Reduced-Order Modeling Techniques for Fluidized-Bed Biomass Pyrolysis

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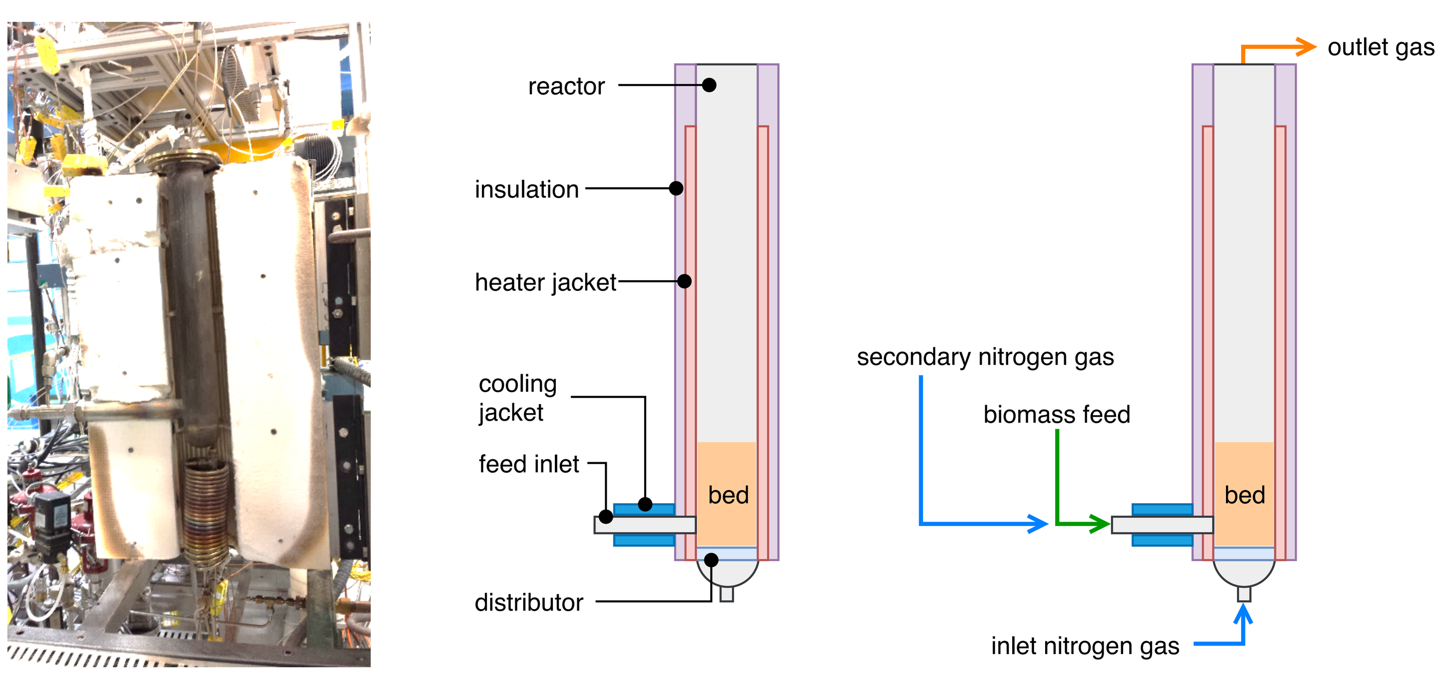
Introduction

Fast pyrolysis is a leading candidate technology for the thermochemical conversion of solid biomass into liquid bio-oil which can be used for biofuel and high-value chemical production.

Bio-oil is commonly generated in fluidized bed reactor systems where biomass particles rapidly devolatilize in the absence of oxygen into mixtures of light gases, condensable bio-oil vapors, and solid char.

A bubbling fluidized bed (BFB) pyrolysis reactor model has been developed to predict the effects of particle size, temperature, pressure, and flow on operating conditions and product yields. This reduced-order model provides a flexible process modeling tool for biomass fast pyrolysis without the need for time consuming simulations and expensive computer hardware.

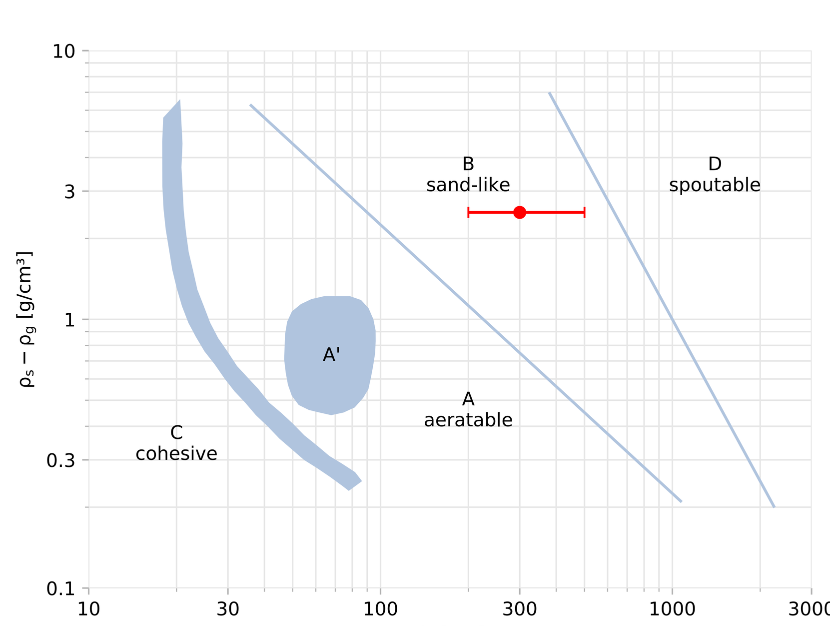


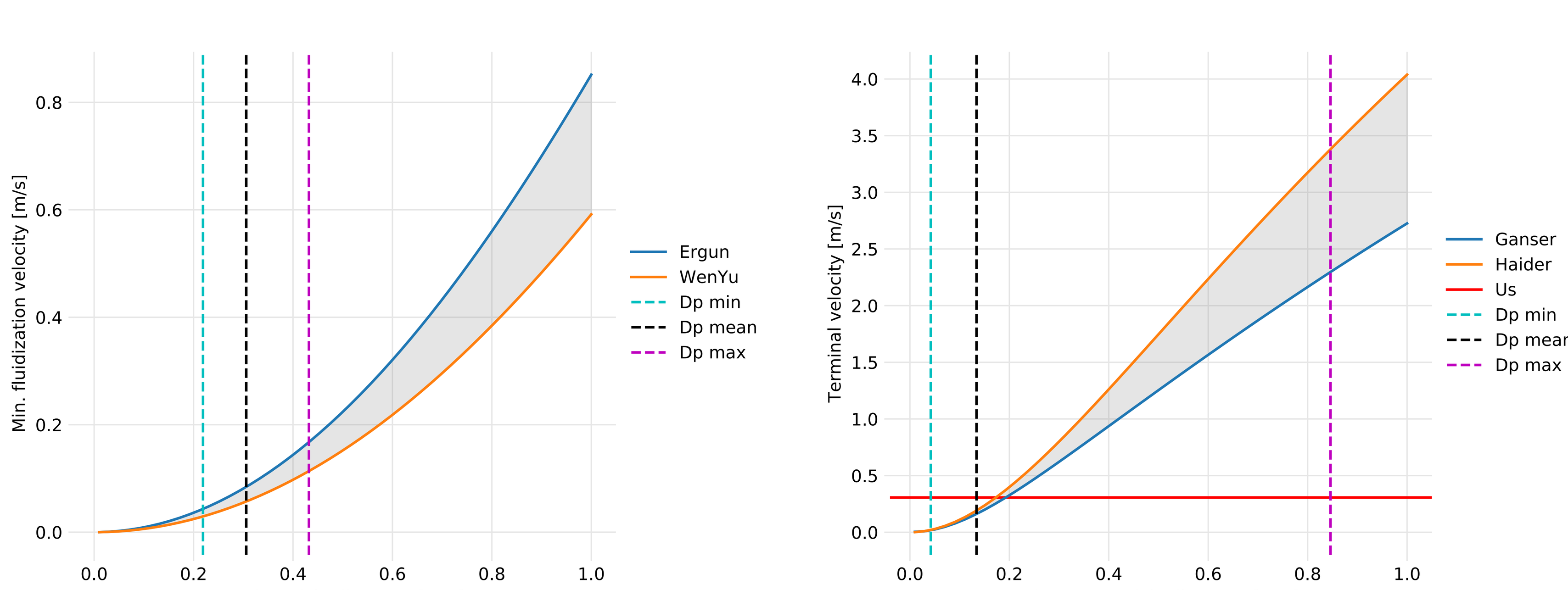
Left – BFB reactor at NREL. Right – reactor components and main process flows. Diameter 2.3 inches, height 17 inches.

Fluidization model

The BFB pyrolyzer model calculates fluidization parameters such as minimum fluidization velocity (Umf), terminal velocity (Ut), bed expansion, fluidization regimes, etc. This information can help reactor operators understand effects of particle size, pressure, and temperature on the operating conditions of the unit before experiments are conducted.

Geldart chart for particle classification. X-axis is particle diameter and Y-axis is relative fluidizing density. Red bar represents bed particle size distribution in NREL reactor.





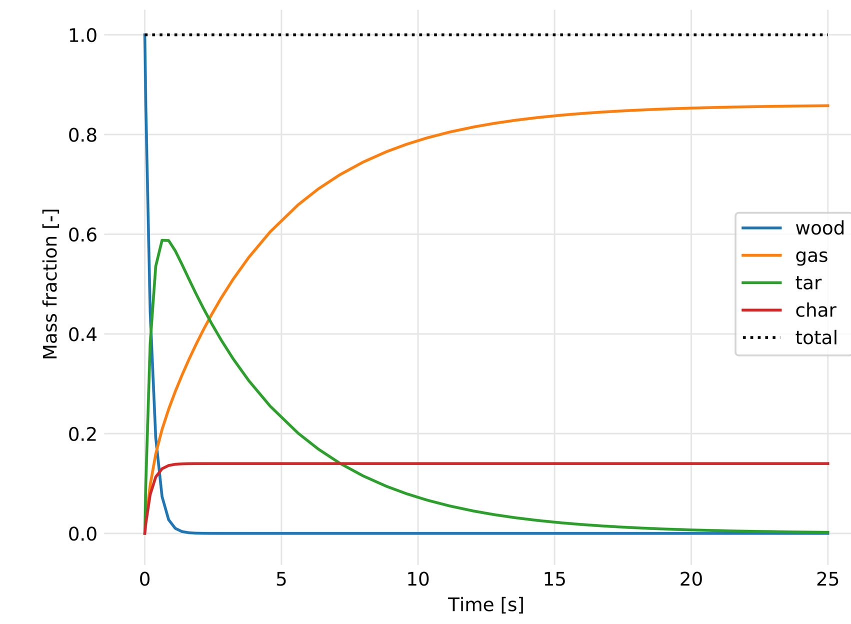
Left – Minimum fluidization velocity for the bed particles as determined from the Ergun and Wen and Yu equations.
Right – Terminal velocity of biomass particles calculated from the Ganser and Haider equations. Dashed lines represent the NREL particle size distribution. Solid red line is superficial gas velocity.

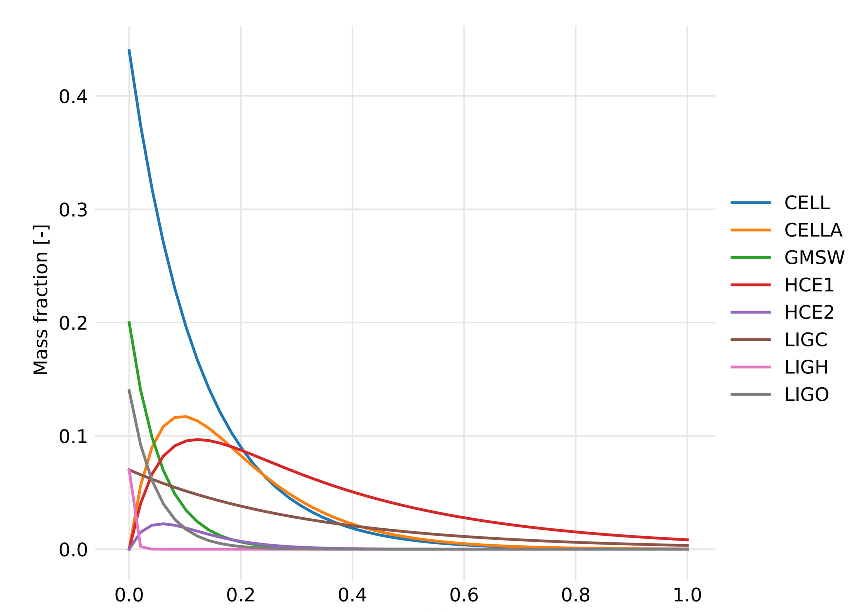
Biomass pyrolysis kinetic model

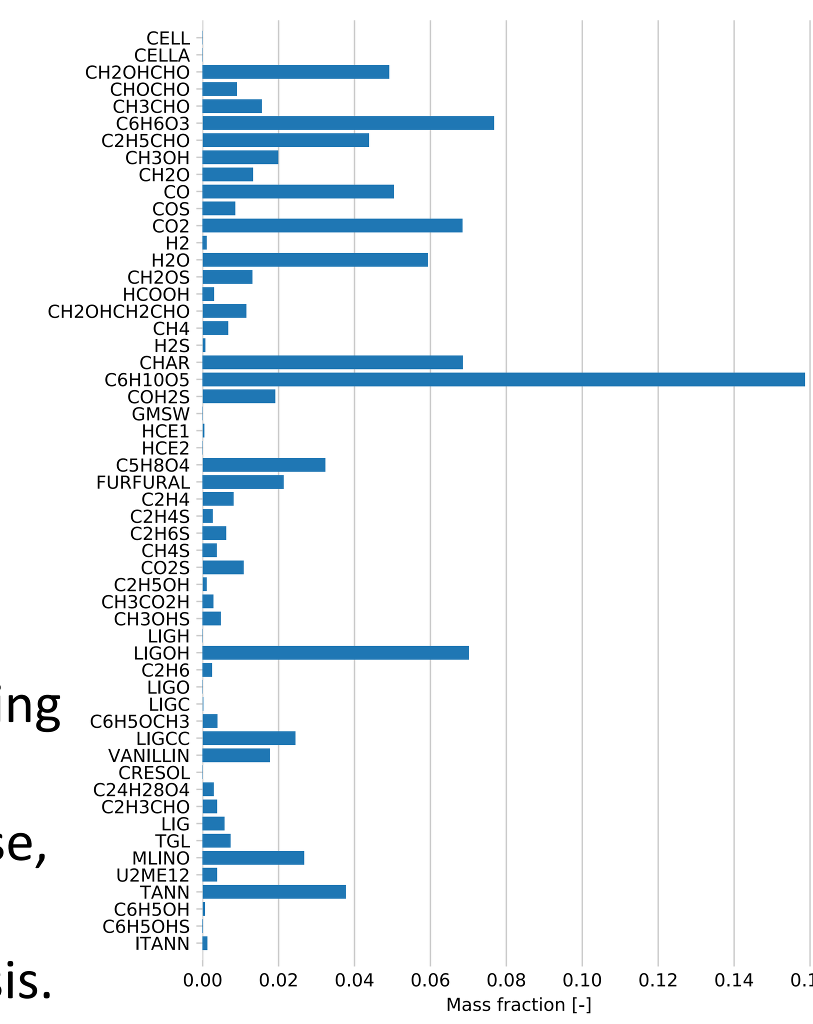
The BFB reactor model makes it possible to rapidly estimate biomass conversion effects for a variety of operating conditions and feedstock properties based on gas and solid residence times within the reactor.

Two biomass pyrolysis kinetic schemes are implemented in the BFB pyrolyzer model. The Liden scheme provides product yields as lumped species of tar, gas, and char. The Debiagi, Ranzi, et al. scheme utilizes the cellulose, hemicellulose, lignin, and ash composition of the biomass to predict pyrolysis yields from hardwood, softwood, and grass feedstocks.

Conversion of wood to pyrolysis products using the Liden kinetic reactions in a batch reactor environment at 773 K.





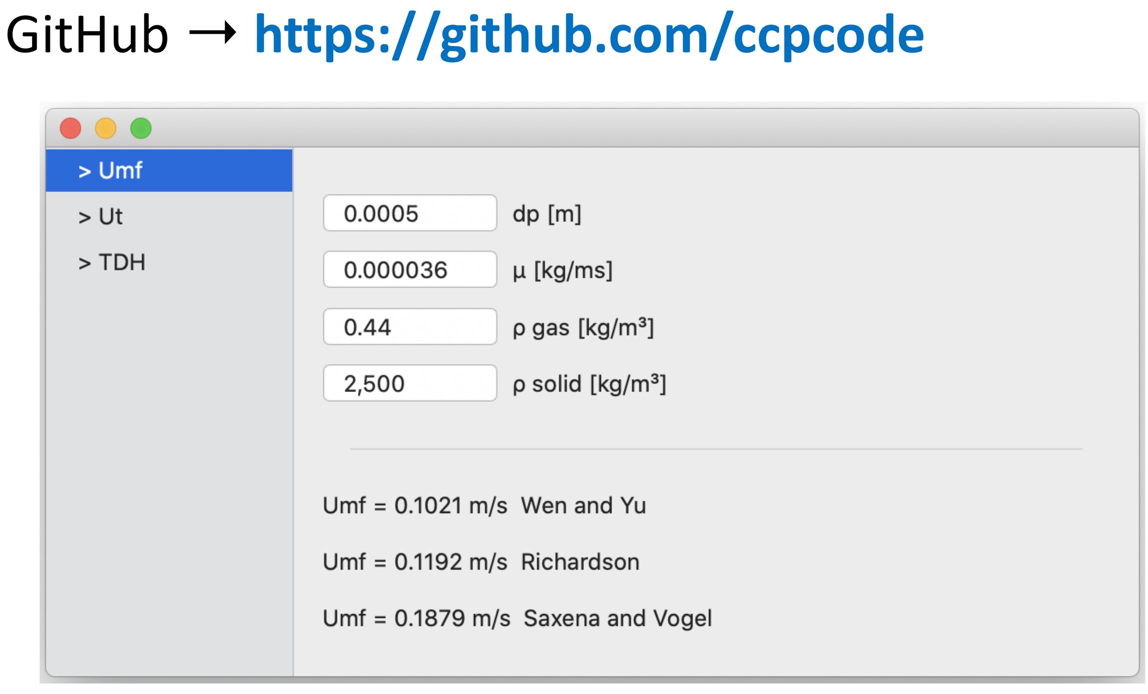


Pyrolysis of pine feedstock at 773 K according to the Debiagi, Ranzi, et al. kinetics. Top – Conversion of initial cellulose, hemicellulose, and lignin composition in pine. Right – Product yields after two seconds of pyrolysis.

Open source code and software

Chemics is a collection of Python functions for chemical reactor engineering → **https://chemics.github.io**

Python code for the BFB pyrolysis reactor model, native Mac desktop app, and cross-platform web app are available on the CCPC GitHub → **https://github.com/ccpcode**



Acknowledgment

The authors would like to thank the U.S. DOE Bioenergy Technologies Office and program managers Kevin Craig, Jeremy Leong, Trevor Smith, Andrea Bailey, and Beau Hoffman. This work is part of the Consortium for Computational Physics and Chemistry (CCPC). Visit **https://www.cpcbiomass.org** for more information.