Use of appropriate ratio of scum mixed with coffee residue as briquette derived fuel

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Abstract

Attempts to use of waste residue generated from production processes to energy have currently been increased. This research was conducted to study the production of briquette fuel from scum mixed with coffee residue in different ratios. Totally, eleven mixed ratios i.e., 100:0, 90:10, 80:20, 70:30, 60:40, 50:50, 40:60, 30:70, 20:80, 10:90 and 0:100 by weight were tested to find the most appropriate ratio in briquette fuel production. Data were analyzed to verify physical and fuel properties as specified by ASTM. Emission of air pollutant concentration from briquette combustion was also determined. The result showed that the ratios of 80:20, 70:30 and 60:40 were more appropriate use for further analysis of physical and fuel properties. Significant differences in compressive strength and shatter index were observed in the test ($P < 0.05$). In addition, significant differences were found in the ash content, volatile matter, fixed carbon, total sulfur and heating value ($P < 0.05$). The emission of air pollutants for the CO, CO_2, SO_2 and NO_2 were lowest at the ratio of 80:20. Regarding the finding, the mixed ratio of 80:20 was appropriate for the application due to the significantly high compressive strength ($0.325\pm0.02 kg/cm^2$), shatter index (0.272 ± 0.02), volatile matter ($89.00\pm3.51\%$), heating value ($6,725.30\pm9.38$ kcal/kg) and low moisture content ($4.00\pm0.20\%$). This appropriate ratio is suggested to be used for the production of briquette fuel.

Keywords: scum, coffee residue, briquette derived fuel

Introduction

In 2000, an estimated amount of scum (fat oil and grease) from grease traps in Bangkok was surveyed by Bureau of Environmental Health, Department of Health, and Bangkok Metropolitan Administration (Bureau of Environmental Health, 2000). It appeared that there was a lot of scums released from grease traps approximately 4 tons/day and this amount would increase up to 13.333 tons/day in 2019. The occurrence of scum in grease trap is hardly removed by microorganisms, so it is always accumulated in the grease traps. If discharged, it will inhibit the functioning of microorganisms in the wastewater treatment system. Therefore, the practice of scum disposal has been, at present, attempted to send to the landfill site, and it was found that this will cause more problems to the disposal site due to the limitation of the remaining capacity of the landfill facility.

Additionally, one of interesting waste materials is a residue coffee generated everywhere in the country which can also cause the environmental harms. The general materials of coffee beans, with amount of 19,590 tons are produced yearly in Thailand and 40-60% of this amount are unwanted waste and residue. This occurrence of coffee residue was about 7,840-11,750 tons/year from the coffee production

(Economic Research and Training Center, 2001). According to work done by Sivetz (1979), there were compounds of 60% with carbohydrate, cellulose and fiber substances which are the flammable materials in coffee residue. In fact, the coffee residue can be a flammable material that is likely to use as the briquette fuel. Therefore, there is a good possibility to develop a coffee residue and replace it as the fuel from the firewood and charcoal. In addition, advantages of coffee residue as the briquette fuel production in terms of heat recovery are to make it valuable and reduce the amount of waste in the environment.

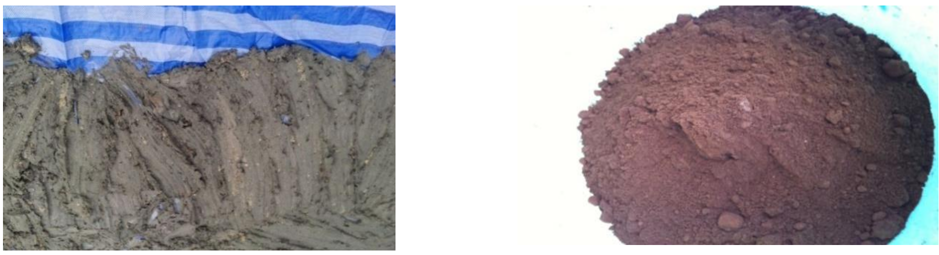
For the above reasons, it is interesting to investigate the utilization of scum generated from Mahidol University canteen's grease trap to mix with the coffee residue from coffee shop for the production of briquette derived fuel. Results could also be a promising alternative energy resource in the future.

Materials and Methods

Preparation of raw materials.

The mixed scum (fat oil and grease)(Figure 1) generated from Faculty of Public Health, Mahidol University canteen's grease trap was randomly collected and other mixed up wastes were separated . The coffee residue (Figure 2) was obtained from coffee shop in Faculty of Public Health, Mahidol University and other mixed up wastes were also separated as well. Both scum and coffee residue were left to air-dry in the open space for 24 hrs to reduce moisture and subsequently kept in the plastic container until use.

(a) Mixed scum was collected from grease trap and dried.



(b) Coffee residue was collected from shop and dried.

Figure 1 Raw materials used for the experiment.

Raw materials Analysis.

Analyses of physical and fuel properties of scum sample and coffee residue were conducted. The physical properties including density, color, odor and texture characteristics were observed. Whereas, the fuel properties including moisture content, ash content, volatile matter, fixed carbon, total sulfur and heating value were also detected. Standard methods of analysis for the American Society for Testing and Materials (ASTM) was applied for the test.

Sample mixing and preparation of briquette derived fuel.

The prepared scum was mixed with coffee residue to produce the briquette derived fuel (scum: coffee residue) by weight for eleven ratios were tested namely 100:0, 90:10, 80:20, 70:30, 60:40, 50:50, 40,60, 30:70, 20:80, 10:90 and 0:100. Five replications were prepared for each tested ratio. The briquette fuel was produced by pressing the mixture of scum and coffee residue with screw press (Manual type) to obtain briquette fuel in cylindrical shape (Figure 2). The obtained briquette fuel with 5 cm. in diameter, 1 cm. in diameter of the center hole and 10 cm high was used in the test. All briquette fuels were then dried for 48 hrs at 105 °C before the test.

Three proper ratios were chosen to produce the briquette derived fuel for subsequent experiment. Each ratio was prepared and replicated five times for the test. Observation of briquette morphology (formable and surface texture) and compressibility were conducted.

Figure 2 The finished briquette derived fuel.

Physical and fuel properties analysis.

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

Analysis of air pollutants.

The emission of air pollutant concentration was analyzed from the briquette fuel combustion in various ratios. Flue gasses, namely CO, CO_2, NO_2, SO_2, were obtained, and analyzed with electrochemical measurement cell type during the experiment. Analysis was done by the method as described the study of Donkrasin (2002).

Analysis of data

Data analysis was conducted using one way Analysis of Variance (ANOVA). The mean comparison of parameters was conducted using Fisher's Least Significant Difference Test (LSD) at the α level of 0.05.

Results

Determination of selected ratios of the briquette derived fuel.

After preparation of the raw materials, scum and coffee residue were mixed by weight to produce the briquette derived fuel by using the screw press (Manual type) at Knowledge Center of Energy, Department of Alternative Energy Development and Efficiency, Ministry of Energy, Pathumthani province. Eleven ratios of briquette derived fuel, namely 100:0, 90:10, 80:20, 70:30, 60:40, 50:50, 40,60, 30:70, 20:80, 10:90 and 0:100 by weight were tested (Table 1). Five replications were conducted for each ratio. Three proper ratios for making briquette derived fuel were selected.

Table 1 Production of briquette derived fuel made from scum mixed with coffee residue in various ratios.

Scum : Coffee residue (by weight)	**Parameters**		
	Compressibility	**Formable**	**Surface (smoothness)**
0 : 100	O	O	O
10 : 90	O	O	O
20 : 80	X	O	O
30 : 70	X	X	O
40 : 60	X	X	X
50 : 50	X	X	X
60 : 40	/	/	/
70 : 30	/	/	/
80 : 20	/	/	/
90 : 10	/	X	X
100 : 0	X	O	X

Remark: / = easy / good briquetting
X = difficult or bad briquetting
O = failed to produce briquette

Physical properties of briquette derived fuel.

After producing the briquette derived fuel made from scum mixed with coffee residue, the physical properties were analyzed. Only three ratiosdue to the assigned parameters were used to analyze for density, compressive strange and shatter index as shown in Table 2

Table 2 Mean (±S.D.) of physical properties of briquette fuel made from scum mixed with coffee residue in various ratios.

Scum : Coffee residue (by weight)	**n**	$\bar{x}$	**SD**	**F**	**P-value**
1. Density (g/cm^2)				2.960	0.128
60 : 40	3	0.473*	±0.02		
70 : 30	3	0.486*	±0.04		
80 : 20	3	0.565*	±0.06		
2. Compressive strength (kg/cm^2)				5.499	0.044
60 : 40	3	0.275[a]	±0.01		
70 : 30	3	0.300[ab]	±0.01		
80 : 20	3	0.325[b]	±0.02		
3. Shatter index				37.88	<0.001
60 : 40	3	0.184[a]	±0.01		
70 : 30	3	0.202[a]	±0.01		
80 : 20	3	0.272[b]	±0.02		

Note: * No multiple comparisons of mean were conducted.

Different letters in superscript show significant difference in pair.

No significant difference of density of the briquette fuel was observed for the ratios of scum mixed with coffee residue ($P>0.05$). The mean of density of briquette fuel ranged from 0.473±0.02 to 0.565±0.06 g/cm^3. For the compressive strength, there were the significant differences in the compressive strength of briquette ranging from 0.275±0.01 to 0.325±0.02 kg/cm^2 ($P<0.05$). The highest compressive strength of briquette was observed for the ratio of 80:20 at 0.325±0.02 kg/cm^2. For shatter index of the briquette, there were the significant differences in shatter index of briquette ranging from 0.184±0.01 to 0.272±0.02. The highest shatter index of briquette was observed for the ratio of 80:20 at 0.272±0.02.

Fuel properties of the briquette derived fuel.

The briquette fuel from scum mixed with coffee residue at ratios of 80:20, 70:30 and 60:40 by weight, was analyzed for moisture content, ash content, volatile matter, fixed carbon, total sulfur and heating value. The results are presented in Table 3

Table 3 Mean (±S.D.) of fuel properties of briquette fuel made from scum mixed with coffee residue in various ratios.

Scum : Coffee residue (by weight)	**n**	$\bar{x}$	**SD**	**F**	**P-value**
1. Moisture content (%)				8.005	0.020
60 : 40	3	7.79[a]	±0.20		
70 : 30	3	6.00[a]	±2.00		
80 : 20	3	4.00[b]	±0.01		
2. Ash content (%)				5245.26	<0.001
60 : 40	3	3.31[a]	±0.03		
70 : 30	3	4.87[b]	±0.05		
80 : 20	3	6.72[c]	±0.04		

Table 3 (Cont.)

Scum : Coffee residue (by weight)	**n**	$\bar{X}$	**SD**	**F**	**P-value**
3. Volatile matter (%)				9.835	0.013
60 : 40	3	82.38[a]	±0.14		
70 : 30	3	88.82[ab]	±0.03		
80 : 20	3	89.00[b]	±3.51		
4. Fixed carbon (%)				117.22	<0.001
60 : 40	3	14.42[a]	±0.06		
70 : 30	3	14.68[b]	±0.11		
80 : 20	3	15.67[c]	±0.13		
5. Total sulfur (%)				33.78	0.001
60 : 40	3	0.28[a]	±0.01		
70 : 30	3	0.26[a]	±0.04		
80 : 20	3	0.21[b]	±0.03		
6. Heating value (kcal/kg)				379.28	<0.001
60 : 40	3	6,412.90[a]	±19.32		
70 : 30	3	6,498.20[b]	±12.53		
80 : 20	3	6,725.30[c]	±9.38		

Note: Different letters in superscript show significant difference in pair.

The moisture content of briquette fuel at the ratio of 80:20, 70:30 and 60:40 were 4.00±0.20%, 6.00±2.00% and 7.79±0.01%, respectively. The significantly lowest moisture content appeared at the ratio of 80:20 (4.00±0.20%) ($P < 0.05$). The ash content of briquette fuel at the ratio of 80:20, 70:30 and 60:40 were 6.72±0.04%, 4.87±0.05% and 3.31±0.03%, respectively. The average of ash content was significantly greater at the ratio of 80:20 ($P < 0.05$). In addition, volatile matter of briquette fuel at the ratio of 80:20, 70:30 and 60:40 were 89.00±3.51%, 88.82±0.03% and 82.38±0.14%, respectively. Significantly highest average of volatile matter was found in the ratio of 80:20 ($P < 0.05$). While, fixed carbon of briquette fuel observed at the ratio of 80:20, 70:30 and 60:40 were 15.67±0.13%, 14.68±0.11% and 14.42±0.06%, respectively. The significant difference in the average of fixed carbon was also found in the ratio of 80:20 ($P<0.05$). Regarding the amount of total sulfur of briquette fuel, it showed that the concentration of sulfur contained at the ratio of 80:20, 70:30 and 60:40 was 0.21±0.10%, 0.26±0.03% and 0.08±0.10%, respectively. The average of total sulfur were significantly lowest at the ratio of 80:20 ($P < 0.05$). Finally, result indicated that heating value of briquette fuel at the ratio of 80:20, 70:30 and 60:40 was 6,725.30±9.38 kcal/kg, 6,498.20±12.53 kcal/kg and 6,412.90 ±19.32 kcal/kg, respectively. Significantly highest in the average of heating value was observed at the ratio of 80:20 ($P < 0.05$).

Air pollutant concentrations emitted from the combustion of briquette fuel.

Air pollutants.i.e., CO, CO_2, SO_2 and NO_2 were collected from the combustion of briquette derived fuel (Table 4). The amount of CO emission from the combustion of briquette fuel at the ratio of 60:40, 70:30 and 80:20 was 400±13.10 ppm, 479.8±14.61 ppm, and 376.5±9.01 ppm, respectively. The significant high concentration of CO was observed at ratio of 70:30 whereas the significant low concentration was found at ratio of 80:20 ($P < 0.05$). For CO_2 concentration, the amount of CO_2 emission at the ratio of 60:40, 70:30 and 80:20 was 424.6±11.10 ppm, 429.3±7.10 ppm and 415.7±13.60 ppm, respectively. No significant amount of CO_2 emission was observed among these ratios. Nevertheless, the emission of CO_2 was lowest at the ratio of 80:20.

In addition, the amount of SO_2 emission from the combustion of briquette fuel was not significantly different ($P > 0.05$). The concentration of SO_2 at the ratio of 60:40, 70:30 and 80:20 was 0.005±0.01ppm, 0.005±0.02 ppm and 0.006±0.01 ppm, respectively. Finally, the amount of NO_2 emitted from the combustion of briquette fuel at the ratio of 60:40, 70:30 and 80:20 was found to be 131.9±7.80 ppm, 150.3±10.20 ppm and 121.8±15.30 ppm, respectively. Significant lowest amount of NO_2 was found in the ratio of 80:20 ($P < 0.05$).

Table 4 Mean (± SD) of air pollutant concentrations emitted from the combustion of briquette fuel made from scum mixed with coffee residue in various ratios.

Pollutants	**Pollutant concentrations ($\bar{X}$ ± SD)**		
	Scum : Coffee residue (by weight)		
	60 : 40	**70 : 30**	**80 : 20**
CO (ppm)	400.5±13.10^{a}	479.8±14.61^{b}	376.5±9.01^{c}
CO_2(ppm)	424.6±11.10^{a}	429.3±7.10^{a}	415.7±13.60^{a}
SO_2(ppm)	0.005±0.01^{a}	0.005±0.02^{a}	0.006±0.01^{a}
NO_2(ppm)	131.9±7.80^{a}	150.3±10.20^{b}	121.8±15.30^{ac}

Note: Different letters in row with superscript show significant difference in pair.

Discussion

Results of three ratios of briquette derived fuel, 80:20, 70:30 and 60:40, showed a better ability for pressing, production and stability. The selected ratios for the test agreed with the study of Donkrasin (2002) who found that the ratio of scum increased as the high quality of briquetting and agreed with the study of Sudjaitham (2003) who found that the ratio of coffee increased as the difficulty to briquetting.

Regarding the physical properties of the briquette derived fuel study, the investigation showed no differences in the density of briquette derived fuel. The high density briquette fuel is actually desirable in terms of transportation, storage and handling. In addition to that, it also contains the higher heating value and longer period of burning. The parameters affecting the compressive strength and shatter index of the binderless briquette samples are moisture content and briquette pressure (Demirbas, & Sahin-Demirbas, 2005, pp. 83-91). For the low density briquette fuel, although the quick burning occurred and it would not be suitable for use (Demirbas, 1999, pp. 141-150; Royal Forest Department, 1985; Nakviroj, 1982). In this finding, the increase proportion of scum in briquette resulted in the increase of compressive strength. In addition, the briquette durability is, in fact, required for uses and depended on its compressive strength. Whereas the compressive strength is directly associated with the density. If the briquette fuel has a high compressive strength, the ability of the briquette fuel to hold the weight should be much better (Demirbas, 1999, pp. 141-150; Pintuam, 1995).

For the suitable briquette fuel of physical requirement, it is recommended that the shatter index should be between 0.5-1.0 (Pintuam, 1995; Demirbas, & Sahin-Demirbas, 1998, pp. 175-183). In this study, the highest shatter index was found in the ratio of 80:20 at 0.272± 0.02, approaching the recommended value at 0.5. The shatter index depends on the density and compressive strength. When the briquette fuel had high density and compressive strength, it usually had the high shatter index (Donkrasin, 2002).

In the study of fuel properties of the briquette, the moisture content is one of significant parameters reflecting a remaining water after drying the waste which will affect the heat directly. If the waste has a high moisture, it can lose the heating value due to the evaporation of moisture during the burning (Department of Industrial Works, 2012). The observed moisture content for these ratios was not over the Standard of Community Production Standard (not exceed 8%) (Thai Industrial Standard Institute, 2004).

In addition, it was found that the ash content increased if the ratio of scum increased. Result indicated that ash content of briquette fuel depended on the amount of scum that was increased. The ash content is the part of waste that cannot be burnt. The waste containing high amount of ash will clearly be a problem in the burning and increase a difficulty in getting rid of the ash (Department of Industrial Works, 2012). Nevertheless, the ash content for these ratios was still not over the recommended guideline and standard of waste for use to briquette fuel and interlocking block. The study of Department of Industrial Works, Ministry of Industry indicated that the ash content should be not more than 20% (Department of Industrial Works, 2012).

For volatile matter of briquette fuel, the significantly highest volatile matter was found at the ratio of 80:20 (89.00±3.51%). This indicated that the higher proportion of scum in the ratio increased, the greater volatile matter increased (Paul, & Angelo, 1976, pp. 413-436). The volatile matter represents the components of carbon, hydrogen and oxygen in the biomass that can volatile after getting the heat. Waste with a high volatile matter will tend to have a high heating value (Department of Industrial Works, 2012). The study of Department of Industrial Works for the appropriate ash content from waste as briquette fuel it was found that the high amount of volatile matter was due to the high burning of briquette fuel. It was found that the volatile matter for these ratios was still better than the briquette fuel from scum mixed with sawdust (Paul, & Angelo, 1976, pp. 413-436). The increase of ratio of volatile matter would result in the high quality of briquette derived fuel (Department of Industrial Works, 2012).

For the fixed carbon of briquette fuel, the similar pattern of increase amount was also found in the increase of proportion of scum. The fixed carbon is directly associated with the heating value. It is an amount of carbon compounds which are difficult to volatilize. When the oxidation occurs, it will decompose and release the heat out. Fuels with high fixed carbon makes the high heating value (Pintuam, 1995; Department of Industrial Works, 2012; Panumas, 1986). This investigation showed that the amount of fixed carbon met the recommended guideline and standard of waste for use as the briquette fuel and interlocking block (not less than 15%) (Department of Industrial Works, 2012).

Similar increase amount of total sulfur of briquette fuel was detected when the proportion of scum increased. When burning the briquette fuel, sulfur in the fuel will react with oxygen to form the sulfur dioxide. Therefore, if the waste contains the large amount of sulfur it will not be suitable to use as a fuel due to the occurrence of large amount of the sulfur dioxide from the burning process (Department of Industrial Works, 2012; Paul, & Angelo, 1976, pp. 413-436). However, this finding seems to indicate that low total sulfur was found in the ratio of 80:20 (0.21±0.10%) and all ratios were much less than the Standard of Community Production Standard (not over than 2%). Result were similar to other briquette fuels such as briquette fuel from chili scrap mixed with garlic (0.22%), briquette fuel from vegetable waste and fruit waste (0.18%) and briquette fuel from seed of rambutan (0.12%) (Department of Industrial Works, 2012). However, the observed amount of total sulfur from these ratios was higher than other briquette fuels such as the briquette fuel from durian shell mixed with sludge from wastewater treatment plant of pulp industry (3,625-3,699kcal/kg), charcoal trash mixed with molasses (4,498 kcal/kg) and oil palm cluster mixed with palm shell (5,555 kcal/kg) (Department of Industrial Works, 2012).

Result revealed that heating value of briquette fuel increased when the amount of scum increased. The highest heating value was observed at the ratio of 80:20 (6,725.30±9.38 kcal/kg) and met the requirement of refuse derived fuel of Community Production Standard (238/2547) (not less than 3,000 kcal/kg.)(Thai Industrial Standard Institute, 2004). The heating value for these ratios was found to be higher than the briquette produced from the bagasse and coffee husk in the ratio of 3:1, 2659.17 kcal/kg (Pallavi, Srikantaswasmy, Kiran, Vyshnavi, & Ashwin, 2013, pp. 160-172).

Finally, the study of air pollutant concentrations emitted from the combustion of briquette fuel clearly indicated that significantly low emission was observed at high proportion of scum. Therefore, the scum will help to reduce the air pollutant emitted from the burning process. However, the user should avoid to directly expose to the emission from briquette fuel during fuel for the better long term health.

From the results, the physical and fuel properties of briquette derived fuel from scum mixed with coffee residue were clearly observed. It was found that the trend of quality of briquette derived fuel from scum mixed with coffee residue depended on the content of scum in the briquette fuel when proportion of scum at ratios increased, the ash content, volatile matter, fixed carbon and heating value were increased, as well. In addition, it was suggested that the ratio of 80:20 was quite appropriate to use for the production of briquette because it had the significantly high compressive strength, shatter index, volatile matter, and heating value but low moisture content. Although, the result of this research demonstrates that the use of this waste residue as fuel production is very promising, the economic value analysis for the production project is still in need. This will ensure that the fuel production from this waste residue is worthwhile to further a large scale investment.

Conclusion

Result indicated that ratio of 80:20, 70:30 and 60:40 were appropriate to produce the briquette fuel from scum mixed with coffee residue. For the physical and fuel properties in this study, significant differences in the average of compressive strength and shatter index for those ratios were observed in the test ($P < 0.05$). For fuel property analysis, there were significant differences in the ash content, volatile matter, fixed carbon, total sulfur and heating value ($P< 0.05$). In addition, the emission of air pollutants for the CO, CO_2, $SO_2$and NO_2were lowest at the ratio of 80:20. Therefore, this findings suggest that the mixed ratio of briquette at 80:20 is appropriate for the application of the production of briquette derived fuel due to the significantly high compressive strength (0.325 ± 0.02 kg/cm^2), shatter index (0.272 ± 0.02), volatile matter ($89.00\pm3.51\%$), heating value ($6,725.30\pm9.38$ kcal/kg) and low moisture content ($4.00\pm0.20\%$).

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