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Design, Construction and Evaluation of a Flat Plate Collector for Heating the Anaerobic Digestion Reservoir Water

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A B S T R A C T

Solar collectors are a kind of heat exchangers in which solar radiation energy is transmitted to the internal energy of a transferring substance such as water. In any solar system, collectors are the main system of the system. In fact, a solar collector is a device that absorbs and absorbs the sun's intake of radiation energy. This heat is then absorbed, transmitted by a fluid (usually air, water or oil) flowing through the collector. This solar energy is absorbed or converted directly to hot water through a rotating fluid in the collector, or transferred to air conditioners and can easily be consumed. The stored energy can also be stored in a heat storage tank to be used at night or when cloudy sky is used for various uses. In the present study, a laboratory scale was used to construct and evaluate a solar collector and use it to heat the anaerobic digestion reservoirs. The test and test of the collector made in the month of October and the measurement of its thermal efficiency in November 2012 in two sunny and cloudy days. Heating systems in an anaerobic digestion system that operates in an energy-efficient way generate high energy consumption, which is not economically feasible. For this purpose, a collector with rectangular cube plates with dimensions of 50 * 110 cm was designed and tested. The results of the research showed that the collector is well heated with anaerobic digester reservoir and provides a suitable temperature for producing biogas.

1. Introduction

In recent decades, the increased use of fossil fuels, which has led to increased emissions of greenhouse gases and other environmental pollutants from the same time, and the near-completion of fossil fuel resources in the near future, has led the world to adopt a new approach to the use of renewable energy sources To find. One of the main sources of renewable energy is solar energy, which is the direct source of almost all renewable energies. The energy in the sun's rays can be extracted in a variety of ways. One of the technologies in this field is solar collectors. Types of solar collectors are divided into three main categories, which include flat collectors, vacuum collectors, and collector collectors. Among collector types, flat collectors are the simplest and most used [1].

The sun is the most abundant and most available source of energy for the planet. All other types of energy include wind, fossil fuels, Biomass and rooted in the sun. The solar energy is at 120 pw. This means that the energy received from the sun in one day can meet the needs of the world for 20 years. With future developments, the potential for consumption for each renewable energy source will increase. However, global needs lead to an increase of 5% per annum in the energy sector [2].

Using solar water heater, you can supply 70% of the energy needed for water heating each year. Most solar water heaters can be easily installed on the roofs of the house and can be used with plumbing and connecting the storage tanks to the internal water heater system. The use of solar water heater reduces up to 70% of the cost of energy for spa use. Due to the use of solar energy, the risks of poisoning, fire, explosion and electric shock caused by the consumption of gas and liquid fuels, solid and electricity, are completely eliminated (Iran Fuel Conservation Company, 2009).
Iran is a country with 333 days of sunshine in more than two thirds of it and an average radiation of 4.5 - 5.5 Kwh per square meter per day, one of the countries with high potential for solar energy. According to international standards, the use of solar energy models such as solar collectors or photovoltaic systems can be economical and affordable if the average solar energy of the sun is higher than 3.5 kilowatt hours per square meter per day [2].

Evaluate and compare the efficiency of a thermos-syphon solar water heater with parallel flat panel collectors in both numerical and laboratory methods. He found that the thermal efficiency of the entire system was greater for flat panel collectors than tubular collectors [9].

Solar energy converters are special types of heat exchangers that converters solar radiation energy into the internal energy of the transmitting substance. The solar converter is the main component of any solar system. Also, the solar converter is a device that absorbs the incoming radiation of the sun and turns it into heat, and then transfers to the fluid circulating in the collector (usually air, water or oil). Therefore, solar energy is stored in hot water as heating or ventilation equipment in tanks to be used at night or for hours that are cloudy. Generally, there are two types of solar collectors: decentralized or fixed and concentrating [10].

The greenhouse effect of flat plate collectors is usually in a steady state and does not require the pursuit of the sun. Collectors should be directed directly along the equator and southward in the northern hemisphere and northward in the southern hemisphere. The optimal angle of the curvature of the collector is equivalent to a latitude position with a deviation of more than or less than 10° to 15°, which depends on its application [10].

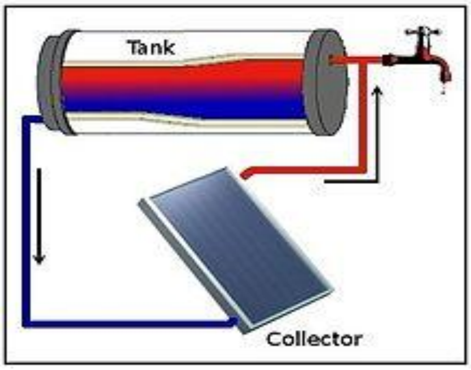

Figure 1. View of the solar collector flat panel Thermo-syphon type

A low-cost mechanical construction method is proposed for optimal levels of solar adsorbent. An efficient solar collector should absorb solar radiation and convert it to thermal energy, and deliver this heat energy to the same heat transfer interface with the least waste at each stage. Today solar adsorption plates are made by methods of analysis, evaporation, sputtering and optimization colors [15].

Solar collectors are generally distinguishable due to their movement (constant, single-axis rotation, two-axis rotation) and their operating characteristics [11].

Hellstrom et al. [8] examined the effect of physical and thermal properties on the performance of flat plate collectors. They concluded in their work that the increase in Teflon film as a secondary coating resulted in an overall performance increase of up to 6.5% at 50 degrees Celsius. While the increase in Teflon honeycomb to reduce waste discharges, the overall performance increases to 12.1%. It also increases the operation to reduce reflection from the glass cover to 6.6% at 50 °C.
Collector plates absorb large amounts of diffusion through the glass. Although losing a small amount of heat through the atmosphere and the compartment. The collector screens transfer the remainder to the transfer fluid. The absorption capacity of the collector plate depends on the short-wave radiation of the sun to the nature and the color of the coating, as well as the angle of the upright. Usually staining is used in black [16].

Morrison and Sepford, [6] examined the performance of six solar water heaters with household capacities and evaluated them in terms of configuration and daily use, especially during peak periods of consumption. He said the natural circulation system was more suitable in the early hours of the morning compared to the compulsory

circulation system, and in non-peak hours, the efficiency of the system increased by 15%.
The open space collector can be placed in a steady state, but this will limit the test time to an acceptable range of angles. The more subtle way is to move the collector so that it can track the sun at its own angles by manual or automatic tracking. Fluctuating flow by heat transfer of fluid in solar collectors can significantly increase heat transfer [12].

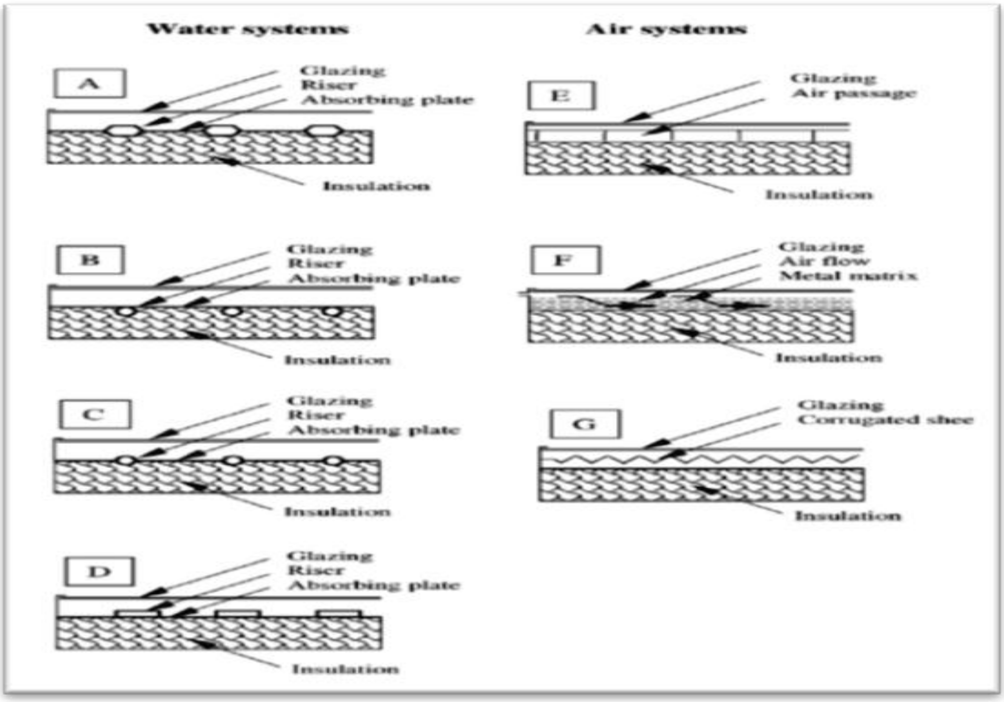

Figure 2. Different types of flat plate collectors

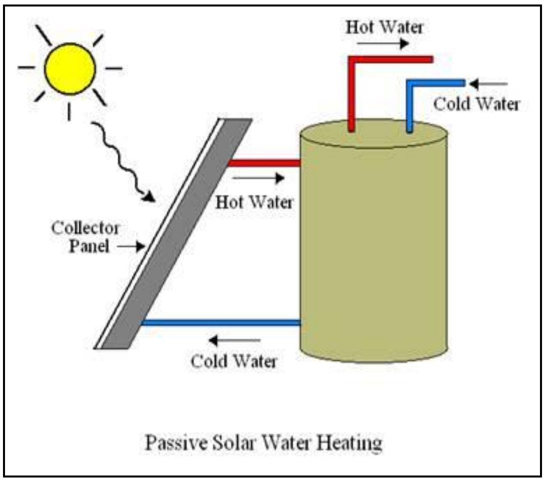

Figure 3. A view of the solar collector by direct absorption

Soteris, [13] in Cyprus compared the use of conventional water heater with a solar water heater, and concluded that the use of a solar water heater instead of a conventional water heater would result in about 80% savings in electrical energy consumption.

Hang, [7] in his article on the economic and environmental analysis of the use of solar water heater in the United States in three regions of Atlanta, Chicago and Los Angles. In his analysis, Mr. Huang used two different solar water heater systems (sheet and vacuum tube) that worked with two auxiliary heating systems, natural gas and electricity, and concluded that the solar water heater system the term heating heat is used and its collector is of a plate type, it has the highest performance among other systems. The time of returning capital for the solar water heater system, according to the situation and the area considered, is between 4 to 13 years.

Farahat et al. [5] analyzed the combination of energy-exergy optimization on solar flat panel collectors. They concluded that the exergy efficiency increased with increasing optical efficiency and thermal fluctuation of sunlight and decreased with increasing temperature and wind speed. They also found that the optimal inlet temperature for the existing fluid and the tube diameter had little impact on the exergy efficiency.

By using the solar collector, you can dramatically reduce gas, gasoline and electric consumption costs, which will be tangible in large projects, so that after a short while, with the saving of fuel, the initial investment is depreciated and after it will be profitable for the long life of the devices. Maintenance and repair costs of these systems are very low and zero because they have no moving parts and the lifetime of standard and high quality technical systems is up to 20 years old [3].

2. Materials and methods

This project was carried out at Khuzestan Agricultural and Natural Resources University, located 25 km northeast of Ahwaz. The research included two steps: the design and construction of a flat plate collector and its testing using an anaerobic digester reservoir sample. The research analysis of this study was to replace the solar collector instead of the heating systems of biogas plants powered by electricity. Given that mesophilic (30 to 45°C) is usually used to produce biogas, we tried to make simple, low-cost, water-flow, and tailored to the needs of digestion reservoirs. The designed collector is shown in Fig. 4 an anaerobic digestion reservoir was designed to justify the precise construction of the collector and its application.

2.1. Screwed collector components:

- Two pride scoops with copper tubes
- Copper pipes with internal diameter 1 in
- Thickness of insulation 1 in
- Flat plate absorbent plate with a thickness of 4 mm and dimensions of 50 cm ×110 cm
- Fiberglass water tank with a capacity of 15 liters
- Radiator holder and MDF board in thickness of 1
- Inlet hose to reservoir in1 in diameter
- Water hose to radiator in diameter 1 in
- Hose Outlet of hot water from radiator to tank in 1 in diameter

Calculation of collector water consumption in a day (Tabatabaei, 1998):

$$Q = \rho V C (T_2-T_1) \quad (1)$$

Q: The load of hot water consumed in terms of (kJ)
C: Specific heat of water (kJ / kg 0C) 4.18
V: The actual amount of water used per day in lit
ρ: Specific gravity of water (1 kg/L)

The average water intake to collector on sunny day was T_1= (30°C)

The average temperature of the outlet water from the collector on sunny days was T_2 = (57 ºC)

Q_1= 1× 60 × 4.18× (57-30) = 6772 w/h

≈6.8 Kw/h Calculation of the average load of water consumed on the sunny day of November

Average water temperature entering the collector on cloudy days T_1= (25°C)

Average temperature of the outlet water from the collector on cloudy days T_2= (36°C)

Q_2= 1× 60 × 4.18× (36-25) = 2976 w/h

≈3 Kw/h Calculation of the average load of water consumed on the cloudy day of November

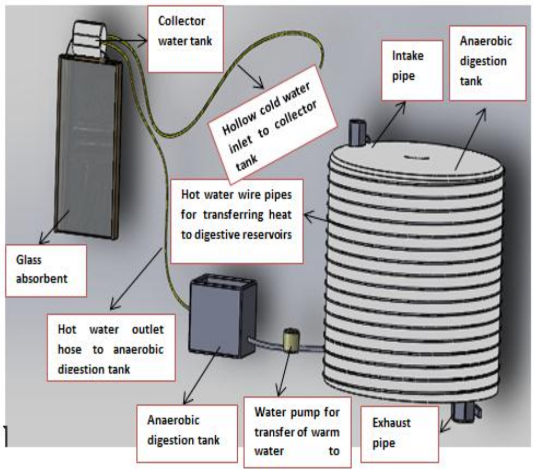

Figure 4. Collector design and made digestion using solid works software

Figure 5. Is a real collector image

2.2 Type and performance of collector made:

In this research, a thermos-syphon type collector (natural circulation system) was selected to build. As a result of exposure to the collector's adsorption screen and absorption of heat energy by this page, the fluid in the collector is heated by sunlight. Due to the difference in density caused by the difference between the temperature of the hot and cold fluid, the thermos-syphon property is created and, due to this property, the fluid moves upwards and flows into the reserve. In this part, the heated fluid is the same water that will be used. The collector tank was filled with ordinary water and the water inside the copper pipes was flowing slowly toward the storage tank when the sun was flowing onto the glass plate. The water from the reservoir was also flowing through the other tube to the bottom and as long as the solar radiation was enough to heat the water, this continued. A thermometer was used to measure the inlet and outlet temperature of the collector (Fig. 5). At the end of a sunny day, a test on the collector showed that the reservoir's water temperature reached 40 degrees in the winter and reached 90 degrees Celsius in the summer. If the glass sheet with a width of 50 cm and a length of 110 cm and a reservoir capacity of 15 to 20 liters is considered, this collector can meet the water needs of the water reservoir of the biogas plant with a capacity of 300 to 400 liters per day.

Figure 6. Mercury Thermometer for measuring water temperature

In order to always have a collector absorber plate, perpendicular to the entrance of the sun's rays, a movable base was installed at the rear of the collector to place the water heater at different angles and directions to the horizon. Due to the change in the sun's height in different days of the year, the angle of the collector can be changed at different times, hours, months and chapters, and the collector's screen always stays perpendicular to the sun's rays to get the highest radiation from the sun by absorbing the screen. The solar power meter was used to measure sunlight (Fig. 6), which measured the solar radiation in two sunny and cloudy days from 7 am to 9 pm, and data from the measurements were recorded. The main and final goal of this project was to absorb the highest amount of solar radiation by collector adsorbent plate and convert it into suitable heat for heating the water storage reservoir of biogas production plants.

Figure 7. The solar power meter datasheet model TES-132

2.3. Calculate collector returns per day:

$$\eta = \frac{mc(T_e - T_i)}{GA} \times c \quad (2)$$

M: Water mass (kg), C: Special thermal heat for water ℃, T_e: Daily output temperature ℃, T_i: Daily input temperature ℃, A: Collector Cross section $m^{2,}$ G: Daily sunlight in w/m^2, C= Collector heat dissipation during the day

$$C = U \times A \times DT \quad (3)$$

Q: Heat loss, A: Useful area, U: Thermal conductivity, DT: higher temperature - lower temperature

2.4. Calculate Collector Returns on Sunny Day:

C= 0.1×1×27=2.7

$$\eta = \frac{mc(T_e - T_i)}{GA} \times c = \frac{1\times 4200\,(57-30)}{6772\times 2} = 17\times 2.7 = 46\% \quad (4)$$

2.5 Calculate Collector Returns on cloudy Day:

C= 0.1×1×11=1.1

$$\eta = \frac{mc(T_e - T_i)}{GA} \times c$$

$$\eta = \frac{1\times 4200\,(36-25)}{2976\times 1} = 16\times 1.1 = 18\% \quad (5)$$

3. Results and discussion

The collector electrical efficiency was calculated based on the relationships and formulas in the materials and methods section. By increasing the intensity of the sun's radiation, the collector efficiency also increased due to increased energy and, consequently, the production of potential differences. It should be noted that the study of changes in electrical efficiency compared to time and from 7am to 19days on sunny and cloudy days, so here is plotted the corresponding diagram and its interpretation for sunny and cloudy days. As shown in Fig. 5, the collector efficiency also increased with increasing ambient temperature and sunlight intensity. Efficiency decreases over the course of the day and at the same time as the sun goes down and the intensity of the sun's radiation decreases. Changes in thermal efficiency are shown in relation to the time (hour) for a sunny day in November. The analysis of measured data indicates that the maximum absorption of solar energy in the collector occurred in the noon range (12 to 15 hours), which resulted in the maximum flow of the collector fluid during this time period. During the day and in the afternoon, with the increase in the intensity of the sun's radiation, the flow rate in the radiator copper pipes also increased, and peaked at 12 to 15 hours due to the maximum radiation intensity and also the maximum gradient of temperature. In the afternoon, with a decrease in the intensity of radiation, the heat of the outlet water decreases with a faster process than before. The average sunlight was measured in terms of w/m^2 on sunny days at different hours, and the relevant data are shown in Fig. 6 the highest amount of radiation was obtained at 13 o'clock at 876 $\frac{w}{m^2}$ and the lowest amount of sunshine was at 19 o'clock at 385 $\frac{w}{m^2}$. The results of the solar radiation measurement showed that the amount of irradiation is directly related to the amount of water output from the collector, the higher the amount of sunlight, the higher the water outlet temperature from the collector.

As shown in Fig. 7, the thermal efficiency changes are shown in relation to the time (hour) for a cloudy day in November. As the ambient temperature and intensity of the sun's radiation increased, collector efficiency also increased, but compared to the sunny day, overall efficiency was reduced due to cloudiness and a decrease in average daily temperature, because on cloudy days, due to the lack of sunlight and the reduction of daily radiation, we saw less heat production than sunscreens.

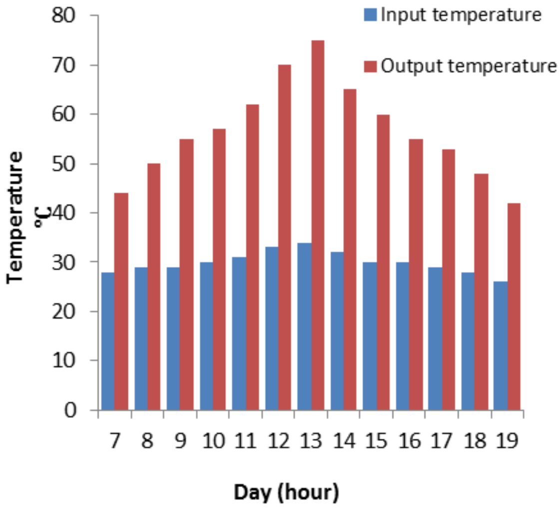

Figure 8. Average Inlet and Outlet Temperature of Collector on Sunny Day (November)

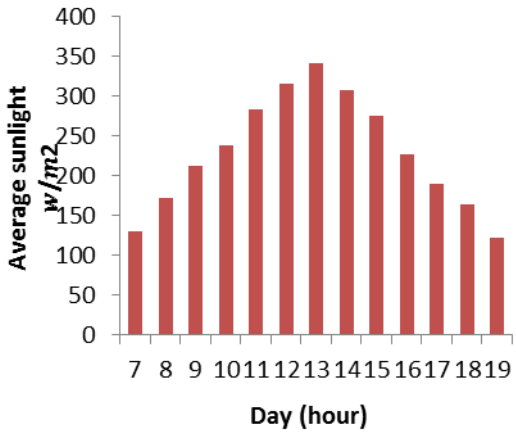

Figure 9. Shows the average amount of sunlight on a sunny day in terms of $\frac{w}{m^2}$ (November)

The analysis of the measured data shows that the maximum absorption of the sun's energy in the collector occurred in the noon range (12 to 15 hours intervals), which resulted in the maximum flow rate of the collector during this time interval. During daytime and in the afternoon, as the temperature of the sun increases, the flow rate in the radiator copper pipes also increases and rises to peak during 12 to 15 hours due to the maximum absorption of heat by the collector and decreases in the afternoon The intensity of the heat of the sun decreases as well as before the afternoon.

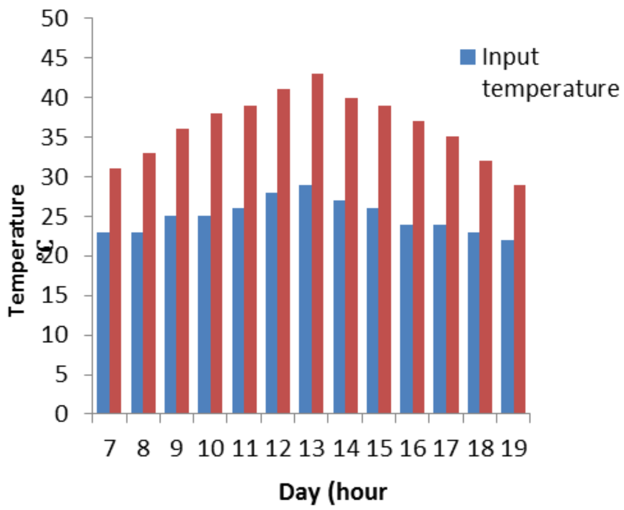

Figure 10. Average flow and collector temperature in cloudy days (November)

The average sunlight was measured in terms of $\frac{w}{m^2}$ in cloudy days at different hours, and the corresponding data are shown in Figure 8. The changes in the sun's rays were the same on a sunny day on a cloudy day, but the amount of radiation was less than sunny days. The highest amount of radiation at 13 o'clock was obtained at 342 $\frac{w}{m^2}$ and the lowest amount of sunshine was at 19 o'clock with an average of 122 $\frac{w}{m^2}$. The results of the solar radiation measurement showed that the amount of irradiation is directly related to the amount of water output from the collector, the higher the amount of sunlight, the higher the water outlet temperature from the collector.

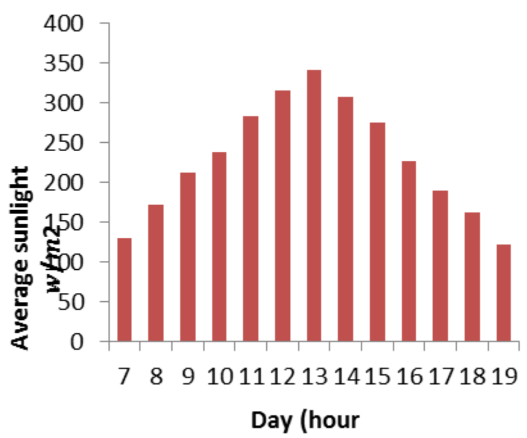

Figure 11. Shows the average amount of sunlight in the cloudy day in terms of $\frac{w}{m^2}$ (November)

4. Conclusion

Flat panel collectors are very useful for collecting low to moderate heat from the sun. They can be used for various applications, including the supply of biogas production from low to moderate capacities. Flat panel collectors have simple specifications. they are easily assembled and work comfortably. A system that converts solar radiation into thermal energy is the application of thermal energy innovators. Solar thermal energy can be used directly as heat or indirect for the production of useful thermal energy. The solar thermal collector's goal is to absorb solar radiation and transfer significant heat to a fluid. This energy is furthered to the desired location for use. As seen, fortunately, given the climatic conditions existing in Khuzestan province, this province has a good potential for using solar collectors. Due to cloud conditions in most days, as well as low levels of sunlight, the total efficiency of the solar collector fell on some days. However, since biogas plants can produce biogas at two mesophilic temperatures of 30 °C to 40 °C and thermophilic 40 °C to 55 °C, this collector can meet the thermal requirements of biogas plants in Khuzestan province at all temperatures during the whole year. The results of this study show that replacing solar collectors with biogas production plants instead of heating systems will significantly increase the annual energy consumption of electricity.

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