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Production of briquette fuel using wastewater sludge and banana peel waste

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Abstract

The objective of this study was to examine the production of briquette fuel using wastewater sludge and banana peel waste. Briquette fuel produced from wastewater sludge mixed with banana peel waste at various ratios by weight was studied. Performance indicators include moisture content, ash content, volatile matter content, fixed carbon content, total sulfur content, and heating value. The assessment also determined the most appropriate ratio of waste water sludge to banana peel in briquette fuel, as well as the economic value of the fuel. The ratios of wastewater sludge to banana peel selected for the test were 90:10, 80:20, and 70:30. It was found that all ratios for the briquette fuel have significantly different compressive strength, ash content, and amounts of volatile matter. The density at the ratio of 70:30 was significantly higher than those at 90:10 and 80:20. Fixed carbon content at the ratio of 90:10 was significantly lower than those at 80:20 and 70:30. The heating value at the ratio of 70:30 was significantly higher than that at 90:10. No significant differences were observed in terms of moisture content or total sulfur in the briquette fuel. The heating value of the briquette fuel was still lower than the standard value. Economic value analysis revealed that a price of 1 baht/briquette (29 baht/kg) had a break-even point of 223,024 briquettes, and a payback period of 4.58 years. It is, thus, suggested that the appropriate ratio used in briquette fuel production should be 70:30 based on optimal heating value, fixed carbon content, volatile matter content, and moisture content.

Keywords: briquette fuel, wastewater sludge, banana peel waste, utilization of waste

1. Introduction

Wastewater treatment plants in Bangkok currently produce a large amount of wastewater sludge. Din Daeng wastewater treatment plant is a biological activated sludge system with a treatment capacity of 350,000 cubic meters/day. In 2012, this plant generated 2,718 cubic meters of sludge by volume [1], an amount that has increased annually. This waste requires proper disposal in order to reduce environmental pollution. The Bangkok Metropolitan Administration currently mixes the sludge that is produced with excreta or other organic waste to produce compost or to use in land reclamation. Nevertheless, due to the large amount of sludge generated by this plant and others in Bangkok, the development of an alternative disposal method is still necessary.

In addition, large amounts of crops are produced each year in Thailand. This has, in turn, led to the production of large amounts of residual waste that require suitable disposal that is not harmful to the environment. There is a particularly large amount of banana peel waste, which is generated from banana production in the country. This corresponds to the growth in banana production that has occurred in response to growing demands on both the household and industrial levels. It was estimated that a total of 1,115,101 tons of bananas were produced from 2008 to 2009 [2], resulting in an enormous amount of banana peel waste. However, this waste has a heating value of 18.89 MJ/kg [3] and the peels can be used as an alternative energy source through the production of briquette fuel.

Therefore, this research aims to demonstrate the potential of using sludge from wastewater treatment plants mixed with the banana peel waste to produce briquette fuel. The production of this briquette fuel could be an alternative strategy to managing residual waste and reduce the cost of fuel in the future.


a. Dried wastewater sludge


b. Dried banana peel waste


c. Briquette-derived fuel

Figure 1 Raw materials used in the test and the finished briquette-derived fuel**.**

2. Materials and Methods

2.1. Preparation of tested materials

2.1.1. Wastewater Sludge from Din Daeng Wastewater Treatment Plant

Wastewater sludge in the test was obtained from Din Daeng wastewater treatment plant using the activated sludge process. After being dewatered by a pressing machine, the cakes of sludge were collected and allowed to air-dry in the sunlight to reduce moisture. They were then kept in containers for subsequent testing.

2.1.2. Banana Peel Waste

Banana peels obtained from cultivated banana species that appeared to be half ripe were used in the test. The peels were randomly collected from the street vendors who sell roasted bananas. The banana peels were finely chopped to make them suitable mixing using a crushing machine. Reduction of moisture content in the peel waste was achieved by exposing the waste to the sunlight and then keeping it in a container until it could be used.

2.2. Experiment and analytical method

2.2.1. Mixture of Briquette Fuel

The dried wastewater sludge (Figure 1.a) from Din Daeng wastewater treatment plants was thoroughly mixed with the dried banana peel waste (Figure 1.b) by hand in a plastic tub. Eleven ratios of the mixture (wt.) were prepared (100:0, 90:10, 80:20,70:30, 60:40, 50:50, 40:60, 30:70, 20:80. 10:90, and 0:100) and preliminarily screened. Three of these ratios were selected to be used in the next test.

2.2.2. Preparation of Briquette Fuel and Test

After the preliminary screening, hollow cylinders of briquette fuel (outer diameter of 2.4 cm, inner diameter of 0.6 cm and length of 8.30 cm) were prepared from the mixture of sludge and banana peel waste (Figure 1.c). Three ratios of the mixture were obtained by using a briquette-pressing machine. Each ratio of the mixture was replicated three times. These briquette fuel samples were allowed to dry in the sun in an open area for seven days prior to the test.

Tests of physical properties were performed to measure compressive strength (ASTM Standard D2166-85) shatter index (ASTM Standard D3038), and density (ASAE Standard S 269.4). In addition, tests were carried out to evaluate moisture content (ASTM Standard D3173-03), ash content (ASTM Standard D3174-04), volatile matter content (ASTM Standard D3175-02), fixed carbon content (ASTM Standard D3172-07), total sulfur content (ASTM Standard D3177), and heating value (ASTM Standard D5865). These tests were performed to determine the most appropriate sludge-banana peel ratio for briquette fuel.

2.2.3. Analysis of Economic Value as Break-even Point and Payback Period of the Project

The appropriate sludge-to-peel ratio of the briquette fuel was used to calculate the fixed and variable productivity costs for the five-year production project. The assumptions made in determining the total cost in are as follows:
- The project period would be five years.
- The operation system would be operating eight hours/day (300 days/year).

-The productivity rate would be 120 kg/day.
- Two briquette-pressing machines would be used.
- Two crusher machines would be used.
- It would require two labor forces at a cost of 300 baht/person/day.
- The maintenance cost would be 10 percent of the cost of the machines.
- There would be no raw-materials cost.

Determination of the break-even point and payback period was performed. The calculation used to determine the break-even point was:

$$N = \frac{F}{C-V} \quad (1)$$

Where:
$N = Product\ quantity, briquette$
$F = Fixed\ cost, baht$
$C = Product\ price, baht/briquette$
$V = Variable\ cost, baht/briquette$

The payback period calculation was:

$$Paybackperiod = \frac{Investment\ cost}{Average\ net\ of\ return} \quad (2)$$

Where:

$$InvestmentCost(baht) = TotalCost(baht) \quad (3)$$

$$Average\ net\ of\ return\ \left(\frac{baht}{year}\right) = \frac{Profit\ (baht/briquette)\ x\ Productivity}{yield\ (briquettes/year)} \quad (4)$$

2.2.4. Analysis of Data

The data analysis was conducted using one-way Analysis of Variance (ANOVA). The mean comparison of parameters was conducted using least significant difference (LSD) with a significance level of 0.05.

3. Results and Discussion

3.1. Preliminary screening of various ratios of wastewater sludge and banana peel.

Preliminary results (Table 1) showed that ratios of 90:10, 80:20, 70:30, 60:40, 50:50, and 40:60 were easy to obtain through compaction and appeared to result in a relatively rough surface. However, ratios of 30:70, 20:80, and 10:90 were difficult to compact, and the morphology of briquette appeared rough on the surface. In addition, although the sludge (100:0) at these ratios was easy to compact, the banana peel (0:100) was not compactable. This is probably due to the water contained in the sludge acting as the binder for the both sludge and banana peel in the briquette fuel. Therefore, mixing ratios of 90:10, 80:20, and 70:30 by weight were selected to produce the briquette fuel for the next test, due to the mixture being easy to compact at this ratio, and the relatively rough surface that resulted.

3.2. Physical properties of briquette derived fuel

As illustrated in Table 2, the densities of the briquette fuel at ratios of 90:10, 80:20, and 70:30 were 0.96$\pm$ 0.09 g/cm^3, 1.10$\pm$0.10 g/cm^3, and 1.29$\pm$0.05 g/cm^3**,** respectively, and the compressive strength was 16.73$\pm$2.08 kg/cm^2, 27.11$\pm$2.58 kg/cm^2, and 38.50$\pm$4.19 kg/cm^2**,** respectively. In addition, the average shatter indexes at each ratio were 0.60$\pm$1.01, 0.77$\pm$1.02, and 0.96$\pm$0.98**,** respectively.

The density of the briquette fuel in the 70:30 mixture was significantly higher than those at 90:10 and 80:20 ($p<0.05$), while the difference in density between the 90:10 and 80:20 mixtures was not significant ($p>0.05$). In addition, the compressive strength and shatter index at the ratio of 70:30 were significantly higher than those at 90:10 and 80:20 ($p<0.05$).

The highest density, compressive strength, and shatter index were found at the ratio of 70:30 (Table 2). These improvements were clearly due to the high proportion of banana peel in the briquette. This is because banana peels have many fibers that capture particles of wastewater sludge, resulting in improved physical properties of the briquette.

High-density briquette fuel is desirable in terms of transportation, storage, and handling. High-density briquette fuel will generate greater heating value and burn longer than an equal volume of lower density fuel. Low-density briquette fuel, on the other hand, burns too quickly to be suitable for use [4], [5], & [6]. In addition, compressive strength is an important criterion in determining the durability of briquette fuel. Compressive strength is directly associated with density. If the briquette fuel has high the compressive strength, it should be able to withstand a greater amount of weight [4], [7] & [8]. It is recommended that briquette fuel should have a shatter index between 0.5-1.0 [8] & [9]. The shatter index depends on the density and compressive strength. When the briquette fuel has high density and high compressive strength, it usually has a high shatter index [10].

These results are consistent with those of a test conducted by Trancharoen in 2007 [11], in which it was found that density and compressive strength increased when the proportion of wastewater sludge was decreased and charcoal residue increased. Therefore, the mix becomes thicker when it undergoes densification using a briquette machine. In addition, these results also agreed those of a study conducted by Chaiyadejtayakul in 2001 [12]. That study found that the compressive strength and the shatter index increased when wastewater sludge was decreased and fine wood chip increased. Moreover, these results also aligned with those of a 2003 investigation by Dechphon [13], which found that the shatter index increased when the amount of bagasse in the fuel was increased. This is because bagasse contains many fibers for capturing particles of wastewater sludge, resulting in the briquette fuel having a higher shatter index.

Table 1 Compaction ability and morphology of briquette fuel made from wastewater sludge mixed with banana peel at various ratios.

Ratio of Sludge : Banana peel (wt.)	Compaction ability			Morphology of briquette fuel		
	Easy compaction	Difficult compaction	No compaction	Smooth surface	Relatively rough surface	Rough surface
100 : 0	✓	×	×	✓	×	×
90 : 10	✓	×	×	×	✓	×
80 : 20	✓	×	×	×	✓	×
70 : 30	✓	×	×	×	✓	×
60 : 40	✓	×	×	×	×	✓
50 : 50	✓	×	×	×	×	✓
40 : 60	✓	×	×	×	×	✓
30 : 70	×	✓	×	×	×	✓
20 : 80	×	✓	×	×	×	✓
10 : 90	×	✓	×	×	×	✓
0 : 100	×	×	✓	×	×	×

Note: ✓= yes
× = No

Table 2 Physical properties of briquette fuel made from wastewater sludge mixed with banana peel at various ratios.

Physical properties	Ratios Sludge : Banana peel	n	$\bar{x}$	SD	F	p-value
Density (g/cm^3)	90 : 10	3	0.96^a	0.09	12.773	0.007
	80 : 20	3	1.10^a	0.10		
	70 : 30	3	1.29^b	0.05		
Compressive strength (kg/cm^2)	90 : 10	3	16.73^a	2.08	37.405	<0.001
	80 : 20	3	27.11^b	2.58		
	70 : 30	3	38.50^c	4.19		
Shatter Index	90 : 10	3	0.60^a	1.01	9.201	<0.001
	80 : 20	3	0.77^b	1.02		
	70 : 30	3	0.96^c	0.98		

Note: Different letters (superscript) indicate significant differences.

3.3. Fuel properties of briquette derived fuel

3.3.1. Moisture content

The moisture content of briquette fuel made from wastewater sludge mixed with dried banana peel at ratios of 90:10, 80:20, and 70:30 were 3.05± 0.41%, 2.16± 0.12%, and 2.07± 0.15%, respectively. The moisture content of the briquette fuel increased in accordance with the proportion of the wastewater sludge in the briquette. The highest moisture content was observed in the 90:10-ratio fuel (Table 3). Moisture content, which is the remaining water after the waste is dried, directly affects the amount of heat that is produced by the fuel. If the waste has a high moisture content, it may produce less heat, due to the evaporation of moisture during burning [14]. The moisture content of the briquette fuel did not exceed the "community product standards" issued by the Thai Industrial Standard Institute (< 8 %) at any ratio [15]. These results are consistent with those of a 2007 test conducted by Trancharoen [11], in which it was that a decrease in moisture content was observed when the ratio of wastewater sludge was decreased and charcoal residue increased.

3.3.2. Ash content

The ash content of briquette fuel made from wastewater sludge mixed with banana peel at ratios of 90:10, 80:20, and 70:30 were 36.49± 0.82%, 33.57± 0.90%, and 30.56± 0.46%, respectively (Table 3). The highest ash content was observed at the ratio of 90:10. The ash content of briquette fuel depended on the amount of wastewater sludge, due to ash being present in the sludge. Ash is the part of the waste that cannot be burned. Waste that contains a high amount of ash may not burn properly. In addition, it is more difficult to dispose of the ash that remains [14]. This result supports that of an investigation conducted by Chaiyadejtayakul in 2001 [12], which found that ash content decreased when the amount of wastewater sludge was decreased and fine wood chip increased. In addition, wastewater sludge contains phosphate and potassium, which are the compounds in ash.

3.3.3. Volatile matter

The volatile matter of briquette fuel made from wastewater sludge mixed with banana peel at ratios of 90:10, 80:20, and 70:30 were 14.86± 0.79%, 17.00± 0.17%, and 19.15± 0.75%, respectively (Table 3). The highest volatile matter content was found at the ratio of 70:30. This indicated that the amount of volatile matter in briquette fuel depended on the amount of volatile matter in the banana peel. Volatile matter is composed of carbon, hydrogen, and oxygen in the biomass, which can volatilize after being exposed to heat. Waste with a high volatile matter content tends to have a high heating value [14]. These results are consistent with the finding of a 2001 study by Chaiyadejtayakul [12], who observed that volatile matter content tended to increase when the amount of fine wood chip was increased, due to elements of wood disintegrating into these gases.

3.3.4. Fixed carbon

The fixed-carbon content of briquette fuel made from wastewater sludge mixed with banana peel at ratios of 90:10, 80:20, and 70:30 were 45.60± 0.87%, 47.27± 0.94%, and 48.22± 0.41%, respectively (Table 3). The highest fixe-carbon content was found at the ratios of 80:20 and 70:30. The fixed-carbon content depended on the amount banana peel the briquette fuel contained. Fixed-carbon content is directly associated with heating value, as the carbon compounds are difficult to volatilize. When oxidation occurs, it will decompose and release heat. Fuels with high fixed-carbon content have high heating values [8], [14] & [16]. These results correspond with those of a 2003 study by Dechphon [13], in which it was found that the fixed carbon increased when ratio of bagasse in the mixture was increased.

3.3.5. Total sulfur

The total sulfur content of briquette fuel made from wastewater sludge mixed with banana peel at ratios of 90:10, 80:20, and 70:30 were 0.40± 0.07%, 0.47± 0.11% and 0.49± 0.07%, respectively (Table 3). No significant difference among these mixture ratios in terms of total sulfur content was observed ($p>0.05$). When burning the briquette fuel, sulfur in the fuel reacts with oxygen to form sulfur dioxide. Therefore, if the waste contains a large amount of sulfur, it will not be suitable for use as a fuel due to the large amount of sulfur dioxide produced during the burning process [14] & [17]. A 2003 study by Benjamatarakul [7] found that the total sulfur content of briquettes made from wastewater sludge and paddy husk varied based on the amount of wastewater sludge that was used. This is due to wastewater sludge a having higher total sulfur content than the paddy husk. Therefore, if paddy husk is mixed with wastewater sludge, the sulfur content of the briquette fuel should decrease.

3.3.6. Heating value

The heating value of briquette fuel is presented in Table 3. The heating value of briquette fuel made from wastewater sludge mixed with banana peel at ratios of 90:10, 80:20, and 70:30 were 2,694.6$\pm$ 54.51 kcal/kg, 2,785.8$\pm$ 37.75 kcal/kg, and 2,830.2 $\pm$ 58.36 kcal/kg, respectively. This clearly shows that the heating value of briquette fuel increased when the amount of banana peel was increased. The highest heating value was demonstrated at the ratio of 70:30. The heating value of briquette fuel depended on the amount of banana peel the fuel contained. The heating value set by the Thai Industrial Standard Institute as part of its "community product standards" is > 5,000 cal/g [15]. In this test, the heating value of briquette fuels at various ratios was lower than the standard. However, the heating value in this test was still higher than that found in an investigation by Wzorek conducted in 2002[18] on the briquette fuel made from sewage sludge and coal slurry (1,900 kcal/kg). Heating value, which is the amount of heat that occurs when waste is completely burned, is a major quality index for fuels. This value can vary depending on the amount of water or moisture in the waste [4] & [14]. These results align with those of a study conducted by Trancharoen in 2007 [11], which revealed that the heating value of fuel increased when the proportion of wastewater sludge was decreased and charcoal residue increased.

3.4. Appropriate mixing ratio for the Briquette Fuel

When the properties of the briquette fuel were with those laid out in the Thai Industrial Standard Institute "community product standards," it was found that fuel mixed at ratios of 90:10, 80:20, and 70:30 had suitable moisture content, but that the heating value was lower than the standard. However, the briquette fuel mixed at a 70:30 ratio was most appropriate in terms of having the lowest moisture and ash content, highest volatile matter content, highest fixed-carbon content, and highest heating value, with no significant difference in in terms of total sulfur. Due to the heating value of briquette fuel being lower than the standard, this briquette fuel would probably only be appropriate for small and medium industries or as fuel in boilers for industries that do not require fuel with high heating value [6] & [19].

Table 3 Fuel properties of briquette fuel made from wastewater sludge mixed with banana peel at various ratios.

Fuel properties	Ratios Sludge : Banana peel	n	$\bar{x}$	SD	F	p-value
Moisture content (%)	90 : 10	3	3.05^{a}	0.41		
	80 : 20	3	2.16^{a}	0.12	-	0.066
	70 : 30	3	2.07^{a}	0.15		
Ash content (%)	90 : 10	3	36.49^{a}	0.82		
	80 : 20	3	33.57^{b}	0.90	47.205	<0.001
	70 : 30	3	30.56^{c}	0.46		
Volatile matter content (%)	90 : 10	3	14.86^{a}	0.79		
	80 : 20	3	17.00^{b}	0.17	34.565	0.001
	70 : 30	3	19.15^{c}	0.75		
Fixed-carbon content (%)	90 : 10	3	45.60^{a}	0.87		
	80 : 20	3	47.27^{b}	0.94	8.801	0.016
	70 : 30	3	48.22^{b}	0.41		
Total sulfur content (%)	90 : 10	3	0.40^{a}	0.07		
	80 : 20	3	0.47^{a}	0.11	-	0.381
	70 : 30	3	0.49^{a}	0.07		
Heating value (Kcal/Kg)	90 : 10	3	$2{,}694.6^{a}$	54.51		
	80 : 20	3	$2{,}785.8^{ab}$	35.75	5.623	0.042
	70 : 30	3	$2{,}830.2^{b}$	58.36		

Note: Different letters (superscript) indicate significant differences.

3.5. Economic value analysis in terms of the break-even point and payback period of the project

A sludge-banana peel ratio of 70:30 was determined to be optimum. Total fixed and variable cost analysis was carried out to determine the economic value of the briquette production project. It was found that a price at 0.95 baht/briquette or 27.55 baht/kg was not appropriate. This is because it was higher than the project period (five years). Therefore, a price of 1 baht/briquette or 29 baht/kg with a break-even point of 223,024 briquettes and payback period of 4.58 years was determined to be appropriate. This price did not include the cost of raw materials or transportation. In addition, , the price of briquette fuel produced by mixing wastewater sludge and banana peel was higher than the market price of normal charcoal (15-20 Baht/kg) [20].

4. Conclusion

This study was conducted to produce a briquette-derived fuel using wastewater sludge and banana peel waste. The conclusions can be summarized as follows:

1) The moisture content and ash content of briquette fuel decreased when the amount of wastewater sludge was decreased and banana peel increased.

2) The volatile matter content, fixed carbon content, and heating value of briquette fuel increased when the amount of wastewater sludge was decreased and banana peel waste increased.

3) The moisture content, ash content, volatile matter content, fixed carbon content, and heating value of the fuel mixed at a ratio of 70:30 performed significantly better than those mixed at ratios of 90:10 and 80:20. No significant difference in the amount of total sulfur of the briquette-derived fuel was observed among the different ratios ($p>0.05$).

4) The briquette-derived fuel at the mixing ratio of 70:30 was found to be appropriate for production due to its exhibiting better fuel properties.

5) Economic value analysis revealed that a price of 1 baht/ briquette (29 baht/kg) had a break-even point of 223,024 briquettes and a payback period of 4.58 years.

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