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Effect of polymer plastic binder on mechanical, storage and combustion characteristics of torrefied and pelletized herbaceous biomass

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HIGHLIGHTS

- LLDPE may be used as binder for pelletizing torrefied herbaceous biomass.
- MSW has potential to provide a portion of raw material for the fuel pellet industry.
- Addition of LLDPE improved the tensile strength of the torrefied fuel pellets.
- Ash content of biomass pellets decreased with the increase of LLDPE as an additive.

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ABSTRACT

Currently one of the main challenges of the wood pellet industry is the limitation of raw materials. The solution to this limitation can be either increasing the efficiency of the materials or finding new sources to replace them. To maintain the sustainability of global production and consumption, extra resources can be found in waste instead of natural resources. Plastic wastes may be considered as a replacement source due to their effect on environmental pollution which is caused by changing production and consumption patterns of the human population in addition to population increase. Linear low density polyethylene (LLDPE), one of the extractable plastics from municipal solid wastes (MSW) was investigated as an additive and binder for torrefied biomass pellets. Non-ground wheat and barley straws were torrefied at 250 °C for 15 min. The torrefied biomass was mixed with LLDPE as an additive at four levels (1, 3, 6 and 10%). The results showed that addition of 6% LLDPE to the biomass pellets led to a maximum increase in density by 1.8% for wheat and 1.7% for barley. Adding 10% LLDPE to the torrefied biomass pellets resulted in a 280% and 253% increase in tensile strength for wheat and barley pellets, respectively. Adding LLDPE from 1% up to 10% resulted in increasing higher heating values and a decreasing ash content for both torrefied wheat and barley straw pellets. The higher heating value (HHV) of the pellets at all levels of added LLDPE except 10% meet the current standard specifications of DIN 51731 for commercial pellets. The ash content of the torrefied barley pellets at all levels of LLDPE addition except at 1% were in agreement with the requirement of the Pellet Fuels Institute Standard Specification for Residential/Commercial Densified Fuel (⩽6.0%).

1. Introduction

To avoid the possible risks of increasing climate change, all countries under the Paris Agreement committed to keep the increase of the worldwide temperature under 2 °C threshold [1]. Reducing the amount of produced greenhouse gases (GHG) as one approach to this goal may be carried out by shifting to renewable energy sources like biomass [2]. As a result, the wood pellet trade could rapidly expand to new regions of the world to satisfy the GHG emission cut down policies; this will increase the market for fuel pellets. Canada, with massive forests and an established wood industry, is currently the largest exporter of wood pellets [3]. The export rate reached almost 10% of its production which is 1.32 million tonnes [4].

The availability of herbaceous biomass in high quantities like in Western Canada provides a good solution for the shortage of raw material in the wood pellet industry. Herbaceous biomass such as wheat and barley straw is sufficiently available and acceptable to be used as a biofuel but of lower quality compared to wood materials [5]. Torrefaction has been suggested as a solution to increase biomass quality [6]. Torrefaction does not only change

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the proximate and ultimate composition of biomass but also improves its physical properties, making it more suitable for fuel applications [7]. In general, an increase in torrefaction temperature results in an increase in carbon content and a decrease in hydrogen and oxygen content due to the formation of water, carbon monoxide and carbon dioxide. This process also causes the hydrogen to carbon ratio (H/C) and oxygen to carbon ratio (O/C) to decrease with increasing torrefaction temperature and time. This results in a product with less smoke and less water-vapor formation, and low energy losses during the combustion and gasification processes [8]. Although production and consumption of torrefied pellets produces almost the same amount of emissions as conventional pellets, torrefied pellet production and co-firing has lower emissions than conventional pellets if they were transported farther than 400 km using lorry, 1850 km by rail or 25,500 km by ship [9]. However, torrefied biomass particles have poor binding properties and will not form durable pellets [10,11]. Similar binders that are being used for non-torrefied biomass can be used for torrefied ones. The suggested amount of added binders depends directly on the level of torrefaction. Biomass subjected to extreme torrefaction conditions such as high temperatures require more binders during pelletization. Torrefaction conditions adversely affect the ability of lignin to bind torrefied particles without using binders [10]. Generally, pellets formed from herbaceous biomass do not have enough strength due to the limitations of binding between particles. As a result, processing, transportation and using these pellets would be costly, difficult and sometimes dusty [12]. Furthermore, pellets made from softwoods may easily decompose and form some gases including carbon monoxide which are unsafe to human health [13]. The use of binder additives not only boosts the binding of biomass particles but also improves the quality of the pellet produced from herbaceous biomass. Lignosulfonate, starch, dolomite, corn potato flour, and motor/vegetable oils are some examples of the most common additives which are currently in use [10]. Generally, the fraction of added biological binders to the wood pellets varies from 0.5 to 20 wt% or even more [14]. Literature shows that mixing one of these additives with a certain type of biomass may result in a pellet with individual specific qualities.

Researchers extend their investigation on new materials to evaluate their potential use as an additive for herbaceous pellets to decrease the existing limitations of current additives. Low density polyethylene (LDPE) and linear low density polyethylene (LLDPE) which can be sorted out from municipal solid waste [15,16] or recovered as waste plastic from the agricultural sector [17] have good potential to be used as binders. Using plastics originating from municipal solid waste (MSW) can reduce not only the pollution of the environment but also GHG emissions [18]. For instance, researchers found that the addition of small mass fractions of agricultural plastic (LDPE) in a piled silvicultural debris does not change the emissions while low-moisture-content wood is burned [19]. Data shows the high availability of plastics originating from MSW around the world, i.e. almost 11% (39.3 million tonnes) of the total MSW in the U.S. consists of different plastics [20]. It is also reported that the rate of recycling plus energy recovery from MSW plastics increased from 14.3% in 2008 to 17.3% in 2011. Therefore, using these recovered plastics as binders for herbaceous pellets have good potential in achieving sustainable energy production.

Literature shows no study has been performed on using LLDPE or recycled plastics as binder for torrefied biomass. Also, only few studies were conducted on microwave-assisted torrefaction biomass. Thus, developing a method for adding LLDPE, a MSW component, to microwave torrefied wheat and barley straws to produce bio-pellets of acceptable levels to current standards was the objective of this research. For this purpose, the effect of LLDPE as a binder at four levels (1%, 3%, 6%, and 10%) on the physical, mechanical and combustion properties of pellets were investigated. Density and dimensional stability, tensile strength, HHV and ash content of the pellets were particularly evaluated.

2. Materials and methods

2.1. Herbaceous biomass

Two common herbaceous biomass, wheat and barley straws were provided as square bales from an experimental farm near Saskatoon, Saskatchewan, Canada. The initial moisture content for a 25 g sample was measured using an oven drying method (103 ± 2 °C for 24 h) based on ASABE standards, ASABE [21]. The moisture content was found to be 9.06 and 8.73% wet basis (w.b.) for wheat and barley straw, respectively. For torrefaction, the experimental setup explained by Satpathy et al. [5] was improved and used (Fig. 1). The reactor was equipped with a mechanically driven agitator rotating at 30 r/min to avoid uneven heating and hot spots reported by Satpathy et al. [5]. The raw straws were cut to an average length of 70 mm in order to facilitate loading of the cut biomass into the reactor. The straws were not ground to simulate a real industrial process. The weight of sample inside the reactor for each torrefaction run was 35 g. The optimum microwave power of 250 W and residence time of 15 min suggested by Satpathy et al. [5] were used for torrefaction treatment of both types of herbaceous biomass. After torrefaction, the straws were ground by a hammer mill (Retsch GmbH, 5657 HAAN, West-Germany) using a screen size of 0.75 mm. The ground torrefied biomass was used as raw material for sample preparation. They were kept inside Ziploc bags in a cold storage room (4 °C) until sample preparation for pelletizing.

2.2. LLDPE

LDPE/LLDPE are common extractable plastics from MSW. Waste streams provide a plentiful amount of LDPE/LLDPE which carries desirable energy and binding characteristics [15]. Virgin LLDPE (LLP8460.29 Rotational Molding Resin, Table 1) was used as an additive in this research. This resin is suitable for applications that require optimum balance of stiffness, process ability, and low temperature toughness. Torrefied biomass was mixed with LLDPE in four different concentrations of 1%, 3%, 6%, and 10% by weight for both ground torrefied wheat and barley straw samples. The concentration levels were selected based on preliminary experiments within the common range of additives (up to 10%) for bio-pellets. These levels of inclusion are designated in order as 1, 3, 6 and 10, representing the percentage of LLDPE in the mixture. These were further pelletized (see next section). Non-torrefied pellets and torrefied pellets without any additive were designated as C (control) and T (torrefied) samples, respectively. Weight percentage was applied for measuring all components. As adding LLDPE would decrease the final moisture content of the mixture, the moisture content of each mixture was measured and it was conditioned to 8% (w.b.) by adding specific amount of water. The samples were mixed thoroughly before they were individually kept in the Ziploc bags and were stored in a controlled storage room (4 °C). They were stored for at least two days to reach uniform moisture content before pelletizing.

2.3. Pelletizing the torrefied biomass

Torrefied straws at different levels of added LLDPE were pelletized. As this was the first trial for pelleting biomass and LLDPE, the method and parameters for pelleting had to be optimized.