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Experimental trials to make wheat straw pellets with wood residue and binders

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ABSTRACT

Crude glycerol, bentonite, lignosulfonate, and softwood residue (wood residue) were investigated in this study as binders for biomass fuel pellets for thermochemical conversion to enhance pellet quality for transportation and storage. The mass fraction of water of the wheat straw and the wood residue used for pelleting were 0.0676 and 0.0949, respectively. Wheat straw with crude glycerol, bentonite, lignosulfonate, wood residue, and pretreated wood residue with crude glycerol were compressed in a single pelleting unit at a temperature of 95 °C. The specific energy consumption, density, dimensional stability, tensile strength, calorific value, ash content, and chemical composition of the pellets made were determined. Results showed that the specific energy consumption for wheat straw pelletization significantly decreased with the addition of lignosulfonate, bentonite, wood residue, and pretreated wood residue with crude glycerol. With the addition of binders chosen in this study, the tensile strength of wheat straw pellets was improved with values ranging from 1.13 to 1.63 MPa. There was a significant increase in the higher heating value (17.98 MJ kg^{-1} to 18.77 MJ kg^{-1}) when crude glycerol, wood residue, and pretreated wood residue were used as binders. The addition of both pretreated and non-pretreated wood residue significantly decreased the ash content of wheat straw pellets.

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1. Introduction

There is increasing activity in the development of economical and environmentally friendly bioenergy production technologies to substitute fossil fuels. Agricultural residues are an abundant and inexpensive source of renewable energy. Agricultural residues are the largest, in terms of mass, biomass feedstock in the world [1]. About 1.5 Gt of straw from cereal crops are annually produced worldwide which is considered as a potential feedstock for biofuel production [2]. Densification of biomass is considered important to achieve efficient handling, transport, and storage operations [3]. Densification can enhance the volumetric calorific value and

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physical properties producing uniform, clean, stable, and energy denser biomass as environment-friendly fuels [4]. Pellets are the most energy intensive densified product. Pellets have higher density and can be easily handled, stored, and transported long distances compared to briquettes or cubes. Pellets can also be efficiently utilized for biochemical or thermochemical conversion because of the large superficial area of pellet particles.

Constituents such as lignin, protein, starch, and water soluble carbohydrates are natural binders in biomass materials [5,6]. Agricultural straws usually do not contain an adequate amount of these natural binding components and the lignin is bound to the lignocellulosic matrix of biomass. Since the chemical structure of agricultural straw is a lignocellulosic matrix, this matrix could be debonded by using physico-chemical and biological pretreatments such as the application of different chemicals and additives, microwave pretreatment, steam explosion, and other pretreatments [7]. A number of pretreatment methods have been explored to enhance pellet durability and strength [7–9]. These pretreatment methods debond the lignocellulosic matrix structure and the free lignin acts as a binder for biomass particles during pelletization, thus improving the durability of the pellets.

High concentrations of hydrophobic extractives with weak boundary layers may limit the adhesion mechanism by van der Waals forces that were most likely responsible for the pellets' low compression strength [10]. Removal of the extractives significantly increased pellet strength but also increased the energy requirements [11]. Binder addition could be another solution to improve the straw pellet durability and strength. A binder (or additive) can be a liquid or solid that forms a bridge, film, matrix, or causes a chemical reaction to make strong inter-particle bonds [5,12]. Additives in the range of 0.005–0.05 (fraction total mass basis) could be added to improve pellet quality or to minimize pellet quality variations [12]. Biological binders (more than 0.20 fraction total mass basis) such as sawdust, starch, and molasses were suggested to help improve the quality of the densified product [5]. Lignocellulosic materials such as wood residues with high lignin content and higher heating value used as an additive could be a promising way of improving the strength and durability of pellets. Wood pellets have good structural strength, and lower dust and ash contents. Recycling wood residues is environmentally friendly and solves the problem of disposal [13]. Generally, softwood has higher lignin content than hardwood. Durability of wheat straw briquettes was reported to increase from 46.5% to 67.6% by blending the wood residue with straw at a mass ratio of 3:1 (wood to straw) [14]. The durability of rapeseed cake pellets increased proportionally as the amount of sawdust added was increased [13].

Due to the high heating efficiency and ease of operation, microwave irradiation has been extensively used in many applications. It has been demonstrated that microwave irradiation in an aqueous environment changes the structure of lignocellulosic materials. The enzymatic hydrolysis of biomass can be enhanced [15] through microwave treatment. Chemical agents such as NaOH and CaO have been added to wheat straw to reduce the resilience characteristics of the fiber and to enhance the particle interlocking bonding capability to increase pellet durability [16]. The key role of NaOH solution pretreatment is to disrupt the ester bonds between lignins and carbohydrates [7]. Microwave-chemical pretreatment was able to significantly disintegrate the lignocellulosic structure of wheat and barley straw grinds. The pretreatment increased the pellet density and tensile strength of wheat and barley straw pellets [7]. Binders for pelleting are classified into three general groups: a) matrix type, b) film type, and c) chemical binders, of which lignosulfonate and bentonite are film type binders [17]. Lignosulfonate, derived from the pulp industry, is an effective binding agent when used at inclusion levels of 0.01–0.03 (fraction total mass basis) [18]. Bentonite is a colloidal hydrated magnesium aluminum silicate clay used for making firmer pellets [12] and is largely composed of Montmorillonite which is a highly colloidal, plastic clay. When dispersed in water, bentonite breaks down into small plate-like particles and become negatively charged on the surface and positively charged on the edges. This unique ion exchange is responsible for the binding action. Bentonite added at a rate of 0.026 (fraction total mass basis) was reported to reduce dust in poultry feed pellets [19]. The addition of binders considerably improved the durability of alfalfa pellets. Adding 0.0125 (fraction total mass basis) lignosulfonate increased pellet durability from 65.1% to 85.8%, and adding 0.05 (fraction total mass basis) bentonite increased pellet durability from 65.1% to 88.8% [12]. Glycerol is a byproduct of the transesterification process in the production of biodiesel. For every 10 kg of biodiesel produced, 1 kg of crude glycerol is co-produced through transesterification of triglyceride feedstock [20]. The production of glycerol is expected to further expand with the spread of biodiesel production plants [21,22]. If the production of biodiesel increases as expected, the supply of glycerol will be in excess of demand. Thus, there is a growing need to develop new applications to convert glycerol into value-added products [21,22]. Crude glycerol is also a good energy source [23]. Lubricant oil can be added to increase bulk density and improve the flowability of biomass pellets in a pilot-scale pellet mill [24]. The presence of fat above 0.065 (fraction total mass basis) is detrimental to pellet durability [25]. The moisture in biomass acts as both a binder and lubricant [26]. Production of high quality pellets is possible only if the mass fraction of water of the feed is between 0.08 and 0.12 [27]. The density of biomass pellets increases with an increase in compression load (1000 N–4000 N) when the mass fraction of water is 0.09 [9]. Good quality compacts can be produced when the mass fraction of water of corn stover and switchgrass grinds is 0.10 [28]. Biomass with lower moisture produced denser compacts [29].

A description of how wheat straw pellets were made using wood residues and selected binders is presented in this paper. There were two objectives of this study: 1) to make pellets from wheat straw with glycerol, lignosulfonate, bentonite, various mass fraction of ground wood residue, and ground pretreated wood residue with or without glycerol addition using a single pelleting unit; and 2) to determine the effect of different binders on the chemical composition, pellet density, tensile strength and heating value of wheat straw pellets, and specific energy consumption for manufacturing pellets.

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