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Feeding small biomass particles at low rates

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ABSTRACT

Biomass particles (75–1000 μm) were fed at 9.0–66.5 mg min^{-1} (2.9–21.7 W) using a particle feeder that dispensed particles by gravity through an injection tube. Feed rate was controlled by altering the velocity of a pusher block. Particles were agitated using a vibration motor and fed onto a balance and mass readings were continuously logged. Factors impacting reproducibility and feed rate stability were investigated as well as the effects of particle size and of pusher block velocity. Statistical analysis was applied to investigate patterns in particle feed rate data. Particle aggregation was identified as a factor which influenced feed rate stability and thereby also influencing reproducibility. Feed rate correlated well with pusher block velocity ($R^2 = 0.99$). Statistical analysis showed strong indications (P values <0.01) of two patterns (clustering and trends) in the feed rate data which were attributed to changes in particle bed appearance with time. With all else being equal, particle size affected feed rate but not feed rate stability. A higher vibration amplitude was needed to agitate smaller particles. It was concluded that particle agitation control is a key to stable feeding of small biomass particles at low rates.

1. Introduction

European Union (EU) policy documents such as directives from 2003 [1] and 2009 [2] and a white paper from 2011 [3] have set out new policies for the use of renewable energy in the EU member states. This has increased interest in replacing fossil fuels with renewable biomass for the production of heat and motor fuels. Biomass can be used for production of heat through combustion as well as for production of motor fuels through gasification where the biomass is converted to a syngas that is converted to a liquid in downstream catalytic processes. Combustion and gasification of fossil fuels are well known techniques and the mechanisms involved such as soot formation etc. have been extensively researched. However, this is not the case for combustion and gasification of biomass and therefore a need for fundamental studies of biomass has been created where information regarding reaction kinetics [4], coke formation [5], particle emissions [6] etc. are gathered. Such fundamental studies are often carried out using drop tube furnaces (DTFs) where fuel particles are fed into a reactor in which conditions such as temperature and atmosphere can be accurately controlled [4–11]. Particulate and/or gaseous samples are then collected to learn the behavior of the fuel under the conditions it was subjected to.

To achieve relevant and high quality data from a DTF investigation it is crucial to feed small fuel particles at a low and stable feed rate into the reactor. Small fuel particles (100–200 μm) are used in large scale operation of combustion and gasification [12,13]. For the information from the DTF to be relevant, fuel behavior in the DTF needs to be the same as in full scale operation. Therefore, the fuel particles used for DTF studies need to be as small as those used in full scale operation. If the distance between fuel particles inside the reactor is too short then the heat and gaseous compounds that are given off by the fuel particles during the combustion/gasification process will significantly alter the conditions the particles are subjected to. Therefore, the fuel feed rate needs to be low. The feed rate also needs to be stable to avoid changes in the distance between particles with time as this will result in particles fed at different times being subjected to different conditions.

Low rate feeding of small biomass particles has been part of fundamental studies of biomass that has been described previously in the literature [4–11]. However the biomass particle feeding itself was not the focus of those studies. The construction and the mode of operation of the particle feeders used was presented rather than information regarding feed rate stability, reproducibility etc. Such information can be found in the literature on particle feeders. However, the feeders presented in this literature are often used for applications other than fundamental studies of fuels and are therefore aimed at feeding other materials such as metal powders [14,15], fused silica [16] or $CaCO_3$ [17]. There is information on low rate feeding of small coal particles in the literature on particle feeders [18–20] but biomass particles display lower flowability than coal particles [21] which makes them more difficult to feed.

Here, biomass particles (75–1000 μm) were fed at rates of 9.0–66.5 mg min^{-1} (2.9–21.7 W) using a particle feeder that dispensed particles by gravity through an injection tube. Feed rate was controlled by altering the velocity of a pusher block and the particles were agitated using a vibration motor. The design of the feeder was based on the design of a feeder presented by Li [22]. A similar feeder has also been

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presented by Monson and Germane [23]. The feeder comprised a particle injection tube inserted inside a glass tube loaded with particles which was attached to the pusher block of a syringe pump. The feeder dispensed particles downwards through the particle injection tube by moving the pusher block upwards. Factors impacting reproducibility and feed rate stability were investigated. The effects of particle size and of pusher block velocity were also studied. Statistical analysis was applied to investigate patterns in particle feed rate with time.

The information presented here may be used (i) to increase knowledge of feed rate stability with regard to particle feeding in general and biomass particle feeding in particular, (ii) as a reference case for evaluation of other feeders or (iii) as a knowledge base for the development of novel feeders.

2. Material and methods

2.1. Particle feeder construction and mode of operation

The particle feeder consisted of a vertically mounted syringe pump (model no. NE-300, from New Era Pump Systems, NY), two stainless steel tubes (one for introduction of carrier gas and one for particle injection) with inner and outer diameters of 5 and 8 mm respectively and a custom made glass tube (inner diameter 18 mm) with plastic endcaps (size GL25, from SCHOTT, Germany) fitted to both ends of it (Fig. 1). The glass tube was supplied by Saveen Werner (Sweden) and was 200 mm long including endcaps and 180 mm long without endcaps. The glass tube was attached to the syringe pumps pusher block using a holder made from a 1 mm thick sheet of stainless steel (produced by Storfors Plåt AB, Sweden). A vibration motor (model 324–401 from Precision Microdrives, UK) was attached to the glass tube using a holder. The vibration motor was controlled using a programmable power supply unit (model PSP-405 from GW Instek, Taiwan). The vibration amplitude (*g*) of the vibration motor was altered by altering the voltage output from the programmable power supply unit. Information on vibration amplitude (normalized for a 100 g target mass) as a function of voltage was obtained from the vibration motor manufacturer. Note that target mass is defined as the mass that the vibration motor vibrates (in this case the glass tube). When filled with 75–125 μm particles, the mass of the glass tube including the endcaps and the holder was ≈190 g. Given that vibrations were also transferred to other components of the particle feeder (e.g. the stainless steel tubes) the target mass was assumed to be 200 g. Therefore, to calculate the vibration amplitude (*g*) for a given voltage output, the normalized vibration amplitude provided by the vibration motor manufacturer was divided by 2.

By moving the pusher block upwards the particle bed was lifted above the end of the particle injection tube, thus causing the particles at the top of the bed to fall down through the tube assisted by gravity. The vibrations from the vibrating motor were used to disperse the particles which would otherwise aggregate and stick to the glass tube. Forces related to surface activity (i.e. electrostatic effects and the van der Waals force) and moisture work to adhere the particles to each other (i.e. aggregate) as well as to the glass tube wall [24]. The particles were repelled from the wall and from each other by the force derived from the vibration. This method is commonly used in the field of particle feeding to counter aggregation [14,16,25,26]. An alternative is to use a high speed gas flow [27].

2.2. Experimental setup

The syringe pump was mounted vertically above a balance (model PG1003-S/PH from Mettler Toledo, Switzerland) with a maximum capacity of 1010.0 g and a readability of 0.001 g. The glass tube was placed in the holder and the stainless steel tubes were inserted through the endcaps before being secured to ensure that they would not move as the glass tube was moved vertically by the pusher block. Care was taken to ensure that the positions of the stainless steel tubes relative to the glass tube were the same for each run. When the pusher block was in its starting position, the carrier gas tube was inserted 25 mm into the glass tube from the end of the top endcap. The particle injection tube was inserted 160 mm from the end of the bottom endcap, making the distance between the ends of the two tubes 15 mm. The other end of the particle injection tube (which was 440 mm in length) was 80 mm above the weighing pan. The reason for the perhaps surprisingly long length of the particle injection tube was a glass box around the weighing pan. The function of the box was to reduce interference. During runs, particles were distributed into a glass beaker (inner diameter 67 mm, height 130 mm) that was placed on the weighing plan. N_2 (instrument grade, AGA gas, Sweden) was used as carrier gas. A flow of 0.5 L min^{-1} was maintained using a mass flow controller (red-y series, Vögtlin, Switzerland). Note that this resulted in a N_2 flow of 400 mm s^{-1} through the stainless steel tubes. The balance was connected to a PC using BalanceLink software (Version 4.0.4, Mettler Toledo, Switzerland) to enable data logging.

2.3. Operating procedure, data collection and data handling

For each run, the glass tube was filled with particles to a bed height of 150 mm from the end of the bottom endcap. The vibrating motor was operated while the glass tube was filled with particles to avoid aggregation. The syringe pump pusher block was then lifted manually so that the bed height was level with the end of the particle injection tube. The carrier gas flow was started and then the vibrating motor was

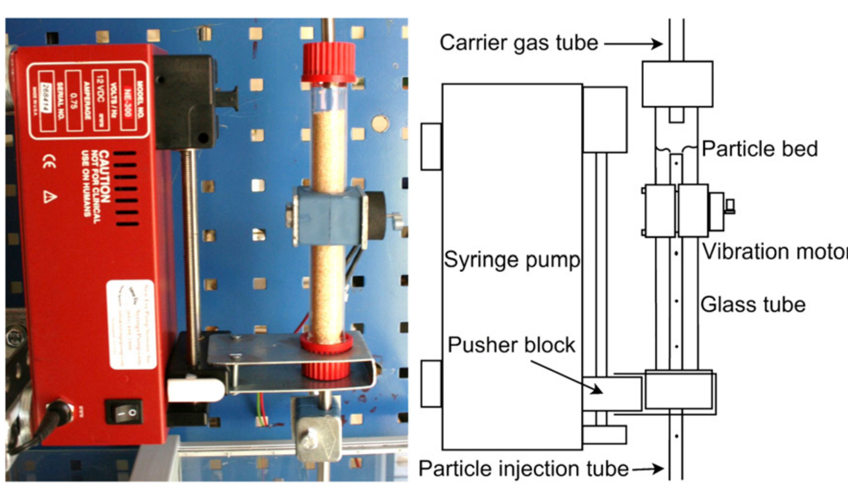

Fig. 1. Photograph of the experimental setup (left) and a detailed schematic of the particle feeder (right).