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Effect of compression pressure on lignocellulosic biomass pellet to improve fuel properties: Higher heating value

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HIGHLIGHTS

- Higher heating value does not show consistent relationship with moisture and ash content.
- Pellet density increases radically at first and then gradually with increasing pressure.
- Weight loss during pelletization is principally related with the moisture content of biomass.
- Higher heating values of biomass pellets show no definite trend with increasing pressure.
- Pattern of bonding between biomass particles is suggested for the anomaly in heating value.

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ABSTRACT

Compaction of biomass through pelletization leads to the formation of a carbon neutral fuel with higher density. The aim of this present work was to determine the extent of influence of pelletizing pressure on pellet density and alteration of higher heating value (gross heat of combustion) of pellets. Eight species of wood sawdust and different compression pressures were used in pellet preparation. The sizes and mass of compressed samples were measured to calculate the pellet density and oxygen bomb calorimeter were used to determine higher heating value. Pellet density was seen to increase radically at first and then gradually with the increase of pelletizing pressure. In case of heating value, with increase in pelletizing pressure no definite trend was observed among the compressed biomass species. The pattern of bonding between biomass particles is the main factor influencing heat of combustion. The alteration of chemical composition, quantity of moisture and extractives, prevalence of favourable condition for lignin flow, migration of extractives to the surface and the presence of inter-particle gaps and voids affect the bonding quality. These factors differ from one biomass species to another which eventually leads to variation in higher heating value pattern.

1. Introduction

In today's world the global energy demand is fulfilled mainly by fossil fuels which accounts for 86% of the actual energy demand [1]. Worldwide availability and relative inexpensiveness had established fossil fuels as an attractive energy source in the last century. The increase of atmospheric CO_2 and other greenhouse gases due to fossil fuel burning is of main environmental concern at the present time. Increased consumption and non-renewable character have led to the depletion of the fossil fuel reserves. The environmental issues together with this potential energy crisis have stimulated the transfer of energy sources from fossil fuel to renewable energy sources such as biomass.

The use of biomass, a 'carbon lean' fuel, as energy source provides significant socio-economic and environmental benefits. It is an abundant resource and its renewable aspect is an assurance of sustainable use. But the dispersal and seasonal production of biomass offset its availability in vast amount. Often long distance prevails between the biomass place of origin and the place of its end use, resulting in higher transportation cost. It has been estimated that, transportation cost is the second highest cost after capital cost for direct biomass fired power plant [2]. The low bulk

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density of fresh biomass as compared to coal restricts the economic transportation distance less than 200 km [3]. These problems associated with biomass can be minimized through densification, a process that enables to produce a solid, densified fuel with uniform properties. By increasing their homogeneity and density, densification of biomass contributes in developing their fuel characteristics. Pellets are the most popular densified product for fuel purposes. High energy density and convenience in handling and transportation make biomass pellet a preferable fuel when compared to their raw feedstock.

Among different mechanical properties, pellet density is considered to be of high significance. According to Mani et al. [4], density is the main indicator of pellet quality. Different variables such as compressive force, particle size and moisture content affect pellet density. Li and Liu [5] had recommended the optimum moisture content to be approximately 8% for producing densified products. Gustafson and Kjelgaard [6] and Rehkugler and Buchele [7] found that as the moisture content increases, the density of the product decreases. Usually pellet density varies inversely with particle size because during densification smaller particles provide greater surface area. Dobie [8] observed that fine grinding of biomass is likely to produce high density pellet.

Little work has been done regarding the study of energy obtained from biomass pellets. In case of biomass, higher lignin and extractive content contributes to higher heat of combustion of biomass [9,10]. For this very reason, softwoods generally have greater heating values compared to hardwood. Significant differences in energy content are observed between various plant organs. Biomass samples from root and main stem of a species show greater heating values whereas lowest value is observed in case of leaves. Seeds and flowers, alternatively, have the highest heating value due to higher lipid content. On the other hand, biomass pellets prepared from agricultural crop and forage residues shows lower heat of combustion than that made from forest residues [11]. According to Lehtikangas [12], a decrease in heating value takes place when the raw biomass is dried and refined to pellets. It probably occurs due to the loss of volatiles during drying. Several extractives such as resins and tannins negatively affect the combustion of pellets and consequently their heating values. It happens because they produce higher percentage of ash and dust [13]. Typically heating values obtained from wood and straw based pellets range 17–18 MJ/kg [14,15].

The objective of this study was to determine the effect of pelletizing pressure on the alteration of higher heating value (gross heat of combustion) of pellets and the change in pellet density in case of several biomass species. This will help in selecting the optimum pressure required to prepare pellets with the highest heating value for a particular species.

2. Materials and methods

2.1. Materials

Eight different species of wood sawdust were used for the present study: Gurjan Balsam (*Dipterocarpus turbinatus* Gaertn.), Teak (*Tectona grandis* L.f.), Burmese Teak (*T. grandis*), Champak (*Michelia champaca*), Scots Pine (*Pinus sylvestris*), Mahogany (*Sweitenia macrophylla*), Jackfruit (*Artocarpus heterophyllus*) and Burma Ironwood (*Xylia kerrii*). Burma Ironwood and Burmese Teak wood were imported from Myanmar whereas Scots Pine was collected from Thailand. Other wood species are indigenous to Bangladesh. Sawdust of these eight wood species were collected from the local wood sawmill in the month of July. The materials had a particle size between 1 and 5 mm in diameter and no further processing of samples were performed after collection. Collected sawdust were then stored in plastic containers until further analysis.

2.2. Moisture and ash content

Moisture content of raw materials was determined following the procedure given in ASTM Standard D 4442-07 for wood and wood based materials. About two grams of the sample were taken in a crucible and oven-dried at 105 ± 2 °C. The moisture content was determined by weight measurement in a 3 h interval and expressed in percent wet basis. These oven-dried samples were then heated in a muffle furnace in order to determine ash content as stated in ASTM Standard E 1755-01 for biomass. The ash content was measured by weighing and expressed as a percentage of sample's oven-dried weight.

2.3. Volatile matter

Analysis of volatile matter was accomplished according to ASTM Standard D 271-48 as used for coal. Raw samples of about four grams were heated in a furnace for 7 min at 950 ± 20 °C. Volatile matter is then determined by measuring the weight loss, excluding weight of moisture driven off at 105 °C.

2.4. Fixed carbon

The fixed carbon in percentage was calculated by difference between 100 and the sum of the volatile matter, moisture and ash content.

2.5. Ultimate analysis

Ultimate analysis of samples was done by organic elemental analyzer (Reactor temp. 900 °C, He: 250 kPa, O_2: 250 kPa, TCD, Flash 2000, Thermo Scientific, USA). This instrument analyzes in accordance with the procedures stated in ASTM Standard D 5291-02.

2.6. Pellet preparation

The pellets were prepared using a universal testing machine (UTM) (FS – 300 kN, Testometric, England) at 25 °C. The cylindrical die used was made of carbon steel and had an opening of 10 mm in diameter. The end of the die was closed using a removable backstop which is basically a carbon steel pellet. Pressure was applied on the sample by another carbon steel pellet, a metal piston and crosshead of the UTM machine. The compression force was measured using a 300 kN load cell, connected to a computer and data analysis software. The die was rinsed with acetone and wiped clean using tissue paper before each use and when changing raw materials. Most of the time, sawdust was loaded in amounts less than 0.25 gram into the die and then compressed at a rate of 2 mm/min until the desired pelletizing pressure was reached. The pressure was released after 10 s and the piston was removed. The pellets were removed from the die by removal of the backstop and pushed out by applying pressure on the pellet by the same arrangement used for pelletization at a compression rate of 2 mm/min. The pelletizing pressures used in the present study are 6 kN, 12 kN, 16 kN and 20 kN. It had been evaluated that the oxygen bomb calorimeter used was unable to determine the heating value of pellets greater than 0.28 gram in weight. So for this study, short pellets of a few millimeters in length were prepared as opposed to the pellets actually made on a large scale that have lengths up to 40 mm.

2.7. Pellet density

The dimensions of pellets pelletized at different pressures were determined using Vernier or slide calipers. Their weights were