SIMULATION AND OPTIMIZATION STUDY ON A SOLAR HEATING HOUSEHOLD BIOGAS DIGESTER SYSTEM

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Abstract

A solar heating household biogas digester system (System C) coupled with auxiliary heating source and operational control system is proposed in this paper. The mathematical model and TRNSYS simulation model of the system were established. Firstly, the heating effect of System C was compared with that of System A (without auxiliary heating and temperature control system) and System B (with auxiliary heating system and without temperature control system). Secondly, the influence of the insulation thickness and the collector area on solar fraction was analyzed. The results show that System C could keep the temperature fluctuation range of manure at ±1 ℃ under the setting condition. Besides, the solar fraction of the system C is higher than the system B, the daily energy net production of System C is higher than that of the system A and B with the value of 19.2 kWh. The solar fraction increased with the insulation thickness increased as logarithmic function, which has the most significant growth rate when the collector area is 14 m^2. In addition the solar fraction increases with the increase of the collector area in the form of sigmoid function. The research results provide a basis for the optimization design of solar heating household biogas digester system.

Keywords: Solar heating; Household biogas digester; TRNSYS simulation; Solar fraction

1. Introduction

The household biogas digesters can provide residents with the necessary energy (biogas) for cooking, lighting, heating and deal with the manure waste of people and livestock. Household biogas digesters are widely used all over the world, especially in developing countries such as China and India (Surendra, Takara, & Hashimoto, 2014). In recent years, the biogas industry of China has developed rapidly. China had possessed 41.93 million household biogas digesters by 2015 (Academy of state administration of grain, 2017).

Temperature has a significant influence on biogas production rate. Three fermentation processes exist, corresponding to different fermentation temperatures, namely, thermophilic fermentation (45-60 ℃),mesophilic fermentation (25-40 ℃),and normal temperature fermentation (10-25 ℃) (El-Mashad, Zeeman, & van Loon, 2004a).When the temperature of the manure is lower than 10 ℃, the biogas production of the digester is very little (Kocar and Eryasar, 2007). During the winter in northern of China, a large number of digesters have been idled due to less biogas production. However, the insufficient energy supplied by the biogas digester and the energy demand of heating and hot water in winter increases rapidly form a sharp contradiction with. Therefore, it is the key to solve this problem that increase the biogas production of the digester by improving the temperature of digester.

At present, many heating methods for the digester such as coal fired boiler heating, electro thermal membrane heating, biogas boiler heating, solar heating and heat pump heating were proposed (Li, Guo, & Qin, 2011). Some heating methods are not suitable for the household biogas digester due to the constraints of economical and environmental conditions. The solar heating for biogas digester has become the research focus with the advantages of less pollution, lower manufacture and operation cost. Hassanein et al. (2015) proposed a passive heating technique to increase the temperature of the biogas digesters using two solar greenhouses, one surrounding the digester and the other heating the digester inlet. The simulation results showed that the digester with the modifications could reach adequately high temperatures in the winter. Although the cost of solar passive warming technology is low, the range of manure temperature increasing is limited, so the biogas production of biogas digesters is still little, which can only meet the needs of cooking.

The system consists of high efficiency solar collectors and other equipment is also the main research direction of

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solar heating digesters. Axaopoulos, et, al. (2001), proposed an active solar heating biogas digester system, and established the corresponding system mathematical model. The performance of the system is studied both by simulation and experiment, and the results show that the system could efficiently increase the manure temperature and reduce the heat loss of the digester envelope at the same time. The energy required for the digester heating in the system is directly supplied by solar collectors, so that the temperature of the manure is subject to fluctuations in the solar radiation. However, the biogas production rate will decrease when the manure temperature changes more than 3 ℃ (Zhang, et al., 2016). El-Mashad et al. (2004b) and Pollard & Blanchard (2014) have designed a solar heating digester system with auxiliary heater. When the energy supplied by solar collector is insufficient, the auxiliary heat collector is worked to ensure that the digester runs under relatively stable conditions. But the system above may run abnormally for them without any monitor and control system of manure temperature, auxiliary heating source and the solar collector, which leads to the lower system efficiency and solar fraction and larger conventional energy consumption.

In this study, a solar heating digester system with auxiliary heater and heating control system is proposed. The heating effect for the biogas digester and net energy production performance of the system under different system forms were compared through TRNSYS simulation. Besides, the influence of the insulation thickness and the collector area on solar fraction was analyzed.

2. System description and Modelling

2.1 System description

As shown in Fig. 1, the solar heating household biogas digester system is composed of heating collection and heating utilization loop, the above loop were connected by heat storage water tank. The heating collection loop is consisted of flat plate collector, circulation pump-1, expansion tank and pipeline. The heating utilization loop is consisted of underground biogas digester, heating coil, heat storage tank and auxiliary heater. The energy collected from solar collector is used to heat the digester and the extra heat is storaged in the heat storage water tank in the day time. The heat in the water tank is transferred to heat the digester and the insufficient energy is supplied by the auxiliary heater in the nighttime. The control system automatically controls the opening and closing of the components according to the pre-set control strategy by monitoring the temperature parameters in the system loop.

2.2 Assumptions

There are several assumptions used for establishing mathematical model of the solar heating household biogas digester system:

(1) Physical properties of the soil, digester material, and insulation material are uniform (Perrigault, Weatherford, & Mart íHerrero, 2012).

(2) During biogas fermentation, microbial heat generation is neglected (Hashimoto, & Chen, 1979).

(3) The heat carried by the biogas flow during biogas fermentation is neglected.

(4) Liquid manure in the digester is assumed to be water.

(5) The temperature of the manure in the digester is uniform.

2.3 Mathematical model description

The mathematical model of the solar heating digester system consists of the system energy balance equation and the mathematical expressions of the subcomponent. The energy balance equation of the system could be written as:

$$\rho_m V_m c_m \frac{dT_m}{d\tau} = Q_{heating} - Q_{cover} - Q_{floor} - Q_{wall} - Q_{feed} \quad \text{(eq.1)}$$

$$Q_{heating} = Q_{col} + Q_{aux} - Q_{loss} \quad \text{(eq.2)}$$

$$Q_{loss} = Q_{loss,\,aux} + Q_{loss,\,tank} + Q_{loss,\,pipes} \quad \text{(eq.3)}$$

where; c_m is the manure specific heat capacity, J kg^{-1} K^{-1}; ρ_m is the manure density, kg m^{-3}; V_m is the manure volume, m^3; T_m is the manure temperature, ℃; τ is the time, s; $Q_{heating}$ is the heat supplied by the heating system, W; Q_{cover} is the heat losses through the digester cover, W; Q_{wall} is the heat losses through the digester wall, W; Q_{floor} is the heat losses through digester floor, W; Q_{feed} is heat required to raise temperature of the influent manure to the operating temperature, W; Q_{col} is the heat supplied by the solar collector, W; Q_{aux} is the heat supplied by the auxiliary heater, W; Q_{loss} is the total heat loss of the system, W; $Q_{loss,\ aux}$ is the heat loss from heater to environment, W; $Q_{loss,\ tank}$ is the heat loss from water tank to environment, W; $Q_{loss,\ pipes}$ is the heat loss from pipes to environment, W.

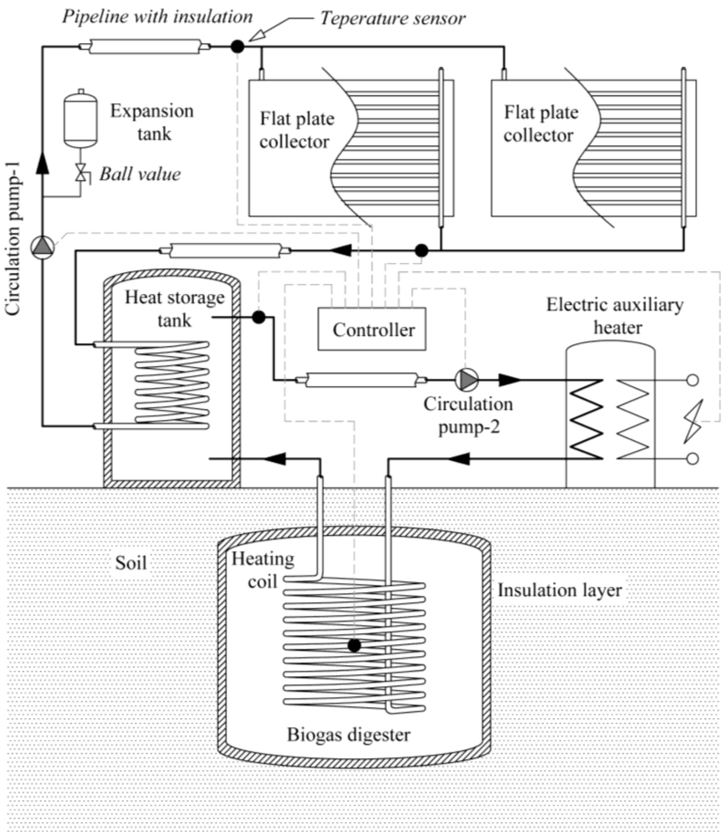

Fig 1. Schematic of the solar heating household biogas digester system

2.3.1 Energy delivered from solar collectors and auxiliary heater

The heat gain from the solar collector can be calculated using following equations (Duffie & Beckman, 1991):

$$Q_{col} = A_{col} I_T \eta_{col} = m_{hm} c_{hm} (T_{co} - T_{ci}) \quad \text{(eq.4)}$$

where A_{col} is the solar collector area, m^2; I_T is the solar radiation rate on the collector surface per unit area, W m^{-2}; η_{col} is the collector efficiency, dimensionless; m_{col} is the mass flow through the collector, kg s^{-1}; c_{hm} is the specific heat capacity of heat medium, J kg^{-1} K^{-1}; T_{co} is the temperature of the fluid flowing out of the collector, ℃; T_{ci} is the temperature of the fluid flowing into the collector, ℃.

$$\eta = F_R (\tau\alpha)_n - F_R U_{col} (T_{ci} - T_{amb}) \quad \text{(eq.5)}$$

where F_R is the overall collector heat removal efficiency factor, dimensionless; $(\tau\alpha)_n$ is the cover transmittance and the absorber absorptance of the collector at normal incidence, dimensionless; U_{col} is the overall thermal loss coefficient of the collector per unit area, W m^{-2} K^{-1}; T_{amb} is the ambient temperature, ℃.

$$F_R = m_{hm} c_{hm} [1 - \exp(-A_{col} U_{col} F' / m_{hm} c_{hm})] / (A_{col} U_{col}) \quad \text{(eq.6)}$$

where F' is the collector fin efficiency factor, dimensionless.

The heat gain from the auxiliary heater can be calculated using following equations:

$$Q_{fluid} = m_w c_w (T_{set} - T_{ai}) \quad \text{(eq.7)}$$

$$Q_{loss,\ aux} = U_a (\bar{T} - T_{amb}) + (1 - \eta_{aux}) Q_{max} \quad \text{(eq.8)}$$

$$Q_{aux} = Q_{max} \quad \text{(eq.9)}$$

$$Q_{\text{aux}} = Q_{\text{fluid}} + Q_{\text{loss, aux}} = \frac{m_{\text{w}} c_{\text{w}} (T_{\text{set}} - T_{\text{ai}}) + U_{\text{a}} (\bar{T} - T_{\text{amb}})}{\eta_{\text{aux}}}$$

(eq.10)

where Q_{fluid} is the rate of heat addition to the water, W; m_{w} is the mass flow rate of water flowing into the auxiliary heater, kg s^{-1}; c_{w} is the water specific heat capacity, J kg^{-1} K^{-1}; T_{set} is the set temperature of heater internal thermostat, ℃; T_{ai} is the inlet temperature of auxiliary heater, ℃; U_{a} is the overall loss coefficient between the heater and its surroundings, W; $\bar{T}$ is the average temperature of fluid in heater, ℃; η_{aux} is the efficiency of auxiliary heater, dimensionless; Q_{max} is the maximum heating rate of heater, W.

The solar fraction is calculated by (Deng et al. 2016):

$$f = \frac{Q_{\text{solar}}}{Q_{\text{solar}} + Q_{\text{auxiliary}}} \qquad \text{(eq.11)}$$

where Q_{solar} is the heat supplied by the collector, W; $Q_{\text{auxiliary}}$ is the heat supplied by the auxiliary heater, W.

2.3.2 Heat transfer between digester and soil

Household biogas digesters are usually buried underground, and those heat transfer process are affected by the surrounding soil temperature and soil thermal properties. Therefore, the function of soil temperature field and soil physical parameters are needed to establishing the heat transfer model of the digester (Liu, Chen, & Li, 2017).

The soil initial temperature field can be calculated by (Zhang, Ren, & Mei, 2007):

$$T_{\text{s}}(z, \tau_0) = T_{\text{ave}} + A_{\text{w}} \exp\left(-z\sqrt{\frac{\pi}{ak}}\right)\cos\left(\frac{2\pi}{k}\tau_0 - z\sqrt{\frac{\pi}{ak}}\right) \qquad \text{(eq.12)}$$

where T_{ave} is the annual average temperature of ground surface, ℃; A_{w} is the annual temperature fluctuation of ground surface, ℃; k is the annual fluctuation period, h; a is the soil thermal diffusivity, m^2 s^{-1}; and τ_0 is the initial time, s.

The amount of heat loss from digester to the soil can calculated by:

$$Q_{\text{cover}} = \frac{(T_{\text{m}} - T_{\text{s}})A_{\text{cover}}}{\left(\frac{1}{h_1} + \frac{\delta_1}{\lambda_1} + \frac{\delta_2}{\lambda_2}\right)} \qquad \text{(eq.13)}$$

$$Q_{\text{wall}} = \frac{(T_{\text{m}} - T_{\text{s}})A_{\text{wall}}}{\left(\frac{1}{h_2 \pi d_1} + \frac{1}{2\pi\lambda}\ln\frac{d_2}{d_1} + \frac{1}{2\pi\lambda}\ln\frac{d_3}{d_2}\right)H} \qquad \text{(eq.14)}$$

$$Q_{\text{floor}} = \frac{(T_{\text{m}} - T_{\text{s}})A_{\text{floor}}}{\left(\frac{1}{h_3} + \frac{\delta_1}{\lambda_1} + \frac{\delta_2}{\lambda_2}\right)} \qquad \text{(eq.15)}$$

where T_{s} is the soil temperature, ℃; h_1, h_2, h_3 are the convective heat transfer coefficient of inner surface of cover, wall, floor, respectively, W m^{-2} K^{-1}; λ_1 is the thermal conductivity of digester, W m^{-1} K^{-1}; δ_1 is the wall thickness of digester, m; λ_2 is the thermal conductivity of insulating layer, W m^{-1} K^{-1}; δ_2 is the wall thickness of insulating layer, m.

The heat loss caused by manure feeding can be calculated by the formula:

$$Q_{\text{feed}} = m_{\text{f}} c_{\text{m}} (T_{\text{m}} - T_{\text{f}}) \qquad \text{(eq.16)}$$

where m_{f} is mass flow rate of the feed liquid, kg day^{-1}; T_{f} is the temperature of the feed liquid, ℃.

2.3.3 Biogas production rate

A methane production model was proposed during the anaerobic fermentation process, calculated as (Chen, & Hashimoto, 1978):

$$\gamma = \frac{B_0 S_0}{HRT\beta_{\text{methane}}}\left(1 - \frac{K}{HRT\cdot\mu_{\text{m}} - 1 + K}\right) \quad \text{(eq.17)}$$

where γ is volumetric biogas production rate, m^3 CH^4 m^{-3} digester day^{-1}; B_0 is biochemical methane potential, m^3 CH4 kg^{-1} VS; S_0 is influent VS concentration, kg m^{-3}; HRT is hydraulic retention time, days; K is the kinetic constant, dimensionless; and μ_m is maximum specific growth rate of micro-organisms, day^{-1} $\beta_{methane}$ is percentage of methane content in biogas.

K is a kinetic parameter related to the influent VS concentration, and is expressed as:

$$K = 0.6 + 0.0206e^{0.051S_0} \quad \text{(eq.18)}$$

Pham et al. (2014) predicted the dynamic methane production based on the Chen et al. (1978) model, making it available for the performance prediction of UHBD. Concurrently, Hashimoto (1982) proposed a relationship between the maximum specific growth rate of microorganisms and the temperature under mesophilic and thermophilic fermentation as:

$$\mu_{\text{m}} = \begin{cases} 0.0026e^{0.1319T_{\text{m}}} & 15°\text{C} \le T_{\text{m}} \le 30°\text{C} \\ 0.013T_{\text{m}} - 0.129 & 30°\text{C} < T_{\text{m}} \le 60°\text{C} \end{cases} \quad \text{(eq.19)}$$

2.3.4 Heat storage tank with immersed heat exchanger

$$\rho_{\text{w}} V_{\text{w}} c_{\text{w}} \frac{dT_{\text{w}}}{d\tau} = Q_{\text{hx}} - Q_{\text{in, out}} - Q_{\text{loss, tank}} \quad \text{(eq.20)}$$

Where ρ_w is the water density, kg m-3; V_w is the manure volume, m3; c_w is the water specific heat capacity, J kg^{-1} K^{-1}; T_w is the water temperature, ℃; Q_{hx} is the heat transfer between the water and the heat exchanger, W; $Q_{in, out}$ is the heat taken by the hot water, W.

2.4 TRNSYS simulation model description

According to the system mathematical model established in the 2.3 section, the TRNSYS system simulation model (TRNSYS, 2012) is further established, and the details of the model are shown in Fig. 2. The meteorological parameters used in the system simulation are imported by Type 109, the solar collector adopts Type 73, and the auxiliary heat source adopts Type 2b. The coupled heat transfer model of digester and soil (J. Zhao et al., 2008) is consist of the ground coupling model (Type 707b) and thermal storage tank (Type 534) to calculate heat loss through the digester envelope to the ground and hourly manure temperature. The periodic manure feeding was imported into dates readers (Type9e) and New Equation to calculate heat transfer from manure inflow.

The biogas production model is embedded into the solar heating digester system model by using the New Equation to calculate the amount of biogas production during the operation of the system. The detailed TRNSYS components and parameters adopted were explained in Table 1.

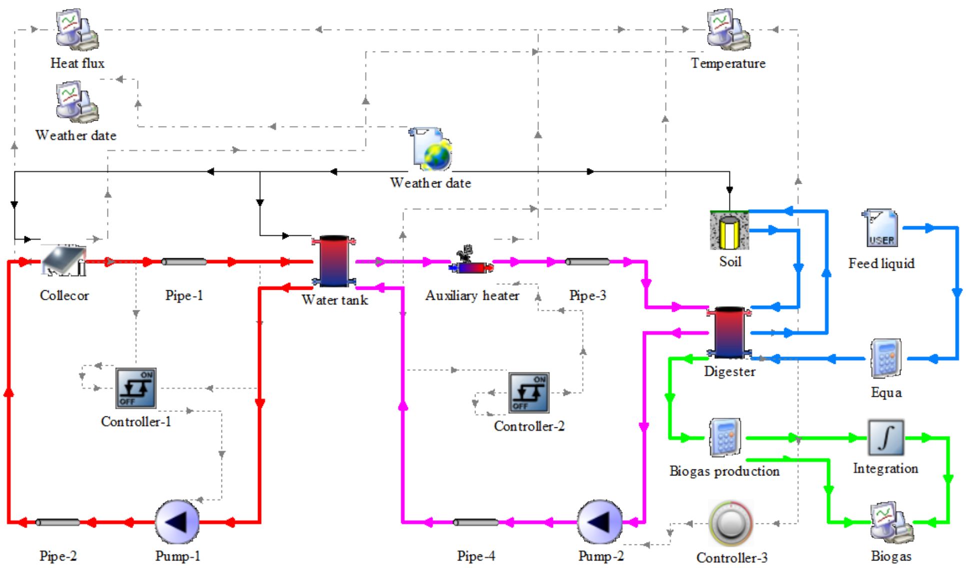

Fig 2. TRNSYS model of the solar heating digester system

Table 1. The main components of the TRNSYS simulation program

Components	Key parameter	Descriptions
Type 73 (flat-plate solar collector)	Collector area: 2, 8, 14, 20, 26 m^2; Bottom, edge loss coefficient: 0.56 W m^{-2} K^{-1}; Collector fin efficiency factor: 0.7;	Calculate the heat supplied by the solar collector
Type 707b (ground coupling model)	Mean surface temperature: 11.64 ℃; Amplitude of surface temperature: 18.73 ℃; Day of minimum surface temperature: 5 day; Soil column radius and height: 10, 10 m;	To calculate the energy exchange through the bottom, top, and sides of a digester that is entirely buried beneath the ground surface
Type 534 (biogas digester)	Digester radius and height: 1.3, 1.5 m; Thickness of insulation layer: 0, 30, 60, 90, 120, 150 mm; Number of tank nodes: 1 Length of coiled tubes: 32.68 m; Coiled tubes thermal conductivity: 0.33 W m^{-1} K^{-1}; Coil diameter: 1.3 m; Number of tubes: 8; Coil pitch: 0.1 m;	The hourly manure temperature is calculated by heat balance calculation。The gas production rate and total gas production of biogas digester are further calculated
Type 4c (heat storage tank)	Tank volume: 0.5 m^3; Tank heat loss coefficient: 0.5 W m^{-2} K;	The extra heat stored in the heat storage tank, which plays a role in peak shaving and valley filling
Type 6 (auxiliary heater)	Maximum heating rate: 3 kW; Efficiency of auxiliary heater: 0.95;	Added to supply heat when the collector heat is insufficient
Type 109 (TMY-2 weather data)	Import typical meteorological year weather date;	Used for the optimization analysis
Type 1502 (simple thermostat)	Setpoint temperature for stage: 35 ℃; Temperature dead band: 1 ℃;	Keep slurry temperature at 35±1 ℃
Type 2b (controller)	Upper and Lower dead band dT: 1, 8 ℃;	Control whether the heat medium flows through the collector
Type 2b (control auxiliary heater)	Upper input temperature Tl: 50 ℃; Upper and Lower dead band dT: 0, 5 ℃;	Control the start-stop of the auxiliary heater
Type 3d (pump)	Flow rates of the solar system and the heat supply were 0.4, 0.4 m^3 h^{-1}, respectively;	Drive system to circulate
Type 31 (pipe)	Pipe length: 8 m; Inside diameter: 0.02 m; Loss coefficient: 0.14 0.5 W m^{-2} K^{-1};	Connect each equipment unit and calculate heat loss of pipeline

The control logical diagram of the solar heating digester system are shown in Fig 3. The control system consists of solar collector control, auxiliary heating control and biogas digesters heating control subsystem. As shown in Fig 1, Firstly, the solar collector inlet and outlet water temperature, heat storage tank outlet water temperature and the manure temperature were monitored by the control system. Secondly, the temperature above would be compared with the temperature or the temperature difference set before. Finally, the automatic control of the heating system were achieved by controlling on and off of the circulating pump and auxiliary heater. The control logic details are as follows:

- The control logical of heat collection system: Comparing the inlet and outlet temperature of the heat collector, the pump-1 opens at next moment when pump-1closes at present and the temperature difference ≥8 ℃, and the pump-1 closes at next moment when pump-1opens at present and the temperature difference ≤1 ℃.

- The control logical of auxiliary heater: The auxiliary heater closes at next moment when the auxiliary heater opens at present and the outlet temperature of the heat storage tank ≥ 50 ℃, and the auxiliary heater opens at next moment when the auxiliary heater closes at present and the outlet temperature of the heat storage tank ≤ 45 ℃.
- The control logical of digester heating system: The pump-2 closes at next moment when pump-2 opens at present and the temperature difference ≥1 ℃, and the pump-2 opens at next moment when pump-2 closes at present and the temperature difference ≤-1 ℃.

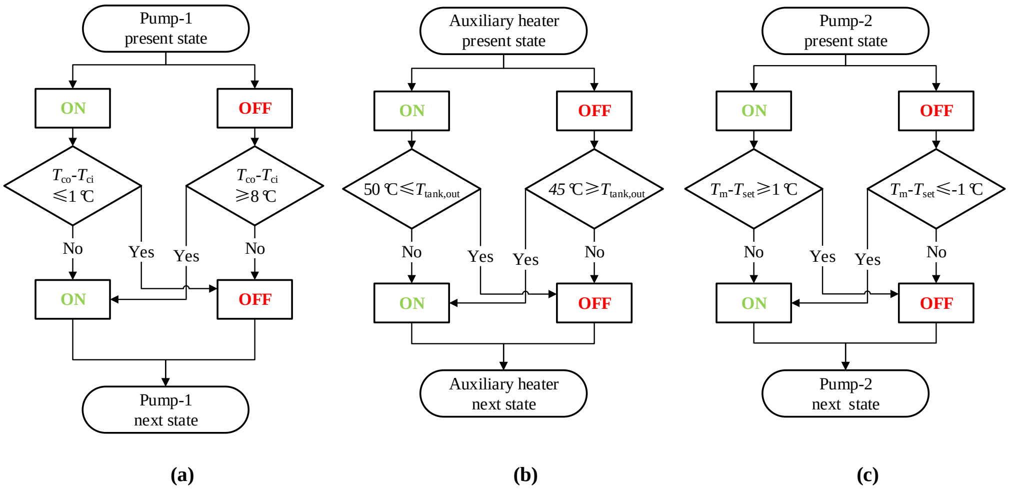

Fig 3. Control logical diagram of the solar heating digester system. (a) the control of heat collection system, (b) the control of the auxiliary heater, (c) the control of the digester heating system.

3. Results and discussion

3.1 Weather data

Lhasa (latitude 29 °36 'N, longitude 91 °06' E) is located in the Qinghai-Tibet Plateau, the solar energy in this region is abundant and suitable for solar heating digester system application. The weather parameters includes the hourly horizontal solar radiation intensity, the hourly outdoor dry bulb temperature and the underground 1m and 2m soil temperature derived from TRNSYS are shown in Fig 4. The difference of horizontal solar radiation intensity of Lhasa in different seasons is small, and the annual average solar radiation intensity is 227.4W m^{-2}. The outdoor air temperature difference between winter and summer is about 25 ℃, and the lowest temperature in winter is about -10 ℃. The soil temperature at underground 1m is greater than 0 ℃ throughout the year, and the soil temperature at underground 2m is greater than 5 ℃ throughout the year.

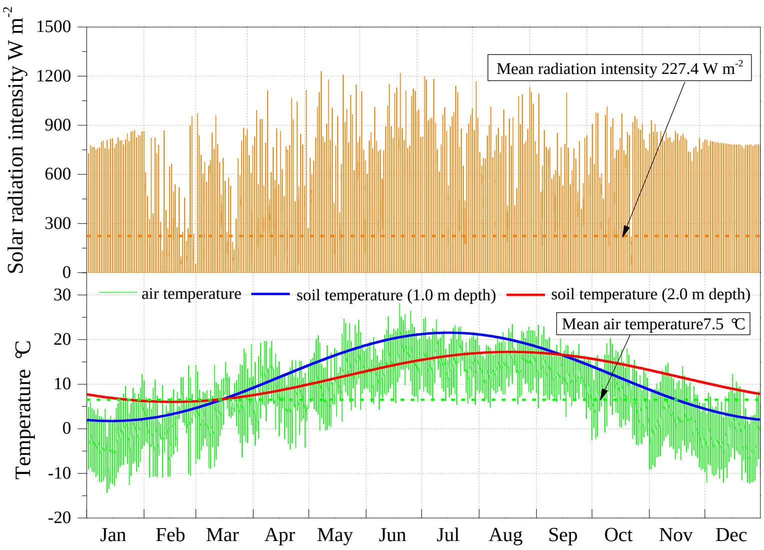

Fig. 4: Outdoor meteorological parameters in Lhasa

3.2 System form optimization analysis

The operation performance of three different forms of solar heating biogas digesters is compared and analyzed. The system A has no auxiliary heat source and no temperature control system, the system B has auxiliary heat source but no temperature control system, the system C has both auxiliary heat source and temperature control system. The polar temperature is 35 ℃ under the condition of medium temperature fermentation (Y. Lu et al., 2016), so the biogas fermentation temperature in system C is set to 35 ℃. The simulated manure temperature under different system forms are shown in Fig5. As shown in Figure, The biogas digester keeps at 6-8 ℃ when it without any heating system, and its biogas production can be basically ignored. The manure temperature of System A is significantly higher than the system without heating measures, the manure temperature can be increased to 25 ℃ before February, the manure temperature in February to March decreased significantly for cloudy days in February to March is larger than other months(Fig4).

The manure temperature in system B is the largest among three system forms, the manure temperature keeps at 50 ℃ before February, and the manure temperature decreased continually in February to March. The results shows that the auxiliary heater continually operated has consumed amounts of conventional energy, and the manure temperature fluctuates greatly when the solar radiation is insufficient. The manure temperature of the system C is basically the same as the design temperature, the manure temperature fluctuation is about ±1 ℃ before February and increased slightly which is no more than 3 ℃ in February and March.

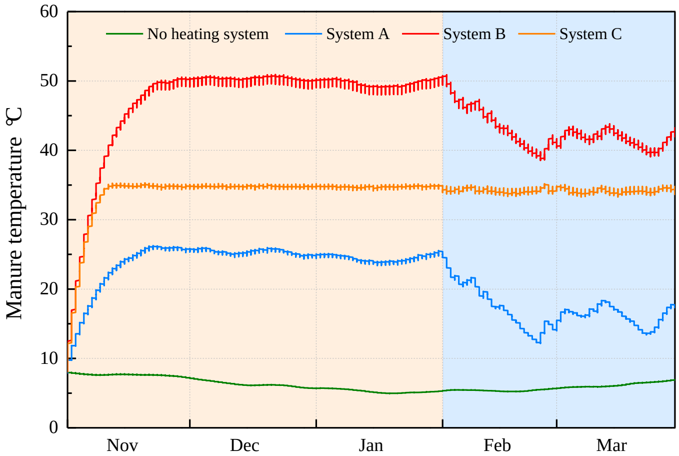

Fig. 5: The simulated manure temperatures under different system forms

Fig. 6 shows heat supply biogas production and the system net energy production of three system forms. As shown in figure, the heat supplied by System B to the digester is the most, followed by System C, and System A provide the least amount of heat. 71% of the heat provided by the auxiliary heater in System B, while 42% of the heat provided by the auxiliary heater and 58% is supplied by the collector in System C. The biogas production of the System B is the largest among three system due to its higher manure temperature. The daily biogas production of System B is 1.41m^3 larger than that of System C, and 4.35m^3 than that of System A. The daily net energy production refers to the converted heat of daily biogas production minus energy consumed by the auxiliary heater. The daily net energy production of System C is the largest (19.2kWh), and daily net energy of System B is the smallest (8.6kWh). The results showed that the performance of System C is better. However, the solar fraction of System C is not high, so it is better to improve the solar fraction of the system by optimizing the components in system.

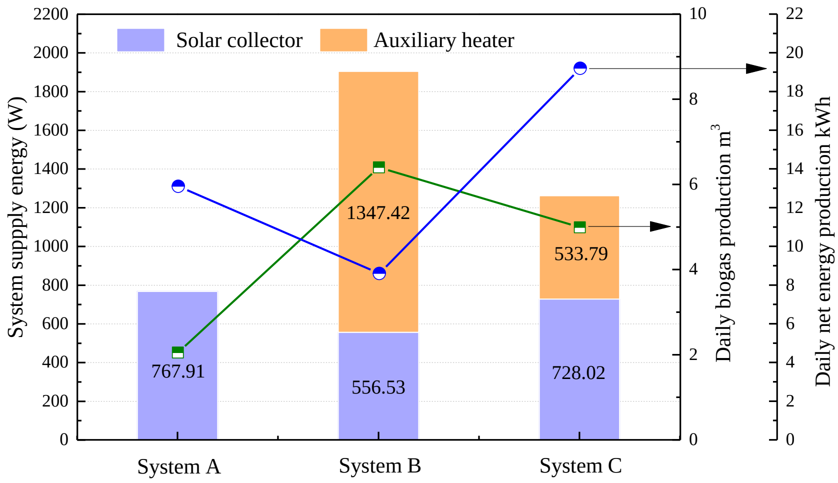

Fig. 6: System Heat supply, daily biogas production and daily net energy production under differant system forms

3.3 The influence of the thickness of insulation layer on solar fraction

The heat supply of the system could be reduced by decreasing digester heat loss. Therefore, the solar fraction can be improved by reducing the energy supply of auxiliary heater under the condition of solar collector area unchanged. Fig. 7 shows the variation of the solar fraction with the insulation thickness. The solar fraction increase logarithmically with the increases of insulation thickness, and the growth of solar fraction is not obvious when the thickness of insulation layer exceeds 120mm. Accordingly, it is necessary to comprehensively compare the increase of investment with the insulation thickness increase and the decrease of the operating cost caused by the reduction of the auxiliary energy to select the economical insulation thickness. Besides, the increase of insulation layer thickness is not significant to enhance solar fraction of the system when the collector area is larger or smaller. The solar fraction increased from 0.47 (no insulation) to 0.73 (150 mm insulation) when the collector area is set as 14 m^2.

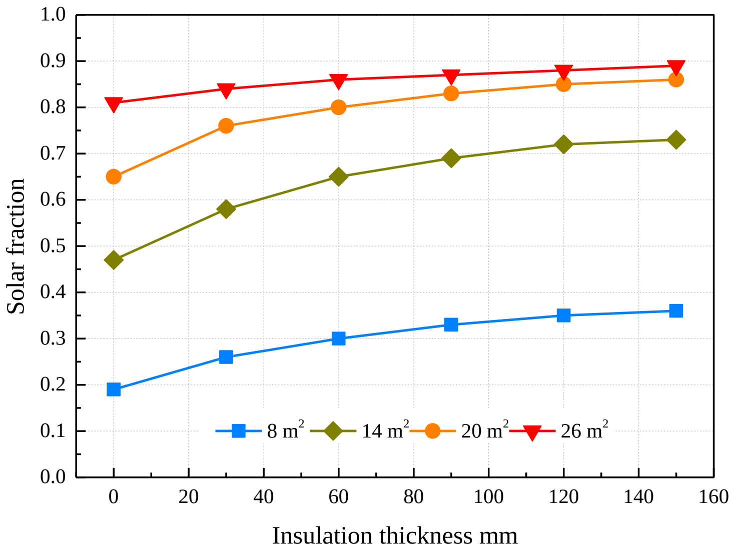

Fig. 7: The variation of the solar fraction with the insulation thickness

3.4 The influence of the collector area on solar fraction

The heat production of the heating collection loop can be directly improved with the increasing of the solar collector area, and then the solar fraction of system can be improved. Fig 8 shows the variation of the solar fraction with the collector area. The solar fraction increases with the increase of solar collector area in the form of the sigmoid function. The solar fraction increases most (from 0.33 to 0.69) when the collector area is increased from 8 m^2 to 14 m^2. Hence, it is also necessary to select the appropriate collector area in combination with economic factors.

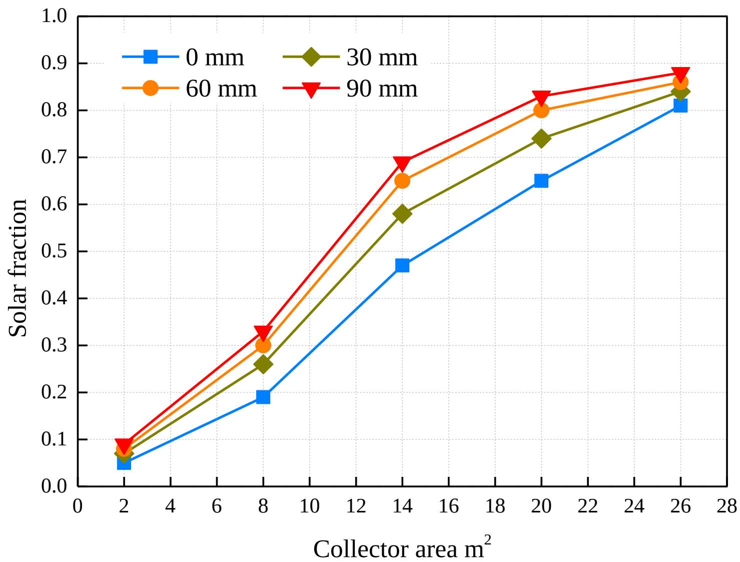

Fig. 8: The variation of the solar fraction with the solar collector area

4. Conclusion

In this study, the mathematical of the solar heating household biogas digester system and the simulation model based on TRNSYS were established. The conclusions drawn from the results are stated as follows:

- System C could maintain the stable operation of the biogas digester under the designed conditions, and the range of temperature is about ±1 ℃. Besides, the solar fraction of System C is higher than that of System B. The daily net energy production of System C is the highest among three system forms with the value of 19.2 kWh.
- The solar fraction increased with the insulation thickness increased as logarithmic function, which has the most significant growth rate when the collector area is 14 m^2.
- The solar fraction increases with the increase of the collector area in the form of sigmoid function. The solar fraction increases most (from 0.33 to 0.69) when the collector area is increased from 8 m^2 to 14 m^2.

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