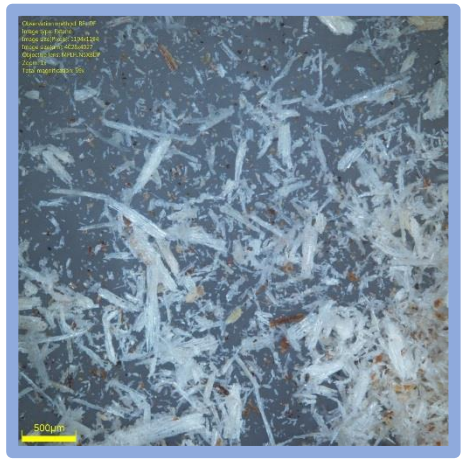


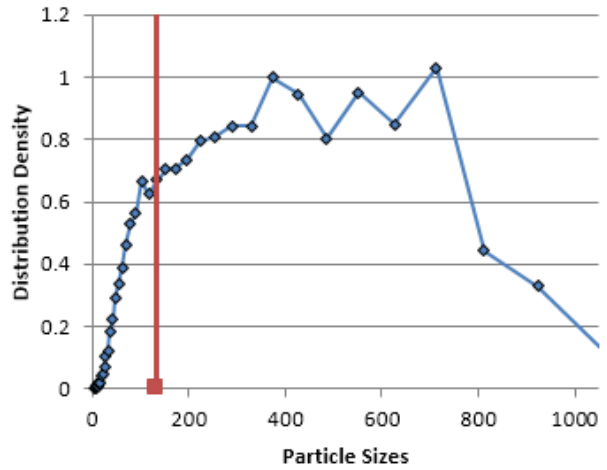


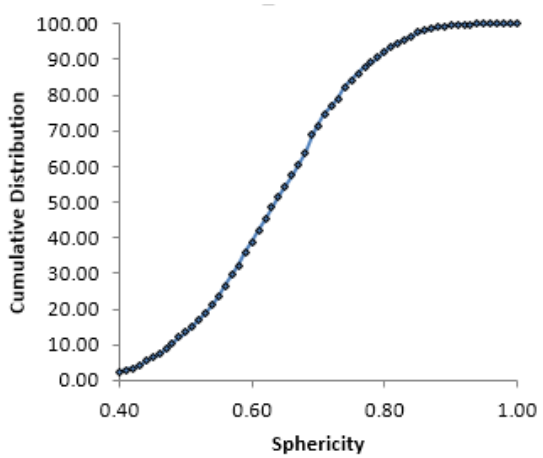


Sample #	Sample Name	SMD [um]	90% Size Distribution [um]	Sphericity	80% Sphericity Distribution	Aspect Ratio	80% Aspect Ratio Distribution
NETL-MAT-237	(250-425 micron) Black Rock W-430 Sand	**306.02**	219 ~ 432	**0.903**	0.84 ~ 0.93	**0.729**	0.58 ~ 0.85
NETL-MAT-242	Loblolly Pine + Midrange Ash Tree	**129.49**	41 ~ 805	**0.626**	0.468 ~ 0.788	**0.373**	0.21 ~ 0.66

Loblolly Pine
Midrange Ash Tree







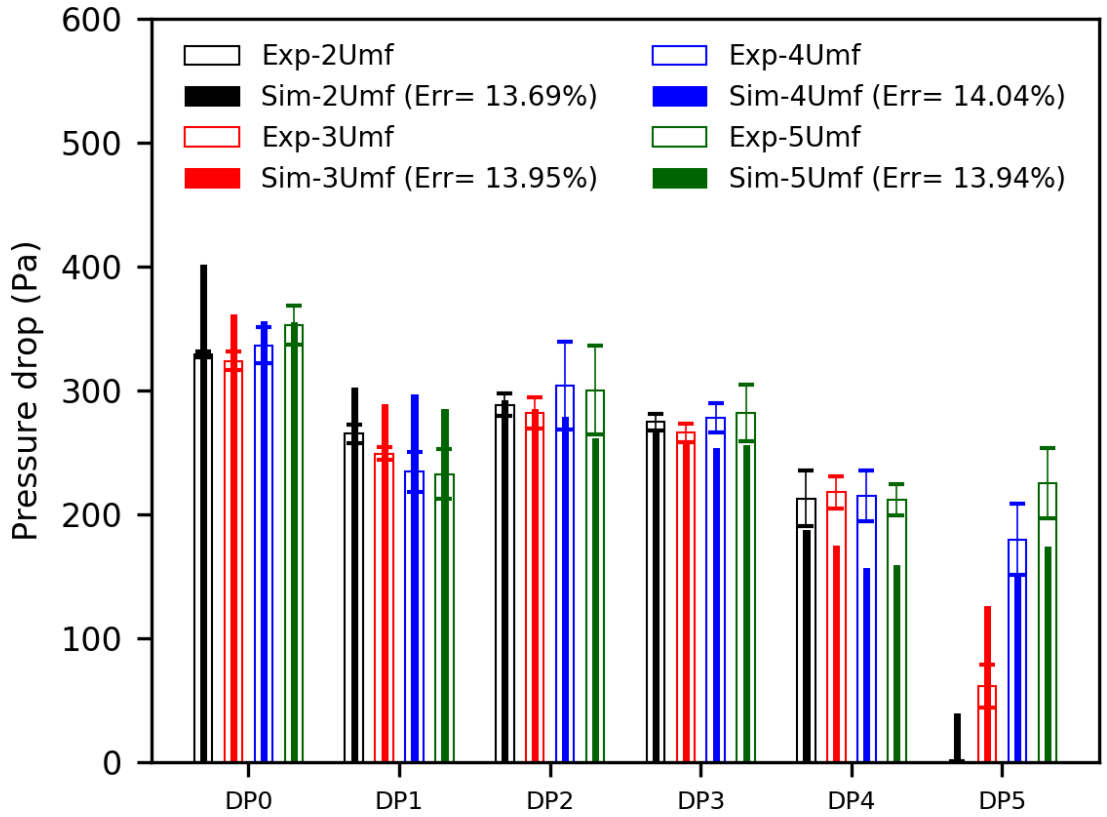
Research 2: Black Rock Sands (Geldart B) + Small Loblolly Pine & Midrange Ash Tree (Geldart A)

3 Umf

Sands Only

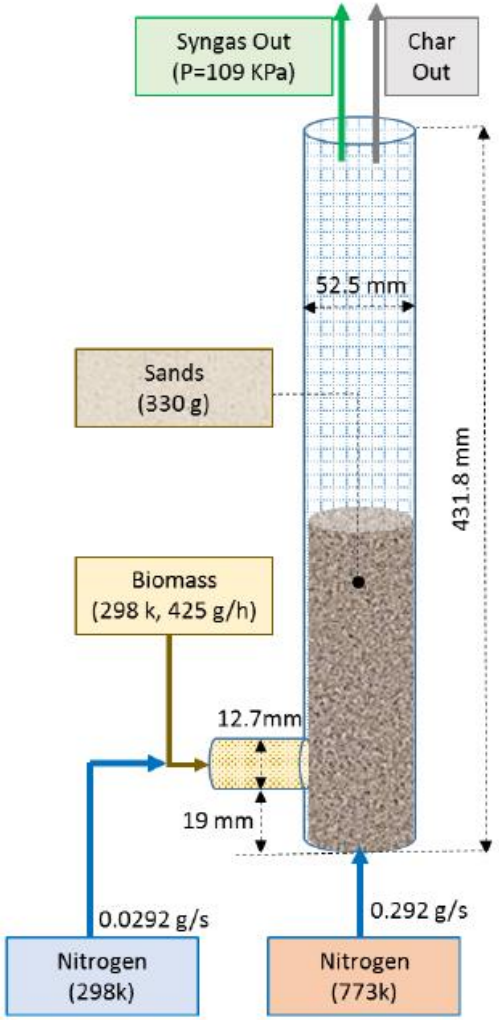
Sands & 5% Biomass

Simulation

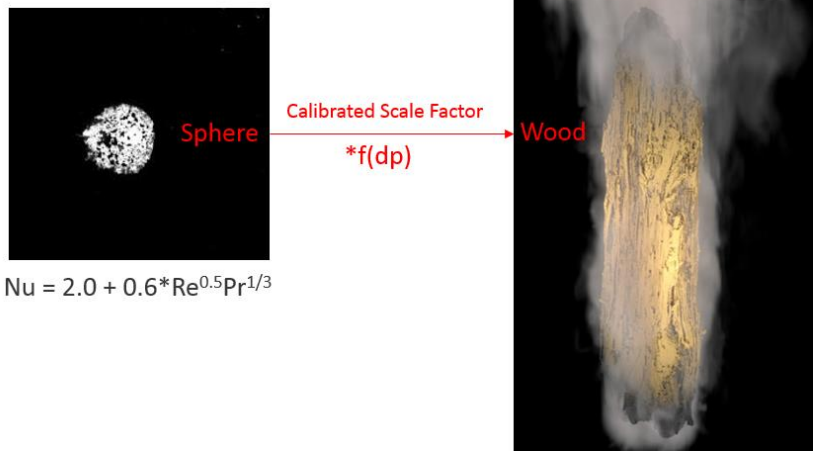


The video has been slowed down by a factor of 6.

Research 3: 500 micro Sands + polydispersed micro pine pellets



Heat Transfer



$Nu = 2.0 + 0.6*Re^{0.5}Pr^{1/3}$

Chemical Reactions

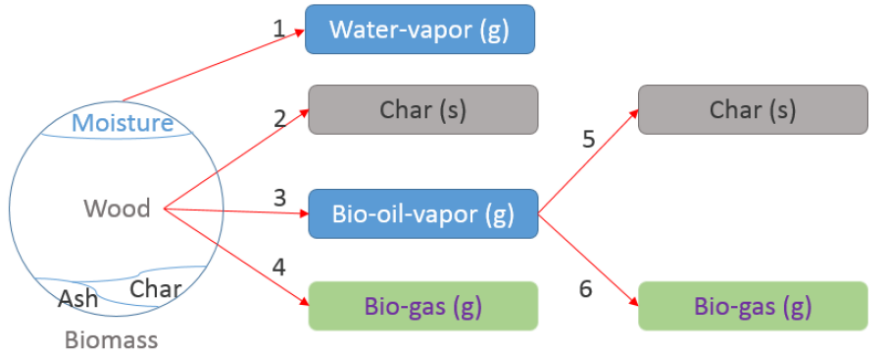
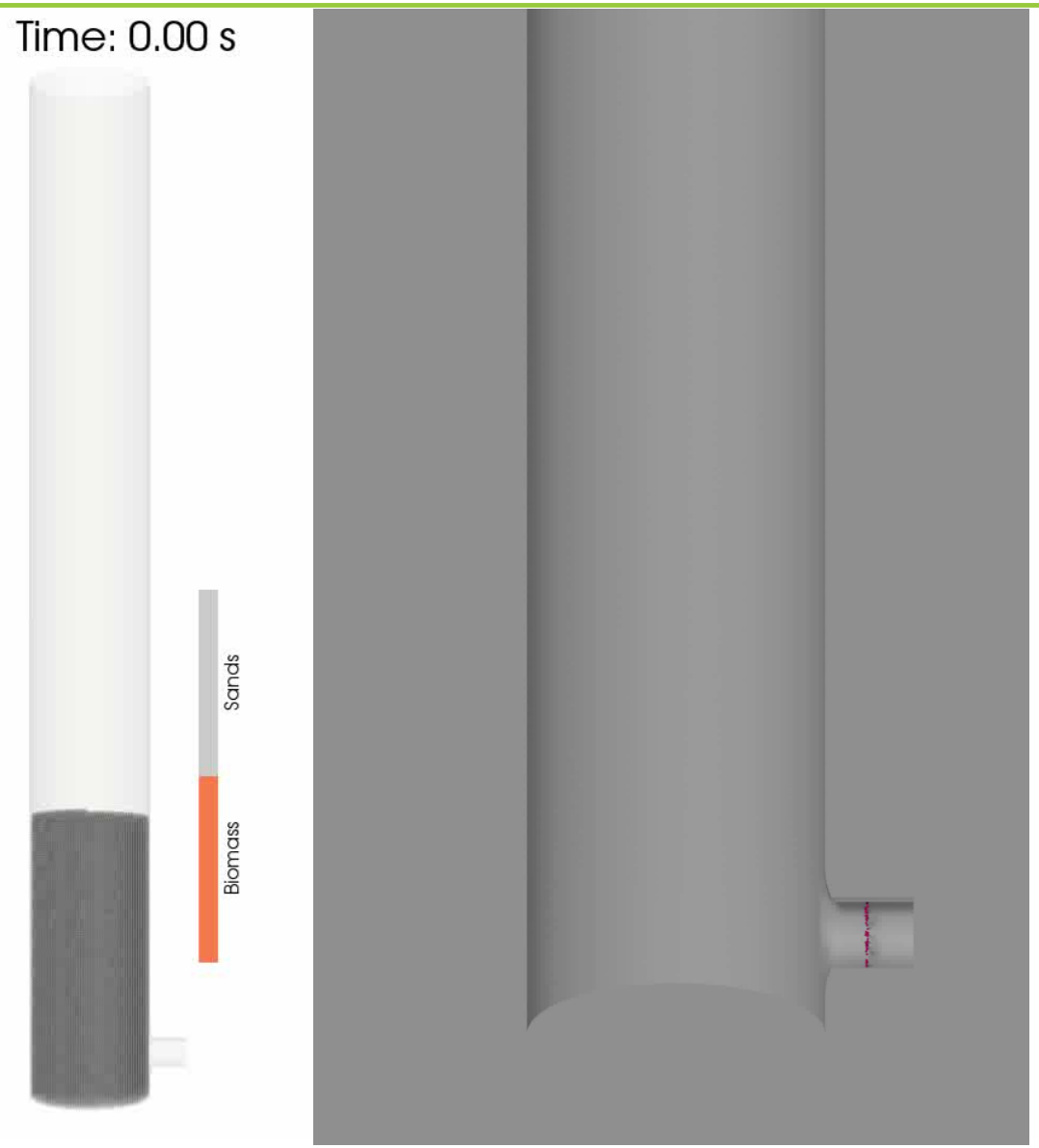


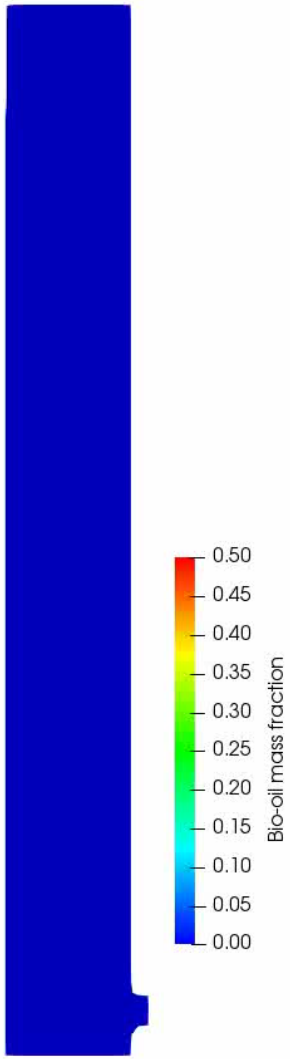
Table 1 Values of the pre-factor, the active energy, and the reaction heat

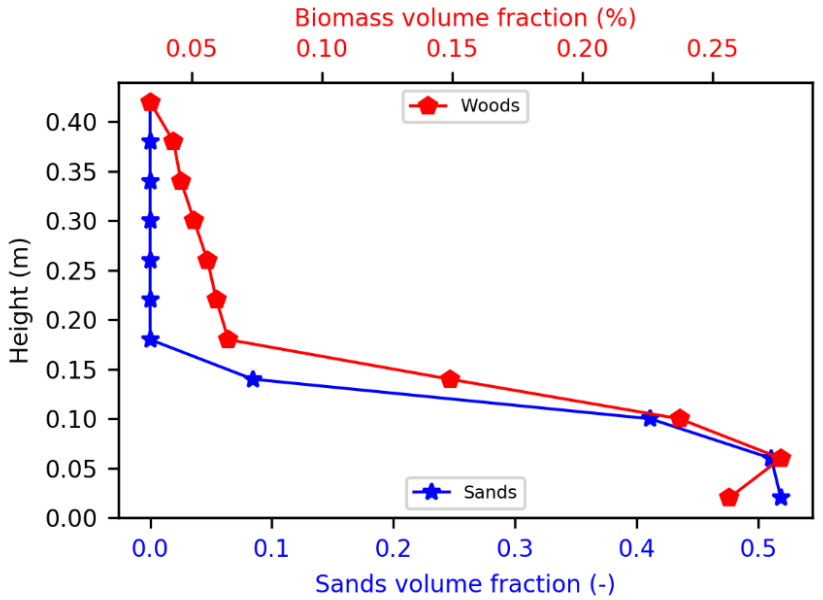
Reactions	A_i (s^{-1})	E_i (kJ/mol)	Reaction Heat (kJ/kg)
1. Moisture(s) → water-vapor(g)	5.13×10^6	87.9	2700
2. Wood(s) → 8.33333 Char(s)	3.75×10^6	111.7	-20
3. Wood(s) → 0.78020 Bio-oil-vapor(g)	1.08×10^{10}	148.0	255
4. Wood(s) → 6.23346 Bio-gas(g)	4.38×10^9	152.7	-20
5. Bio-oil-vapor(g) → 7.99 Bio-gas(g)	4.28×10^6	108.0	-42
6. Bio-oil-vapor(g) → 10.681 Char(s)	1.00×10^5	108.0	-42

Reference: Pecha, M.B., Ramirez, E., Wiggins, G.M., Carpenter, D., Kappes, B., Daw, S., Ciesielski, P.N., 2018. Integrated Particle-and Reactor-Scale Simulation of Pine Pyrolysis in a Fluidized Bed. *Energy & Fuels* 32, 10683-10694.

Research 3: 500 micro Sands + 200-400 micro pine pellets Hydrodynamics

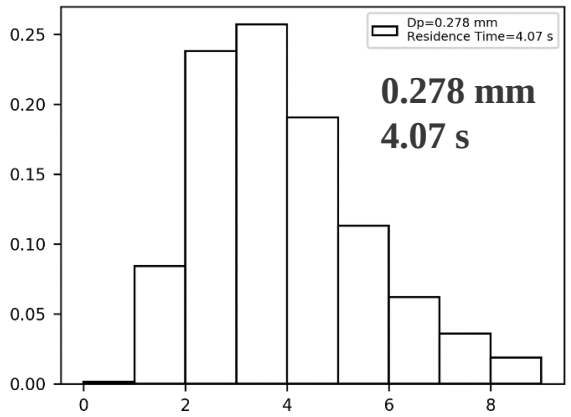


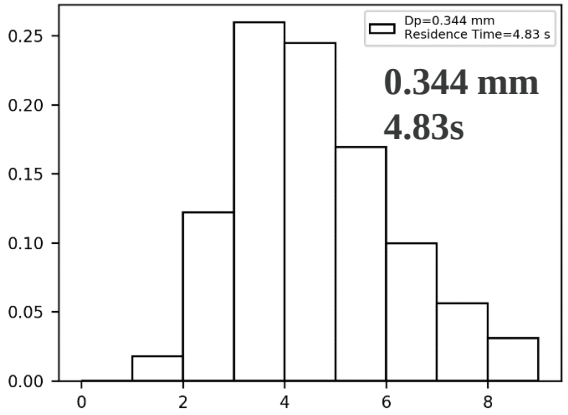


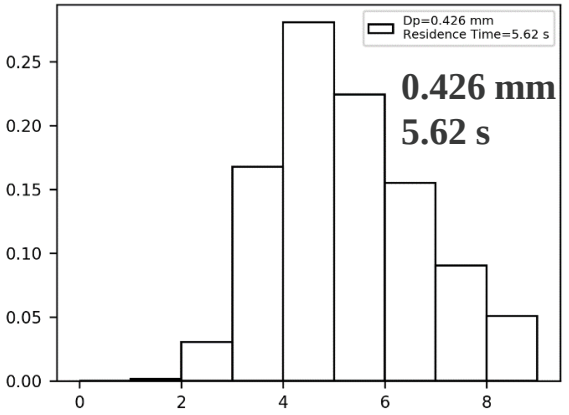


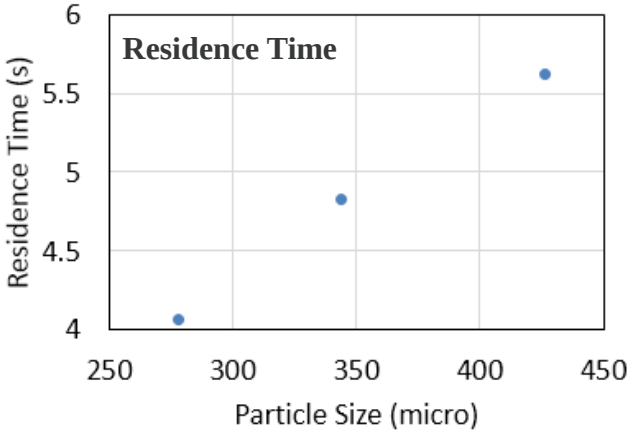
Sands formed a dense bed in the bottom region of the reactor, with no sand present above 0.20 m from the bottom of reactor. The biomass axial profile is very similar to that of sand, but the biomass particles also have a dilute region in the top region of the reactor.

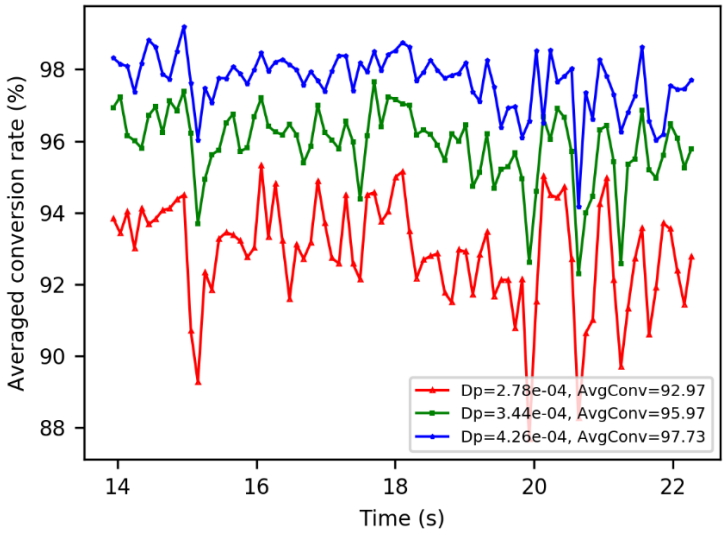
Research 3: 500 micro Sands + 200-400 micro pine pellets Residence Time





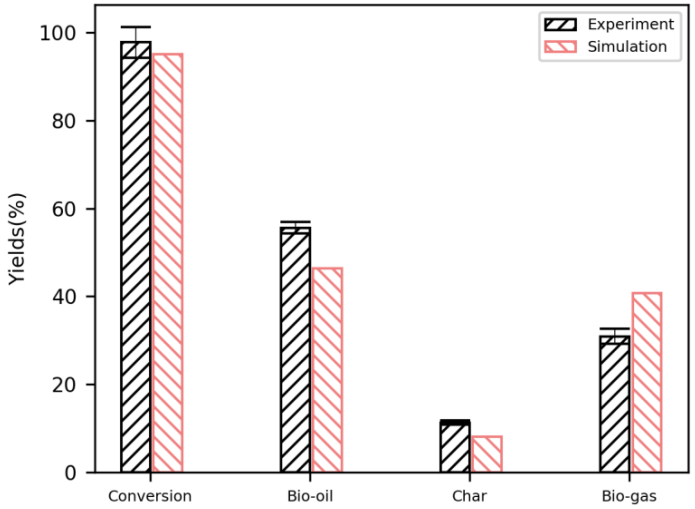






Conversion rate

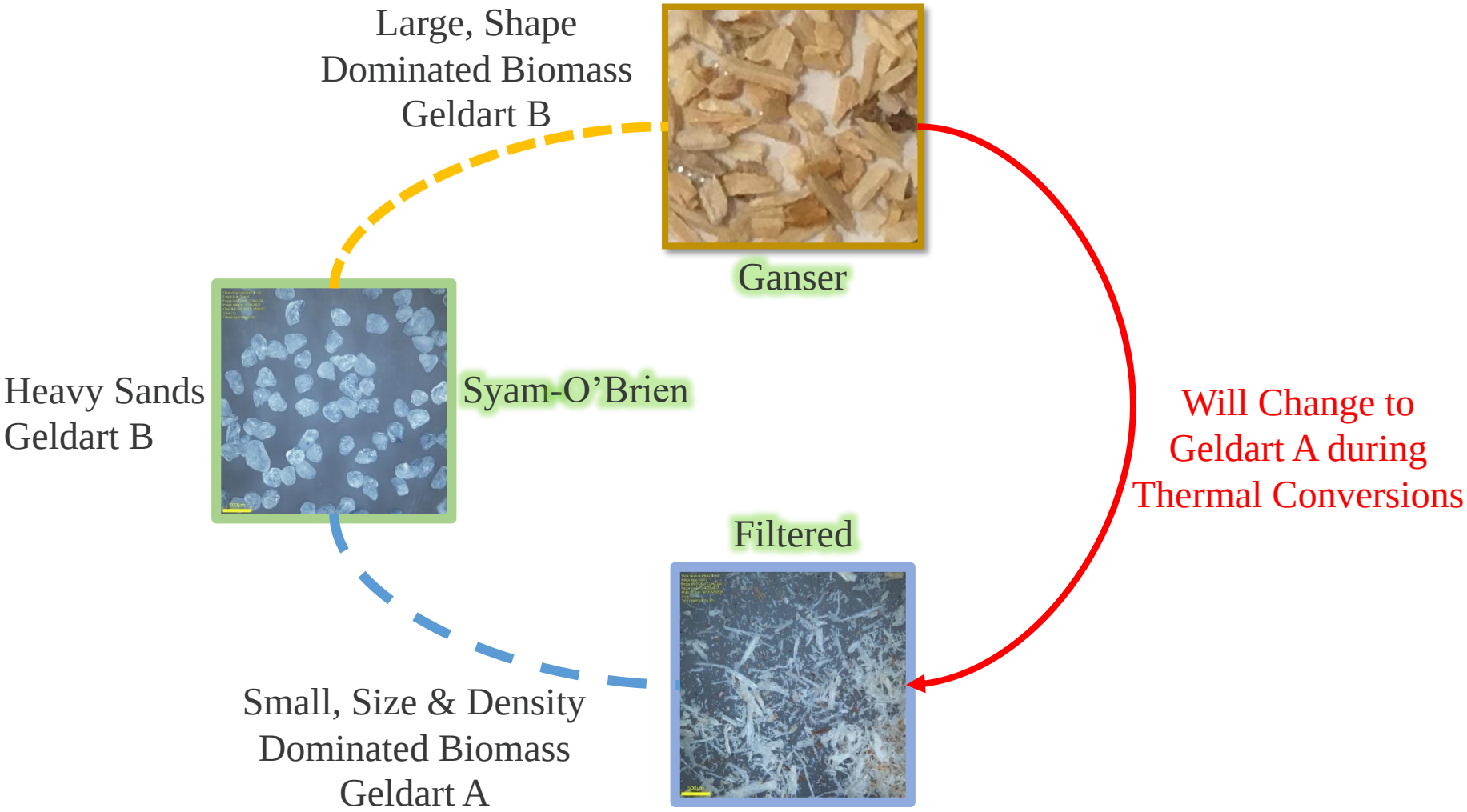
(Red: small particles, Blue: large particles)



Compare with NREL Experiment

- The small particles can be heated more quickly and pyrolyzed faster than the larger particles.
- However, the small particles has a smaller residence time.
- Here the results indicate that the influence of residence time is stronger than the reaction kinetics and heat transfer speed.
- This means there is no need to futher grind the biomass particles for higher conversion rate.

Summary


Large, Shape
Dominated Biomass
Geldart B
Ganser
Heavy Sands
Geldart B
Syam-O'Brien
Will Change to
Geldart A during
Thermal Conversions
Filtered
Small, Size & Density
Dominated Biomass
Geldart A