

Modeling Gas Effects in a Bubbling Fluidized Bed Reactor for Biomass Pyrolysis

Gavin M. Wiggins, ??

March 9, 2020

Contents

1	Introduction	1
2	Experimental apparatus	2
3	Modeling approach	2
3.1	Gas properties	3
3.2	Fluidization correlations	3
3.3	CFD simulation	3
3.4	Pyrolysis kinetics	4
3.5	Parameters	4
4	Results and discussion	5
5	Conclusion	5
6	Source code	5

Abstract

Fast pyrolysis of biomass in a fluidized bed reactor is typically conducted in a nitrogen gas environment. Recycling product gas can improve the economics of operating such a system by reducing reliance on pure process streams.

1 Introduction

Fast pyrolysis is a versatile method for thermochemical conversion of solid biomass into liquid bio-oil which can be used for bio-fuel and high-value chemical production. Bio-oil is commonly generated in bubbling fluidized bed and circulating fluidized bed reactor systems in which biomass particles rapidly devolatilize in the absence of oxygen into mixtures of light gases, condensable

bio-oil vapors, and solid char [2, 3, 7]. Since biomass pyrolysis normally occurs in a non-oxidizing environment, the fluidization gas (carrier gas) is often pure nitrogen [7]. To maximize bio-oil yields, the reactor typically operates at temperatures near 500°C and must maintain particle residence times up to 10 seconds and gas residence times less than 2 seconds [3]. Deviations from these conditions can result in significant production and quality penalties, therefore optimal reactor design and control become crucial to achieving commercially viable bio-oil production.

To improve the economic possibilities of biomass fast pyrolysis systems, char can be burned for process heat while recycled pyrolysis gas can assist with fluidization [2, 5]. The major generated components of pyrolysis gas are CO, CO₂, CH₄, H₂, and other light hydrocarbons [1, 11]. Several experiments investigated the effects of these gases on reactor conditions and pyrolysis yields [5, 8, 11] but modeling the effects of the different gases was not discussed.

There are several models available that investigate the hydrodynamics and conversion of biomass at fast pyrolysis conditions in fluidized bed reactors [9, 6]. As is typical for biomass pyrolysis, these models assume the fluidization gas is pure nitrogen. The authors are not aware of any published models in the biomass pyrolysis literature that account for the effects of fluidization or carrier gas other than nitrogen.

This paper uses engineering correlations, reduced-order modeling techniques, and CFD simulations to investigate the effects of gas mixtures in a fluidized bed biomass pyrolysis reactor. The scope of this study is to evaluate different gas mixtures and their effects on the hydrodynamics and biomass conversion in fluidized bed reactors operating at fast pyrolysis conditions.

2 Experimental apparatus

The NREL 2FBR system thermochemically converts biomass particles at fast pyrolysis conditions. The system is comprised of a bubbling fluidized bed reactor for fast pyrolysis of woody biomass particles. This reactor is referred to as the “pyrolyzer” in this work. An overview of the system is shown in Figure 1. Dimensions and typical operating conditions of the pyrolyzer are given in Figure 2. More information about the NREL pyrolysis system is available elsewhere [4, 10].

3 Modeling approach

Engineering correlations, reduced-order models, and CFD modeling techniques were used to investigate the effects of recycled gas on the operation of a fluidized-bed biomass pyrolysis reactor. The following sections discuss approaches implemented in this work for calculating gas properties and the associated effects on fluidization conditions and pyrolysis yields.

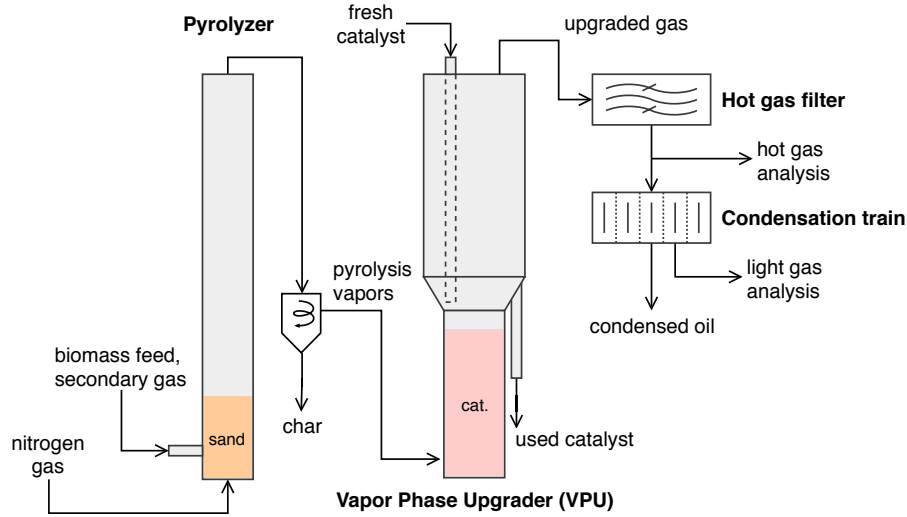


Figure 1: Overview of the NREL 2FBR system. Biomass fast pyrolysis occurs in the pyrolyzer (left) and gaseous products are catalytically upgraded in the vapor phase upgrader (right).

3.1 Gas properties

Density (kg/m^3) of an individual gas is calculated from the ideal gas law

$$\rho_{gas} = \frac{P M}{R T} \quad (1)$$

where P is pressure (Pa), M is molecular weight (g/mol), R is the gas constant [$(\text{m}^3 \text{ Pa}) / (\text{K mol})$], and T is temperature (K). Gas viscosity (μP) is given as

$$\mu_{gas} = A + B T + C T^2 + D T^3 \quad (2)$$

where coefficients A , B , C , and D are obtained for a given gas from tables in Yaws' Handbook and T is gas temperature (K).

For a gas mixture, density is calculated as a weighted average of the individual gas densities. The viscosity of a gas mixture can be calculated from a variety of correlations.

3.2 Fluidization correlations

Here.

3.3 CFD simulation

Here.



Figure 2: Dimensions and typical fast pyrolysis operating conditions of the NREL 2FBR pyrolyzer.

3.4 Pyrolysis kinetics

Here.

3.5 Parameters

Parameters for the reduced-order model and CFD simulations are provided in Table 1. Biomass particle parameters and properties are representative of loblolly pine. Bed particle parameters are for typical sand material. Operating conditions and reactor dimensions are based on the previously discussed NREL 2FBR fluidized bed pyrolysis unit.

Table 1: Biomass, bed, and reactor modeling parameters. Particle diameters represent the Sauter-mean diameter.

Parameter	Description	Value
$d_{p,bed}$	diameter of bed particle	$235 \mu\text{m}$
ϕ_{bed}	sphericity of bed particle	0.0
$d_{p,bio}$	diameter of biomass particle	$135 \mu\text{m}$
ϕ_{bio}	sphericity of biomass particle	0.0
ρ_{bio}	density of biomass particle	540 kg/m^3
$h_{reactor}$	reactor height	43.18 cm
h_{static}	static bed height	10.16 cm
tk	reactor temperature	773 K

4 Results and discussion

Here.

5 Conclusion

Here.

6 Source code

Python models used to generate results for this article are available on the CCPC GitHub at <https://github.com/ccpcode> in the X repository. Functionality provided by the Chemics package was used for gas properties and various fluidization calculations. See the Chemics documentation at <https://chemics.github.io> for more information.

References

- [1] M. Asadullah et al. “Jute stick pyrolysis for bio-oil production in fluidized bed reactor”. In: *Bioresource Technology* 99 (2008), pp. 44–50.
- [2] A.V. Bridgwater. “Principles and practice of biomass fast pyrolysis processes for liquids”. In: *Journal of Analytical and Applied Pyrolysis* 51 (1999), pp. 3–22.
- [3] Tony Bridgwater. “Challenges and Opportunities in Fast Pyrolysis of Biomass: Part I”. In: *Johnson Matthey Technology Review* 62.1 (2018), pp. 118–130.
- [4] Daniel Howe et al. “Field-to-Fuel Performance Testing of Lignocellulosic Feedstocks: An Integrated Study of the Fast Pyrolysis-Hydrotreating Pathway”. In: *Energy & Fuels* 29 (2015), pp. 3188–3197.
- [5] Ofel D. Mante et al. “The influence of recycling non-condensable gases in the fractional catalytic pyrolysis of biomass”. In: *Bioresource Technology* 111 (2012), pp. 482–490.
- [6] Pelle Mellin, Efthymios Kantarelis, and Weihong Yang. “Computational fluid dynamics modeling of biomass fast pyrolysis in a fluidized bed reactor, using a comprehensive chemistry scheme”. In: *Fuel* 117 (2014), pp. 704–715.
- [7] Dinesh Mohan, Charles U. Pittman, and Philip H. Steele. “Pyrolysis of Wood/Biomass for Bio-oil: A Critical Review”. In: *Energy & Fuels* 20 (2006), pp. 848–889.
- [8] Charles A. Mullen, Akwasi A. Boateng, and Neil M. Goldberg. “Production of Deoxygenated Biomass Fast Pyrolysis Oils via Product Gas Recycling”. In: *Energy & Fuels* 27.7 (2013), pp. 3867–3874.

- [9] K. Papadikis, S. Gu, and A.V. Bridgwater. “Computational modelling of the impact of particle size to the heat transfer coefficient between biomass particles and a fluidised bed”. In: *Fuel Processing Technology* 91 (2010), pp. 68–79.
- [10] Anna Trendewicz et al. “Evaluating the effect of potassium on cellulose pyrolysis reaction kinetics”. In: *Biomass and Bioenergy* 74 (2015), pp. 15–25.
- [11] Huiyan Zhang et al. “Biomass fast pyrolysis in a fluidized bed reactor under N₂, CO₂, CO, CH₄ and H₂ atmospheres”. In: *Bioresource Technology* 102 (2011), pp. 4258–4264.