Available online at www.sciencedirect.com

ScienceDirect

Energy Procedia 79 (2015) 657 – 662

Energy Procedia

2015 International Conference on Alternative Energy in Developing Countries and Emerging Economies

Fuel Properties of Bio-Pellets Produced from Selected Materials under Various Compacting Pressure

Tanakorn Unpinit [a], Thanaporn Poblarp[a], Narongrit Sailoon[a], Prasong Wongwicha[a], Mallika Thabuot[a,b*]

[a]*Department of Chemical Engineering, Faculty of Engineering, KhonKaen University, Thailand*
[b]*Center of Knowledge Development of Rubber Tree in Northeast group (KDRN), KhonKaen University, Thailand*

Abstract

The purpose of this study is to investigate the fuel properties of biomass pellets prepared from six different biomasses: bamboo sawdust, eucalyptus sawdust, corn cob, rubber tree branches, palm fibre and lippia grass. These materials were milled into small particles less than 5 mm before binderless pelletization using the labscale hydraulic press under forces of 56-166 MPa for 20 seconds into the pellets. Thermal degradation of each biomass was analyzed by TGA. The increase in compaction pressure makes the L/D ratio of pellets decrease and the pellet density increase, and rather maintained the constant value after 139 MPa was applied. Moreover, higher applied pressure also gave the pellets with higher tensile strength and less water impermeability.

Peer-review under responsibility of the Organizing Committee of 2015 AEDCEE

Keywords: Biomass; Solid Fuel Pellets; Calorific Value; Densification; strength;

1. Introduction

Since the energy demand has been increased with the population growth, fossil fuels are depleted very fast. Alternative energy is gained more interested to replace this non-renewable energy to improve the environment. Biomass is converted into the green energy as it is the carbon-neutral material, cheap and abundant available. Compared to the fossil fuel, biomass is the sustainable energy feedstock and supports the reduction of greenhouse gas (GHG) emission. Agricultural lignocellulosic wastes have been paid high attentions to be converted into the bio-fuel in different states; liquid, gas and solid. Pyrolysis and gasification processes are investigated on the purpose to obtain the two former, however, high investment

* Corresponding author. Tel.: +6643362240; fax: +6643362240.
E-mail address: tmallika@kku.ac.th.

Peer-review under responsibility of the Organizing Committee of 2015 AEDCEE
doi:10.1016/j.egypro.2015.11.551

is needed. Densification is the promising technology to be applied for solid-fuel production from these wastes because it is the simply technology which can be adjusted for the local area. The bulk volume of the material can be reduced by mechanical compaction for easy handling, transportation and storage [1]. High density pellets is environmentally friendly solid bio-fuel, very comfortable in use for both households and industrial plants. In this study, the pelletization of selected biomass wastes without binder were investigated under different compacting pressures in order to obtain pellet with the satisfied fuel properties.

2. Methodology

Six types of biomass wastes; bamboo sawdust, eucalyptus sawdust, corn cob, rubber tree branches, palm fibre and lippia grass; were achieved from the local area of Khon Kaen Province, Thailand. As shown in Fig. 1, the materials were sundried for 3 days to reduce the moisture content, afterward they were milled using hammer mill. The ground materials with the particle size less than 2 mm were sieved and collected. The sieved samples were compressed into the pellets at ambient temperature using a laboratory scale Specac hydraulic press. A steel cylindrical die of dimension 1.3 cm diameter with the maximum load of 555 MPa was used. Each sample was weighed about 1.5 g before applied into the die, the compaction was help for 20 seconds under the applied pressure of 56-166 MPa. The prepared pellets were kept for 3 weeks before analysis. Bulk density of the starting materials was found out by weighing sample in a known volume. The energy content was determined using bomb calorimeter. Thermal degradations of these materials under nitrogen atmosphere were investigated using Thermo gravimetric analyzer (TGA50, Shimadzu). The condition was swept from 30°C to 700°C at 10°C/min, and 10 minutes of the holding time at the final temperature. The moisture content and volatile mater were estimated from the temperature degradation curve. The ash content (ASTM-E80) was determined in the muffle furnace at 750°C for 2 h. The fixed carbon content was calculated from the weight difference. Elemental compositions were estimated using the same equations as provided in the other study [2]. The heating value was determined using Gallenkamp Adiabatic Bomb Calorimeters. The apparent density of pellet was determined by dividing its mass by its volume. A digital weighing scale and a standard vernier caliper were used for checking the mass and dimensions of the pellets. The sample strength was determined by the tensile crushing strength test, using the universal testing machine (LAX-Plus, Lloyd Instrument). The densified product was horizontally placed on the stainless steel base platen, and the load cell of 1 kN was perpendicular applied at a constant cross-head speed of 2 mm/min until the pellet began to crush. The maximum force at which each sample cracked was recorded and the tensile crushing strength was calculated as in the other report [3]. To estimate the water impermeability, pellets were placed in the 27°C water for 30 second and then the ratio of amount of absorbed water to original weight was calculated [4].

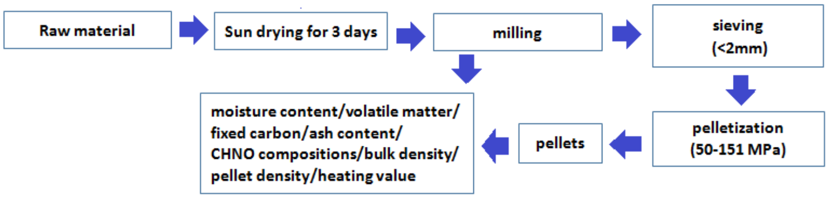

Fig. 1. Experimental procedure.

3. Results and discussion

Since the main components of biomass are cellulose, hemicellulose and lignin, the thermal degradation behaviors in the nitrogen atmosphere of all selected biomass are shown in the similar trends as evident from Fig 2. Water was evaporated from the material surface at 110°C, and the decomposition of hemicelluloses occurred between 200-260°C. Cellulose polymer was destroyed from 260°C to get water, CO_2, CO and char. These decomposed gases and liquids in the form of volatiles were released increasingly with the temperature increased up to 600°C. Volatile matter was evolved out into two different degradation rate, the last step was faster due to the material surface was getting charred. It can be seen that the structures of corn cob, rubber wood and lippia grass were easier to be broken at the low temperature than bamboo sawdust and eucalyptus sawdust. Among these materials (Table 1), bamboo sawdust has the highest moisture content which effected on low heating value. However, low ash amount is preferred for the fuel purpose and large carbon content is favored for calorific heating value. Bulk density shows the weight per volume of biomass waste, it can be said that material with low density should not be suggested to be direct used as the fuel in the combustion system because of low thermal efficiency. Even these bulky materials have the density between 157-326 kg/m^3, but they are composed of high volatile matter and carbon composition that indicate the high potential fuel being.

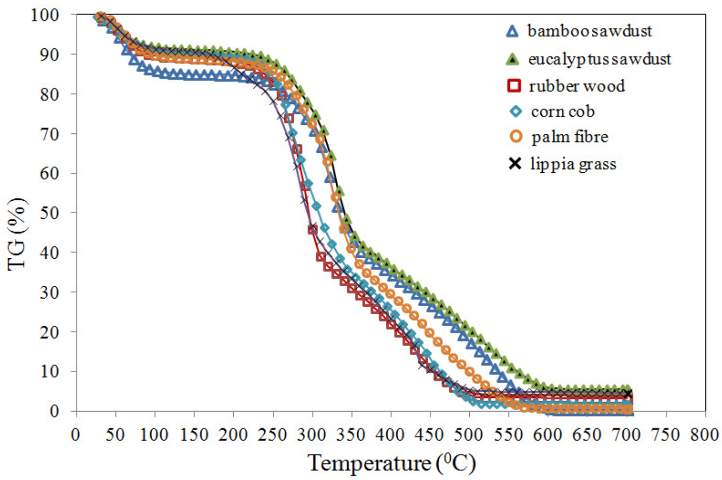

Fig. 2. TGA curves of selected biomass in this study.

Table 1. Analysis of selected biomass wastes.

Properties	bamboo sawdust	eucalyptus sawdust	rubber wood	corn cob	palm fibre	Lipia grass
Moisture (wt.%)	14.00	9.10	10.90	9.14	9.90	8.10
Volatile matter (wt.%)	80.36	90.51	85.69	88.88	89.30	86.94
Ash content (wt.%)	0.11	0.17	0.15	0.13	0.20	0.45
Fixed carbon (wt.%)	5.53	0.22	3.21	1.28	0.67	4.34
C (wt.%)	40.09	41.32	41.03	41.26	41.06	42.32
H (wt.%)	5.27	5.62	5.48	5.58	5.57	5.62
O (wt.%)	39.93	43.15	41.76	42.70	42.71	42.70
Bulk density (kg/m^3)	280.95	288.4	305.54	157.3	325.65	283.23
Heating value (MJ/kg)	15.69	18.48	16.00	15.84	15.66	16.32

To increase the density of these biomass wastes, pelletization using the laboratory scale Specac hydraulic press and characterization according to the fuel properties were done. Fig. 3(a) shows the physical shapes of some produced pellets prepared under different applied pressures, and length of pellet decreased with the increase of compaction pressure and material types. More uniform in shape were for the pellets formed at higher pressures as well. Therefore, L/D ratio (length to diameter) of pellet can be performed as a good metric for the degree of compression during pelletization. This ratio decreased with the increase of compaction pressure as presented in Fig. 3(b). Under the same press, bamboo sawdust was the easiest material to be pressed. This might be caused by high adhesion between individual molecular of material structure. Also, only the slightly decrease in L/D ratio between using pressure of 139 MPa and 166 MPa. However, to produce pellets with high durability value, a smaller die with higher L/D ratios has been suggested to be used in pelletization [1].

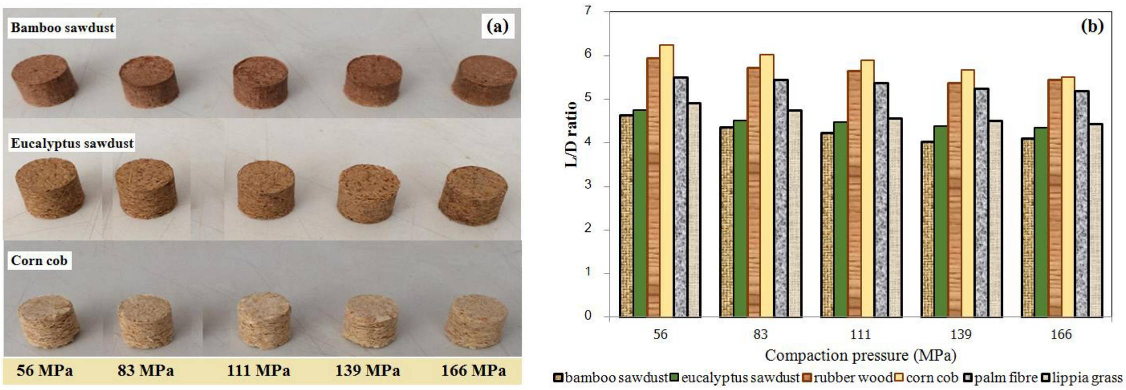

Fig. 3. (a) Bio-pellets produced at different compaction pressures from bamboo sawdust,eucalyptus sawdust and corn cob. And (b) the effect of compaction pressure on L/D ratio of bio-pellets

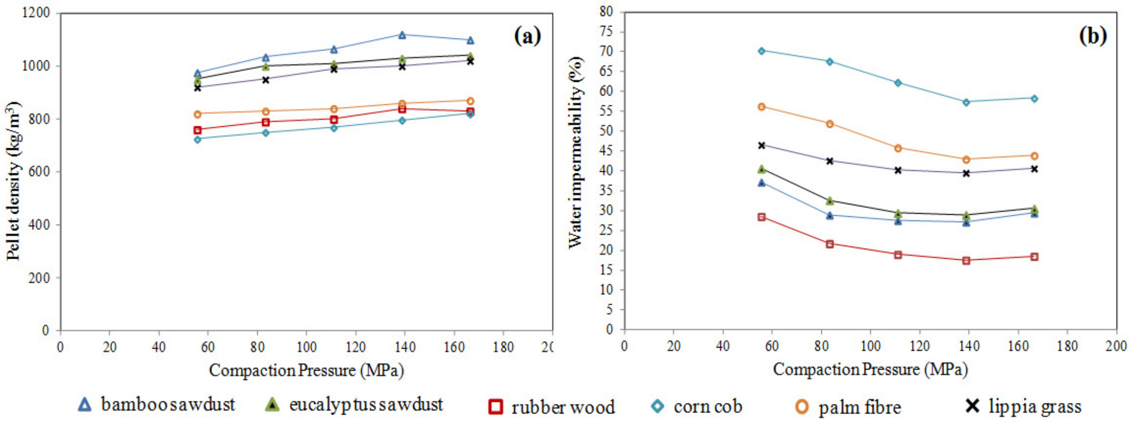

Fig. 4. (a) Effect of compaction pressure on the density of bio-pellets, (b) the effect of compaction pressure on the water impermeability of bio-pellets.

From the ratio of material amount to the pellet dimension, higher compaction pressure gave the increase of pellet density (Fig. 4(a)) in which same pattern of all curves was found. The most dense pellet was prepared from the bamboo sawdust whereas pellets prepared from corn cob was the most loose products. As the pressure increased from 55 to 139 MPa, the density of bamboo sawdust pellet increased from 975 to 1120 kg/m^3 while the density of corn cob pellet increase from 724 to 820 kg/m^3. This might be explained that bamboo sawdust required lower compression energy to fill the inter-particle spaces during the compression process. In addition, the increase of pellet density will increase the bulk density and the volumetric energy density which make easier handling, transportation and storage. Water impermeability is a value of showing the capability of solid pellets to absorb the moisture or water penetration during handling, transportation or storage. Pellets with satisfied quality should have low water impermeability in order to be stored for a long period without water absorption. The level of compaction pressure has effected on water impermeability of biomass pellets as seen in Fig. 4(b). With increasing the pressure level from 56 to 139 MPa, water impermeability of pellet decreased to the minimum value and then slightly increased at the higher pressure. Corn cob pellet has the largest value of water impermeability than others when the pressure level is all the same. This might be caused by the strongest water absorbing power of corn cob. Pellets prepared from bamboo sawdust and eucalyptus sawdust have a little bit differences in water impermeability. The lowest water permeability of 17.56% was found in this pellet prepared 139 MPa.

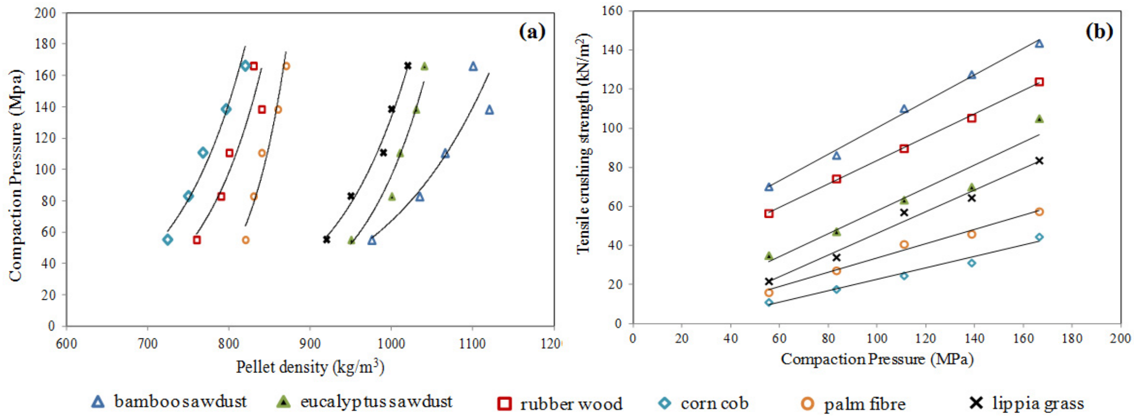

Fig. 5. (a) Relationship between pellet density and compaction pressure, (b). Relationship between compaction pressure and tensile crushing strength of bio-pellets.

Table 2. Constant values of the power relationship between the pressure (P) and pellet density (ρ).And the constant values of the linear relationship between the pressure (P) and tensile crushing strength (TS) of produced pellets.

	$P=ke^{n\rho}$			TS=mP+c		
Biomass residue	k	n	R^2	m	c	R^2
bamboo sawdust	0.045100	0.0073	0.9253	0.678700	32.4090	0.9950
eucalyptus sawdust	0.000500	0.0121	0.9620	0.558000	-0.9917	0.9330
lippia grass	0.003100	0.0107	0.9841	0.556000	-9.3947	0.9828
palm fibre	0.000004	0.0200	0.9342	0.366200	-3.0598	0.9858
rubber wood	0.003300	0.0129	0.9094	0.598100	23.6820	0.9989
corn cob	0.016600	0.0113	0.9646	0.290500	-6.3325	0.9743

The relationship between pressure and pellet density were suggested as a simple exponential [5]. In this study also presented an exponential increase in density with the increase in pelletisation pressure as shown in Fig. 5(a). All constant values of these relationships is presented in Table 2, the regression values were between 0.90-0.99, smaller k and n value mean material is easier to be pressed to get the same density. Two groups of materials were separated as obviously seen in Fig. 5(a); easy press and difficultly press. Bamboo sawdust, eucalyptus sawdust and lippia grass were in the former group. Palm fibre, rubber wood and corn cob were in the latter group. Herein, bamboo sawdust was the easiest pressed while corn cob was the most difficult one. From the results of tensile strength test as seen in Fig. 5(b), the increase of applied pressure from 56 MPa to 166 MPa can improve the strength of obtained pellets. So pellets formed at higher pressures were found to be stronger and more uniform in shape. Although a rather slightly change in pellet density was observed between 139 and 166 MPa, the strength of the pellet was still increased. Herein, pellet produced from bamboo sawdust was the strongest product (144 kN/m^2 at 166 MPa), while corn cob pellet was the weakest one (11 kN/m^2 at 56 MPa). The linear regressions R^2 of all curves are higher than 95% as indicated in Table 2, higher m value or steeping slope means tensile strength larger increased with the increase in compaction pressure. Therefore, the linear relationship with presented constant values could be used to predict the tensile strength of pellets which produced at each applied pressure.

4. Conclusion

In pelletization of selected biomass wastes, the optimum pressure was investigated for the formation of good quality bio-pellets. Bamboo sawdust was the easiest material to be pressed, which reached to the minimum L/D ratio of 4.03 and highest pellet density of 1120 kg/m^3 under the applied pressure of 139 MPa. This result was confirmed by an exponential relationship between the pellet density and compaction pressure which also revealed that corn cob was the most difficult material to be pressed. The linear relationship between the tensile crushing strength and compaction pressure presented that bamboo sawdust gave the stronger pellet than other material. The maximum tensile strength of 144 kN/m^2 was obtained with the bamboo sawdust pellet prepared at 166 MPa. Corn cob pellet has the largest value of water impermeability than other prepared pellet when the pressure level is all the same. Pellet prepared from rubber wood residue at 139 MPa had the lowest water permeability of 17.56%.

Acknowledgements

We would like to thank Center of Knowledge Development of Rubber Tree in Northeast group (KDRN), KhonKaen University (Thailand) for the fully funded support to conduct this research.

References

[1] Theerarattananoon K, Xu F, Wilson J, Ballard R, Mckinney L, Staggenborg S, Vadlani P, Pei ZJ, Wang D. Physical properties of pellets made from sorghum stalk, corn stover, wheat straw, and big bluestem. *Industrial Crops and Products* 2011; **33(2)**: 325-332.

[2] Mythili R, Venkatachalam P. Briquetting of Agro-residues. *Carbon* 2013; **42(41.80)**: 42-08.

[3] Bazargan A, Rough SL, McKay G. Compaction of palm kernel shell biochars for application as solid fuel. *Biomass and Bioenergy* 2014, **70**: 489-497.

[4] Fengmin L, Mingquan Z. Technological parameters of biomass briquetting of macrophytes in Nansi Lake. *Energy Procedia* 2011; **5**: 2449-2454.

[5] Razuan R, Finney KN, Chen Q, Sharifi VN, Swithenbank J. Pelletised fuel production from palm kernel cake. *Fuel Processing Technology* 2011; **92(3)**: 609-615.