Available at www.sciencedirect.com

ScienceDirect

http://www.elsevier.com/locate/biombioe

BIOMASS & BIOENERGY

Biomass granular screw feeding: An experimental investigation

Jianjun Dai, John R. Grace[*]

Department of Chemical and Biological Engineering, University of British Columbia, 2360 East Mall, Vancouver, BC, V6 T 1Z3, Canada

ARTICLE INFO

Article history:
Received 18 August 2009
Accepted 4 November 2010
Available online 4 December 2010

Keywords:
Biomass
Feeding
Screw feeder
Torque
Blockage
Hopper

ABSTRACT

Successful feeding is critical to biomass utilization processes, but difficult due to the heterogeneity, physical properties and moisture content of the particles. The objectives of the present study were to find the mechanisms of blockage in screw feeding and to determine the effects of particle mean size (0.5–15 mm), size distribution, shape, moisture content (10–60%), density and compressibility on biomass particle feeding at room temperature. Wood pellets, sawdust, hog fuel and wood shavings were tested in a screw feeder/lock hopper system previously employed to feed sawdust into a pilot-scale circulating fluidized-bed gasifier. Experimental results showed that large particles, wide size distributions, large bulk densities and high moisture contents generally led to larger torque requirements for screw feeding. The "choke section" and seal plug play important roles in determining the torque requirements.

1. Introduction

Interest in using biomass feedstocks to produce heat, power, liquid fuels, and hydrogen and to reduce greenhouse gas emissions is increasing worldwide. Biomass feedstocks are potentially available in five categories: mill wastes, urban wastes, forest residues, agricultural residues and energy crops. Approximately 50% of the biomass globally available is woody, whereas 20–40% is grassy [1]. Demolition woods (both pure and mixed with sewage sludge and paper sludge) may also be used for gasification [2].

The chemical composition and physical properties of the feedstocks influence the design of biomass-processing reactors, such as gasifiers, combustors and pyrolysers, as well as the composition of the product gas and downstream cleanup methods. In general, fuels with high energy contents, high carbon-to-nitrogen ratios, relatively little sulfur and ash, regular shapes, small particle size, narrow size distribution, moisture content <55% (wet basis), suitable bulk density, and low contaminant level are preferred as raw materials. Biomass fuels (such as sawdust, hog fuel, straw, rice hull, sugar cane, bagasse and grass) are unique materials, with particles varying greatly in size and shape. Some are wet, leading to sticking. They also tend to be compressible and pliable. Some may be easily fractured (e.g., wood pellets, walnut shells), while others may be stringy and resilient (e.g., grass, straw, hay, cotton stalk, corn stover, wood chips).

Many biomass processes, including combustion, gasification, and pyrolysis, are under development. A critical problem in all cases is how to feed biomass into reactors. Feeding problems often impede smooth operation. Such properties as mean particle size, size distribution, shape, particle surface (e.g., smooth, rough or sharp edges), density, moisture content, compressibility and other fuel properties (e.g., strength of large particles, consolidation over time) can all affect the ability to feed the material.

In biomass energy processes, several kinds of feeders and their combinations have been reported, in particular hopper

[*] *Corresponding author*. Tel.: +1 604 822 3121; fax: +1 604 822 6003.
E-mail address: jgrace@chbe.ubc.ca (J.R. Grace).

0961-9534/$ – see front matter © 2010 Elsevier Ltd. All rights reserved.
doi:10.1016/j.biombioe.2010.11.026

or lock hopper systems, screw feeders, rotary valves, piston feeders and pneumatic feeders. They can also be combined rather than be separate, especially for continuous operations. These feeders have been developed for a variety of solids, but they have limitations in handling certain types of biomass and/or in feeding to pressurized reactors. Screw or piston operated plug feeders, common in feeding coal, have also been tested with biomass [3–10].

Hopper–screw feeders are common in biomass applications. Lack of flow is a common and serious solids handling problem. Flow stoppage may be caused by a bridge or "rathole" in the hopper, or by blockage or slippage in the screw itself. The flow patterns developed by screw feeders coupled to a hopper have been studied extensively, and mechanics and transport function of screw feeders have been investigated in detail [11–18]. Mixing and transportation of the particles inside screw feeders have also been analyzed [19]. However, biomass fuels have largely been ignored in previous research. The present study focuses on the feeding of biomass particles. The objectives are to define what limits screw feeding in terms of the mechanisms of blockage and to examine the effects of mean particle size (0.5–15 mm), size distribution, shape, moisture content (10–60%), density and compressibility. The work does not emphasize hopper flows, which have been widely studied, but rather the flow of biomass particles through the screw feeder.

2. Background on screw feeders

Screw feeders are volumetric devices, with delivery depending on the screw's outside and inside (shaft) diameter, pitch (distance between adjacent flights) and fullness. If the solids are compressible (e.g., sawdust, hog fuel), the mass delivered per unit time varies.

The velocity of conveyed solid material is a vector having an angle to the direction of rotation. As the screw rotates, particles move in helical paths of direction opposite to that of the screw. The frictional effects of the solids on the screw flights and on the casing surface, together with the configuration of the screw, determine the efficiency of the feeder. The efficiency decreases as the clearance between the discharge casing surface and screw flight tips increases. The screw feeder design must complement the hopper design so that the bulk solids do not arch or "rathole" across the feeder inlet [12,16,18,20–23].

Screw feeders used to feed biomass operate in a manner similar to piston feeders, but have a somewhat lower pressurization range (0.5–1.5 MPa). In a screw feeder, an auger compresses the feedstock into a compact plug, aided by tapering the feed channel, or by gradually reducing the pitch of the screw. The feed plug then forms a barrier, preventing backflow of gases and bed material from the reactor [5,9].

The feeder volumetric flow capacity is calculated based on the screw and casing dimensions at the entrance to the choke section. The volumetric feed rate is given [15] by:

$$V = Av\eta_v \tag{1}$$

where A is the cross-sectional area of the screw feeder, and v is the ideal axial feeding velocity of the screw, $=\omega P/(2\pi)$, P is the pitch, ω is the angular velocity, and η_v is the volumetric efficiency, i.e., the volumetric flow divided by the flow if the pockets were completely full and particles traveled at the feeder speed without slip or rotation.

The corresponding mass flow rate M is obtained by multiplying the bulk density, i.e., $M = V \times \rho_b$. The thickness of the screw flight is usually neglected in predicting the flow rate.

The volumetric efficiency, η_v, is less than 1 for several reasons:

(1) The axial velocity of particles is less than the ideal or optimum velocity owing to the rotary motion imparted by the screw.
(2) Slip may occur in the clearance space between the screw and casing.
(3) The filling fraction of screw pockets decreases as rotational speed increases because the screw has a capacity greater than what can be filled in practice.

3. Experimental set-up, methodology and materials fed

Two screws were tested in our study. Except where otherwise specified, the work below refers to screw-1. Schematics of the experimental lower hopper and screw feeder appear in Fig. 1,

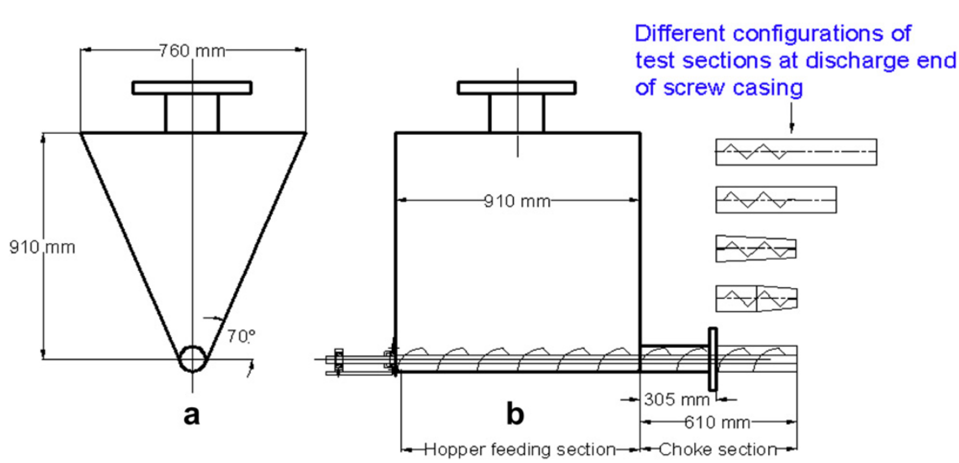

Fig. 1 – Schematic of lower hopper and screw feeder.