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Properties of Densified-Refuse Derived Fuel Using Glycerin as a Binder

Jindaporn Jamradloedluk[a,*], Chaloenporn Lertsatitthanakorn[b]

[a1]Post-Harvest and Agricultural Machinery Engineering Research Unit, Factulty of Engineering, Mahasarakham University, Khamriang, Kantarawichai, Maha Sarakham 44150, Thailand

[b]School of Energy, Environment and Materials, 126 Pracha Uthit Rd., Bang Mod, Thung Khru, Bangkok 10140, Thailand

Abstract

Much attention has been recently paid to the refuse derived fuels (RDFs) due to its benefits in aspects of municipal solid waste management and waste to energy technology. Densified-refuse derived fuel (RDF5) with different raw materials were produced and characterized in this study. Municipal solid wastes used as raw materials for the RDF5 production were sawdust, corrugated paper, plastic bag, and dry cooked rice. Influences of raw material volumetric mixing ratio, extrusion temperature and addition of glycerin as a binder on properties of the RDF5 produced were experimentally investigated. It was found that an increase of dry cooked rice amount and an addition of the glycerin in the mixture led to an increase of density and a decrease of compressive strength of the RDF5. Densities and compressive strengths were in the ranges of 1.4-2.3 g/cm^3 and 75-457 N/cm^2, respectively. Addition of the glycerin also increased the overall thermal efficiency of the cookstove using RDF5 as a fuel. While greater amount of dry cooked rice in the mixture had a negative effect on the overall thermal efficiency. However, extrusion temperature had no obvious effect on the properties of the fuel.

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1. Introduction

Pollution Control Department, Ministry of Natural Resources and Environment, Thailand reported that total

* Corresponding author. Tel.: +66-4375-4316; fax: +66-4375-4316.
E-mail address: jindaporn.msu@gmail.com

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municipal solid waste (MSW) produced in Thailand was increased from 24.73 million tons in 2011 to 26.77 million tons in 2012. The MSW was composed of a large proportion of organic materials (64%) followed by plastic (17%) and paper (8%) [1]. Approximately 78% of MSW was disposed in non-regulated 10 open dumps, 9.4% of the waste generated was recycled while 10% of the waste was properly treated in sanitary landfills, anaerobic digestion, windrow composting and incineration [2]. Incineration is one of the proper management technology facilities that could convert waste to energy. Due to its high content of moisture, low bulk density and low energy density, however, MSW is recommended to be processed to refuse densified fuel (RDF) prior to be used as a fuel for the incinerator. There are four main processing steps associated with an RDF process, namely, physical separation of incombustible materials, drying of MSW, size reduction and palletizing/briquetting. The main rationale for palletizing/briquetting MSW is to ensure size homogeneity, facilitate handling and combustion of MSW [3].

During the past decades, there are extensive research works proposing RDF utilization. Recently, the combustion characteristics of densified-refuse derived fuel (RDF-5) produced from a mixture of oil sludge, coal powder, and polyethylene (PE) were investigated. It was reported that the burning time exhibited a strong relation with the mass ratio of oil sludge in the RDF composition and it decreased as temperature increased. Replacing an equivalent mass ratio of oil sludge with PE in the RDF led to a higher burning mass rate and a lower ignition temperature [4]. Plastic wastes and cassava root stem with different mass ratio were used as raw materials for preparing RDF briquettes. The produced RDF was tested in a small-scale down-draft gasification system. The produced gas contained average energy content of 1.76 MJ/m^3, yielding cold gas efficiency of 66% [5]. Pellets were produced from wheat straw and binders (wood residue, pretreated wood residue, lignosulfonate, bentonite, and crude glycerol). The specific energy consumption, density, tensile strength, and calorific value 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 to 18.77 MJ/kg) when crude glycerol, wood residue, and pretreated wood residue were used as binders [6]. It was found from literature reviews that RDF5 is an interesting waste to energy technology. This research work is therefore aimed at preparation and characterization of municipal wastes using glycerin as a binder.

2. Materials and Methods

2.1. Raw Materials Preparation and Basic Properties Determination

Sawdust from a wood furniture manufacturing factory in Kantarawichai, MahaSarakham province was sieved and screened to the size of 2.36-9.49 mm. Corrugated paper and polyethylene plastic bag collected from the community were selected, cleaned and cut to the dimensions of 1cm×1cm and 1cm×2cm, respectively. Cooked rice was open sun dried, resulting in the size of 0.2 cm diameter and 0.6 mm long. Proximate analysis viz. contents of moisture, volatile matter, and ash of the raw materials was conducted according to ASTM 3173, ASTM D 3175, and ASTM D 3174, respectively. Elemental composition of the raw materials was determined using an elemental analyzer (Leco, TruSpecMicro CHNS, USA). Colorific value was determined according to ASTM D 5865, using a bomb calorimeter (Gallenamp, Adiabatic, UK). Bulk density was measured according to EN 15103.

2.2. Briquetting Procedure

To prepare RDF5, all raw materials were well mixed at the volumetric mixing ratios of 7:1:1:1, 6:1:1:2 and 5:1:1:3 (sawdust: corrugated paper: polyethylene plastic bag: dry cooked rice). Glycerin, used as a binder, was added into the raw material with the volumetric ratio of 0.25:100 and the mixture was then hot extruded at the operating temperatures of 200, 230, and 260°C. Geometry of the densified fuel obtained is octagon hollow-cylinder with the inner diameter of 1 cm, outer diameter of 5 cm, and length of 15-20 cm. The prepared briquettes were kept in polypropylene bags for further characterization.

2.3. RDF5 Characterization and Combustion Test

n-Heptane replacement method was used to determine apparent density of the RDF5. Compressive strength of the RDF5 was investigated via a universal testing machine (Universal tensile tester-CY-6040A12, Chun Yen Testing Machines, Co., Ltd., Taiwan). Ring probe no. 15744 was used with cross head speed of 1 mm/min. The RDF5 was used as a fuel for combustion process, via a high efficiency cookstove, to boil water in a pot. Five hundred grams of the briquette was used to boil 1 kg of water at the air velocity of 0.82 m/s. Temperatures of flame and water during combustion process were measured and recorded every minute.

3. Results and Discussion

3.1. Characteristics of Raw Materials of the RDF5

Proximate analysis, elemental composition, bulk density, and calorific value of the obtained RDF5 were tabulated in Table 1. It was obvious that for all raw materials, carbon atom was in majority (>40%). Calorific value of polyethylene plastic bag was higher than those of sawdust, dry cooked rice, and corrugated paper, respectively. Since plastic is a petroleum derived product (hydrocarbon compound) which carbon and hydrogen are the major elements, polyethylene plastic bag has the larger amount of fixed carbon, leading to the higher calorific value compared to the remaining biomass. Proximate analysis of polyethylene plastic bag in this study was comparable to those reported earlier [7-9]. It was also found from the table that dry cooked rice possessed highest bulk density.

Table 1. Characteristics of raw materials of the RDF5*.

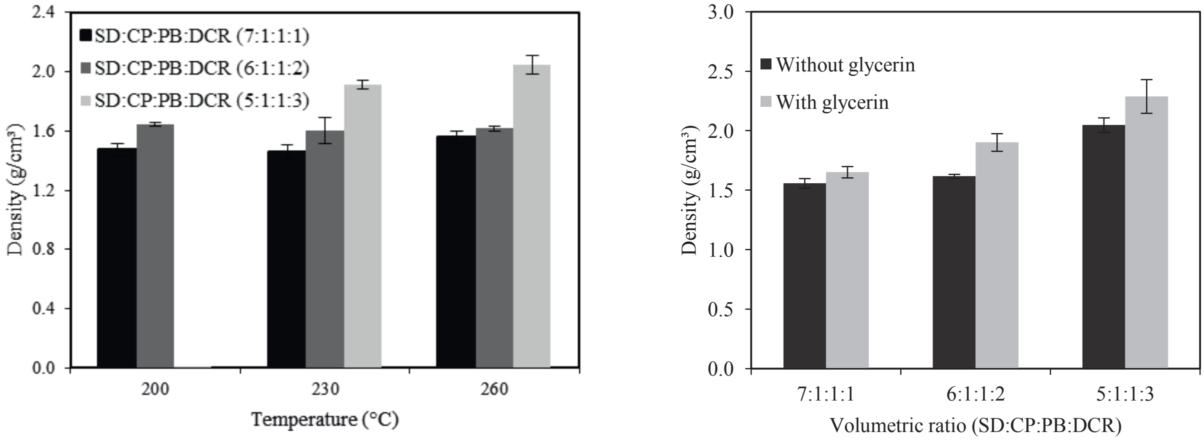
		Sawdust	Corrugated paper	Polyethylene plastic bag	Dry cooked rice
Proximate analysis (% wt)	Moisture	7.97±0.01	7.40±0.12	0.25±0.06	9.43±0.13
	Volatile matter	70.74±0.01	73.70±0.10	5.38±0.61	72.41±0.28
	Fixed carbon**	20.74±0.09	18.55±0.31	94.37±0.86	15.67±0.56
	Ash	0.55±0.05	0.31±0.01	0.004±0.001	2.49±0.05
Ultimate analysis (% wt)	C	49.01	40.56	73.12	40.19
	H	5.75	5.49	8.81	6.05
	N	1.97	2.87	0.82	3.07
	S	4.11	2.71	3.58	2.86
Bulk density (g/cm^3)		0.449±0.012	0.435±0.006	0.388±0.0004	1.483±0.035
Calorific value (cal/g)		3,208.63±112.35	2,819.24±72.36	8,345.62±20.91	3,012.84±9.12

**By different

3.2. Physical and mechanical properties of the RDF5

Influences of raw material volumetric mixing ratio, extrusion temperature, and addition of glycerin on the physical and mechanical properties of the RDF5 was experimentally investigated. General appearance (not shown) was found to be affected by the raw material ratio, extrusion temperature, and also glycerin addition. Smoother surfaces with fewer cracks were observed when using fewer amounts of dry cooked rice and higher extrusion temperature, and also adding glycerin as a binder. This was because higher temperature might resulted in the melting raw materials and glycerin added probably acted as a binding agent, resulting in the better adhesion of raw materials.

As illustrated in Fig. 1, apparent density of the RDF5 tended to increase with increasing extrusion temperature, amount of dry cooked rice in the raw material, and addition of glycerin. Attributed to its much higher bulk density, dry cooked rice was the key raw material affecting apparent density of RDF5. Apparent density of RDF5, therefore, increased as the dry cooked rice amount. Higher extrusion temperature and addition of glycerin caused the better adhesion of raw materials, as previously described, thus making apparent density of RDF5 increase.



(a) (b)

Fig. 1. Effects of (a) extrusion temperature and material mixing ratio and (b) addition of glycerin on apparent density of the RDF5 (SD=Sawdust; CP=Corrugated paper; PB=Polyethylene plastic bag; DCR=Dry cooked rice).

Effect of extrusion temperature, mixing ratio, and addition of glycerin on compressive strength of the prepared RDF5 is presented in Table 2. It was apparent that effects of mixing ratio and glycerin addition were more pronounced than that of the extrusion temperature. Compressive strength of the RDF5 significantly decreased when changing the mixing ratio from 7:1:1:1 to 5:1:1:3 and adding the glycerin into the raw material mixture. The lower compressive strength might be a consequence of non-uniform and homogeneous raw material within the RDF5. Force-displace curve of the compression test suggested that the fuel was rather brittle.

Table 2. Compressive strength of RDF5 prepared at different conditions*.

Extrusion temperature (°C)	Volumetric mixing ratio**	Compressive strength (N/cm^2)	
		With glycerin	Without glycerin
200	7:1:1:1	$297.47\pm133.14^{A,b}$	$451.11\pm99.53^{A,a}$
	6:1:1:2	$209.21\pm37.13^{ABC,b}$	$408.61\pm83.41^{AB,a}$
230	7:1:1:1	$254.97\pm49.03^{AB,b}$	$415.15\pm73.60^{AB,a}$
	6:1:1:2	$137.29\pm39.28^{BCD,b}$	$294.20\pm50.96^{AB,a}$
	5:1:1:3	$111.14\pm14.98^{CD,a}$	$130.76\pm29.96^{C,a}$
260	7:1:1:1	$284.39\pm64.31^{A,b}$	$457.64\pm40.83^{A,a}$
	6:1:1:2	$219.02\pm88.44^{ABC,b}$	$313.81\pm103.32^{B,a}$
	5:1:1:3	$75.184\pm24.68^{D,a}$	$114.41\pm14.98^{C,a}$

* Values in the same column with different capital letter superscripts mean that the values are significantly different ($p < 0.05$). Values in the same row with different superscripts mean that the values are significantly different ($p < 0.05$).
**Volumetric mixing ratio of sawdust: corrugated paper: polyethylene plastic bag: dry cooked rice

3.3. Utilization of RDF5 as a Fuel for a Cook Stove

Overall thermal efficiency of the cook stove fueled by RDF5 prepared at different condition was depicted in Fig. 2. The overall thermal efficiency was found to be improved by reducing amount of dry cooked rice in the raw material and adding glycerin into the mixture. This was due to the higher calorific value of saw dust compared to dry cooked rice husk and the higher calorific value of glycerin (4,541 cal/g) compared to most of the raw materials. Similar result was found for glycerin-biomass briquette fuel previously reported [10].

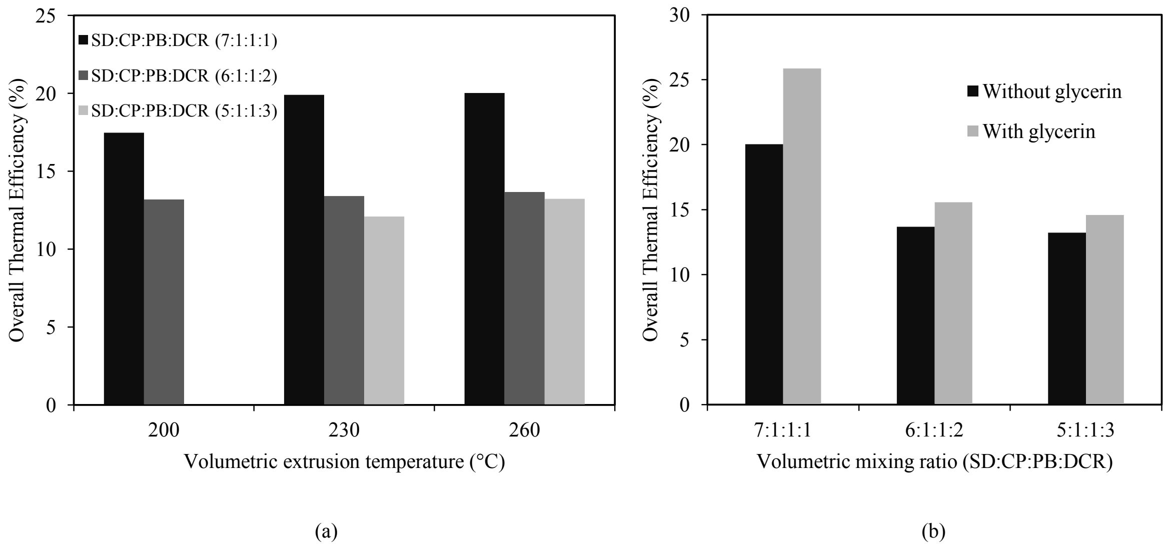


Fig. 2. Effects of (a) extrusion temperature and material mixing ratio and (b) addition of glycerin on overall thermal efficiency of cook stove using RDF5, prepared at different conditions, as a fuel (SD=Sawdust; CP=Corrugated paper; PB=Polyethylene plastic bag; DCR=Dry cooked rice).

During the combustion process, flame temperature continuously increased to the maximum value (648^{o}C) at the 6th minute, kept almost constant and then gradually decreased (See Fig. 3). It required 5 minutes to increase water temperature from room temperature to the boiling point. Compared to wood fuel, the RDF5 required a shorter time to ignite with the stable flame. The reddish-orange flame produced small amount of smoke at the beginning of the combustion test and then no smoke was noticed.

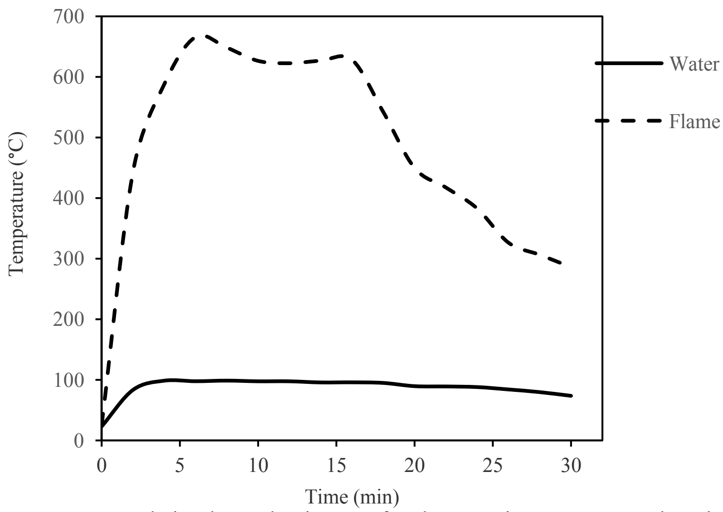


Fig. 3. Flame and water temperatures during the combustion test of cook stove using RDF5 prepared at mixing ratio of 7:1:1:1, extrusion temperature of 260^{o}C and addition of glycerin as a fuel.

Conclusions

Volumetric mixing ratio of raw material and addition of glycerin had stronger effects on properties of RDF5 than extrusion temperature. An increase in amount of dry cooked rice and addition of glycerin in the raw material provided the RDF5 with higher density and lower compressive strength. Dry cooked rice content had a negative effect on overall thermal efficiency of the cook stove while glycerin addition had a positive effect. Maximum thermal efficiency (25.86%) was observed when using RDF5 prepared at mixing ratio of 7:1:1:1, extrusion temperature of 260^{o}C and addition of glycerin as a fuel. RDF5 prepared in this study was an alternative fuel for the combustion process. Pollutant emission of the fuel will be investigated in the future work.

Acknowledgements

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