Complementary effects of torrefaction and co-pelletization: Energy consumption and characteristics of pellets

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HIGHLIGHTS

- Caster bean cake improves the features of pellets produced from torrefied biomass.
- Grindability and lubricant are available to decrease the energy consumption.
- Complementary effect of protein and enlarged contact area improve pellet strength.
- Co-pelletizing biomass torrefied at 270 °C with 15% CAS are the optimal conditions.

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ABSTRACT

In this study, complementary of torrefaction and co-pelletization for biomass pellets production was investigated. Two kinds of biomass materials were torrefied and mixed with oil cake for co-pelletization. The energy consumption during pelletization and pellet characteristics including moisture absorption, pellet density, pellet strength and combustion characteristic, were evaluated. It was shown that torrefaction improved the characteristics of pellets with high heating values, low moisture absorption and well combustion characteristic. Furthermore, co-pelletization between torrefied biomass and cater bean cake can reduce several negative effects of torrefaction such as high energy consumption, low pellet density and strength. The optimal conditions for energy consumption and pellet strength were torrefied at 270 °C and a blending with 15% castor bean cake for both biomass materials. The present study indicated that complementary performances of the torrefaction and co-pelletization with castor bean cake provide a promising alternative for fuel production from biomass and oil cake.

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1. Introduction

Biomass pellets have become a sustainable and environmental energy resource as its attractive characteristics, such as renewable, none net CO_2 emission and low production cost (Du et al., 2014; Jiang et al., 2014; Nunes et al., 2014; Xu et al., 2014)). In general, pelletization of biomass makes its density 4–10 times higher than those without pelletization which can significantly reduce the transportation/storage costs (Li et al., 2012a,b; Liu et al., 2014).

However, due to the high moisture absorption, low energy density and rapid combustion reactivity of biomass, all of those significantly hinder the large-scale application of biomass pellets (Chin et al., 2013; Zhou et al., 2014). Therefore, the advancements of the properties of biomass pellets have gained widespread attention.

Among the technologies for improving the properties of biomass, torrefaction was regarded as one of the efficient and feasible method (Li et al., 2011; Chen et al., 2014; Du et al., 2014; Li et al., 2012a,b; Iroba et al., 2014; Basu et al., 2014). Wen et al. (2014) reported that pretreatment of torrefaction is a pyrolytic process at 200–300 °C in an inert atmosphere. It is well known that torrefied biomass is a material characterized by hydrophobicity, grindability and high heat value because of the removal of

hemicellulose, lignin, protein, starch and fatty compounds in biomass (Chen et al., 2014; Li et al., 2012a,b; Mišljenović et al., 2014). Moreover, the combustion performance of pellets produced from torrefied biomass approaches to that of coal, which can be due to the removal of free water and volatile components during torrefaction (Du et al., 2014). However, compaction and extrusion energy consumptions during pelletization were remarkably augmented for the torrefied biomass materials, while the density and strength of the pellets made from torrefied biomass were decreased compared with those of untreated biomass (Li et al., 2012a,b). Different methods and other various torrefaction and pelletization conditions were adopted in order to resolve the disadvantages mentioned above (Chen et al., 2014; Du et al., 2014; Li et al., 2012a,b).

Among the existing technologies, co-pelletization process has become a widespread used technology to improve the characteristics of pellet (Ståhl and Berghel, 2011; Shang et al., 2013; Jiang et al., 2014; Nunes et al., 2014). The major advantage of co-pelletization is to eliminate the negative properties of pellets with the aid of additives. For example, Jiang et al. (2014) investigated that biomass mixed with sludge can enhance the pellet density and strength as the protein in sludge can act as a binder between biomass particles. Ståhl and Berghel (2011) studied that energy consumption decreased with an increasing content of rapeseed cake, which was due to the reduction of friction during pelletization caused by the presence of rape oil in rapeseed cake. Zhou et al. (2014) managed to improve the combustion progress by blending biomass with coal to increase the content of fixed carbon. Therefore, several studies have investigated the effects of torrefaction and co-pelletizing on the pellet properties. It was carried out by Reza et al. (2014) that pellets produced from dry torrefied and hydrothermal carbonization (HTC) biomass blends possessed higher pellets density and better durability than those from torrefied biomass. Shang et al. (2013) investigated the blending of rapeseed oil with torrefied biomass can reduce the energy consumption during pelletization (Shang et al., 2013). However, no further study was carried out to reveal the potential effect of rapeseed oil on pellets' strength (Shang et al., 2013). In addition, the higher price of additives compared with conventional biomass resulting in the economic infeasibility of biomass were seldom considered (Ahn et al., 2014; Chau et al., 2009; Reza et al., 2014). In this respect, more attention should be paid on the low-cost additives during co-pelletization. In China, oil cake is a main byproduct in the oil expression process with a total annual amount of 16–20 Mt. Nevertheless, large amount of oil cake carries hazardous substances such as sinapic acid, saponin and tannins; and poor palatability and nutritional imbalance make it difficult to be utilized as animals feed. Meanwhile, several specific features of oil cake, such as the higher energy content and functional components (starch, protein and bio-oil, etc.) in oil cake reveal that oil cake could be utilized as fuel and additives in the co-pelletization with torrefied biomass. To our best knowledge, few studies are available on the complementary effects of torrefaction and co-pelletization of oil cake on energy consumption and pellets characteristics.

In this study, two kinds of biomass (cedarwood and camphorwood) were pretreated at different torrefaction temperature (240 °C, 270 °C, and 300 °C), respectively. Caster bean cake, one kind of high-production oil cakes in East Asia, was selected as the additive. The torrefied biomass materials were blended with caster bean cake for co-pelletization. Subsequently, the effects of torrefaction and caster bean cake on the energy consumption and pellet properties were investigated. The primary objective of this study was to reveal the complemlentary mechanisms between torrefaction and co-pelletization for biomass pellet preparation.

2. Methods

2.1. Materials

Two types of wood sawdust were selected in the present study: cedarwood (CED) and camphorwood (CAM), which were collected from local forest in Changsha and further grounded into fractions with particle size below 1 mm (Table 1). The selected oil cake was castor bean cake (CAS) obtained from the expression process of castor bean in a pilot of Hunan Academy of Forestry. The selected materials were dried (40 °C, 48 h) and stored in plastic containers at 4 °C for further study.

2.2. Torrefaction

The torrefaction reactor is a tubular furnace which belongs to a bench-scale fixed bed reactor (Fig. 1). The reactor contains a tubular unit, an electrical heater and a gas supply. The biomass was heated up to the desired temperature with a rate of 10 °C/min^{-1} and a nitrogen flow of 100 mL/min^{-1} as a carrier gas was used during torrefaction. The set torrefaction conditions were 240 °C (light torrefaction), 270 °C (medium torrefaction) and 300 °C (heavy torrefaction) with a residence time of 30 min, respectively. Table 1 records the weight loss and particle size of the torrefied samples at different temperature with respect to raw samples.

2.3. Co-pelletization

The pellets were prepared using a DWD-10 pressure unit installed with a cylinder die and a piston (Fig. 1). The cylinder die encircled with a heating tap had an opening of 7 mm in diameter and 120 mm in length. The end of the die was a removable plug. The piston with sizes of 6.8 mm in diameter and 80 mm in length was installed to supply the pressure for the sample. In this work, the additive (CAS) was added into raw and torrefied samples with the proportion of 0%, 15% and 30%, respectively. The loaded sample (around 0.7 g) was compressed with a rate of 2 mm/min until the desired pressure was achieved. The maximum pressure was 4000 N with a residence time of 30 s. Prior to pelletization, the cylinder die was preheated up to 150 °C. The transducer was used to measure the compression force and displacement and the relevant data were recorded by a computer. Compression and extrusion energy consumption were calculated by the formulation as following:

$$EC = \sum F \cdot S \qquad (1)$$

where EC is the energy consumption (J), F is the compression force (N), S is the displacement (mm).

Table 1
Weight loss and particle size distribution of raw and torrefied samples.

Sample	Weight loss	Size distribution			
		1000–840 μm	840–420 μm	420–180 μm	<180 μm
CED					
Raw	0	5.73	42.32	38.49	13.46
240 °C	7.69	4.28	37.89	42.33	15.51
270 °C	19.92	3.78	35.18	42.56	18.49
300 °C	33.54	2.91	38.05	42.82	16.22
CAM					
Raw	0	8.09	59.68	27.48	4.76
240 °C	13.72	5.93	57.14	31.34	5.58
270 °C	16.81	7.16	56.30	30.90	5.63
300 °C	34.00	2.91	38.05	42.82	16.22