Impact of Organic Loading Rates of Waste Water from Broilers’ Manure on CSTR Biogas System

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This research examines the impact of Organic Loading Rates (OLRs) on a Continuous Stirred Tank Reactor (CSTR) biogas system from the waste water of broilers’ manure. The CSTR biogas system is comprised of a 12 m³ raw material mixing tank, a solid/liquid separator, a liquid tank, a 60 m³ reactor, a 15 m³ biogas balloon, and a biogas flare system. The experiment was performed by examining the changes in the organic loading rates from 1.0, 1.5, 2.0, 2.5, 3.0, 3.5, and 4.0 kg-COD/m³-day. The following parameters of the waste water were measured in order to monitor and control the biogas system: 1) pH, 2) the temperature, 3) the alkalinity, 4) the Volatile Fatty Acids, 5) the Chemical Oxygen Demand (COD), 6) the Total Solids, 7) the Total Dissolved Solids, and 8) the Suspended Solid & Volatile Solid (VS). From the experiment, it was found that the average biogas production was 19.34 m³/day and that the average biogas production rate was 0.30 m³/kg-COD or 0.35 m³/kg-VS. The composition of the biogas was methane (62.37%) and carbon dioxide (31.33%). In addition, the results showed that the production rate regarding the volume of biogas increased as the OLRs increased, then decreased after the Organic Loading Rates reached 3.0 kg-COD/m³-day. The appropriate organic loading rate for operating the CSTR system was found to be 3.0 kg-COD/m³-day, which yielded the maximum biogas production rate for the system.

Keywords: Organic Loading Rates, Broilers’ Manure, CSTR Biogas System

Introduction

Our study conducted at livestock farms revealed that wastes generated from the livestock industry in Thailand can be used to produce biogas. However, what remains missing is the in-depth information regarding the efficiency of biogas system control. From the assessment, it was found that various types of feedstock waste1 can be used in biogas production, such as pig slurry, cow slurry, chicken manure, farmyard manure, harvest remains, and garden wastes including energy crops, wastes, and waste water from industries related to agriculture. Studies have been conducted on the following: 1) wheat straw as a raw material in biogas production by the CSTR and UASB methods2, 2) biogas production from banana stalks, cabbage stems, and coriander by an anaerobic system in a moderate-temperature laboratory3, and 3) methane gas production from organic wastes from community sludge and food residues4. Ten factors have been found that can control the efficiency of biogas production, i.e., temperature, pH, alkalinity, volatile fatty acids, the organic loading rate, toxic substances, retention time, total solids content, mixing, and nutrients. By managing these factors, the efficiency of the biogas production system can be enhanced. Furthermore, we found that the initial COD concentration, metallic nutrients, and food supplements have an effect upon the microorganisms and the temperature of the decomposition of the organic matter. This increases the efficiency of organic decomposition5. In order to assess if biogas system could be more efficient, studies have been conducted on the impact that changes in the organic loading can have on biogas production efficiency6. Similarly, it was shown that in biogas production from chicken manure and wheat straw, different temperatures and rates of organic loading had an effect on the rate of formation of the biogas and the methane gas7. Many previous research studies have examined the organic loading rates (OLR) and their effects upon biogas production, such as the effect of OLR on the production of methane from the anaerobic digestion of vegetable wastes8, the anaerobic digestion of municipal solid waste as a treatment prior to landfill9, the anaerobic digestion of organic municipal solid waste9, the semi-continuous co-digestion of solid slaughterhouse waste, manure, fruit & vegetable waste10, the anaerobic digestion of waste food and animal manure11, and the anaerobic digestion of the Barcelona Central Food Market organic wastes10. However, there are no results to be found in the literature on the effects

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of OLR to biogas production from broilers' manure because no studies have been conducted. As a result, this paper will examine the effects of OLR on biogas production from broilers' manure in order to improve the efficiency of biogas production. Presently, Thailand is seeing an expansion in manufacturer farming and broiler farming. However, due to complications in obtaining broilers' manure, only a few farms have biogas production systems. Nevertheless, in the process of obtaining biogas from broilers’ manure, added steps in processing are required in order to separate the rice husks contained in broilers’ manure. This makes the production process more complicated. Currently, the biogas production from broilers’ manure has just begun to be studied in Thailand. More studies are now being undertaken to explore CSTR biogas production from broilers’ manure. However, the problems, encountered with the control system for biogas production, were the adjustment factor control parameters used for maximizing the efficiency of the system. The control of the organic loading rates in the CSTR reactor affected the performance of the biogas generated from the broilers’ manure. Hence, this study has been undertaken to examine the impact that changes in the concentration of COD in the CSTR biogas process have had in the form of organic loading rates from the waste water of broilers’ manure. The concentration of COD from waste water of broilers’ manure with respect to changes in the CSTR biogas production system was investigated. The suitable organic loading rate was studied from the waste water of broilers’ manure to obtain the greatest possible efficiency of system by controlling the various concentrations of COD. In order to gain control of biogas production, these parameters were then analyzed so that the biogas could be truly utilized. Then the amount of broilers’ manure could be determined to provide adequate energy production to meet the farm’s demands.

Experimental devices and methods

Waste sources and characteristics

In this study, the broilers’ manure, which was used for experimentation, had been brought from a chicken farm in Lopburi Province, Thailand. At the farm, rice husks had been laid on the ground which resulted in a mixture of broilers’ manure and husks. Before the manure could be utilized for producing biogas, the husks had to first be removed. From the study, the researchers found that the ratio of chicken manure and husk was 30:70 per farm unit. The first step in the experiment was to prepare the waste water by using a mixture of chicken manure and water at a ratio of 1:4 by volume in a mixing tank for a period of 30 minutes. The husks were then removed using the solid/liquid separator. The obtained waste water was fed into the biogas fermentation pond.

Experimental set-up

This biogas production from broilers’ manure was studied by means of the Continuous Stirred-tank Reactor (CSTR), as shown in Figure 1. The CSTR biogas system consists of the following parts: 1) the raw material mixing tank, 2) the solid/liquid separator, 3) the liquid storage tank, 4) the fermentation reactor, 5) the sludge tank, 6) the biogas balloon, and 7) the biogas flare system. In the experiment, a 12 m³ mixing pond, a 60 m³ reactor, and a 10 m³ sedimentation tank were used to collect excess sludge from fermentation. In addition, a 15 m³ gas balloon was used to collect the biogas from broilers’ manure in the reactor.

Organic loading rate and operating set-up

COD is an important factor affecting the rate of biogas formation from the manure of chickens. The COD removal of the biogas system is related to the biogas production as well. Studies, focusing on biogas production, have shown that by increasing the organic loading rates (OLRs) can lead to an increase in biogas production. As a result, a study of increasing of the organic loading rates (OLRs) from 1.0, 1.5, 2.0, 2.5, 3.0, 3.5, and 4.0 COD kg/m³-day has been examined for biogas production to determine the appropriate of organic loading rates (OLRs).

Experimental method

The experiment began by charging the prepared waste water into the CSTR biogas reactor. Parameters, such as pH, Temperature, Alkalinity (Alk), Volatile fatty acids (VFA), Chemical Oxygen Demand (COD), Total Solids (TS), Total Dissolved Solids (TDS), Suspended Solids (SS), and Volatile Solids (VS) of the waste water were measured at the Environmental Laboratory of Khon Kaen University before the waste water was fed into the system. When the COD concentration for each batch of broiler manure was known, the daily amount of waste water, which was fed into the system, was calculated in order to predetermine the OLR. The average volume of the waste water is shown in Table 1. Next, the calculated amount of waste water was pumped into
the fermentation tank (or reactor), and the process of continuous stirring was begun. As the biogas was produced, the biogas production rate was recorded each day. This was done by an in-pipe flow sensor, and the amount of biogas production was measured using a biogas analyzer (Geo-tech Biogas 5000) in a gas balloon. Experiments were performed on each of the organic loading rates for 7 days. Then the OLRs were changed according to the initially set parameters at 1.0, 1.5, 2.0, 2.5, 3.0, 3.5, and 4.0 COD kg/m$^3$-day. In order to calculate the amount of waste water to be fed into the reactor, other parameters were checked every day. Experiments based on OLRs were conducted for the purposes of studying the impact of COD concentrations on biogas production system and analyzing the efficiency of the system.

Results and Discussion

Biogas production

The main objective of this research was to increase the efficiency of biogas production from broilers’ manure by changing the organic loading rates in order to determine the most suitable organic loading rates in CSTR biogas production from the broilers’ manure. The major purpose in evaluating the biogas formation efficiency is to study the impact that changing the organic loading rates has on the rate of biogas formation in the CSTR system. Experiments showed that with the increased organic loading rates, the daily formation of biogas had a tendency to increase. The system was set to operate for 7 days to find the average of each the organic loading rates. The amount of waste water was added into the reactor on a daily basis.
basis. The volume of waste water was changed every day due to the different values of COD for each batch of the broiler manure. At the organic loading rates of 3.5 and 4.0 kg-COD/m³-day, the volume of waste water was about double to that of the others due to the low inlet COD as shown in Table 1. The amount of fed waste water was calculated by the relationship between the OLRs and COD. From the experiment, with organic loading rates from 1.0, 1.5, 2.0, 2.5, 3.0, 3.5, to 4.0 kg-COD/m³-day, the average biogas production rates were 8.44, 11.20, 14.31, 17.12, 22.87, 26.97 and 34.48 m³/day, respectively. The results showed that the different amounts of waste water had an effect on the amounts of biogas production. It was also found that there was an increase in the amount of biogas production as the OLRs increased. The average biogas production for each of the OLRs increased stepwise as shown in Figure 2.

**Performance characteristics**

The pH parameters from the reactor were found to be in the range of 7.55 - 8.34. These were found to be neutral as a result of organic decomposition. The VFA concentration in the reactor ranged from 5,000 - 13,000 mg/l, and the alkalinity in the reactor was from 3,000-8,000 mg/l. When organic loading rates ranged from 1.0 to 3.0 kg-COD/m³-day, all parameters increased, and then decreased after the organic loading rate became 3.5 kg-COD/m³-day. The average temperature of waste water in the reactor ranged from 31-35 degrees Celsius. This is the temperature range that best enables the anaerobic decomposition of organic matter. The ratio of Alk/VFA of the waste water in the reactor was from 0.15 - 0.22. The standard parameters of Alk/VFA for operation of biogas production in the reactor did not exceed 0.25 for stability of biogas production13, as shown in Table 1.

In the reactor, COD parameters are very important since they are used for analyzing and controlling the production of biogas. In the experiment, it was found that the average COD value of waste water before entering the system was 40,034 mg/l and that the average COD value of waste water in the reactor was 11,723 mg/l. The average COD value of the waste water in the sludge tank was 11,681 mg/l. The results showed that when the organic loading rates ranged from 1.0 to 3.0 kg-COD/m³-day, and the changes in the COD rates were relatively constant when a comparison of the waste water was done before it entered the system and after it has been placed in the reactor. This means that the biogas production system was stable and that the operation was efficient. However, at organic loading rates ranging from 3.5 to 4.0 kg-COD/m³-day, there was a decrease in the COD parameters between waste water before it enters the system and after it had been placed in the reactor. An average of the anaerobic organic decomposition of the biogas system and the biogas production are shown in Table 2.

**Process efficiency**

The impact of the organic loading rates on the efficiency of the biogas production process was considered from the percentage of VFA, COD, SS, and VS reduction. These parameters became the indicators for efficiency assessment at each of the

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**Table 1** — Biogas Production and Biogas Production Rates

<table>
<thead>
<tr>
<th>Organic Loading Rates (kg-COD/m³-d)</th>
<th>Chicken Boilers’ Manure (ton/d)</th>
<th>Biogas Production (m³/d)</th>
<th>Biogas Production Rate (m³/kg-COD)</th>
<th>Biogas Production Rate (m³/kg-VS)</th>
<th>BP/CBM (m³/ton-CBM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.00</td>
<td>0.50</td>
<td>8.44</td>
<td>0.35</td>
<td>0.27</td>
<td>16.88</td>
</tr>
<tr>
<td>1.50</td>
<td>0.77</td>
<td>11.20</td>
<td>0.31</td>
<td>0.30</td>
<td>14.55</td>
</tr>
<tr>
<td>2.00</td>
<td>0.85</td>
<td>14.31</td>
<td>0.25</td>
<td>0.35</td>
<td>16.84</td>
</tr>
<tr>
<td>2.50</td>
<td>0.79</td>
<td>17.12</td>
<td>0.16</td>
<td>0.24</td>
<td>21.67</td>
</tr>
<tr>
<td>3.00</td>
<td>0.96</td>
<td>22.87</td>
<td>0.19</td>
<td>0.27</td>
<td>23.82</td>
</tr>
<tr>
<td>3.50</td>
<td>1.81</td>
<td>26.97</td>
<td>0.41</td>
<td>0.30</td>
<td>14.90</td>
</tr>
<tr>
<td>4.00</td>
<td>1.66</td>
<td>34.48</td>
<td>0.42</td>
<td>0.69</td>
<td>20.77</td>
</tr>
<tr>
<td>Average</td>
<td></td>
<td>19.34</td>
<td>0.30</td>
<td>0.35</td>
<td>18.49</td>
</tr>
</tbody>
</table>

Remarks: CBM = Chicken Boilers’ Manure
predetermined organic loading rates. The set organic loading rates in the experiments were 1.0, 1.5, 2.0, 2.5, 3.0, 3.5, and 4.0 kg-COD/m³–day, respectively. The average percentage of VFA, COD, SS, and VS reduction are shown in Figure 3. It was found that at the organic loading rates of 1.0 to 3.0 kg-COD/m³–day, the percentage of COD reduction was in the range of 60 - 80 %. This indicated that the COD had been removed and had become biogas. When the OLRs increased, the volume of biogas production increased. However, when the OLR was at 3.5 kg-COD/m³–day, the percentage of COD reduction dropped below 60 percent, which means that the COD was less removed than that of the low OLRs. From this study, the production rates of the biogas and percentages of methane content are shown in Table 3 and have been compared to that of other waste water. The maximum biogas production rate, which was yielded from the organic loading rate of 3.0 kg-COD/m³–day, is shown in Figure 4.

### Table 3 — Performance Data of Different Anaerobic Processes

<table>
<thead>
<tr>
<th>Substrate</th>
<th>Organic loading rates (kg VS/m³.d)</th>
<th>Biogas yield (m³/kg VS)</th>
<th>Methane (%)</th>
<th>Reduction (% of VS)</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chicken Broiler Manure</td>
<td>2.34</td>
<td>0.27</td>
<td>62</td>
<td>64</td>
<td>This study</td>
</tr>
<tr>
<td>Organic fraction of municipal solid wastes</td>
<td>0.8</td>
<td>0.26</td>
<td>60</td>
<td>61</td>
<td>[8]</td>
</tr>
<tr>
<td>Municipal solid wastes</td>
<td>2.5</td>
<td>0.38</td>
<td>61</td>
<td>70</td>
<td>[9]</td>
</tr>
<tr>
<td>Fruit and vegetable wastes</td>
<td>0.3-1.3</td>
<td>0.3</td>
<td>54-56</td>
<td>67</td>
<td>[10]</td>
</tr>
<tr>
<td>Vegetable wastes</td>
<td>1.4</td>
<td>0.4</td>
<td>64</td>
<td>88</td>
<td>[13]</td>
</tr>
<tr>
<td>Fruit and vegetable wastes</td>
<td>1.6</td>
<td>0.47</td>
<td>65</td>
<td>88</td>
<td>[14]</td>
</tr>
</tbody>
</table>

Fig. 3 — VFA, COD, SS, and VS reduction for various organic loading rates

Fig. 4 — The biogas production with broilers’ chicken manure at various organic loading rates

### Biogas Production per chicken broilers’ manure (BP/CBM)

Biogas production and amount of biogas production rate from organic loading rates changes were shown in Table 2. It was found that the organic loading rates of 1.0 - 3.0 kg-COD/m³–day and biogas production from the broilers’ chicken manure (BP/CBM) increased and then decreased at the organic loading rates of 3.5 to 4.0 kg-COD/m³–day. The biogas production rate per broiler chicken manure was the highest at the organic loading rate of 3.0 kg-COD/m³–day. It was found that the average biogas production was 19.34 m³/day and that the...
average biogas production rate was 0.30 m$^3$/kg-COD or 0.35 m$^3$/kg-VS, as shown in Table 2. A comparison of the biogas production rate from other raw materials is shown in Table 3. The average biogas production rate from the broilers’ manure was 0.35 m$^3$/kg-VS which is close to that of municipal solid waste.

The biogas composition
CSTR biogas production is a biogas fermentation system with constant efficiency. From our experiments, biogas components have illustrated the following: 1) the average methane concentration in the biogas was 62.37%, 2) the average carbon dioxide concentration in the biogas production was 31.33%, and 3) the average hydrogen sulfide concentration in the biogas production was 2.862 ppm. When the methane concentration was compared to material from other biogas production, it was shown to have similar results as shown in Table 3.

Conclusion
This research was conducted on the impact of the change of COD concentration from the waste water of broilers’ manure in CSTR biogas production. In order to achieve the maximum biogas production rate, the appropriate organic loading rates (OLRs) were studied. The experiments were conducted with the organic loading rates ranging from 1.0 to 4.0 kg-COD/m$^3$–day with an increase of 0.5 kg-COD/m$^3$–day. The averages of the related parameters were then calculated. The results showed that the pH, VFA, and alkalinity changed in similar directions. All parameters were increased at the organic loading rates of 1.0 to 3.0 kg-COD/m$^3$–day and were then decreased after the organic loading rates of 3.0 kg-COD/m$^3$–day. The percentages of VFA, COD, SS, and VS reduction tended to decrease until the organic loading rate became 3.0 kg-COD/m$^3$–day. It was also found that the average biogas production was 19.34 m$^3$/day, and that the production rate of biogas was 0.30 m$^3$/kg-COD or 0.35 m$^3$/kg-VS. The average concentration of methane was 62.37%. The suitable value of the organic loading rate for CSTR biogas production was found to be 3.0 kg-COD/m$^3$–day since this organic loading rate had yielded the maximum biogas production for the system.

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