Briquette fuel production from wastewater sludge of beer industry and biodiesel production wastes

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Abstract. The production of industrial wastes is increasing each year. Current methods of waste disposal are severely impacting the environment. Utilization of industrial wastes as an alternative material for fuel is gaining interest due to its environmental friendliness. Thus, the objective of this research was to study the optimum condition for fuel briquettes produced from wastewater sludge of the beer industry and biodiesel production wastes. This research is divided into two parts. Part I will study the effects of carbonization of brewery wastewater sludge for high fixed carbon. Part II will study the ratio between brewery wastewater sludge and bleaching earth for its high heating value. The results show that the maximum fixed carbon of 10.01% by weight was obtained at a temperature of 350 °C for 30 minutes. The appropriate ratio of brewery wastewater sludge and bleaching earth by weight was 95:5. This condition provided the highest heating value of approximately 3548.10 kcal/kg.

1. Introduction
The consumption of beverage products in Thailand is increasing in quality significantly every year, one of the beverage products is beer. According to the bank of Thailand statistics, beer’s sale expanded 24.36% from 2004 to 2014 [1]. Following the sale expansion, it caused the environmental problems, especially wastewater pollution. During the production, a liter of beer, wastewater generates around 3-10 liters [2]. The most famous industrial wastewater treatment methods are biological treatment with activated sludge process. Therefore, a large amount of brewery wastewater sludges was generated, which required proper management before disposal. Most of these brewery wastewater sludges are disposed of in landfills that is the resulting in environmental impacts on surface and
groundwater. Brewery wastewater sludge can be served as a potential renewable fuel, due to a significant amount of organic matter of adequately high heating value.

The oil and gas situation in Thailand drives the economy and increased sharply. As a result, the Thai government has been promoting domestic production biofuel as a substitute crude oil import, such as gasohol, palm diesel, and biodiesel. Mostly, the commercial scale biodiesel plants use crude palm oil as a raw material. The palm oil bleaching process as the most important activity in palm oil refinery, which removes contaminants and color [3]. Bleaching earth is one of the residuals in palm oil refinery that required proper management before disposal as same as brewery wastewater sludge.

Biodiesel production process is a chemical reaction called esterification between vegetable oils or animal fats and alcohol. The products of this reaction are biodiesel as a main product and glycerol as a by-product, which produces 100 kilograms of biodiesel, generates 11 kilograms as crude glycerol [4]. Crude glycerol from biodiesel production plant is not commonly used in the pharmaceutical and cosmetic industries because of its low purification, Thus, the aim of this study was to investigate the potential of the briquettes made from brewery wastewater sludge mixed with bleaching earth and crude glycerol as alternative fuel and wastes utilization.

2. Experimental methods

2.1. Materials

The technique of full factorial design was used to study the optimum condition of two factors, namely, temperature and time. Each experiment is performed by 3 replicated at 95% confidence interval. The carbonization process was operated at different temperatures (300, 350 and 400 °C) and times (30, 60 and 90 minutes) in a limited-air electrical furnace. During the briquetting process, certain amounts of bleaching earth were mixed with brewery wastewater sludge. Note that the type of briquetting process carried out here was a cold process using crude glycerol (30% by weight of the mixture) as the binder. Five different ratios (brewery wastewater sludge to bleaching earth) used in the briquetting process were: 55:45, 65:35, 75:25, 85:15 and 95:5. This experiment was observed by using mixture design. Each experiment is performed by 2 replicated at 95% confidence interval.

2.2. Testing procedures

The fixed carbon was determined after carbonization process at various temperature and time according to ASTM D3172-07 [5]. After the briquetting process, fuel briquettes were obtained and their heating values were measured based on ASTM D1989-97 [6].

3. Experimental results

3.1. Characteristics of Raw Materials

From table 1, it was found that brewery wastewater sludge exhibited the higher fixed carbon and heating value than bleaching earth.
### Table 1. Properties of brewery wastewater sludge, bleaching earth and crude glycerol

| Material                | Fixed carbon (% wt) | Heating value (kcal/kg) |
|-------------------------|---------------------|-------------------------|
| Brewery wastewater sludge | 4.36                | 3,045.35                |
| Bleaching earth         | 2.66                | 2,553.25                |
| Crude glycerol          | -                   | 3,534.98                |

3.2. Optimum conditions for carbonization process

As shown in figure 1, with the temperature and time rising from 300 to 400 °C and 30 to 90 minutes, respectively, the fixed carbon of brewery wastewater sludge increases up to a certain point then decreases. It was found that increasing temperature and time caused the mass conversion [7] and devolatilization of organic compounds or hydrocarbons during carbonization [8]. But increasing high temperature affects the amorphous carbon atoms inside brewery wastewater sludge and removes surface functional groups [9].

![Figure 1. The effect of temperature and time for fixed carbon of brewery wastewater sludge.](image)

3.3. Optimum ratios for briquetting process

The effect of ratios for briquette process is shown in figure 2. The increasing in an amount of brewery wastewater sludge and decreasing in an amount of bleaching earth ratio in briquette mixture, the heating value showed an incremental from 3,269.80 kcal/kg to 3,548.10 kcal/kg. It is because brewery wastewater sludge has a higher heating value than bleaching earth.
3.4. Statistical analysis

It is evident from table 2 and table 3 that the fixed carbon and the heating value are affected by both factors. Firstly, analyzing the effect of each factors. It was found that both the temperature (P < 0.05) and time (P < 0.05) significantly affected the fixed carbon in brewery wastewater sludge. Also, the ratio of brewery wastewater sludge (P < 0.05) and bleaching earth (P < 0.05) significantly affected the heating value in briquette. Secondly, there was no significant interaction effect of temperature and time (P > 0.05). On the other hand, there was significant interaction effect of brewery wastewater sludge and bleaching earth ratio (P < 0.05).

Table 2. ANOVA table for the factorial design (fixed carbon is the output)

| Term                | DF | F-value | P-value |
|---------------------|----|---------|---------|
| Temperature         | 2  | 17.06   | 0.000   |
| Time                | 2  | 346.24  | 0.000   |
| Temperature*Time    | 4  | 1.68    | 0.198   |

Table 3. ANOVA table for the mixture design (heating value is the output)

| Term                | Coef | SE Coef | P-value |
|---------------------|------|---------|---------|
| Brewery Sludge      | 3567.5| 6.951   | > 0.000 |
| Bleaching Earth     | 2476.2| 70.246  | > 0.000 |
| Brewery Sludge*Bleaching Earth | 770.5| 127.728 | 0.001   |

3.5. Relationship between the heating value and the material ratio

The relationship between the heating value and the brewery wastewater sludge and bleaching earth ratio could be written in the equation 1:

\[
HV_{CAL} = 0.7693m_{BS}HV_{BS} + 0.7693m_{BE}HV_{BE} + 0.7693m_GHV_G
\] (1)
where $HV_{CAL}$ is the calculated heating value of the briquette (kcal/kg), $0.7693$ is the conversion factor from 130% to 100%, $m_{BS}$ is the mass fraction of brewery wastewater sludge (%), $HV_{BS}$ is the heating value of brewery wastewater sludge after carbonization (kcal/kg), $m_{BE}$ is the mass fraction of bleaching earth (%), $HV_{BE}$ is the heating value of bleaching earth, $m_{G}$ is the mass fraction of crude glycerol (%) and $HV_{G}$ is the heating value of crude glycerol. The mass fraction of crude glycerol was 30% and the heating value of brewery wastewater sludge after carbonization, bleaching earth and crude glycerol were 3,480.65 kcal/kg, 2,553.25 kcal/kg and 3,534.98 kcal/kg, respectively.

Based on equation 1, the calculated heating value of the briquettes were obtained. Figure 3 shown the calculated heating value of the briquettes compared to the actual heating value. It was found that the actual heating value was correlated well with the calculated heating value within $\pm 5\%$ errors. It could be seen that increasing an amount of brewery wastewater sludge and decreasing in an amount of bleaching earth ratio in mixture led to increasing the heating value of briquette. The optimum brewery wastewater sludge and bleaching earth ratio found in this study was 95% by weight.

![Figure 3](image_url)

**Figure 3.** The comparisons of the calculated heating value and the actual heating value in difference ratio of material.

4. **Conclusions**

This research investigated the optimum condition for fuel briquettes produced from brewery wastewater sludge bleaching earth and crude glycerol. The results showed that the optimal condition for carbonization process was at temperature 350 °C for 30 minutes of heating time, which is provided highest fixed carbon. In addition, the highest heating value from this studied was from 95% by weight of brewery wastewater sludge mixed with bleaching earth as optimal ratio. To make the briquette made from brewery wastewater sludge mixed with biodiesel production wastes more efficient, the development such as compressive strength, the ratio of crude glycerol, reducing of ash and toxic gas emission are required in the future study.
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