The Effects of Different Concentration Glucose on Methane Fermentation

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Keywords: Glucose, Biogas Production Potential, Energy Conversion Efficiency.

Abstract. With the different concentrations of glucose of 20\%, 50\%, 80\% respectively, we used it as raw material for anaerobic digestion. The results showed that, gas production, organic matter content, and energy conversion efficiency were different, with the best experimental group of 20\%. Using glucose as the raw material, the low concentration glucose can achieve the rapid start-up of the biogas anaerobic system, as well the energy conversion efficiency was higher than others.

Introduction

Anaerobic digestion is more complex biochemical interaction process. In the year of 1967, Lawrence and P. L. McCarty put forward the three stage theory of anaerobic digestion, including the hydrolysis stage, hydrogen production stage and methane production stage [1-3]. First, the large molecular substances were hydrolyzed to small molecular substances, which were used by hydrogen-producing acetogen. Then, under the action of hydrogen-producing acetogen, the small molecule substances were further decomposed into the volatile organic acids such as acetic acid, propionate, butyrate and ethanol that provide the substrate for methanogens. Finally, acetic acid and ethanol were used to methanogens, which produced methane and carbon dioxide. Analysis on thermodynamic, the free energy of the anaerobic digestion reaction was greater than 0, and the reaction could not be carried out spontaneously. When the hydrogen partial pressure of system reduced, the above processes could be ended[1].

Materials and Methods

Experimental Equipment

The experimental apparatus of glucose anaerobic digestion make use of a conventional laboratory biogas fermentation equipment, which was shown in Fig. 1.
Experimental Materials

Fermentation material was glucose that was from Nantong Food Company China. In addition, the inoculum was mixed with anaerobic activated sludge that under long-term acclimation in laboratory that TS and VS were 10.11% and 30.34% respectively. The pH value was 7.0.

![Experimental equipment](image)

Figure 1. Experimental equipment.

Experimental Methods

At ambient temperature, the semi-continuous feeding method was used in the fermentation process. Feed glucose solution 10mL every two days. The basic experiment parameters were shown in Table 1.

<table>
<thead>
<tr>
<th>Serial number</th>
<th>Inoculum (mL)</th>
<th>Raw materials</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control Group</td>
<td>1200</td>
<td>----</td>
</tr>
<tr>
<td>Experimental Group 1</td>
<td>1200</td>
<td>20% Glucose solution 10ml</td>
</tr>
<tr>
<td>Experimental Group 2</td>
<td>1200</td>
<td>50% Glucose solution 10ml</td>
</tr>
<tr>
<td>Experimental Group 3</td>
<td>1200</td>
<td>80% Glucose solution 10ml</td>
</tr>
</tbody>
</table>

Analysis Items and Methods

The pH value was determined by 5.5~9.0 accurate pH test paper; Gas production was measured by drainage gas collection method. The gas production rate of each group was recorded for every two days; According to the measuring method of methane production, we measured TS and VS[1]; We detected the content of volatile organic acids and gas composition by gas chromatograph( Equipmental Model: FuLiGC9790).

Data Processing

The energy conversion efficiency of different fermentation concentration of glucose was calculated as follow[2].

\[
E = \frac{V_{H_2} \times Q_{H_2} + V_{CH_4} \times Q_{CH_4}}{Q \times m} \times 100\%
\]

In the above formula, \(E\) represented the energy conversion efficiency, its unit was %; \(V_{H_2}\) represented the volume of hydrogen experimentally determined, in units of mL; \(Q_{H_2}\) represented calorific value of hydrogen for 12.86J/ml; \(V_{CH_4}\) represented the volume of methane experimentally determined, in units of mL; \(Q_{CH_4}\) was calorific value of methane, being 35.822 J/mL; \(Q\) was expressed as the combustion heat value of raw materials, and the calorific value of glucose was 16000 J/g; \(m\) is the quality of the glucose which used in this experiment.
Experimental Results and Analysis

Analysis on Gas Production Situation

The experiment period was 31 days, and gas production was recorded every two days. The curve of daily gas production which had been minused gas production of control group was shown in Fig. 2.

![Gas production curves](image)

After calculation and analysis, we could find the relationship between gas production and fermentation time. Experiments were carried out for 31 days, started producing biogas at the first day. The first day gas production of experimental groups 1, 2, 3 achieved 300mL, 1300mL, 100mL respectively. In experimental group1, the range of gas production was between 100mL and 2000mL. In experiment group 2, the range of gas production was between200 and 1200mL. For the experimental group 3, the range of gas production was between 100 and 2900mL. The reason was that the experiment fermented at ambient temperature and affected by air temperature. Biogas fermentation was closely related to temperature. To some extent, the higher the temperature was, the more active the microbes were in the biogas fermentation system, so gas production was higher. As the weather and temperature changing, gas production would be affected obviously. In addition, After the day of twenty-fifth, the gas production of experimental group 1, experimental group 2 and experimental group 3 became stable, respectively reached 1000mL (methane content: 8%), 600mL (methane content: 22%), 500mL (methane content: 27%). Under stable condition, gas production rate of glucose (using methane production) was 40.0mL/g, 26.4 mL/g, 16.9 mL/g.

For experimental group 1, 2 and 3, the indicators of gas production were shown in Table 1.

<table>
<thead>
<tr>
<th>Serial Number</th>
<th>Total Gas Production (mL)</th>
<th>Methane Yield (mL)</th>
<th>Hydrogen Yield (mL)</th>
<th>Hydrogen Production Rate(mL.H2/g)</th>
<th>Methane Production Rate(mL.CH4/g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Experimental</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Group 1</td>
<td>16750</td>
<td>760</td>
<td>181</td>
<td>5.66</td>
<td>23.75</td>
</tr>
<tr>
<td>Group 2</td>
<td>11700</td>
<td>1505</td>
<td>803</td>
<td>10.03</td>
<td>18.81</td>
</tr>
<tr>
<td>Group 3</td>
<td>12150</td>
<td>2127</td>
<td>1562</td>
<td>12.20</td>
<td>16.62</td>
</tr>
</tbody>
</table>

From the Table 1, we could see following contents. Compered with experimental group 1 and 2, the hydrogen yield rate of experimental group 3 was the highest, reaching 12.20
ml.H₂/g. Experimental group 2, reached to 10.03 mL.H₂/g (1.22 times of experimental group 3), and for experimental group 1, only it was 5.66 mL.H₂/g (2.16 times of experimental group 3). Otherwise, the methane yield rate of experiment 1 reached 23.75 mL.CH₄/g, which was 1.26 times and 1.43 times of experimental group 3 and experimental group 2. Therefore, we could take different concentration of fermentation to acquire H₂ or CH₄. If the final product is dominated by hydrogen, relatively high concentration of fermentation could be used, vice versa.

**Organic Matter Analysis**

The organic matter content of experiments was shown in Fig. 3.

We could see from Fig. 3 that the content of organic matter was different with different concentration of glucose fermentation. For three experiments, the change of organic matter content had two common points. On the one hand, during the anaerobic digestion, organic matter content was improved, but increased in different degree; On the other hand, there was almost no change in the content of organic matter in the fermentation system between the first day and tenth day; After 10th day, the organic matter content began to increasing rapidly; The 20th day, organic matter content tended to be stable. But there were differences in the three groups of experiments. First, the increase of organic matter was different. The organic matter of Experiment 1, 2, 3 respectively was 40%, 37.5%, 44.4% respectively. Secondly, in the process of organic matter increasing, the rate of organic matter increasing is different. It is clear that organic matter increased much faster in experimental group 1 than experimental group 2 and 3. The above phenomenon showed that microorganisms in the biogas fermentation system usded glucose and other organic matter as nutrition, which not only did product the methane and carbon dioxide, but also increased the microbial content. Because of the fermentation concentration of glucose and volatile organic acids being different, the carbon source utilization and organic matter content in raw materials were different.

**Changes of pH in Anaerobic Fermentation**

In Fig. 4, in initial fermentation (1~3d), pH values of experiments were 7, which is the best pH extent of methane. With the longer fermentation time, the pH began to showing different changes. For the experimental group 1, pH value varied in the range of 6.7~7.0, which belong to the normal growth of the microorganism and guaranted the normal operation of the glucose anaerobic digestion. The pH value of the experimental group 2 abruptly reduced to 6.5 at third day and kept constant. For experimental group 3, there were two more obvious pH reduction stages at anaerobic digestion. At the first period (1~5d), pH gone down from 7 to 6.5; At second period (15~20d), pH declined from 6.5 to 6.0 at 17th day. The reason may be that
glucose concentration was higher in experiment group 3, and the volatile organic acid could not be used timely by methanogens, which formed a phenomenon named acid accumulation. For low concentration glucose, the acetic acid, propionic acid and butyric acid provided an adequate substrate at hydrogen producing acid stage, and methanogens could quickly be took use, so pH remained [4].

Analysis on Volatile Organic Acid (VFA)

The content of volatile organic acids was shown in Table 3.

Table 3. VFA contents.

<table>
<thead>
<tr>
<th>Serial number</th>
<th>Acetic Acid (mg/L)</th>
<th>Propionic Acid (mg/L)</th>
<th>Butyrate (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Experimental Group 1</td>
<td>2860</td>
<td>725</td>
<td>98</td>
</tr>
<tr>
<td>Experimental Group 2</td>
<td>1261</td>
<td>530</td>
<td>702</td>
</tr>
<tr>
<td>Experimental Group 3</td>
<td>1257</td>
<td>531</td>
<td>703</td>
</tr>
</tbody>
</table>

As could be seen from the table 3, volatile fatty acids of Experiment 1 were the most where acetic acid content was 2.27 times and 2.28 times as much as the experiment 3 and 2. In addition, butyrate was too low, only being 98 mg/L. During the process of anaerobic digestion, the organic compounds were decomposed into small molecular substances, which provided the substrates for the hydrogen-producing acetogen. At hydrogen production stage, hydrogen and VFA were produced, and methanogens made use of acetic acid to produce methane [5,6,7,8]. In experimental group 1, the acetic acid content was so high that hydrogen-producing acetogen was active, and butyrate did not form accumulation. They provided lots of extracellular matrix for methanogens, which made methanogenic possible and made experiment 1 methane yield higher than experimental group 2 and 3.

Analysis on Energy Conversion Efficiency

The energy conversion efficiency was shown in Fig. 5.

As could be seen from Fig. 5, the energy conversion efficiency of experiment was lower than 10%. The reason might be that the utilization of raw materials was too low in the fermentation system. In the glucose anaerobic digestion, the system was in the situation of normal fermentation and could produce hydrogen and methane. VFA were too much to do not utilize timely, which caused by "acid drowning" phenomenon [4], which resulted in the methanogenic phase inhibited, and the energy conversion efficiency decreased. But for experimental group 1, 2 and 3, the energy conversion efficiency of experimental group 1 was
the highest, which was 1.15 times and 1.21 times as much as experimental group 3 and 2 respectively. Therefore, it was possible to improve the energy conversion efficiency of the system by using the low concentration glucose as the fermentation material.

![Energy conversion efficiency of different glucose in anaerobic fermentation](image.png)

**Figure 5. Energy conversion efficiency of different glucose in anaerobic fermentation.**

**Conclusions**

1. Analysis on the gas production, anaerobic digestion with low concentration of glucose as substrate was more favorable for the formation of methane, and anaerobic digestion with high concentration of glucose as the substrate was more favorable for the formation of hydrogen.
2. Analysis on organic matter, anaerobic digestion with low concentration of glucose as substrate was more favorable for the formation of anaerobic activated sludge, and the quality of activated sludge was better than high concentration.
3. Analysis on energy conversion efficiency, the experimental energy conversion efficiency was less than 10%. Then, compared with others, the energy conversion efficiency of anaerobic digestion with low concentration of glucose was the highest.

**Acknowledgements**

Funds: Jointly funded by the education department fund project (2013Y437), the Yunnan provincial Biogas Engineering Technology Research Center (2013DH041) and the National Fund Project (51366015).

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**References**


