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A bio-fuel briquette from durian peel and rice straw: Properties and Economic feasibility

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ABSTRACT

Durian peel and rice straw are considered as agricultural wastes. These two materials have high potential for a bio-fuel through the briquetting process according to their quantities and thermal qualities. In this study, cold densification method and extrusion process are adopted for solid bio-fuel briquettes. Durian peel and rice-straw were pyrolysed, milled and combined together by adding ten percent of cassava starch as a binder. Physical properties of the briquette at various mass ratios of durian peel char and rice straw char were investigated for heating value, compressive strength, ash and moisture content. The burning test of the briquette was also observed. The results show the highest heating value of 24.674 MJ/kg for the briquette made with durian peel char and rice straw char at a mass ratio of 9:1. The percentage of ash and moisture content and the compressive strength of the briquette were 14.6%, 6.5% wet basis and 10.6 kg/cm^2 respectively. A heating value higher than 20.92 MJ/kg and a moisture content of less than 8 % are acceptable in the market according to the Thailand community standard. Moreover, a payback period less than two years can be achieved.

Keywords: Bio-fuel, Briquette, Durian peel, Rice straw, Properties

INTRODUCTION

Biomass is used as a fuel; particularly, wood, a primary source of energy, is famously consumed in both rural and city area. Wood fuel and charcoal is widely utilized in Thailand. They are used for cooking by rural people and in the restaurants of big cities. Department of Alternative Energy Development and Efficiency (DEDE) reported the final energy consumption for the wood fuel was 57.9% in the renewable energy criteria with the total amount of 11328 ktoe (Thailand energy situation, 2004). The statistical data recorded by the forest department shows the reduction of forest area from 53.3 % to 30.92% during the years 1961- 2006. The deforestation is in reality caused by many factors. The use of wood for fueling can be inferred as one of the causes. Trees cut down for energy supply can be further deducted if substitution of fuel wood is offered. DEDP reports that the use of agricultural residues as a renewable energy resource is extremely low even though Thailand is one of the leading agriculture producers in the world. The energy potential of some agricultural wastes is shown in Table 1. However, many other agricultural wastes have shown their energy potential and should be investigated for their best utilization.

Table 1. Energy potential of some agricultural wastes (Sathitruangsak, 2003).

Sample	Rice husk	Coconut shell	Palm fiber	Corn cob	Palm shell	Soybean (stem and shell)
Heating value (MJ/kg)	14.27	16.23	17.62	18.04	18.46	19.44

Durian peel is one among those agricultural residues that have rarely been considered and promoted. The proximate analysis for durian peel has shown carbon (C), oxygen (O) and hydrogen (H) components of 60.31%, 28.06% and 8.47% respectively (Chandra *et al*, 2009). Compare those three main chemical elements, the durian peel has higher carbon and the total percentage of the three than many other wastes such as palm shell and rice husk. This has shown its energy potential. In Thailand, durian is grown more in the eastern and southern area. The total durian product of the country is about 870,889 tones a year in 2002/2003. Durian is consumed in the country approximately 350,000 tones per year. It can roughly approximate that one third of the whole fruit is left to waste as peel. The calculation of durians peel gives about 117,000 tones each year. This has shown its potential in terms of quantity. The literature study showed that durian peel can be used to make briquette (Poonkasem, 1999). The durian peel was sun-dried until it has moisture content of 45% for cold densification methods and 10% for hot densification methods. It was found that the final product from the hot densification method offered slightly higher heating value with 20.265 against 15.483 MJ/kg from the other method. The quality enhancement to achieve higher heating value is of interest for further investigation. The utilization of corn, wheat and rice straw to make a briquette is commercialized in China (Zeng *et al*, 2007). A screw press is a dominant producing machine. This offers several advantages such as stable operation, continuous production and easy combustion in regarding to the product shape. Rice straw and maize cob were employed as raw materials for briquetting (Chindaruksa *et al*, 2005). The maximum heating value of 24.277 MJ/kg at the mass ratio of 5:5 was found. The producing of biomass solid fuel from coconut shell and fiber by extrusion method was studied (Sathitruangsak, 2003). The compressive strength was found to be improved by increasing the mass fraction of a binder. On the contrary, the density and heating value was reduced by decreasing the binder mass fraction. Briquetting of palm fiber and shell using a hydraulic press received the heating value 16.4 MJ/kg, ash content of 6% and moisture content of 12% (Husain *et al*, 2002). However, more understanding on this densification process needs further work to achieve a good product quality. Two types of biomass briquetting technologies are well known. Those are hot and cold briquette techniques (Husain *et al*, 2002; Zhou and Zhang, 2007). The first one was developed and has been widely used in Japan, EU and USA; however, government subsidies would be necessary due to high investment, high operating cost and space demands. The latter technique is simple, mobility and less energy consuming that is utilized in countries such as Tibet, Malaysia, and Thailand. It was found that the energy consumption in the cold densification process is about one-sixth of the hot densification process (Poonkasem, 1999).

In Thailand, the majority of durian peel is thrown away. Although, the research shows that durian peel could be employed in processes such as fertilizer, thermal insulation and food packaging film, but these is little amount compared to the total waste. At the same time, more than 50% of the rice straw is burned at the field, to prepare the farming land. Instead of causing the problem to the residue disposal, a large amount of durian peel, high energy potential, and rice straw, easily ignited, are considered for making the solid bio-fuel briquette. These two raw materials were collected in Phitsanulok. Converting residues to an energy resource using briquette technology has many advantages, including the increase of a net calorific value per unit volume, convenience to transport and storage, uniform size and quality and to provide a substitute to a wood fuel or charcoal.

In this research, the briquette made at various mass ratios of the rice straw and durian peel is investigated. A screw press process is selected for briquetting due to its simplicity, convenience and low cost. Physical properties including the heating value, compressive strength, ash, and moisture contents are examined in the laboratory testing. An economic feasibility is presented through a simple payback period.

MATERIALS AND METHODS

Materials

The raw materials as durian peel and rice straw are collected for free from the available source in Phitsanulok province; therefore, no initial cost can be assumed in this experimental study. The moisture content of materials is carried out in the laboratory. Durian peel and rice straw have shown their initial moisture content of 38 % and 12 % wet basis, respectively.

Briquetting

Converting the durian peel and rice straw into char by pyrolysis method, the process diagram is shown in Figure 1. Then rice straw and durian peel chars are grinded into powder separately. The study has varied the mass ratio of the durian peel and rice straw chars at 9:1, 8:2, 7:3, 6:4, 5:5, 4:6, 3:7, 2:8 and 1:9 respectively. A cold densification method is employed in which a binding material is necessary to unite the materials. Cassava starch is used to bind the char mixture. In this study, cassava starch is added to the char mixture at 10 % by weight for every sample mass ratios. The natural binder liked starch obtained from cassava flour has proved that it is strengthen briquette and combine it quite efficient (Teixeira *et al*, 2010). The screw press machine is utilized to form the briquette. The combined chars are fed into the extruder where they have been pressed for a bar shape with the hole at the center as shown in Figure 2. This product is dried and used as a fuel. In order to indicate the feasibility of utilizing the briquette, its physical properties are analyzed under standard testing methods.

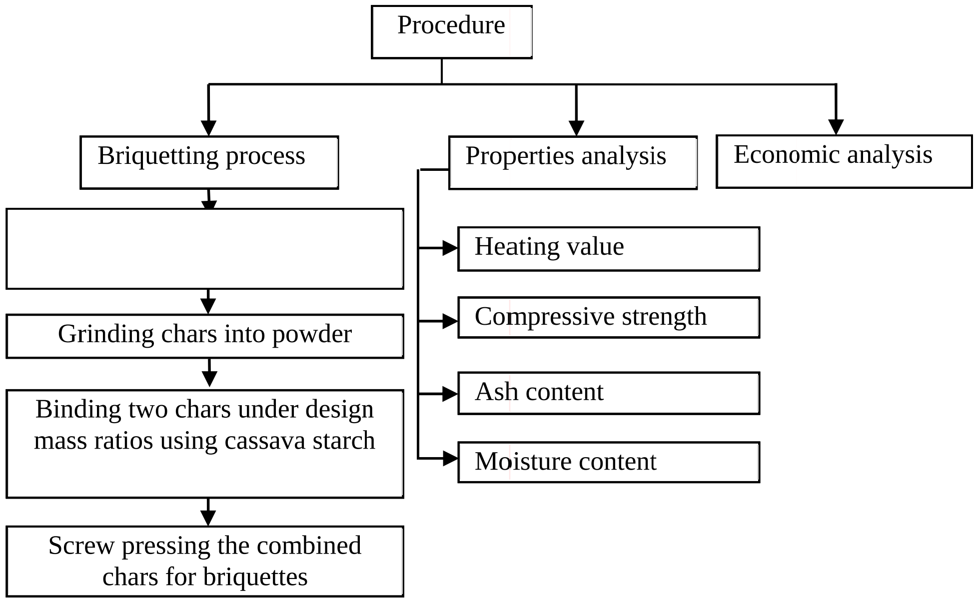

Figure 1 The diagram of the study procedure.

Figure 2 Bio-fuel briquettes from durian peel and rice straw chars.

Laboratory equipment

The three main laboratory equipments are shown in Figure 3 (a), (b) and (c). The oven is used to find the moisture content of the sample. Heating value of the briquette can be determined by the oxygen bomb calorimeter while the strength of the briquette is measured by the force applied on the sample in the compressive strength machine.

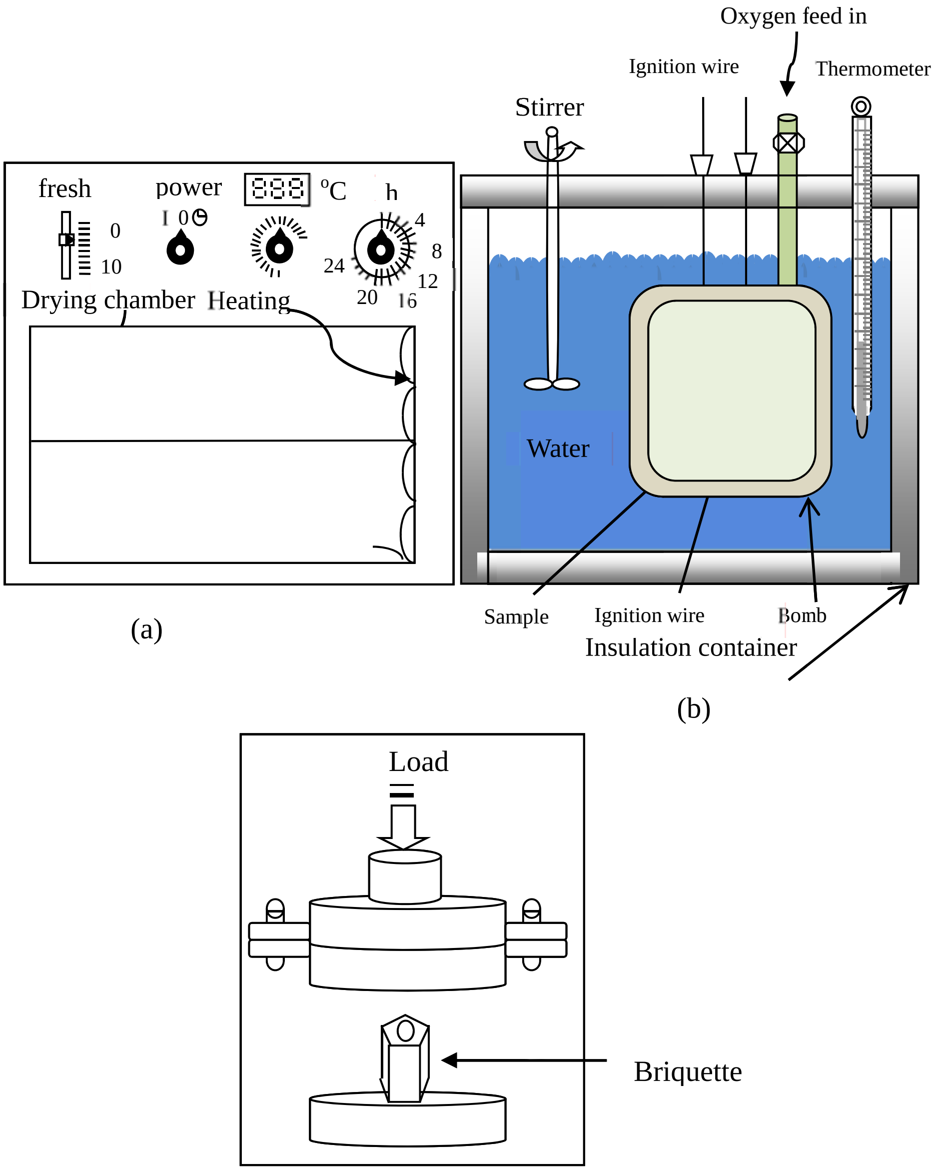

Figure 3 (a) An oven, (b) An oxygen bomb calorimeter and (c) A compressive strength machine.

Properties analysis

Physical properties of the briquette are measured in the laboratory. The moisture and ash contents of the solid bio-fuel briquette are investigated with the methods referred to as ASTM, American Society for Testing and Materials, D 3173 and D3174, respectively. An oxygen bomb calorimeter shown in Figure 3 (b) is used to determine the heating value of the briquette in which the testing procedure ASTM D 2015 is followed. The sample was weighed and loaded in a combustion cup. The fuse wire was cut at the length of 10 cm and then tied in the bomb calorimeter and covered by the lid. The water in the container, to maintain the calorimeter jacket at constant temperature of 25 ^{o}C, was weighed. The oxygen gas of 30 psi was fed in the bomb calorimeter, to combust the briquette and hence obtains the heating value. Finally, the briquette strength was examined by using the compressive strength machine shown in Figure 3 (c). A vertical force was added on top of the sample until it deformed. This was indicated in kilogram per square centimeter. The last two tests were carried out under the supervision of a laboratory technician in the Department of Mechanical Engineering, Faculty of Engineer, Naresuan University.

RESULTS AND DISCUSSION

The bio-fuel briquette made of durian peel and rice straw chars is in a pentagonal shape, due to the available compressed machine, with the center hole. In combustion process, a solid fuel requires a higher fuel-air ratio than liquid fuel and gas fuel to achieve a complete combustion. This pentagonal shape with a hole has been proved to reach the complete combustion more easily than the briquette with a solid shape. That is because the air interacts with more surface area of the briquette (both inner and outer) which results in enhancing the combustion efficiency. The dimension of the briquette is shown in table 2 and the picture of the bio-fuel briquette can be seen from Figure 2.

Table 2 Approximate dimension of the bio-fuel briquette.

Inside diameter (mm)	Length (mm)	Wide (mm)	Shape
15.6	100	28.8	Pentagonal 

Properties of the bio-fuel briquette

Heating value

The heating value of the briquette with different mass ratio of the materials is presented in Figure 4. The highest heating value of 24.674 MJ/kg could be achieved from the briquette made of durian peel char and rice straw char at mass ratio of 9:1. That approximates to the heating value of sub-bituminous coal. The higher the mass fraction of durian peel is offering the greater the heating value. The solid bio-fuel briquette has a high heating value so it can be compete with a briquette made from other agricultural wastes such as rice husk, pure durian peel and coconut shell and fiber (Sathitruangsak, 2003; Poonkasem, 1999).

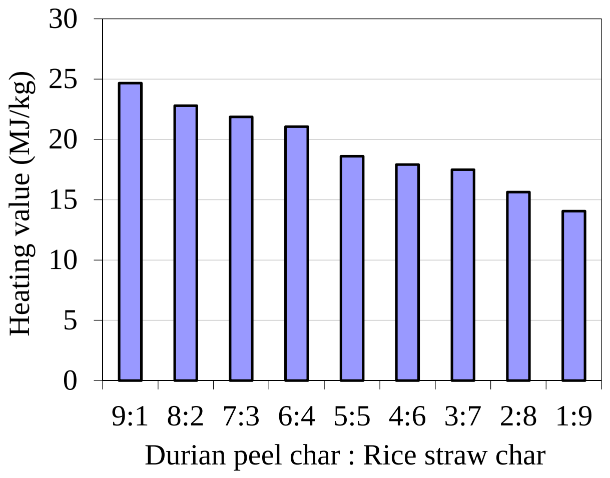

Figure 4 Heating value of the biofuel briquette at various mass ratios of durian peel char and rice straw char.

Compressive strength

The compressive strength of the bio-fuel briquette was examined under vertical force in a compressive strength machine shown in Figure 5. The maximum value was found at 10.6 kg/cm^2 for the sample with the mass ratio between durian peel char and rice straw char of 9:1. The trend of compressive strength is similar to the heating value. That is the more durian peel material provides a higher the heating value. All briquette samples have the compressive strength over 375 kPa, which means the product would be acceptable for the commercial market (Sathitruangsak, 2003).

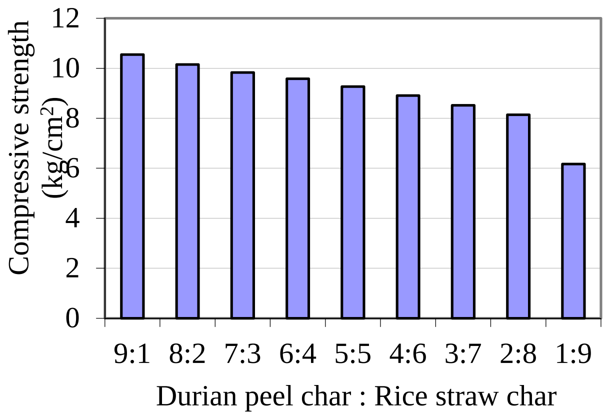

Figure 5 Compressive strength of the bio-fuel briquette at various mass ratios of durian peel char and rice straw char.

Moisture content

Figure 6 shows the minimum moisture content of the briquette at the mass ratio between durian peel and rice straw chars of 1:9. According to fuel and combustion theory (Winterbone, 1997), the heating value and combustion efficiency of a fuel could be influenced by the moisture content. The experimental findings here show the briquette with the highest heating value also has the highest moisture content for the sample with mass ratio of 9:1. This is different from typical briquette trends. The difference between the maximum and minimum moisture content for these samples is 1.66 % w.b.; however, this value is low compare to other studies. One could be explained that durian peel char must having higher calorific value than rice straw char, in which has overcome the effect of low water content in the sample. The literature data from an ultimate analysis show that a durian peel has higher percentage in carbon, hydrogen and oxygen elements than a rice straw which infer to greater heating value (Sathitruangsak, 2003; Chandra *et al*, 2009; Winterbone, 1997). With the moisture content of lower than 8%, the briquette product would be qualified and accepted by the local standard. The disagreeable situation could be met if the product has high moisture content due to the smoke creation and unpleasant smell while the product is used.

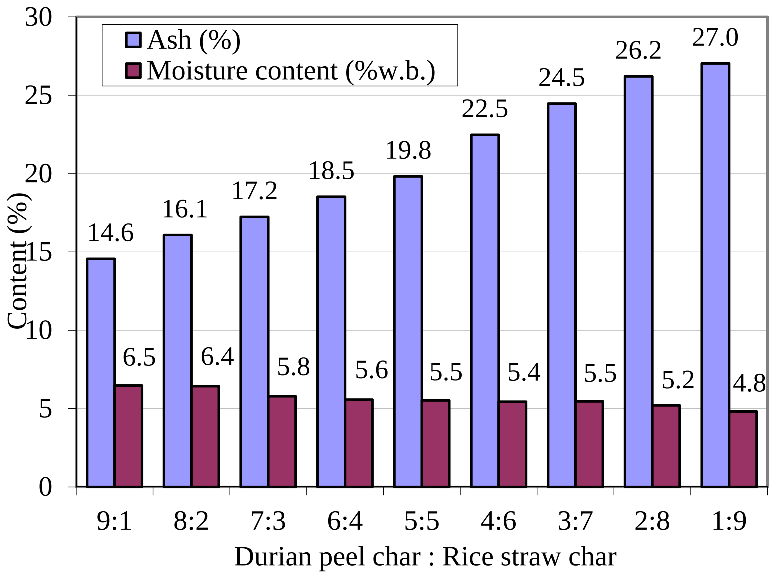

Figure 6 Moisture and ash content of the bio-fuel briquette at various mass ratios for durian peel char and rice straw char.

Ash content

The ash content was less at higher mass fraction of durian peel char as can be seen from Figure 6. The percentage of ash at minimum value of 14.6 was met for the product at mass ratio between durian peel char and rice straw char of 9:1.

The higher ash content for the sample with mass ratio of 1:9 is because of the high content of ash in the raw materials as rice straw over durian peel.

Burning test

A burning test of the briquette was carried out by using a locally made stove in the open air. Operating characteristics were observed during the test. It was seen that no sparkle occurred when the briquette was on fire, there was no a small piece of briquette on fire escaping into the air. No smell or smoke were observed by a research assistant during the burning test. An appearance of ash was in a piece after burning. The burning characteristics of the solid bio-fuel briquette made of durian peel and rice straw are positive compared to traditional wood charcoal which could have little sparkle, unpleasant smell, white smoke and ash dust dispersing into the air.

Economic feasibility

The payback period was adopted for the economic analysis. In the analysis, the assumptions were made as the following;

(1) A cost of one kilogram of biofuel briquette is 7 baht.
(2) An average inflation rate between year 2004 and 2008 is 3.9 %.
(3) An interest rate is at 6.75%.
(4) A capability of biofuel briquette production is 500 kilograms per day.
(5) A production process operates for 250 days a year.
(6) A project lasts for 5 years.

Capital costs of a biofuel briquette from durian peel and rice straw can be divided into two parts. The first part is an initial cost or a fixed cost which includes an extrusion machine, grinder, mixer and operating building. Total cost for this part is 153,500 Baht. Another part is a variable cost that the detail are as followings;

• Cost of electricity 1600 Baht/month	19,200 Baht
• Maintenance cost (10 percent of the investment)	15,350 Baht
• Cost of rice straw 200 Baht/ton (96 tons a year)	19,200 Baht
• Cost of durian peel 50 Baht/ton (375 tons a year)	18,750 Baht
• Cost of cassava powder 7 Baht/kg (11250 kg a year)	78,750 Baht
• Labor cost 148 Baht/day (5 employees)	185,000 Baht
• Cost of tap water	7,100 Baht
• Others equipment cost	36,900 Baht
Total variable costs	380,250 Baht

The amount of 875,000 baht is received from selling the biofuel briquette 125,000 kg at the rate of 7 baht/kg. The materials for making the briquette are durian peel char, rice straw char, cassava powder and water at the ratio of 9:1:1:0.56. In other words, the ingredient weight per a kilogram of product is 0.78, 0.09, 0.09 and 0.05 kg respectively.

The equations employed in this analysis are shown below (Stoecker, 1989).

$$\text{Present amount} = \text{Future amount x PWF} \quad (1)$$

$$\text{PWF} = \frac{1}{(1+i)^n} \quad (2)$$

$$\text{PW} = \text{Cl} + \sum_{i=1}^{n}\left[\frac{\text{Fn}}{(1+i)^n}\right] \quad (3)$$

$$\text{CRF} = \frac{i(1+i)^n}{(1+i)^n - 1} \quad (4)$$

$$\text{LAC} = \text{PW x CRF} \quad (5)$$

where

Fn = Future amount at year nth
CI = Initial capital cost
PW = Present Worth
i = Nominal annual interest rate
n = Number of years
LAC = Level Annual Cost
CRF = Capital Recovery Factor
PWF = Present Worth Factor

The annual investment is 405,586.35 Baht which can be calculated by equation (5). Therefore, the cost of investment per one kilogram of biofuel briquette from durian peel and rice straw is 3.25 Baht. This gives the profit of 468,750 Baht in the first year as can be seen in the Table 3.

Table 3 An income from briquette production

Year	Net profit (Baht)	Present amount (Baht)
1	468,750	439,110.07
2	487,031.25	427,386.76
3	506,025.47	415,976.43
4	525,760.46	404,870.74
5	546,265.12	394,061.54
	total value	2,081,405.54

The payback period can be found by dividing the annual investment with the annual present income. The result shows the return of all cost within 1 year and 3 months.

CONCLUSIONS

The highest heating value of the bio-fuel briquette made of durian peel and rice straw is 24.674 MJ/kg for the mass ratio of the char of the two materials at 9:1. The percentages of ash and moisture content and the compressive strength of the product are 14.6%, 6.5% wet basis and 10.6 kg/cm^2, respectively. According to the Thailand bio-fuel briquette standard, a calorific value higher than 20.92 MJ/kg and a moisture content lesser than 8 % are accepted. Moreover, a payback period with less than two years can be achieved. This shows that durian peel and rice straw are efficient raw materials. High heating value can confirm that the bio-fuel briquette made of durian peel and rice straw is applicable for an alternative energy resource and the commercial market.

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REFERENCES

Chandra, T.H., Mirna, M.M., Sunarso, J., Sudaryanto, Y. and Ismadji, S. (2009). Activated carbon from durian shell: Preparation and characterization, *Journal of the Taiwan Institute of Chemical Engineers*, *40*, 457–462.

Chindaruksa, S., Mornpair, P., Jaijoon, L. and Thawonwong, P. (2005). Green briquette from Rice-Straw and Maize-Cob, *Thaksin Science Journal*, 78-89.

Department of Alternative Energy Development and Efficiency. (2004). *Thailand Energy Situation 2004*.

Husain, Z., Zainac, Z. and Abdullah, Z. (2002). Briquetting of palm fibre and shell from the processing of palm nut to palm oil. *Biomass and Bioenergy*, *22* (6), 505-509.

Poonkasem, T. (1999). *A study of fuel briquette from durian peel substitute for firewood and charcoal in household uses*. Thesis, Mahidol University.

Sathitruangsak, P. (2003). *A Study of Solid Fuel Produced from Biomass by Extrusion Process*. Thesis, King Mongkut's University of Technology Thonburi.

Stoecker, W.F. (1989). *Design of thermal system*, 3rd edition, McGraw Hill International Edition, New York, 53-79.

Teixeira, S.R., Pena, A.F.V. and Miguel, A.G. (2010). Briquetting of charcoal from sugar-cane bagasse fly ash (scbfa) as an alternative fuel. *Waste Management*, *30*, 804–807.

Winterbone, D.E. (1997). *Advanced Thermodynamics for Engineers*, Arnold, John Wiley & Sons, London.

Zeng, X., Ma, Y. and Ma, L. (2007). Utilization of straw in biomass energy in China. *1Renewable and sustainable energy reviews*, *11*, 976-987.

Z0hou, S. and Zhang, X. (2007). Prospect of briquetting biomass fuel by forest residues in Tibet. *Korean Journal of Chemical Engineering*, *24*(1), 170-174.