Hydrothermal pre-treatment of hospital food waste for efficient bio-methane generation

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Abstract. Municipal solid waste management (MWM) in Malaysia has become a challenging task in recent years due to the growth of population, industrialization and an increase in quantity and variation in the types of waste generated. Major solid waste generated in Malaysia is organic waste which includes mainly food waste from households, food processing facilities, markets, food and beverages industry and hospitals. Therefore, it is crucial to identify ways to manage food waste (FW) properly and improve the energy recovery efficiency. This paper is aimed to study the impact of pre-treatment on food waste from Hospital Pakar Sultanah Fatimah (HPSF) as a method to decompose FW faster and to determine the potential of bio-methane generation. A compositional study showed that total solid waste generated was 2,301 kg with 67% waste from lunch followed by 31% from breakfast sessions daily. Hydrothermal pre-treatment was done using a Multipurpose Recycling Machine (MRM) at 1.6MPa for 15 minutes followed by anaerobic digestion with and without the inoculum addition. Un-treated FW with inoculum was used as control in this experiment. It was found out that at a controlled pH of 7, hydrothermal pre-treatment and addition of inoculum i.e. cow manure played an important role in anaerobic digestion process for enhancement of bio-methane production. It significantly reduced the lag phase by 4 days and produced biogas faster compared to non-treated FW and hence, increased the biogas volume up to 638.53 mL compared to 504.08 mL in non-treated FW at the same experimental conditions. Therefore, this study signified that hydrothermal pre-treatment is an effective and a beneficial technique added to the waste through the generation of biogas energy.

1 Introduction
Solid Waste Corporation Malaysia (SW Corp), reported that 17,000 tonne of organic waste mainly food waste was generated daily; which could feed around 1,300 persons three times daily. Food waste (FW) mostly contain carbohydrate polymers, lignin, proteins, lipids, organic acids and a smaller inorganic portion. The most common type of waste disposal is landfilling and most landfills in Malaysia are still at low sanitary levels in terms of leachate treatment, gas venting and lining system [1].

Technology based alternatives like anaerobic digestion (AD) which is eco-friendly could play a role to convert these FW to energy or products. It was reported by Deepanraj et al. [2] that, AD with substrate maintained at pH 7 resulted better biogas yield and at mesophilic temperature portrays high methanogenic activity which contributed to the efficient bio-methane generation. Besides that, the approach of co-digestion also helps in balancing the nutrients inside the digester. According to Panigrahi et al. [3], the biogas generation increased up to 48.7% compared to the untreated substrate. Therefore, due to the massive amount of daily food waste, pre-treatment should be done to shorten the AD process and also increase the efficiency of energy recovery. Among the four stages in AD, hydrolysis is the slowest and is therefore the rate determining step [4]. According to Panigrahi et al. [3], the biogas generation increased up to 48.7% compared to the untreated substrate. Therefore, due to the massive amount of daily food waste, pre-treatment should be done to shorten the AD process and also increase the efficiency of energy recovery. Among the four stages in AD, hydrolysis is the slowest and is therefore the rate determining step [4].

Hydrothermal treatment is considered to be one of the most environmentally friendly processes to shorten and enhance the hydrolysis process [5]. Pre-treatment is essential to expose and accelerate the cellulose and hemicellulose content in the food waste for enzymatic hydrolysis and bacterial attacks and hence increase the bio-methane (CH₄) yields [4][6]. Temperature and residence time are crucial operating parameters of hydrothermal treatment as it will resulted in greater cellulose degradation. As mentioned in Dasgupta and Chandel [7], greater methane yield at moderate treatment temperature around 90°C whereas temperature more than 180°C decreased the biodegradability of substrates and created detrimental impacts for the bio-methane generation.

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Nevertheless, this process is complex where all substrates are digested in order to produce the substrate for the next phase reaction. This requires a stable environment for the different microbial growth. Therefore, it is important to maintain the key parameter especially the pH value so that the digestion process is within the correct range so that the operation is efficient [5][8] for the production of bio-methane. Hence, it is essential to investigate the effect of hydrothermal pre-treatment before AD process to determine the production efficiency of bio-methane at various conditions.

2 Methodology

The food waste (FW) collected from Hospital Pakar Sultanah Fatimah (HPSF), Muar which comprises of waste from food preparation and left over from breakfast and lunch sessions. The indigestible materials such as plastics, bones and papers were manually removed. The activity was conducted during pandemic COVID-19. Hence, the sampling activity complied in accordance to the Standard Operating Procedure (SOP) instructed by Kementerian Kesihatan Malaysia (KKM) with personal protective equipment (PPE) including gloves, masks and antibacterial hand soap and sanitizer. The FW measured covered 550 in-patients except for the high risk group. The weight of the cooked and uncooked FW were recorded and tabulated accordingly in order to identify the daily production of FW and to determine the percentage of FW from the total solid waste generated, respectively.

The FW was then pre-treated under subcritical water conditions using Multipurpose Recycling Machine (MRM) for 15 minutes at 1.6 MPa. The pre-treated FW was further finely blended to ensure the homogeneity for anaerobic digestion (AD) process. Cow manure (CM) was used as the inoculum in order to enhance the production of biogas because it contained high amount of nitrogen and also acts as the buffer to maintain the pH around 7 to provide optimum condition for the microbe to be active.

Three different substrates of AD were studied which are untreated FW, pre-treated FW with and without inoculum. The bioreactor was flushed with nitrogen to ensure anaerobic condition and incubated at mesophilic temperatures of 37°C for a maximum of 30 days. A long incubation period was necessary to account for the long lag phases observed in the biogas production [9]. The pH condition of the medium is adjusted and maintained at pH 7 with 3M NaOH as the initial pH of the FW is highly acidic. The biogas produced was analysed using micro gas chromatography in order to measure the volume of biogas generated. Figure 1 shows the methodological framework of this study and Table 1 shows the details of the anaerobic batch reactors operated in this research.

Fig. 1. Methodological framework of the study

Table 1. Anaerobic batch reactors composition

<table>
<thead>
<tr>
<th>Reactor name</th>
<th>Pre-Treat</th>
<th>Feedstock used</th>
<th>Inoculum ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-treated FW</td>
<td>YES</td>
<td>FW</td>
<td>1:10</td>
</tr>
<tr>
<td>Pre-treated FW+CM</td>
<td>YES</td>
<td>FW+CM</td>
<td>1:10</td>
</tr>
<tr>
<td>Untreated FW+CM</td>
<td>NO</td>
<td>Untreated FW+CM</td>
<td>1:10</td>
</tr>
</tbody>
</table>

3 Results and discussion

The total FW generation comprised of uncooked waste (from food preparation) and cooked waste (from patient trays) was 2,301 kg. The majority waste comes from the kitchen during the food preparation with 1,292 kg of waste and the FW generation rate expressed in kg/bed/day is estimated at 0.17 kg which was higher compared to FW from breakfast and lunch sessions estimated from food trays at 0.04 kg/bed/day and 0.09 kg/bed/day, respectively as mentioned in Table 2. From this findings, it is proven that FW from hospitals are also one of the main contributors in generation of organic waste and therefore, it is essential to promote the importance of reducing and reuse of the organic waste by transforming them into alternative energy.

Table 2. Food Waste Generation in Hospital Pakar Sultanah Fatimah (HPSF)

<table>
<thead>
<tr>
<th>Category</th>
<th>Waste generation (kg)</th>
<th>Generation rate (kg/bed/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>FW from Preparation</td>
<td>1,292</td>
<td>0.17</td>
</tr>
<tr>
<td>FW from Breakfast</td>
<td>312</td>
<td>0.04</td>
</tr>
<tr>
<td>FW from Lunch</td>
<td>677</td>
<td>0.09</td>
</tr>
</tbody>
</table>

The collected FW was slightly acidic with pH in the range of 5.67 to 6.27. Hence, the collected hospital FW was hydrothermally pre-treated and adjusted in pH value as these factors could affect the volume of biogas generation. Table 3 shows the data of biogas and biomethane (CH₄) volume at adjusted pH on the un-treated and treated FW. As mentioned by Zhang et al. [10], one of its system instability is caused by rapid conversion by easily digestible FW of organic acid in acidogenesis phase to volatile fatty acid in early stage. This scenario caused pH to drop if no buffering agent is presented in order to neutralize the medium to optimum process.
temperature. Therefore, the pH was adjusted between pH 7 to 8 to reduce inhibition of microbial activities required for biogas production.

<table>
<thead>
<tr>
<th>Sample</th>
<th>pH Before</th>
<th>pH After</th>
<th>Biogas Volume (mL)</th>
<th>CH$_4$ Volume (mL)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-treated FW</td>
<td>5.67</td>
<td>7.00</td>
<td>158.85</td>
<td>40.49</td>
</tr>
<tr>
<td>Un-treated FW+CM</td>
<td>6.27</td>
<td>7.00</td>
<td>504.08</td>
<td>182.54</td>
</tr>
<tr>
<td>Pre-treated FW+CM</td>
<td>5.75</td>
<td>7.76</td>
<td>638.53</td>
<td>226.52</td>
</tr>
</tbody>
</table>

Table 3. Biogas and Bio-methane production in mL after 30 days digestion

It can be seen that hydrothermal pre-treatment has a significant influence on the biogas volume up to 638.53 mL with 226.52 mL of CH$_4$ gas. Therefore, it is without a doubt that this pre-treatment is beneficial in hydrolysing complex organic matter and thereby enhancing its biodegradability that led to increase in biogas generation during anaerobic digestion [7]. Addition of CM as inoculum also helped the biogas volume to rise from 158.85 mL to 638.53 mL, accordingly as seen in pre-treated FW with and without CM addition.

It was also found that pre-treated FW with and without inoculum generated CH$_4$ almost immediately i.e. after 2 days of digestion as shown in Figure 2 as compared to 6 days for untreated FW. The biogas trend increased until 28 days of digestion before it reached a stationary phase. The short lag phase recorded indicated the fact that the microbes in the feedstock adapted easily for the AD process to begin the biogas production [11]. This also due to the effect of hydrothermal pre-treatment towards the organic matters where it enhanced the solubilisation and subsequent degradation during digestion process, higher CH$_4$ yield and reduce overall digestion time as reported by Dasgupta and Chandel [7]. This method also enhanced the substrate characteristics and augmenting hydrolysis reaction in order to attain higher CH$_4$ yield and reduce overall digestion time as seen in pre-treated FW with inoculum with total CH$_4$ volume of 226.52 mL.

4 Conclusion

In this investigation, it was shown that food waste is generated daily not only from households but also from the service industries like hospitals. This is reflected by the significant amount of uncooked FW with 56% followed by the cooked FW with 44% produced. Therefore, in order to manage the biodegradable waste properly, hydrothermal pre-treatment of food waste proved to be an alternative way to enhance the biogas generation within 2 days up to 638.53 mL by the end of 28 days. As such, we propose that the local authority and industries handling waste should consider technological alternative such as the combination of hydrothermal pre-treatment and AD to continuously reduce the landfilled FW and recover higher energy.

The authors express highest gratitude to Hospital Pakar Sultanah Fatimah (HPSF) for allowing us to conduct the sampling activities in Jabatan Dietetik dan Sajian (JDS) for 14 days during the pandemic situation.

References

7. A. Dasgupta, M.K. Chandel, Enhancement of biogas production from organic fraction of...


