Influence of biomass particle size on bed agglomeration during biomass pyrolysis in fluidised bed

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Abstract

Bed agglomeration in fluidised bed was recently discovered to be an important consideration during biomass pyrolysis under the conditions pertinent to bio-oil production. The results in this study show that biomass particle size has a significant effect on bed agglomeration during biomass fast pyrolysis at 500 °C. Sand loading, which is defined as the mass of sand sticking to the biomass particles normalised to the total mass of biomass fed, is used for quantifying the interaction between the pyrolysing biomass particle and sand in fluidised bed to form bed agglomerates. Under the experimental conditions, at biomass particle sizes ≤430 μm, sand loading increases with increasing biomass particle size. At biomass particle sizes >430 μm, sand loading decreases with further increase in biomass particle size. The results further show that mass transfer of the sticky agent produced from biomass pyrolysis plays a key role in bed agglomeration. At small particle sizes (≤430 μm), sand loading is dominantly influenced by convective mass transfer of sticky agent while at large particle sizes (>430 μm), sand loading is mainly controlled by diffusive mass transfer of sticky agent within the pyrolysing biomass particle.
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1. Introduction

Fluidised-bed reactors are often employed for biomass fast pyrolysis at 450–550 °C to produce bio-oil that can be subsequently upgraded and refined into liquid transport fuels [1–4]. Recent research conducted by the same authors discovered that substantial bed agglomeration can take place during biomass fast pyrolysis in fluidised-bed reactors, leading to detrimental defluidisation [5,6].

During biomass fast pyrolysis, biomass thermal decomposition may produce sticky organic matter which acts as the "glue" for forming bed agglomeration between the pyrolysing biomass particles and sand particles [5,6]. Such sticky organic matter is referred to as "sticky agent", which is a generic term and proven to consist of various aromatic-ring systems [5,6]. In a recent publication [7], the analysis of the so-called "bio-asphaltene", which is separated from a fast pyrolysis bio-oil as the fraction insoluble in n-heptane but soluble in toluene, further confirms the presence of various aromatic systems in the product of biomass fast pyrolysis. The interaction between pyrolysing biomass

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particles and sand particles can be quantified experimentally via a new diagnosis parameter (i.e. sand loading, S_L) [8]. It is also shown that bed agglomeration during biomass fast pyrolysis is not a random event but is dependent on pyrolysis conditions and biomass properties [6,8,9]. Thus far, all those experiments were conducted using biomass powders (355–500 μm) under "thermally thin" conditions (i.e. Biot number<0.1) where intra-particle heat transfer limitation is negligible. Practically, fluidised bed reactors typically take large (mm-sized) particles but the effect of biomass particles size on bed agglomeration is largely unknown. Consequently, this paper further investigates the interaction between pyrolysing biomass particles and sand particles in fluidised bed responsible for bed agglomeration during pyrolysis at 500 °C, considering a wide range of biomass particle sizes.

2. Experimental method

2.1. Sample preparation

The leaf and bark components were separated from mallee trees harvested in Western Australia. The samples were dried, milled then sieved to yield a series of biomass samples of different size fractions: <106, 106–150, 150–250, 250–355, 355–500, 500–710, 710–1000, 1000–2000 and 2000–4000 μm, with the corresponding average particle sizes of 53, 128, 200, 303, 428, 605, 855, 1500 and 3000 μm, respectively. Sand was sieved into the size fraction of 125–250 μm, washed with demineralised water, filtered, dried and then calcined for 30 min at 600 °C in air. The calcined sand was washed again with demineralised water, filtered and dried to yield the sand bed material for experiments.

2.2. Pyrolysis of biomass samples in fluidised bed

Fast pyrolysis experiments (estimated heating rate: >200 K s^{-1}) were carried out using a quartz fluidised bed reactor, which was placed and preheated in an electrical induction furnace, following the procedure described elsewhere [5]. Briefly, the fluidised bed reactor was loaded with 19.5 g sand and preheated to 500 °C in an electrical furnace, using argon as fluidisation gas. The fluidisation velocity was twice of the minimum fluidisation velocity of the sand particles. A total of 1.95 g of biomass sample was then fed into the bed using argon as carrier gas via a gas-cooled feeding tube at ~0.3 g min^{-1}. After the feeding was completed, the reactor was further held at 500 °C for 15 min, giving a total reaction time of approximately 21.5 min. Upon the completion of a pyrolysis experiment, the reactor was immediately lifted out of the furnace and allowed to cool down to below 40 °C with the argon gas continuously flowing through the reactor. The reactor before and after pyrolysis experiment was weighed for determining

char recovery X_R. The resulting sand and chars in the bed (termed as bed sample) was then collected.

For the purposes of comparison, a set of slow pyrolysis experiments were also conducted using the same reactor. The reactor was preloaded with sand and the biomass sample and then fluidised using argon gas before inserted into the electrical furnace at room temperature. The fluidised-bed reactor was then heated in the electrical furnace to 500 °C slowly at 10 K min^{-1}, followed by further holding at the temperature for 15 min, giving a total reaction time of approximately 61.5 min. Upon the completion of a pyrolysis experiment, the reactor was immediately lifted out of the furnace and allowed to cool rapidly to below 40 °C with the argon gas continuously flowing through the reactor. Subsequent determining char recovery and sample collection followed the same procedure outlined in the fast pyrolysis experiments.

2.3. Sample analysis and characterisation

The size distributions of the bed samples were determined using a series of sieves according to the procedure described elsewhere [5]. The interaction between pyrolysing biomass particles and sand particles (responsible for fluidised bed agglomeration) can be quantified using a recently-developed diagnosis parameter (i.e. sand loading S_L) that is defined as the mass of sand that sticks with the pyrolysing biomass particles in the bed to form bed agglomerates normalised to the total mass of biomass fed into the fluidised bed [8]. Quantification of char in various size fractions of the bed samples was carried out via determining the weight loss after the combustion of the samples. Table 1 lists the fuel properties of the leaf and bark biomass samples used in this study.

3. Results and discussion

3.1. Effect of biomass particle size on sand loading

Figure 1 shows that sand loading initially increases with an increase in biomass particle size, reaches a maximum at a transit biomass particle size of ~430 μm and decreases with further increase in biomass particle size. It should be noted that S_L quantifies the products produced from biomass pyrolysis to form the "active sites" or "sticky agent" that are responsible for forming bed agglomerates.

Figure 1 shows that the actual values for S_L are dependent on pyrolysis conditions (fast or slow) and biomass used (leaf or bark). This result is also verified by the previous research reported into the differences in the agglomeration behaviour of the different biomass components [6]. There is also a transition particle size (~430 μm), suggesting that there is a change in the mechanism responsible for