CRITICAL ANALYSIS OF CONSTRUCTED FOOD WASTE-BIOGAS SYSTEM ON METHANE PRODUCTION USING BUSWELL APPROACH

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ABSTRACT

Conversion of food waste into methane has been very important way to cater the energy source crisis. The application of waste to energy technologies such as the production of biogas is considered to be one of the finest options that meet the increasing global demand for energy consumption. In this project, a food waste-biogas system converter was developed to observe the methane production using Buswell approach. The methodology used are customer surveillance, house of quality in defining customers' needs, morphological chart in defining concepts and Pugh method for selection of best design. The methane volume was taken cumulatively everyday for 15 days. Results show that biogas volume keep increasing until day 15, which was 6.852 L. The highest decrement can be observed at biogas production of day 5 while the highest increment can be observed at day 10 where it was influenced by temperature and climate change.

Keywords: food waste, methane, buswell approach, climate change.

INTRODUCTION

Mankind facing a very serious energy source crisis due to the challenges of diminishing climate changes. The severity of the crisis further rose with the depletion of fossil energy [1]. Discussions on carbon alleviation pathways and strategies have been going on for decades while fossil energy consumption and consecutive emission keep on rising. Thus, the application of waste to energy technologies such as the production of biogas is considered to be one of the finest options that meet the increasing global demand for energy consumption. The production of biogas as renewable energy decreases the dependence on fossil energy. Additionally, these practices also contribute to efficient waste management. The energy consumption of the world is rising by approximately 2% annually. Brazil, Thailand, China, the United States of America, and European countries already using biomass sources like wood as an alternative for coal and oil [2]. Out of several types of alternative renewable energy, biogas is one of the most favored because it can be utilized easily and can be used directly in different applications such as fuel cells, micro-turbines, combustion generators, etc. Furthermore, biogas is also favored because the digested waste can be used as organic fertilizer. Food and Agriculture Organization (FAO) of United Nations calculated that approximately 3/4 of the entire food created for humans in the world is squandered annually which led to endemic and epidemic illness. Food Waste (FW) is a vital part of Municipal Solid Waste (MSW) which encompasses restaurant waste, canteen waste, food processing waste, and household food waste [3]. The average FW produced by a person is 250 to 300 kg per year. Ninety-seven tons of FW are wasted every year in India. Meanwhile, FW produced in Japan, the United States, Europe, and China have been approximately around 22, 90, 61, and 195 metric tons respectively per year [4]. According to [5], FW is more reactive to AD due to its high moisture and various organic nutrient content. These conditions promote the production of methane as a promising alternative energy source. Co-digestion is concurrent digestion of multiple substrates in AD while mono-digestion is the digestion of a single substrate. The co-digestion is basically executed to improve biogas generation, balance supplements, and control acid genesis in the anaerobic absorption process. Due to the various benefits of co-digestion, it has a better performance compared to mono-digestion [6]. From the research done by Algapani *et al.* [7], it was identified that the methane output by the co-digestion of sewage sludge and FW is greater in comparison to mono-digestion with FW only. There are already lots of technologies or systems that are being applied to convert organic matter into food waste in several countries. The best example is the United States where they have the largest food waste digester. To reduce food waste dumping at the domestic level, a small-scale food waste digester is necessary. Further, the newly developed small-scale biogas digester is expected to produce a large volume of methane which were analysed using the Buswell approach [8].

METHODOLOGY

A simple random sampling method was selected to gain information with respect to customer's needs toward the prototype [9]. The questionnaire was distributed to 100 respondents. From this survey, the decision will be undertaken to solve the leftover food

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problem faced by households and to create the prototype due to customer requirements. Quantitative data was collected in the aspects of cost, lightweight, reliability, the durability of the machine, and maintenance. The questionnaire was distributed to a random sample in Malacca. From the survey, the house of quality was constructed. House of quality incorporates deciding, clarifying, and determining the customer needs. These mean establishing the framework for a plainly characterized venture and will guarantee an undertaking or procedure is well-considered before any further improvement. A morphological chart was then developed to determine and understand the requirement of customer needs and define the conceptual design. From the conceptual design, the pugh method is used to compare the conceptual design by giving a rating point for each design [10-11]. The gas produced by the digester will be measured by using a water displacement technique. The volume of the gas produced by the digester was compared to the theoretical value. According to [12], Buswell approach can be used to calculate total biogas production based on the amount of food waste as following;

$$C_xH_yO_z + (x - y/4 - z/2)\ H_2O \rightarrow (x/2 + y/8 - z/4)\ CH_4 + (x/2 - y/8 - z/4)\ CO_2 \quad (1)$$

RESULTS AND DISCUSSIONS

Out of 100 participants, 89% of participants aware of the fossil fuel depletion on earth while 11% of the participants are still unaware of the fossil fuel depletion on earth. Respondents are likely to be aware of fossil fuel depletion. But some still did not see or read the news. The percentage was somehow very low so it was easy to promote the need for biogas and biogas digester. It is important for people to understand the status of current world fossil fuel so that people can understand the importance of biogas Meanwhile, 63% of participants agree that alternative energy source is important while 30% of the participants agree that it is very important followed by 7% of the participants who agree that it is less important. Most of the respondent who aware of the fossil fuel depletion agrees that it is important to have an alternative energy source and a large portion of them responded that it is very important. Some of the respondent who agreed that alternative energy source is less important maybe those who are not aware of fossil fuel depletion. In terms of affordability, 86% of participants agree that it is very important while 12% of participants agree that it is important followed by 5% of participants who agree that it is less important. Most of the participants chose that affordable price for the biogas digester is very important. This is because everyone wants something at the lowest price so they can have them in their home. A big portion of the participants also said it is important while only 2% of the said it is less important. This is because most of the participants are from standard single-story houses so their salary may not be high enough to afford the small scale digester but the minority of the participants may get salary high enough that the price is not a big issue. On the amount of waste produced, 45% of participants answered that they throw away less than 0.5kg of waste food every day while 36% of the participants answered that they throw away between 0.5kg to 1.5kg of waste food every day followed by 18% of participants who answered between 1.5kg to 2.5kg and the least at 1% answered that they throw away more than 2.5kg of waste food per day. This question was to analyse the waste dumping per day at a house in relation to build a proper small-scale digester which is suitable for home application. So, this is a positive response since the biogas digester is for small scale applications. But a second large number of participants also throw 0.5 to 1.5kg of waste food every day. So, this also will have to be taken into consideration since more people can use the small-scale biogas digester the better the impact on the environment and community.

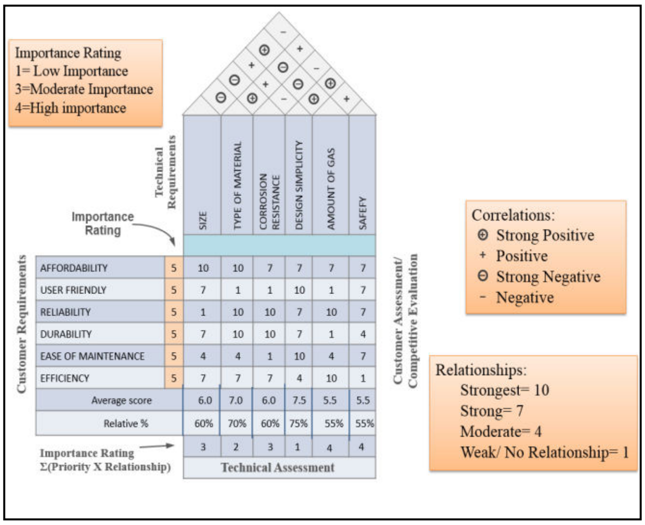

Figure-1. House of quality on small scale biogas digester.

Based on Figure-1, design simplicity should be given the highest priority followed by the type of material, size & corrosion resistance, and the lowest priority for the amount of gas produced & safety. The next stage of the design and development of the prototype was based on this priority ratings. The correlation between each technical requirement was also identified which is plotted in the form of strong positive, positive, negative, and strong negative. The correlation between technical requirements is also a vital part of the prototype design and development. The correlation will decide on how big the impact of one technical requirement on other technical requirements. If there is a positive relationship, both technical requirements should be taken into consideration when doing design in contrast with the negative correlation where it does not need consideration of both technical requirements. For instance, the type of material and corrosion resistance have a strong positive correlation because different materials react differently in terms of corrosion. Some may corrode fast, some may corrode slowly while some do not corrode at all. So, it is important to select the best material that has resistance against corrosion depending on the application and environment.

Based on the Pugh method ratings from Table 1, it shows that the overall sketch designs have a great advantage over the datum in terms of material cost and development cost. The results show that the total of disadvantage is the least for Concept 3. At the same time, it also has the highest advantage over the other concepts. Meanwhile, Concept 1, 2, and 4 ties with similar advantages and disadvantage ratings. Since concept 3 has the highest advantage compared to the other two concepts, it was selected for the prototype development.

Table-1. Pugh method.

Criteria	Sketch Design 1	Sketch Design 2	Sketch Design 3	Sketch Design 4	Datum
Design simplicity	-1	+1	-1	+1	D
Development cost	+1	+1	+1	+1	
Gas production	-1	-1	-1	-1	A
Material cost	+1	+1	+1	+1	
User friendliness	-1	-1	-1	-1	T
Durability	+1	-1	+1	-1	
Reliability	-1	-1	+1	-1	U
∑ SUM +	3	3	4	3	M
∑ SUM -	4	4	3	4	

is being done, there were a few important data

Table-2. Daily biogas production in volume.

Day	Volume of Gas (L)
1	1.203
2	1.892
3	2.366
4	2.608
5	2.860
6	3.641
7	4.133
8	4.828
9	5.365
10	6.852

The volume of biogas produced using 4 kg of waste food consisting of chicken meat was recorded for ten days continuously as shown in Table-2. The monthly temperature of October 2019 in Malaysian is around 31°C to 34°C based on Trading Economics, Malaysia Average Temperature. The month of October is the period at which the anaerobic digestion for biogas production occurred. According to [13], the type of digestion occurred in the biogas digester is mesophilic digestion. This is because mesophilic digestion occurs efficiently around 30 to 38 ° C or at 20 to 45 ° C ambient temperatures, where the predominant microorganisms are mesophiles. The digester started producing gas after twelve days from the time the feedstock was fed. The time for initial biogas digesting if affected by too many factors namely pH, size, temperature, amount of initial acids, salt, toxic, contaminants, etc [14]. Since there is no proper tool to study all these factors, the time taken for initial gas production was not taken into the scope of research. The cumulative volume of biogas produced for ten days are as shown in Figure-2. The volume of biogas was recorded at 5 pm each day where the sun starts to set off and the surrounding temperature is lower. The purpose of taking the data at the same time is so that the measurement taken is exactly after 24 hours for each day.

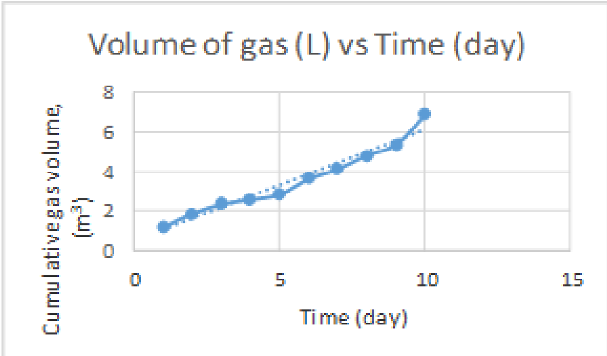

Figure-2. Cumulative biogas volume vs time.

Based on Figure-2, the trend line shows a linear correlation of the cumulative biogas volume with time. The biogas production for ten days was at a steady rate which produces almost the same volume of biogas each day. There are some noticeable increase and decrease in the overall biogas production pattern. The highest decrement can be observed at biogas production of day 5 while the highest increment can be observed on day 10. The temperature of the surrounding played a primary role in the increment and decrement of biogas production. According to [15], the higher the digester temperature, the greater the rate of biogas production. On day five, the decrement may have been caused by the specific temperature of the day. There was heavy raining for several hours during the daytime. This has caused the digester temperature to drop to a certain degree and causing a slight drop in the rate of production on a specific day. While the increment of the biogas may be caused by the highest temperature of the month where the temperature is slightly higher than the temperature of the other days. The graph trend or pattern from the data of the prototype was also compared with the data of other sources. Figure-3 shows the graph of the biogas production rate over the incubation time according to research by [16].

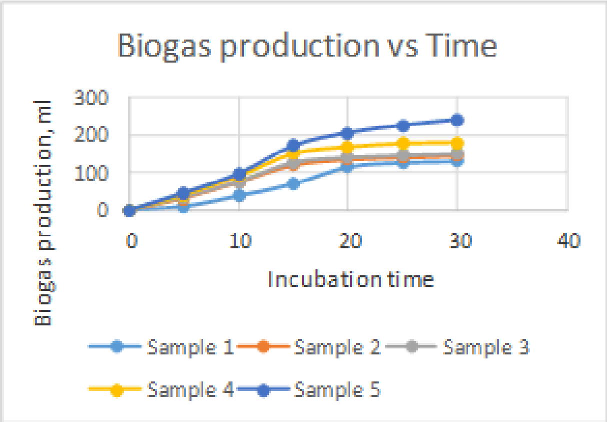

Figure-3. Relationship between biogas production and incubation time.

The graph shows that the trend line of biogas production over time is in a linear pattern. The study was done using five different samples. Sample 1 until Sample 5 used are duckweed, cow dung, food waste, corn straw, and sewage sludge respectively. There are 400g of feedstock used for each sample in a 1-liter bottle. The graph trend line is very steady because the incubation is done at a constant mesophilic temperature which is at 35°C. The graph shows that, for most of the feedstock, there is a steady rate of biogas production until it reaches day 15. After day 15, the rate of biogas production is dropping until it stops producing biogas after a certain amount of days. When compared to the test data of the prototype using 4kg of chicken meat, it shows a similar biogas production rate or trend line but in a higher volume due to higher feedstock input. Since the data of the testing was only taken for the first ten days, the drop in the biogas production could not be observed. The prototype test data is predicted to take a longer time to complete its gas production since the total amount of feedstock is in a far higher amount. But after a certain amount of days, the biogas production should be slowing down and stops eventually in a similar pattern to the compared graph.

To predict the time the biogas production will stop, the total amount of biogas was calculated using the Buswell equation. Chicken meat consists of 75% water, 20% protein, and 5% fat where the mass of the meat is 3000g, 800g, and 200g respectively. The water in the meat can be ignored since it does not produce biogas. The amino acid is made of various substrates such as glycine, proline, valine, lysine, etc [17]. The number of methane and carbon dioxide mole was taken on average. The average number of moles was also taken for the fat because it is made of two substrates which are hydrogen and carboxyl. According to [18], the typical composition of biogas produced by fat is 67% methane and 33% carbon dioxide while protein is 70% methane and 30% carbon dioxide. Compared to other substrates, protein and fat produce a considerably higher amount of methane. The estimated time taken for the 4kg meat to complete its biogas production takes about 502 days which is a year and 135 days. The actual biogas production will always be lower than the theoretical calculation due to various external and internal factors [19]. The digester has to be continuously fed with feedstock so that it can continue to produce a higher volume of biogas and a constant rate because the rate of production will decay over time.

1m^3 of biogas contains approximately 6 kWh of heat energy. Since the biogas production from the prototype is for small scale applications, it could not generate enough energy for electrical appliances. Based on this statement, the prototype cumulative biogas produced for ten days lasts for less than 1 minute. So, it should produce flame longer compared to stoves but in contrary produces less heat. To cook for several hours the amount of feedstock has to be increased considerably. The hydraulic retention time (HRT) is also an important factor that has to be considered. The hydraulic retention time is the time required for the influent feed to spend inside the digester. The hydraulic retention enables the digester to produce more efficiently up to 40% [20]. The HRT was calculated using the basic HRT formula. Since meat is made up of 75% of water, only 25% of meat is considered to be solid. The meat has to be made as a substrate (meat + water) so that substrate has 4% - 8% solid content. Water is added to the meat so that the percentage of solid of the feedstock is reduced to 4% - 8% solid content which is necessary to determine the amount of feed inside digester in volume. Adding 3.68 liters of water will cause the solid content percentage drop to 8%. To produce an effective biogas production to a significant amount, an HRT of 33 days is required for the prototype with 4kg of meat as feedstock.

CONCLUSIONS

Methane production is highly influenced by the surrounding temperature. The higher temperature produced a larger volume of methane. Malaysian weather temperature causes mesophilic digestion in the digester tank, which is slower compared to thermophilic digestion but for that, custom made environmental temperature is required. The design can be used as biogas harvester for small scale applications, which produced more than 6-liter gas in 10 days. For future works, the longer incubation time can be considered to get the overall trends of methane production.

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