Benefit Analysis of Hydrothermal Processing of Biogas Slurry Applied to Biogas Power Generation Project

Ke Sun¹, Dachen Liao¹, Qiang Ye¹, Yuanshang Zhang¹, Xinglan Chang¹, Shuang Xi¹, Tianrong Zhang²*

¹ Zhejiang Tiandi Environmental Protection Technology Co., Ltd. 311121, Hangzhou, China
² Zhejiang A&F University, 311300, Hangzhou, China
*Correspondence: Tianrong Zhang, zhangtr@zafu.edu.cn

Abstract. Taking a large-scale anaerobic fermentation biogas power generation project as an example, the biogas slurry was hydrothermal processed and then reused to the anaerobic reactor, so as to reduce the biogas slurry discharge and increase the biogas production. The benefit analysis is carried out on the basis of increasing the gas production and the economic benefit as far as possible in the biogas power generation project. Through analyzing the amount of biogas slurry returning to field, the increase of biogas production, and the ammonia nitrogen concentration of the material in the anaerobic reactor, it is concluded that the reasonable amount of hydrothermal processing in this project is 150 t·d⁻¹~200 t·d⁻¹ (the ratio of the hydrothermal processing capacity to the material in the anaerobic reactor is 22.4% ~ 29.9%), which can increase the biogas production to 338.2 Nm³·d⁻¹ ~ 346.6 Nm³·d⁻¹ per ton of dry solid.

1. Introduction
Biogas power generation technology is an effective way of utilizing organic wastes such as livestock and poultry manure. In this technology, CSTR[1] or HCPF[2] anaerobic fermentation technology is used to produce biogas, and the internal combustion engine generator is used to generate electricity. However, it will produce a large amount of biogas slurry in biogas power generation project. Biogas slurry has complex composition and high content of organic matter, ammonia nitrogen, etc., which can easily cause pollution and hazards to water and soil if not properly disposed. The level of harmless and resource utilization of biogas slurry has seriously restricted the development of large-scale biogas power generation projects.

At present, hydrothermal processing has been applied to the sewage sludge[3-5]. Its main principle is to decompose some organic matter which is difficult to be biodegraded through input energy (such as steam), so as to improve the reaction rate and increase the gas production efficiency of anaerobic fermentation in the anaerobic reactor. In addition to the sludge, technical experts are also trying to apply the hydrothermal processing to other organic waste such as kitchen waste and animal waste [6,7]. But the related research and engineering application is less reported, and the follow-up project is hard to get and validate the guidance of relevant data.

2. Methods
The technological process of hydrothermal processing of biogas slurry applied to biogas power
Fig. 1. The technological process of hydrothermal processing of biogas slurry applied to biogas power generation project

As shown in Fig. 1, organic waste is pumped into the regulating pool, mixed with water and biogas slurry after hydrothermal processing from the storage pool. The mixture is pumped into the anaerobic reactor and the anaerobic fermentation is carried out to produce biogas. The biogas is processed by desulfurization, drying and pressurization, and then goes into the internal combustion engine generator for power generation. And the flue gas is emitted after denitrification. The biogas slurry of high concentration is pumped into the solid-liquid separator for separation. The biogas residue is fed into the organic fertilizer production equipment to produce organic fertilizer. And the biogas slurry from the solid-liquid separator is stored in the biogas slurry pool. Part of it is returned to the field, and the rest of it is pumped into the preheating reactor. After preheated, the biogas slurry is pumped into the hydrothermal reactor, mixed with steam (130 ~ 180 degree) which is from the steam waste heat boiler. At the same time, heat is preservation and pressure is holding for a period of time (30 ~ 45 min), and then the biogas slurry is flashed in to the flash reactor, so that large molecules such as cellulose lignin can be broken to small and medium-sized organic molecules. And then the biogas slurry is cooled in the cooler and separated in the solid-liquid separator. The solid is fed into the organic fertilizer production equipment, and the liquid is transported to the storage pool and finally is fed into the anaerobic reactor for anaerobic fermentation.

3. Results and discussion

3.1 Reduce the biogas slurry of returning to the field

In a particular project, the organic waste is pig manure and the total amount of material is designed to be 670 t·d⁻¹ in the anaerobic reactor, and the maximum amount of water from the storage pool can be added to the regulating water pool is 270 t·d⁻¹. Due to the need to add steam to the biogas slurry, the maximum amount of hydrothermal processing decreases to 242 t·d⁻¹ which takes place of the water added to the regulating water pool. At this amount of hydrothermal processing, the ratio of the hydrothermal processing capacity to the material in the anaerobic reactor is 36.1%. If the amount of hydrothermal processing increases, the amount of organic waste should decrease and the economic benefit of the whole project will decrease. The amount of biogas slurry of returning to the field and the ratio of biogas slurry of returning to the field to the material in the anaerobic reactor is shown in Tab. 1.
Table 1. The amount of biogas slurry of returning to the field and the ratio of biogas slurry of returning to the field to the material in the anaerobic reactor

| No. | A (t·d⁻¹) | B (%)  | C (t·d⁻¹) | D (%)  |
|-----|-----------|--------|-----------|--------|
| 1   | 0         | 0      | 528       | 78.8   |
| 2   | 50        | 7.46   | 501       | 74.8   |
| 3   | 100       | 14.9   | 473       | 70.6   |
| 4   | 150       | 22.4   | 445       | 66.4   |
| 5   | 200       | 29.9   | 416       | 62.1   |
| 6   | 242       | 36.1   | 390       | 58.2   |

“A” means the amount of hydrothermal processing.
“B” means the ratio of the hydrothermal processing capacity to the material in the anaerobic reactor.
“C” means the amount of biogas slurry of returning to the field.
“D” means the ratio of biogas slurry of returning to the field to the material in the anaerobic reactor.

As shown in Tab. 1, when the ratio of the hydrothermal processing capacity to the material in the anaerobic reactor increases from zero to 36.1%, the amount of biogas slurry of returning to the field decreases from 528 t·d⁻¹ to 390 t·d⁻¹, and the ratio of biogas slurry of returning to the field to the material in the anaerobic reactor from 78.8% to 58.2%. As there are few fields for returning of the biogas slurry around the project, which can consume 450 t·d⁻¹ in average, the optimum amount of hydrothermal processing is 139 t·d⁻¹, and the ratio of the hydrothermal processing capacity to the material in the anaerobic reactor is 20.8%.

Therefore, according to the analysis of biogas slurry returning to the field, the amount of hydrothermal processing is recommended to be 139 t·d⁻¹ ~ 242 t·d⁻¹, and the ratio of the hydrothermal processing capacity to the material in the anaerobic reactor is recommended to be 20.8% ~ 36.1%.

3.2 Increase the biogas production

After hydrothermal processing of biogas slurry, some organic matter which is difficult to be biodegraded will be decomposed into small molecules which are easy to be biodegraded, and finally the biogas increases. The theoretical biogas production and actual biogas production is shown in Fig. 2.

As shown in Fig. 2, when the ratio of the hydrothermal processing capacity to the material in the
anaerobic reactor increases from zero to 36.1%, the theoretical biogas production increases linearly from 300 Nm$^3\cdot$d$^{-1}$ to 369 Nm$^3\cdot$d$^{-1}$ per ton of dry solid. But the actual biogas production only increases from 300 Nm$^3\cdot$d$^{-1}$ to 351 Nm$^3\cdot$d$^{-1}$, and the increase gradually slows down. As shown in Fig. 2, the increases are 15.3, 12.7, 10.2, 8.38 and 4.15 Nm$^3\cdot$d$^{-1}$. Therefore, with the increase of the amount of hydrothermal processing, the benefit has obvious marginal effect. Especially when the ratio of the hydrothermal processing capacity to the material in the anaerobic reactor increases from 29.9% to 36.1%, the increase is only 4.15 Nm$^3\cdot$d$^{-1}$, which is obviously lower than the ratio from 24.4% to 36.1%, and the economic benefit will be greatly reduced at the same time.

To find out the reason, the ammonia nitrogen concentration of the material in the anaerobic reactor is measured. As shown in Fig. 3, when the ratio of the hydrothermal processing capacity to the material in the anaerobic reactor increases from zero to 36.1%, the ammonia nitrogen concentration increases from 2360 mg$\cdot$L$^{-1}$ to 3716 mg$\cdot$L$^{-1}$, and it increases at an accelerating rate. This indicates that with the increase of the amount of hydrothermal processing, the accumulation rate of ammonia nitrogen is getting faster.

Some studies$^9$ have shown that when the ammonia nitrogen concentration of the material in the anaerobic reactor is too high, the activity of biological flora will be inhibited, especially the methanogens. However, the thresholds of inhibition of ammonia nitrogen are not the same with different materials for anaerobic fermentation. Generally, the thresholds is 3000 mg$\cdot$L$^{-1}$ ~ 4000 mg$\cdot$L$^{-1}$ with the pig manure$^9$.

In the hydrothermal processing of biogas slurry applied to biogas power generation project, the ammonia nitrogen is in a dissolved state, and the only way to discharge is returning to the field with the biogas slurry. As shown in Fig. 3, when ammonia nitrogen is gradually accumulated, the influence on the anaerobic fermentation process is gradually increased, and the negative effect is more obvious between 3370 mg$L^{-1}$ and 3716 mg$L^{-1}$. When the ratio of the hydrothermal processing capacity to the material in the anaerobic reactor reaches 36.1%, the increase of biogas production has a much more significant marginal effect.

Therefore, considering the marginal effect and project cost, it is recommended that the amount of hydrothermal processing is 150 t$\cdot$d$^{-1}$ ~ 200 t$\cdot$d$^{-1}$, and the ratio of the hydrothermal processing capacity to the material in the anaerobic reactor is 22.4% ~ 29.9%.
4. Conclusions
The hydrothermal processing of biogas slurry applied to biogas power generation project can not only reduce the biogas slurry of returning to the field, but also increase the biogas production. By analyzing the benefit concretely, the conclusions are as follows:

1) The maximum amount of hydrothermal processing is 242 t·d⁻¹, and the ratio of the hydrothermal processing capacity to the material in the anaerobic reactor is 36.1%.

2) According to the analysis of biogas slurry returning to the field, the amount of hydrothermal processing is recommended to be 139 t·d⁻¹ ~ 242 t·d⁻¹, and the ratio of the hydrothermal processing capacity to the material in the anaerobic reactor is recommended to be 20.8% ~ 36.1%.

3) Considering the marginal effect and project cost, the amount of hydrothermal processing is recommended to be 150 t·d⁻¹ ~ 200 t·d⁻¹, and the ratio of the hydrothermal processing capacity to the material in the anaerobic reactor is recommended to be 22.4% ~ 29.9%.

In summary, the reasonable amount of hydrothermal processing in this project is 150 t·d⁻¹~200 t·d⁻¹, and the ratio of the hydrothermal processing capacity to the material in the anaerobic reactor is 22.4% ~ 29.9%.

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