

Effects of Different Material Total Solid on Biogas Production Characteristics

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Abstract. In China, livestock manure emission has resulted in severe pollution to the environment and it is an efficient spreading agent of diseases. For this reason, the biogas has gotten a rapid development in the past few decades. As a kind of renewable and clean energy, many studies have indicated the prospect of biogas to replace fossil fuels in the future. However, the methane industrial production process is unstable due to various factors. Therefore, it is necessary to enhance the biogas fermentation efficiency. In this paper, the influences of the raw materials and the total solids (TS) concentration on biogas production characteristics are studied, where the utilization of raw materials can be reflected by the biogas production rate in the results. The results showed the anaerobic fermentation cycle is prolonged and biogas yield increases, but the utilization decreases with TS increases.

1 Introduction

With the exploration of world population and the rapid development of social economy, the earth's resources and environment are under great pressure in the 21st century [1]. Therefore, increasing interest and confidence have been paid to biomass, which is deemed as a valuable renewable energy from solar energy [2]. In China, biomass energy mainly derives from urban living garbage, forestry and timber waste, animal manure, industrial effluents, crop stalks, etc. All of them are featured with high carbon content and easy availability [3]. The development of biomass energy technique can not only reduce the ecological vicious cycle and greenhouse effect, but also substitute fossil fuels in the form of natural gas, coal, and petroleum. Thus it becomes an important pathway to relieve the energy crisis and environmental pollution [4].

As a new process converting the organic waste into usable energy, the biogas fermentation technology has received worldwide attention. In terms of technology, policy, economy and environment, Europe leads the utilization of biogas. It has the largest number of promotions, best efficiency, most mature technology of biogas anaerobic digestion in the world [5-6]. Among European countries Germany is the greatest biogas producer currently. Furthermore, Germany is transforming the raw material from livestock manure and crop straw into industrial scale production [7], such as organic crops (corn, straw, grass, etc.), municipal sewage sludge, livestock manure, industrial and food-processing enterprises waste, and urban household waste [8]. It also adopts different anaerobic digestion processes according to the engineering requirements. The United States started later until the 1970s to establish biogas facilities

[9] because of the oil crisis. Therefore, biogas projects in the United States mainly concentrate upon farms. Most are used to generate electricity. In addition, since the 70's of the last century, Sweden has focused upon the development of biomass, proposing substituting renewable energy for fossil fuels before 2020. It has a great target to become the first country which doesn't rely on oil and coal throughout the world [10]. Besides, the raw materials of the biogas project in Sweden are mainly from the local industry, municipal wastewater and agricultural waste [11].

This paper shows that the total biogas yield increases and the anaerobic fermentation cycle prolongs but utilization efficiency of raw materials decreases with the increase in TS on the study of biogas production rate, biogas yield, production cycle and CH₄ content of the anaerobic fermentation through different TS on using different materials.

2 Materials and methods

2.1 Materials introduction

Fermentation materials: The cattle manure and wheat straw as the target fermentation materials and the characteristics of cattle manure and wheat straw listed in Table 1 which measured by a Muffle Furnace and an Elemental Analyzer.

Inoculum: The fermented substrate deriving from the laboratory after anaerobic digestion with dry cattle manure as the fermenting material and remaining in a stable state.

The wheat straw is minced into small segments with scales ranging from 30mm to 50mm in advance. The

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pretreated wheat straw is used as material in a part of the experiment. The wheat straw is soaked in 8% Ca(OH)₂ solutions for 24 hours, soaked and then washed out to neutral before.

Table 1. The characteristics of cattle manure and wheat straw.

| Characteristics | TS (%) | VS (%) | VS/TS | C (%) | N (%) | H (%) | S (%) | C/N |
|-----------------|--------|--------|-------|-------|-------|-------|-------|-------|
| Cattle manure | 85.04 | 72.27 | 0.85 | 31.29 | 4.50 | 1.11 | 0.26 | 6.95 |
| Wheat straw | 89.01 | 74.73 | 0.84 | 41.80 | 1.05 | 1.82 | 0.81 | 39.81 |

2.2 Experimental system of fermentation

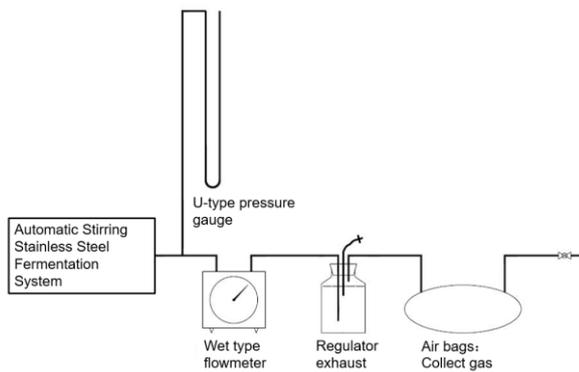


Fig. 1. Experimental system of fermentation.

The experimental system of anaerobic digestion is exhibited in Fig.1. The biogas, produced in the automatic mixing stainless steel fermentation system, passes wet flowmeter, regulator cylinder, and aluminum foil sampling bag in sequence. During the experiments, the internal pressure inside the reactor is kept constantly at 1600Pa.

2.3 Operating conditions

Six sets of experiments with different test materials and TS are involved in this paper, as Table 2 shows. The experiment mainly focuses on how Total Solid (TS) affects biogas anaerobic fermentation under different feed loads, raw materials, raw material processing and conditions as shown in Table 2.

Table 2. Operational conditions of biogas fermentation.

| Groups | Materials | TS | Temperature | Tank pressure |
|--------|--|-------|-------------|---------------|
| I | Cattle manure | 7.4% | 35°C±5°C | 1600 Pa |
| II | Cattle manure + wheat straw | | | |
| III | Cattle manure + pretreated wheat straw | | | |
| IV | Cattle manure | 10.0% | | |
| V | Cattle manure + wheat straw | | | |
| VI | Cattle manure + pretreated wheat straw | | | |

3 Results and discussion

3.1 Effect of TS on anaerobic digestion characteristics

3.1.1 Biogas production rate

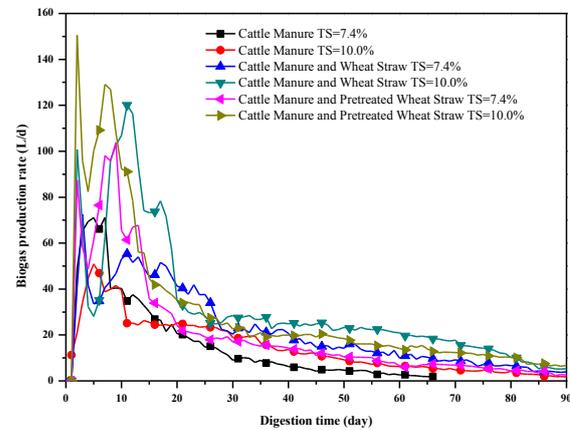


Fig. 2. Biogas production rate at different material and Total Solid.

Although the raw materials and material ratios are varying, Fig. 2 reveals that the biogas production rates of the six sets of cases vary in a similar trend. The curved lines of biogas production rate reach the peak in the early days, and then the rate of daily biogas yield is damped. Compared with the line chart of the same kind of raw materials but different TS, it can be seen that the time of the peak daily biogas yield has been advanced and the daily biogas production rate has increased at TS=10.0%, only one raw material in different situations.

When using cattle manure and wheat straw as the fermentation raw material, compared with TS=7.4%, the biogas yield at TS=10.0% was one day ahead of time and increases by 38.7% at the first peak and by 117.2% at the second peak. In the middle and late stages of fermentation, the daily production rate at TS=10.0% is higher than that at TS=7.4%. By focusing on the set of cattle manure and pretreated wheat straw, the effect of TS on the biogas production rate can be examined. Compared with TS=7.4%, the daily biogas production rate at TS=10.0% is 72% higher at the first peak and 23% at the second. Furthermore, the biogas production rate reaches its peak value 2 days ahead of time. Under the same conditions, when single cattle manure is used as the fermentation raw material, the peak biogas production rate at TS=10.0% is 28.4% lower than that at TS=7.4%. The reason may be that after the capping, an anaerobic environment has not been formed in whole reactor, and the non-methanogens bacterium multiply quickly with the increase of organic matter content, which makes the accumulation of organic acid and the activity of methanogens inhibit in acidic environment.

3.1.2 Biogas yield

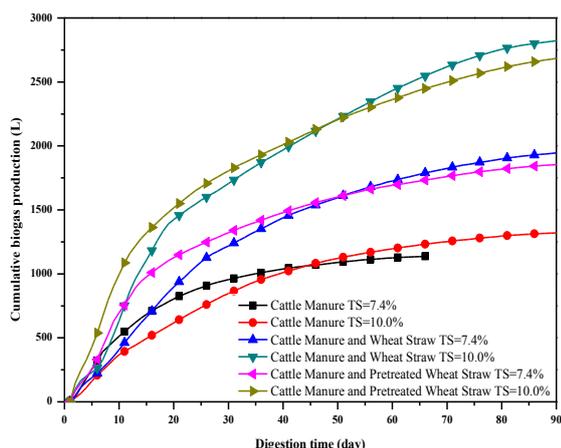


Fig. 3. The cumulative biogas production in different material and total solid.

It is observed that the total biogas production at TS=10.0% is higher than that at TS=7.4% in whole fermentation cycle.

When using single cattle manure as the raw material, in the total anaerobic fermentation cycle, it needs 12 and 38 days to achieve the cumulative biogas production of 50% and 90% at TS=7.4%, but 22 and 59 days at TS=10.0%. It can be seen that the biogas production cycle has a long delay at TS=10.0%. Under the same conditions, when cattle manure and wheat straw are used as the raw material at TS=7.4%, and reaches 50% and 90% of the total biogas production in the first 22 and 63 days. Compared with the former, the total biogas production increases by 45% over the entire reaction cycle, reaching 50% and 90% of the total biogas production on the 22nd and 65th day respectively at TS=10.0%. The total biogas production from cattle manure and pretreated wheat straw is 1853.36 L at TS=7.4%. It reaches 50% and 90% of the total biogas production in the first 14 and 57 days under the same conditions, and the cumulative biogas production in the first 30 days is 71% of the total biogas production. Being different from TS=7.4%, the total biogas production is 2684.54 L at TS=10.0%, although the biogas yield has increased, the time to reach 50% and 90% of total is delayed by 2 and 7 days, the cumulative biogas production in the first 30 days is 67% of the total biogas production.

3.1.3 CH₄ percentage

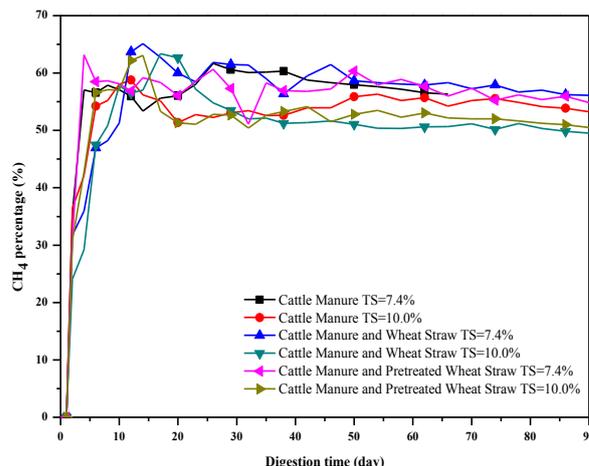


Fig. 4. The cumulative biogas production in different material and total solid.

It can be observed from the CH₄ percentage curve line of single cattle manure that the average percentage of CH₄ is 56.53% at TS=7.4%, the average percentage of CH₄ is 58.89% at TS=10.0%. As shown in Fig. 4, at TS=10.0%, the percentage of CH₄ is lower than that at TS=7.4% for most of time during the whole reaction cycle. In addition, the CH₄ percentage curve line of every groups show a similar conclusion, that the percentage of CH₄ at TS=10.0% is always lower than that at TS=7.4% after the early stage of reaction.

The main reason for this situation is that, in the early stage of reaction, the content of organic matter in the raw materials is more abundant and non-methanogens bacteria metabolize quickly and generates a large amount of acetic acid and CO₂. Then part of the CO₂ dissolves in the feed liquid and reduces the PH, which inhibits the methanogenic activity, and the percentage of CH₄ is low. In the middle and later stages of the reaction, the content of organic matter is sufficient, and the rate of non-methanogens bacterium degradation is faster than methanogens. More CO₂ surplus is overflowed with biogas, and the percentage of methane at TS=10.0% is lower than that at TS=7.4%.

3.2 Analysis of anaerobic digestion time and biogas production rate

3.2.1 Analysis of anaerobic digestion time

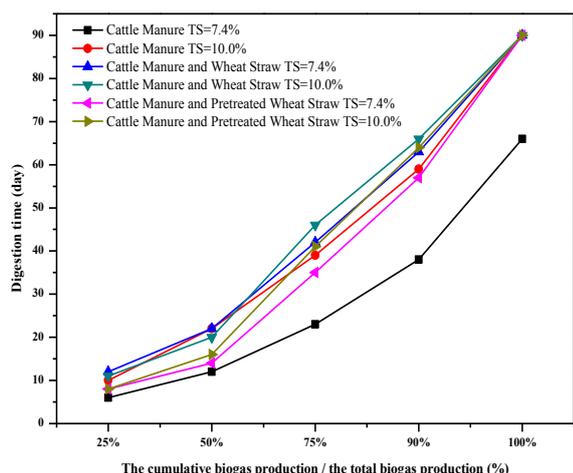


Fig. 5. Hydraulic retention time of anaerobic fermentation.

Fig. 5 shows that the times to reach 25%, 50%, 75% and 90% of the total biogas production are various. The group of single cattle manure is the shortest, the group of cattle manure and pretreated wheat straw is the next, and the cattle manure and wheat straw are the longest at TS=7.4%. It also shows that the time is prolonged by adding wheat straw into the cattle manure for anaerobic fermentation cause. Moreover, when wheat straw is pretreated, the time is less, indicating that the pretreatment process has shortened the biogas production cycle. Except the cases of single cattle manure at TS=7.4%, it takes 56-66 days for the cumulative biogas production to amount to 90% of the total biogas production, and 90 days to amount to 100% of the total production. Therefore, it is most efficient to stop the anaerobic fermentation process after 60 days from the beginning. This will not only significantly shorten the gas cycle, but also ensure that the raw materials are fully utilized.

3.2.1 Analysis of anaerobic digestion time

During anaerobic digestion process, methanogens and non-methanogens bacteria can only decompose to volatile solids content (VS) in the feed while ash cannot be degraded. Therefore, TS or VS biogas production rates can be used to determine the level of raw material utilization.

Table 3. The biogas production rate of TS and VS.

| Nature | Group I | Group II | Group III | Group IV | Group V | Group VI |
|--|---------|----------|-----------|----------|---------|----------|
| TS= | 7.4% | 7.4% | 7.4% | 10.0% | 10.0% | 10.0% |
| Cumulative biogas production in the first 30 days(m ³) | 0.954 | 1.218 | 1.322 | 0.847 | 1.707 | 1.805 |
| Total biogas production(m ³) | 1.138 | 1.946 | 1.854 | 1.320 | 2.822 | 2.685 |
| TS(kg) | 6.609 | 7.145 | 7.145 | 8.564 | 9.501 | 9.501 |
| VS(TS) | 4.878 | 5.361 | 5.361 | 7.665 | 8.478 | 8.478 |
| The relative percentage of the first 30 days (%) | 83.9 | 62.6 | 71.3 | 64.1 | 60.5 | 67.2 |
| TS biogas production rate(m ³ /kgTS) | 0.188 | 0.272 | 0.259 | 0.154 | 0.297 | 0.283 |
| VS biogas production | 0.233 | 0.363 | 0.346 | 0.172 | 0.333 | 0.317 |

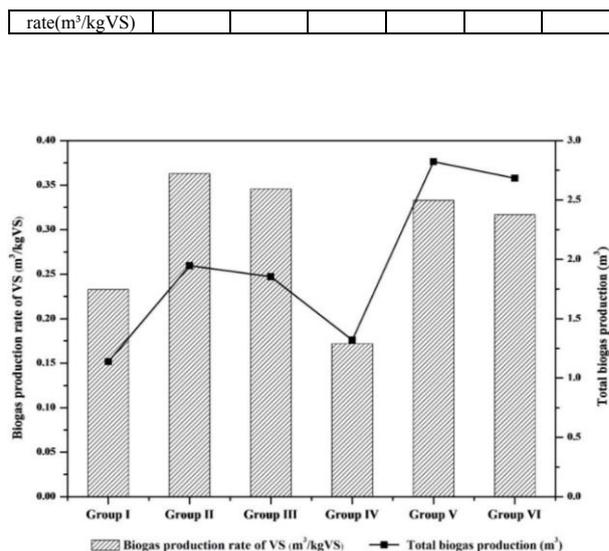


Fig. 6. The biogas production rate histogram of each group.

It can be seen from Table 3 that with the same raw materials, the utilization of raw materials at TS=7.4% is lower than that at TS=10.0% from biogas production rate of TS. However, the utilization of raw materials gets opposite results from biogas production rate of VS, because there is not volatile gravel in the cattle manure, so the biogas production rate of VS is used to reflect the level of raw material utilization in this paper. As shown in Fig. 6 and Table 3, the production rate ranking of the raw material biogas is Group I> Group IV> Group II> Group V> Group III> Group VI. The comparison of biogas yield is Group IV> Group I, Group V> Group II, Group VI> Group III. It is pointed out that under the same raw material and pretreatment conditions, when TS increases from 7.4% to 10.0%, biogas yield increases and the raw material utilization decreases.

4 Conclusions

1) In the same fermentation liquid, the total biogas yield increases with the growth of TS content, and the maximum cumulative biogas production occurs at TS=10.0% when cattle manure and wheat straw are used as the raw material.

2) The anaerobic fermentation of each group mainly occurs on the first 30 days. According to the ratio of the accumulated biogas production to the total biogas production in the first 30 days, it can be concluded that the utilization of the organic matter in the raw materials reduces with the increase of the total solid content. The optimal feeding utilization rate is found at TS=7.4% when cattle manure and pretreated wheat straw are used as the raw material.

3) Under the same conditions, when the TS increases from 7.4% to 10.0%, the anaerobic fermentation cycle is prolonged and the total biogas production increases, but the utilization rate of raw materials decreases and the environment of anaerobic fermentation microbial metabolic activity is more easily formed. In practical engineering, the fermentation cycle and the effect of total biogas production should be taken into consideration. In addition, the optimal total solid content

for different fermentation raw materials should also be determined to achieve the most efficient fermentation of biogas.

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