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Research Paper

Effect of densification parameters on the properties of maize residue pellets

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ARTICLE INFO

Article history:
Received 30 April 2015
Received in revised form
14 August 2015
Accepted 29 August 2015
Published online 15 September 2015

Keywords:
Biomass
Briquette
Corn
Densification
Renewable energy

The effect of the conditioning process parameters on the properties of the pellets was investigated. Maize residues were collected locally from the field and crushed into small sizes, dried, and separated for compaction. The effects of the variation of the die temperature (30–80 °C), the compaction pressure (150–250 MPa), and the biomass type (cob, husk, and stalk) on compact density, relaxed density, and durability index were investigated. It was found that the compact density increased with pressure and temperature to around 950–1100% higher than the residue density. The relaxed density was stable at 60–80 °C, but at 30 °C, it was found to decrease from 800–1000 kg m^{-3} to 660–700 kg m^{-3}. The durability index was observed to improve with increasing pressure and temperature by 30–60% and 70–90%, respectively. This corresponded well with the lignin glass transition temperatures being in the range of 60–80 °C at moderate pressure values between 150 MPa and 250 MPa. Pellet density was also found to increase with increasing compression pressure and temperature. Pellet density was three times higher than bulk density and similar to the particle density. Heating the feed materials during compression decreased the compaction pressure from 250 MPa to 150 MPa, resulting in the formation of pellets with a higher durability index and more stable relaxed density.

1. Introduction

Among the Southeast Asian countries, Thailand ranked third in maize production in 2012, with a total yield of approximately five million tonnes per year. Production yield has been growing steadily every year (OAE, 2014). The potential energy of maize residues has been calculated as being approximately 65,125 TJ coming partly from cobs (11,386 TJ) but mostly from stalks (53,738 TJ) (DEDE, 2007; OAE, 2014). Maize residues therefore have great potential as biomass feedstock for producing energy via thermochemical conversion processes. Many researchers have investigated the pyrolysis of maize cobs (Mullen et al., 2010; Wongsiriamnuay, Panyoyai, & Tantikul, 2012) and *maize stalks* (Ioannidou et al., 2009; Mullen et al., 2010), as well as by gasification (Ioannidou et al., 2009; Lu et al., 2006) and combustion (Sittisun, Tippayawong, & Wattanasiriwech, 2015) for electricity and steam production. Other researchers have focused on bioethanol production from corn stover (Kim & Dale, 2004). Maize cobs have potential not only as an energy feedstock but also as

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http://dx.doi.org/10.1016/j.biosystemseng.2015.08.009

Nomenclature

CD	compact density (kg m^{-1})
d	time (day)
DI	durability index (%)
D	diameter of the pellet (m)
D_0	diameter of the pellet immediately after extrusion (m)
D_5	diameter of the pellet after 5 d storage (m)
ER	expansion ratio
L	length of the pellet (m)
L_0	length of the pellet immediately after extrusion (m)
L_5	length of the pellet after 5 d storage (m)
m	mass of the pellet (kg)
m_1	mass of the pellets before tumbling (kg)
m_2	mass of the pellets after tumbling (kg)
RD	relaxed density (kg m^{-1})
V_C	volume of the pellet immediately after compaction (m^3)
V_R	volume of the pellet after 5 d of storage (m^3)

a raw material for phytochemical products such as simple phenylpropanoids (Ashour et al., 2013) and particleboards (Danladi & Patrick, 2013; Faustino et al., 2012).

In Thailand, maize residues are almost without any suitable uses because of their low density and the high operational costs for their management, transportation, and storage. Most residues are burned in the field, thus causing environmental problems such as particulate and gaseous pollution. Increasing the density of biomass residues is a method that can be used to reduce volume and make the residue better as fuel. Increasing the density can be achieved by densifying the residues into bales, briquettes, cubes, pellets, and pucks. Densification affects product properties and quality. Process variables such as compaction pressure, heating die temperature, die size, die speed, and compaction time are important as far as final product properties such as density and durability as well as energy usage in the process are concerned.

Pressure and temperature are especially of great interest. The relationship between pressure and temperature suggests that a high load with low temperature, or low load with high temperature may be employed, but not temperatures > 120 °C. Using high temperatures demands less weight for compaction with less power consumption (Mani, Tabil, & Sokhansanj, 2003). Additionally, heating wet biomass needs the use of high temperatures with long heating times, but when the temperature > 110 °C, it has less effect (Smith, Probert, Stokes, & Hansford, 1977). The strength and density increases with increasing moisture content until an optimum level is reached (Moore, 1965). The pellet moisture content should be in the range of 11–13% for storage over four months (Samuelsson, Larsson, Thyrel, & Lestander, 2012). Heating the feedstock between periods of compression has been carried out at various temperatures, from room temperature up to 250 °C. Die temperatures of the maize cob and the corn stover compaction have been observed to be in the ranges of 25–30 °C, 70–85 °C, and 100–110 °C (Kaliyan & Morey, 2009a, 2009b, 2010a, 2010b; Theerarattananoon et al., 2012; Tumuluru, 2014). High temperatures for the densification process resulted in greater durability when compared to room temperature. However, using higher temperatures resulted in higher energy consumption and higher operational costs.

Energy consumption is also a main concern in the densification process. To decrease energy consumption, compaction may be carried out at medium pressure with die temperatures < 100 °C. From the literature, it is evident that there is a lack of detailed studies moderate pressure with low temperatures (<100 °C) for maize residues. Works on different sources of residues such as the maize cob, stalk, and husk are also of interest. The aim of this research was, therefore, to investigate experimentally on a laboratory scale pellet production from maize residues such as cob, husk, and stalk. The results of this study could determine if these moderate process conditions are appropriate for producing high values for durability or abrasion index, pellet density, and relaxation density. It is expected that this information will be useful for the future utilisation of maize residues as an alternative energy source.

2. Material and methods

2.1. Preparation of materials

Maize residues such as cob, stalk, and husk were used in this study. In this research, the effect of process conditioning parameters and biomass type on pellet density and durability was experimentally investigated. These residues were collected from fields around Chiang Mai and then sun dried for 5–7 d. They were later crushed using a hammer mill and graded into the range 0.425–0.8 mm. Moisture content of the feedstock was determined by following an ASAE standard, with 10 g of the material dried at 105 °C for 72 h with moisture at about 10% dry basis.

2.2. Experimental setup

The experimental setup used for compaction is shown in Fig. 1. It consisted of a piston and a closed-end die. The piston had a diameter of 9 mm and a length of 100 mm. The die was composed of two parts: a cylinder and a base. The cylinder has a diameter of 9 mm. The base can be removed after compaction. The apparatus was mounted on a universal testing machine that is used to apply known loads to a hydraulic piston. A pressure gauge was used to measure the applied pressure. The cylindrical die was equipped with a tape heater of 450 W to heat the die and the biomass during compaction. The temperature was controlled by a digital controller. The durability was determined according to the ASABE 269.4 standard. A series of four tumbling boxes was used to test for durability, and a screen of 6.35 mm was used for sieving to remove the fine particles from the pellets.

2.3. Experimental method

After the biomass residues were collected and ground to decrease the size, they were compacted in the densification