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Review on Anaerobic Digestion Treatment Technology of Municipal Surplus Sludge

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Abstract

Based on the principle of anaerobic digestion and its advantages and disadvantages, the influencing factors of anaerobic digestion were summarized. On this basis, the improvement direction and new technology of anaerobic digestion are studied to improve the rate of anaerobic digestion and the efficiency of methane production.

Keywords

Anaerobic Digestion; Excess Sludge; New Technology; DIET.

1. Introduction

According to statistics, sludge production in China in 2020 has exceeded 60 million tons (80% water content), such a huge amount of sludge, if not timely treatment and disposal, will bring a heavy burden on the sewage treatment plant.

2. The Anaerobic Digestion of Municipal Sludge has Been Eliminated

2.1 Treatment Methods of Surplus Sludge at Home and Abroad

The sludge department emphasizes the reduction, stabilization and harmlessness of sludge, as well as the comprehensive utilization of sludge resources. The application of anaerobic digestion process is not high in China, but it has been well used in some European countries, as shown in Table 1 [1].

Table 1. Ratio of sludge treatment methods by country

Countries	Sludge treatment method ratio%					
	Inspissation	Anaerobic digestion	Aerobic digestion	Dehydration	Compost	Lime method
China	43	18	21	72	-	-
Britain	-	55	2	-	2	1
Germany	-	64	12	77	3	0
Netherlands	-	44	35	53	0	0
Italy	75	56	44	90	0	0
Denmark	-	50	40	95	1	5

Note: - means unknown.

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2.2 Sludge Characters and Characteristics of Municipal Sewage Treatment Plant

Urban surplus sludge is an inevitable byproduct of sewage treatment plants, and is a mixed waste gas produced by activated sludge process. It usually contains a large amount of organic matter, high content of nitrogen and phosphorus elements, easy to decay, often has a pungent odor, and unstable chemical properties.It can also contain some toxic, harmful and have a negative impact on the environment.

3. Oxidation and Anaerobic Digestion Process

Anaerobic digestion of sludge is a treatment technology that uses anaerobic bacteria and facultative bacteria to carry out anaerobic biochemical reaction under the condition of no oxygen to decompose biodegradable organic matter in sludge into carbon dioxide, methane and water, reduce the amount of sludge, and produce biogas at the same time, and finally realize the stabilization of sludge. The traditional anaerobic digestion process can be divided into moderate temperature anaerobic digestion and high temperature anaerobic digestion.

3.1 Principle of Anaerobic Digestion

In 1979, Bryant put forward the syllogism of anaerobic digestion based on the research results of methanogens and hydrogen-acetic acid producing bacteria, as shown in Figure 1.

1) The first stage

hydrolysis fermentation stage. At this stage, complex organic matter is decomposed into simple organic matter first under the action of anaerobic bacteria extracellular enzyme. Obligate anaerobes and facultative anaerobes are the main bacteria involved in hydrolysis fermentation at this stage.

2) The second stage

hydrogen production and acetic acid production. Hydrogen-acetic acid producing bacteria convert the intermediate products produced in the first stage into acetic acid and hydrogen, and produce CO2.

3) The third stage

methanogenic stage. Methanogens convert acetic acid, H2, and CO2 from the first and second settlements into methane.

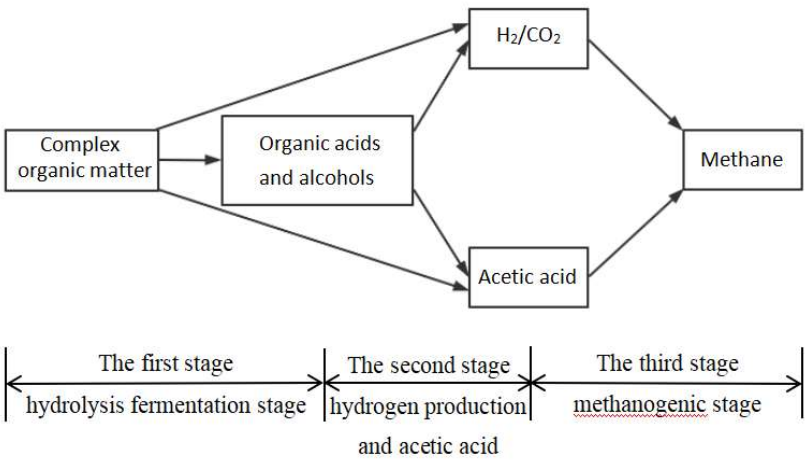

Figure 1. Schematic diagram of three-stage anaerobic digestion process

3.2 Factors Affecting Anaerobic Digestion

1) pH

Changes in pH can change microbial populations and metabolic pathways during digestion. When hydrolysis and acid production rates exceed methanogenesis, organic acids accumulate and inhibit

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the reaction.Fermentation acid-producing intermediates are difficult to control and yield is unstable, but the pH value can be used as an indicator of the overall state of digestion at all stages.

2) The temperature

When the anaerobic digestion is about 55-60℃, the digestion efficiency is the highest and relatively stable, and the digestion time only needs about 10 days. High temperature enhances the abundance of hydrolytic acidifying bacteria, and has a higher removal rate of VS and COD, which can provide more methanogenic substrates and biogas. However, the abundance of methanogenic bacteria is increased at moderate temperature.

3) Argillaceous

The length of sludge age is the most important factor limiting the anaerobic methanogenic performance of sludge. It was found that the methane production rate of sludge decreased with the increase of sludge age, and when the sludge increased from 5 days to 10 days, the anaerobic methane production performance of sludge decreased significantly. It may be because of the high degree of aerobic biodegradation of sludge floc at high sludge age, which leads to the degradation of biodegradability of residual organic matter in sludge. Adding a certain amount of fine sand into the influent can increase the methane production and VS degradation rate of sludge within 60 days. However, when addition exceeds a certain range, this strengthening effect is weakened but does not produce significant inhibitory effect.

4) Stir and mix

Anaerobic digestion is the contact reaction between substrate and enzymes extracted by bacteria, so the two must be fully mixed. There is stratification phenomenon in anaerobic digestion tank, and stratification can be eliminated through stirring, so as to increase the contact between sludge and microorganism, so that the sludge can fully contact with the original raw material, and accelerate digestion speed. In actual production, intermittent or multistage agitation is mostly adopted. However, some studies have shown that there is a strict symbiotic relationship between acetogenic bacteria and methanogenic bacteria, and this symbiotic relationship will be destroyed if continuous intense agitation is carried out in the system.

5) Nutrition and C/N ratio

Generally speaking, the C/N ratio is required to reach (10-20): 1. If the C/N ratio is too high, the nitrogen content of cells is insufficient, the buffer capacity of digestive juices is low, and the pH is easy to decrease. If the C/N ratio is too low, the amount of nitrogen is too high, the pH may rise, and the ammonium salt is easy to accumulate, which will inhibit the digestion process. With the increase of C/N, the values of CST and SRF increase significantly, and the dewatering performance of sludge becomes worse.

6) Toxic substances

Heavy metals, H2S and ammonia can inhibit anaerobic frontal digestion. The addition of metal ions in the influent has an obvious inhibition effect on the anaerobic digestion performance of sludge with different VS/TS values and different sludge ages, that is, the inhibition effect on the anaerobic digestion performance of sludge is universal.

4. Improvement of Oxidation to Anaerobic Digestion

The utilization of methane produced by anaerobic digestion can greatly reduce the cost of sludge treatment, and the biogas slurry produced by anaerobic digestion can be used to prepare organic fertilizer, reduce the volatile substances of sludge, and effectively eliminate the odor, fundamentally eliminating the secondary pollution that may be brought by other treatment methods. However, there are also some problems in anaerobic digestion. In the process of anaerobic digestion, the degradation rate of organic matter is slow, the conversion efficiency is low, and the anaerobic digestion process is not stable, and the start-up time is long. At the same time, the cost of anaerobic digestion technology is high, and China's technology is not very perfect.

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How to improve the rate of methane production from sludge anaerobic digestion is a problem that needs further study now. Some successful technologies that can enhance anaerobic digestion are listed here.

4.1 Pretreatment before Anaerobic Digestion

Pretreatment of sludge before anaerobic digestion can enhance the solubility of organic components and enhance the effect of anaerobic digestion of sludge. The pretreatment mainly includes acid-base pretreatment, ultrasonic pretreatment, biological pretreatment and thermal hydrolysis pretreatment.

1) Alkali pretreatment promoted sludge hydrolysis and shortened the start-up period of anaerobic methanogenesis. First-order kinetics and modified Gompertz model fitting parameters showed that appropriate alkali pretreatment could effectively increase the hydrolysis rate constant and the maximum methane-producing rate of sludge, shorten the delay period of sludge anaerobic digestion, and provide theoretical support for rapid and efficient anaerobic digestion of sludge. The wall breaking technology of alkaline pretreatment sludge is mainly based on the fact that the sludge floc structure is easy to be destroyed under alkaline condition, and the dissolution efficiency of the organic matter in the cell is significantly increased, so as to improve the anaerobic digestion performance of sludge. After alkali pretreatment, the ammonia nitrogen concentration of sludge decreased to a certain extent, and the higher the alkali concentration, the higher the SCOD concentration.

2) Thermal hydrolysis has the potential to break through the bottleneck of anaerobic methane production caused by long sludge age. Thermal hydrolysis pretreatment can kill part of pathogenic bacteria, promote the release of organic matter in sludge, improve the anaerobic digestion rate of methane production and degradation rate of organic matter, and obtain the final product with no odor, no pathogenic bacteria and high solid content, and realize the complete safety of the final solid. Moreover, after thermal hydrolysis pretreatment, the dehydration performance of sludge can be improved, and the biogas production can be increased, and the biogas is of high quality. The energy generated can not only meet its own consumption, but also obtain high quality residual energy materials, which is in line with the low-carbon economy.

3) Proper chemical pretreatment of sludge can rupture cell wall, release organic matter, increase bioavailability of organic matter, and promote anaerobic digestion to produce methane.

4.2 Enhance DIET to Improve Methane Production Efficiency

Produce acid different anaerobic microorganisms of methanogenesis process is the establishment of the relations between electronic exchange camp is considered to be the key of the anaerobic digestion process of organic matter of speed stage, add the establishment of the conductive carbon mediated message camp each relationship can explain the effect of sludge anaerobic digestion, is also considered at present to solve the problem of sludge anaerobic digestion is an effective way[2]. Using the characteristics of DIET, conductive carbon materials such as activated carbon, biochar, carbon cloth, carbon nanotubes, graphite, carbon black and even graphene can be added to promote the anaerobic digestion process.

Compared with the traditional thought of H2/formic acid as medium MIET mutual relations, conductive carbon particles can be mediated anaerobic microorganisms build message mutual relations, more conducive to build a kind of relations between each other camp, anaerobic digestion process stability, conversion of the substrate and methane-producing level ascending simultaneously, improve the overall efficiency of the anaerobic digestion system. The promoting effects of conductive carbon particles in anaerobic digestion system are mainly summarized as shortening methane-producing delay period, improving the stability of anaerobic digestion process, improving methane production rate and methane-producing rate, etc. Some studies also found that conductive carbon particles can promote sludge reduction.

The addition of biochar can slow down the ammonia inhibition in the anaerobic digestion process, promote the methane production process, and finally increase the methane content in the methane to 95%, significantly improve the productivity of the anaerobic digestion system. When the addition

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amount of carbon nanotubes was 0.5g/L and 1.0g/L, the mass transfer rate between the substrate and microbial cells was promoted, and the methanogenesis process was accelerated. The addition of biological nano FeS or magnetic carbon can significantly reduce the accumulation of short-chain fatty acids and avoid acidification, and can promote the activity and growth of microorganisms, and improve the efficiency of methane production by enhancing DIET. At the same time, the type, particle size, amount of conductive carbon particles and the conditions of anaerobic digestion will play a role in the formation of conductive carbon particles in the process of anaerobic digestion, and the influence of particle size seems to be more obvious. On the one hand, porous conductive carbon particles exert their own electrical conductivity to deliver electron DIET to distant microorganisms and assist indirect electron transport through REDOX groups on the particle surface. On the other hand, the porous surface structure can adsorb and fix microorganisms, promote the formation of stable microbial clusters and even biofilm structure, and enhance the contact and connection within the microbial community. It indirectly promotes the occurrence of DIET and ultimately facilitates the construction of multiple links of electron transport pathways among microorganisms.

4.3 Collaborative Anaerobic Digestion Treatment of Kitchen Waste

The synergistic digestion of sludge and food waste can increase the volume utilization rate of digestion facilities, increase the organic load, and greatly improve the methane production rate. At the same time, through mutual dilution of materials, the ammonia inhibition problem in the anaerobic digestion of high solid sludge and the salt inhibition problem in the anaerobic digestion of kitchen waste were obviously alleviated, and the operation stability of the process was improved. Zhenjiang eat hutch collaborative senior anaerobic digestion sludge and demonstration project, is the first domestic urban sewage sludge and eat hutch garbage anaerobic digestion processing projects, mainly adopts "eat hutch source sludge thermal hydrolysis pretreatment + sludge thermal hydrolysis + high solid content of anaerobic digestion + renewal depth dehydration sun able use + biogas purification of natural gas purification system" process. The project more than doubled methane production at the existing sludge anaerobic digestion facility [3].

In the actual production, the sludge carbon and nitrogen is relatively low, easy to produce ammonia inhibition, sludge anaerobic digestion has low gas production, system instability and other problems. In the collaborative digestion of kitchen garbage and sludge, on the one hand, the harmful substances produced by the anaerobic digestion of sludge are diluted, and on the other hand, the volatile acids of nutrients in the collaborative digestion are provided to improve the anaerobic digestion performance of sewage sludge and kitchen garbage alone. When the sludge is digested together with straw, kitchen waste and livestock manure, the problem of anaerobic digestion of sludge and other organic matters can be alleviated, and the methane production, methane production rate and organic matter degradation rate can be improved.

4.4 Improvement of Anaerobic Digestion Device

1) The use of embedding method: The embedding method is simple to operate, has little influence on microbial activity, and can fix microbial cells in a specific polymer network. The immobilized microorganisms have high strength, strong binding force with microbial cells, and stable chemical properties. By embedding, the strength of microorganisms in a certain space can be improved. The fixed biological cells can improve their resistance to external adverse factors, such as resistance to inappropriate external pH value, and at the same time slow down the influence of hydraulic residence time, thus prolonging the relative reaction time of microorganisms.

2) Adding co-digestion substrates: Australian Zirl wastewater treatment Plant uses residual sludge (ES) to add co-digestion substrates for medium-temperature anaerobic digestion, which has significantly improved biogas production and achieved self-sufficiency of energy[4].

3) Two phase anaerobic digestion: Two phase anaerobic digestion is based on the acid producing bacteria and methane-producing bacteria in nutritional needs, growing environment and metabolic substrates such as difference, will produce acid and methane-producing phase points in two reactors,

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the use of acid producing bacteria and methane-producing bacteria growth and metabolism ability, so as to improve the processing capacity of the anaerobic digestion system. Compared with single-phase anaerobic digestion, sludge removal rate, total solids degradation rate and organic matter degradation rate were improved, and methane production rate was even increased by nearly 1.6 times.

5. Summary and Prospect

The technology of anaerobic digestion to treat excess sludge is in the stage of steady development, and through continuous improvement, it can better accelerate digestion rate and increase methane production. Some new technologies, such as adding conductive carbon particles and nanomaterials, are expected to be put into practical production to enhance methane production, while thermal pretreatment, alkali pretreatment and some co-digestion treatments before anaerobic digestion have been well put into production and achieved good results.

In future studies, the relationship between DIET and microbial communities of anaerobic digestion can be studied to improve the activity of acetic acid producing bacteria and methanoproducing bacteria and promote anaerobic digestion of sludge.

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