EXPERIMENTAL STUDIES ON PRE-TREATMENT OF SLUDGE BY COMBINATION OF THERMAL HYDROLYSIS AND ULTRASOUND AND SAND REMOVAL BY HYDROCYCLONE TO OPTIMIZE WASTEWATER AND SLUDGE TREATMENT

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Abstract
In this paper, experimental studies on pre-treatment of sludge by using the combination of thermal hydrolysis and ultrasound were carried by using Bioprocess bench scale system. A set of experiments were conducted under different periods for thermal hydrolysis at 120 degree and various intensity of ultrasound treatment, and under mesophillic and thermophilic conditions. The experimental results were analysed with obvious potential of enhancing sludge digestion efficiency with shorter digestion time and better biogas production. Many WWTPs in southern part of China were built up without primary sedimentation tanks, therefore sand comes into biological system, resulting into accumulation of sand in biological tanks and in waste-activated sludge before digestion. Experimental study on using hydrocyclone on the returned sludge stream has been tested to evaluate the efficiency of sand removal from MLSS to improve MLVSS/MLSS and potential impact on both biological system capacity and anaerobic digestion of sludge.

Keywords
Sludge, digestion, thermal hydrolysis, ultrasound, sand removal, hydrocyclone, MLSS.

Introduction

More than 3000 WWTPs and 30 million tons sludge per year in China

Dramatic increase in construction of wastewater treatment plants (WWTPs) has occurred in last twenty years, especially last decade in China to catch up with the tremendous amount of wastewater discharge from urban areas and sub-urban areas due to rapid urbanization. More than 3000 WWTPs have been built up in China with total wastewater treatment capacity up to 130 million tons /day, compared with around 170 million tons /day in USA. The important experiences gained from last decades for wastewater treatment include 1) clear objectives, 2) clear responsibility, 3) implementation of policies, 4) regulated supervision, 5) reliable technologies, and 6) professional standards. Although wastewater has been much focused on in the last decades, however sludge treatment has long been lagged with only simple treatment to landfill disposal. Dewatered sludge has amounted to around 30 million tons per year and most of them (70%) has not been well dealt with before simple landfill or even dumpling on land.
Only around 50 anaerobic digestion plants built but less than half in operation

Although anaerobic digestion of sludge is widely applied in Europe and North America, it is however not widely used in China for many reasons. Only around 50 WWTPs have installed anaerobic digestion system, but only less than half of them are in normal operation now. The reasons may be the lack of operational cost, not well defined standard for sludge stabilisation, difficulty in operation of digestion, unstable temperature control, low VS content in sludge for less biogas production, sand sedimentation in digesters to block pipelines, insufficient mixing facilities, etc. It is especially noted that low VS content has been focused lately for the main reason for unsuccessful operation of digestion system for low biogas production then unstable temperature control, then worse biogas production until full stop. An obvious bottleneck for low VS content sludge is low VS reduction compared with high VS sludge. Sand sedimentation in digesters is also an obvious reason for quick block of pipelines and weariness of equipment like dewatering machines and pumps.

Enhancement of VS reduction with pre-treatment and sand removal

Among technologies for enhancement of VS reduction, thermal hydrolysis has been widely used in many large scale projects in Europe and North America. However, thermal hydrolysis under high temperature and pressure may require complicated operational and management care. Another potential pre-treatment includes ultrasound. In addition to these, sand removal becomes a more focusing issue due to its impact on digestion system and negative impact on VS reduction. In this paper, combination of thermal hydrolysis at lower temperature and ultrasound treatment was tested to demonstrate the difference of thermal hydrolysis alone, ultrasound alone, and the combination of both two on biogas production. Furthermore, sand removal from returned sludge stream was tested to demonstrate VS improvement under various conditions.

Experimental set-ups and methods

Thermal hydrolysis unit

A standard medical unit was used for thermal hydrolysis of sludge samples to defined time under 120 C degree. The sludge samples were heated for 15 min, 30 min, or 45 min for comparison of effect of time over dissolution of COD, proteins, fats, and hydrocarbons, and particle size distribution.
Ultrasound unit

A normal ultrasound unit was used to treat sludge samples under different time and energy intensity in order to evaluate the impact of dissolution of COD, protein, fats, and hydrocarbon, and particle size distribution as well. The ultrasound unit has 20 KHz, 2-100W, with probe diameter 6 mm and pulse mode.

Combination of thermal hydrolysis and ultrasound was then evaluated for the optimal condition for thermal hydrolysis alone and ultrasound alone, to find out the joint effect of both pre-treatment.

Bioprocess batch anaerobic digestion unit

A set of Bioprocess BA batch anaerobic digestion unit was used for testing combination of thermal hydrolysis and ultrasound under various conditions and compared with control samples with traditional digestion only under mesophilic and thermophilic conditions.
Hydrocyclone unit

A hydrocyclone unit consists of feed pump, hydrocyclone, and pressure measurement. Two different types of hydrocyclone with straight cone and curved cone were used for testing. The pump can deliver different flow rates.

Sludge sampling

Sludge samples were taken from wasted sludge thickening tank from one of WWTPs, characterized by hybrid activated sludge and moving bed biofilm processes with rather long sludge retention time around 20 days. The samples were stored in frig at 4 C degree for use.

Seeding of digestion

Seeding sludge was taken from one of the digesters in Qingdao Tuandao WWTP which is in normal operation. Due to acclimation of anaerobic digestion, the seeding sludge was kept under 35 C degree, 41 C degree, and 55 C degree as well for potential different digestion temperatures.

Experimental results and analysis

Previous results for different conditions of thermal hydrolysis (TH) and ultrasound and the combination

Ran (2013) carried out experiments under various conditions for pre-treatment, i.e., thermal hydrolysis alone, ultrasound alone, and the combination of both two. It was concluded as below:

1. Thermal hydrolysis at 30 min has the best results in dissolution of proteins, COD, and hydrocarbons among three periods, i.e., 15 min, 30 min, and 45 min respectively.
2. Various combinations of ultrasound intensity and time were conducted testing, with the optimal combination of 0.3 W/mL and 30 min.

3. The combination of thermal hydrolysis @ 30 min and ultrasound 0.3 W/mL @30min has better results in dissolution of COD, protein, and hydrocarbon. Experiments were done under TS of 3%, 4%, 5% respectively. Fig. 3 depicts the increase in dissolution of COD when thermal hydrolysis in combined with ultrasound for 4% TS.

![Figure 3](image.png)

**Figure 3:** Impact of ultrasound time after TH for 30 min for TS as 4%

Comparative results of methane production under different pre-treatment conditions

Due to the capacity limit of AMPTS II, anaerobic digestion test was only carried out for 3% TS and 5% TS for different pre-treatment and control condition (without pre-treatment). Three digestion temperatures were defined, i.e., 35 C degree, 41 C degree, and 55 C degree, respectively.

![Figure 4](image.png)

**Figure 4:** Accumulated methane production (mL/gTS) of batch digestion under 35 C degree

When 35 C degree for digestion, the accumulated methane production increased with time and with pre-treatment, depicted in Figure 4 above.
It is shown that batch digestion of sludge at 3% and 5% TS comes quickly to a high level in short time of 6-8 days, and almost topping at 14-16 days. Lower TS content ensures higher methane production. Considerable increase of methane production by pre-treatment is clearly shown. Around 30% increase for 3% TS and 10-15% increase for 5% TS.

When 55 C degree, the accumulated methane production has somewhat different property as shown in figure 5.

![Accumulated Methane Production (mL/gTS) of batch digestion under 55 C degree.](image)

First of all, the pre-treatment effect was much less at 55 C degree than at 35 C degree, and the methane production was close to each other for combination. The digestion time can be even short as 12-14 days.

Batch test for 41 C degree was conducted with around 60% of methane production compared with 35 C degree. It is probably due to short acclimation time from 35 C degree to 41 C degree, therefore the microorganisms for were not well adapted. It could also be another potential that after thermal hydrolysis, the digestion temperature can be kept at 35 C degree. Comparative continuous digestion studies are required to confirm or reveal different phenomenon.

**VS reduction for different pre-treatment conditions**

Plotting VS reduction for all batch digestion test in Figure 6 as below, shows that under the same pre-treatment condition, the VS reduction for 5% TS is actually lower than 3% TS. Additional ultrasound does help with better VS reduction, but the effect becomes less when feed TS becomes higher. The VS reduction is obviously lower than reported in full scale TH pre-treated projects like Cambi references shown.
Investigation of inorganic and sand contents in several WWTPs in Qingdao

Inorganic and sand contents and the particle size distribution have been investigated by Wang (2012) for primary sludge (PS) and wasted activated sludge (WAS) for five WWTPs, denoted as PS1, …… and WAS1…… Results are shown in figures below.

From Figure 7, inorganic content in five WWTPs is very different, in which two of them has relatively low inorganic matter, while other three plants have much higher inorganics, as high as 50% to 65% w/w. The difference comes from the wastewater sources, with higher inorganics from industrial discharges.
Further sand content was analysed by washing out the organics after ultrasound bath and upflow washing of clean water. The sand content shown in Figure 8 below shows that sand content in inorganics could be as high as more than 50%.

Figure 8: Sand content in sludge from five WWTPs in Qingdao

Microscopic photographing of sand particles and measurement of particle size distribution depict the characteristics of sand size and shapes and medium and average sizes. Figure 9 below shows that even big sand particles should be removed after primary settling, but quite a lot of big particles still come into biological sludge. And the sand included quartz and magnetic particles of different shapes, round or bar-types.

Figure 9: Sand particle sizes in different sludge samples in five plants

Comparing Figure 8 and Figure 9, larger sand particles are found in plant 1 and 2 although the sand content is less, but in other plants, the particles are smaller but more amount.
As shown in Figure 10, for PS1 and WAS1 with relatively low inorganic and sand content, the relatively large sand particles of 30-50 microns still come into WAS1. For another plant, say, plant 4 has round but smaller particles than PS1 and WAS1, although the inorganics and sand amounts higher.

Potential of sand separation using hydrocyclone from returned sludge stream

In order to find out potential of sand separation by hydrocyclone, a series of experiments under various flow rates were conducted for two types of hydrocyclones, type1 and type2. The main parameters for evaluating the effect of sand separation was the increase in VS% content in upflow of hydrocyclone. Figure 12 shows that VS% concents increased with increasing flow rate for a 100-mm diameter hydrocyclone sets.
For the returned sludge stream with 67-68% VS, an increase of up to 8% VS content depicted the considerable effect of hydrocyclone in sand separation. It is noted that the sand separation depends on sand particle size, type of hydrocyclone, and flowrate. The more the sand content in sludge, the bigger the particle size, the higher effect.

In many WWTPs in southern China, there are not designed and constructed with primary settling, while the vortex sand removal facilities were designed to remove sand particles larger than 200 micros, but due to many reasons, most of sand comes to biological step, like the picture below shown the accumulation of sand in oxidation ditch processes.

**Figure 12:** Increase in VS content in upflow vs different flowrates for two types of hydrocyclones

**Figure 13:** Sand accumulation in oxidation ditch process (as high as 1 m in channels)
Concluding remarks

Although anaerobic digestion of sludge had been widely used in Europe for stabilization and treatment of sludge, but it is still not well accepted in practice due to low VS content and difficulty in digestion potentials. Experimental studies on pre-treatment by thermal hydrolysis at 120 C degree, ultrasound alone, and the combination of both two, have shown the considerable improvement in biogas production by 30-35% for mesophilic digestion and 10-15% for thermophilic digestion. The combination of thermal hydrolysis and ultrasound has the best results. Large scale and continuous pilot study is required to demonstrate the overall effect of various pre-treatment in both efficiency and energy consumption.

Hydrocyclones can be used to physically separate sand from sludge. Continuous removal of big sand particles from sludge has double effects on biological treatment and sludge digestion as well. It is then suggested to conduct large scale pilot study to evaluate the overall efficiency and impacts on biological treatment and sludge digestion processes.

References


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