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Development of Iron based Materials for Anaerobic Digestion of Organic Waste

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Abstract

Anaerobic digestion is one of the biological treatment technologies for the green and resourced treatment of organic waste, which can use organic matter from perishable waste to generate methane gas, and achieve the goal of the tri chemical treatment of perishable waste. But at present, the anaerobic digestion of perishable waste has problems such as not high stability and poor performance, and research found that the addition of iron-based materials can effectively improve the stability of the system and improve the performance of anaerobic digestion. In this paper, the effects of iron-based materials on perishable waste are analyzed in terms of the main influencing factors of anaerobic digestion and the kind of iron-based materials that are commonly used as additives for anaerobic digestion, and it is found that the effects and effects of different iron-based materials on anaerobic digestive system are not the same, although the effects are not the same because of the different kinds of perishable waste, But in general the promoting effect of conductor materials was more significant.

Keywords

Anaerobic Digestion; Iron based Materials; Additive; Zero Valent Iron; Iron Oxides.

1. Introduction

Anaerobic digestion is a kind of biological treatment technology for green resource treated waste, can decompose and digest organic matter in perishable waste to generate methane gas, to achieve the goal of reducing, harmless, and resourced treatment of organic solid waste, the greatest advantage of anaerobic digestion is the ability to produce clean energy biogas, To a certain extent, the emission of greenhouse gases caused by the use of fossil energy can be reduced to achieve the goal of carbon neutralization, and carbon peaks [1,2]. In addition, the sterilized fermentation residue can be used as an organic fertilizer alternative or Soil Ameliorant, which has some economic value [3-5]. With the waste classification policy being steadily promoted throughout our country, the practical production applications of anaerobic digestion and disposal technology will be more extensive, so it is currently a research hotspot in the disposal of perishable waste technology.

The effectiveness of anaerobic digestive system operation is affected by various factors, in organic anaerobic digestive system often due to the barren deficiency of trace elements, which leads to the inability to synthesize some important enzymes and cofactors and so on, resulting in the system cannot operate stably for a long time, and then limits its wide application [6]. As one of the important metal trace elements, Fe can improve the system microenvironment and improve the performance of anaerobic digestion of organic matter, especially iron-based materials can not only improve the content of iron elements in the system, but also have attracted much attention as a carrier for microbial interspecies electron transport [7,8]. Therefore, this paper will start with the main influencing factors of anaerobic digestion and focus on the influence of different iron-based materials on anaerobic digestion, in the hope of providing a theoretical basis and reference for the strengthening technology of anaerobic digestion of iron-based materials.

2. Major Influencers of Anaerobic Digestion

2.1 Temperature

Temperature mainly contributes to the hydrolytic acidification efficiency of substrates, the total amount and composition of intermediate product volatile fatty acids, and gas production performance by affecting the population structure and the activities of enzymes and coenzymes of microorganisms in the system [9,10]. Microorganisms are able to operate in a certain temperature range (10-60℃), which is divided into normal temperature anaerobic fermentation (10-30℃), medium temperature anaerobic fermentation (30-40℃) and high temperature anaerobic fermentation (50-60℃), depending on the environmental temperature where the microorganisms live, and the main microbial community structure in the system will change under different temperature conditions. At present, moderate and high temperature anaerobic fermentation is commonly used in laboratory studies [11,12]. It has been reported that for every 10℃increase in temperature, the reaction rate of the system will be about double, but too high or too fluctuating temperature can affect the anaerobic digestion efficiency, and using moderate temperature anaerobic digestion as an example, microbial temperature fluctuation range is best controlled within 35±2℃ [13]. With comprehensive consideration of energy consumption, economy, digestion efficiency, and gas production performance, medium temperature anaerobic digestion will have a better development in the future.

2.2 pH

The pH is a response to the alkalinity of the system, and its size is affected by a combination of the dissolution equilibrium of free ammonia,CO2 and OH- in the gas-liquid two-phase, the ion dissolution equilibrium in the solid-liquid phase and the acid-base equilibrium in the liquid phase [14,15]. The microbial species in anaerobic digestive system are complex, and different microorganisms also show great differences in pH adaptation. According to the bacterial functional difference, it can be divided into acidogens and methanogens, and the pH value has a large effect on acidogens and is able to change the microbial community structure and metabolic pathways, and then change the total amount and composition of acidified products (mainly volatile fatty acids), whereas it has an impact on methanogenesis [16]. Compared with acidogens, methanogens have a strict requirement for pH in the system, and their suitable pH range is 6.5-7.5, and too high or too low pH can inhibit the activity of methanogens and affect the gas production performance of anaerobic digestion [17]. So monitoring and controlling the pH in the system can make the anaerobic digestion system in a state of high-efficiency operation.

2.3 C/N

As the two most essential elements for maintaining life, the metabolism of microorganisms for growth requires a certain amount of C and N to be able to proceed, and an appropriate C/N ratio enables a stable and efficient operation of the system [18]. If the C/N ratio is too high, the nitrogen source to maintain the survival of cell organisms will be insufficient, so that the nitrogen source will be rapidly utilized by microorganisms, resulting in lower methane production. On the contrary, a too low C/N ratio can easily cause ammonia nitrogen accumulation, and an excessive concentration of ammonia nitrogen can inhibit the activity of methanogens and affect the anaerobic digestion performance [19]. The optimal C/N ratio for anaerobic digestion has been reported to range from 20-30, which at this time facilitates the growth and reproduction of various microorganisms in the system as well as the activity of various enzymes and enzymatic factors that facilitate the decomposition and digestion of the resulting volatile fatty acids as substrates for methanogenesis [20,21]. Recently, in anaerobic digestion research, C/N of improved substrates is often adjusted in a combined fermentation way by mixing straw, sludge, kitchen waste and other materials, so that it is in the optimal C/N range to improve the performance of the system [18,21].

2.4 Metal Elements

In recent years, anaerobic digestion technology of organic waste has received wide attention, but it is found in the research that the stability of the system in long-term operation is poor due to the lack of trace elements, especially the feed of a single perishable organic solid waste material, which limits its wide application [22,23]. Some specific trace metal elements, such as iron, cobalt, molybdenum, etc., play irreplaceable roles in the synthesis of essential enzymes or cofactors during anaerobic digestion. So the effect of metal elements on anaerobic digestion should be viewed correctly, which usually shows as low pro-and high inhibition, and at lower concentrations, the relationship between microbial anaerobic digestion aerogenic potency and the content of some metal elements is positively correlated, but when the concentration exceeds the threshold value, it will inhibit the microbial growth and metabolism, affecting the aerogenic potency [24]. The demand concentrations of trace elements for anaerobic digestive systems in general are all low, usually in the range of 0.05-0.06 mg /L, with the only exception of Fe element, which has a relatively high demand concentration, usually in the range of 1-10 mg/L [25]. Therefore, when town organic waste or are agricultural crops are used as single substrates, the addition of certain amounts of trace metal elements is very necessary to guarantee or improve the system gas production performance, especially the addition of iron elements to the reaction system. Therefore, when the substrate is the material with higher content of organic waste, based on the trace element background of the substrate, a certain amount of trace elements are supplemented to keep the trace elements in the system in a dynamic and stable state to improve the stability of the system and anaerobic digestion efficiency, especially the addition of green economy and the effect of iron-based materials that can promote the effect of microbial interspecies electron transport is more significant.

3. Types of Additives for Anaerobic Digestion of Iron-based Materials

3.1 Zero Valent Iron

Zero valent iron, with its low redox potential, is a green and economical reductant, which is often used to remove heavy metals from sewage and soil because of its strong reducibility and Adsorbability to the products of hydrogen evolution Corrosion [6]. In recent years, Fe0 has been widely used in anaerobic digestion of perishable waste to improve the stability, hydrolytic acidification effect and gas production performance of the system. The common anaerobic digestion additives of Fe0 can be divided into iron chips, micro zero valent iron and nano zero valent iron by their particle size [26]. Iron chips are the special Fe0 whose surface is in contact with the outside to produce a layer of iron oxides, the interior is nano zero valent iron, the iron oxides on the surface first react with the anaerobic digestion system, reducing the content of inhibitors in the system to improve the stability [7]. Nano zero valent iron has a large specific surface area and better chemical activity than micro zero valent iron, but currently some scholars believe that nanomaterials have some biological toxicity, when the addition concentration is too high, it will destroy the structure of cells and affect biological activity, leading to a decrease in the anaerobic digestion gas production energy, meanwhile its price is higher [27]. At present, the action mechanism of Fe0 on the anaerobic digestion of perishable waste mainly contains the following points [28-31]: (1) improve the buffering capacity of the system, reduce the system redox potential and thus change the fermentation type to benefit the subsequent reaction; (2) The hydrogen evolution corrosion effect releasing Fe2+ and H2 happened to promote the pathway of Hydrogenotrophic methanogenesis gas with H2/CO2 as the main substrate, meanwhile, the reaction of Fe2+ with S2- to generate precipitate decreased, alleviating the toxic effect of S2- on sulfate reducing bacteria and methanogens; (3) As an important constituent element of methanogenic bacteria cells, and the demand is much higher than other elements, promoting the growth and reproduction of methanogenic microorganisms; (4) As an important coenzyme factor,

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improve the synthesis of related enzymes and improve the catalysis of enzymes; (5) The formed hydroxide precipitate can remove heavy metal ions and antibiotic resistance genes.

3.2 Iron Oxides

Iron compounds are widely distributed in nature, mainly in Fe2+ and Fe3+ with other chemicals to form stable compounds, among which iron oxides often act as additives for the anaerobic digestion of perishable waste, and the difference in the crystal structure of iron oxides determines its effect in anaerobic digestion. Iron oxides that are often used as anaerobic digestion additives mainly include magnetite, hematite and goethite. Magnetite has good electrical conductivity properties and is mainly composed of ferrous oxide and a compound of inverse spinel structure, and studies have found that magnetite enhances methane production in anaerobic digestive systems mainly through its role in facilitating interspecies electron transport between microorganisms [32]. Hematite has relatively poor conductive properties, mainly iron oxides with a diamond type structure composed of iron oxides, and a portion of Fe3+ in hematite is easily reduced to Fe2+ under anaerobic conditions, S2- in the immobilization system, improving the stability of the system. Goethite is a common hydrated iron oxide with needle, column and sheet-like crystal structure [31], which can promote the hydrolytic acidification effect and the generation of VFAs during anaerobic digestion, and facilitate the subsequent reaction [33].

4. Conclusion

Anaerobic digestion of perishable waste in long-term operation, due to the system feeding single, often the phenomenon of insufficient trace elements occurs, resulting in the system stability and digestion performance degradation. On the one hand, the addition of iron-based materials can improve the content of iron element in the system, which can promote microbial growth and metabolism and improve the activity of related enzymes, improve the performance of anaerobic digestion system, on the other hand, can act as a carrier for microbial interspecies transmission, and promote the generation of methane. In using iron-based materials as anaerobic digestion additives, suitable iron-based materials should be selected in combination with the properties of substrates. In this paper, we summarize the main factors affecting anaerobic digestion, analyze the kinds and action mechanisms of iron-based materials that are often used as anaerobic digestion additives, and hope to provide some theoretical reference for future related studies.

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