# Flow Characterization Of Compressed Woody Biomass

Ehsan Akbari Fakhrabadi[1], Matthew Liberatore[1]

Jonathan Stickel[2]

[1]Chemical Engineering Department, The University of Toledo

[2]National Renewable Energy Laboratory

THE UNIVERSITY OF TOLEDO 1872

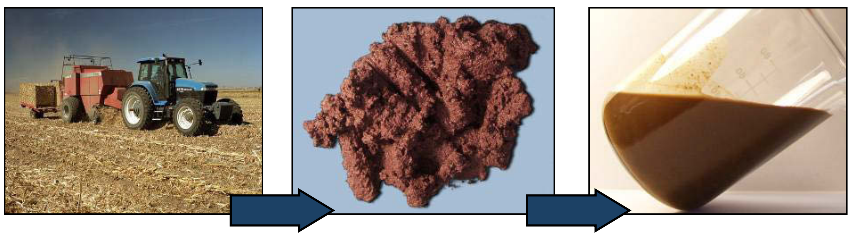
NREL/PR-2700-75653

# Acknowledgements

DE-AC36-08GO28308

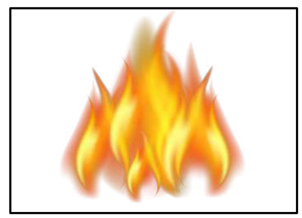
# Biomass conversion technologies

Biochemical Conversion

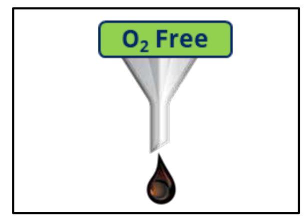


Pretreatment Enzymes

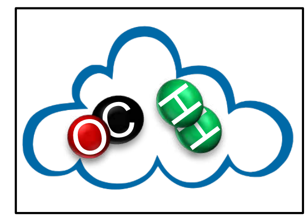
Thermochemical Conversion



Combustion




Pyrolysis




Gasification

Reaction kinetics has been studied extensively

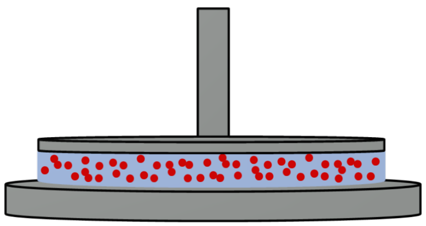
# Process: gasification to Fischer-Tropsch

Handling & Feeding → Pyrolysis & Gasification → Product Upgrading →

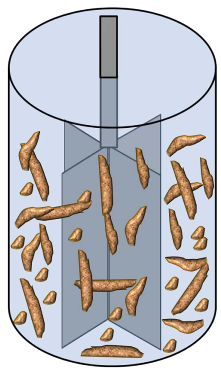
Feeding is problematic at commercial scale

# Flow in particulate systems

Increasing the concentration of solids

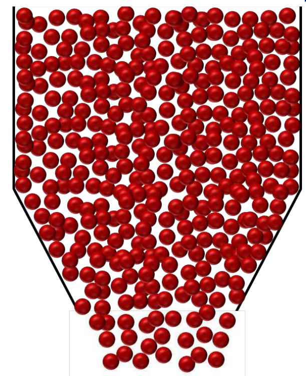


Suspension Rheology

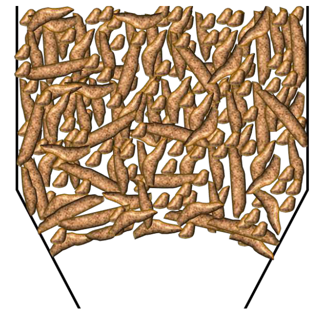


Slurry Rheology

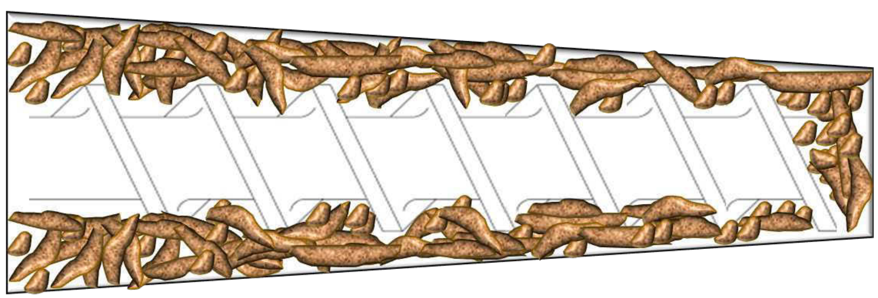
Grey Area



Granular Flow

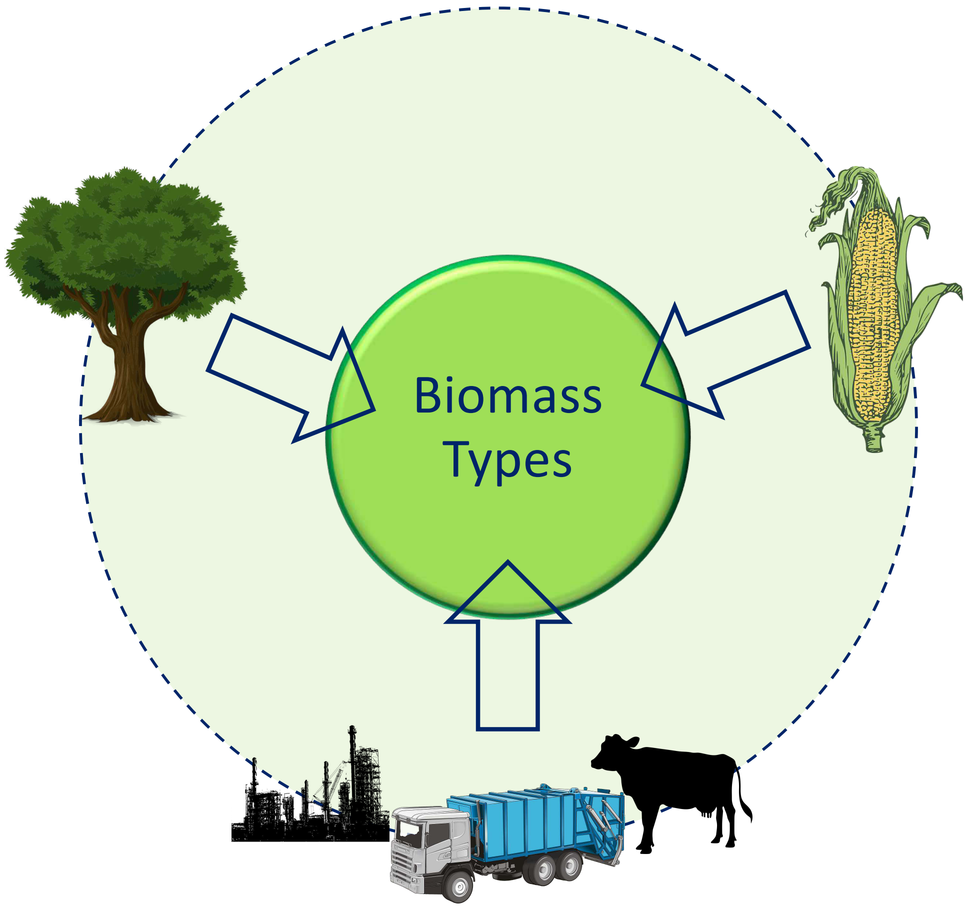


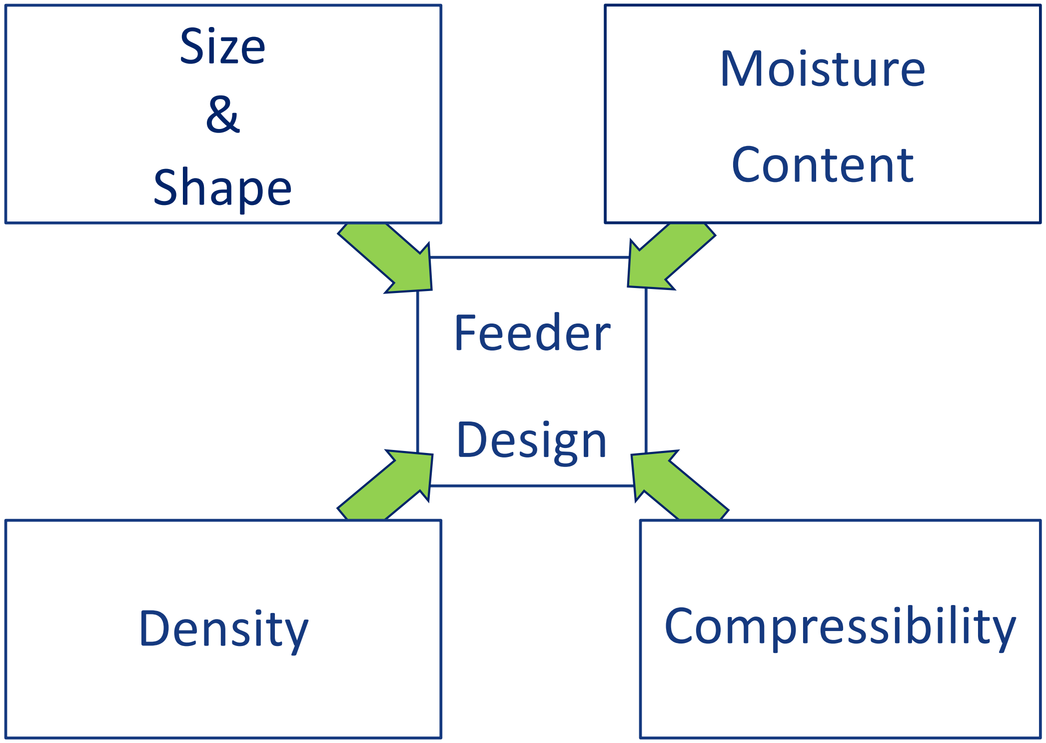
Jammed Granular Flow



Flow of compressed terrestrial biomass in a screw feeder

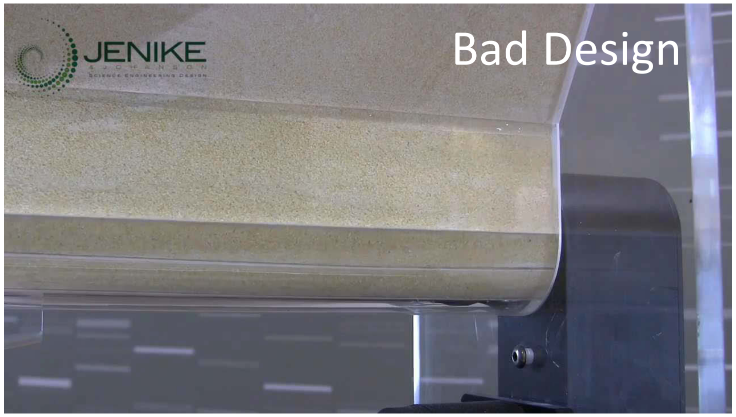
# Biomass properties affect feeder design



# Problems in solids feeding systems

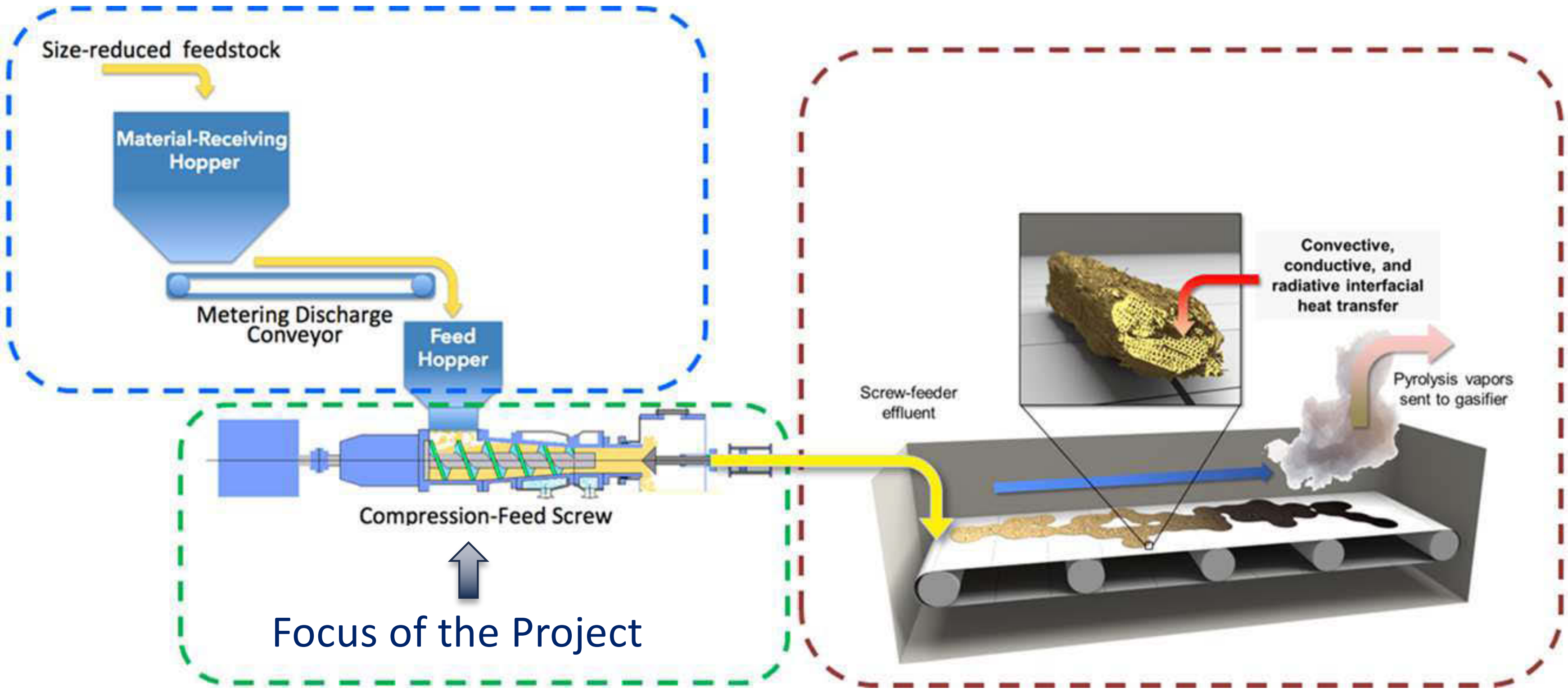
- Rat-hole formation
- Arching
- Flooding
- Seal failure
- Blockage





Jenike & Johanson, https://www.youtube.com/watch?v=ZjKbSnVESDc

# Overall goal: Optimize feedstock handling




Impact of feedstock characteristics on screw feeder

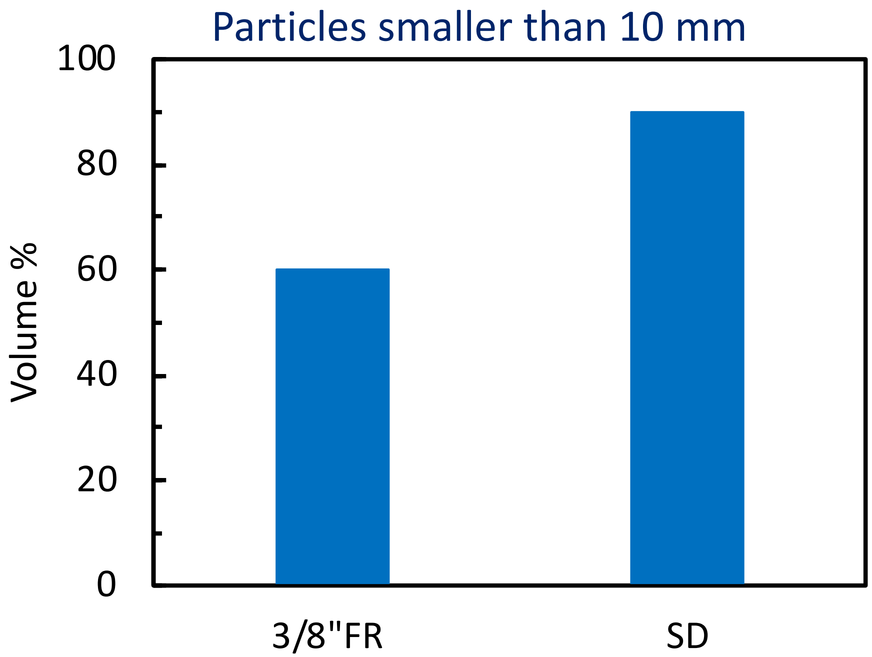
# Woody biomass material

-3/8” FR

SD

Chopped and sieved using standard methods

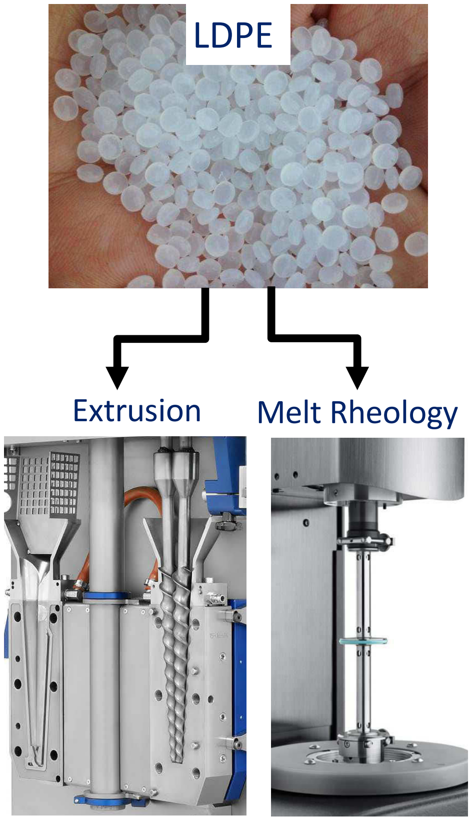
| Sample | Moisture (%) |
|---|---|
| Sawdust (SD) | 50 |
| -3/8” Forest Residual (FR) | 30 |




**Tree types:**

White fir (20%), Ponderosa pine (60%), and Lodgepole pine (20%)

# Feed measurements to models




Connect polymer extrusion + rheology

to biomass screw feeding using modeling


Project's goal requires collaboration

# Modeling compounder viscosity

$$\eta = \frac{F}{N} C_1 \qquad \dot{\gamma} = \frac{N}{C_2}$$

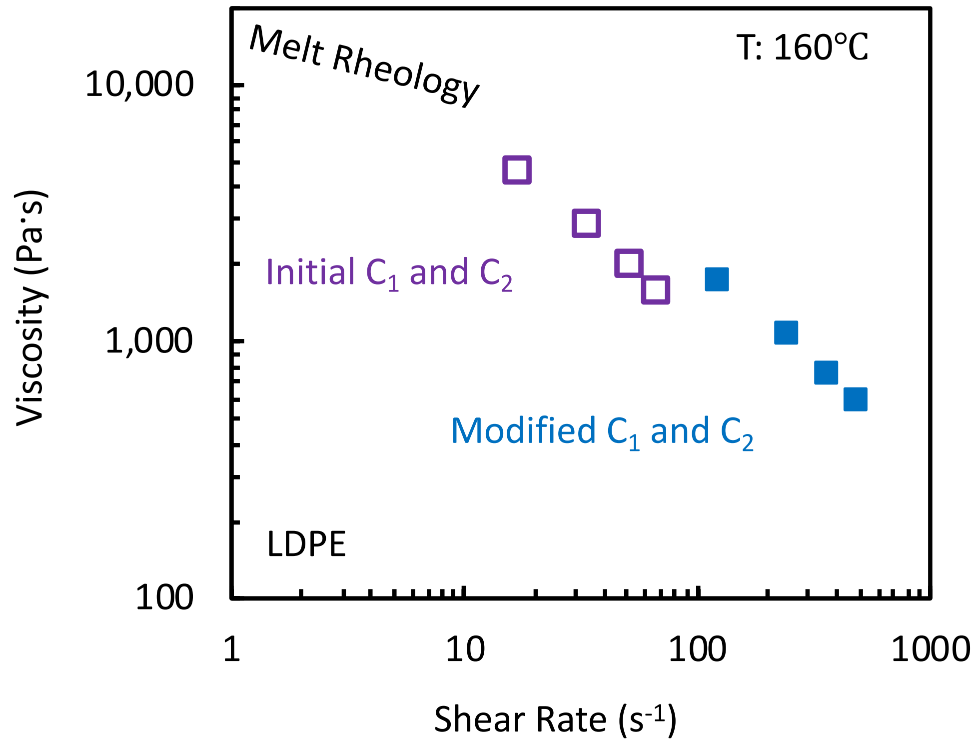
F: Axial force (N)

N: Screw speed (rpm)

$\eta$: Viscosity (Pa.s)

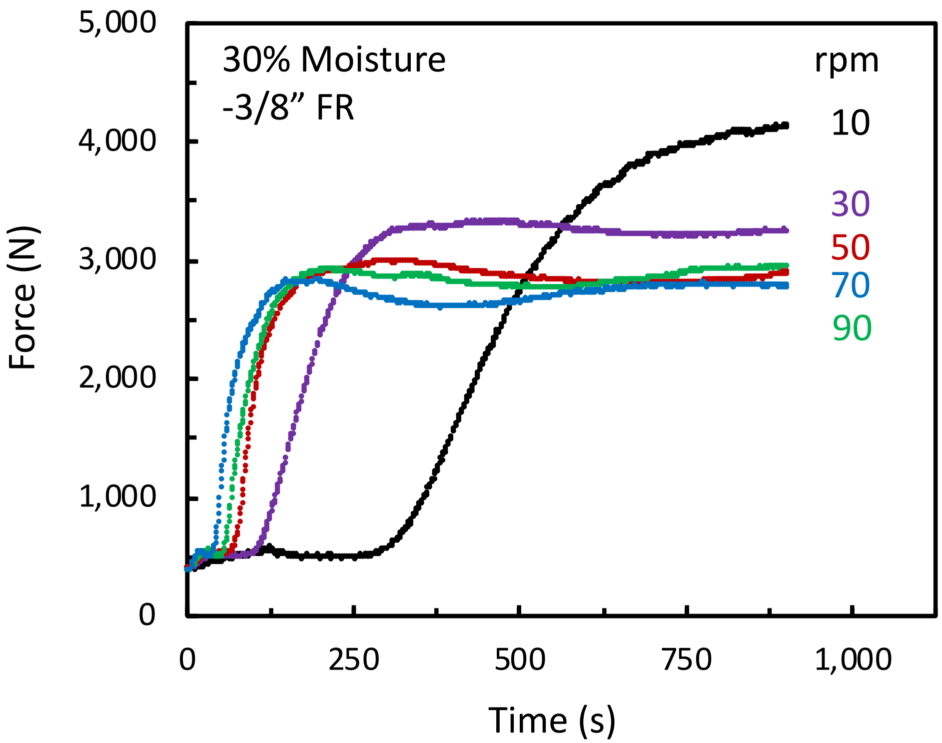
$\dot{\gamma}$ : Shear rate ($s^{-1}$)

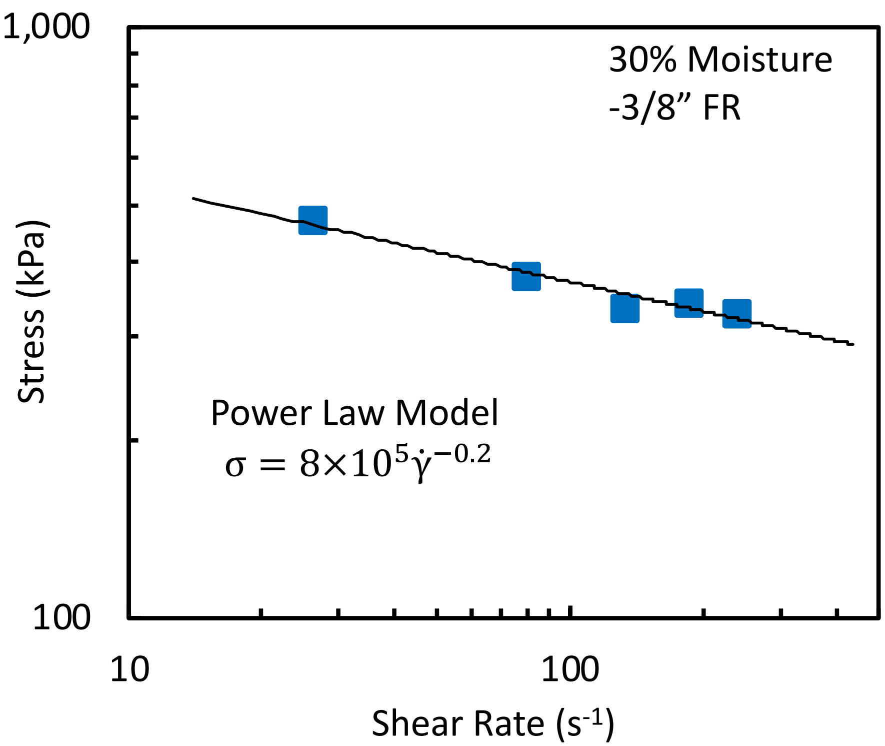
$C_1$, $C_2$: Constants




Banning et al., Estimating the melt viscosity in the Xplore micro extruder, 2012, Xplore, Netherlands.

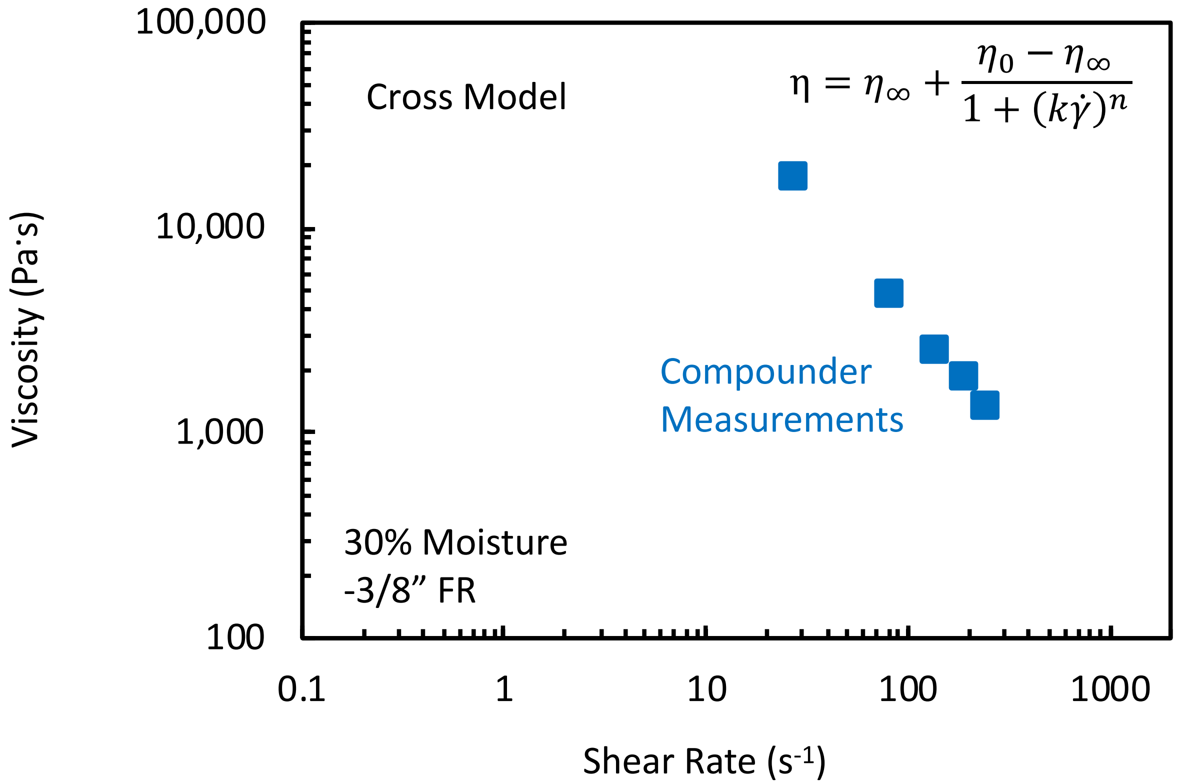
# Stress decreases as screw speed increases




Negative plastic viscosity measured

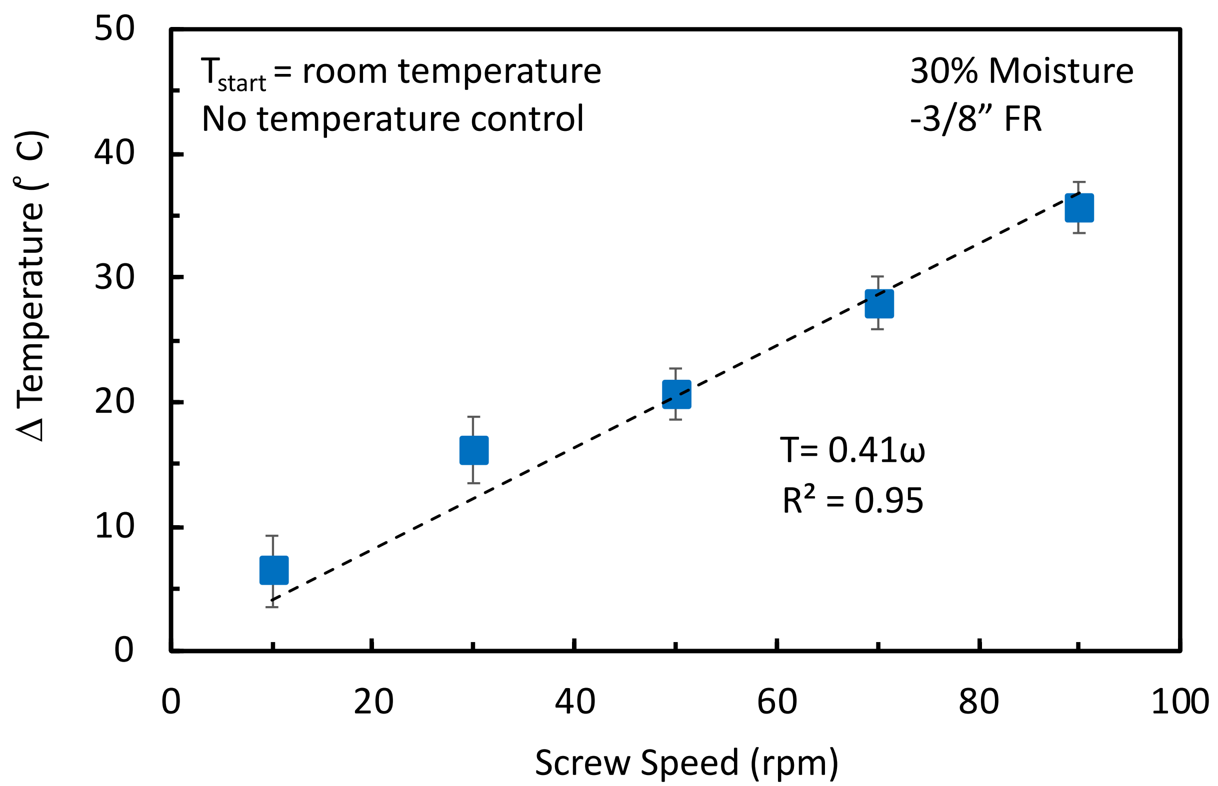
# Viscosity fits Cross model




| Cross Model Parameters | Values |
|---|---|
| $\eta_0$ (Pa·s) | 74,000 |
| $\eta_\infty$ (Pa·s) | 550 |
| k | 0.08 |
| n | 1.5 |

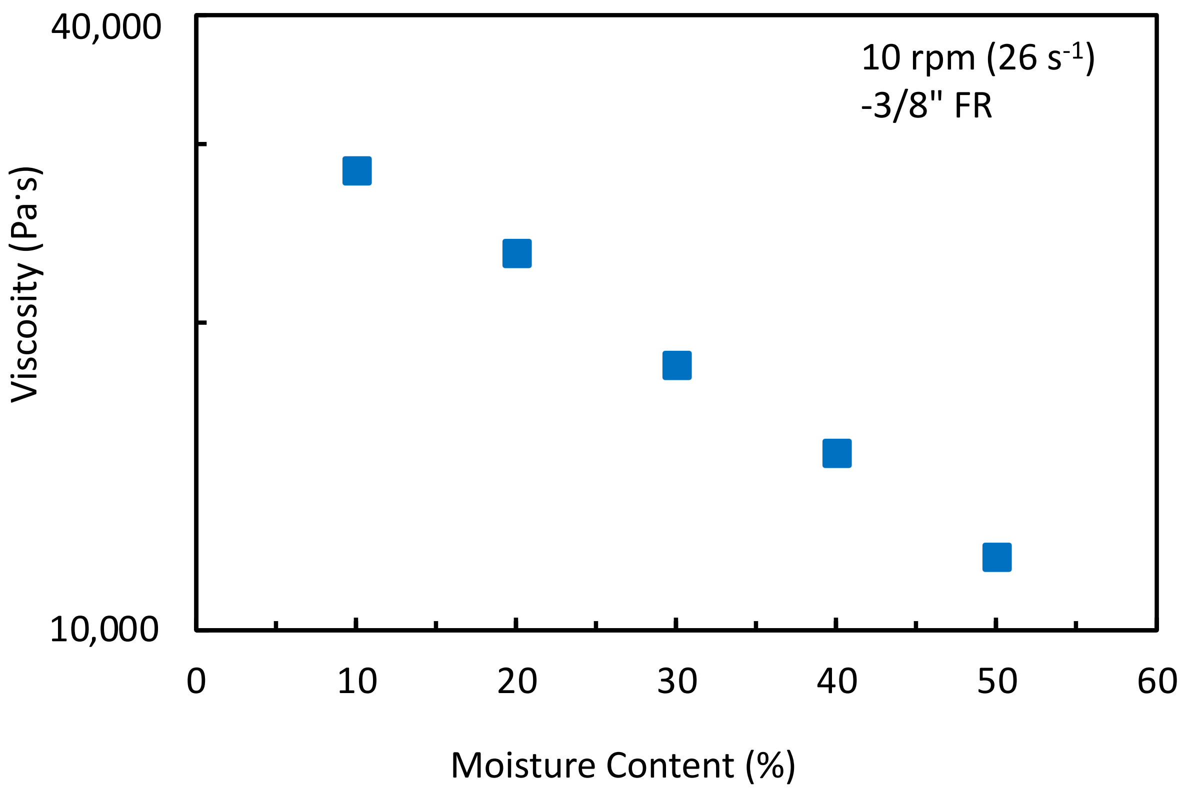
Measurements fall within shear thinning regime

# Impact of screw speed on temperature



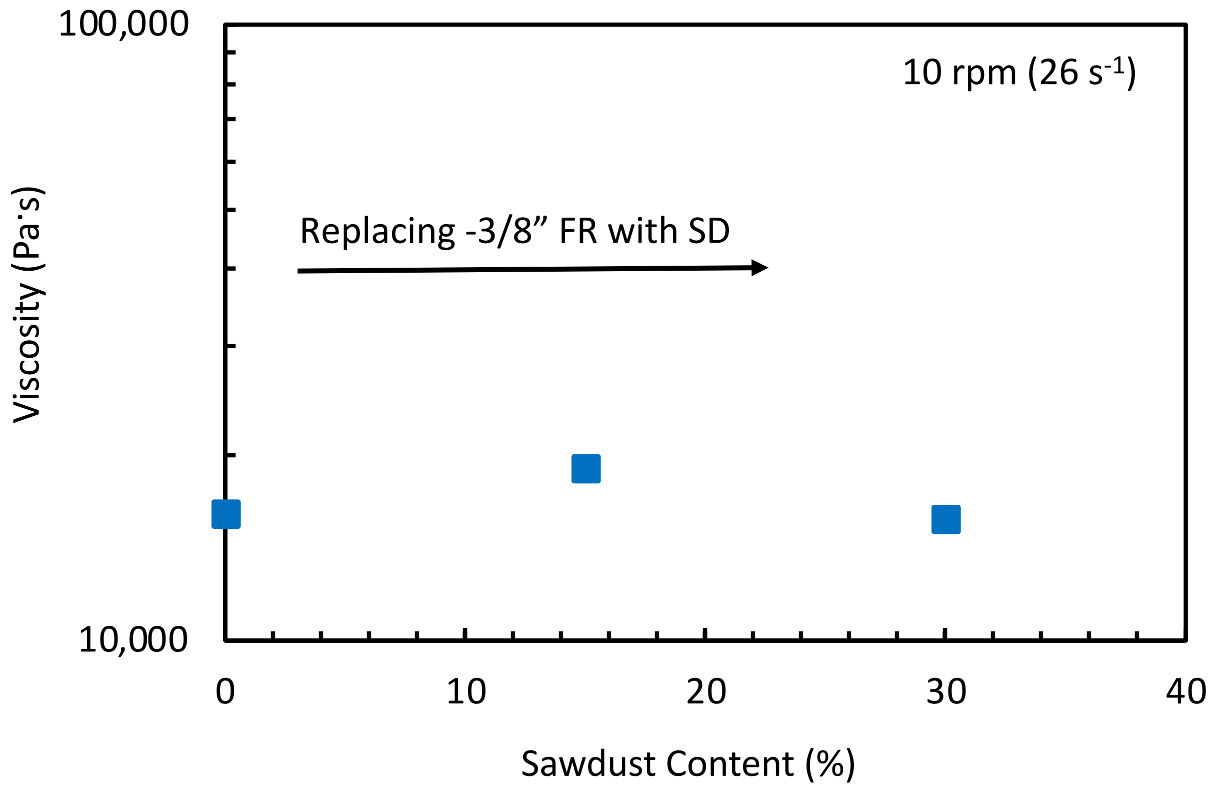

Temperature may need to be accounted for in feeder design

# Higher moisture causes better biomass flow




60% lower viscosity with increasing moisture content

# Particles size has little impact on flowability




Adding 30% sawdust does not change viscosity

# Summary - Questions? Text 720-443-1526

Higher screw speeds improves biomass flowability

Shear stress decreases with shear rate

- Negative plastic viscosity

Viscosity decreases with moisture content

Particle size distribution has little impact on viscosity

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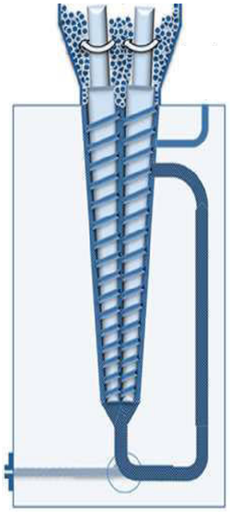
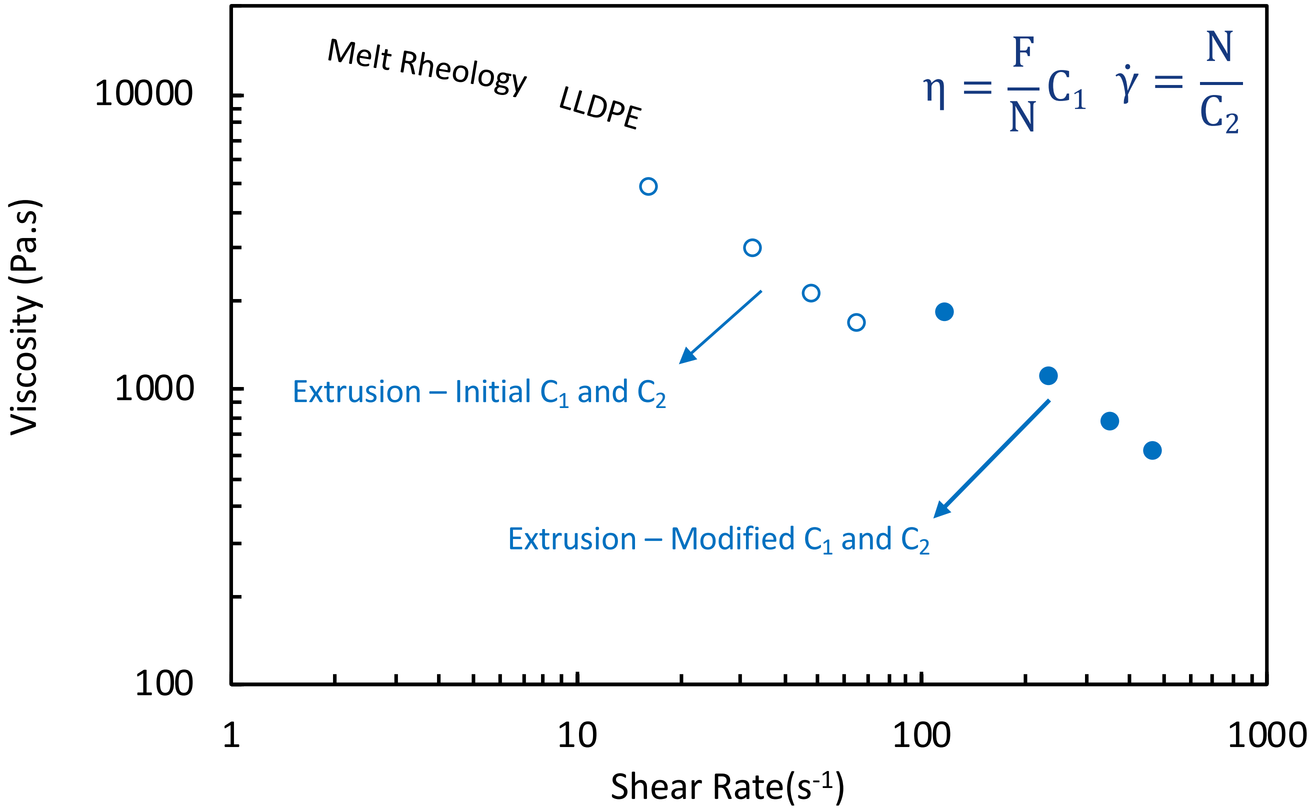
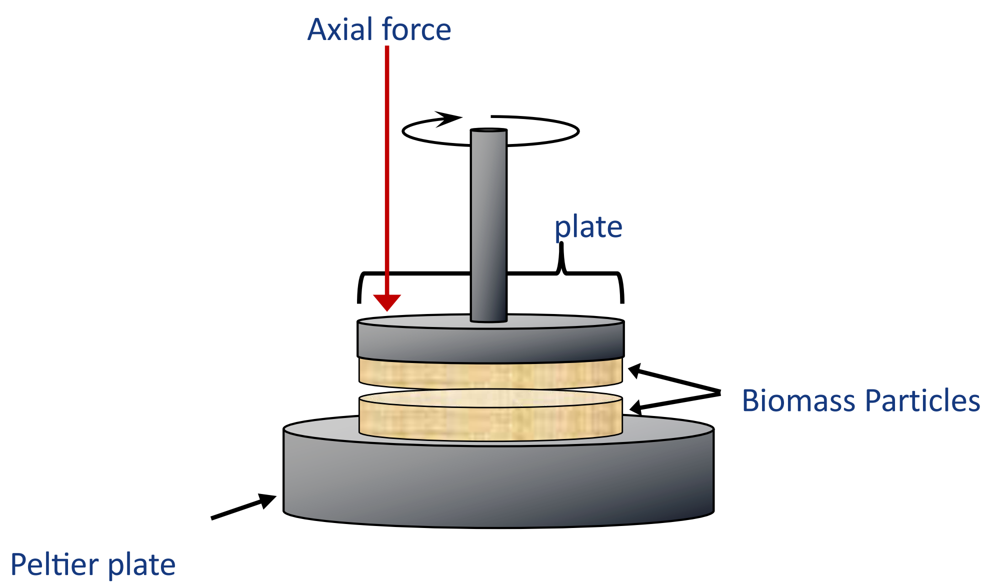
Measurements enhance CFD and equipment design

# Quantify biomass rheology data

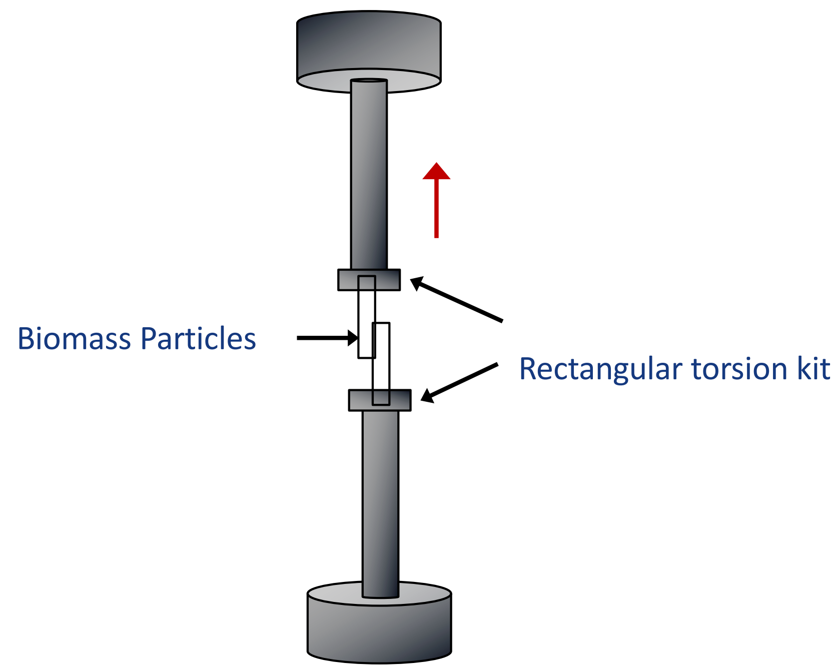





# Measure biomass Particle-Particle friction

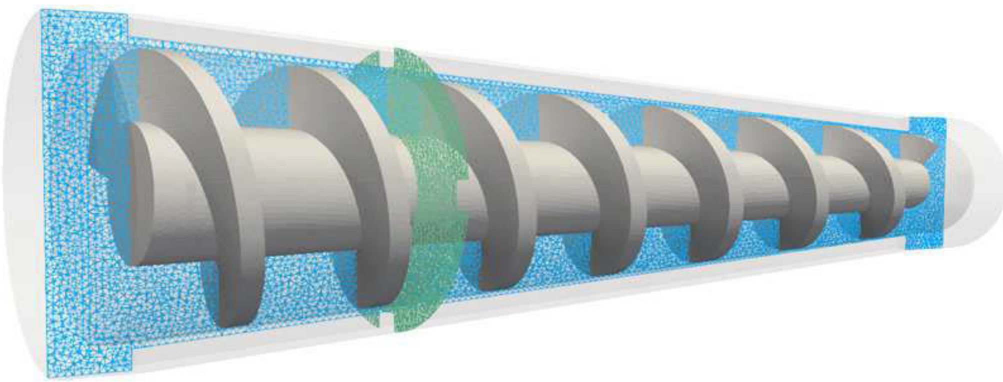


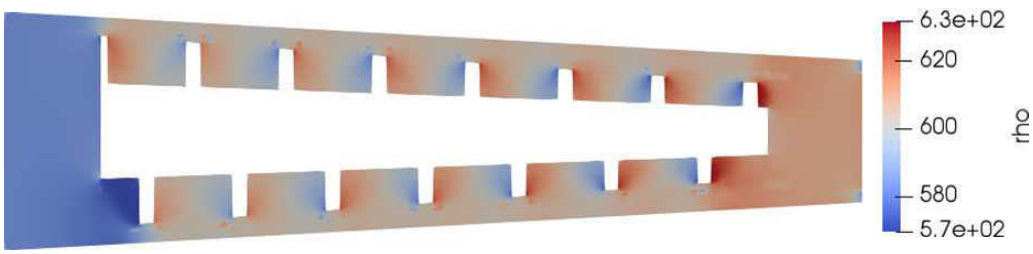

Parallel plate geometry




Rectangular torsion kit

# Develop CFD models for the screw feeder






OpenFOAM

Open source CFD tool

C++ based coding

Customized solvers

Meshing packages

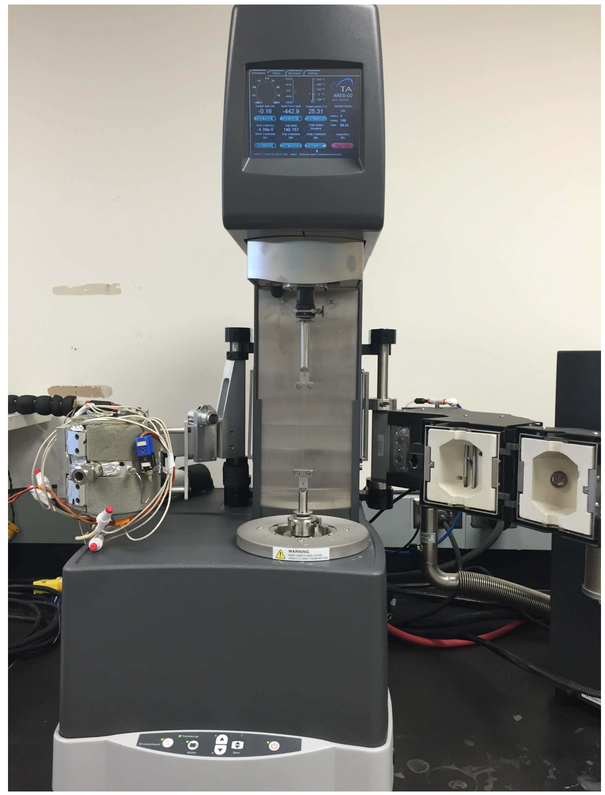
Rahimi et al., Complete Simulation of Pilot-scale Screw Feeder in Milestone Reports FY19Q2. 2019, NREL and INL.

# Timeline to graduation

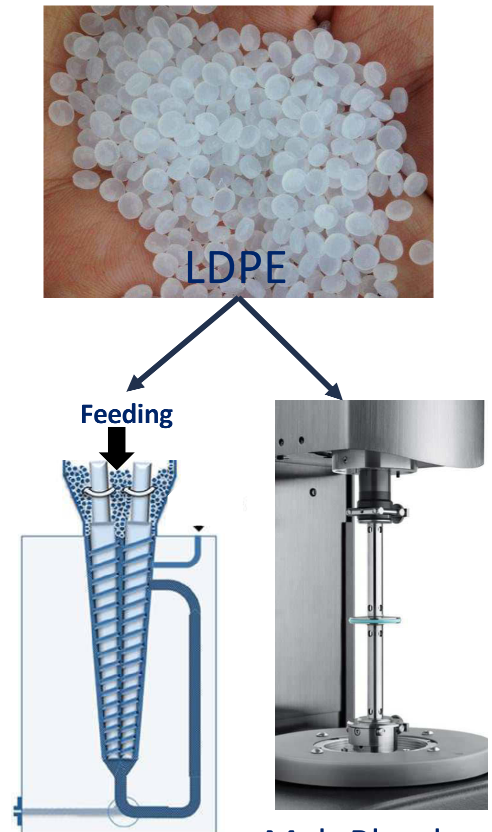
| Time Period | Research Objective |
|---|---|
| Sep 2019-Dec 2019 | High shear rheo-SALS of silica slurries |
| Sep 2019-Dec 2019 | Modeling the rheology data from the microcompounder |
| Sep 2019-May 2020 | Measuring particle-particle frictional interactions |
| Sep 2019-Dec 2020 | Developing CFD models for the screw feeder |

# Combining Measurements

Microcompounder
Xplore MC5



Rheometer
ARES G2




Melt Rheology

# Modeling the Compounder Viscosity

$$\eta = \frac{F}{N} C_1 \qquad \dot{\gamma} = \frac{N}{C_2}$$

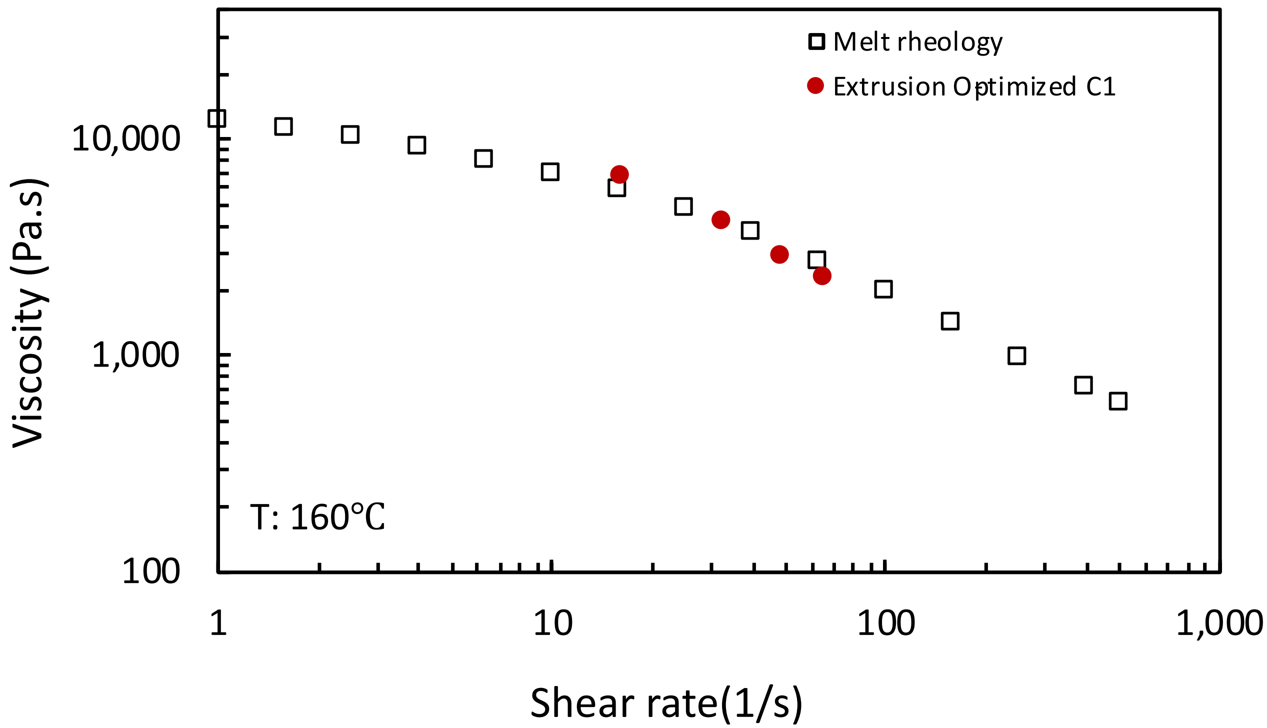
F: Axial force (N)

N: Screw Speed (rpm)

$\eta$: Viscosity (pa.s)

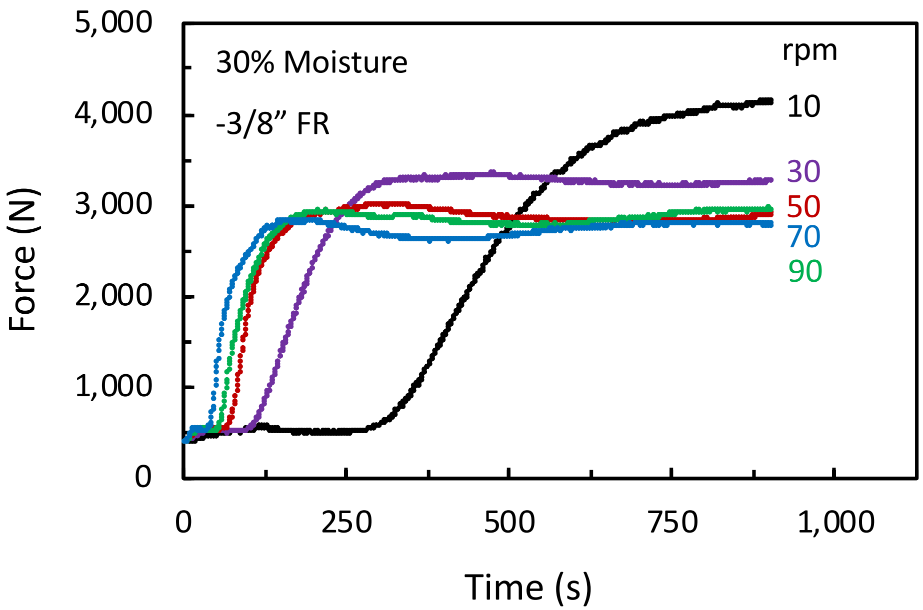
$\dot{\gamma}$ : Shear rate ($s^{-1}$)

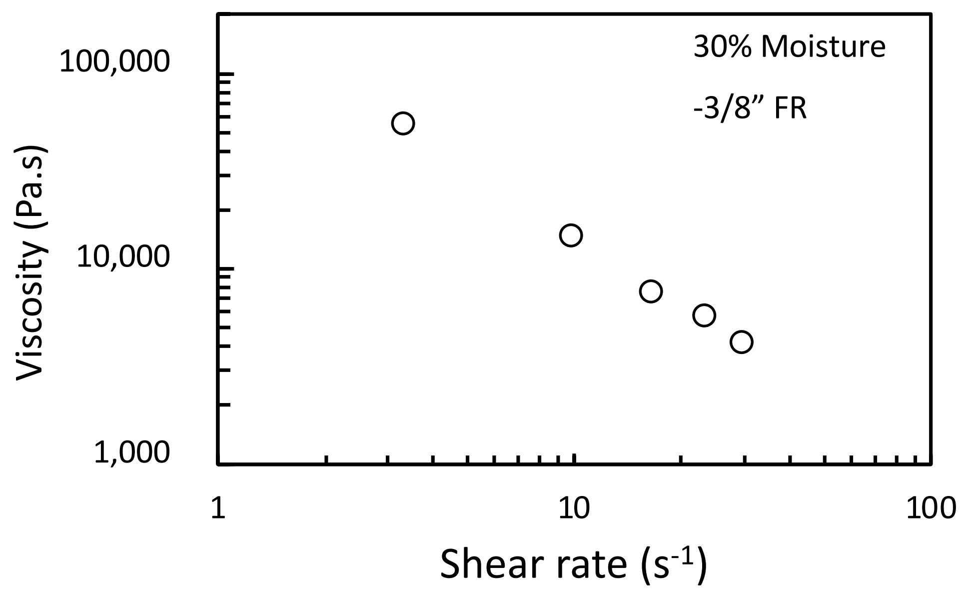
C1, C2: Constants




R.C.M. van Banning, “Estimating The Melt Viscosity in The Xplore Micro Extruder”, 2012, Xplore, Netherlands.

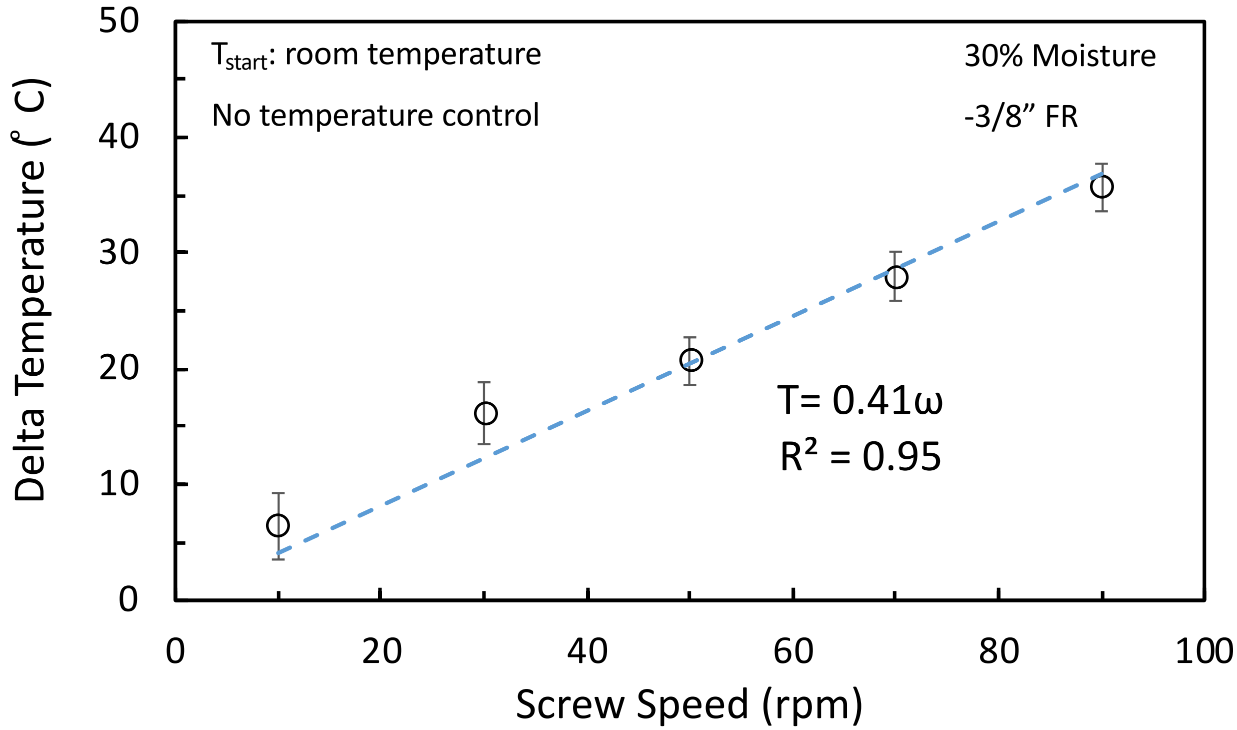
# Impact of Screw Speed on Biomass Flow



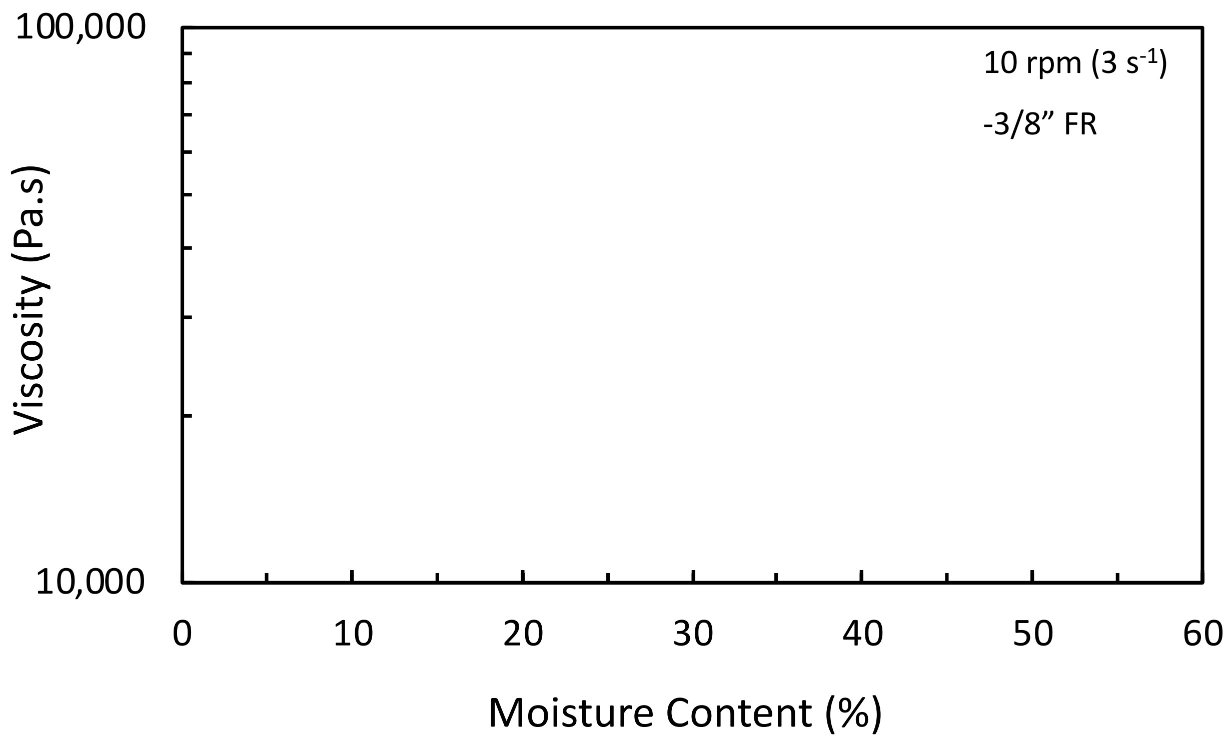

Increasing screw speed increases flowability

# Impact of Screw Speed on Temperature



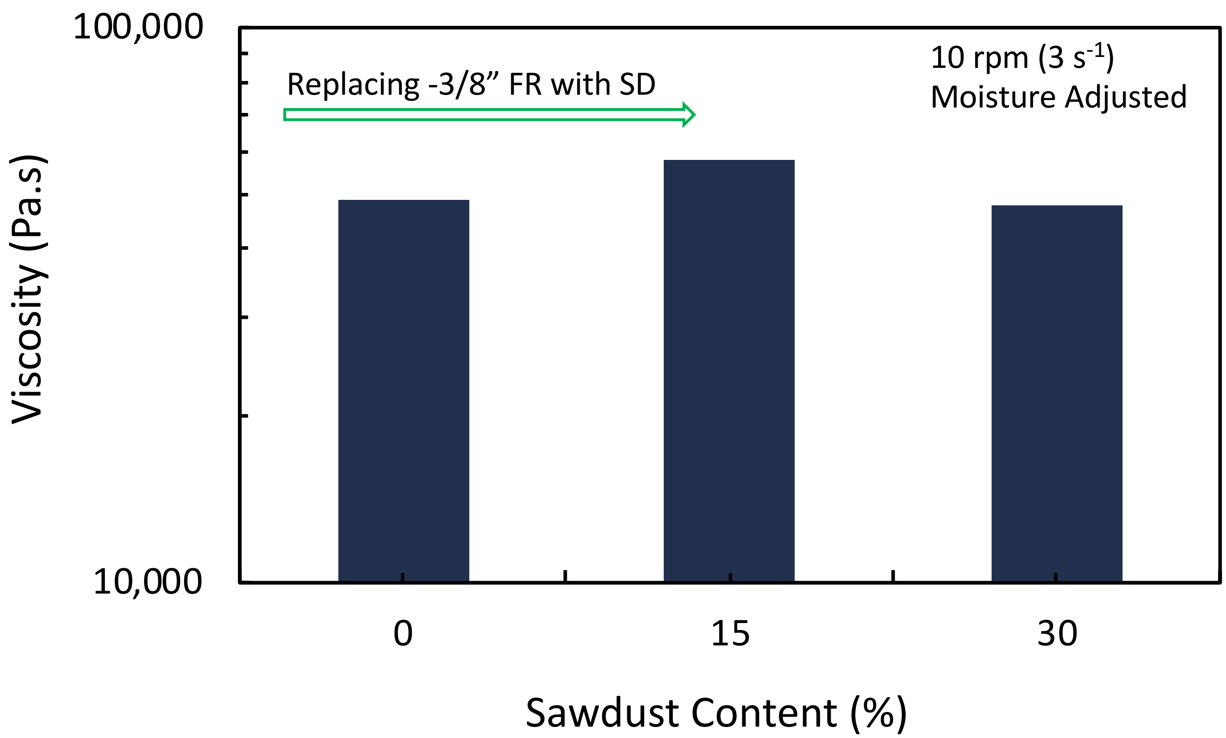

Temperature may need to be accounted for in feeder design

# Impact of Moisture on Biomass Flow



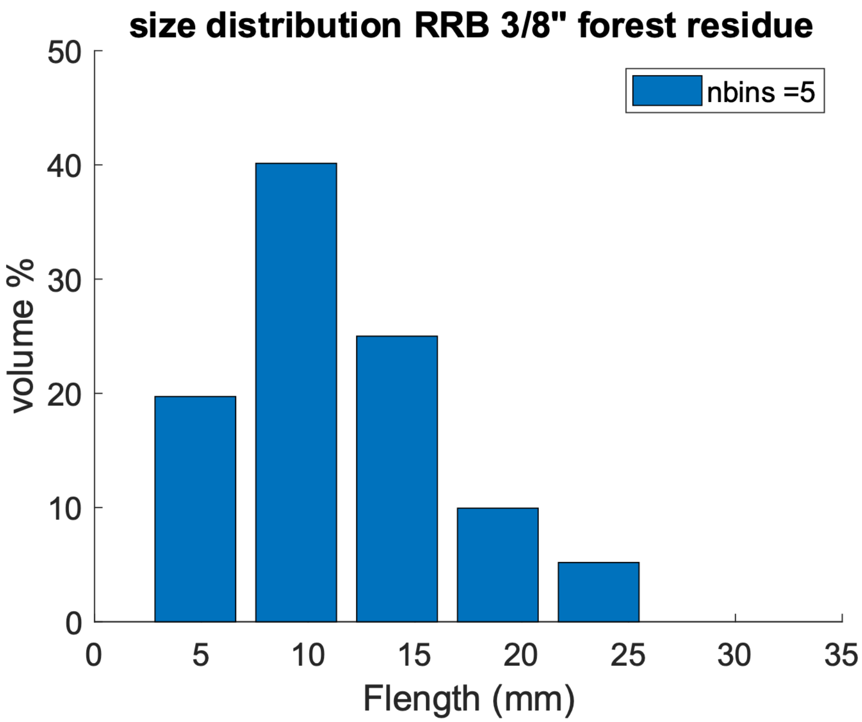

Better biomass flowability as the moisture content increases

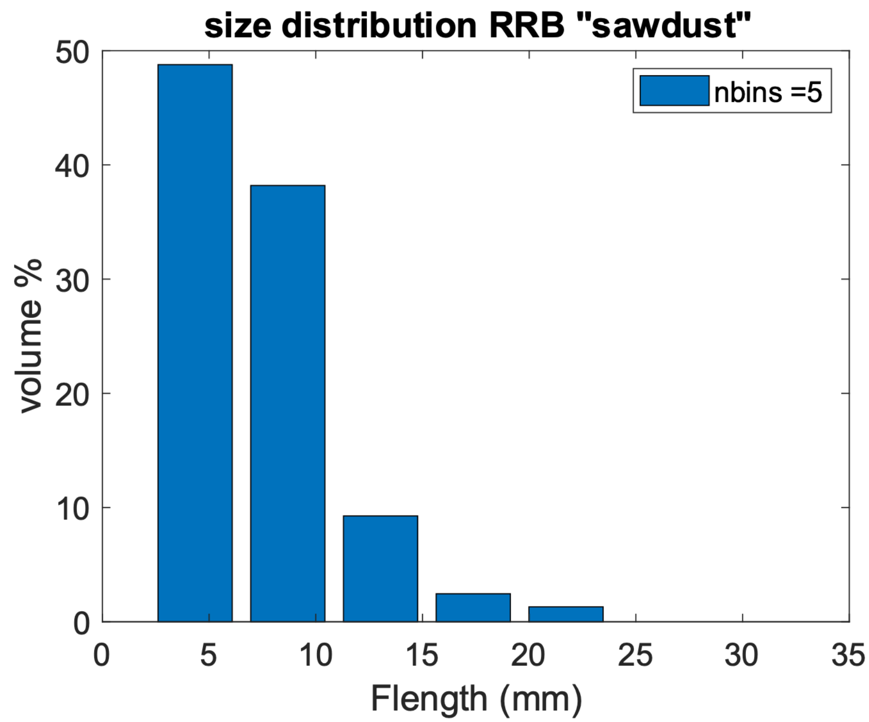
# Impact of Particle Size on Biomass Flow




Particle size distribution has little impact on flowability

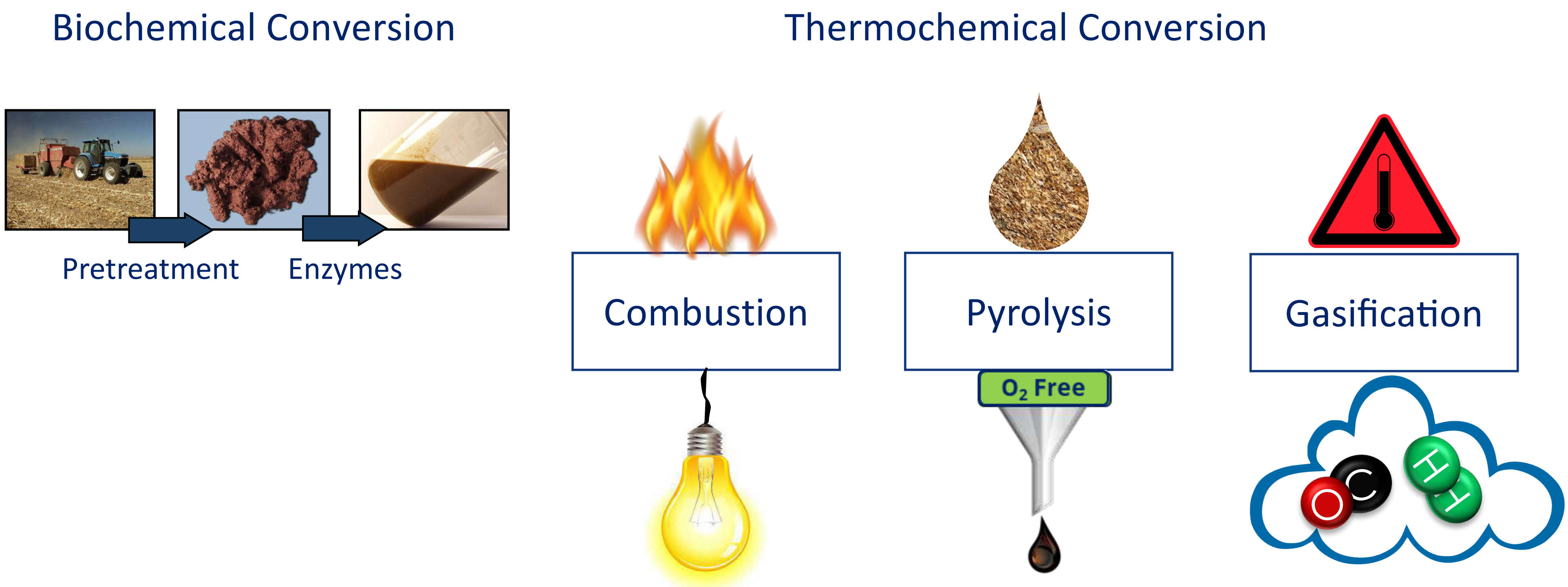
# Particle size distribution of biomass



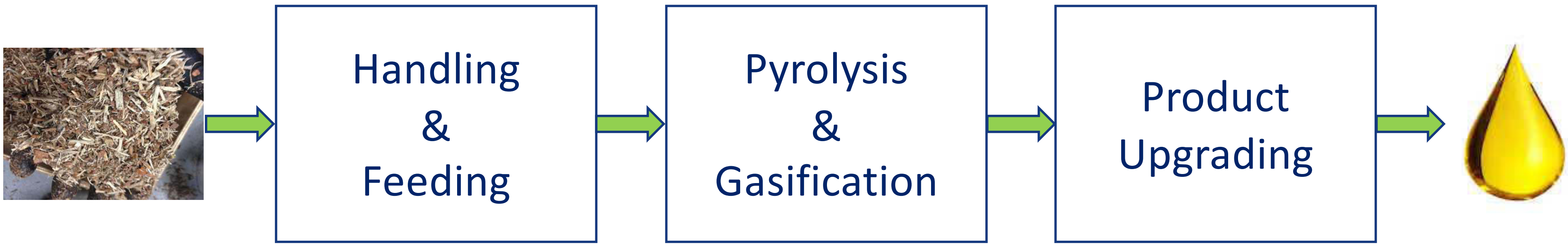

Pecha, M.B., et al., Integrated Particle- and Reactor-Scale Simulation of Pine Pyrolysis in a Fluidized Bed. Energy & Fuels, 2018.

# Biomass conversion technologies



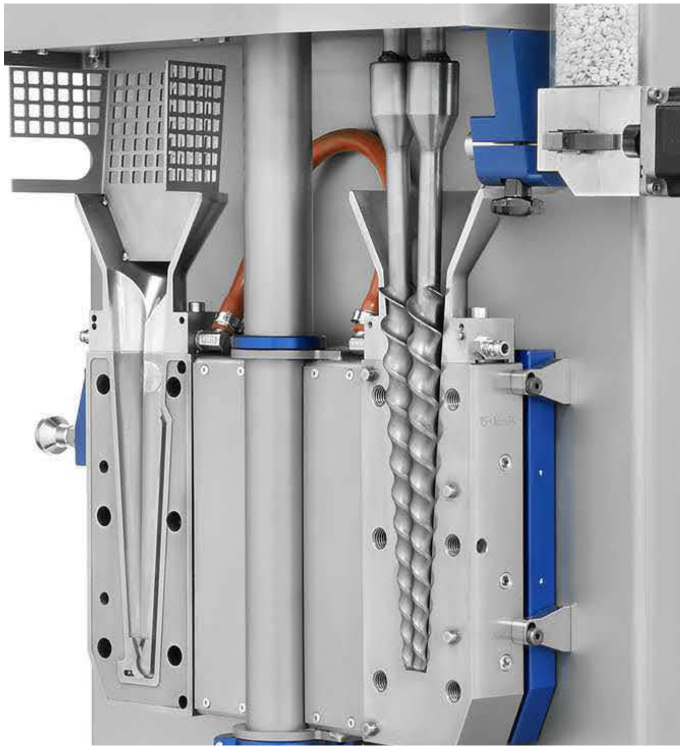

Reaction kinetics has been studied extensively

# Process: gasification to Fischer-Tropsch




Feeding is highly problematic for commercial scale processes

# Method: twin screw microcompounder



Microcompounder
Xplore MC5

$$\eta = \frac{F}{N} C_1$$

$$\dot{\gamma} = \frac{N}{C_2}$$

F: Axial force (N)

N: Screw Speed (rpm)

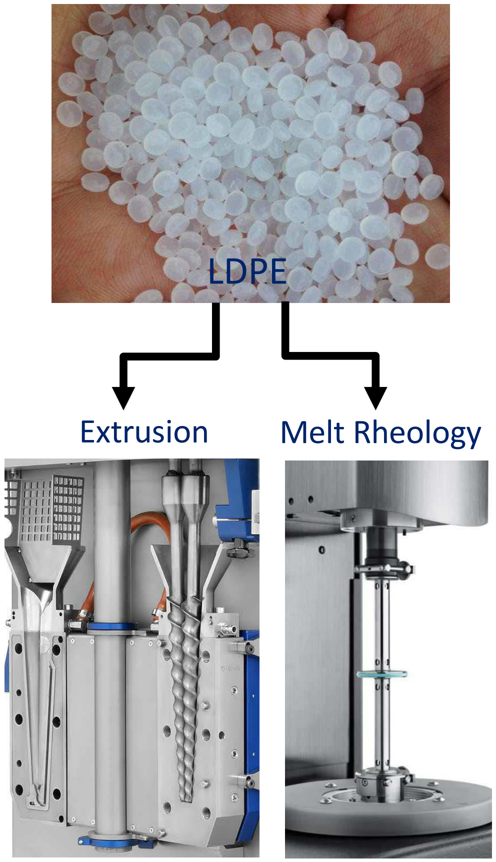
$\eta$: Viscosity (pa.s)

$\dot{\gamma}$ : Shear rate ($s^{-1}$)

C1, C2: Constants

Banning et la., Estimating the melt viscosity in the Xplore micro extruder, 2012, Xplore, Netherlands.

# Modeling compounder viscosity

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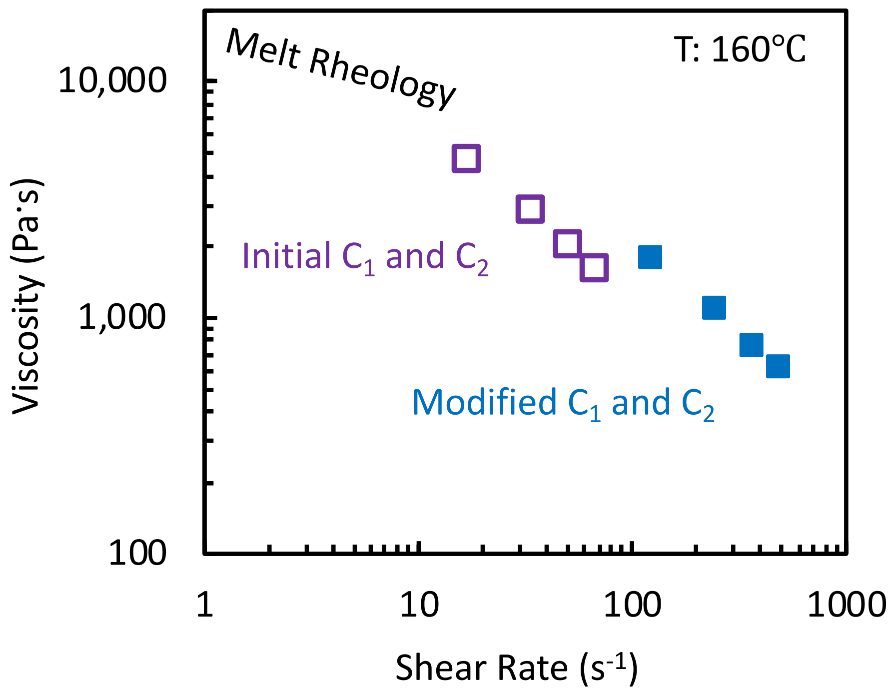


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