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Evaluation of the potential of pelletized biomass from different municipal solid wastes for use as solid fuel

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Four different municipal solid wastes (dog manure, horse manure, apple pomace waste and tea waste) and an industrial by-product (NovoGro) were used to produce solid fuel pellets. The mixtures followed a raw material to NovoGro ratio of 50:1. The pellets diameters varied between 4 and 5 mm, and the average length was 20 mm. The dog manure, horse manure, apple pomace waste and tea waste pellets were denoted as DN, HN, AN and TN, respectively. The combustion characteristics of the pelletized fuels were investigated, such as total moisture, ash content, calorific value and ash fusion point, etc. The physicochemical properties were analyzed by using a number of analytical techniques including X-ray fluorescence spectrometry (XRF), X-ray diffraction spectrometry (XRD), scanning electron microscopy (SEM) and Fourier transform infrared spectroscopy (FTIR). The results of the mechanical, thermal and morphological properties show that the raw materials were effectively combined with the NovoGro binder; furthermore, the DN, HN and TN pellets exhibited excellent mechanical and thermal properties, including high calorific values (>16.30 MJ/kg), high resistance to mechanical shock (>99%), high volatile matter contents, optimal softening temperatures and optimal ash contents. However, the high K, Ca, and Si contents of the AN can form low-melting-point eutectics, which can cause slagging. Moreover, the AN materials had large particle sizes, and high cellulose and hemicellulose contents led to high total moistures, low softening temperatures and low calorific values. The AN was not suitable for use as a fuel. The results suggested that NG is an effective binder for pelletization of biomass and showed the feasibility of using municipal solid wastes for energy production.

1. Introduction

Concerns about the growing shortage of fossil fuels have increased the interest in biomass and other renewable energy sources. A rapid growth of the pellet market has been observed over the last several years. Today, wood pellets are one of the most internationally traded solid biomass commodities used specifically for energy purposes (Henderson et al., 2017; Sikkema et al., 2011). However, because of the lack of raw material for manufacturing fuel pellets, other raw waste materials from energy crops have been used more frequently. Su et al. (2011) used a mixture of fermentation residue and either lignite coal or anthracite coal to produce a solid fuel with a high combustion performance. Later, dewatered-sewage sludge and mixtures of other food wastes were developed to produce solid fuel for treating and disposing of sewage sludge (Wu et al., 2012; Zhao et al., 2013). More recently, a selection of some residual biomasses, such as nonedible oilseed (Doshi et al., 2014), packaging grass/leaves, wood waste and cardboard (Lohri et al., 2015) were evaluated to determine their potential as solid biofuels. Municipal solid waste refers to by-products generated from the urbanization of human society, which includes materials such as product packaging, bottles, batteries, food wastes, and pet manures (Xue et al., 2011). It has been estimated that in 2015, the total amount of municipal solid waste generated worldwide reached 2 billion tonnes (Wilson et al., 2015). The composition of municipal solid waste was mainly organic species. The

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high organic matter confers a high calorific value to the waste (Sheng and Azevedo, 2005). Thus, municipal solid waste could be used as a fuel for energy production. One of the methods of converting waste biomass into energy is to produce solid fuels in the form of pellets or briquettes through pressure agglomeration (Colley et al., 2006; Kaliyan and Morey, 2009; Sokhansanj and Turhollow, 2004). The elemental composition and combustion characteristics of some solid biofuels are shown in Table 1. The elemental composition of solid fuels were determined by their raw materials. The ash contents of bio-waste solid fuels varied between 3.1 and 7.9%, which were much higher than that of the wood pellets, but were comparable to the charcoal. The calorific values of the bio-waste solid fuels were lower than the charcoal, but were similar to that of the commercial wood pellets. Hence, the solid biofuels are potential fuels for combustion.

Pelletization is a process of compacting loose material to form a densified, homogeneous product. Pellets are often favored in fuel applications because of their enhanced physical properties, which include easy feeding and handling (Razuan et al., 2011). Binders play a vital role in the pelletization process. Binder addition could improve pellet durability and strength. Generally, binders affect pellet stability in three ways. Binders occupy spaces, resulting in more compact pellets, act as adhesives, and exert forces such as van der Waals forces and electrostatic forces on compounds present (Kaliyan and Morey, 2010; Ruscoe et al., 2005). NovoGro (NG) is a by-product from the Biological Treatment Plant of Novozymes. NG is produced from a centrifuged fermentation broth through heating and lime amendment to inactivate all microorganisms and contains 19% (mass fraction) organic matter (Qiao et al., 2014; Wang et al., 2014). Thus, NG may be a good binder candidate to evaluate.

Dogs and horses are popular pets in many countries. Consequently, increasing amounts of dog manure and horse manure have to be managed and treated. Apple pomace waste and tea waste are common municipal solid wastes produced in rural areas daily. Table 2 shows the application of these four types of bio-wastes in the literatures. These bio-wastes have been used to produce bio-gas, bio-oil, compost, soil fertilizer, sorbent for contaminant removal, and organic soil amendments for soil remediation, and they directly combust for heat production. However, there are almost no reports in the literature on the production of solid fuel pellets.

In this study, four different municipal solid wastes (dog manure, horse manure, apple pomace waste and tea waste) were used as the raw materials to produce solid fuel pellets. For the first time, NG was used as the binder in the pelletization process. The physicochemical properties and combustion characteristics of the pelletized fuels from the different municipal solid wastes were compared. The bulk and surface element contents of the pellet samples were determined by using an element analyzer and an X-ray photoelectron spectrometer (XPS), respectively. The surface morphology was investigated with SEM. FTIR spectra were measured and used to study the chemical surface structures of the pellets. The ash content and calorific value of the pellets were also measured.

Table 2
Application of the four types of bio-wastes.

Application	Bio-waste	Citation
Bio-gas	Dog manure	Phetyim et al. (2015)
	Horse manure	Mönch-Tegeder et al. (2014)
Bio-oil	Horse manure	Elkasabi et al. (2015)
	Tea waste	Uzun et al. (2010)
Compost	Horse manure	Benito et al. (2009)
	Apple pomace waste	Kopčić et al. (2014)
Soil fertilizer	Horse manure	Azizi (2007); Ferreras et al. (2006)
Sorbent for contaminant removal	Tea waste	Amarasinghe and Williams (2007)
	Apple pomace waste	Chand and Pakade (2015)
Organic soil amendments for soil remediation	Horse manure	Bolan et al. (2003)
Directly combust for heat production	Horse manure	Lundgren and Pettersson (2009)
	Apple pomace waste	Virmond et al. (2010)

2. Materials and methods

2.1. Acquirement and preparation of the raw materials

Dog manure, horse manure, apple pomace waste and tea waste were used to produce the pellets. In Chinese cities, keeping dogs as pets and horses for tourism is common. According to the policy of the Chinese government (Animal Epidemic Prevention Law of the People's Republic of China), dogs and horses should be properly vaccinated and are controlled by the animal epidemic prevention and quarantine system. The manures from dogs and horses are mixed with other municipal solid wastes. Dog manure, apple pomace waste and tea waste were acquired from a residential neighborhood in downtown Tianjin. Horse manure was collected from a horse ranch in the Dongli District of Tianjin.

NG obtained from the Biological Treatment Plant of Novozymes in Tianjin, China, was used as the binder. Novozymes is the largest enzyme company in the world, with biological treatment plants across North America, South America, Europe and Asia (Further information about the company and its productions can be acquired from its homepage at https://www.novozymes.com/). During the enzyme production process, the centrifuged residue of fermentation broth of potato flour, cornstarch and other raw materials is obtained, and then the residue is heated and amended with lime to inactivate all microorganisms. This by-production is NovoGro (NG). NG contains N, P and K elements, mineral nutrients and organic substances. The yield of NG is approximately 100 tons

Table 1
Elemental composition and combustion characteristics of different solid biofuels.

Solid biofuels	C (%)	H (%)	O (%)	N (%)	Total moisture (%)	Ash (%)	HHV (MJ/kg)	LHV (MJ/kg)	Citation
Reed canary grass	48.6	6.8	37.3	0.3	4.7	5.5	19.5	–	Bridgeman et al. (2008)
Wheat straw	40.6	6.0	42.58	0.19	8.6	7.9	17.617	–	Motghare et al. (2016)
Cotton waste	50.5	7.0	22.48	1.18	4.8	3.1	19.652	–	Motghare et al. (2016)
Soybean waste	43.8	6.3	48.5	1.4	5.8	4.7	18.770	–	Motghare et al. (2016)
Municipal solid waste remains	51.2	6.2	40.1	0.1	–	4.4	–	17.2	Edo et al. (2016)
Wood pellets	50.2	5.9	43.2	0.08	7.6	0.5	–	19.0	Johansson et al. (2004)
Bark pellets	52.1	5.9	37.8	0.48	7.8	3.7	–	20.1	Johansson et al. (2004)
Wood logs	50.6	6.4	42.7	0.05	15/26/38	0.3	–	19.0	Johansson et al. (2004)
Charcoal	72.2	2.9	23.6	1.3	4.6	4.7	26.070	–	Motghare et al. (2016)

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