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PRODUCTION OF BIOGAS AS AN ENERGY SOURCE IN COLDER AREA, USING FLAT PLATE THERMAL COLLECTOR

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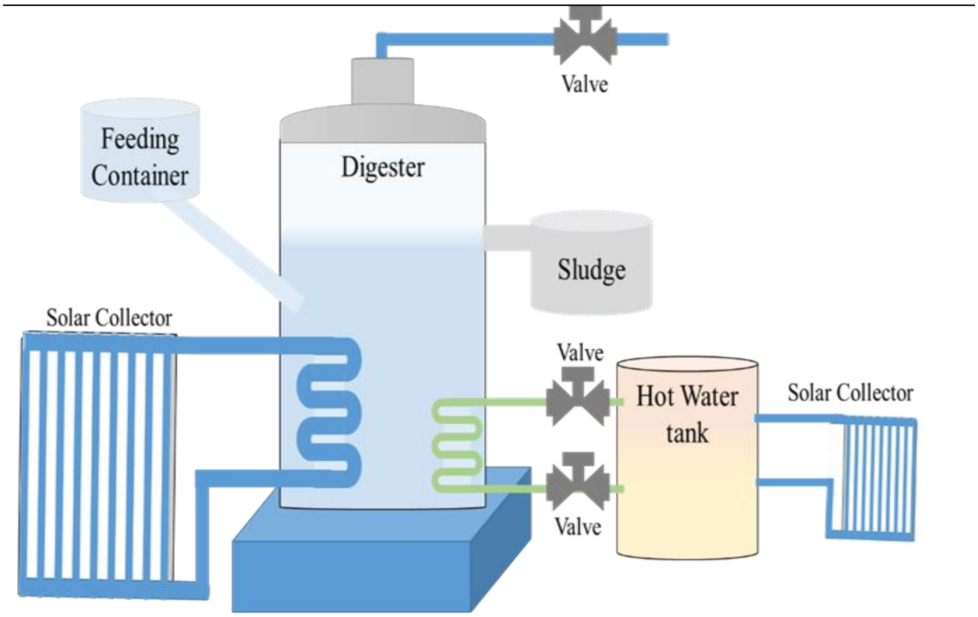
HIGHLIGHTS

- Two pilot scale anaerobic digesters each of volume 750 litters were installed for this research.
- For the heating of slurry, solar flat plate thermal collectors were used in winter in colder areas.
- Hot water was circulated inside digester via copper pipe coils.
- Cow dung was used as starting manure and food waste was filled daily into digester.
- The temperature of digested slurry was enhanced (19-23 °C) during winter in cold climate
- Production of biogas was 2954L that was 3.5 times higher than without thermal collector.
- Fraction of methane was 61% but without thermal collector it was 56%.

GRAPHICAL ABSTRACT



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ABSTRACT

Biogas is a good source of renewable energy. This research work has been done for the design, fabrication, and investigation of a digester with solar thermal flat plate collector to heat slurry inside the digester in order to maintain the temperature in appropriate range (35±2). For production of continuous biogas in winter, a minimum temperature is required for the slurry 3 kg COD/m³ organic waste. The Hydraulic Retention time for this research experiment was 10 days. Flat plat thermal collector is used in this research to heat water and circulate it inside the digester. The hot water is circulated by copper coils during the winter season. By adopting this method the temperature of the slurry enhanced to required minimum temperature and the production of biogas was continued through the whole year in the colder area. The data collected from the experiment showed that using of flat plat thermal solar collector is the appropriate method for heating slurry to produce biogas through the whole year in the colder area in winter season.

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1. INTRODUCTION

To maintain the up going prices of fuels and sources of energy we need an alternative source to replace it. The converting of biomass into energy by anaerobic digestion is convenient way of replacement. In addition to this, biomass technology is a key to control the environmental pollution by converting methane from greenhouse gas into renewable energy source. The anaerobic digestion technologies of food waste is the convenient way for food waste management because of controlling the increasing basic essentials for renewable energy generation and reducing the greenhouse gasses emitting from wasted materials [1]. The management of food waste in the modern world is a major problem faced to various nations [2]. Pakistan Environmental Agency (PEPA) 2005 reported that the average solid waste generation in Pakistan is .613 kg per capita daily and 90% solid waste is biodegradable [3]. The miss management of these wasted materials is a very big source for environmental pollution [2]. Due to high content of water, food waste is easily biodegradable and a big reason for production of bad odour [4].This also emits greenhouse gasses (Methane) in landfills [5]. Heat trapping power and warming effect of methane as compare to carbon dioxide is 25 times and 72 times respectively higher than carbon dioxide [6]. Therefore it is very important to manage these wasted materials in a proper manner. The anaerobic digestion is a best choice for the management of wasted materials [5]. This oxygen free process (Anaerobic digestion) has two types: wet (<10% total solid) and dry (>20% total solid) [7].

Due to many reasons like a renewable energy cause, bio manure, pollution control, management of environment, suitable technology and recycling of wasted materials, many developed and developing countries have a great interest in anaerobic digestion process of biogas technology [8]. This is a natural process where bacteria break or decompose the organic matter in oxygen free environment. The anaerobic digestion treatment is focused due to low power utilization, long cleaning cycle, little sewage volume etc. [9]. The decomposing of organic matter results in 60% methane, 37% Carbon dioxide, 3% Nitrogen, 1% Hydrogen, and 1% Hydrogen sulphide. There are four stages for transformation of organic compounds into biogas; they are Hydrolysis, Acid genesis, Acetogenesis, and Methanogenesis. In the hydrolysis, the organic compound transfer into smaller components. In Acid genesis bacteria use these smaller components to produce volatile fatty acid, ethanol, Carbon dioxide and hydrogen. In Acetogenesis, bacteria transfer these products in CH_3COOH (acetic acid) CO_2 and H. At last Methanogenesis bacteria use hydrogen and acetate to create methane and Carbon dioxide.

The anaerobic digester is designed to accomplish the decomposition. It is constructed in such a way that it can run under mesophilic temperature (20-45^{o}C) or thermophilic temperature (40-60^{o}C) ranges. In addition to these temperatures, Methanogenesis is possible under low temperature less than 20^{o}C. This process is called psychrophilic digestion. But this method is not explored as thermophilic and mesophilic.

Biogas is a mixture of different gases. Methane (CH_4) is main component of biogas. It also contains carbon dioxide (CO_2), hydrogen sulphide (H_2S), nitrogen (N). Methane is odourless, inflammable, and a colourless gas. Biogas is also called marsh gas, sludge gas, sewerage gas, klar gas, gobar gas, bioenergy, and fuel of future. There are 50 to 70% of CH_4, 30 to 40% of CO_2, 3% of N and 1% of H_2S. A 1000 ft^3 biogas is equal to 600 ft3 of natural gas, 5.2 gallons of gasoline, or 4.6 gallons of diesel oil. A family of four members can consume 150 ft^3 (4227L) biogas per day for their lighting and cooking purposes. This amount of biogas can produce from the dung of three cows and family night soil [10]. Methane is a greenhouse gas and plays an important role in the warming of atmosphere. The emission of methane to the atmosphere can be reduced by anaerobic digestion process. The process of production of biogas from digestion method has many benefits like heating, lightning, fuel, converting of organic waste into the best quality fertilizer, reduction of work for collection of firewood and cooking purpose. In spite of above benefits, the most important and the best benefit is the protection of environment from the greenhouse gases.

The production of biogas from the digester depends upon following factors, Material kind, solids loading, ambient temperature, retention time, the temperature of the slurry in the digester. It also depends upon pH level, nitrogen inhibition, Carbon to nitrogen ratio, retention time [10]. Among them, temperature is the most important factor that influences the production of biogas [11]. Up and down in temperature can result in decreasing bacteria or death of bacteria which result in decreasing of production of biogas [12]. Dioha et al 2006 reported that decrease in biogas production in colder season is due to the changes in atmospheric temperature which influenced the soil temperature [13]. Therefore we need a heating system for the slurry of digester. Many sources are used to control and maintain the temperature of the digester like insulation of digester, heat exchanger, heating elements, water bath and steam injection. The solar collector is the most suitable source for heating the slurry inside the digester in order to maintain the temperature to enhance the production of biogas. In winter, to warm up the biogas plant, solar collector is used for this purpose to maintain suitable temperature for fermentation. In the winter season in colder area, the rate of production of biogas is decreased due to the decrease in atmospheric temperature. To obtain optimum range of biogas we should maintain the temperature of the digester up to a certain level. The suitable range of temperature for the production of biogas is 35$\pm$2^{o}C [11].

In this research a flat plate thermal collector has been used to maintain the required temperature of the digested slurry. Heat stored in the water tank can be used as source of heating through circulation in the digester in the absence of solar radiations.

2. METHODOLOGY
2.1. Experimental Setup

A pilot scale two anaerobic digesters each of volume 750 litters was used for this research. The dimensions of the digester are width: 88 cm and length: 195 cm. The walls of the digester are 2 mm thick. Two valves one for inlet and other for outlet were connected with digester. One of the digester is shown in the following Fig. 1. The schematic diagram is given as in the Fig.2.

The inlet valve was used for feeding while outlet valve used for withdrawal of digestate. There are two valves for biogas on the upper portion of the reactor. One of the valves was linked with gas pressure meter and other was joined with gas meter with the help of gas pipes. The ISE50-02-62L gas pressure meter was used. The daily biogas was temporary collected in the upper part of the digester which was well sealed. All the valves were closed tightly with screw caps. A temperature probe with temperature range of -30^{o}C to +55^{o}C with accuracy $\pm$1 were used for measuring the temperatures of ambient air, the digester, surrounding soil and slurry mixing tank. A DC motor stirrer of 1000 rounds per minute was also fixed in the reactor for mingling the digested slurry as shown in Fig. 3. The length of the stirrer was 40cm. It was tightly connected with the digester by screw.

Fig. 1. *A 750L biogas digester*

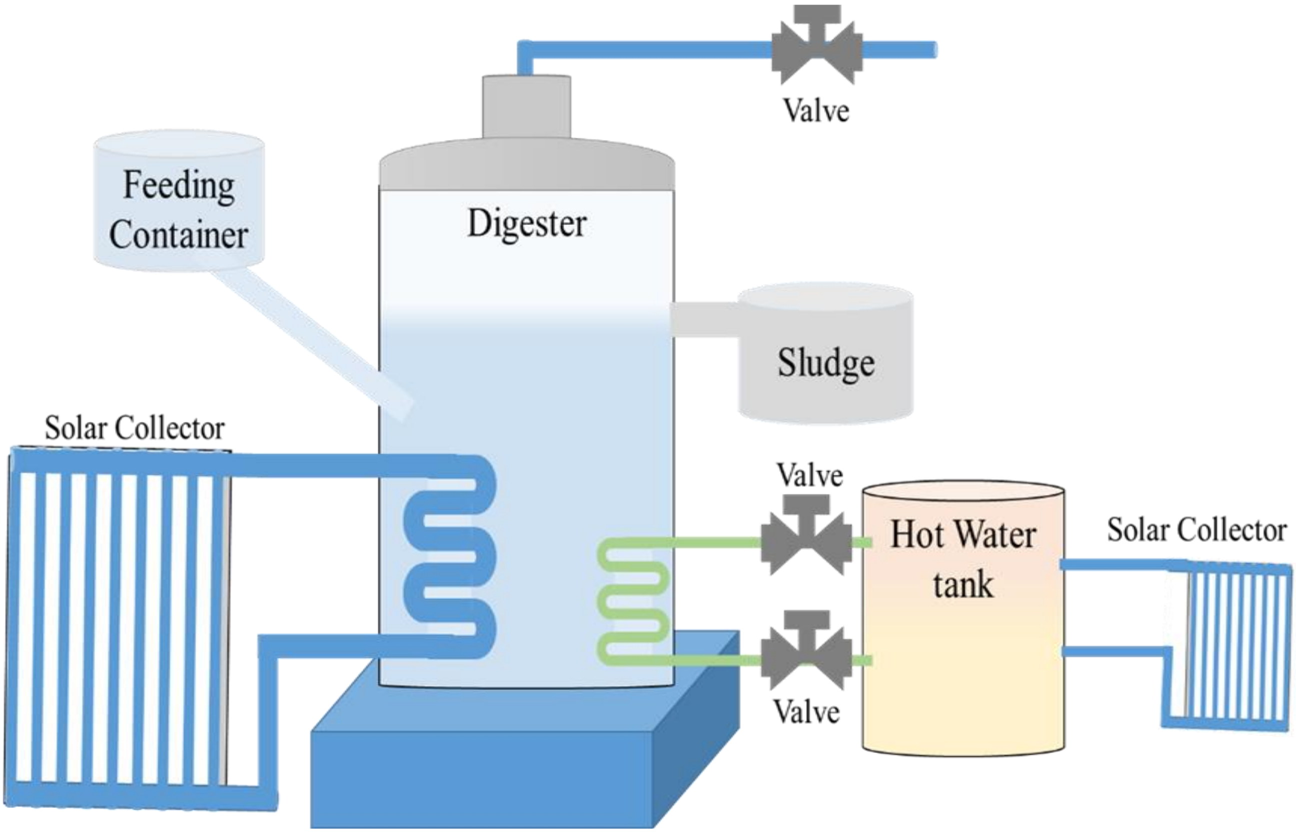

Fig. 2. *Schematic of experimental setup*

Fig. 3. *A DC motor stirrers*

The solar heating system consists of two flat plate thermal collectors each of 2m^2 area and 24^o slope is there for each collector. The spare hot water tank is insulated with 0.8mm black woolen cloth. Water is the heat transfer fluid. One of the collector is applied with the digester in such a way that the cold water comes into the below inlet and the hot water flow out through the above outlet of collector. A copper pipe of diameter 0.75 inch and length 50 feet was whirled inside the digester in a circular shape as shown in Fig. 4. Two valves were used for copper pipe in which one was used for outlet and other was for inlet of hot water.

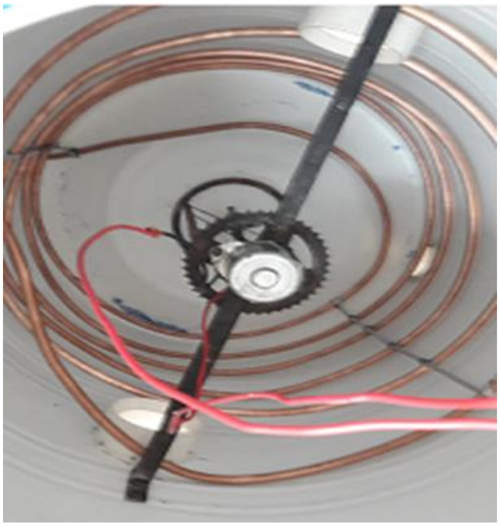

Fig.4. *Inner view of digester with copper coil and stirrer*

The purpose of the collector is to enhance the temperature of the bio digester in cold weather in colder area. This heating system of digested slurry by solar collector is activated automatically when the difference of temperature between output of collector and slurry of digester passes 6^{o}C and the temperature of digester is less than 35^{o}C. When these situations occur the hot water circulates through copper coils which are whirled inside the digester. The digester was placed vertically at a plane piece of wood above earth at 10 centimeters. Water was pumped through the digester to test for leakage before using it for experiment. The digester was insulated by black woolen cloth at night time. A flat plate thermal collector was also applied with digester.

2.2. Feedstock and operating conditions

The initial feeding stock was 400 L slurry of 50% fresh cow dung and 50% of water with 2% dry matter accounting for almost 60% of digester volume was poured into the digester for day 1 of the experiment. The system was left for 10 days to develop microbial community inside the digester. 3kg food waste with water was filled into the digester daily. The cow dung used for this experiment was collected from a farm where the cows were kept in an open cow house. A sample of cow dung was collected for dry matter (DM) finding. A separate mixing tank was also used for storing of cow dung slurry to feed into the digester. The pH of the slurry was determined by OHAUS-ST10 pH meter. The volatile solid (VS), dry matter, total nitrogen, total ammonia nitrogen, volatile fatty acids (VFA), crude fiber (CF) and crude lipid were determined. The temperature of the digester was measured at three different position of the digester that is at middle, bottom and below the surface of digested slurry. Food waste is obtained from different hotels of the city. The different indigestible materials like egg shells, plastic, bones, etc. are removed from food waste. Food waste is cooked rice, potatoes, vegetables, chicken and meat. Then these food wasted materials are chopped to the size of 12mm and filled it into the digester.

3. RESULTS AND DISCUSSION

The main aim of this research work is to utilize the ability of solar radiations via solar flat plate thermal collector to maintain the temperature of digester in winter. The optimal temperature for the production of biogas is 35 ± 2 [11]. In winter, the average temperature of the digester decreases with ambient temperature causes low production of biogas. In this research two methods were used: Using a solar collector to circulate hot water through the digester and without solar collector. The data from these two techniques were compared with each other. The light intensity and atmospheric temperature were measured. The tendency of light and temperature for both methods were same. The intensity of light and air temperature for both methods was similar. That confirms the amount of solar radiations for both methods are identical. Therefore the variance in the yielding of biogas is improved only by method of utilizing of solar radiations to heat up digested slurry. The composition of the gas and pH of the digested slurry was studied and recorded in table 1. The pH value of digested slurry for the production of biogas was in the range of 6.9-7.2. It was also observed that pH value for both methods were at moderate level. For the activity of bacteria, this natural pH value is applicable. The composition of the biogas was analysed during the experiment and recorded in table 1. From this recorded data it was cleared that using flat plate thermal collector, the methane gas was yielded (58-61%) while without collector it was (53-56%). The % composition of other components of biogas was also recorded in table 1. As the organic matter was used as a feeding material in this research therefore the proportion of hydrogen sulphide (H_2S) was very low. The high % proportion of hydrogen sulphide (H_2S) could damage metallic parts of bio reactor [13].

A comparison of different components of biogas, total amount of produced biogas and pH value of the two methods were studied and recorded in the following table 1.

Table 1. *A comparison of biogas composition with and without solar collector*

Experimental Conditions	CH_4%	CO_2%	H_2S%	N%	pH value	Total biogas (L)
Using flat plat solar collector	58-61	30-39	0.4-1	2-9	6.9-7.4	2954
Without solar flat plate collector	53-56	36-44	0.4-1	2-10	6.9-7.4	856

Temperature of the slurry at different positions of digester with and without solar collector was recorded as shown in the Fig. 5 and Fig. 6. The temperature of the digester was measured at three different positions; just under the surface of slurry, middle and bottom of digester. Figure 5 shows the temperature at bottom of the digester. When solar collector was used, the temperature was in the appropriate range but it was lower than optimal range without solar collector. The solar collector continuously maintained the digester temperature from 7:00 am to 6:00 pm directly. From 7:00 pm to 6:00 am the slurry was heated by spare heated hot water tank. Figure 6 shows the calculations of slurry temperature recorded at the mid of the slurry of two methods. Figure 7 shows the temperatures of two different methods (connecting thermal collector and without connecting) under the surface of digested slurry. It cleared from the recorded results that using flat plate solar collector heating system via copper pipes is the suitable method to maintain the temperature of digested slurry a long time in the optimal range of temperature. Temperature of digested slurry was strongly affected by solar radiations and temperature of air. When air temperature increased consequently the digester temperature was increased. After comparing the air temperature with internal temperature of the two methods, the temperature of the digested slurry of each method was studied.

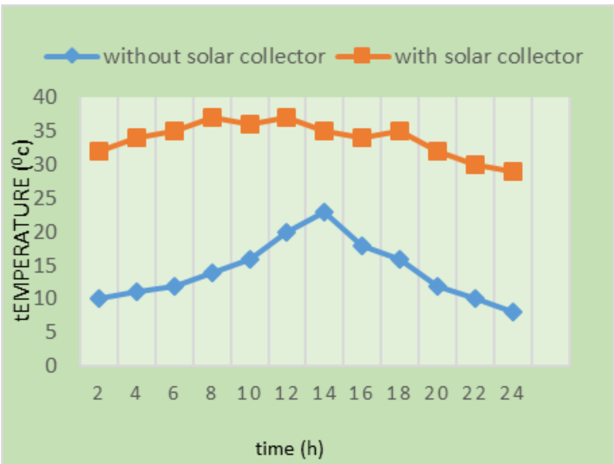

Fig. 5. *The temperature of digested slurry at bottom of digester*

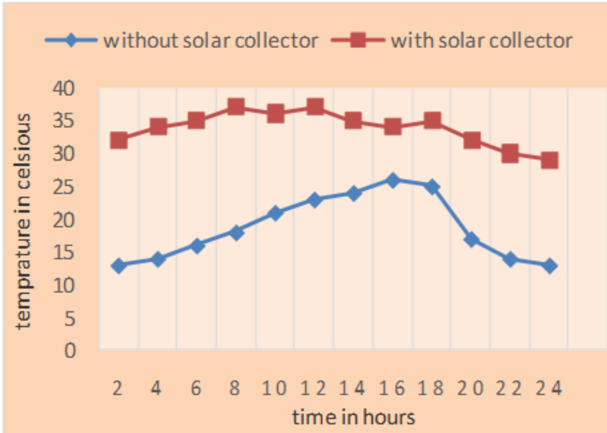

Fig. 6. *Temperature of slurry at mid of the reactor*

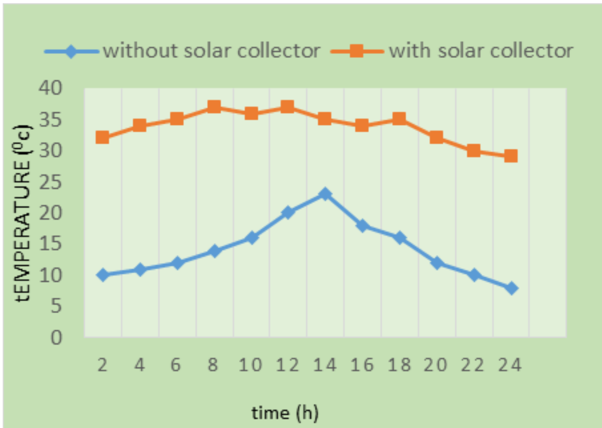

Fig. 7. *Temperature of slurry under the surface of slurry*

The technique of heating digested slurry by solar flat plate thermal collector could increase the temperature of digested slurry from 19 to23ºC during the winter season. The comparison of temperatures of two techniques are recorded in the following table 2.

The fermentation process of organic waste inside the digester was increased with heating by solar collector. As in solar heating process the temperature was in proper range for a long time, therefore this technique is more effective for convert organic compound (COD) removal. The COD removal was higher in solar collector heating system than without solar heating. It was 72.4 % in solar collector but 68 % in without solar collector. The COD removal and methane fraction of two methods are illustrated in the following figures 8 and 9 respectively.

Table 2. *A comparison of change in temperature by applying thermal collector.*

Experimental conditions	December	January	February	March
Without solar collector (°C)	16	11	10	13
With solar flat plate collector (°C)	36	34	33	35

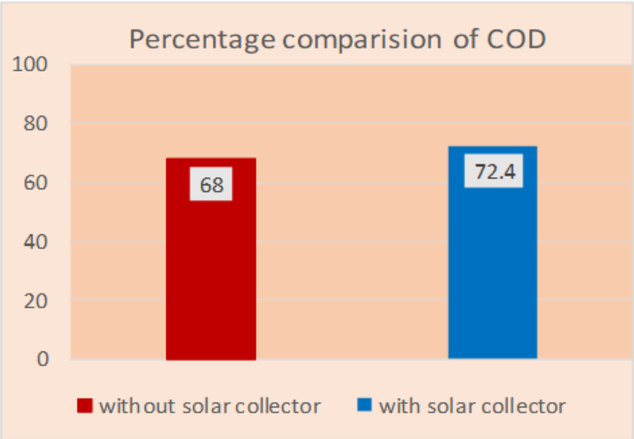

Fig. 8. *A percentage comparison of COD removal of two techniques*

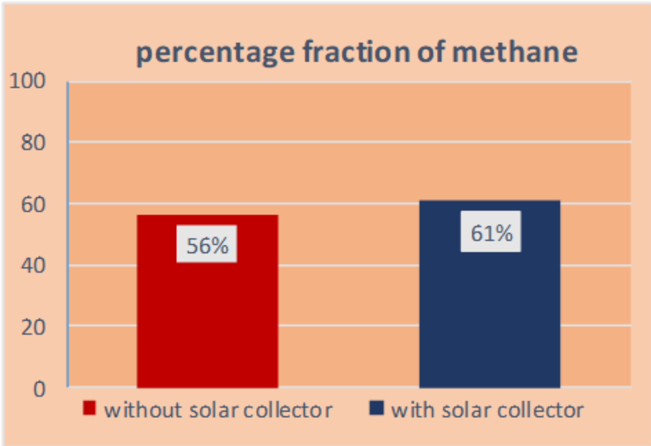

Fig. 9. *A diagram of fraction of methane for two methods*

The comparison of daily produce biogas for each method was recorded in the following table 3.

Table 3. *Production of daily biogas of two techniques.*

Days	1	2	3	4	5	6	7	8	9	10	Total Bio-gas
Non solar collector (L)	20	36	30	60	100	110	130	114	130	126	856
Solar collector (L)	200	300	300	300	300	300	354	300	300	300	2956

According to these results using of solar flat plate collector could conveniently activate the bacterial activity inside the digester. Biogas produced due to this method was greater than without using solar collector because this method maintained the optimal temperature of slurry inside the digester continuously for long time. This means that bacteria are allowed to decompose the organic matters effectively and continuously for the whole experiment [14]. In the case of production of biogas without using solar collector, the temperature of digested slurry was in the lower range of optimal temperature for bacterial activity. Therefore the production of biogas was low. For the decomposing of organic materials during this condition as compared to using solar flat plate thermal collector, the bacteria took longer time. Using of flat collector was more effective to reduce the retention time and to enhance the production of biogas. This confirms that to heat the digested slurry by solar flat plate collector increases the ability of removal of organic waste and allows the quicker immersion of organic waste for following round. A comparison between the yielded biogas with using solar heating and without solar heating methods as illustrated in fig. 11 cleared that the synthesizing of biogas was utmost by heating solar flat plate thermal collector. By using this technique, the amount of produced biogas was 2954 L that was 3.5 times higher as compared to biogas produced without heating by solar collector. The amount of biogas produced by without heating method was 856 L. The comparison of synthesized biogas of two methods is illustrated in the following Fig. 10.

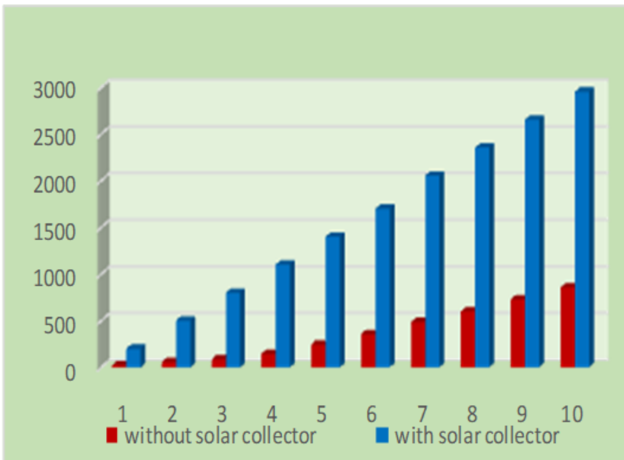

Fig. 10. *Amount of produced biogas of two experimental methods*

4. CONCLUSIONS

Time of the year strongly influenced the temperature of air which affects the temperature of slurry inside digester. Temperature of the digester was affected by the temperature of month. The main purpose of this research is to examine the ability of using radiations of sun for maintaining temperature of digested slurry of 750 L digester to get better production of biogas in winter. This approach of raising temperature consists of two solar flat plate thermal collectors each of $2m^2$ area and 200L spare hot water tank for water storage. The temperature of the slurry was enhanced by circulation of hot water via a copper pipe of diameter 0.75 inch and length of 50 feet. This approach maintained the temperature of the digester within the optimal range of 35 ± 2 °C in winter in colder area. The collected amount of biogas without solar collector was 856 L and that by using solar flat collector was 2954 L. Therefore accumulated biogas by solar heating method is 3.5 times higher than without solar method. This confirms that the use of solar flat plate collector to enhance digested slurry temperature is the most useful approach for production of biogas in colder area in winter. Moreover, from the study of composition of biogas it was confirmed that methane had highest quality by solar heating method. The produced biogas contained 58-61% CH_4, 30-44% CO_2, 2-9% N and 0.4-1% H_2S. The pH value of digested slurry for the experiment was under the range of 6.9-7.2. The COD removal was in highest percentage using solar heating method as the optimal temperature was continued for a long time. It was 72.4 % and in the case of without solar collector it was 68%. The results of this research represent only the period of winter in colder area.

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