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Design investigation of a solar energy heating system for anaerobic sewage treatment

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Abstract

Domestic and international researches of solar energy heating for anaerobic wastewater treatment are described in this paper. The design investigation of a solar heating anaerobic sewage treatment system for cold regions is proposed, (I) developing of a solar water heating system for treatment, (II) developing of a high-rate anaerobic reactor for sewage treatment under normal temperature conditions, and (III) solving problems of joint control between the solar water heating system and the anaerobic reactor. This article provides a reference for design and application of the solar energy heating system for anaerobic sewage treatment.

Key words：Solar Energy, Sewage, Anaerobic treatment, ABR ;

1. Introduction

Aerobic biological treatment technologies are usually used in sewage treatment. In this process, additional energy will be consumed and CO_2 will be produced. Therefore from the perspective of energy saving and emission reduction, this method is indeed an unsustainable way. New energy and environmental problems are caused at the same time of treating sewage and protecting the environment [1]. Anaerobic biological treatment technology becomes the focus of sewage treatment because of low power consumption (can capacity), little sludge volume, long cleaning cycle, etc. However now it is not widely used because the concentration of domestic sewage is very low to survive for anaerobic microorganisms. Another important reason is that the temperature is usually lower (10℃ or less) in the northern winter and autumn china, better treatment effect is difficult to be obtained [2] [3]. Solar energy resources are abundant in many parts of northern China, can be used for improving anaerobic wastewater treatment temperature to achieve efficient of sewage treatment. In summary, based on the utilization of solar energy anaerobic wastewater treatment system design, addresses the vast solar energy-rich region the temperature anaerobic wastewater treatment system upgrade issues for the sewage treatment process to reduce the consumption of conventional energy to provide new ideas.

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2. Research status of solar energy heating anaerobic wastewater treatment

There are two main ideas for exploiting solar energy in sewage treatment. One is collecting the solar energy to provide electricity or heat for sewage treatment devices. Another is solar Photocatalytic wastewater treatment [4]. Solar energy collected to provide heat for sewage treatment systems were only described in this paper.

2.1. International research of solar energy heating anaerobic wastewater treatment

The application of solar energy to improve temperature of sewage treatment abroad is mostly concentrated in the anaerobic digestion of animal wastes [5]. A system of solar energy heating for thermophilic anaerobic animal waste digestion (50℃ and 60℃) and simulated were investigated by Hamed M. El-Mashad, Netherlands. The results show that very good effect can be achieved for small reactors, while temperature increase is very small for large-scale reactors. The daily temperature fluctuations in reactor will lead to decrease of methane produced by 12% and 20% at 50℃ and 60 ℃ [6]. Later, they did the same experiment and simulation in a completely mixed reactor of 10 m^3. the results show that the temperature fluctuation of reactor is lower than 1℃ at night, which it had no influence on the efficiency. Using energy recovery the efficiency of energy use is more than 95%. Solar energy can be used as heater for the anaerobic digestion [7].

In an AF reactor, solar was used for improving sewage treatment temperature by Greece Andreas Ch Yiannopoulos. The temperature 35℃ in the reactor was achieved. A set of mathematical model about temperature were established, also verified by weather conditions around the world. In consequence solar energy heating anaerobic wastewater treatment has good application prospects [8].

2.2. Research of solar energy heating anaerobic wastewater treatment in China

Studies of solar energy heating anaerobic wastewater treatment mainly focus on solar heating digesters (biogas project), and many good results were achieved. A solar energy methane pool was preliminary designed by Aiping Zheng and Xu Zhang (Chang An university), of which the structure and working principle were expound. Through the economic analysis, that combining solar hot water supply technology with methane pool technology to reduce improve gas yield of methane pool in winter, the economic benefit is remarkable [9]. A method of methane produce using solar energy heating was exploited by Jilin medicine design institute and Harbin industrial university building energy laboratory together. The solar heating methane produce system was set up. The heat of exchanger research, the temperature difference between import and export, the temperature change of soil field around the methane pool were studied, and the heat transfer coefficient of heat exchanger was given [10]. A new-style solar glass fiber reinforced plastic methane tank was designed by Shi lei, according to the production practice in the northern region. The low gas production problem in northern winter was well solved using solar energy hot water cycle system to improve the tank temperature and gas yield [11]. A new solar heating constant temperature methane reaction device was designed by Yu Ding. The composition and principle of this system were expounded in detail, and the related calculation method and reasonable parameter were introduced [12]. A thermodynamic model of solar heating methane pool was established by Xiuli Sun, a master of TongJi university, aim at the assistant heating thermodynamic processes. The effects of the system control operation mode, the circulation water flow, heat insulation layer thickness to the whole system were considered, so as to determine reasonable system configuration [13].

The sludge anaerobic digestion using solar energy as the heat source was also studied. The terms of min-scope and medium-scope experiments about the reliability of solar heating sludge anaerobic digestion were studied by Zhongmin Yu. The min-scope experiment showed a high efficiency of the sludge absorption. While the medium-scope experiment showed that the water temperature can be

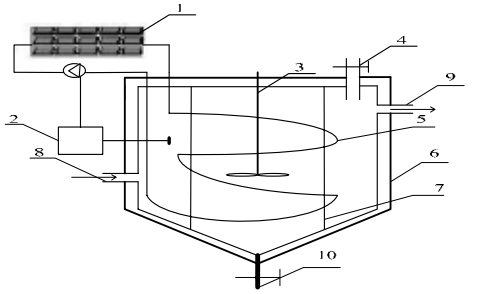
increased to 12.4℃～28.5℃ in low air temperature and 16℃～24.8 ℃ in high air temperature using the solar energy. A solar energy collector can be used as the heat source for sludge anaerobic digestion [14]. The temperature enhance and maintain of anaerobic digestion and a high efficiency in mesophilic digestion (spring, autumn, winter) and thermophilic digestion (summer) was acquired by Chenglin Meng (Chemical engineering University of Beijing) in a greenhouse-solar energy heating system. The results show that: Comparing with the reactor of natural environment, the temperature of reactor in a greenhouse-solar energy heating system respectively increased 13.0℃～28.5℃, 15.0℃～26.5℃ and 10.7℃～12.2℃ in spring, summer and autumn [15].

3. Design investigation of a solar energy heating system for anaerobic sewage treatment

Anaerobic wastewater treatment can be divided into psychrophilic digestion (5℃～ 20℃), mesophilic digestion (33℃～35℃) and thermophilic digestion (42℃～75℃) . The reaction efficiency of three temperatures is different: thermophilic digestion > mesophilic digestion > psychrophilic digestion. However the energy consumption of mesophilic digestion and thermophilic digestion are much larger, so psychrophilic digestion is widely used in the case of increasing scarcity of energy [17]. The effects of anaerobic sewage treatment are poor on account of he pollutants concentration and temperature of sewage is low. To enhance the effect of anaerobic sewage treatment, on the one hand we can increase the sewage treatment temperature steadily utilization of solar heating, the other hand, develop the high-rate reactor for anaerobic sewage treatment. Furthermore, we need to solve the joint control problem between the two.

3.1. Design investigation of a solar energy heating and transfer system [8] [9]

Studies of solar energy heating system are more universal particularly along with intensive study of solar desalination technology. But research of a solar energy transfer system for the sewage treatment is seldom. Solar energy is difficult to provide heat to the anaerobic biological treatment steadily because the climate, region, terrain, season, weather, day or night changes vary widely in different conditions. When we design a solar energy heating and transfer system, we should ensure that the system has a highly heat exchange efficiency and energy recovery in order to maximize the solar energy utilization. It needs a temperature control system to keep the temperature constant. Heat energy can be well stored to balance temperature between day and night, sunny and rainy. At last the heat interchanger and pipeline for the sewage system are corrosion-resistant, and have high heat transfer coefficient. A design investigation of a solar energy heating and transfer system is got according to proposals upside as Figure 1.



1. Solar Energy Collectors 2. Temperature Controller 3. Blender 4. Relief Valve 5. Heat Exchange Tube 6. Insulating Layer 7. Bracket 8. influent 9. effluent10. Mudhole

Fig.1. Solar Energy Heating Adjustment Pool

The system includes heating collector, heat transfer adjustment pool and temperature control system. Solar energy is collected by heating collectors to heat the media material for subsequent heat transfer

which can be heat to a very high temperature, has good liquidity). Heated transfer adjustment pool is connected to heating collector through pipelines. Pipelines in Heated transfer adjustment pool should be arranged as uniform as possible to help heat transfer (Blenders are needed if the pool is larger). The body of pool and pipes should be insulated to reduce heat loss. Temperature control system includes a temperature probe. It can keep track of temperature of the pool and timely feedback to the controller, which is connected the pump in order to adjust the amount of heat to reach the reaction temperature [16]. In addition energy recovery equipment can also be set to exchange energy of the effluent and influent. Waste heat can be recovered well [8].

3.2. Design investigation of high-rate anaerobic reactor

Practice shows that a successful reactor must be: ① It can retain sludge well in order to ensure sufficient biomass; ② biological sludge can be fully mixed with water access to ensure that the contaminations are degradated by microorganisms [2] [17]. Reactor as the micro-ecosystems of microbial, growth and reproduction of various micro-organisms must be steady; material and energy flow smoothly and efficiently. Integrating two high-rate anaerobic reactors, a two-phase anaerobic reactor can not only satisfy the two conditions above, but also provide their own place to live for acid-producing bacteria and methanogens. Acidification phase and methanogenic phase are separated to create the best living environment. The efficiency of anaerobic treatment should increase [19]. Based on these key points, a two-phase high-rate anaerobic reactor was designed for sewage as shown in Figure 2.

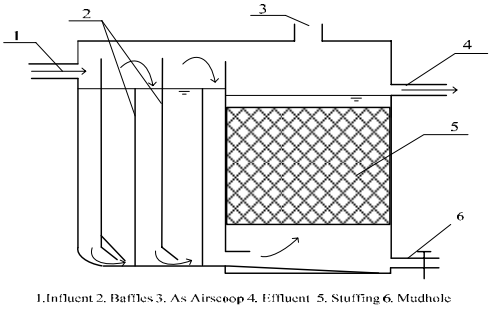


Fig.2. Integrated Two-Phase Anaerobic Reactor

This two-phase reactor combines with ABR (Anaerobic Baffled Reactor) and UASB (Up-flow Anaerobic Sludge Bed) as one. Sewage flows horizontally in a slower speed [20]. The reactor has characteristics both ABR and UASB. The ABR in left as acidification phase ensure stable of the entire system. The UASB in right as methane phase has no three-phase separator but fillers. Sludge can be retained to improve the quality of effluent [21].

3.3. Design investigation of joint Control system [8] [22]

It is a key to solve the joint Control problem of solar heating, heat exchange system and high-rate anaerobic reactor to a solar energy heating system for anaerobic sewage treatment. The design investigation of joint Control should basis several issues following:

①Solving the limitations of solar that can not be utilized continuously, a thermal storage tank can be set to supply of excess heat in night or rainy.

②Making temperature constant sure in the reactor, the system should be isolated well to reduce the impact of temperature change around.

③An intelligent control system must be set. The reasonable temperature will be determined by collecting of numerous local climatic conditions. The temperature control parameters also should be set combining with thermal storage, real-time monitoring the temperature inside the reactor, of water and solar hot water. The temperature inside the reactor will be always within a constant scope by regulating the heat exchange and storage.

④The problem of phase separation in two-phase anaerobic reactor should be resolved.

4. Conclusion

Anaerobic wastewater treatment based on solar energy heating as an effective way for the temperature increase and normal operation of sewage treatment systems in solar-rich regions has important practical value because it reduces the consumption of conventional energy in process of the sewage treatment, even do not use with. Design investigations of a solar energy heating system for anaerobic sewage treatment were proposed in this paper to provide some ideas for other research.

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