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Pilot scale evaluation of fuel pellets production from garden waste biomass

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ABSTRACT

Pelletization of garden waste, without additional binder, was investigated to produce high quality fuel pellets for energy utilization. The influence of pelletization parameters viz. feedstock moisture content (5, 15, 25, and 35%), milling size (25.4 and 6.25 mm) and die size (12 and 15 mm) on pellet quality and pelletization process was studied. The results showed that the studied parameters had significant effect on pellet quality. A reduction in average durability value (95.0% to 92.5%) was observed when moisture content of garden waste increased from 5% to 15%. Appropriate regression models were also developed for each quality attribute by using multiple linear regressions. Eventually, a feedstock moisture content of 5 ± 1%, milling size of 6.35 mm and die size of 15 mm were found to offer standard quality pellets with optimum throughput capacity. Scanning electron microscopy image analysis showed a closer agglomeration of biomass particles when feed materials were pelletized at low moisture content. The equilibrium moisture content due to adsorption for garden waste pellet was found to be 14.6% which was quite low as compared to other feedstocks. Furthermore, we deduced from the combustion test that garden waste pellets may be conveniently used in a residential cookstove. In a nutshell, pelletization of garden waste biomass has been demonstrated at pilot scale in this study.

Introduction

Densification of biomass through pelletization allows one to use carbon neutral fuel with higher energy density thereby reducing the transportation, handling and storage costs (Tumuluru, Wright, Hess, & Kenney, 2011; Miao, Grift, & Ting, 2014). Fuel pellets have various applications, ranging from residential stoves to full-scale power plants (Holm, Henriksen, Hustad, & Sørensen, 2006; Moya, Rodríguez-Zúñiga, Tenorio, Valdez, & Valaert, 2015; Chen et al., 2016). The commonly used biomass feedstock is wood and the market of wood biomass pellets has shown an exponential rise of 0.5 million tonnes (8.5 Peta Joule) to 6.6 million tonnes (120 Peta Joule) between 2000 and 2010 (Lamers, Junginger, Hamelinck, & Faaij, 2012); further the production is projected to increase to 45.2 million tonnes in 2020 (Guo, Song, & Buhain, 2015). The growing demand of fuel pellets has stimulated search for alternate lignocellulosic biomass. After wood wastes, agricultural residues are being considered as potential feedstock available in substantial quantities. Several researchers have investigated pelletization of agricultural residues using binders such as starch, wood powder, lignosulphate etc. to produce highly durable pellets (Serrano, Monedero, Lapuerta, & Portero, 2011; Mediavilla, Esteban, & Fernández, 2012; Said, Abdel Daiem, Garcia-Maraver, & Zamorano, 2015; Stasiak et al., 2017). However, external binder may add to the production cost of the pellets (Jiang et al., 2016). In contrast, garden waste i.e. leaf litters from various tree species, has natural binder such as lignin (Kaliyan & Morey, 2010) which favours solid bridge formation during the pelletization process and hence, the additional cost of binder can be avoided.

In recent times, garden waste is disposed off in open dumps and landfills, which raises socio-environment problems. According to an estimate, the cities in China namely, Beijing and Shanghai, generate about 2.5 million tons of garden waste per year (Shi, Ge, Chang, Shao, & Tang, 2013) and in New Delhi, India, the garden waste shares up to 23% of total landfill waste i.e. 1150 tonnes per day (Chakraborty, Sharma, Pandey, & Gupta, 2013). Thus, garden waste, a potentially huge underutilised biomass can be considered as an alternate guaranteed biomass feedstock to pellet manufacturers relying on wood and agricultural residues (Lamers et al., 2012). Therefore, there is a need to study the pelletizer performance and quality of pellets produced using garden waste which in itself is a unique raw material when its chemical composition is compared with standard pellets made from wood sawdust or homogeneous agricultural residues such as wheat straw, and corn stover (Theerarattananoon et al., 2011).

Various pellet quality standards have been prescribed to maintain homogeneity of pellets both at national and international markets (Table A.1). These pellet properties depend on the type of feedstock, type and quantity of additives, machine specific parameters and expertise

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of operator (for manually operated machines). Among the feedstock parameters, moisture content is an important parameter as it regulates the friction between the compression channel and the feedstock (Stelte et al., 2011a). There is substantial data available on the desired moisture content range for woody biomass, e.g. 11.2% for sugar maple particles (Nguyen, Cloutier, Achim, & Stevanovic, 2015) and 10% for olive tree pruning residues (Carone, Pantaleo, & Pellerano, 2011). High moisture pelletization with various types of biomass feedstocks were also evaluated by researchers; for example 40% moisture content for compost (Zafari & Kianmehr, 2013), 11 to 41% for wood sawdust (Poddar et al., 2014), 38% for corn stover (Tumuluru, 2015), and 60–80% for crop species like *S. bicolor*, *P. purpureum* and *A. donax* (Aragón-Garita, Moya, Bond, Valaert, & Filho, 2016). Further, for a city where the rainy season prevails almost 4 months a year, coupled with high relative humidity region (for example, Mumbai in India), it is difficult to get dry garden waste throughout the year. Therefore, in the present investigation on garden waste, a wide range of the moisture content (5–35%) has been considered.

Milling size of feedstock is also important as larger size results in more voids in the press channel, and reduces bonds interlocking significantly (Kirsten, Lenz, Schröder, & Repke, 2016). Mani, Tabil, and Sokhansanj (2006) reported the ideal milling size of 3.2 mm at 12% moisture content to produce corn stover pellets. Next, the die geometry, i.e. die hole diameter and channel length, also affects the throughput capacity of pellet mill, pellet quality and other process requirements (Theerarattananoon et al., 2011). Holm et al. (2006) developed a model to explain the influence of channel length and die size on pelletization pressure. Tumuluru et al. (2011) also reviewed the influence of die geometry on the quality of the densified material. They reported that the durability of pellets improved with smaller die of higher L/D ratios. Theerarattananoon et al. (2011) reported that use of a thicker die (44.5 mm instead of 31.8 mm die thickness) resulted in a significant increase in pellet durability for wheat straw pellets, corn stover pellets, and sorghum stalk pellets. Further, a single pellet press cannot simulate all aspects such as die choking, fines generation, and throughput capacity of a large scale pelletization plant. Thus, a pilot scale study is needed to examine the effects of above process parameters before scale up scenarios can be evaluated. Only few systematic studies in pelletization of biomass are reported in literature (Mediavilla et al., 2012; Monedero, Portero, & Lapuerta, 2015; Jackson, Turner, Mark, & Montross, 2016; Kirsten et al., 2016) and to the best of our knowledge, pelletization of garden waste as a feedstock has still not attracted attention of researchers in this area.

The overall objective of this study was to evaluate the fuel pellets production from garden waste at pilot scale. Specific objectives were (1) to investigate the influence of pelletization parameters on pellets quality and pelletization process; (2) to examine the combustion behaviour of produced fuel pellets in a residential cookstove.

The article is organized as follows: First we describe the experimental protocol used to assess the feedstock characterization, pellet quality and pelletizer performance, including micro-structural analysis, moisture adsorption test and combustion behaviour. This is followed by the development of a correlation between the pelletization parameters and pellet quality using statistical approach. This section also includes results obtained from scanning electron microscopy analysis, moisture adsorption test and combustion experiment.

Materials and methods

Feedstock

Fresh Garden waste was collected from the Indian Institute of Technology, Bombay (IIT B) campus, Mumbai, India. The biomass was comprised of leaf litters of Mango (*Mangifera indica*), Raintree (*Siamese cassia*), Jackfruit (*Artocarpus heterophyllus*), and other sticks and grasses. Around 3 tons of the mixed waste was prepared and homogeneity of the feedstock was maintained throughout the experiment. The typical composition of mixed garden waste was: *Mango* leaves (15.5%), *Raintree* leaves (34.7%), *Jackfruit* leaves (29.3%), grasses (2.2%) and miscellaneous matter containing sticks and barks (18.3%).

Characterization

Proximate analysis was performed using a thermogravimetric analyser (TGA) (Model: Perkin Elmer-SII). The elemental composition (C, H, N, S, and O) of biomass was determined by a CHNS (O) analyser (Make: Thermo finnigan, Italy; Model: FLASH EA 1112 series). The lignocellulosic weight percentages were estimated from neutral detergent fiber (NDF), acid detergent fiber (ADF) and acid insoluble lignin (AIL) content of biomass. The NDF and ADF were estimated using Van-soest detergent fiber analytical techniques (Van Soest, Robertson, & Lewis, 1991) and AIL was determined by following NREL protocol for structural carbohydrates and lignin (Sluiter et al., 2008). The higher heating value (HHV) of biomass was obtained using an oxygen bomb calorimeter (Model: IKA C 200).

Process description

A process flow diagram of the pelletization process from garden waste is described in Fig. 1. Soils and stones present in garden waste were separated using a soil separator. Two stationary hammer mill type shredders i.e. a coarse shredder (Make: CRPL, mill screen size: 25.4 mm, power requirement: 15 hp, capacity: 160–180 kg h^{-1}) and a fine shredder (Make: CRPL, mill screen size: 6.35 mm, power requirement: 7.5 hp., capacity: 80–100 kg h^{-1}) were used to reduce particle size. During the experiment, moisture content in the garden waste was raised by sprinkling water over the biomass and it was lowered by using a rotary drier as per requirement. The conditioned garden waste was then kept overnight to reduce the non-uniformity of moisture. Garden waste (bulk density of 80–120 kg m^{-3}) was fed to the pelletizer using a screw conveyor to ensure uniform rate of feeding during the run. Before each test, 5 kg of oily biomass was used to preheat the die. Oily biomass was prepared by mixing 500 ml of furnace oil with 5 kg of garden waste. The die was preheated to 80–90 °C due to frictional heat by flushing the oily material in through the channel and subsequently the biomass was fed to pelletizer for smooth operation. Just before the completion of each run, the oily biomass was again fed to the pelletizer to prevent choking of press channel in the next run. Each run was performed to densify 50 kg of garden waste which lasted for about an hour and pellet samples were collected at an interval of 15 min. Detailed specifications of the pelletizer are given in Table 1.

Measurements of pellet quality

The pellets produced were allowed to cool at ambient temperature before measuring quality parameters for a representative sample as per the ASABE Standards S269.4 (ASABE, 2007).

Moisture content (%)

The moisture content was measured using a digital moisture meter (Make: Amprobe; Model: MT10; Measurement range: 8–60%; Resolution: 0.1%; Accuracy: ±2%) after 2 h once the pellets are made. The moisture contents of samples were also measured intermittently using oven drying method (105 °C for 24 h). Measurements were repeated twice to report the average moisture content.

Pellet diameter and length (mm)

The pellet diameter and length were measured using a vernier calliper (Make: Aerospace, Range: 0–150 mm, Accuracy: 0.02 mm) and average value was calculated from ten random samples of each run. For this, the pellets were sampled in every 15 min during a run.