Thermal Properties of Green Fuel Briquettes from Residue Corncobs Materials Mixed Macadamia Shell Charcoal Powder

Suminya Teeta [1], Mali Nachaisin[1], Suchana Wanish[2]

[1] Program of Physics, Faculty of Science and Technology, Rajabhat Maha Sarakham University, MahaSarakham, Thailand, 44000
[2] Program of Chemistry, Faculty of Science and Technology, Rajabhat Maha Sarakham University, MahaSarakham, Thailand, 44000

E-mail: Suminya99@gmail.com

Abstract. The objective of this research was to produce green fuel briquettes from corncobs by adding macadamia shell charcoal powder. The study was sectioned into 3 parts: 1) Quality improvement of green fuel briquettes by adding macadamia; 2) Fuel property analysis based on ASTM standards and thermal fuel efficiency; and 3) Economics appropriateness in producing green fuel briquettes. This research produced green fuel briquettes using the ratio of corncobs weight and macadamia shell charcoal powder in 100:0 90:10 80:20 70:30 60:40 and 50:50 and pressing in the cold briquette machine. Fuel property analysis showed that green fuel briquettes at the ratio 50:50 produced maximum heating values at 21.06 Megajoule per kilogram and briquette density of 725.18 kilograms per cubic meter, but the percent of moisture content, volatile matter, ash, and fixed carbon were 10.09, 83.02, 2.17 and 4.72 respectively.The thermal efficiency of green fuel briquettes averaged 20.22%. Economics appropriateness was most effective where the ratio of corncobs weight to macadamia shell charcoal powder was at 50:50 which accounted for the cost per kilogram at 5.75 Baht. The net present value was at 1,791.25 Baht. Internal rate of return was at 8.62 and durations for a payback period of investment was at 1.9 years which was suitable for investment.

1. Introduction

Rural Thailand has been at the forefront of a crisis in the availability of affordable energy and has continued to resort to using charcoal and wood to provide fuel. These fuels contribute to the continued deforestation of Thailand. To reduce such deforestation requires the identification of a low cost energy source actually capable of replacing charcoal and wood as fuels. One such energy source that can be identified as a possible replacement for these fuels maybe the to use energy obtained from biomass resources,especially waste agricultural residues.The usual barrier to such alternatives is the higher cost of these fuels, and the inability to generate such fuel in quantities that enable mass consumption and which are easy to use as a genuinely alternative fuel source. The green briquettes fuel examined in this paper can provide a viable and more renewable source of energy replacement than the current use of charcoal or wood. This research considered and examined different types of green fuel bars produced from corn stalks using a hydraulic press without heat. It generated heating values of 4,247.25 cal/g [1] and 4,216 cal/g [2] where different values were depend on the process of production. By comparison, the heating value of wood was 5,026 cal/g [3]. Initially, this research shows that fuel productions from the residue of waste argricultural materials alone produces a less efficient fuel than the burning of wood or charcoal.Therefore, this research has examined methods of improving the thermal efficiency of green fuel bars by combining the bars with compressed macadamia charcoal. Previous research has shown that macadamia shell charcoal has benefits over conventional wood burning stoves in so far as it is able to capture free electrons to free radicals such as super oxides that exists in nature and can radiate increased infrared, which is 6-14 micron wavelength radiation with a high penetrating power. As a result, it can be used to cook foods faster, which in turn generates energy savings of almost 20 percent[4-5]. Therefore, this research has attempted to study whether it is possible to combine green fuel briquettes from waste agricultural materials (corn stalks) with charcoal to improve fuel quality by combining these waste agricultural materials with macadamia shell charcoal. The green briquettes also used tapioca starch as a binding agent at consistent concentrations of 10% by weight. The study then analyzed the thermal properties of green briquettes fuel according to ASTM standards. It has also assessed the economic feasibility and sustainability of this fuel.

2. Materials and Methods

2.1. Preparation of the materials and production of green fuel briquettes.

The binder was mixed with water at a ratio of 5:100 by weight. The residue corncob material was sun dried to reduce its average moisture content of 15% wb, and this was then ground using a hammer mill as shown in figure 1.

Figure 1. The waste corncob material after being ground.

The macadamia shells were carbonized at temperatures of approximately 850 ºC and can be seen in figure 2 and converted into charcoal powder in figure3.

Figure 2. The macadamia shell charcoal before convert into charcoal powder.

Figure 3. The macadamia shell charcoal converted into charcoal powder.

The corncobs residue material and macadamia shell charcoal powder were then combined. The two materials were combined at mixing ratios of 100:0, 90:10, 80:20, 70:30, 60:40 and 50:50 (corncob residue : macadamia shell charcoal) using the tapioca starch at a concentration of 10 % by weight. In each sample, ratios were pressed using a hydraulic press without heat as shown in figure 4. The diameter of the mold was 4 cm, the samples were then sun dried to reduce moisture content to about 15% wb. as shown in figure 5.

Figure 4. The hydraulic press**.**

Figure 5. The green fuel briquette samples were then dried in the sun.

2.2. Thermal property analysis and thermal efficiency.

2.2.1. The moisture content. The samples were determined using a moisture content analysis with the ASTM D 3173-73. All samples were weighing 2 g in a laboratory oven at a temperature of 103 ºC. Each sample was dried until the difference in mass between two successive weighings separated by an interval of two hours was 0.01 g or less. The moisture content of sample calculated following equation 1, where A is air-dry weight and B is oven-dry weight.

$$Moisture\ \ content\,(\%) = \frac{A-B}{A} \times 100 \tag{1}$$

2.2.2. The ash content. The samples were determined by following ASTM D 3174-732. The samples were all calculated following equation 2, where C is oven-dry weight after heating to 750 ºC.

$$Ash\ \ content\,(\%) = \frac{C}{A} \times 100 \tag{2}$$

2.2.3. The volatile matter. The samples were determined by following ASTM D 3175-77.The sample calculated following equation 3, where C is oven-dry weight after heating to 900 ºC.

$$Volatile\ \ matters\,(\%) = \frac{B-C}{B} \times 100 \tag{3}$$

2.2.4. Fixed carbon. The samples were also measured according to standardization measures on ASTM D 3172-73. The samples were each calculated following equation 4.

$$FC\,(\%) = 100 - (\%Moisture + \%Volatile\,matter + \%\,Ash) \tag{4}$$

2.2.5. The heating value. The samples were determined using an Oxygen Bomb Calorimeter with according to standardization on ASTM 3D 3286-77.

2.2.6. The density.The briquettes from each was determined and this was calculated from the ratio of the mass to the volume of briquette green fuel.

2.2.7. Thermal fuel efficiency of the energy. Calculated following equation 5, where η is the thermal fuel efficiency of the energy, m is the mass of water in the pot (kg), c is the specific heat of water (kJ/kg-K), t_1 is the initial temperature of water (K), t_2 is the boiling temperature of the water (K), t_3 is the final temperature of water (K), n is the number boiling of the water (times), q is the heating value of green fuel briquettes (kJ/kg-K), w is the mass of fuel burnt (kg) [6].

$$\eta = \sum_{i=1}^{n} \frac{mc(t_2 - t_1) + (t_3 - t_1)}{Wq} = 0 \tag{5}$$

2.3. Economic analysis. [7-8]

2.3.1. Net present value (NPV). The present value of the cash flows at the required rate of return of your project compared to your initial investment calculated following equation 6, where n is the number of periods, t is the analytic year, B is initial investment, C is cash flow and i is discount rate.

$$NPV = \sum_{t=0}^{n} \frac{(B_t - C_t)}{(1+i)^t} \tag{6}$$

*2.3.2. Internal rate of return (IRR).*The interest rate that makes the net present value as zero. The IRR is therefore expressed by equation 7.

$$\sum_{t=o}^{n} \frac{B_t - C_t}{(1+i)^t} = 0 \tag{7}$$

2.3.3. Payback period. The length of time required to recover the cost of an investment. It can be calculated as the investment required for a project, dividing by the net annual cash inflow.

3. Results and discussion

3.1. Fuel property analysis was measured based again on the ASTM standards for thermal efficiency. The results showed the thermal properties of green fuel briquettes manufactured from corncobs residue materials were improved by adding macadamia shell charcoal. Thermal properties (moisture content, ash content, volatile content, fixed carbon, heating value, and bulk density) of the samples were improved. The results are shown in table 1.

Table 1. Physical and fuel characteristics of green briquettes fuel of different composition

Properties of green briquettes fuel	Corncops residue: Macadamia shell charcoal (W/W)						Thai community Production Standard (238/2547)
	100:0	90:10	80:20	70:30	60:40	50:50	
Moisture content (%)	13.97	13.85	12.02	11.52	11.29	10.09	≤ 8
Ash content (%)	3.76	3.62	3.31	2.47	2.37	2.17	-
Volatile matter (%)	78.79	79.03	81.02	82.02	82.02	83.02	-
Fixed carbon (%)	3.48	3.5	3.65	3.99	4.32	4.72	-
Heating value (MJ /kg)	17	17.41	18.89	19.98	20.11	21.06	≥ 20.93
Bulk density (kg /m^3)	344.7	346.1	543.05	545.04	576.77	583.87	-

The moisture content of the green fuel briquettes was found in the range of 13.97-10.09 % wb. The lowest moisture content as 10.09 % wb. at the ratio 50:50. The lower amount of moisture may be due to the removal of moisture from corncob residue due to compression during the briquetting process.

The ash content decrease as the ratio of macadamia shell charcoal increased to a minimum of 2.17 % at 50:50 wt.% caused by decreasing the residue of corncobs. This is because the waste corncobs contained more fiber than the macadamia charcoal. The volatile matter of the green fuel briquettes was found in the range of 78.02 - 83.02%. The volatile matter increased in line with the decreasing moisture content of the samples. The main effect of the volatile matter measure was the change noted in the ignition times which were shortened. Conversely, the fixed carbon remained consistently at levels of 4.72%. In the same way the highest heating values were recorded as 21.06 MJ/kg and met the requirement of the Thai community Production Standard (238/2547) (http://tcps.tisi.go.th).The maximum bulk density was found 583.87 kg/m^3 in residue corncobs : macadamia charcoal at 50:50 ratios. The bulk density of green briquette fuels increased as the mass of macadamia charcoal increased. The density is an important parameter, which characterizes the effectiveness of the briquetting process. If the density is higher, the energy/volume ratio is higher too.The thermal efficiency was tested by mass of fuel about 0.5 kg, water as 1 kg the result showed the efficiency average as 20.22 % by the time it started boiling at 12.5 mins, at the ratio 50:50 it produced maximum heating values.The value of thermal efficiency is more than of Kittikorn and et.al [9] as 16.31 %. In addition, increased heating value increasing the thermal efficiency of green briquettes.

3.2. Economic appropriateness of producing green fuel briquettes.

The result of cost-benefit analysis found that the production of green briquettes fuel at ratios of 50:50 is shown in table 2.

Table 2. Economic analysis of green briquettes fuel at ratio 50:50 wt.%

Year	0	1	2	3	4	5
Benefit						
Green briquettes fuel						
= 5.75 Baht/kg						
Rate production = 300 kg/day						
Total (Baht)	-	89,700	89,700	89,700	89,700	89,700
Variable cost						
Human labor = 2.00 Baht/kg						
Electrical power = 0.16 Baht/kg						
Water = 0.0011 Baht/kg						
Tapioca starch = 0.28 Baht/kg						
Macadamia Shell = 0.20 Baht/kg						
Corncobs = 1.25 Baht/kg						
Maintenance = 1,000 Baht/kg						
Total 3.95 Baht/kg (Baht)	-	61,701	61,701	61,701	61,701	61,701
Fixed costs						
Machine hammer mill	-35,000					
= 35,000 Baht	-75,000					
Machine hydraulic press						
= 75,000 Baht						
Clash flows (Baht)	-110,000	25,925	24,004	22,226	20,579	19,056
Net cash flows (Baht)						1,791.25
Internal rate of return; IRR (%)						8.62
Payback period (Years)						1.9
Cost per kilogram (Baht)						5.75

The project has assumed that the project duration is 5 years, and the discount rate has been assumed to be 8% (www.bot.or.th/thai). The daily production times have been calculated at 8 hours per day. These results are contained in the feasibility study shown in table 2. The result shows that the production of green briquettes fuel are improved by adding macadamia shell charcoal and that it is suitable for investment due to the present value calculations being positive at 1,791.25 Baht, the internal rate of return as 8.62 which more than satisfies the Minimum Loan Rate (www.bot.or.th/thai) the payback period was reached at 1.9 years, and the overall production cost of green fuel is 5.75 Baht/kg.

4. Conclusions

This research assessment concluded that the appropriate ratios were 50:50 for green fuel briquettes comprising agricultural waste and macadamia shell charcoal. Additionally tapioca starch used as a binding agent at 10% produced consistent results. All properties passed the requirement of the Thai community Production Standard (238/2547). The thermal efficiency of green fuel briquettes was an appropriate and economics analysis was suitable for investment. Therefore, this study has concluded that the addition of macadamia charcoal to green fuel briquettes can provide sufficient efficiency improvements to the standard green fuel that is an effective alternative energy to replace wood.

Acknowledgments

The authors would like to gratefully acknowledge the Office of National Research Council of Thailand (NRCT, Thailand) for financial support. (Contact No.2558A14702050)

References

[1] Chindaruksa S, Mornpair P, JaiJoon L and Thawornwong P 2005 *Thaksin Science Journal*. **2** pp 78-90

[2] Jekayinfa S O and Scholz V 2009. *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects*. **31** pp 687-97

[3] Damrongthai P 1999 *Thai Journal of Forestry*. **57** pp 53-60

[4] Penoni E S, Pio R, Rodrigues F A, Maro L A C and Costa F C 2011 *Rural Science*. **41** pp 80-83

[5] Xavier T P, Lira T S, Schettino Jr M A and Barrozo M. A S 2016 *Brazilian Journal of Chemical Engineering*. **33** pp 15-22

[6] Tayade S, Pohare J and Mahalle DM 2010 *International Journal of Agricultural Engineering*. **3** pp 23-27

[7] Jianjun H, Tingzhou L, Zhiwei W, Xiaoyu Y, Xinguang S, Zaifeng L, Xiaofeng H and Quanguo Z 2014 *Energy*. **64** pp 57-66

[8] Mariusz J, Stefan S, Józef T, Michal K, Pawel G and Miroslaw M 2013 *Renewable Energy*. **57** pp 20-26.

[9] Kittikorn S, Warapong S, Nattapong W and Natthawud D 2015 *Thaksin Science Journal*. **18** pp 5-14