HIGH-SOLIDS ANAEROBIC DIGESTION OF SEWAGE SLUDGE IN CHINA

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Abstract
Because of the rapid development of economy and urbanization in China, a huge number of waste water were discharged, more and more waste water treatment plants were built to treat the waste water. The sludge production increases also year by year. The treatment and disposal of sludge from WWTPS becomes one of the most important environmental topics in China. This paper introduced the current situation of sludge treatment and disposal in China, and compared the situation of sludge anaerobic digestion between China and other countries. Feasibility of high-solids anaerobic digestion of sewage sludge was investigated. The result shows, that high-solids anaerobic digestion of sludge can improve the efficiency of system, and is proved to be feasible. At the end, the prospect of high-solids anaerobic digestion in China will be mentioned.

Keywords
Anaerobic digestion; High-solid; Mesophilic; Sewage sludge

Introduction
Sewage sludge, the by-product of biological wastewater treatment processes, is expected to increase continuously in the next decade, due to increasing population connected to sewage networks, building new waste water treatment plants (WWTPs) and upgrading existing plants to meet the more stringent local effluent regulations. In China, over $3 \times 10^{10}$ kg dewatered sludge (80% moisture content) from municipal wastewater treatment plants is generated in 2011, and almost 80% of it has not be sufficiently stabilized (Duan et al., 2012). Most of the dewatered raw sludge is directly disposed in landfills (Figure 1). The bio-energy in sludge was rarely utilized. It is estimated that sludge production might reach $6 \times 10^{10}$ kg per year by 2020. Thus, it is essential to develop proper treatment processes to reduce the amount of sludge. Anaerobic digestion and landuse of sewage sludge is adopted to be one of the key technology roadmap in China. It can realize sludge stabilization by converting a part of its organic matter into biogas which is a renewable energy source. The volume reduction rate could reach 30%-50%. This technology has been successfully implemented in the treatment of agricultural wastes, food wastes, and sewage sludge (Chen et al., 2008).
Figure 1: Ratio of sludge disposal in China

Sludge anaerobic digestion is the most applied stabilized technology in EU. There are more than 50,000 municipal wastewater treatment plants in EU countries, producing more than 50 million tons of sludge every year (estimated with water content of 80%). Over 50% of sludge is stabilized with anaerobic digestion (European Commission, 2010). Using anaerobic digestion to produce methane can not only reduce the pollution load of sludge to the environment but also produce biogas, which could supply energy for sewage treatment plants and surroundings to a certain degree (Bungay, 2004; Rubio-Loza and Noyola, 2010).

However, the use of traditional anaerobic digester is not always feasible in China. Until now about 60 anaerobic digestion facilities of sludge were built, and only about 15 Plants among them are in operation. Anaerobic digestion was not well applied in China mainly due to sludge characteristics. Low organic matter of sludge causes less biogas production; high content of inorganic sands causes easy abrasion of equipment. Low efficiency of sludge anaerobic digestion is also due to poor management, unprofessional operation, economical limitation and inadequate planning. Hence, how to improve the efficiency of sludge anaerobic digestion became a key issue to be researched in China.

Research and Results of High-Solids Anaerobic Digestion of Sewage Sludge

Many papers have been published dealing with the improvement of the efficiency of sludge anaerobic digestion. Some of them focus on improvement of conversion efficiency, such as pre-treatment, multistage process or superior microorganisms. Some of papers discuss co-fermentation. One viable option to improve the efficiency is increasing organic loading, such as shortening the sludge retention time (SRT) or increasing the solid content of sludge, which is called high-solid anaerobic digestion. High-solid anaerobic digestion is usually characterized by a high TS content of the feedstock, typically greater than 15% (w/w) (California Environmental Protection Agency, 2008) and has been claimed to be advantageous over traditional low-solid anaerobic digestion for several reasons, such as smaller reactor volume, lower energy requirements for heating, less material handling, and so on (Guendouz et al., 2008).
Currently, there are already a lot of research about high-solids anaerobic digestion of domestic waste and livestock/poultry manure, including organic fraction of municipal solid wastes (MSW) (Martin et al., 2003; Bolzonella et al., 2006; Lu et al., 2007), food wastes (Cho et al., 1995; Mosier et al., 2005), vegetation wastes (Lissens et al., 2004; He et al., 2008; Pang et al., 2008). However, the research of sludge anaerobic digestion are mostly focused on the solid content less than 10% (Fujishima et al., 1999; Nges and Liu, 2010). There is relatively little research about anaerobic digestion with high solids contents. In order to better understand the impact of solid content on anaerobic digestion, researches were carried out, and the effect of OLR, SRT and TS content was examined, with special attention paid to ammonia inhibition and system stability in high-solid state.

Effect on OLR and degradation rate of sludge

In order to figure out the impact of solid content on degradation rate of sludge, many experiments were taken with the sludge from Jiading WWTP in two years. The VS/TS was about 50%-60%. As a result, Figure 2 showed the impact of solid content on degradation rate of sludge. With the same sludge retention time, the organic loading rate (OLR) increased with the rise of solid content, but the solid content had no significant impact on the degradation rate of sludge.

![Figure 2: The impact of solid content on degradation rate of sludge](image)

Ammonia inhibition and system stability

Ammonia inhibition can cause the decreasing methanogenic activity, which can affect the methane yield (De Baere et al., 1984; Lay et al., 1997; Hansen et al., 1998). Since free amino nitrogen (FAN) has been suggested to be the actual toxic agent, it is an important factor influencing the stability of the system. Curve of FAN changing with different solid
content is shown in Figure 3. The FAN concentration in system increases with the rise of solid content of sludge.

**Figure 3:** The impact of solid content on free amino nitrogen (FAN)

Taken into consideration of volatile fatty acid (VFA) accumulation and biogas production as the main factors to evaluate the real stability degree (VFA accumulation without dramatic drop of biogas production was considered steady state, and dramatic drop of biogas production was considered a sign of great instability), the inhibitory effect of free ammonia can be classified to several degrees as listed in Table 1.

**Table 1:** Inhibition degree with different ranges of FAN concentration

<table>
<thead>
<tr>
<th>Inhibition Degree</th>
<th>FAN (mg/l)</th>
<th>TAN (mg/l)</th>
<th>VFA (mg/l)</th>
<th>VFA/TA</th>
<th>Stability of System</th>
</tr>
</thead>
<tbody>
<tr>
<td>No/Slight</td>
<td>&lt;250</td>
<td>&lt;2000</td>
<td>&lt;400</td>
<td>0.02-0.04</td>
<td>Stable</td>
</tr>
<tr>
<td>Slight</td>
<td>250-400</td>
<td>2000-4000</td>
<td>400-800</td>
<td>0.03-0.12</td>
<td>Stable</td>
</tr>
<tr>
<td>Medium</td>
<td>400-600</td>
<td>3000-4000</td>
<td>1000-3000</td>
<td>0.05-0.20</td>
<td>relatively stable</td>
</tr>
<tr>
<td>relatively strong</td>
<td>600-750</td>
<td>3000-4000</td>
<td>3000-4500</td>
<td>0.19-0.26</td>
<td>relatively fragile</td>
</tr>
<tr>
<td>very strong</td>
<td>&gt;800</td>
<td>&gt;7000</td>
<td>&gt;6000</td>
<td>&gt;1.0</td>
<td>fragile-crash</td>
</tr>
</tbody>
</table>

As shown in Table 1, the stability of high-solids anaerobic digestion of sludge is related to the FAN concentration in the system. In the situation of “slight inhibition”, the system is stable with FAN lower than 400 mg/l. In the situation of “medium inhibition”, the system is in a relatively stable state with FAN of 400-600 mg/l. As the inhibition degree reached
“strong”, high FAN and VFA concentration lead to great instability of the system. According to Figure 3, with input solid content of 20% (VS/TS=50%), the FAN concentration in system is 550 mg/l. FAN has no threat to the stability of system.

Sludge viscosity

Figure 4 shows the relationship between sludge viscosity and stirring speed in the same concentration of sludge. The stirring speeds were 0 r/min, 15 r/min and 30 r/min respectively. The operating time was from 0 d to 2.6 d for each test. As shown in Figure 4, the viscosity of sludge is related to the time and intensity of stir. When the stirring speed increased from 0 r/min to 15 r/min, the apparent viscosity of sludge decreased significantly. When the stirring speed increased from 15 r/min to 30 r/min, the apparent viscosity of sludge only had a slight decrease. With longer operating time, the sludge viscosity decreased and then became constant gradually. The results showed that the apparent viscosity of high-solids content sludge decreases with the increase of the stirring intensity and the extension of the stirring time due to the shear thinning character of the sludge.

Figure 4: The impact of the time and intensity of stir on sludge viscosity

The temperature has a great effect on apparent viscosity of sludge. Figure 5 shows the impact of the temperature of the anaerobic digestion system on sludge viscosity. The temperatures were 20 °C, 40 °C and 60 °C respectively. The solid content was from 5% to 20% for each test. As shown in Figure 5, with low solid content sludge, the temperature has no influence on the sludge viscosity. With high solid content sludge (TS > 15%), the viscosity of sludge reduces with the decrease of solid content and decreases with the rise of temperature.
Figure 5: The impact of solid content on free amino nitrogen (FAN)

The impact of thermal high-pressure pretreatment (THP)

THP has been studied to improve the anaerobic digestibility. Figure 6 shows that THP can effectively increase the ratio of soluble COD. The results indicate that the increase of temperature is in accordance with an increase of the ratio of soluble COD. Figure 7 shows that THP can greatly reduce the viscosity of sludge. With higher solid content, the reduction of sludge viscosity is more obviously. Moreover, THP can increase 15% of the degradation rate of sludge, and it can realize the hygienization by killing the pathogens.

Figure 6: The impact of THP on soluble COD
Figure 7: The impact of THP on sludge viscosity

The impact of PAM

High-solids sludge contains usually relatively high concentration of PAM. Figure 8 shows that routine dosing of PAM would not affect the performance of high-solids anaerobic digestion.

Figure 8: The impact of PAM on high-solids anaerobic digestion of sludge
The impact of organic content (VS/TS)

In order to study the impact of organic content, the sludge from Jiading WWTP (TS = 19%) was blended with SiO₂ to make different VS/TS ratios and experimented. As a result, Figure 9 showed that VS/TS affected the performance of high-solids anaerobic digestion of sludge. The Biogas yield of input organic reduced with the decrease of VS/TS. The degradation rate of sludge reduced with the decrease of VS/TS.

![Figure 9: Correlation between the organic content (VS/TS) and biogas yield](image)

**Figure 9:** Correlation between the organic content (VS/TS) and biogas yield

Conclusions

High-solids anaerobic digestion of dewatered sludge (input TS 20%) was approved feasible. FAN concentration higher than 600 mg/l was the main factor influencing system stability. As listed in Table 2, high-solids system could adapt to higher OLR (4-6 times as high) and obtains similar methane yield and VS degradation rate as conventional low-solids system with the same SRT, thus reaches much higher volumetric methane production rate.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>High-solids System</th>
<th>Traditional Low-solids System</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>TS 20%</td>
<td>TS 10%</td>
</tr>
<tr>
<td>VS/TS</td>
<td>60%</td>
<td>60%</td>
</tr>
<tr>
<td>SRT</td>
<td>20d</td>
<td>20d</td>
</tr>
<tr>
<td>OLR (kg VS/m³ d)</td>
<td>6.0</td>
<td>3.0</td>
</tr>
<tr>
<td>BPR (m³ biogas/m³ d)</td>
<td>2.2</td>
<td>1.1</td>
</tr>
</tbody>
</table>

Table 2: Biogas production rate (BPR) with different systems

[www.european-biosolids.com](http://www.european-biosolids.com)
Organised by Aqua Enviro Technology Transfer
Technical Models of High-Solids Anaerobic Digestion of Sewage Sludge

Since 2010 there are lots of researches about efficient anaerobic digestion. In order to improve the efficiency of anaerobic digestion, and to adapt Chinese sludge characteristics (low organic matter and high content of inorganic sands), as well as to take into account less place for anaerobic digestion facility, it is an effective way to use centralized pretreatment. In high-solids anaerobic digestion of dewatered sludge, high ammonia concentration is a potential factor influencing system stability. An alternative is co-fermentation with suitable municipal organics to improve the efficiency of anaerobic digestion.

The application of high-solids anaerobic digestion includes the following models:

Model 1: High-solids anaerobic digestion without pretreatment

The solid content of dewatered sludge is diluted to 10% or the solid content of raw sludge is thickened to 10%. It could be directly treated with high-solids anaerobic digestion. This model can be used for update of old WWTPS or centralized treatment.

Model 2: High-solids anaerobic digestion with thermal biological pretreatment

A two-stage biological treatment system is used. The solid content of dewatered sludge is diluted to 10% or the solid content of raw sludge is thickened to 10%. Thermal biological pretreatment is used at the first stage for enhanced acidification and sludge viscosity reduction. The temperature is 40°C-60°C and a solids retention time is 4 days. At the second stage mesophilic anaerobic digestion is used.

Model 3: High-solids anaerobic digestion with thermal high-pressure pretreatment

The solid content of sludge is more than 10%. After centralized collection it can be treated with thermal high-pressure pretreatment and high-solids anaerobic digestion. Heating temperature is determined according to the sludge characteristics. The main purpose of thermal pretreatment is to reduce sludge viscosity, and to increase mixing performance and dewatering performance during subsequent digestion, so that grit removal and hygienization of sludge can be better achieved, and the quality of sludge can be improved.

Projects of High-Solids Anaerobic Digestion of Sludge in China

According to the technical models above, there are already several demonstration projects under construction or in operation.
Xiajiahe WWTP: High-solids anaerobic digestion without pretreatment

Xiajiahe WWTP in City Dalian of China adopts high-solids anaerobic digestion without pretreatment with a capacity of 600 t/d dewatered sludge with 80% water content and a solids retention time (SRT) of 22 days under mesophilic conditions. Input solid content is 10%. The biogas of 25000-30000 Nm³/d can be produced every day.

Xiajiahe WWTP began operation in 2011. The solid content of dewatered sludge is diluted to about 10% and pumped into digester. In order to improve the biogas yield, adding food waste was considered. Biogas is fed into the natural gas network after purification.

Ninghai WWTP: High-solids anaerobic digestion with thermal pretreatment

Ninghai WWTP in City Ningbo of China adopts high-solids anaerobic digestion with thermal pretreatment with a capacity of 75 t/d dewatered sludge with 80% water content and 30 t/day feces, and with a solids retention time (SRT) of 20 days under mesophilic conditions. Input solid content is 10%. The biogas of 3200-4000 Nm³/d can be produced every day for electricity generation. Ninghai WWTP began operation in 2012.

Changsha WWTP: High-solids anaerobic digestion with thermal pretreatment

Changsha WWTP in China adopts high-solids anaerobic digestion with thermal pretreatment with a capacity of 435 t/d dewatered sludge with 80% water content and 65 t/d food waste with 60% water content, and with a solids retention time (SRT) of 20 days under thermophilic conditions. Input solid content is 12%. The biogas of about 30000-40000 Nm³/d can be produced every day. Changsha WWTP has now entered the commissioning phase.

Conclusions

China needs suitable high-efficient anaerobic digestion technology for sludge stabilization. Because of Chinese sludge characteristics with low organic matter (30-50%) and high sand content, the key issue is to improve the efficiency of anaerobic digestion of sludge. High-solids anaerobic digestion of sludge or co-fermentation with urban organic waste can improve the efficiency of system, and it is proved to be feasible. The application of high-solids anaerobic digestion of sludge and co-fermentation with food waste just started in China.

We hope that with the further research and optimization of high-solids anaerobic digestion of sludge, the technologies of sludge treatment and disposal, as well as bio-energy recovery, can be promoted.

Acknowledgements

This work was financially supported by the key projects of National Water Pollution Control and Management of China (2011ZX07316-004, 2013ZX07315-001).
References


