Quality analysis of briquette made of faecal sludge

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Abstract. The purpose of this study is to convert slack waste into charcoal briquettes. The process for making briquettes was carried out by adding polyacrylamide as adhesives. The results showed that the best briquettes were obtained from 16 (sixteen) briquettes, namely the heating value, moisture content, density, and length of combustion were 7436.55 Cal/g; 7.277%; 1.06 g/cm³; and 613 seconds respectively with the ratio of raw material: adhesive, pressure scale, and drying time were 5:2 105 kg/cm²; and 120 minutes respectively. The characteristics of the calorific value and water content have accordance with the SNI 01-6235-2000 standards, which were ≥ 5000 Cal/g and 7.75%, and the American standard for the density value was 1.0 g/cm³.

1. Introduction

As a biological creature, humans in living their lives are also environmental destroyers and producers of waste. Humans are required to manage the development (repairing the damaged, enhancing and developing) a livable environment. In Law no. 23 of 1997 on Environmental Management, article 5 (1) states that everyone has the same rights to a good and healthy environment [1].

The Regional Drinking Water Company (PDAM) Tirtanadi, Medan, is starting to worry about the accumulation of waste in the form of feces. Efforts to process feces are being planned in the largest city on the island of Sumatra. One of the feces that PDAM Tirtanadi plans to treat is to convert the waste into fertilizer or briquettes (solid fuel). PDAM Tirtanadi Medan is already thinking about processing (feces) into fertilizer and briquettes. Medan City already has IPLT which has been inaugurated since January 2018 [2].

The briquette production process is an effort to process the feces into briquettes. The manufacture of briquettes is done so that they can use dirt/feces as raw material used to replace renewable fuels. However, the facts in the field of briquettes produced are still far from the right standard, seen from the cracked, broken, and damaged briquettes as shown in Figure 1 [3], so it is necessary to analyze the quality of the briquettes that should have been produced through testing the briquette quality standards using the experimental design method. The following is a visual defect of briquettes which can be seen in Figure 1.
So, it is necessary to do a concept design for making briquettes for a more precise quality of briquettes [4].

2. Materials and methods

2.1. Experimental Design

The basic principles that are commonly used and known need to be recognized, terms related to these principles include treatment, experimental error, and experimental unit. The treatment is a set of experimental conditions that will be used on the experimental unit within the selected design scope. This treatment can be singular or occur in combination [5, 6, 7].

| Group Resources | Degrees of Freedom | Middle Square Expectation Value |
|-----------------|--------------------|---------------------------------|
| A               | a – 1              | $\sigma^2 + \frac{abc \Sigma a^2}{(a - 1)}$ |
| B               | b – 1              | $\sigma^2 + \frac{rac \Sigma \beta^2}{(b - 1)}$ |
| C               | c – 1              | $\sigma^2 + \frac{rab \Sigma \gamma^2}{(c - 1)}$ |
| AB              | (a – 1) (b – 1)    | $\sigma^2 + \frac{r \Sigma(\alpha \beta)^2}{(a - 1)(b - 1)}$ |
| AC              | (b – 1) (c – 1)    | $\sigma^2 + \frac{rb \Sigma(\alpha \gamma)^2}{(a - 1)(c - 1)}$ |
| BC              | (b – 1) (c – 1)    | $\sigma^2 + \frac{ra \Sigma(\beta \gamma)^2}{(b - 1)(c - 1)}$ |
| ABC             | (a – 1) (b – 1) (c – 1) | $\sigma^2 + \frac{r \Sigma(\alpha \beta \gamma)^2}{(a - 1)(b - 1)(c - 1)}$ |
| Error           | (r – 1) (ABC – 1)  | $\sigma^2$ |

The following is an analysis of variance consisting of various models including:

1. Fixed Model or Model I

It is called a fixed model because of the assumption that the level of treatment is fixed and the experiment has a mathematical model. Table 1 is presented with the mean square expected values with respect to the three models for the three factorial experiment.

2. Random Model or Model II (Variance Component Model)

Imagine that there are three populations at the levels of factors A, B, and C. From each population, all the levels of each factor that have been taken are contained in the experiment conducted, so a random model or model II is obtained. Table 2 is presented with the mean square expected values with respect to the three models for the three-factorial experiment.
Table 2. Expectation value squared mean value for factorial experiment with three factor randomized model

| Group | Degrees of Freedom | Middle Square Expectation Value |
|-------|--------------------|---------------------------------|
|       | r – 1              | σ² + abc σ²                     |
| A     | a – 1              | σ² + rbc σ² + rσ²               |
| B     | b – 1              | σ² + rac σ² + rσ²               |
| C     | c – 1              | σ² + rab σ² + rσ²               |
| AB    | (a – 1) (b – 1)    | σ² + rσ²                        |
| AC    | (b – 1) (c – 1)    | σ² + rb σ²                      |
| BC    | (b – 1) (c – 1)    | σ² + raσ²                       |
| ABC   | (a – 1) (b – 1) (c – 1) | σ² + r σ²                  |
| Error | (r – 1) (ABC – 1)  | σ²                             |

Table 3. Expectation value squared mean value for factorial experiment with three factor mixed model (A and B fixed, C random) [8]

| Group | Degrees of Freedom | Middle Square Expectation Value |
|-------|--------------------|---------------------------------|
|       | r – 1              | σ² + abc σ² + abc Σρ²/(r – 1)   |
| A     | a – 1              | σ² + rbc Σα²/(a – 1) + r(a/(a – 1))σ² |
| B     | b – 1              | σ² + rac Σβ²/(b – 1) + r(b/(b – 1))σ² |
| C     | c – 1              | σ² + rab σ²                     |
| AB    | (a – 1) (b – 1)    | σ² + rΣ(αβ)²/(a – 1)(b – 1) + r(ab/(a – 1)(b - 1))σ² |
| AC    | (b – 1) (c – 1)    | σ² + r(a/(a – 1))σ²             |
| BC    | (b – 1) (c – 1)    | σ² + r(b/(b – 1))σ²             |
| ABC   | (a – 1) (b – 1) (c – 1) | σ² + rΣ(αβ²)/(a – 1)(b - 1))σ² |
| Error | (r – 1) (ABC – 1)  | σ²                             |

3. Mixed Model or Model III
Experiments with only a factor level A factor, only b factor level B and c factor level C taken randomly from a population consisting of all factors C will provide a mixed model with fixed a and b while c is random. Table 3 is presented with the mean square expected values with respect to the three models for the three factorial experiment.

4. Mixed Model
This model will occur if in the experiment he conducts, the researcher is involved with a random sample from a population consisting of all factor levels only as much as a factor level A, all of which are used as many as B factor B which has been taken randomly from a population consisting of all levels of factor B are c of factor C which is C. Table 4 is presented
with the expected value of the middle square with respect to the three models for the three factorial experiment.

Table 4. Expectation value squared mean value for factorial experiment with three factor mixed model (A fixed, B and C random) [9]

| Group Resources | Degrees of Freedom | Middle Square Expectation Value |
|-----------------|--------------------|---------------------------------|
|                 | r – 1              | \( \sigma^2 + abc \sigma^2 + abc \Sigma \sigma^2 / (r – 1) \) |
| A               | a – 1              | \( \sigma^2 + rbc \Sigma \sigma^2 / (a – 1) + r(a/(a – 1)) \sigma^2 \) |
| B               | b – 1              | \( \sigma^2 + rac \sigma^2 \) |
| C               | c – 1              | \( \sigma^2 + rab \sigma^2 \) |
| AB              | (a – 1) (b – 1)    | \( \sigma^2 + c \Sigma \sigma^2 / (a – 1) \) |
| AC              | (b – 1) (c – 1)    | \( \sigma^2 + rb \Sigma \sigma^2 / (a – 1) \) |
| BC              | (b – 1) (c – 1)    | \( \sigma^2 + rbc \Sigma \sigma^2 / (a – 1) \) |
| ABC             | (a – 1) (b – 1) (c – 1) | \( \sigma^2 + r(\sum (\alpha)^2 / (a – 1)) \sigma^2 \) |
| Error           | (r – 1) (ABC – 1)  | \( \sigma^2 \) |

2.2. 3 x 2 x 2 x 2 Factorial Experimental Design

The experimental design of the 3 x 2 x 2 x 2 factorial is Model I, namely the Fixed Method. This model is used when the researcher only deals with many fixed levels for each factor, as many as a for factor A, b for factor B, c for factor C and d for factor D, all of which are used in the study. The conclusion certainly applies to the constant tailored. Symbolically, this assumption can be written as:

\[
\sum_{i=1}^{a} A_i = \sum_{j=1}^{b} B_j = \sum_{k=1}^{c} C_k = \sum_{l=1}^{d} D_l = \sum_{i=1}^{a} \sum_{j=1}^{b} AB_{ij} = \sum_{i=1}^{a} \sum_{k=1}^{c} AC_{ik} = \sum_{i=1}^{a} \sum_{l=1}^{d} AD_{il} = \sum_{j=1}^{b} \sum_{k=1}^{c} BC_{jk} = \sum_{j=1}^{b} \sum_{l=1}^{d} BD_{jl} = \sum_{k=1}^{c} \sum_{l=1}^{d} CD_{kl} = \sum_{i=1}^{a} \sum_{j=1}^{b} \sum_{k=1}^{c} ABC_{ijk} = \sum_{i=1}^{a} \sum_{j=1}^{b} \sum_{l=1}^{d} ABC_{ijl} = \sum_{i=1}^{a} \sum_{j=1}^{b} \sum_{k=1}^{c} \sum_{l=1}^{d} ABCD_{ijkl} = 0
\]

The null hypothesis that can be tested for this model is that there is no effect of factors and no interaction effect between factors. In the formulation of H0 we get:

- H01 : \( A_i = 0, \) (i = 1, 2, …., a)
- H02 : \( B_j = 0, \) (j = 1, 2, …., b)
- H03 : \( C_k = 0, \) (k = 1, 2, …., c)
- H04 : \( D_l = 0, \) (l = 1, 2, …., d)
- H05 : \( AB_{ij} = 0, \) (i = 1, 2, …., a and j = 1,2,….., b)
- H06 : \( AC_{ik} = 0, \) (i = 1, 2, …., a and k = 1,2,….., c)
- H07 : \( AD_{il} = 0, \) (i = 1, 2, …., a and l = 1,2,….., d)
- H08 : \( BC_{jk} = 0, \) (j = 1, 2, …., b and k = 1,2,….., c)
- H09 : \( BD_{jl} = 0, \) (j = 1, 2, …., b and l = 1,2,….., d)
\[ H_{08} : CD_{kl} = 0, (k = 1, 2, \ldots, b \text{ and } l = 1, 2, \ldots, d) \]
\[ H_{09} : ABC_{ijk} = 0, (i = 1, 2, \ldots, a \text{ and } j = 1, 2, \ldots, b \text{ and } k = 1, 2, \ldots, c) \]
\[ H_{10} : ABD_{ijl} = 0, (i = 1, 2, \ldots, a \text{ and } j = 1, 2, \ldots, b \text{ and } l = 1, 2, \ldots, d) \]
\[ H_{11} : BCD_{jkl} = 0, (j = 1, 2, \ldots, b \text{ and } k = 1, 2, \ldots, c \text{ and } l = 1, 2, \ldots, d) \]
\[ H_{12} : ABCD_{ijkl} = 0, (i = 1, 2, \ldots, a \text{ and } j = 1, 2, \ldots, b \text{ and } k = 1, 2, \ldots, c \text{ and } l = 1, 2, \ldots, d) \]

The critical area boundaries for each test are determined by the significant level \( \alpha \) selected from the F distribution with the numerator degrees of freedom taken from the F-value tables according to the respective treatments paired with the denominator's degrees of freedom equal to the degrees of error of freedom. The ANOVA list for the a x b x c x d factorial experimental design can be seen in Table 5.

2.3. Conceptual Framework
The conceptual framework is a model that shows a logical relationship between the identified factors / variables to analyze research problems. In other words, the conceptual framework explains the relationship between all factors/variables that are related or explained in the theoretical basis.

2.4. Research Type
This type of research is experimental research (experimental research). Experimental research aims to find a causal relationship between factors that are deliberately caused by eliminating or reducing other disturbing factors [10]. Experimental research aims to investigate the causal relationship and how big the relationship is by applying a treatment to one or more experimental groups and comparing the results with one or more control groups.

2.5. Research Sites
The location of this research was carried out in PDAM Tirtanadi on Jl. Plantation No. 1 Medan, PDAM Tirtanadi, Province of North Sumatra, IPA Waste Cemara. This research started from January 2019.

2.6. Research Methodology

Table 5. ANOVA list of factorial experiment design a x b x c x d

| Source of Variation | Dk | JK | KT | F |
|---------------------|----|----|----|---|
| Average Treatment:  |    |    |    |   |
| A                   | a – 1 | Ay | A  |   |
| B                   | b – 1 | By | B  |   |
| C                   | c – 1 | Cy | C  |   |
| D                   | d – 1 | Dy | D  |   |
| AD                  | (a – 1)(d – 1) | AD | AD |   |
| BC                  | (b – 1)(c – 1) | BC | ABC|   |
| BD                  | (b – 1)(d – 1) | BD | BD |   |
| CD                  | (c – 1)(d – 1) | CD | CD |   |
| ABC                 | (a – 1)(b – 1)(c – 1) | ABC | ABC|   |
| ABD                 | (a – 1)(b – 1)(d – 1) | ABD | ABD|   |
| ACD                 | (a – 1)(c – 1)(d – 1) | ACD | ACD|   |
| BCD                 | (b – 1)(c – 1)(d – 1) | BCD | BCD|   |
| ABCD                | (a – 1)(b – 1)(c – 1)(d – 1) | ABCD | ABCD|   |
| Errors of numbers   | a b c (n – 1) | Ey | E  |   |
| Errors of numbers   | a b c d | ΣY² | -  |   |

No exact test can be used

Determined by the nature of the factor level

E
The research stage is the steps to find the problem and look for the factors that cause the problem. These factors will be analyzed to determine the extent of their influence on the problems that occur.

2.7. Research Stages
2.7.1. Production Process Description
Utilization of human feces that have been dried and processed by gluing, drying, molding and shaping so that they become briquettes that are safe, environmentally friendly, meet quality briquette criteria and of course can be used as alternative fuels.

2.7.2. Briquette Making Process
The process of making briquettes by weighing predetermined materials, weighing adhesives, mixing raw materials and adhesives, weighing dough, printing, pressing and drying with a predetermined temperature and time to produce briquettes.

2.7.3. Briquette Analysis
The briquette analysis aims to obtain the characteristics of the briquettes that have been produced, especially to obtain the quality of these briquettes. The analysis carried out such as analyzing moisture content, briquette flame, density, and heating value consists of:

a. Water Content Analysis
Percent moisture content can be calculated from the percentage value of water content inversely proportional to the resulting calorific value. Good briquettes are briquettes that have low water content so that their heating value and combustion power are high [11]

b. Briquette Density Analysis
Density analysis or density analysis is a parameter in determining a good briquette. Higher density of ingredients will result in better briquette quality than lower briquette density.

c. Analysis of the Briquette Flame
The analysis of briquette flame consists of calculating the length of ignition time and the ignition time period. The length of time for burning the briquettes is calculated when the briquettes are burned to heat the water until the water is boiling, awaited until the fire in the briquettes stops burning and the briquettes turn to ashes and calculates how long the briquettes burn during the burning process.

d. Calorific Value Analysis
The calorific value of a biomass fuel is the amount of heat energy (kJ) that can be released for each unit weight of the fuel (kg) if it burns completely, a perfect briquette is if all of the carbon element (C) in the briquette reacts with oxygen to carbon dioxide (CO$_2$).

2.7.4. Experimental Design Calculations
Based on the experimental data obtained, tests were carried out to determine whether there was a significant effect between the treatments given on the heating time of the briquettes. Where the treatment given is the ratio of raw materials and adhesive, jack pressure and drying time. In this test, H$_0$ and H$_1$ are determined as follows:

H$_0$ : There is a significant effect of a factor or an interaction between the factors on the briquette production.

H$_1$ : There is no significant effect of a factor or the interaction between the factors on the briquette production.

2.7.5. Calculation with SPSS
After doing the calculations manually, it is better if you do the test with SPSS to get more accurate results. Statistics SPSS is a software used for statistical analysis. Calculations are performed using
SPSS by means of univariate analysis, which is a simple form of quantitative (statistical) analysis. Analyzes were performed with descriptions of a single variable in terms of the unit of analysis tool.

2.7.6. Analysis and Evaluation
The analysis carried out on briquettes made from human feces is a classification of the things that affect the quality of the briquettes produced in the description of the production process. Processing with time and temperature at the specified briquette drying process and the appropriate jack pressure. The evaluation carried out was that during the briquette production process the appropriate ratio of raw materials and adhesives was needed, the duration and temperature of the briquette drying process had been determined and the appropriate jack pressure so that the briquettes produced were quality briquettes that were durable, safe and environmentally friendly [12].

2.7.7. Conclusions and recommendations
After the analysis is carried out, conclusions will be drawn from the research results. The conclusion is the result of data processing and data analysis. This research starts from looking at the existing symptoms, then formulating the problem and making the objectives of this research. The final result of this research is a design to obtain the latest alternative energy sources using materials that are easily available to the environment, such as feces (human waste).

2.8. Data Collection
2.8.1. Briquette Making Material Data
The raw material used in the research process of making briquettes is dried human feces or feces. The feces were taken from the sewage treatment plant (IPLT) of PDAM Cemara, Medan. As much as 200 kg of waste is taken and stored in a container for further use and analysis. We recommend that the ingredients are dry to shorten the curing time.

2.8.2. Machine and Equipment Data
In the process of making briquettes, several machine tools are used, namely inlet tub, ph valve motor, receiving tank, coarse screen, fine screen, equalization tank, thickener, centrifugal pump, polymer mixer, belt press, aeration tub, cake drying bed, and other equipment. others that are used to facilitate the briquette production process such as plastic basins, shovels, digital scales, stopwatches, digital pocket scales, and thermometers [13].

2.8.3. Experimental Design Data
The data used in the briquette production process are drying time, jack pressure, the ratio of raw material and adhesive (polyacrylamide).

3. Discussion
3.1. Analysis of the Description of the Production Process
The analysis of the heating value (heat heating value, HHV), six types of samples with the best burning time were used to analyze their calorific values. In the third and fifth experiments, the calorific value obtained was different from the heating value in other experiments. This may be due to the operator's lack of accuracy in reading the scale on the thermometer so that the temperature value read is incorrect.

It can be concluded that the calorific value contained in briquettes is equal to the average calorific value of the five experiments, namely:

\[
HHV_{mean} = \frac{5861.75 + 5949.23 + 6386.68 + 7436.55 + 5336.82}{5} = 6194.21 \text{ Cal/g}
\]
Based on the results of the calorific value of 6194.21 Cal/g is an indicator indicating that the briquette has a medium energy/calorie content. This determines that the briquette has a fairly good combustion rate with a large enough energy level.

3.2. Experimental Design Analysis

ANOVA calculation, if $F_{\text{count}} \leq F_{\text{table}}$ then $H_0$ is accepted otherwise if $F_{\text{count}} > F_{\text{table}}$ then $H_0$ is rejected. In calculating ANAVA, it can be concluded that:

1. $F_{\text{AB}} < F_{\text{table}}$, $H_0$ is accepted, there is no significant effect of the interaction between the ratio of raw materials and adhesive with the jack pressure.

2. $F_{\text{AC}} < F_{\text{table}}$, $H_0$ is accepted, there is no significant effect of the interaction between the ratio of raw materials and adhesive with the drying time.

3. $F_{\text{BC}} > F_{\text{table}}$, $H_0$ is rejected, there is a significant effect of the interaction between the jack pressure and the drying time.

4. $F_{\text{ABC}} > F_{\text{table}}$, $H_0$ is rejected, there is a significant effect of the interaction between the ratio of raw material and adhesive, the pressure of the jack and the drying time.

4. Conclusion

The calorific value of 6194.21 Cal/g is an indicator indicating that the briquette has a medium energy/calorie content. This determines that the briquette has a fairly good combustion rate with a large enough energy level.

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