Factors affecting properties of fuel pellets from compaction of mixed biomass and waste plastics

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Abstract: The purpose of this research is to investigate the densified solid fuel from mixed plastic wastes which were recovered from dumpsites. Corn stover was used as natural binder of the fuel. In this study, the corn stover can bind plastic materials into the fuel using compaction. The densification of mixed plastic wastes and corn stover was investigated at 150 MPa compression pressure. The size of pellet was 8 mm in diameter and 20 mm in length. The parameters effect on the fuel properties of this research were moisture content (5%-20%w.b.), types of material, mixed plastic wastes and corn stover ratio (55:45, 65:35 and 75:25), and preheating temperatures (75°C and 100°C). Results found that corn stover could improve chemical properties (reducing sulfur and chlorine content) and physical properties of the fuel pellet. It was also found that mixed plastic wastes and corn stover was superior to corn stover pellet without plastic wastes in terms of calorific value and carbon content.

Keywords: biomass, densification, refused derived fuel (RDF), renewable energy, waste-to-energy

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1 Introduction

In Thailand, there are a number of agriculture wastes which cannot be managed and are increased every year. Burning method is usually applied because of less time disposal, but it makes pollution including air pollution and loss of mineral and water in soil. Thailand's governments realizes and suggests to reduce agriculture waste burning. These wastes can be used as fertilizer. It can reduce the destroying of ground soil, cost of production and air pollution. However, most of farmers select the method of burning which is more comfortable and less time to disposal.

Municipal solid wastes (MSW) are increasing every year. These wastes have to be disposed with an appropriate method. Conventional disposal methods are sanitary land-filling, open dumping and burning, and mass incineration. In Thailand, 64% and 35% of MSW are disposed by open dumping and sanitary landfill, respectively. There are many problems associated with waste disposal, including lack of landfill sites, waste and logistics management, budgeting, labor shortage, public opposition, and others (Pollution Control Department, 2009). The calorific heat values of agriculture waste, or biomass, and plastic waste were 15-20 MJ kg^{-1} and 20-50 MJ kg^{-1} (Demirbaş, 1997; Li et al., 2001; Energy Policy Office [EPPO], 2012), respectively. These wastes may be utilized as fuel by energy conversion techniques, including densification into refused derived fuel (RDF), thermal conversion into heat, gaseous or liquid fuels (ASTM, 2000a). The compaction into several forms is called RDF. It is used as other commercial fuel since its

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calorific heating value is nearly commercial fuel (such as coal, natural gas).

Waste to energy offers an alternative solution. MSW may be converted into RDF. Normally, RDF consists of the combustible fraction recovered from MSW such as waste plastic, wood, paper, textile, leather, and rubber (Chang et al., 1997; Rotter et al., 2004; Velis et al., 2010).

Many factors have influenced the RDF quality and properties. The most mentioned factors are type of binding agents, type of materials (Rotter et al., 2004; Taylor, 1988; Demirbaş and Şahin, 1998), pressure of densification (Li and Liu, 2000; Kaliyan and Morey, 2009), moisture content (Demirbaş and Şahin , 1998; Beker, 1997; Li and Liu, 2000), ratio of material and binding agent (Chiemchaisri et al., 2010; Yaman et al., 2001), type of densification equipment, particle size (Adapa et al., 2009; Mani et al., 2004; Mani et al., 2006; Mani et al., 2003; Tumuluru et al., 2011; Kaliyan and Morey, 2010; Kaliyan and Morey, 2008) and preheating temperature (Grover and Mishra, 1996; Tumuluru et al., 2011; Chou, et.al., 2009b; Chou et al., 2009a; Kaliyan and Morey, 2009; Grover and Mishra, 1996). The properties of RDF are mechanical strength, calorific value, density, durability of briquette form and characteristic of combustion Natural binding agents are biomass, organic substances and inorganic substances. Biomass binding agent consists of starch, protein, fiber, cellulose and hemicellulose, fat, lignin, and extractives (Kaliyan and Morey, 2009; Pollution Control Department, 2009). Organic and inorganic substances are asphalt, sawdust, shell of sunflower seed, cassava starch, tar, clay, gum, molasses, starch solution, paraffin, glue, organic oil waste, limestone, etc. (Lope, 1996; Yaman et al., 2001). These binding agents can improve strength and durability of RDF. In addition, the material particles of the RDF were tighten together to form a briquette. RDF with high compressive strength were easily to pile up and transport without damage (Chen et al., 2011; Sotannde et al., 2010).

RDF technology is used to improve quality, composition, chemical property, mechanical property, calorific heating value, environmental effecting, and commercial ability of waste fuel. Many researchers also studied biomass compaction from agriculture waste such as briquette fuel from coal and biomass, briquette fuel from wood-plastic and paper with and without binding agent, and briquette fuel from biomass and paper. Then, it is an advantage to study the improvement of pellet fuel from mixed plastic waste and corn stover. This is because plastic waste has high calorific heating value and corn stover is monoculture crop which is natural binding agent for solidification improvement. Using natural binding agents (starch, protein, fiber, and lignin) which are compositions of corn stover, can improve pellet's quality such as calorific heating value, density and mechanical strength. It is hoped that the mixed plastic waste and corn stover pellization can be used as an alternative fuel in the future. The objectives of this research are to investigate the variation in preheating temperature, moisture content of material, types of material, and mixed plastic waste and corn stover ratio which affect pelletization of mixed plastic waste and corn stover.

2 Materials and methods

2.1 Mixed plastic wastes

Mixed plastic wastes sample used in this study were collected from 5-year dumpsite of Chiangrai Rajaphat University. Soil and other materials were separated from the collected mixed plastic wastes. Mixed plastic wastes sample are polyethylene (plastic carry bag, trash bags, or other plastic cover) and polypropylene (hot or cold food bags). Chemical and physical properties of the waste sample, such as moisture content, ash, heating value, chlorine and sulfur, were determined. Mixed plastic wastes sample were cut into small piece less than 1 mm in size.

2.2 Corn stover

Dried corn stover sample used in this study was from corn field. Chemical and physical properties of corn stover are moisture content, ash, heating value, chlorine and sulfur. Corn stover is cut into less than 1 mm by using grinding machine as shown in Figure 1. This machine is powered by 5-HP diesel engine and its capacity is 20 kg hr^{-1}. After cutting, the corn stover and plastic wastes were kept in a zip lock plastic bag to prevent the changing of moisture content.

All mixed plastic wastes and corn stover sample were dried to reduce moisture content to 5% (wet basis). Then, it was kept in a zip lock plastic bag and stored in a control room.

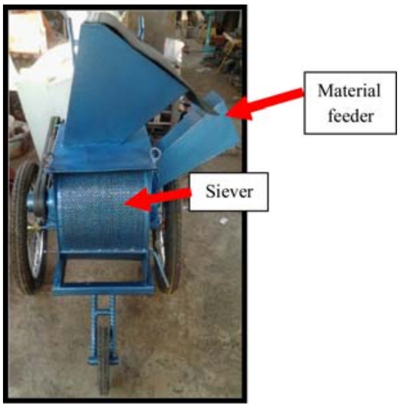

Figure 1 Grinding machine

2.3 Pelletization methods

Mixed plastic wastes and corn stover were mixed at a desired mass ratio in total 100 g of mixed sample. 1.4000 g of mixed sample was compressed in mold for palletization in lab scale as shown schematically in Figure 2. The size of densified pellet was 0.8 cm in diameter and 2.0 cm in height with the compression pressure of 150 MPa. In order to determine the appropriate condition for palletization, the following conditions of the compression process were used:

1) Mass ratio of mixed plastic wastes and corn stover: 55:45, 65:35, 75:25

2) Preheating temperature of raw materials: 25°C, 75°C, 100°C

3) Moisture content of mixed plastic wastes and corn stover: 5%, 10%, 15%, 20% (wet basis)

Varying the moisture content of material to 10%, 15% and 20%w.b. was done by filling an amount of water to the mixed sample and kept them for two days in a zip lock plastic bag for tempering.

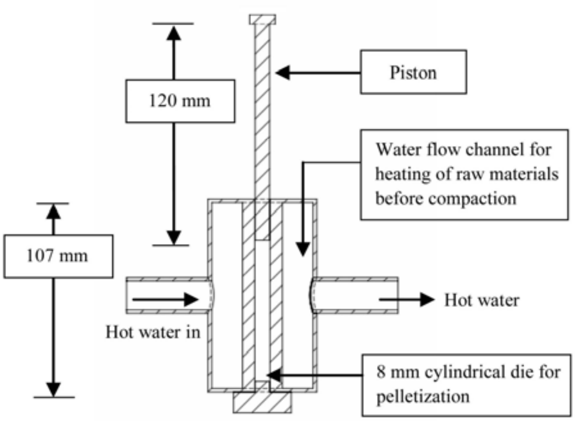

Figure 2 Pelletization device of plastic wastes and corn stover compression

2.4 Physical and chemical properties of pellets

Densified plastic and corn stover pellets were tested to determine their chemical and physical properties. In this study, the pellets were tested as guided by American Society for Testing and Material (ASTM, 2000) and The European Commission (European commission 2014). Gross calorific (ASTM , 2000b), sulfur content (ASTM, 2000c), chlorine content (Energy dispersive X-ray spectrometer), carbon hydrogen nitrogen oxygen (ASTM, 2000e), pellet density (ASABE, 2003a), moisture (ASABE, 2003b), ash (ASTM, 2000d) and durability index (ESO, 2000) were discussed.

3 Results and discussion

3.1 Composition and chemical characteristic of mixed plastic wastes and corn stover

The composition and chemical characteristics of mixed plastic wastes and corn Stover before compaction are listed in Table 1. It is found that mixed plastic wastes appeared to have lower moisture and ash content than corn stover. However, the calorific value of the waste was significantly higher than that of biomass.

Table 1 The Composition and chemical characteristics of corn stover and mixed plastic wastes

Composition and chemical characteristics	Corn stover	Mixed plastic wastes
Moisture content (%)	8.33±1.91	3.90±0.60
Ash (%)	8.62±0.08	0.22±0.05
Sulfur (%)	0.08 ± 0.01	0.17±0.01
Chlorine (%)	0.11±0.03	0.15±0.03
Carbon (%)	53.19±0.23	91.97±0.23
Oxygen (%)	43.79±0.51	2.42±0.32
Calorific value (MJ kg^{-1})	15.40±0.13	58.0±0.32

3.2 Composition and chemical - physical characteristic of corn stover pellet, and mixed plastic wastes and corn stover pellet

Table 2 presents the characteristics of the pelletized fuels from corn stover only and from a mixture between plastic wastes and corn stover with weight ratio of 55:45, 65:35 and 75:25. It was found that average calorific value of corn stover pellet was 15.40 MJ kg^{-1}. Average carbon content was 53.19%. Average ash content was 8.62%. Moisture content of corn stover pellet increased with the increasing moisture content of feed materials as expected. The calorific value of plastic waste and corn stover pellets were much higher than that of corn stover pellet because of the high carbon content. The highest calorific value was found at the ratio of 75:25 of mixed pellet. Sulfur content and chlorine content of the mixture pellets were 0.12%-0.16% and 0.11%-0.16%, respectively. Sulfur and chlorine contents were found lower than that of the European standard limit which was 0.4% sulfur contents and 0.5% chlorine content (European Commission-Directorate General Environment, 2003). It was also found that the calorific values of mixture pellets were about 27-40 MJ kg^{-1} which meet the specified European standard in terms of calorific value (>15 MJ kg^{-1}). Therefore, properties of the mixed pellet could be improved by changing the ratio of mixtures and conditions of pelletization. Table 3 presents the characteristics of the pelletized fuels that was made from corn stover under 150 MPa compression. As shown in Table 3, densities of corn-stover pellet were between 0.94 g cm^{-3} and 1.22 g cm^{-3}. Durability index was between 86%-99%. Density and durability index of corn stover pellet depends on preheating temperature and moisture content in the raw material as shown.

Variation in moisture, durability index and density due to the mixture ratio of pellet of 55:45, 65:35 and 75:25 are presented in Figures 3 to 5, respectively. It was found that density and durability index decreased as increasing plastic volume. The moisture of mixed pellets increased with increasing material moisture.

Table 2 Characteristics of corn stover, mixed plastic waste and corn stover

Characteristic	Corn stover	Weight ratio of mixed plastic waste : corn stover		
		55:45	65:35	75:25
Moisture content (%)	8.33±1.91	12.20±0.03	11.45±0.06	10.75±0.03
Ash (%)	8.62±0.08	6.30±0.14	3.41±0.03	1.31±0.04
Sulfur (%)	0.08 ± 0.01	0.12±0.01	0.14±0.01	0.16±0.01
Chlorine (%)	0.12±0.03	0.11±0.03	0.14±0.01	0.16±0.01
Carbon (%)	53.19±0.23	66.23±1.94	70.25±0.19	76.46±0.19
Oxygen (%)	43.79±0.51	20.08±1.94	15.31±0.13	7.97±0.37
Calorific value (MJ kg^{-1})	15.40±0.13	27.39±0.43	35.68±0.55	39.88±0.11

Table 3 Pellet characteristics of corn stover

Preheating temperature (°C)	Moisture content of material (%)	Pellet characteristics		
		Moisture content (%)	Durability index (%)	Density (g cm^{-3})
25	5	2.17±0.12	86.40±0.54	0.94±0.01
25	10	3.62±0.07	72.73±0.36	1.01±0.01
25	15	5.36±0.10	89.74±0.53	1.01±0.01
25	20	7.30±0.08	82.22±0.68	1.03±0.08
75	5	3.95±0.07	85.00±1.00	1.12±0.01
75	10	4.43±0.07	86.96±0.17	1.15±0.03
75	15	6.53±0.09	81.40±0.56	1.12±0.01
75	20	7.26±0.08	80.00±0.14	1.11±0.10
100	5	0.96±0.07	86.21±0.31	1.11±0.01
100	10	1.05±0.05	99.15±0.30	1.22±0.08
100	15	2.37±0.07	98.32±0.42	1.17±0.01
100	20	5.50±0.11	97.10±0.24	1.09±0.01

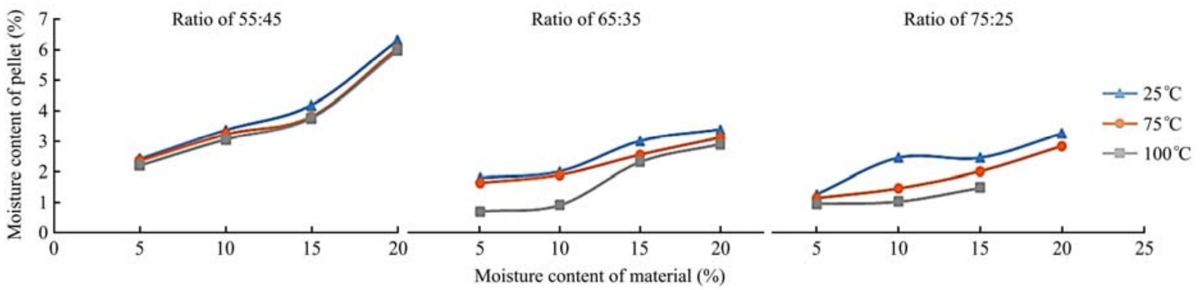

Figure 3 Effect of material moisture content and material ratio on the pellet moisture content

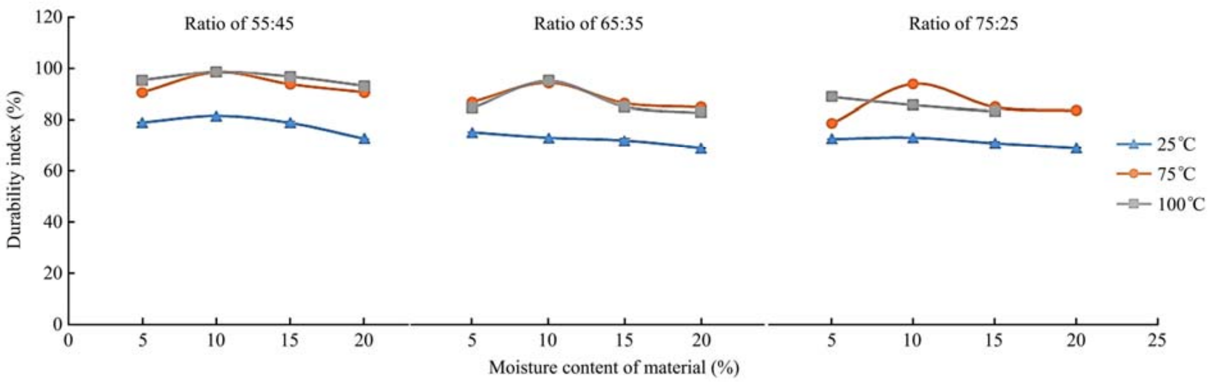

Figure 4 Effect of material moisture content and material ratio on the pellet durability

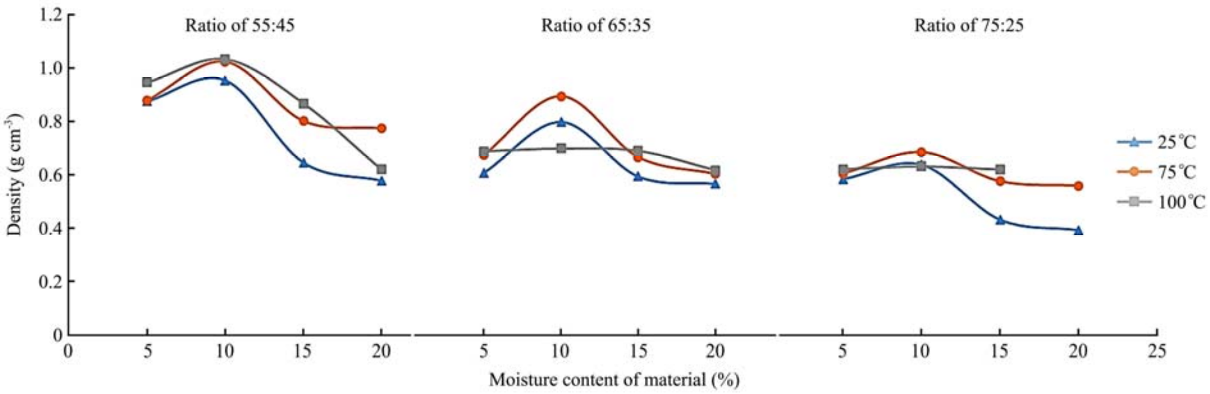

Figure 5 Effect of material moisture content and material ratio on the pellet density

Compression process can be done easier at high preheating temperature. Strong densified product and high density of the pellet were produced as shown in Figure 4 and Figure 5. The reason is that it takes fewer loads and makes soften natural binder (such as oil, starch, lignin or protein) during compaction process (Kaliyan and Morey, 2009; Chou, et al., 2009b). Higher preheating temperature makes soften fiber, decreases energy consumption and resistance between particles. These behavior makes particles binds easier as tested densified strength at preheating temperature of 25°C to 150°C by Grover and Mishra (1996). These results found that the strength of densified product was increased with the preheating temperature. However, particles may not be bonded at higher preheating temperature and higher moisture content. The reason is that moisture migrates to the bottom of material which effect to loose particle bonding during compression at lower part of pelletization and consequently less durability pellet is obtained. . Figure 3 showed that durability index was reduced as increasing the plastic volume. Pellet with plastic waste and corn stover ratio of 75:25 provides the lowest durability, while the highest durability index was found at 55:45 of mixed plastic and corn stover ratio. It can be explained that more plastic content decrease durability index at the same condition. In addition, corn stover has fiber, protein and lignin which can improve pellet durability. This means that pellet with high content of corn stover should have high durability index. Figure 4 shows that density was reduced with the increasing of plastic volume. The lowest density was found at 75:25 of mixed plastic and corn stover ratio, while the highest density was found at the mixed ratio of 55:45. At the same condition, it can be explained that more plastic content makes the pellet density decrease. It can be seen that affecting factors on pellet properties are mixed plastic wastes and corn stover mass ratio, preheating temperature and moisture content of material which discussed as follows:

1) Calorific value of corn stover pellet was increased when adding plastic wastes. Plastic wastes has high sulfur and chlorine content which can be reduced by mixing it with corn stover. Corn stover can improve the properties of mixed pellet in terms of chemical and physical properties as reported in Chen et al. (2011), Li and Liu (2000) and Yaman et al. (2000) found that mixed paper briquette had low higher heating value (HHV) because of high ash content. When the briquette was made from mixed paper and plastics, their properties were improved. Preheating temperature can affect durability index, density and moisture content of pellet. Pellet with the highest content of corn stover (mixed plastic waste: corn stover ratio of 55:45) has the highest durability and density because high content of corn stover provides a large amount of natural binding components, i.e. fiber, lignin, protein and starch.

2) Preheating temperature of 75°C to 100°C makes reduce air void between particles. Natural binding components are changed into crystallization of soluble which is called 'solid bridge'. It also occurs during densification process. After pelletization, the pellet should be stronger after cooling. Increasing preheating temperature from 75°C to 100°C was found to increase durability index from 97%-99% and 89%-99% for mixed plastic waste and corn stover pellet. The highest density of pellet was found at 100°C preheating temperature.

Furthermore, there was some moisture loss during compression process which reduced moisture content of pellet.

3) Moisture content of material affects pellet properties including density and durability. Higher moisture content lets the pellet has higher density and durability index. The pellet density and durability either low or high content of plastic waste are to be high if it is compacted under the appropriate moisture content (Li and Liu, 2000). The research found that the appropriate moisture content of material was 10% which give the highest pellet density and durability.

4 Conclusion

Plastic waste and agriculture waste can be upgraded to densified fuel. Pellet properties depended on type of material, material mixture ratio, moisture content and preheating temperature. Type of feed material affected quality of pellet in terms of density, durability index, moisture content, calorific value, and sulfur and chlorine components. Mixing plastic wastes with corn stover offered densified pellet with higher calorific value and lower ash content, hence improved quality. Furthermore, moisture content of the material, material mixture ratio and preheating temperature before compaction were observed to have influence on moisture content, density and durability index of the pellets. This research found that the optimum of material mixture ratio was 55:45, moisture content was 5%-15%, and higher preheating temperature can result in higher pellet density and durability index.

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