Design and performance evaluation of a novel biomass feeding system

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A novel feeding system has been designed and fabricated in order to provide an uniform and continuous flow of low bulk density biomass in a circulating fluidized bed (CFB) unit. The novel feeding system removes the difficulties associated with the various existing biomass feeding system such as bridge formation in the feeder and choking. In the novel design, a hollow pipe with holes at its surface has been installed at the core of the hopper to provide the aeration effect. The experiments were carried out at four different inventories of 250, 500, 750 and 1000 gm and at three different sawdust particle sizes of mean diameter 732, 853 and 921 µm. Results of the experiment show that, the developed feeding system is suitable for supplying biomass without choking to a CFB reactor to generate power for more than 5 kW-hr.

Keywords: Biomass, circulating fluidized bed (CFB).

Introduction

Circulating fluidized bed (CFB) has emerged as an environmentally acceptable technology for burning wide range of solid fuels such as coal, biomass etc. to generate steam and electricity with improved plant efficiency. Recently, CFB biomass gasification for generating producer gas has gained great attention because of its reduced emission characteristics. Besides, waste biomass and biomass residue, generally accepted as a CO₂ neutral and renewable source of energy. Biomass feeding into the CFB reactor is one of the critical problems. Feeding problems often impede smooth operation. The biomass properties such as 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) affects the ability to feed the material into the reactor\(^1\)-\(^3\). Development of several kinds of feeders has been reported, in particular hopper or lock hopper systems, screw feeders, rotary valves, piston feeders and pneumatic feeders. For continuous operations, they can also be combined rather than operating individually. 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. Biomass screw feeders operate in a manner similar to piston feeders, but have a somewhat lower pressurization range (0.5 MPa). Hopper screw feeders are widely used in biomass energy processes. The flow patterns developed by screw feeders connected to hoppers have been studied extensively by Dai and Grace\(^1\). Dai and Grace\(^2\) developed a model for biomass screw feeding for the torque requirement of a screw feeder by considering the bulk solid mechanics of a material element within a pocket. Screw or piston operated plug feeders, common in feeding coal, have also been tested with biomass\(^3\)-\(^10\). In screw feeders, lack of flow is a common phenomenon and have serious solids handling problem. Flow stoppage may be caused by a bridge or \textit{rathole} in the hopper, or by blockage or slippage in the screw itself. The various aspects such as flow mechanics, design, and the flow patterns developed by screw feeders coupled to a hopper have been studied by various investigators\(^3\)-\(^10\). Zhang \textit{et al.}\(^3\) developed an automatic shake mechanism in a screw feeder hoper in order to provide continuous flow of sawdust which removes the bridge formation problem. Yin \textit{et al.}\(^11\) mentioned that, the amount of biomass like rice husk required to generate 1kW-hr of energy is about 2.2 kg. Although, much work has been done on various type of hoppers and on modifications of the screw feeding system, no work has been reported on the use of porous rod in the core of the hopper for providing aeration for continuous flow of loose biomass to a reactor. In the present investigation, a conical hopper has been
fabricated which is attached to a blower. An aeration pipe is provided at the core of the cone hopper. The effect of particle size and biomass inventory on the flow of solid along with the hydrodynamics has been investigated.

Materials and Method

The purpose of this study is to develop a simple, low cost, energy efficient and a reliable feeding system to supply biomass continuously to a CFB unit without flow blockage and bridge formation. The novel feeding system comprises of a hopper, an aeration pipe, a flexing hose pipe, a feed control valve, a blower, an auto-transformer and a delivery pipe. The photograph of the setup is shown in the Fig.1. The inlet and outlet inner diameter of the cone hopper is 30 cm to 3 cm respectively and the height of the cone hopper is 70 cm. A mild steel pipe of ID 3.0 cm and length of 15 cm is welded at the smaller diameter end of the cone. The outer diameter and length of the porous pipe are 3 cm and 80 cm, respectively. A small pipe of OD 0.5 cm and the length of 6 cm is welded at one end of the porous pipe. Necessary hanging support is provided inside the cone. Holes of 3 mm diameter were drilled on the pipe installed at the core. The total number of holes drilled on the pipe is 64. The holes were spaced at 3 cm intervals along the axis. The diameter, number of holes and spacing between the holes were decided based on the experimental investigation with different particle sizes of biomass and its hydrodynamics. For each operation, a known quantity of biomass is fed into the hopper and rested on the neck of the cone hopper till the porous pipe is lifted up to a certain height after the blower is turn on. The control of required feed rate of biomass is regulated by supplying voltage through an auto-transformer (rating 6 A). Once the required air flow is achieved, biomass is allowed to flow into the CFB unit by lifting the porous pipe upto a certain height. The blower became operational only if the power supply was above 50 V and the flow is initiated at this voltage. The experiments were carried out at four different inventories of sawdust such as 250, 500, 750 and 1000 gm and at three different particle size of average mean dia 527, 732 and 853 µm. Sieve analysis were carried out to investigate the particle size of sawdust. In each experiment, time taken to discharge a known biomass inventory completely at a particular supply voltage has been recorded. The hydrodynamics of the sawdust is also investigated. The moisture content of the biomass used for the experiment has been measured and it is found to be 3 %. The property of the sawdust used in the present study is shown in the Table 1. All the experiments were repeated thrice in order to establish the repeatability.

Results and Discussion

The flow rate of the blower used in the biomass feeding system is calibrated with the voltages supply. The velocity of flow is measured by an anemometer at the blower outlet. A linear variation of velocity has been observed with supply voltage.

<table>
<thead>
<tr>
<th>Properties</th>
<th>Weight %</th>
</tr>
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<tbody>
<tr>
<td>Volatile matter</td>
<td>77.0</td>
</tr>
<tr>
<td>Fixed carbon</td>
<td>19.9</td>
</tr>
<tr>
<td>Ash</td>
<td>0.7</td>
</tr>
<tr>
<td>Moisture</td>
<td>2.6</td>
</tr>
<tr>
<td>Higher Heating Value (kJ/kg)</td>
<td>19891</td>
</tr>
<tr>
<td>Carbon (C)</td>
<td>48.5</td>
</tr>
<tr>
<td>Hydrogen (H)</td>
<td>6.4</td>
</tr>
<tr>
<td>Nitrogen (N)</td>
<td>0.1</td>
</tr>
<tr>
<td>Sulphur (S)</td>
<td>0.3</td>
</tr>
<tr>
<td>Oxygen (O)</td>
<td>44.6</td>
</tr>
</tbody>
</table>
Fig. 2 shows the variation and comparison of solid flow with blower exit velocity at four different inventories of 250, 500, 750 and 1000 gm. The sawdust particle size of mean diameter of 732 μm has been used for this comparison. From the figure, it has been observed that, with the increase in blower exit velocity, the solid flow rate increases. The solid flow rate also increases with the increase in inventory. This may be due to the increase in gravitational force with increase in weight. In all the inventories and at the sawdust particle sizes of 732 and 853 μm, no choking has been observed. Biomass appears to have smoothly discharged along the opening area between the pipe and the cone while there was air suction via the pipe, carrying the biomass along with it at the bottom. Unlike other models of biomass feeding systems, this apparatus was successful in avoiding choking and bridge formation.

The comparison of variation of biomass discharge time with blower exit velocity at four different inventories of 250, 500, 750 and 1000 gm is presented in the Fig. 3. From the figure, it is observed that, the biomass discharge time is found to be maximum at lower blower exit velocity and it decreases with the increase in velocity. No flow blockage has been observed at all the inventories. In all the experiments, the voltage is varied from 50 V to 90 V. The plot explains the ability of this feeder to deliver 1 kg of the biomass in about 18 min 3 sec and at 55 V. The pipe with holes proved to be extremely worthy. The flow through pipe without holes is initiated at a supply voltage of 100 V, while with holes the flow is initiated at 55 V. This implies that by using a porous pipe, the power consumption may be reduced significantly. Further experiments with different particle sizes and different flow rates, no process difficulties have been observed. This may be probably due to decrease in intermolecular force because of aeration.

In case of the larger particles having particle diameter of more than 921 μm, the pipe with holes was
have unable to provide sufficient suction and agitation for the feed and the flow was intermittent, even forming rat holes around the pipe unless the feeder is shaken momentarily in intervals of 5 minutes. Besides, with this sawdust having irregular particle shape and size the flow through the blower initiated only at 75 V and solid discharged very quickly. The discharge time taken is as low as 1 min 57 sec for 1 kg of biomass inventory. The snapshot of the bridge formation, formation of rat holes and shocking is shown in the Fig. 4. The physical properties such as spherocity, bulk density also affects the flow and hence different hydrodynamic flow behavior has been observed at different velocities.

Conclusions

Performance of the feeding system has been evaluated at four different biomass inventories of 250, 500, 750 and 1000 gm and at three different particle sizes of 732, 853 and 921 $\mu$m. Absolutely no choking has been observed at all the inventories at particle sizes of 732 $\mu$m and 853 $\mu$m. The bridge formation and shocking has been observed in case of the particles having particle size 921 $\mu$m. The developed system is a very flexible one, depending on the requirement of the feed, the appropriate voltage may be supplied in order to control the speed. The biomass feeding range of the developed feeding system is found to be 1-12 kg/hr, which is capable of supplying feed to a reactor of power generating capacity of 1-5 kW-hr. The developed feeding system is very much suitable for feeding of low bulk density biomass such as sawdust having particle size lower than or equal to 853 $\mu$m to the circulating fluidized bed unit. Feeding of biomass without porous rod has also been tried, however, a continuous flow could not be achieved after some time of operation.

References