



Contents lists available at ScienceDirect

Fuel

journal homepage: www.elsevier.com/locate/fuel



Effect of biomass heating time on bio-oil yields in a free fall fast pyrolysis reactor

Preston Gable, Robert C. Brown*

Bioeconomy Institute – Iowa State University, 1140 BRL, Ames, IA 50011-3270, United States

HIGHLIGHTS

- The effect of pyrolysis heating time on bio-oil yield was studied.
- The analysis shows that pyrolysis continues well beyond the 1–2 s frequently assumed.
- All biomass components contribute to this extended pyrolysis time.

ARTICLE INFO

Article history:

Received 25 August 2015
 Received in revised form 7 October 2015
 Accepted 16 October 2015
 Available online xxxxx

Keywords:

Biomass
 Heating time
 Free fall reactor
 Devolatilization
 Bio-oil

ABSTRACT

The goal of this study is to evaluate the role of biomass heating time on bio-oil yield during fast pyrolysis in a free fall reactor. Biomass heating times were controlled using several configurations for conveying solids from the bottom of the free fall reactor. In all tests reactor wall temperature was 550 °C, sweep gas flowrate was 18 L/min, and heated reactor length was 2.77 m, which set the minimum biomass heating time of approximately 1.4 s (particles falling downward in sweep gas). Analysis of products included solid, liquid and gas mass yields; proximate analysis of the solids; and water-soluble sugar and carboxylic acid content of the liquid. These experiments showed that biomass continued to pyrolyze well beyond the few seconds frequently assumed to be adequate to achieve fast pyrolysis. Bio-oil yield increased with biomass heating times even for times exceeding 40 s. Analysis of liquid products suggests that hemicellulose, cellulose, and lignin all contributed toward the longer than expected pyrolysis times.

© 2015 Elsevier Ltd. All rights reserved.

1. Introduction

Fast pyrolysis is the rapid heating, followed by rapid cooling, of a finely ground biomass feedstock in the absence of oxygen to produce predominately liquid product that can ideally be a drop-in replacement for current liquid fuel applications such as heat, power, transportation fuels, and specialty chemicals. Techno-economic analyses of a variety of biomass conversion pathways indicate that fast pyrolysis is among the most cost effective of these technologies [1–9].

Fast pyrolysis is often thought to be essentially complete in just a few seconds [10]. Computational studies performed by Kersten et al. [11] evaluated several intrinsic kinetic schemes proposed in the literature. They found that fast pyrolysis at 500 C is expected to be complete in 2–12 s. To our knowledge no experiments have been performed to investigate this question under conditions of

high heat rates (>100 C/s) characteristic of fast pyrolysis. Fluidized bed and auger reactors, the two most common configurations for fast pyrolyzers, do not lend themselves to measurements of devolatilization times for pyrolyzing biomass. Typically biomass remains in a fluidized bed until it is converted to char sufficiently fine to be elutriated from the reactor [12]. Auger reactors move biomass through the pyrolysis zone at rates that are much longer than the one to two seconds usually assumed for completion of fast pyrolysis [13]. Micropyrolyzer systems are usually operated in conjunction with a gas chromatograph–mass spectrometer (GC–MS), making dynamic measurements of pyrolysis impractical. Thus, an investigation of biomass devolatilization times during fast pyrolysis requires a reactor that allows some level of control over biomass heating time after it has been rapidly heated to pyrolysis temperature.

This study investigates fast pyrolysis in a free-fall reactor, designed to rapidly heat biomass to the desired pyrolysis temperature as it falls through a long, vertical column followed by controlled biomass heating time in a heated catch pot at the bottom of the column. We have found that biomass continues to

* Corresponding author.

E-mail addresses: pagable@iastate.edu (P. Gable), rcbrown3@iastate.edu (R.C. Brown).

pyrolyze in the heated catch pot, contrary to our original expectation that essentially devolatilized biomass (char) would exit the bottom of the column [14]. The present study is to understand the effect of biomass heating time on bio-oil yields from pyrolyzing biomass.

2. Materials and methods

The reactor system used in this study, shown in Fig. 1, was designed to allow for continuous operation. Biomass was fed into the system using an Acrison BDFM volumetric feeder with the ability to meter feedstock at rates ranging from 0.25 kg/hr to 2 kg/hr. The reactor was 3.05 m tall. The reactor was built from 1 1/4" Schedule 40 316 L stainless steel pipe providing an inside diameter of 0.035 m. The drop tube portion of the reactor was heated using Watlow high temperature ceramic radiative heaters while the remaining parts of the reactor were heated using high temperature heat tapes. All heaters and exposed surfaces were insulated using high temperature ceramic insulation.

Particle heating time is equal to the reactor height divided by the particle velocity. In the absence of sweep gas, the particle velocity is equal to the terminal velocity of the particle in free fall. In the presence of co-flowing sweep gas, the particle velocity is the sum of the terminal velocity of the particle and the velocity of the sweep gas. In the former case, particle heating time was about 2.5 s, decreasing to 1.4 s in the presence of sweep gas.

Temperature was controlled via manipulation of individual heater zone set points. These heaters were controlled via thermocouples placed on the exterior surface of the reactor underneath the corresponding heater. Sweep gas volumetric flow rate was manipulated by altering the amount of sweep gas introduced at the top of the reactor. Particle heating time was mainly a function of the heated length of the reactor and the time that the biomass was heated in the system.

Two methods were used to capture solids exiting the bottom of the vertical heating zone of the reactor. The static solids catch method simply allows the solid particles to accumulate in a catch pot for the duration of the test as illustrated in Fig. 2(a), a method previously used by Ellens and Li [14,16]. In some experiments the

catch pot was heat traced to the pyrolysis temperature allowing the collected solids to continue to pyrolyze, giving a biomass heating time that was effectively infinite. In other experiments a conical quench section was interposed between the bottom of the vertical column and the catch pot, shown in Fig. 2(b). At the bottom of the quench section, cold nitrogen gas at approximately $-196\text{ }^{\circ}\text{C}$ was injected to quickly cool the biomass and prevent further devolatilization. In this case, the biomass heating time was approximately 1.4 s.

An alternative solids collection system allowed control of biomass heating time at the bottom of the vertical reactor. This was accomplished by interposing a cooled auger between the bottom of the heated vertical reactor and the unheated catch pot. By controlling the rotational speed of the auger, the heating time of the biomass could be controlled, ranging from five to forty seconds. This configuration is illustrated in Fig. 2(c).

Six experiments were performed specifically to understand the relationship between the yields of pyrolysis products and biomass heating time (see Table 1). The biomass chosen for these experiments was ground red oak sieved to 250–850 μm (average of 500 μm). One experiment was conducted with both the heated and cooled static solids catch systems and four tests were performed using the conveyed solids catch system operating at different auger speeds. Previous experience with this reactor indicated as high level of repeatability between tests. Thus, uncertainty in the data for the several experiments was determined by repeating one of the test condition in triplicate, determining their standard deviation and 95% confidence interval and using this confidence interval to estimate the uncertainty in the other tests.

Pyrolysis operating conditions were identical for the six tests, the only variable altered in the tests being the particle heating time. The lower 2.77 m of the 3.05 m reactor was heated to $550\text{ }^{\circ}\text{C}$ wall temperature, which was accomplished with six independent electric heaters controlled by a thermocouple placed on the exterior wall of the reactor. Nitrogen gas at room temperature was used as a sweep gas at a flow rate of 18 L/min. While 18 L/min is high for a free fall reactor, this rate was used to dilute produced vapors and to promote volatilization and tertiary reactions. The sweep gas created a cold flow velocity of 0.42 m/s. Therefore, the average particle terminal velocity was calculated to be 1.13 m/s.

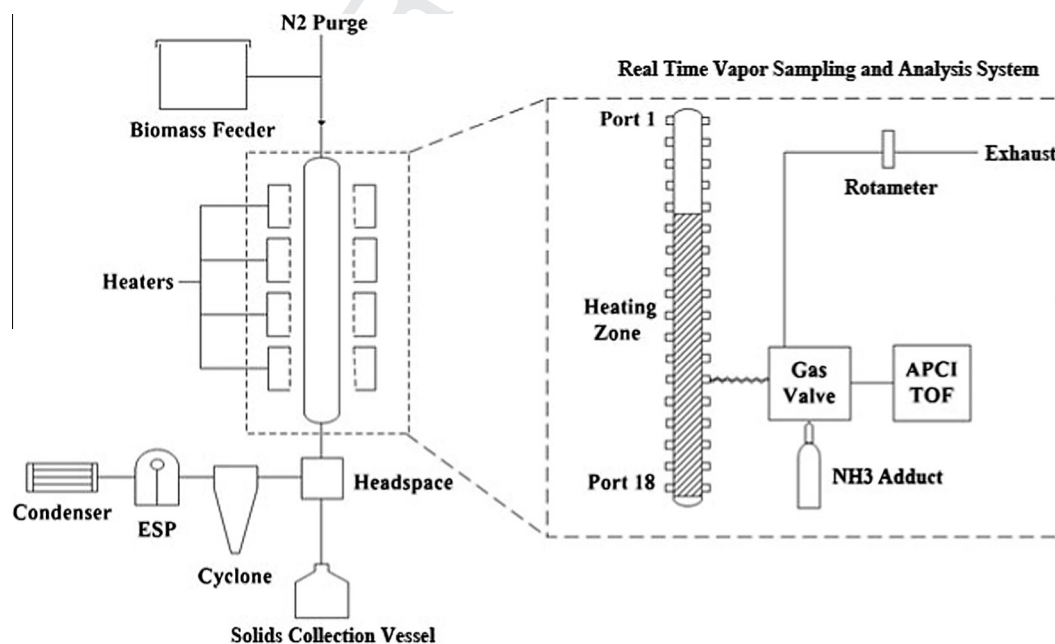


Fig. 1. Schematic of experimental apparatus including pyrolysis reactor, solids collection, and gas analysis.

Download English Version:

<https://daneshyari.com/en/article/6634341>

Download Persian Version:

<https://daneshyari.com/article/6634341>

[Daneshyari.com](https://daneshyari.com)