Outdoor testing of an evacuated tube closed two phase thermosyphon solar water heater charged with Nano-fluid

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Abstract. This paper reports the performance of two types of evacuated tube heat pipe solar water heater systems that have been experimented outdoors under the local meteorological conditions of the capital of Iraq. Tests were conducted using two systems made of the same materials but with different design specifications. To build each of the two trail system, a single evacuated tube to two phase thermosyphon is used to make the investigation of the experiments simpler. With the absence of loading conditions, experiments with the first system were conducted. Graphene water Nano-fluid (GW) was used as the working fluid in this system. The water storage tank system capacity was varied, to analyze the performance for different storage capacity. The system was operated with a flat reflector plate and without this reflector. A modified second system was built with a longer evaporator section for higher performance and with tank that enables hot water removed from it. The hot water from the storage tank was withdrawn intermittently and continuously. Graphene water (GW),Graphene acetone (GA) and distilled water (d-W) were used as the working fluids in this second system. Energy stored at the water storage tank and overall efficiencies were calculated and found to be comparable to those obtained using natural circulation solar water heating systems. A comparison between the obtained Results and other works was made. The comparison showed that the present systems were just as good in performance. An improvement in the overall efficiency was found when operating the system under load conditions. This improved value is about 10% higher than that without load condition.

Keywords: Solar two phase thermosyphon, Solar Evacuated tube water heater, Two phase thermosyphon with Nano fluid,
1. Introduction

Since the eighteenth century, scientists and engineers have been interested in the use of solar energy for water heating systems. (CTPT) is able with a very small temperature gradient to transfer high rates of heat [1]. Compared to the more conventional flow absorber, a (CTPT) absorber has many advantages in a solar collector system such as superior freeze tolerance, less parasite pumping demands, a thermal diode benefit, where heat loss is minimized when the collector temperature is less than ambient [2]. The evaporator end of a heat pipe was first inserted in a flat plate collector by Bienert and Wolf using one of the early solar water applications [3]. A number of experiments were carried out to include the heat pipe in collectors [4, 5, 6] but the results were not certain or promising [4]. Bairamov and Toiliev [7] conducted experiments on two type solar water heating systems, namely, with and without heat pipe. Experimental results on a model converted into a solar collector with and without a heat pipe, shows that at the end of water heating period in summer, the water temperature in the storage tank of the System with a heat pipe is (10 - 11 °C) higher than that without a heat pipe. They mentioned, the diode effect being the cause. Akyurt [8], designed, and manufactured heat pipes incorporated into a prototype solar water heater developed for this purpose, and was tested under actual insolation conditions. It was observed that the heat pipes perform satisfactorily as a heat transfer element in solar water heaters. Number of the heat transfer factors of a heat pipe absorber array connected to a common manifold were analyzed by Hull [9]. It was shown that the number of absorbers and the heat transfer rate at the condenser were key factors in determining array efficiency. Georgier [10] presented a mathematical simulation for a vacuum solar collector with a heat pipe. Hammed [11] described the performance of a flat plate solar collector cooled by a set of heat pipes designed and manufactured locally to work at low temperature conditions equal to that of the flat plate solar collector. Chun, et.al [12] conducted a series of tests on solar domestic hot water systems manufactured with heat pipes. Results showed interesting performance data stemming from the difference in the working fluids, presence of a wick, and other various design parameters associated with the collection and utilization of solar energy. Ismail and Abogderah [13] carried out a comparative study between theoretical prediction and experimental results of a flat plate solar collector with heat pipes. Lima and Palanyana [14] described the experimental behavior of a flat plate solar collector with heat pipes and selective surfaces. It was observed that the thermal degradation of energy absorbed and the climate conditions influence the overall energy loss coefficient. However, their losses are comparable to the other devices produced for the same purpose. Corliss et.al [15] conducted a detailed study of a heat pipe augmented passive heating system with different kinds of heat pipes made of different pipe materials, with different working fluids and collector configurations. Lu, et al. [16] fabricated an open thermosyphon system with an evacuated tube collector to reach a high temperature. They concluded that the evaporating heat transfer coefficient was increased by about 30% compared with deionized water. Senthil kumar et al. [17] designed a two identical solar collectors with a flat surface water was the working fluid in first collector, while CNT-water Nano fluid was in the second system. They concluded that the collector charged with Nano fluid is better compared with that with purr water. Nh.Mujawar and S.M.Shaikh [18] designed and developed an evacuated heat pipe solar water heating systems using Nano fluid. It was found a marked rise in the collector efficiency using nano fluid. Sumeh S. Jagtap et al [19] made an experimental investigation of evacuated tube two phase thermosyphon charged with copper oxide Nano fluids. They found that the collector charged with Cuo is 20% more than purr water in term of transfer capacity and heat absorption.

Most of the above studies were conducted without removing the hot water from the storage tank of the solar heat pipe system. In this study a complete solar water heater, utilizing an evacuated tube two phase thermosyphon, was developed and tested under actual insolation conditions. Two systems were tested outdoors. The performance of both systems was investigated experimentally. Experiments were carried out on the first system with different amounts of water in the storage tank and with and without a flat reflector. Experiments on the second system were conducted with and without hot water removal out of the storage tank. Hot water withdrawal was continuous and intermittent. The objective of the present work is to investigate the performance of an evacuated tube two phase thermosyphon solar water heater under various operating parameters with and without load.
1.1 System Description

Experiments were carried out with two solar water heater systems made of the same materials but with different design specifications. To build each of the two trial system, a single evacuated tube to two phase thermo syphon is used to make the investigation of the experiments simpler. The first system was basically a solar water heater utilizing the evacuated tube heat pipe technology with no hot water removed from its storage tank. This system consisted of Pyrex glass evacuated tube of (100 cm) length and (5 cm) outer diameter. The heat pipe was 22 mm in outer diameter a 20 mm inner diameter, and 1270 mm-long. The heat pipe was installed inside the glass tube. A wick is built of enfolded screen wick of 100 mesh size. The length of the evaporator is 1000 mm, the length of the adiabatic is 70 mm, and the length of the condenser is 200 mm. Part of the heat pipe called the condenser portion is directly inserted into the storage container as shown schematically in Fig. 1. Graphene–Water GW was used as the working fluid in this CTPT. The system was operated with a flat reflector plate, and without this reflector. With the reflector the collector receives radiation heat from the back as well as the top of the absorber surface. This effect was pioneered by Owens-Illinois [16]. It is achieved by using a highly reflective aluminium sheet surface behind the assembly to illuminate the rear surface, as shown in Fig. 1.

Figure 1: Schematic diagram of the solar collector heat pipe
Figure 2: Evacuated tube heat pipe solar.

Collector details.
2. Manufacture and Assembly

The solar collector tested in the present trial system is shown in Fig. 1. A conventional tubing and piping with a 22 mm nominal diameter was chopped to (1270 mm) length. Ends caps were of copper and were mechanically modified in a way allows them to go inside the pipe. The condenser end cap was drilled providing the necessary access for the charging tube. All CTPT components were cleaned thoroughly before assembly with a series of chemical and mechanical processes to remove all possible contaminates. A rig was specifically built to charge the heat pipe on. After filling operation, the filling tube was crimped. Then, the excess tube was clipped off and brazed which would lead to producing a heat pipe. Paint was used to cover the area exposed to sun of the evaporator section. The evaporator section was then installed within a glass envelop forming a collector with its ends closed by two conical rubber stoppers as shown in Fig. 2. The stoppers were modified by a machine in a way that allows them to fit in the evacuated glass tube. The top end was drilled providing the necessary access holes. The centre hole was used for the insertion of the heat pipe tubing, while the other was used for drain tube. The drain tube has a vacuum shut-off valve to subject the glass tube to a vacuum after coupling it with vacuum pump. The complete solar collector was supported by a steel stand with a tilt angle of 45℃ facing south as shown in Fig. 1. The water storage tank of the system was fabricated from a galvanized steel of 0.6 mm thickness and measuring 0.11m * 0.15m*0.325m in size, and it can contain 5L of water. Fig. 3 shows a schematic cross-sectional diagram of the water storage tank with tank accessories. To minimize heat losses to the environment, the storage container of the water was surrounded with 3cm thick glass wool insulation placed between the tank outer surface and the outer covering made of aluminium sheet with 1 mm thickness. The storage tank included a hole in the lower part through which the condenser portion of the heat pipe was inserted directly through a rubber stopper. The mains cold water inlet and hot water outlet of the storage tank were position as shown in Fig. 3. Cold mains water enters from the bottom side of the storage tank and hot water leaves from the upper opposite side through a 5mm copper tube. The copper tube was drilled for a temperature sensor.
The water storage tank was supported by a steel stand Fig. 3. The water storage tank was instrumented with three thermocouples were located inside the storage tank and two in the inlet and outlet for water temperature measurement. The three thermocouples were distributed into a vertical centreline probe, to determine the distribution of the temperature distribution along the height of the tank. The probe shown in Fig.4 was made of a copper tube 5mm in diameter with holes drilled in its outer surface used for inserting the thermocouples wires. The complete solar collector system was supported by a steel stand with a tilt angle of 45° above the horizontal facing south. This inclination angle was chosen to provide approximately the optimum performance of the heat pipe and highest heat transport rate [17]. In addition, it symbolizes a decent wintertime tilt angle for solar collectors in the capital of Iraq where the latitude angle is 33°N. Fig. (4a) typical solar radiation intensity during a sunny day.

3. Test Procedure

Experiments were carried out with two solar water heater trial systems with different design specifications. With the purpose of gaining usual everyday data with perfect skies, test measurements were conducted on sunny days. The trials were conducted in May, June, July, and August 2019. The experimental preparation and test procedure of each system is described below:

3.1 Solar CTPT system.

The performance of the first system was conducted outdoors. The solar collector which consisted of a single evacuated tube CTPT inclined at 45°C toward south. G.W was used as the working fluid in the CTPT. The system was tried in steady – state conditions wherein the solar intensity and ambient temperature were assumed constant for a window of time. This window was usually 30 minutes for an operating from 16:00 p.m. till 24 p.m.

At the onset of each experiment the storage tank was filled with a specified quantity of fresh water, the glass tube was cleaned thoroughly; the thermocouple connections were checked for contact. The measuring instruments were switched on. For this system the temperature distribution of the water inside the storage tank was determined by a probe containing three thermocouples. The mean tank temperature was determined from the average experimental temperature data. The same experimental procedure was repeated for each of the different storage capacities and the two different configurations (with and without solar reflector). The temperatures of the storage tanks at the beginning and end of each operation were used to determine the overall collected heat. In this case from 7:30 or 8:00 a.m. till 17:00 p.m. The overall stored heat was given by [18] as:

\[
Q_{ove} = M_1 C_W (T_{mf} - T_{ms})
\]

While the overall or bulk efficiency of the system was counted using the following equation;

\[
\eta_{ove} = \frac{M_1 C_W (T_{mf} - T_{ms})}{\int_0^T A_a(t) dt}
\]

3.2 Solar CTPT system with hot water removal.

In the same manner as in the first trial system, the second trial system was tested out- doors. The system was tested with flat reflector behind the collector and with a fixed quantity of 5 kg of water in the storage tank. The system was tested with and without hot water withdrawn from the storage tank and for different patterns, of hot water-removal. Three working fluids were used with this system namely GW,GA and dw. For the case of water withdrawal from the storage tank, the load was connected to the storage tank such that the cold inlet water entered at the bottom of the tank and the hot water outlet was taken from the top of the tank. The mass flow rate of load water was regulated by a valve at the outlet of the storage tank. The load mass flow rate was measured by timing the water collected in a vessel of 1 litter capacity. The inlet and outlet temperatures of the load were noted simultaneously with the other data. Two types of water withdrawal programs were employed. In the first test, the water was withdrawn intermittently. Three patterns of hot water removal were used with this type of test with two different CTPT working fluids. Limited trials were carried out forcing a big
load on the system in a small period of time to determine the response of the solar collector. Load water in the range from 2.5 litres to 3 litres was removed rapidly from the tank at a 10 minutes period. In this case the average temperature of the water withdrawn from the tank and the temperature of mains water entering the tank were recorded in addition to the other measurements. The overall heat or bulk heat collected by the system with intermittent load conditions was estimated and compared for the different CTPT working fluids which were G.W and G.A. In the second type of tests, the water was withdrawn continuously from the storage tank and for seven different load mass flow rates of water through the tank. These flow rates were (0.5 for 1 I/hr, 2 I/hr, 3 I/hr, 4 I/hr, 5 I/hr, and 6 /hr). In each case, the load usually started at 9:00 a.m. and continued until 17:00 p.m. The overall or bulk heat collected by the system with load conditions was estimated from the following equation [20];

\[ Q_{\text{ave},t} = M_t CW(T_{mf} - T_{ms}) + \int_0^t m \text{ load } CW(T_{out},T_{in,L}) \, dt \]  

(3)

Further simplifications were done to the equation to generate the following form;

\[ Q_{\text{ave}} = M_t CW(T_{mf} - T_{ms}) + M_l CW(T_{out},T_{in,L}) \]  

(4)

Where;

\[ M_l = \sum m_L \Delta t \]  

(5)

\[ (T_{out} - T_{in}) = \frac{\sum m_L (T_{out} - T_{in,L}) \Delta t}{\sum m_L \Delta t} \]  

(6)

Where the System Overall or Bulk Efficiency was determined using the Following Equation;

\[ \eta_{\text{ave}} = \frac{M_t CW(T_{mf} - T_{ms}) + M_l CW(T_{out},T_{in,L})}{\int_0^t I(t) A_d dt} \]  

(7)

4. Discussion of the results:

Experiments were conducted with the aim of evaluating the behaviour of an evacuated tube CTPT solar water heater system. Two systems with different specifications were experienced for the following condition:

| Condition       | First system                  | Second system               |
|-----------------|-------------------------------|----------------------------|
| CTPT working fluid | Graphen-water                  | Graphen-acetone, Graphen-water, d-water |
| Collector inclination angle | 45 degree                     | 45 degree                  |
| Evaporator length | 1000 mm                       | 1200 mm                    |
| Condenser length | 200 mm                        | 200 mm                     |
| Storage capacity | 2.5,3,4 and 5 kg              | 5 kg                       |
| Weather capacity | Clear sky                     | Clear sky                  |
| Load condition   | No load                       | Continuous and intermittent load |

The effect of the various operating factors on the performance of the above systems will be discussed in the following sections. The first experiments were conducted, on the first system, without the reflector. These experiments were ‘carried out in the same weak such that the weather conditions were considered similar. Fig.5 shows a comparison of the increase in the mean tank temperature in the month of May for different storage tank capacity. The trend of variation is similar. The temperature of the mean tank was found to rise with time and reach its highest magnitude at mid-day and then slightly decreases. The difference in temperature is due to the stored water. Also, the figure shows that the maximum mean tank temperature is 65°C for 2.5 kg with a daily temperature increase of 33°C, whereas this maximum is only 55°C for the 5kg storage capacity with a daily temperature rise of 25°C. The maximum mean tank temperature for the other storage capacities lies between those two values. Also it is observed from Fig.5 that, the maximum temperature for water occurs at earlier times with the lower storage capacity. A number of experiments had been carried out through the same month and conditions and it would be tedious and repetitive to show all such results in the form of performance curves similar to those discussed above. An example of this is Fig.6. When a flat reflector is used behind the collector of the solar water heater system as shown in (Fig.1), a slight
increase in the maximum mean tank temperature is noticed for 4 and 5 kg storage capacity when compared to that without reflector as shown in Fig. 7.

This increase in temperature is approximately 4°C for 4kg storage and 6°C for 5kg at approximately 12.00 noon. In order to assess the effect of the flat reflector, Figs. 8 and 9 are plotted for each of two storage capacities of 2.5 and 5 kg respectively. It is clear that for the system with the flat
reflector at 5kg storage capacity shows a higher mean tank temperature than without the reflector. At 2.5 kg, Fig.9, an approximately similar maximum mean tank temperature at 12.00 noon. This is because the maximum possible temperature attainable with this system is limited by the storage even with using the flat reflector. The distribution of tank temperature is a tremendously complex fiction of the delivered energy, the mixing effect and energy losses that the body of water causes at various temperatures. Heat transfer inside the storage tank is essentially controlled by convection phenomena that cause temperature redistribution. Fig.10 illustrates the temperature differences at three positions within the storage tank, of 5kg water capacity, at several times on a standard clear day in May. The natural convection mixing effect within the storage tank is proven and illustrated well and the tank content becomes nearly at the same temperature. Once the mean tank temperature and its rate of increase have been determined, the heat stored at the storage tank can then be calculated employing equation 1 and also the bulk or overall efficiency employing equation 2. The overall heat stored was taken in the period between 9.00 a.m. and 19.00 p.m. Fig.11 shows the daily bulk heat stored as mathematically counted from equation 1. The incident solar radiation intensity was determined by the method of Faber and Morrison [18]. The data points represent actual values. The connecting lines have no physical significance other than connecting the data points. Values of overall heat stored range between 580 kJ for 2.5 ke and 667 kJ for the 5 ke water. The system without flat reflector and 5kg water storage capacity provided a 2.5% higher heat stored than with 4kg storage, 4% higher than 3kg storage and 7% higher than 2.5 kg storage water. This increase in overall heat stored was 4, 9 and 11% for the case in which the system operated with flat reflector. As the system operates with a flat reflector is more advantageous in clear climates. .The overall daily system efficiency for the operating period is calculated from equation 2 and range from 45 to 50%depending on the system configuration and storage tank capacity as displayed in Fig.-12.
Firstly, the CTPT of the second solar water heater system was charged with G.W. in order to compare its results with the “system. Fig. 13 shows the variation of mean tank temperature for the two solar water heater systems. The second system shows a significant increase in the mean tank temperature, the temperature difference is approximately 6°C at 12.00 noon. This improvement is due to the longer evaporator length (larger collector area) of the second system, which enables it to collect and transfer more energy to the storage tank. In order to assess the effect of the working fluid, Fig. 14 shows the variation of the mean tank temperature during the operation period with no load condition for the various working fluids. A maximum temperature difference of 8°C between G.A. and d.W is observed at 12.00 noon. This is because G.A. has a larger value of the overall heat transfer coefficient than G.W. and d.W. [17]. At the end of operating period, the final storage tank temperature was 53.8°C for G.A., 52.6°C for G.W and 49.2°C for d.W. Fig. 15 shows the variation of calculated bulk heat stored during the operation period for the three working fluids. For the effect of load condition on the system performance to be shown, trials were conducted while withdrawing hot water from the storage tank during the operation period. The hot water withdrawn was taken intermittently and continuously. The first load pattern of hot water withdrawn from the storage tank is shown in Fig. 16 was suggested by reference [19]. Fig. 19 shows the variation on mean tank temperature, load outlet and load inlet temperature during the operation period. The system is observed to operate at a lower temperature than that without load. Also Fig. 19 shows that the mean tank temperature and the load outlet temperature are increasing throughout the period between 8.00 a.m. and 14.00 p.m., which indicates that the energy transferred to the water in the storage tank, is higher than that carried out by the load water. A maximum temperature difference. Of 2°C between mean tank temperature and load outlet temperature is also observed. These temperatures start decreasing after 14.00 p.m. This is because the useful energy transferred to the water storage tank is lower than the heat carried away with the load water. The overall bulk efficiency was calculated to be 53% for this continuous load condition. This value is 5.6% higher than the value for no-load condition. It can be concluded that the overall bulk efficiency improved by operating the system under load conditions. The second load pattern of hot water withdrawal is shown in Fig. 17 which was suggested by reference [20]. Fig. 20 shows the variation of mean tank temperature with load condition. The load was taken for an hour and half starting from 8.00. Till 9.30 am. At 12.00 noon water was withdrawn at intervals of 1/4 an hour starting from 12.00 noon till 13.30 p.m. It is clearly observed from Fig. 20, that the mean tank temperature does not increase smoothly between 12.00 noon and 14.00 p.m. This is of course is due to the introduction of fresh cold water to the tank. During the period between 14.00 p.m. and 17.00 p.m., it is noted that the fluctuation in mean tank temperature diminishes because of the large interval of time between loading and unloading. However, the rate of increase of the mean tank temperature is small compared to that obtained with no load condition.
Fig. 21 shows the variation of mean tank temperature during the operation period: with a 3rd pattern of intermittent load condition as shown in Fig. 18. A relatively large volume of hot water was withdrawn from the storage tank at relatively short periods of time. It is seen in Fig. 21, that the increase in the mean tank temperature is not uniform between 9.00 a.m. and 14.00 p.m. The system shows a good response to the large load variation of hot water withdrawal. Also, it is observed that the rate of increase of mean tank temperature is lower compared to that obtained with no load condition.
Fig. 22 shows a comparison of the overall bulk heat collected in the load patterns and that collected with no load condition. The heat stored is observed to be higher with loading. Loading pattern no.2 appears to give the best results in terms of heat stored. The preceding discussion shows that the variation in system performance is mainly dependent on the flow rate of load water. However, this effect is not very clear. Therefore, it was decided to test the system with differing constant continuous loads. Hot water withdrawal was carried out between 9.00 a.m. and 17.00 p.m. in June and July 2004. at the 2 flow rates of 0.5, 1, 2, 3, 4, 5 and 6 L/hr. All three working fluids were used with this continuous loading. Figs. 23, 24 and 25 show the system performance for each of the three working fluids with the seven loading conditions. These figures show that a higher loading resulted in the system operating at a lower temperature. Consequently, the hot water removal rate also affects the overall heat collected. It is observed that, G.A. shows a higher mean storage tank temperature than G.W. and d.W., resulting in a higher overall heat stored. This is clear depicted in Fig. 26. However, for water, there is a trade-off between the benefit of large hot water removal rate and loss of performance due to low overall heat transfer coefficient of the CTPT as we will see in the following discussion. It is seen from Fig. 26, that in the range 0.5 to 4 L/hr all working fluids show a significant increase in the overall heat collected. This is because increasing the rate of hot water removal resulted in decreasing the storage tank temperature, which in turn decreases the heat losses from the storage tank. However, for water and for rates higher than 4 L/hr a substantial decrease in overall heat occurs. Whereas, G.W. and d.W maintain approximately constant values. This behaviour is due to the effect of the overall heat transfer coefficient of the CTPT with these fluids. The reduction in the overall heat, for water, is thought to be caused by the lower overall, heat transfer coefficient of the CTPT at lower operating temperature. G.W. and d.W render approximately constant overall heat transfer coefficient with variation in operating temperature [17]. Therefore, there is an optimum value of hot water removal rate with water at. Which the overall bulk heat is maximum. Fig.27 shows the variation of calculated. Overall daily system efficiency as a function of hot water removal rate for the experimental working fluids. The rate-of hot water removal at which the maximum system efficiency occurs is 4 different for different working fluids. It is observed that the overall bulk system efficiency follows the variation of the bulk heat collected by the system. Fig.27 shows that, for water, the overall bulk efficiency reaches its maximum value of 61.2 at approximately 3 to 4 L/hr hot water removal rate. It is also observed that at high hot water removal rate there is a slight decrease in the overall efficiency resulting from the reduction in the bulk heat as was shown in Fig. 26. However, the bulk efficiency of G.W. and d.W are less sensitive to the variation of hot water removal rate with maximum values of 55% for G.W and 47% for d.W at approximately 5 L/hr hot water removal rate. In this study, the mean tank temperature distribution is similar in trend to the works of Akyurt [8] and Chun [12]. As illustrated in Fig. 28. However, the peak value is vary which is caused by the difference in design requirements of the present work as compared to that employed by the above workers, direct comparison between mean tanks temperature alone is not really valid. As a result of the above discussion, comparison can be made only for the overall bulk efficiency of the current system with those deduced from the available literature. Table 1 below shows the overall bulk efficiency obtained with the conditions listed for this work and the works of Akyurt [8] and Chun [12].
Figure 23: The variation of tank temperature with for various hot water removal rates

Figure 24: The variation of tank temperature with for various hot water removal rates

Figure 25: The variation of tank temperature with for various hot water removal rates

Figure 26: The effect of hot water removal rate on the overall heat various working fluid

Figure 27: The effect of hot water removal rate on the overall bulk efficiency for various working fluid

Figure 28: variation of tank temperature for various investigator
Table (1) overall bulk efficiency of some solar heat pipe system

| Load condition | Design specifications | overall efficiency (%) |
|----------------|-----------------------|------------------------|
|                | Collector type        | Le (m) | Le (m) | Working fluid |                |
| Present work   | Evacuated Tube CTPT   | 1.2    | 0.2    | G.W           | 48%            |
| Continuous     | Evacuated Tube CTPT   | 1.2    | 0.2    | G.A           | 61%            |
| Reference [8]  | Flat Plat CTPT        | 2.1    | 1.2    | Ethanol       | 52%            |
| Reference [12] | Panel Type Flat Plat  | 1.7    | 0.2    | Ethanol       | 45%            |

5. Conclusions

Several essential conclusions can be drawn from this study on the single evacuated tube solar water heater system.

1. The maximum value of the mean tank temperature and the overall bulk heat stored depend mainly on the storage capacity.
2. The larger evaporator length system, the higher maximum mean storage temperature and a higher bulk heat stored is obtained.
3. For no load condition, the system performance was found to be similar for both G.A. and G.W. working fluid, whereas d.W shows relatively a slight reduction in system performance.
4. Through the operation period, the system with constant continuous load has shown unchanging temperature distribution in comparison with intermittent load condition.
5. The system has a good response and it is sensitive to the large variation in the hot water removal rates.
6. The overall bulk heat stored of the system improves with operating under load condition.
7. In the range of study, the overall bulk heat collected of such system depends on the rate of hot water removal.
8. The performance of the system charged with water is maximized when the daily hot G.A. removal rate is approximately equal to 3-4 W/hr.

6. Nomenclature

| Symbol | Definition |
|--------|------------|
| Aa     | Absorber area [m²] |
| C_w    | Specific heat of water [kJ/kg °C] |
| I      | Solar radiation intensity[W/m²] |
| T      | Temperature [°C] |
| Tmean  | Mean Temperature [°C] |
| m      | Mass flow rate [kg/s] |
| Mt     | Mass of water in the storage [kg] |
| Q      | Heat collected [kJ] |
| GW     | Graphen - water |
| GA     | Graphen – aceton |
| d-W    | Distilled Water |
| CTPT   | Closed tow phase thermosyphon |
| η      | Efficiency % |
| mf     | End temperature (°C) |
| ms     | Start temperature (°C) |
| L      | Load |
| out,L  | Outlet temperature of load water (°C) |
| in,L   | Inlet temperature of load water |

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