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Experimental Study on Biogas Digester Combined with Solar Heating System

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Abstract. In order to solve the problem of low gas production of biogas digester fermented at natural temperature in winter and possibly freezing biogas digester in northern cold areas, the biogas digester combined with solar heating system is proposed to maintain the normal fermentation temperature of biogas digester and ensure the continuous and efficient gas production of biogas digester throughout the year. Through the experiment and analysis of the system, in cold area, the temperature of biogas digester can be maintained above 12.5 ℃, which can meet the temperature requirements of normal fermentation in biogas digester, so it is concluded that developing solar heating biogas digester project is feasible in cold area.

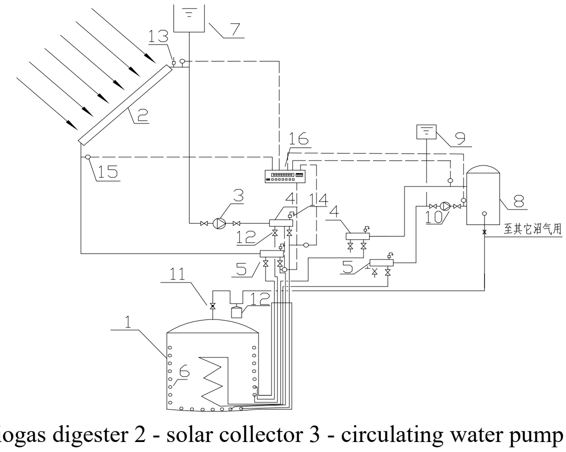
1 Introduction

Developing biogas is one of the ways to realize the sustainable development of rural economy. The key factor affecting biogas digester gas production rate is temperature. When the temperature is above 15 ℃, the gas production rate of biogas digester per cubic meter (m^3) can reach 0.1-0.2m^3 per day, but when the temperature is below 10 ℃, the biogas fermentation is seriously inhibited, and the gas production rate is only about 0.01m3 per day[1-2]. When the temperature suddenly increases or decreases by 5 ℃, the gas production decreases significantly, or even stops [3]. In the cold area of northern China, the temperature is low in winter, the gas production rate is extremely unstable, and the biogas digester may freeze. In order to ensure a stable gas production rate, it is necessary to take appropriate heat preservation measures and matching heating system to ensure a relatively stable fermentation temperature of biogas slurry [4]. China is rich in solar energy resources. The annual sunshine hours are more than 2200h, and 76% of the areas have annual radiation of more than 4200MJ/m2. Even in Northeast China, solar energy is also very rich, which makes it feasible to use solar energy to heat biogas digester to produce biogas [5].

In this paper, solar energy is used to heat the biogas digester to improve the fermentation temperature of biogas digester. In northern cold areas, biogas digester combined with solar energy heating system is used to maintain the normal fermentation temperature of biogas digester above 10 ℃, so as to ensure the continuous and efficient gas production of biogas digester throughout the year.

2 Schematic diagram of biogas digester combined with solar heating system

The system consists of biogas digester, solar collector, biogas boiler, heat exchange coil, circulating water pump, water distributor, water collector and expansion tank. The schematic diagram of the whole system is shown in Fig. 1.



1 - biogas digester 2 - solar collector 3 - circulating water pump of solar system 4 - water distributor 5 - water collector 6 - heat exchange coil 7 - expansion water tank 8 - biogas boiler 9 - make-up water tank 10 - circulating water pump of biogas boiler system 11 - biogas plug valve 12 - gate valve 13 - Automatic exhaust valve 15 - temperature measuring point 16 - microcomputer multi-channel data acquisition instrument

Fig. 1. Schematic drawing of solar energy combine biogas boiler for heating up biogas plant

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3 Experimental study on biogas digester combined with solar heating system

3.1. Establishment of test bed

The test bench of biogas digester combined with solar heating system is built in Harbin. The lowest temperature in winter is about - 30 °C, which represents the climate characteristics of the northern alpine region.

Fig. 2. The experiment cite for biogas plant associated solar energy

The concrete biogas digester was built in the experimental base according to the national standard size of 8m3 cylindrical water pressure biogas digester. The size data is shown in table 1, and the simplified model is shown in Fig. 3. The thickness of soil layer of biogas digester is 0.3m.

Table 1. Sizes for 8m3 biogas plant

Dimension (m^3)	Embedment (m)	Pool inside diameter (m)	Height of the pool (m)	Cut the spherical pool cover		Cut the spherical pool low		The water pressure between(and make the material mouth)	
				Radius of curvature (m)	Loss of high (m)	Radius of curvature (m)	Loss of high (m)	Diameter (m)	Height (m)
8	2.24	2.7	1	1.96	0.54	2.86	0.34	1	2.24

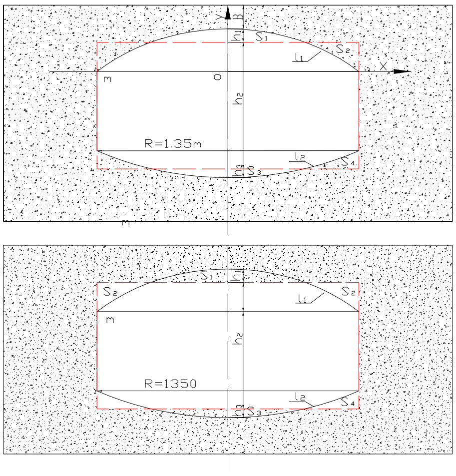

Fig. 3. The simple model for biogas digester

Two kinds of collectors, flat plate collector and vacuum tube collector, are used in the experiment, as shown in Fig. 4 and Fig. 5. The collector faces 15°south by West with an inclination of 55º45 '[6]. Ethylene glycol antifreeze was used as the heat exchange medium of the system. Ethylene glycol transfers the heat collected by the solar collector into the biogas through the PEX heat exchange coil in the biogas digester.

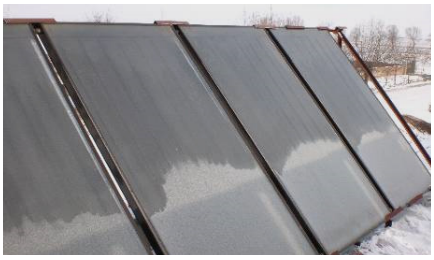

Fig. 4. Photo of flat plate collectors

Fig. 5. Photo of evacuated tube collectors

In order to supply heat to biogas digester at low temperature to maintain a certain temperature, biogas boiler is equipped as auxiliary heat source.

3.2. Experimental scheme

The experimental test started on December 21, and the biogas digester was heated the next day. During the experiment, the first step is to use coal-fired boilers for heating, the second step is solar heating, the third step is to stop heating, and finally solar heating is used. From December 22 to December 30, small coal-fired boiler is used to heat biogas digester. From December 31 to

January 5 of the next year, solar energy is used to heat biogas digester. From January 5 to January 16, stop heating biogas digester. From January 17, solar energy is used to heat biogas digester again.

4 Analysis of experimental results

4.1. Air temperature and soil temperature

During the experiment, the outdoor air temperature, ground surface temperature, and daily average temperature at the depth of 1 m and 2 m underground were measured. These temperature curves clearly reflect the climatic conditions under which the experimental study is carried out, as shown in Fig. 6. It can be seen from the figure that with the increase of depth, the influence of air temperature on soil temperature becomes smaller and smaller, and the fluctuation becomes smaller obviously, which is later than the fluctuation of air temperature. The outdoor air temperature is between -24 ℃ and - 6 ℃. Under such climate conditions, it is of great significance to study the biogas project in cold areas.

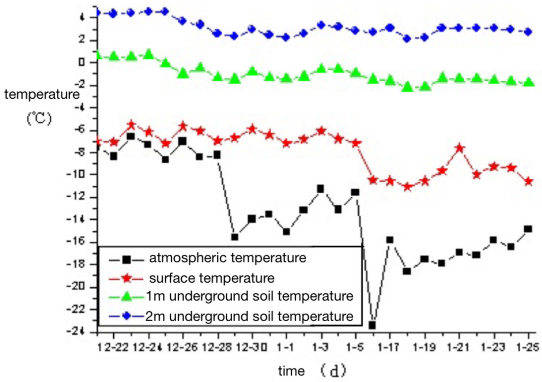

Fig. 6. Weather temperature, earth surface temperature and soil temperature during experiment period

4.2. Temperature distribution of concrete biogas digester

The following mainly analyzes concrete biogas digester fermentation layer average temperature, biogas digester average temperature and solar heating biogas digester average temperature condition to study.

4.2.1 Average temperature of fermentation layer in biogas digester

Fig. 7 shows the average temperature change of fermentation layer of ordinary concrete biogas digester during the whole experiment period.

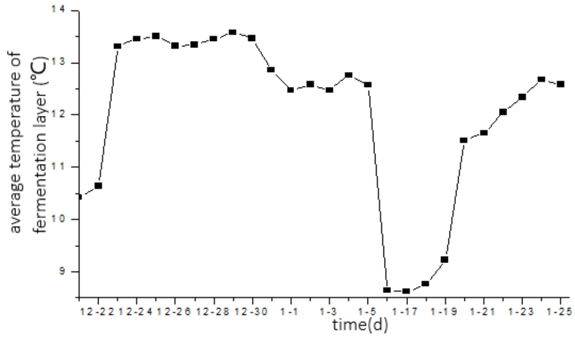

Fig. 7. Average temperature of the leavening layer in the concrete plant

4.2.2 Average temperature of biogas digester

It can be seen from the figure that the temperature rise of biogas digester is slow at the beginning of heating. The main reason is that the temperature of soil around biogas digester is low at the beginning, and a lot of heat is needed to raise the temperature of biogas digester and soil. The outlet medium temperature of coal-fired boiler is about 40 ℃, and that of solar collector is about 22 ℃. When the coal-fired boiler is used to heat the biogas digester for one day, the biogas digester begins to show obvious temperature rise, and then reaches stably about 13.5 ℃. When the solar energy is used to heat the biogas digester for three days, the biogas digester begins to show obvious temperature rise, and then the temperature rise is slightly slow until it reaches about 12.5 ℃. Within 11 days after stopping heating the digester, the temperature of the digester decreased about 4 ℃, which was lower than the normal fermentation temperature of the digester.

It is concluded that without heating the digester, the digester cannot maintain the normal fermentation temperature at all; heating the digester with solar energy can maintain the normal fermentation temperature of the digester in the coldest season.

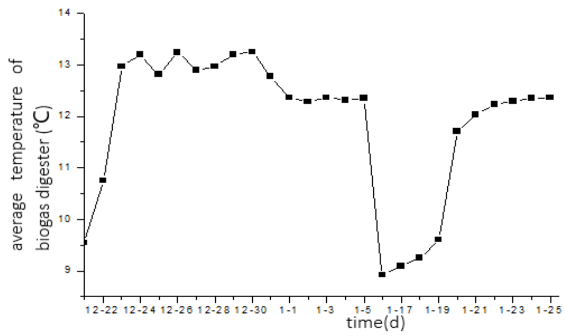

Fig. 8. Average temperature in the concrete plant

It can be seen from Fig. 8 that the trend of average temperature of concrete biogas digester is similar to that of fermentation layer, and there is little difference between the average temperature of biogas digester and that of fermentation layer. In the experiment, the average area of heat collector for each biogas digester is 75 vacuum tubes and 5m2 flat plate heat collector. In the coldest time in Harbin, 8m3 can basically maintain the

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average temperature of biogas digester about 12.5 ℃. If the system is reformed and the heat loss is reduced, it is estimated that the temperature of biogas digester can reach above 15 ℃.

4.2.3 Average temperature change of biogas digester during solar heating

The gas production rate of biogas digester is greatly affected by the temperature fluctuation. The research shows that when the temperature fluctuation is greater than 5 ℃, the gas production rate decreases sharply. The process of heating biogas digester with solar energy is accompanied by temperature rise and temperature drop of biogas digester. The temperature change of biogas digester heated by solar energy is analyzed, as shown in Fig.9.

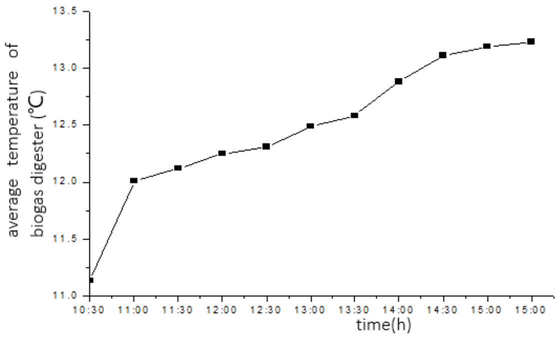

Fig. 9. Average temperature fluctuation when the sun heating up the concrete plant

As can be seen from the figure above, the temperature shows a steady upward trend during the heating process. During the whole heating process, the average temperature of biogas digester increased by about 2.5 ℃, which was within the allowable range of temperature fluctuation.

5 Conclusion

In view of the phenomenon that the household biogas digester in cold area cannot produce gas normally due to the influence of low temperature weather, this paper proposes to use the biogas digester combined with solar heating system. Through the experimental research on the temperature field of the biogas digester combined with solar heating system, it is concluded that under the experimental conditions, each biogas digester is equipped with 75 vacuum tubes and 5m^2 flat plate collector, and in cold area the temperature of biogas digester can be maintained above 12.5 ℃, which can meet the temperature requirements of normal fermentation in biogas digester. In the process of heating biogas digester with solar energy, the average temperature of biogas digester rises about 2.5 ℃, which is within the allowable range of temperature fluctuation. It is feasible to develop solar energy heating biogas digester project in alpine area.

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