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Biomass-biogas Recycling Technique Studies of Municipal Food Waste Disposal: A Review

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1. Introduction

As huge new metropolises take shape, urbanisation is becoming a defining 21st century social trend. In the context of global economic integration, the process of urbanization speeds up in the economic transition. Municipal solid waste (MSW) represented by food waste particularly known as organic or biodegradable waste is initiating a growing concern from governments of various countries [1, 2]. 3R activities (Restraining generation(Reduce), Reuse (Re-use) and Regeneration (Recycle))could well be the future direction and the main principle on food waste treatment and management in terms of sustainability. 3R would certainly break a new ground at the road to sustainable development, which could alleviate ambient pollution burden and reclaim organic matter. On this account, it could substitute the consumption on fossil fuel, relieve excessive dependence on fossil fuel presently, and gather collecting, transporting, treating, recycling as its distinguishing feature [2].

Cities that readily adopt alternative forms of energy will be able to increase their urban competitiveness and use wastes to generate energy, which is an approach of ecological and economical efficiency [3]. To develop techniques of biogas fermentation and biomass gasification is one of the main ways on the agenda in solving the stringent energy shortage and decreasing the rising environmental pollution under the current situation [4].

By 2050, 75% of the population of the world will live in cities [5]. The quantity of food waste then would attain several times as many as the existing amount. Food waste is commonly referred to swilling. According to the definition in Beijing Administrative Measures for Food Waste Collection &Transportation &Treatment, food waste is residue of food, discarded liquor and abandoned oil which generates from activities derived from food processing, eating and drinking service, regular meat by hotel, restaurant, eatery and entities covering institution, troops, academy and enterprises & institutions [6]. Food waste consists of rice & flour residue, vegetables, plant & animal oil, meat & bone and more. It is composed of starch, fibrin, protein, lipid and inorganic salt in chemical constitution, which concretely incorporates kitchen leftovers, root & leaf of vegetables, skin & nucleus of melon and fruit, discarded animal tissues [7]. Food waste coming from residential regular life, food processing, diet service, activities of entity food supplying is generally referred to kitchen waste and discarded edible grease. Food waste has formed a major source of municipal domestic waste. Because of its features of possessing abundant nutrition, high moisture content, weak dehydration property, corruptible putrefaction, easy generation of stink and spoilage organisms during transportation, this brings about great difficulties to cleaning, saving, carrying, dumping and incinerating this waste [8, 9]. On the other hand, organic content is higher with animal protein in food waste, and it holds abundant nutrition constituent with a relatively balanced proportion, containing minor or uncontaining any hazardous substance. So it is considered as the ideal energy substrate for sufficient anaerobic biogas production [10, 11].

Because of unique catering culture and dinner custom, food waste proves to be an exclusive phenomenon in China [12]. It is extravagant on

Chinese dining table. There exists enormous amount of food waste. According to Beijing City food waste treatment experience introduction from Beijing's National Development and Reform Commission, there had been about 1200t/d food waste formation in this city in 2010. According to a statistic data from solid waste pollution control and recycle institute, Tsinghua University, There exists the total amount of food waste no fewer than 60 million tons in Chinese cities in 2009 [13]. It has been established that it is necessary to found technology developing patterns of recycling economy in key industries and key cities. This is the major objective for Chinese scientific and technological development in future 15 years definite by China's National Long- and Medium-term Program of Sci-Tech Development Planning. There into, technological research and development for recycling waste derived typically from society has become one of the primary missions for cities which aim for sustainable development at the present stage in China. The resource utilization of food waste, regarded as one of the typical wastes derived from society source, has become an important content in promoting recycling economy development for China [14–16].

In recent years there have been a sequence of problems triggered by illegal disposal of food waste, such as food security, feedstuff safety, environmental quality sanitation safety, drinking water security. They mainly refer to illegal cooking oil extracting, feeding domestic animal directly, waste discarding and informal swilling transportation, colibacillus in percolating liquid endangering human health individually [17]. And they had aroused an extensive attention and controversy from the public. Of course, these also fall under high attention from relative government departments, that requires an immediate solution. May 2010, China's National Development and Reform Commission issued the Notification of Promoting Trial Work to Realize Food Waste Reclamation & decontamination jointly with Ministry of Agriculture, Ministry of Environmental Protection, Ministry of Housing and Urban-Rural Development. Next to it, July 2010 Chinese General Office of the State Council launched Guidance about Strengthening Illegal Cooking Oil Punishment and Restaurant Waste Management [18, 19]. It puts forward that it should be obliged to strengthen effective management on restaurant waste and to promote reclamation & harmlessization [20] with food waste.

On the other hand, non-renewable sources of energy represented by petroleum, coal, natural gas are generally becoming exhausted, whose excess consumption brings about serious problems of energy shortage and environmental pollution [21], and all these significant challenges are encountered by mankind in new century and should be settled perfectly. Simultaneously, the gross CO_2 emission in China has ranked 1st around the globe, which runs counter with the established national fundamental policy of cleaning development, sustainable development and harmonious development [22]. MA Fucai, deputy director of Chinese National energy leading group office, forecasted that at present Chinese multi element biomass stock amounts to 350 million tons coal equivalent, including various biowaste. In line with present engineering level and economic feasibility, available stock number of available biogas fuel, including all kinds of biowastes, amounts to 250 million tons coal equivalent. It could be converted to equivalent natural biogas(methane) of 120 billion cubic meters, equal to the amount of natural gas consumed in 2010 in China. As we know, there are abundant nutrient constituents in food waste. This waste has a better biodegradability especially. And there exists abundant biomass energy in it. Abundant biomass resources reveals broad industrial prospect. In addition, the highly hydrated characteristics are some advantageous to convert this waste of bioenergy to some desirable energy resources. Food waste, whose essential components are abundant in protein, starch, food fiber and adipose, has a high potential in exploiting bioenergy and bio-fertilizer. On one hand, anaerobic digestion could remove organic matters from the waste, accelerate process of stabilization, decrease sludge accumulation, protect the environment, and keep ample nutrient contents in it, thus it could be exploited to yield new energy biogas or serve as industrial chemicals after purification, as well as be developed into some efficient organic fertilizer by its feature of not losing activity after a long reserving time [23].

Regarded as an effective carrier of energy and matter, food waste could be converted to biogas, which is one Bio-NG of low carbon, clean, efficient, convenient for carrying after anaerobic treatment. Study indicates that there is a biogas production of 450 cubic meters after full-fermentation with food waste of 1 ton, offering electric energy of about 700 degrees and the amount nearly meeting the domestic consumption of a family of three in a half year [24].

Total generation amount of the food wastes came up to 60 million tons in China in 2009. If the whole waste fermented into biogas and converted to electricity, the energy amounts to the total power generation of several power plants. Anaerobic digestion has been applied in the context of disposing waste water, sewage sludge and biomass waste previously [25]. Food waste disposal and recycling is a term which focusing both on ecology and human health. So anaerobic digestion has been proven to be one of the best approaches for municipal food waste dispose and recycle. Due to its obvious advantages, biomass energy should be promoted vigorously in China's 11^{th} Five-Year Plan period. It is clear that developing biomass potential rationally and developing biomass to biogas recycling technology from municipal organic waste have a vital strategic significance on the effective remission of increasingly severe burden of garbage disposal and energy shortage crisis, guarantee of quality of life of the masses and ensuring national sources of energy safety in China. During China's 11^{th} Five Year Plan Period (2006–2010), the state had launched some preliminary trials on biomass to biogas recycling technique. These efforts had acquired some effect. And there have been certain demonstrating projects founded for biomass to biogas recycling [26]. But these projects are in stage of production halting for the time being because of unstable process operation and difficult safe-absorption of vice product. It is clear that regeneration of biomass from food waste has not completely broken via efficient utilization of core technical bottleneck in China. The problems of high efficiency utilization, Secondary pollution prevention and control and safety control of product remains to be solved urgently [27]. These problems seriously restrict the establishment of recycling economy mode of food waste resources recovery. The aim of this research is to carry out the systematic research of organic solid waste anaerobic digestion desperately according to China's actual situation, and to make a thorough inquiry into the advances in anaerobic digestion.

2. Technique's principle & influence factors of anaerobic digestion

2.1. Technique's principle of anaerobic digestion

Anaerobic digestion is a biological process in which organic matters are transformed into methane and carbon dioxide by biochemistry of facultative anaerobe and obligate anaerobe, meanwhile materials of cell is synthesized [28]. This is an effective approach to accomplish hazard free and reclamation of organic solid waste. Many intermediate products and intermediate processes are involved in the process of anaerobic digestion. It is a complicated biochemical process. Scholars at home and abroad were undertaking a mass of researches on metabolic pathway, conversion of substances and interactions of inter-species of bacterium in the process of anaerobic digestion. The theory of anaerobic digestion attains continuous improvement hereon. Following the development of anaerobic microorganism and ceaseless studies of anaerobic digestion process, the principle of anaerobic digestion has undergone three major developmental stages of two-, three- and four-stage models. In two-stage model there are two stages of anaerobic digestion: hydrolysis-acidogenesis, methanogenesis. In three-stage model there are three stages of anaerobic digestion: hydrolysis/liquefaction, acetogenesis, methanogenesis. And in four-stage model there are four stages of anaerobic digestion: hydrolysis, acidogenesis, dehydrogenation & acetogenesis, and methanogenesis. Among these theories, the three-stage model is an anaerobic digestion model comprehended thoroughly and recognized relatively [29]. According to this theory, anaerobic digestion process is consisted of three stages that consists of hydrolisation, acidification and methanation. And the three anaerobic stages could go ahead simultaneously. Here Fig. 1 shows Reaction mechanism for anaerobic digestion of food waste. After three different stages of hydrolysis, acidification and methanogenesis, it is finally accomplished with the anaerobic digestion purpose of biowaste recycling.

Three-stage theory is proposed in 1979 by M. P. Bryant in terms of research results of hydrogen-producing acetogens and methanogens [30]. The first phase serves as the acidogenic phase, first the carbohydrates such as sugar in food waste, fat and protein are subsequently broken down into the low molecular materials under the action of acidogenic bacteria. These substances give priority to volatile fatty acid (VFAs). So in this stage pH value will present a phenomenon of falling. The second phase is hydrogenesis in acetogenicstage. Methanogens can't use most middle product generated in the first stage. The intermediate products, such as long chain fatty acids and alcohols hard to be used directly by methanogens, need to transform into the products which could be used directly by methanogens.

The third stage is methanogenesis stage, in which the intermediate products generated in the first two parts could be broken down into methane and carbon dioxide under the function of methanogens. In this stage, because a large number of organic acids continue to be transformed into methane and carbon dioxide, and simultaneously there are $NH_4^+$and HCO_3^- existing in the system, acid changes in the substrate will be buffered consequently, rendering pH value increased in zymotic fluid. So this stage is also called alkaline fermentation stage.

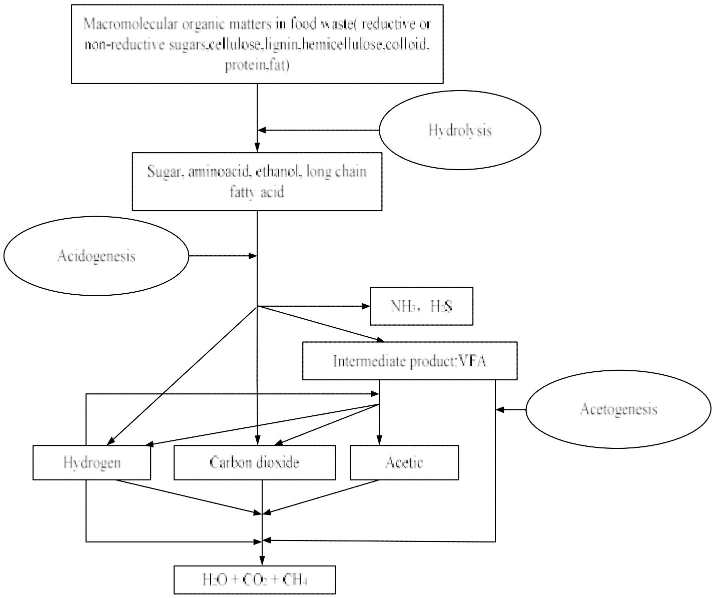

Fig. 1. Reaction scheme for anaerobic digestion of food waste
Rys. 1. Schemat reakcji beztlenowej fermentacji odpadów spożywczych

Anaerobic digestion is an ecological balance system actually in which microorganisms of diverse species with different function and pollutants survive together, interdependent and restrict mutually in practice, so it is considered as a complicated biochemistry process [31]. It contributes to improve and enhance technological level of anaerobic treatment by gaining some deep insight into the mechanism of reaction and influencing factors in each phases of anaerobic digestion.

2.2. Superiority of anaerobic digestion technology

Due to its more significant economy, security and capacity efficiency, anaerobic digestion technology has leaded to an increasing number of attention. It has shown some merits below in processing municipal organic solid waste [32].

No consumption of oxygen in anaerobic digestion process, it can reduce power consumption, save energy, and reduce costs.

Anaerobic digestion shows a greater organic loading rate(OLR), a higher efficiency of reactor, a less volume and a less space coverage. Thus, capital expenditure could reduce accordingly as little as possible and a better treatment effect could be guaranteed.

No aerobic microorganism participation in anaerobic process with few excess sludge, this reduces disposal cost and sludge generated is relatively stable.

Recyclable methane energy, reducible pollution load, with lower methane emission of greenhouse effect gas.

Fermentation residues, like biogas slurry and biogas residue, could be converted to soil additive or fertilizer. This increases its economic benefit.

In a word, offering a twin solution for energy generation and waste disposal, anaerobic digestion could achieve wastes processing principle of safety disposal, reducing treatment and recycling treatment. This makes a tremendous contribution in economizing biomass.

2.3. Influence factor of anaerobic digestion

There are several environmental factors and operating parameters affecting the process of anaerobic digestion. The environmental factors include pH value, temperature, food stuff, ammonia nitrogen, alkalinity and more. The operating parameter incorporates pre-treatment, Hydraulic retention time (HRT), inoculation amount, recirculation of biogas slurry, etc.

(1) pH value

Microbial physiological activity is closely related with pH value of culture medium. Only under a suitable pH value, microorganism could show a normal physiological activity. pH value is a crucial factor influencing anaerobic digestion of food waste. It affects microbial activity and then impacts the whole process of anaerobic digestion. Because of acidogenic phase and methanogenic phase taking place in a one-phase anaerobic digestion reactor, anaerobic digestion best fits pH 6.8–7.2. Irreversible suppression would come up if pH is too low to maintain a normal pH level, and the whole process of anaerobic digestion would then be influenced. In a two-phase anaerobic digestion process the hydrolysis (acidification) reactor could select the specific shift of bacterial community and then farther regulate acidogenic pathway and subsequent methanogenic pathway. pH value has a crucial influence on the growth and reproduction of methanogen. Whenever the value of pH is too high or too low to maintain the normal activity of methanogen immediately, and even cause the death.

Lay etc. [33] found out that pH 6.6–7.8 and moisture of 90–96% are more important to the primary purpose of a greater methanogenic rate in those anaerobic processes. If the pH value is below 6.1 or higher than 8.3, the efficiency of methanogenic phase would descend obviously and even a fail would be inevitable. Especially in the preliminary stage of fermentation, a great amount of organic acid would be yielded in the system. Local acidification and extension of the fermentation period would be brought about if pH value is uncontrolled properly. This would damage the whole reaction system in turn. ZHANG Bo [34] studies influences of the product to acidogenic phase on three different conditioning methods of pH, including pH in initialcharge is regulated to pH7 by single NaOH solution, by mix aqueous alkali of NaOH and $Ca(OH)_2$ every 12h and by C/N in reaction mass, by means of intermittent experiments. The three methods all could reduce sodium ion content in acidification products. Yet the third method receives an optimum efficiency. That level 1 hydrolysis rate constant attains 0.199 d^{-1}. Content of lactic acid reaches the supreme in a short time. Propionic acid is not the main component. This could supply abundant substrate to subsequent methanogens for methanogenesis.

Owning to the rapid reflection ability for the performance of anaerobic reactor with pH in time, many waste treatment plants judge whether or not it is on the rails of normal anaerobic digestion by monitoring pH value in actual operations.

(2) Temperature

The influence of temperature on anaerobic digestion is mainly embodied in affecting the growth of microorganism metabolic pathway through influencing the activity of an enzyme, as well as impacting the forming process of the intermediate product of organic solid waste in reactors directly, and even the whole reaction process is under the influence ultimately. In certain temperature range, any kind of microbial growth, metabolism and the fermentation rate of organic matter all speed up with the temperature increasing. According to Van't Hoff's LAW, in a strict temperature range the temperature rise every 10°C could speed up chemical reaction twofold, and metabolic rate of microorganism would drop quickly with temperature rising when more than one optimal temperature. Sometimes system also can show an irreversible influence.

Anaerobic digestion of organic solid waste goes ahead under intermediate-temperature (30–35°C) or high-temperature (50–55°C) generally. In general conditions, although high energy consumption is needed in high-temperature reaction, it could yield more energy than intermediate temperature. This could shorten retention time of organic matter and diminish volume demand of reactor. Thus high-temperature is more effective on both degradation of theorganic waste and destruction of the pathogen. Methanogen is very sharply sensitive for temperature change. Even though the temperature only reduce 2°C, it could produce immediate adverse effects with gas production declining. Its activity could recover only when the temperature rises again. On the other hand, if the temperature rises too fast, large temperature difference appears could also harmfully effect gas production. For this reason, in addition to the right temperature range for digestion anaerobic fermentation process also requires temperature relatively stable. It is advisable that the variation scope is no more than 2°C in a day.

Bouallagui [35], etc. take advantage of a tubular reactor to digest rubbish of fruits and vegetables under three different temperature ranges of low-temperature (5–15°C), intermediate-temperature (30–35°C) and high-temperature (50–55°C). It is observed that gas production of high-temperature digestion is greater than mediate-temperature and low-temperature, with 144% and 41% respectively. Nevertheless, high temperature requires a higher power needs with an unstable reaction performance, leading to an easy organic acid suppression [36]. K. Komemoto, etc. undertook both hydrogenic and acidogenic efficiency with food waste under temperature of 25, 35, 45, 55, 65°C respectively [37]. The result implies that hydrolysis rate of 70% and 72.7% could be reached under 35°C and 45°C respectively. A greater gas production is guaranteed simultaneously. And in a high temperature conditions, because of the activity of microorganism under control, a greater hydrolysis rate emerges only in the early time with a lower gas production.

(3) C, N, P

Microorganism lives by main external nutritions of carbon and nitrogen, in which carbon is a crucial matter to constitute microorganism cells, heterotrophic bacteria could use organic carbon sources and autotrophic bacteria could use inorganic carbon sources. And nitrogen is the significant element to constitute protein and nucleic acid in microbial cell. The nitrogen source incorporates inorganic nitrogen of NH_3 and NH_4^+ and organic nitrogen of carbamide, amino acid and protein and more. The growth and metabolism of Microbial do not need only a certain amount of C and N, but also the certain proportion has to be ensured to maintain its normal life activities mainly through influencing the growth and breeding of microorganism and even the formation and accumulation of metabolic product to affect gas formation. It is suggested that the optimal carbon-nitrogen ratio(C/N) should be controlled at 13/1–28/1 in general. Appropriate C/N could promote the rapid decomposition of various organic substrates for fermentation and generate enough methanogenic substrates without causing acid accumulation to bring about fermented liquid acidification, thus the activity of methanogens is affected. if C/N is too high, acidification is subsequently brought about easily, and the buffering ability of system could be weakened for this. But if C/N is too low, digestive process is often suppressed by increasing NH_3-N concentration. Some scholars undertook batch fermentation researches on hybrid materials of pig manure and air dry straw with different C/N. It is concluded that C/N has a little impact on the gas production of fermentation in start-up phase. However there exists a greater impact on methane content in start-up phase. A greater methane production is obtained at a high C/N. The gas production can get a good effect when C/N is between 28/l–38/1. As a result, the inoculum of a higher C/N should be selected and used to enhance methane content in start-up phase and to regulate C/N of 28/1–38/1 in the materials for fermentation [38].

C/N of anaerobic fermentation system is also often regarded as a kind of regulation method in the acidogenic fermentation. It is more complicated on acidogenic phase. Different researchers produce diverse acidogenic fermentation mechanisms in terms of different C/N. They mainly concern the two contents that on one hand it is via the adjustment of the microbial itself anabolic processes to influence the biological oxidation process of organic matter in the microbial body, thus it could further adjust reduced ratio of coenzyme and oxidizing coenzyme (NADH/NAD +) and fermented product quantity change inside cell of anaerobic microbe. On the other hand, it is to lure anaerobic bacteria with different acidogenic function to gather in the system so as to control the formation of acidogenic fermentation of different type. Lin and Lay tested synthetic wastewater of different initial C/N value digested by mixed bacteria to influence hydrogenesis. It was found that when the initial C/N lays in the range of 47–130, the butyric acid has a higher content than acetic acid, and it becomes the main terminal products in acidogenic fermentation [39].

Phosphorus is the crucial element in composing nucleoprotein, lecithin and other phosphorus compound. It plays a crucial role in the microbial metabolic pathway and material transformation. Coenzyme I, coenzyme II and phosphoric acid adenosine all contain phosphorus. Microbe gets phosphorus mainly from inorganic phosphorus compound. The shortage of phosphorus source will affect the activity of enzymes, and even the physiological function of the microbe will be affected. Generally it is recommended that the ratio of nitrogen source to phosphorus source be at the following proportion for N:P of 5:1.

(4) NH_3-N

Nitrogen balance is a crucial factor in the process of anaerobic digestion of organic matter. Nitrate in the anaerobic digestion system of food waste can be reduced into nitrogen existing in the anaerobic digestion system. Only a small amount of nitrogen is the used by cell in the microbial growth and reproduction. Most of the biodegradable organic nitrogen is reduced to ammonia nitrogen existing in digestive system. In each phase of anaerobic digestion methanogens of microorganisms receive the greatest impact by ammonia nitrogen (NH_3-N) suppression. In the course of anaerobic digestion ammonia nitrogen (NH_3-N) mainly comes from degradation of organic matter containing nitrogen, the decomposition of amino acids and proteins. Moderate concentration of ammonia nitrogen (NH_3-N) is necessary. But if its concentration is too high, that will fast inhibit activity of methanogenic bacteria. The inhibition mechanism of ammonia nitrogen (NH_3-N) has drawn more and more attention from numerous researchers. For example, the inhibition effects are reflected on the change of the pH in cells, changing energy demand and inhibit the enzyme's activity [40].

JIANG Jianguo [41], etc. investigated the concentration change of ammonia nitrogen (NH_3-N) and its inhibitionon the process of anaerobic digestion of food waste. When the ammonia nitrogen (NH_3-N) concentration is up to 1700 $mg \cdot L^{-1}$ in the 80d methanogenic bacteria are inhibited by this [42]. Gas formation rate drops. From the 116 d 126 d glucose is added to improve carbon-nitrogen ratio in the feed liquid, concentration of ammonia nitrogen (NH_3-N) is lowered, then the system stabilizes gradually. When the concentration of ammonia nitrogen (NH_3-N) improve to 3000$mg \cdot L^{-1}$ once again the inhibition of ammonia nitrogen (NH_3-N) on methanogenic bacteria would not emerge. This is the result of the long-term domestication. It is implied by some studies that when ammonia nitrogen (NH_3-N) concentration reached 4051–5737 mg L^{-1}, acidogenic bacteria sufferthe impact scarcely, but methanogens has been losing the activity of 56.5%. There are different points of view for ammonia nitrogen (NH_3-N) restraining the activity of acetic acid-decomposing microbes and bacteria of nutritional type-hydrogenin the past researches [43]. Some people draw out through comparing the gas production rate and microbial increment speed that ammonia nitrogen (NH_3-N) has a stronger inhibitory action on acetic acid-decomposition microbes than bacteria of nutritional type-hydrogen. And yet some researchers think that acetic acid decomposing anaerobic bacteria have a stronger resistance than bacteria of nutritional type-hydrogen for a high concentration of ammonia nitrogen (NH_3-N).

(5) Alkalinity

Alkalinityis the main material to neutralize organic acid generated in anaerobic acidogenic phase and to maintain the stability of pH in system. It is an important parameter to reflect anaerobic reactors operating steadily. Alkalinity is usually divided into total alkalinity and part alkalinity. Total alkalinity can't reflect buffering ability of anaerobic system well. Part alkalinity represented by bicarbonate alkalinity could neutralize the inhibitory action of volatile organic acids in the system and truly reflect the buffering ability of system. Only when bicarbonate alkalinity comes up to a certain range it could play a buffering role on the accumulation of organic acid. So in the actual operation the content of the bicarbonate alkalinity should be monitoredat any time. When the system generates a lot of volatile fatty acid (VFAs), beyond the buffering ability of systemic alkalinity, system pH value will fell rapidly and inhibits the activity of methanogen. There are some studies suggesting that alkalinity has a great influence on the performance of pollutants degradation. In the anaerobic treatment process of printing and dying industry wastewater, alkalinity has little impact on COD removal rate when alkalinity drops from $3000mg \cdot L^{-1}$ to $550mg \cdot L^{-1}$. And COD removal rate dropping from 88% to 68% [44]only takes place on the time of alkalinity dropping to $250mg \cdot L^{-1}$.

(6) Pretreatment

If some pretreatment is imposed on food waste before anaerobic digestion of food waste, it not only can promote the following anaerobic digestion process, but also can reduce costs and improve the gas production rate. The commonly used methods of pretreatment include biological, mechanical, chemical methods and various combinations thereof [45]. Mechanical pretreatment decreases the volume of raw materials, reduces the complexity of the molecules and improves the contact area of the reaction mainly via the physical effects of mechanism and heat, such as shredding or smashing raw material. Some study shows that if kitchen waste is frozen in -20°C for more than 24 h firstly and subsequently thawed again in 25°C for the 12 h, it can improve the concentration of soluble COD(SCOD)in digest fluid and VFA concentration in the acidogenic phase of the reactor, and then subsequently improve the rate and efficiency of methanogenic phase [46]. Chemical pretreatment is to use chemical reagent to soak or treat raw material with acid/alkali. This method has been successfully used in the pretreatment of the straw fermentation. KANG Jiali treated straw with sodium hydroxide for solid chemical pretreatment, the results show that unit TS gas production increased by 49.9% after the treatment of wheat straw with 6% sodium hydroxide, and the digestive time shortens by 19d. The biological pretreatment, that is to hydrolyze raw materials by the effect of microbial biochemical before the hydrolysis reaction, making the degradation easier, so as to improve the efficiency of the subsequent anaerobic treatment. PAN Yajie, etc [47]. put forward that the gas formation efficiency could be improved after the biological pretreatment with white-rot fungus, and the preparation of fermentation liquid easy to anaerobic bacteria fermentation.

Thus it can be seen that pretreatment play an important role in anaerobic digestion process. And it is necessary to lay emphasis on pretreatment and make it play a positive role in the process.

(7) Hydraulic retention time

Hydraulic retention time (HRT)is a time that is used to describe reaction time of organic matter within a reactor. For the reactor with a fixed volume, the greater the HRT, the reaction time of the waste is longer. And the smaller the HRT, the reaction time of the waste is shorter. But this could cause a high load, in which organic matter could not degrade to the full to lead to a failure in the biochemical reaction. According to different substrates, the hydraulic retention time generally needs twenty days or so in a single-phase continuous anaerobic reactor. However, the hydraulic retention time in 2–10 d or so is needed for each phase in a system of two-phase anaerobic reaction, in which hydrolysis-acidogenesis, methanogenesis are divided artificially. B. Rincon [48], etc. investigated the impact of retention time on single-phase anaerobic digestion for the solid waste of olive branch and studied gas formation under anaerobic condition. It was observed when organic load rate and retention time are 9.2 g $COD·L^{-1}$ and 17 days respectively, methanogenic rate reaches the highest value of 1.7 $L·d^{-1}$. However, when organic load rate extend more than 9.2 g $COD·L^{-1}$ and retention time is less than 17 days, the system begins to become unstable until reaction fails.

(8) Inoculation amount

Inoculation is to provide microorganisms for anaerobic digestion system. The quantity and quality of inoculation material play a crucial role in the gas formation performance and stability of the anaerobic digestion system. If the inoculum concentration is too low, the number of microorganisms available would become too little. Methanogens would grow slowly, so it needs an enrichment process. However the acidogenic rate is quicker than methanogenic rate. And then the acid accumulation becomes inevitable. And if the inoculum quantity is too high, the volume demand of reactor would become higher and the cost would rise. When the inoculum amount increases, a relative lack of nutrition takes place subsequently in a certain condition, and microorganism reaches a certain number, this can lead to the struggle for existence, and then lead to lower the activity of microorganism. Generally it is better when inoculation amount reaches 20–30% of medium weight. And inoculation quantity also should rise [49] along with the improvement of solid content.

Nallathambi also found out that gas production quantity rises with the increased amount of inoculation amount in the study of different inoculation amount influencing the degradation of forage [50]. Some study has proved that the different inoculation amount will influence the reaction efficiency of anaerobic digestion, which is undertaken with batch type experimental study under different TS concentration and different inoculation amount in 55°C condition. The study revealed that the condition of TS concentration at 20%and the rate of inoculation at30% is best available for the ideal biogas production. And the rate of methane production comes up to 490 $mL{\cdot}gVS^{-1}$ [51]. MA Lei [52], etc. tested amounts of six different inoculation influencing food waste anaerobic digestion in a high temperature. The result indicates that 480 g of food waste and 120g of inoculum comes out to be the best proportion with the best effect of gas production in the gross 600g condition with 6 different inoculum proportions of 600g food waste, 540 g food waste with 60g the inoculum, 480g of food waste with 120g of inoculum, 420g of food waste with 180g of inoculum, 360g of food waste with 240g of inoculum and 300g of food waste with 300g of inoculum. In addition, various process indexes, such as removal rates of TS, VS, COD all reach the highest value without exception.

(9) Recirculation of zymotic fluid

Recirculation of zymotic fluid is to let the digested material reflow after centrifugal separation into the reactor. Thus it could make the residual organic component reused by microorganisms, and raise the microbial concentration in reactor, and enhance the reactor buffering ability, and improve the moisture inside the reactor and promote the even distribution of nutrient and enzyme, thus the efficiency of anaerobic digestion is raised. But both high recirculation rate leading to an imbalance between the acidogenic phase and the methanogenic phase could also cause the accumulation of some toxic substances or salt. Then the depression is bound to take place with thereduction of bacterial activity in methanogenic phase. Therefore, the recirculation of anaerobic zymotic fluid has tobe controlled in the right range, so as to reduce the discharge volume of digestion liquid, and to ensure the VFA, COD in zymotic fluid to maintain at a relatively low level. Because salt is rich in food waste, the accumulation of salt also need to consider in the process of zymotic fluid recirculation.

In the experiment of food waste anaerobic digestion it is concluded that enhancing the reflux ratio could increase the gas production rate at a lower OLR. But at a higher OLR, increasing recirculation ratio would cause the accumulation of both volatile fatty acid (VFAs) and sodium ions, which easily causes suppression to impact the entire anaerobic digestion process [53]. Some study think that in two-phase anaerobic digestion, acidification phase recirculation of food waste could promote the anaerobic digestion process, and the time required for forming the same amount of methane could reduce by 40% [54]. Delia Teresa Sponza [55], etc. undertook food waste anaerobic digestion experiment by using 70 L of biological reactor with2 different reflux ratios and no backflow conditions. The result showed that there exists an obvious difference of methane content after the 50 days, which were 50% , 40% and 30% respectively. So the right recirculation could promote the activity of methanogenic bacteria, but a higher recirculation ratio often leads to acidification of the substrate, and restrain the normal output of methane and the growth of methanogenic bacteria.

3. Progress in food waste anaerobic digestion research

Food waste anaerobic digestion technology stems from the anaerobic industrial wastewater and sludge treatment, whose technology has gradually matured. It has been thought there are some ecological rationality and economic feasibility in technology of food waste anaerobic digestion [56]. At present the research of food waste anaerobic digestion focuses on influencing factors among anaerobic digestion process, intermediate product in anaerobic digestion process, the anaerobic digestion processes suitable for kitchen waste, and so on.

3.1. Gas formation efficiency and potential

Gas production efficiency and potential from Biomass waste usually use sequencing batch reactor (SBR). It is in a batch operation, and each time the reaction are fed one time. It is no longer required for feeding any stuff into reactor until the end of reaction. The reactor is easy to operate. It can be commonly carried out in 500 mL–1.5 L serum bottle, and the gas collection is usually carried through the drainage method.

In 37°C and 28 d digestive conditions Cho [57], etc. drew a conclusion about gas production potential from different kitchen wastes, that the final methanogenic rate of cooked meat, steamed rice, fresh Chinese cabbage and hybrid kitchen waste achieve 482L·kgVS^{-1}, 294 L·kgVS^{-1}, 277 L·kgVS^{-1} and 472 L·kgVS^{-1} respectively. According to the basic composition of kitchen waste, their anaerobic biodegrade abilities were 82%, 72%, 73% and 86% individually. Wang, etc. employ the type of fed-batch and continuous feeding to deal with food waste by a solid-liquid reactor. The methanogenesis achieve 0.49 m^3·g VS^{-1}and 0.71 m^3·kg VS^{-1} with VS removal rate of 77% and 78% respectively. And in its demonstration engineering tests the quantities of methane production achieve 0.33m^3·gVS^{-1} and 0.49 m^3·kgVS^{-1} with VS removal rate of 72% and 74% respectively. K. Komemoto [37], etc. studied the efficiency of hydrogenic phase and acidogenic phase with food waste in25, 35, 45, 55, 65, 75°C condition respectively. The result shows that the removal rate of suspended solids under different temperature attain 47.5%, 62.2%, 70.0%, 72.7%, 56.1% and 45.9% respectively. L. Neves [58], etc. undertook a batch type gas formation experiment by using lard, cabbage, chicken breast and potato chips to simulate the fat, cellulose, protein and carbohydrate in kitchen waste, getting VS removal rate of 94–99.6% and methanogenic rate of 0.40–0.49m^3·kgVS^{-1}. W. Parawira [59] undertook a batch experiment with potato and beet leaf with different mix proportion, in which the proportion of potatoes is increased from 10% to 80%. The rate of gas production reaches the highest ratio of 0.32 LCH_4·gVS^{-1} when the potato content reaches 40%, with methane content of 84%.

In China there have been many researches engaged in gas formation with food waste. THU [60] applies process of high solid anaerobic digestion in a fed-batch single phase reactor under mesophilic conditions (35°C) to initiate fermentation of kitchen waste prepared by itself. It is found the rate of gas production achieves 705.77 L·kgVS^{-1}when organic loading rate reaches 6.98 kg·m^{-3}·d^{-1}. And all the indicators in system are very stable. LI Juntao [61], etc. of Tongji University conducted researches of gas forming with different kitchen waste and moisture content. The result implies that a better gas production effect could be gained at inoculation rate of 80% and moisture content of 90%. And the gas yield reaches 0.65 L·gVS^{-1}. LIU Huiyou [62], etc. carried out the wet fermentation process on food waste. The best rate of gas production achieves 52 0L·kgVS^{-1} at trial period of 40 days and inoculation rate of 82%.

And it is appropriate to emphasize that it is necessary to guarantee a greater inoculation rate in the initial phase of operation, and the organic load rate should be strictly controlled to ensure a stable gas production.

3.2. Different substrates and joint inoculation

Components in food waste mainly include fat, protein, carbohydrate and cellulose. The components of different proportion determine the different performance of gas formation. So some scholars specialize in researching the influence of gas formation and digestive process derived from different composition in food waste. L. Neves [45], etc. undertook batch type gas formation experiment by using lard, cabbage, chicken breast and potato chips to simulate the fat, cellulose, proteins and carbohydrates in kitchen waste under a mesophilic condition (35°C). Gas formation potential is gained under different proportions that if there is abundant fat in digestive system, hydrolysis constant would be lowered because of the higher COD content usually existing in it. And when the content of carbohydrate and protein is lifted, it is gained with a higher hydrolysis rate of 0.32 d^{-1} and 0.22 d^{-1}. And excessive carbohydrates can get the highest rate methane production and the lowest VFA accumulation.

Due to the characteristic of food waste acidifying easily, it is difficult to operate and control by using single food waste as raw materials of reaction, and it is difficult to accomplish an ideal result. While co-digestion is to set up a kind of complementary relationship between different materials, by which an ideal reaction speed and conversion extent can be promoted. And For instance, an ideal performance of gas formation could be accomplished by co-digestion with straw of low nitrogen content and animal manure of high nitrogen content. Sang Hyoun Kim [63], etc. undertook a three stage fermentation system experimental study of food waste for an integrated hydrogenesis, in which the quantity ratio of food waste-municipal sludge are gained according to 100:0, 80:20, 60:40, 40:60, 20:80, 0:100 and 0.5%, 1.0%, 1.5%, 2.0%, 3.0%, 5.0% respectively. It is observed that the specific hydrogen production rate reaches 122.9 $mL\cdot g\ COD^{-1}$, higher than the single hydrogen production rate of 121.6 $mL\cdot g\ COD^{-1}$ and the single hydrogen production rate of 32.6 $mL\cdot g\ COD^{-1}$ when the quantity ratio is 87%:13% and the VS content is 3%. LI Rongping [64], etc. carried out a hybrid anaerobic fermentation with kitchen waste and dairy manure. A batch type gas formation experiment is undertaken under the mixing ration of 1:1, 1:2 and 1:3 in his research. Study results indicate that the actual potentials of methane production are enhanced by 173%, 6.9% and 3.6% respectively.

And consequently, co-digestion is not the simple addition of organic matter, but to promote mutually, there is a certain synergy in it.

3.3. Intermediate product

In terms of the principle of anaerobic digestion, organic matter in the system was firstly hydrolyzed into sugar, amino acid, alcohol, long chained fatty acids and other substances, and both the intermediates such as volatile fatty acid (VFAs) and some other short chain materials are subsequently formed via acidification, these materials then continue to be degraded into formic acid, acetic acid and methanol, etc. easy to be utilized, at last methanogenic bacteria transform these substrate into methane. This series of transformation pathway and characteristics of product all can be changed as the raw material pretreatment, temperature, pH, feeding concentrations and different kinds of additives & bacteria are differed, and methanogenesis is affected directly. There exist two kinds of common inhibition phenomenon. One is that long chain fatty acids accumulating to a certain amount suppresses the activity of methanogens. The other one is that the accumulation of VFAs especially propionic acid inhibits the activity of methanogens. Foodwaste is extremely easy to acidify. So the recent years researches mainly focus on acid changes in the anaerobic digestion process of food waste.

It is very crucial to study fermentation type in acidogenic phase and its end product for a two-phase anaerobic reaction. According to the main constitution of end product of fermentation, anaerobic acidogenic fermentation of sludge could be divided into four types of fermentation, they are ethanol-type fermentation, propionic acid type-fermentation, butyric acid type-fermentation and mixed acid fermentation. In which ethanol-type fermentation is the newly discovered fermentation type. There would be abundant hydrogen production in the biogas transformed. And liquid products give priority to ethanol and acetic acid. Propionic acid-type fermentation gives priority to acetic acid, propionic acid and CO_2. Butyric acid-type fermentation gives priority to acetic acid, butyric acid, H_2 and CO_2, and mixed acid fermentation is peculiar to the fermentation of enterbacteriaceae genus, in which the main end products of anaerobic fermentation give priority to a complex acid mixture. The products are mainly lactic acid, acetic acid, succinic acid and formic acid. The two main types of fermentation are alcoholic fermentation and lactic acid fermentation. In alkaline fermentation methanogens can only break down compounds of C1 and acetic acid. Only when ethanol, propionic acid and ethylacetic acid transformed into acetic acid firstly, they could be used for methanogenesis. And methanogens is vulnerable to suppression and cause imbalance between acidogenic phase and methanogenic phase. This could lead to a higher partial hydrogen pressure and make the whole fermentation reaction eventually fail. From the change of Gibbs free energy ΔG0 in hydrogenesis and acidogenesis, it is known that the partial hydrogen pressure should be strictly controlled below the 0.01 kPa from the transformation of propionic acid to acetic acid, while the partial hydrogen pressure could be low under 10kPa during the transformation from ethanol to acetic acid. There exist three points which could be used to determine whether the type of fermentation is the ethanol-type fermentation. The first is whether or not it is easy with converting to acetic acid from end products of acidogenic phase, thus to know whether or not it is beneficial to methane production. The second is whether or not it is possible with converting to propionic acid from end products of acidogenic phase, if it is converted to propionic acid, pH value falls due to propionic acid accumulation. And the third is whether or not the end product of acidification is some neutral product, because neutral product could make the system still ran normally in the low pH value. From the above three points, ethanol and acetic acid are the two most suitable intermediate products to form end product. So the optimal fermentation type should choose ethanol-type fermentation. LI Baikun, LV Bingnan [65], etc. figured out that it should control ethanol-type fermentation to be in strictly anaerobic environment, in which start up has to be a static system of absolutely anaerobic activated sludge process. Oxygen is the crucial environmental factor that impacts ethanol-type fermentation. Inefficiency test of intermittent ethanol fermentation, the environmental factors should be controlled at pH 5.0, COD 40000 mg/L and T 35°C.

Generally, sequencing batch reactor (SBR) or Single reactor will be suppressed due to accumulation of volatile fatty acids (VFAs), especially the accumulation of propionic acid. When lower pH value and escalation of H_2 partial pressure is beyond the suitable range of pH and H_2 partial pressure in corresponding with oxidation type, eventually it would lead to the reaction stop or failure. Especially when dealing with municipal food waste and fruit vegetable waste, single-phase reactor is more likely to generate an accumulation of volatile fatty acids (VFAs) to inhibit hydrogenic phase and acidogenic phase, bringing about hydrolysis stage becoming a limiting step of methanogenic phase from a complex substrate. And the accumulation of fatty acids damages growth environment of methanogens. ZHANG Bibo [66], etc. studied relations between gas formation and the change of VFA concentration at the high temperature anaerobic digestion with one-phase reactor to process municipal organic waste. The result shows that the depression of gas production rate is influenced directly by a too-high VFA concentration and the activity of methanogens is suppressed by the obvious accumulation of organic acid. SHI Hongzuan investigated the influence of the product in acidogenic phase on the different pH values of 5, 7, 9, 11 individually. The result shows that both VFA yield and acidification rate could attain the ceiling values at pH of 7, and they are 35.100 g $VFA \cdot L^{-1}$ and l096.8 mg $VFA \cdot gTS^{-1}$. Among which, acetic acid and lactic acid are two major products, and the concentration of propionic acid and butyric acid is relatively low. A greater butyric acid occurs at PH of 7, and concentration of propionic acid is higher at pH higher than 7. Butyric acid is the main product in the anaerobic treatment of fruit & vegetable garbage and municipal organic waste. Its concentration can reach 4000 mg L^{-1} or a greater value to fail reaction.

In addition, efficiency of conversion and level of hydrolysis acidification in acidogenic phase could be assessed via the calculation of acidification rate by utilizing the information of VFA produce law. For problems in single-phase anaerobic digestion, Ghosh [67] proposed the two-phase anaerobic digestion system, in which acidogenic phase and methanogenic phase are separated from each other to achieve their best reaction condition respectively. In a two-phase anaerobic system, it has an important impact on methanogenic phase by controlling products and approachesofacidogenic phase. LIU Min [68], etc. used molasses waste water as the substrate to study fermentation type in acidogenic phase and the law of transformation in the anaerobic methanogenic phase. The result shows that VFA concentration, its form and the proportion among acids is one of the importantindicators to measure the anaerobic performance, and fermentation type in acidogenic phase directly affects the subsequent transformation efficiency of its substrate. LI Baikun, LV Bingnan [65], etc. undertook experiments on organic acids conversion in methanogenic phase of the two phase anaerobic process. The result shows that ethanol oxidation may withstand a wider partial hydrogen pressure, microbial degradation rate of the transformation of organic acid abide by the rule of acetic acid > ethanol > propionic acid > butyric acid, and ethanol-type fermentation is the best fermentation type to play the two-phase anaerobic system function sufficiently.

So inquiry into the intermediate product could help realize the efficient access to comprehensive utilization of municipal organic solid wastes.

3.4. Waste complex

There have been abundant three big nutrient compositions of carbohydrate, protein and fat existing in waste water of food waste and dairy industry, so it belongs to the wastewater difficult to deal with the conventional biochemical technology, and it is defined as a waste complex. The existence of the protein and fat can make methane content in the biogas produced remarkably [35]. It is identified that hydrolysis and acidification of carbonate, protein and fat is the rate-limiting step to accomplish biomass conversion from raw material of food waste. Hydrolysis of grease and carbohydrate increases with the sludge retention time. And the hydrolysis of proteins occurs only in the stage of methanogenic phase. For the transformation of carbohydrates, hydrolysis is its rate-limiting step. Whereas in the case of acidification condition, only acidification is considered as the rate-determining step for the transformation of oil. While both hydrolysis and acidification have been considered as the rate-limiting step for the transformation of proteins [69].

L Masse [70] , etc. tested the experiment of the oil particles hydrolyzed with alkali and enzyme in the wastewater of slaughterhouse. And it is found that pancreatic lipase is more significant than alkaline liquor on the effect of decreasing oil particle size. Hydrolysis by pancreatic lipase PL-250 could be regarded as the best pretreatment method in dealing with particles of oils and fats existing in slaughter plant. CHEN Yinguang [71], etc. undertook some experiment of hydrolysis and acidification with abandoned activated sludge in different pH. And the pH in substrate is adjusted by different type reagent. It is found that at a room temperature the hydrolysis of activated sludge follow the following order: alkalinity>acidity>neutral and blank experiment. At 8th day the concentration of VFAs were 354.49, 842.00 and 2708.02 mg/L in pH 4.0, 7.0 and 10.0 digestive conditions respectively. Thus it can be seen that in an appropriate condition, pancreatic lipase and alkali liquor could both achieve the fast rate of hydrolysis and acidification.

Ingredients of biodegradable organics in waste complex have their unique degradation rules, so a comprehensive research should be conducted according to their respective features.

3.5. Anaerobic digestion process

The anaerobic digestion process has gone through the evolution of single-phase and two-phase, and the technical performance of various types matures gradually. Single-phase is that all the microbial activities exist in the same space or in the same reactor. About six kinds of microbe come into play in anaerobic digestion. The condition for maintaining the activity of different microbe is different. Consequently, single-phase reactor could only deal well with the efficiency of biogas producing in a certain range. Single-phase reactor incorporates continuous stirred tank reactor (CSTR), upflow anaerobic sludge blanket (UASB), anaerobic filter reactor (AFR) or anaerobic fixed membrane reactor (AFMR), anaerobic contact process (ACP) or plug flow reactor (PFR). Two-phase anaerobic digestion process of organic solid wastes, first expressed by Pohland and Ghose in 1971, is also called two-step anaerobic digestion or two-stage anaerobic digestion. Which divide the anaerobic reaction process artificially into hydrolysis-acidogenesis and methanogenesis, in order to meet the microbial activity demand at different stages of anaerobic digestion and to accomplish the best reaction efficiency. A acidogenic phase both controlling acid yield rate and avoiding overload in methanogenic step is generally set before the methanogenic phase. On the other hand, it could avoid shocks on the whole system from complex, unstable and toxic substance, could improve the dynamics of anaerobic digestion process and enhance the stability of operation in the system. However, a consensus has not been reached by the researchers on whether the technology is more suitable for the anaerobic digestion of food waste. WANG Xing [72], etc. contrasted single phase process and two phase process of food waste. The result implies that gas production accumulated by the two methods differs obviously from each other. Although there exists a larger fluctuation in daily gas-produce in the single-phase process, it is simple with the operation of this process, and it is short with the gas production cycle, it has a superiority of industrialization to a certain extent. Jung KonKim [73], etc. in Korea used a process of three-phase anaerobic digestion to deal with food waste. That consists of half anaerobic hydrolysis-acidogenesis, strictly anaerobic acidogenesis and strictly anaerobic methanogenesis. It is conducted with a partial-type test and a successive test, in which the first stage is undertaken under 45°C in a CSTR, the second stage is undertaken under 35°C in a UASB, and the third is undertaken under 50°C in a UASB. It indicates that this system of anaerobic process could process food waste with a high efficiency. The removal rate of COD could reach 90.1%, and rate of methanogenesis could reach 254LCH^4·kg COD^{-1} degraded.

Sun-KeeHan [74] also studied the hydrogenesis and methanogenesis using a two-level method with four fluidized bed reactors employed for hydrogen production and one UASB reactor employed for methane production. When the load reaches 11.9 kg·m^{-3}·d^{-1}, conversion rate of hydrogen reaches 28.2%, conversion rate of methane reaches 69.9%, and their rate of production attain 3.63 m^3·m^{-3}·d^{-1} and l. 75m^3·m^{-3}·d^{-1} individually. R. Sarada [75], etc. used the two-phase method and the single-phase method respectively to process tomato anaerobically for biogas production, in which their conversion rates of methane attain 80% and 70% respectively, and conversion rate of methane of the two-phase method is greater than that of single-phase method by 40–50% in methane content. Yet Mtz. Viturtia [76] compared the minced fruits and vegetables for biogas formation, and it was found that there is some indistinctive difference between two-phase method and single-phase method. The loaded gas production rate could achieve 0.63 m^3·kgVS^{-1} and 0.623 m^3·kgVS^{-1}respectively. In a high load the hydrolysis of substrate would be inhibited, and this would cause a gas yield decline.

XU Jianbo, ZHANGBo [77], etc. used a two-stage ASBR to deal with kitchen waste. Under a mesophilic condition it is conducted with a 2.5 L reactor for hydrolysis-acidogenesis and a 2 L reactor for methanogenesis, and the capabilities of acidogenesis and methanogenesis are both considered. It is obtained that under a working condition of the solid content at 8%, the HRT at 13.3 d and loading rate of TS at 5.23 $g \cdot L^{-1} \cdot d^{-1}$, the total COD removal could reach 77.6%, and TS removal could reach 72.21%.

In all these ways a high-rate biomass to biogas technique is to maintain a high-rate activity of different microbe in the whole process of anaerobic digestion. The rate-limiting step should cause enough attention. And all kinds of solutions should be taken to run anaerobic digestion smoothly.

3.6. Dry-type fermentation & wet-type fermentation

Yield of municipal solid waste, such as sewage sludge, food waste and domestic organic refuse, etc. is driven upward dramatically along with the development of economy and society along with the boosting of urbanization in China, has becoming one of the largest pollutants damaging the environment, and this restricts the sustainable development of economy and society greatly. The process of research mostly concentrated in the wet-fermentation before the late 80's. Due to requiring pretreatment for raw materials with wet anaerobic fermentation, tons of water have to be consumed. This makes the difficulty of processing increased and the cost raised. In recent years, more and more scholars begin to research dry-type fermentation and its application, and make numerous significant accomplishments. Dry-type fermentation, also known as solid-phase fermentation or solid fermentation, use the original solid materials to ferment [78]. French VALORGA, Belgian DRANCO, Swiss KOMPOGAS, etc. all belong to the typical representative of dry-type fermentation. Fig. 2 demonstrates the basic process of dry-type fermentation. The most prominent feature of this process is to achieve zymotic fluid recirculation, so as to realize the effective conditioning and inoculation of fermentation materials. The several typical dry-type fermentation projects possess the treatment capacity of 10,000–50,000 tons of solid garbage per year, 100–200 $m^3 \cdot t^{-1}$ of gas yield, 1000 m^3 of single pool volume or so. Since adopting solid-phase fermentation, dry-type fermentation reactor can deal with both fresh biomass raw materials and dry biomass raw materials. Furthermore, this method won't bring about the problem such as fermentation raw material rising and crusting. So dry-type fermentation could be widely used to process both agriculture and city solid waste such as droppings of livestock and poultry, crops straw, wastes in food processing, wastes in fermentation industries and living rubbish [79], etc. For TS concentration in the material greater than 20%, the gas formation performance and garbage biodegradation would drop with the increase of TS [80]. For TS concentration in food waste constantly between 15% and 20%, it allows to consider pre-treatment of no water additive, but direct dry-type fermentation. WU Manchang [81], etc. tested dry-type fermentation with different solid content under different temperature, it turned out that in room temperature (25°C) and temperature (35°C) conditions individually, there exists no biogas yield basically or with the increase of the concentration of TS gas yield gradually would stop when TS concentration is greater than 20%. Only in high temperature conditions (55°C) this method could accomplish a good performance of biogas yield. Whereas, it should be recognized that there would be more equipment demand. And the reaction process is vulnerable to the inhibition of substance in the zymotic fluid, such as ammonia nitrogen (NH_3-N) and salt. In practical application, it is recommended to choose different operating process applying to the actual background information and requirements.

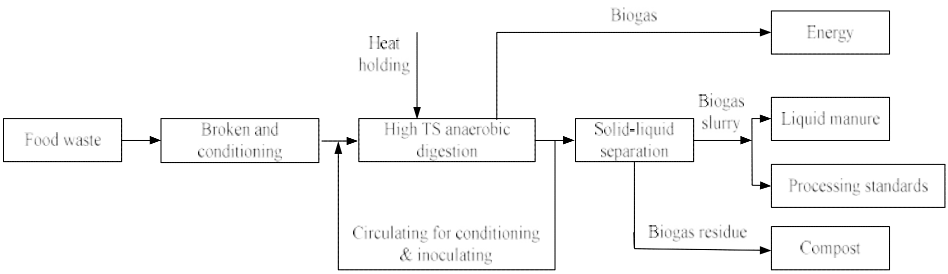

Fig. 2. Flow chart of dried fermentation for food waste
Rys. 2. Schemat przepływowy suchej fermentacji odpadów żywnościowych

Dry-type fermentation & wet-type fermentation have their respective advantages and adaptive scope. Type of fermentation need to be applied flexibly according to the practical demands in practical operation.

4. Conclusion

As a rule of thumb, to develop techniques of biogas fermentation and biomass gasification is one of the main ways in solving urban energy shortage and decreasing environmental pollution in present urban regions. Anaerobic digestion technology is practicable for the treatment of organic solid waste to combine material recovery and energy yield, by which organic solid waste such as food waste becomes biomass for some biodigester, which produces biogas. Overall, dry-type fermentation technology for methane production changes the traditional pattern of fermentation utilizing the organic fraction of MSW Municipal Solid Waste. Comparing with obvious advantages of wet-type fermentation, dry-type fermentation remains some shortages so far. It is concluded that dry-type fermentation could guarantee a smooth fermentation for biowaste even under a higher concentration of dry matter, and generate high qualities of organic fertilizer and sufficient biogas as biofertilizer and clean energy, and meet zero emission in demand. In one sense, disposal of anaerobic digestion could turn food waste, representative of the city biowaste, into fortune to benefit mankind to manage our future in a metropolis [82, 83]. And it is highly recommended that ethanol-type fermentation be the most promising acidification type in it. With increasing use of anaerobic technology for disposing the growing burden of various municipal solid organic waste, it is expected that metropolis would become more economically competitive because of its more judicious utilization of natural resources. Therefore, anaerobic digestion technology proven the best approach in municipal food waste disposing and recycling is almost certainly assured of increased usage in the future.

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Badania nad technologiami odzysku biogazu z biomasy z żywnościowych odpadów komunalnych: przegląd

Streszczenie

Źródła energii znalazły się w centrum zainteresowania pod względem prawnym, etycznym, społecznym i gospodarczym z powodu rosnących problemów środowiska. Powszechnie wiadome, że nieodnawialne źródła energii są w coraz większym stopniu zastępowane innymi, które są odnawialne i mniej zanieczyszczające, z wykorzystaniem technologii mających na celu zrównoważony rozwój. Utylizacja stałych odpadów żywnościowych jest wciąż poważnym problemem dla wielu społeczności. Technologia beztlenowej fermentacji jest możliwa do zastosowania przy przetwarzaniu organicznych odpadów stałych i łączy odzysku materiału oraz produkcję energii. Recykling odpadów spożywczych w procesie beztlenowa fermentacja na biogaz, zawiesinę biogazu oraz nawóz organiczny jest podstawowym zadaniem utylizacji bioodpadów komunalnych. Bazując na sortowaniu odpadów spożywczych, technologia ta może zlikwidować zanieczyszczenia z odpadów spożywczych, w odniesieniu do ich źródeł. Z jednej strony złagodzić presję na środowisko pochodzące z spożywczych odpadów komunalnych oraz uniknąć wtórnego zanieczyszczenia, osiągnąć zasadę „3R" (Reduce, Reuse, Recycle) w gospodarce odpadami jeszcze bardziej. Zasada ta wprowadza zasady technik, przewagę technologiczną oraz postęp w dziedzinie badań nad beztlenową fermentacją. Fermentacja beztlenowa dzieli się na mokrą i suchą. W porównaniu z oczywistymi zaletami fermentacji na mokro, jest jeszcze wiele braków w procesie fermentacji suchej. Ostatecznie stwierdzono, że technologia suchej fermentacji do produkcji metanu zmieniła tradycyjne podejście do fermentacji. W pewnym sensie, usuwanie i recykling odpadów spożywczych jest w przybliżeniu podobny do zgazowania komunalnych odpadów spożywczych, co może zamienić odpady w majątek, który ludzkość może wykorzystać do zarządzania w metropoliach. I zdecydowanie rekomenduje się fermentację typu etanolowego jako najbardziej obiecujący typ acydyfikacyjny.