Single Particle Reactor for Pyrolysis of Biomass Feedstocks

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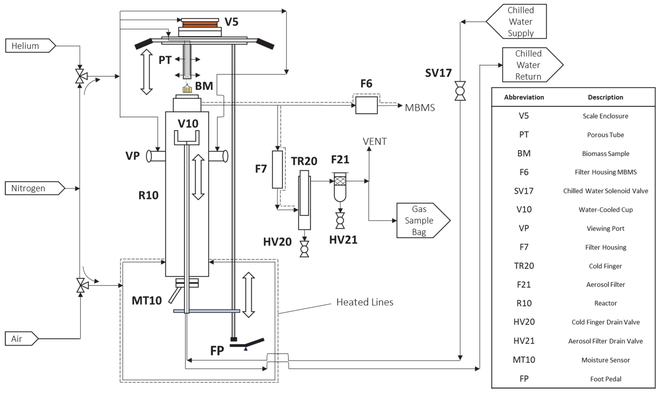
Background

- Knowledge of feedstock micro-structural properties is desired for fundamental understanding and modeling of intra-particle transport phenomena.
- A single particle reactor (SPR) was designed and built to investigate the pyrolysis process on biomass and MSW feedstock particles and pellets.
- The SPR allows for experimental validation of single particle pyrolysis model which will inform industry on effects of particle size, shape, density, and composition on the reaction kinetics.

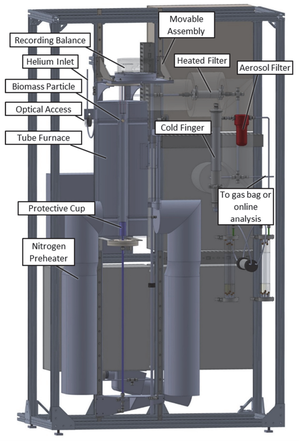
SPR Features

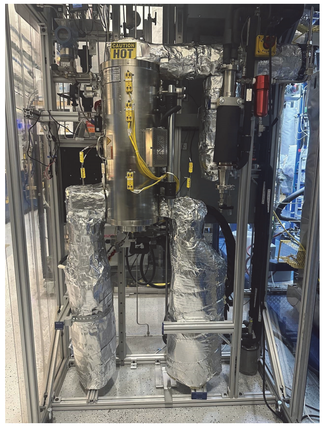
- Pyrolyzing single particles with mass up to 2 g and size up to 12 mm.
- Loss-of-weight recording over time as in a Thermogravimetric Analyzer (TGA) [1,2].
- External heating rates of 50˚C/s by fast exposure to convection and radiation via removal of water-cooled cup. Exposed to nitrogen flow rate of ~1 m/s.
- Temperature range 500-700˚C, measured by free-stream thermocouple.
- Possibility of internal temperature measurement with embedded thermocouple.
- Available side ports for optical observation of pyrolysis process.
- Analysis of product gas composition.

SPR Diagram / Pictures



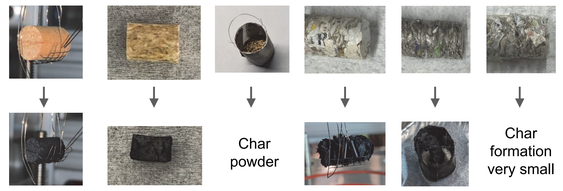
Abbreviation	Description
V5	Scale Enclosure
PT	Porous Tube
BM	Biomass Sample
F6	Filter Housing MBMS
SV17	Chilled Water Solenoid Valve
V10	Water-Cooled Cup
VP	Viewing Port
F7	Filter Housing
TR20	Cold Finger
F21	Aerosol Filter
R10	Reactor
HV20	Cold Finger Drain Valve
HV21	Aerosol Filter Drain Valve
MT10	Moisture Sensor
FP	Foot Pedal





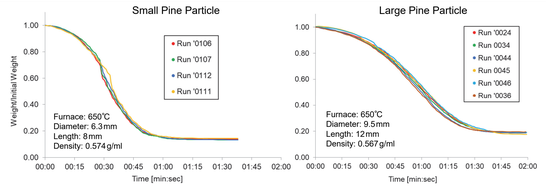
Feedstocks

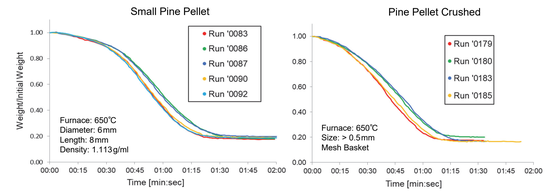
Coring of pine at different locations and orientations

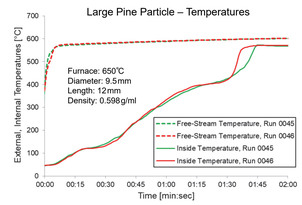


Results

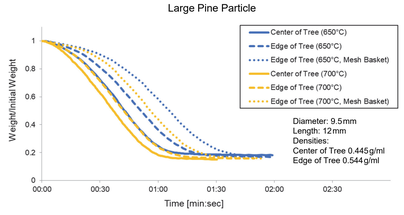
- Comparison of particle size – smaller particle decrease pyrolysis time. Experiments show good repeatability of multiple runs.
- Pelletized particles show longer pyrolysis times.
- Ground feeds or crushed pellets have higher heating rates, but use of mesh basket reduces initial heating rate.
- Temperature Measurement in center of particle (0.001” thermo-couple wire) shows significantly lower values than outside temperature during the pyrolysis process.
- Lower density feeds (center of tree) show shorter pyrolysis time. Experiments using mesh basket (90 mesh) show profile shifted later in time.
- Gas composition and yields were similar between different pine experiments.

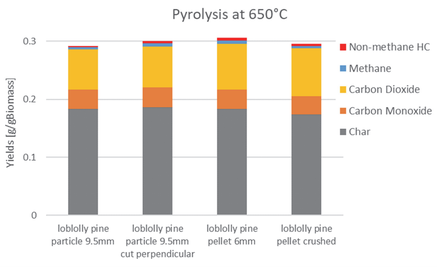




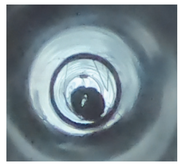


Connecting Internal Thermocouple Wire



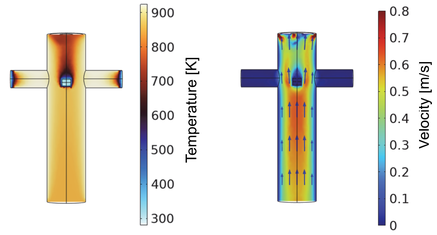


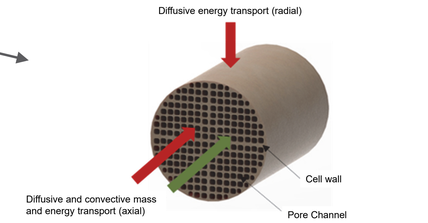
- Optical observation shows occasional cracking of particles during pyrolysis (perpendicular to tree rings).



Modeling

- Reactor models directly matched to the SPR configuration and operating conditions were developed in COMSOL Multiphysics.
- A particle model to predict the conversion of the biomass particle and the main products yields was developed. The model considers a shrinking anisotropic cylindrical particle containing biomass pseudo-components, with the formation of liquid intermediates, intra-particle mass and heat transport, and secondary volatile reactions.
- COMSOL Multiphysics simulations were conducted using physical particle attributes including dimension, porosity, and permeability to investigate the impact of the change in transport properties of milled and pelletized pine particles [3].





Conclusions

- In both model and experiment, the rate of conversion to char during pyrolysis was slowed for the pelletized pine particles due to the decreased porosity and permeability, limiting heat and mass transfer and impeding the pyrolysis conversion process. The results emphasize the impact of intraparticle heat and mass transport on biomass conversion.
- Experiments consistently showed faster pyrolysis for lower density particles, such as the type of wood or center of the tree.
- Experiments on ground feedstocks or plastic-containing feeds had to be conducted on a bed of quartz wool inside a wire-mesh basket. The basket slowed down the initial heatup, but the rate for the proceeding pyrolysis process was similar to the tests with the wire basket.

Future Work

- Coupling of heated vapor outlet to Molecular Beam Mass Spectrometer (MBMS).
- Increase of reactor temperature to 800C and allowing for steam/oxygen atmospheres for gasification experiments.
- Including in-situ catalysts with milled feedstocks inside mesh basket for catalytic fast pyrolysis.

References / Acknowledgments

References

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