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Experimental Study to Evaluate the Performance of Flat Plate Solar Collector with Natural Circulation

Dr. Jamal H. Waheb
Lect. Mechanical Engineering Dept., University of Anbar, Iraq

Abstract
In this research, a practical study was carried out on a flat plate solar collector covered by transparent layer faced toward the south and tilted 30^o from horizon. The collector is low cost and simple design with 170 litters volume capacity. The collector works according to the natural circulation phoneme where the flow occurs due to the differences in water density. The practical data were collected for Baghdad (33.3^o N, 44.3^o E) during the period 15 Sep – 31 Dec 2007. The performance of solar collector had evaluated for various conditions and water demands. The obtained data show confident results. It is noticed that the maximum temperature of the water on 15 Dec could reach (43^{o}C) where the inlet temperature was (18^{o}C). Based on that, the using of mentioned collector is reliable and applicable to supply domestic hot water in conjugation with auxiliary heater.
Keywords: Solar Collector, Natural Circulation, Hot Water, Renewable Energy

1. Introduction
The solar energy is an inexhaustible source of energy can be exploited to solve the energy problems in the world especially with the rapid decline of the index of global oil reserves and the increasing of energy demand for traditional industries. In Iraq, interest is appeared to invest the solar energy, where there is about (3600 hours) of solar radiation annually (Bishir & Ibrahim 1984). Hence many studies were carried out in research centres and universities. These researches have been focused on electricity generation, desalination of water, distillation and air-conditioning. Solar water heaters are the simplest of solar energy applications and the most widespread at the present time.
This research is focused on the using of solar collectors to supply domestic hot water. Solar collectors are usually designed to rise the water temperature up to (100^{o}C) using means of simple technology and inexpensive by the benefit of both direct and diffuse radiation without the needing of track system or maintenance mechanism (Duffe &Beackman 1997). That simple solar collector is made of black absorber plate to absorb maximum radiation and transform it into heat to the circulated fluid then used for domestic application or stored. Some of the gained heat could be lost out to the atmosphere. Therefore, a good insulator is needed from the bottom and sides of the collector. The glass covering is required to ensure greenhouse effect.

2. Review
Several studies have been done by Iraqi researchers within the last years. (Nihad 1989) had presented a computational program to analyze the thermal performance of a solar heater designed to satisfy Iraqi ambient conditions. The collected data and the mathematical model are converted to a simple program. Numerical and experimental study had done by (Wisam 2004) to simulate the behaviour of solar receiver of prismatic shape and triangular Section. The testes were done using 190 litters heater. The performance of solar collector had evaluated for various conditions and water demands. The results show that the maximum temperature of the water on 15 Feb could reach (44^{o}C) where the inlet temperature was (16^{o}C). An experimental test by (Amer A. 2005) was illustrated to study a portable type of solar heater in Baghdad. The rectangular PVC solar collector has the dimensions 58 cm x 87 cm and tilted 30o with the horizon. The study showed the possibility of using such type with the demand of an auxiliary electrical heater.

3. Experimental Work
A flat plate solar collector was used in this study and covered by transparent layer faced toward the south and tilted 30o from horizon. Some modifications were done on this device in order to satisfy desire requirements and conditions. Figure (1) shows a schematic diagram for the mentioned device, while figure (2) shows the actual view. The collector consisting from the main following parts:
The Core: This part of the solar collector is consisting of ten riser tubes made from aluminium, each has 1.5 cm ID and 2 cm OD, a header tube of 2.5 cm ID and 3 cm OD collects them. The tubes are welded by an absorber aluminium plate with 115 mm apart for each couple of tubes. Silver wires were used for welding due to the high thermal conductivity, low melting temperature and keep the absorber plate from any contact damage. The absorber surface coating by a matte black paint has absorbency of 0.96 and emissivity of 0.81 (Khalifa & Mehdi 1999).
Insulated Case: The case is used to contain the absorbed plate and tubes and keep the heat gained by insulating from back and edges by 5 cm of rock wool. The headers are insulated also to decrease heat loss.

Glazing Cover: A glass panel of 4 mm thickness is used to cover the collector, and a tape of rubber material is used along the edge of the glass to prevent hot air leakage. The frame that made from aluminium has (L) shape and installed in the front edge of the collector to the provisions of installed glass panel. The clearance between the glass and the absorber plate is 2.5 cm which is the perfect distance (Sabah 1978).

The Holder: The solar collector is installed on a metal holder faces the south to obtain largest amount of solar energy during the day. The collector had installed so that the lower edge is 50cm from the ground. The orientation had identified depending on the sun path, as well as, the appropriate tilted angle according to (Mahdi 1974).

4. Measurements

The experiments were done on the system during the period 15 Sep – 31 Dec, which represents the needing for domestic hot water. Several thermocouples were used to collect the data in many points within the collector. Readings were recorded every hour from 08:00 AM to 03:00 PM, and for several parameters like: ambient air temperature, absorber plate temperature, glass temperature, inlet water temperature and exit water temperature. The research was conducted in two cases; the first case includes checking the performance of the system without any load (without water demand). The second case of the research evaluates the performance for certain load of water.

5. Results and Discussions

Several experiments had selected to evaluate the performance of the solar collector. The obtained results are represented in several graphs showing the behaviour of the parameters. In order to show the results in good manner they are classified into several groups which are:

- **Solar Radiation and Heat Gained**: Figures (3) and (4) clarify the relationship between the intensity solar radiation and the heat gained for both theoretical and actual on various days during the tested period. There is a gradual increasing in the intensity of solar radiation that reaches its highest value at midday and then begins to decrease. Hence, the gained energy is increased gradually in the same manner. The calculated value of the useful energy is less than that obtained experimentally due to heat losses.
- **Accumulated Heat Storage:** The stored energy is a key function of the useful solar energy and it is a function of the average temperature of the water inside the tank with the conjugation of other parameters. Figure (5) shows that the amount of stored energy is in a continuous increase during the probationary period depending on the water temperature increase rate.
- **Variation of Water Temperature:** The temperature of the water rate is an important variable in determining the solar collector efficiency. Figure (6) illustrate the solar collector water temperature rate change during the daylight hours. It is noticed that, the average water temperature in a continuous increase until the end of the experiment (in the evening), which is identical to what mentioned by (Zia 1987) and (Khudhair 1985) in terms of seeking the increasing behaviour but different values as well due to the difference in the collector specifications and weather conditions.

In the current design, the stratified phenomenon is achieve thermal gradient of heat gained since the density difference gives the possibility of withdrawing the required heat from the hot part of the tubes, and add other quantity of new water for part cold from the reservoir and that is what makes solar collector works efficiently. Figures (7) and (8) illustrate the variation of maximum water temperature and the minimum water temperature in the reservoir, respectively. As shown in figures, there is a continuous increasing in the temperature until it reaches the great values at 2:00 PM or 3:00 PM, hence, it is prefect to withdraw the hot water that period and offset new water.

- **Collector Efficiency:** Figure (9) shows the efficiency of the solar collector for both actual and theoretical with the daylight hours in the absence of water loads. It is noticed that the efficiency is low during the first hours of the day because of low solar radiation and heat losses at this time, and then begins to increase by the time as thermal energy accumulated and heat losses decreasing. The actual efficiency of the collector is less than the theoretical efficiency due to extra heat losses and unexpected declination in solar radiation as well.
- **Rate of Water Demand:** Figure (10) shows the effect of the rate of water withdrawal during daylight hours on the collector efficiency. Different amounts of water are withdrawn, usually after 1:00 PM. It is noticed increasing in daily efficiency gradually with the rate of withdrawal of water from the reservoir, because of accumulated heat and stable highly water temperature.

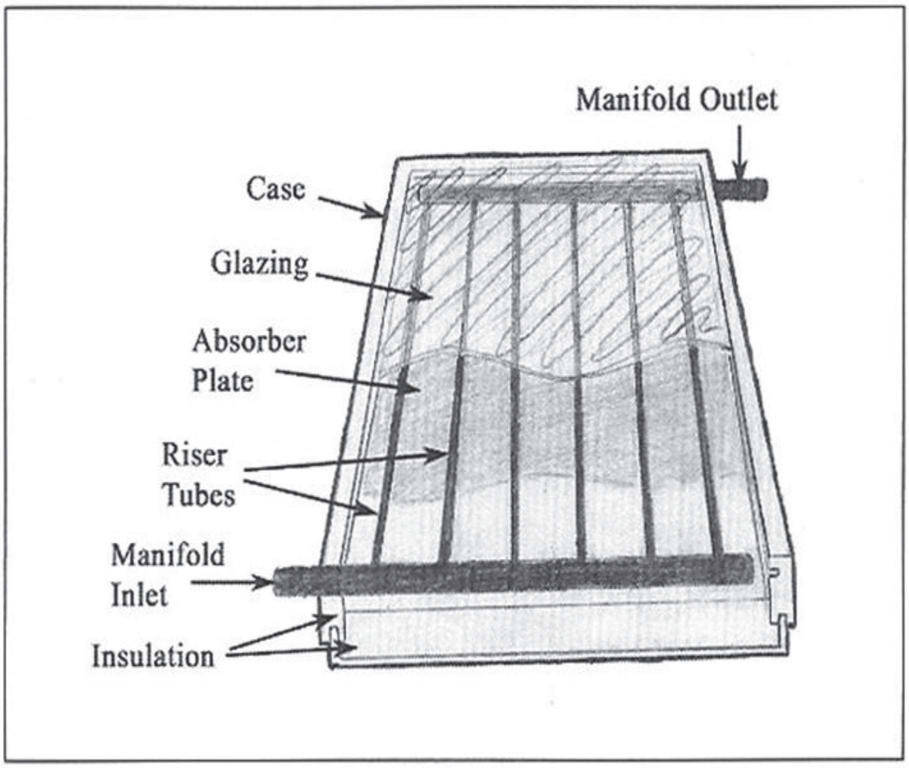

Figure 1, Schematic diagram of the tested solar collector

Figure 2, Actual view of the tested solar collect

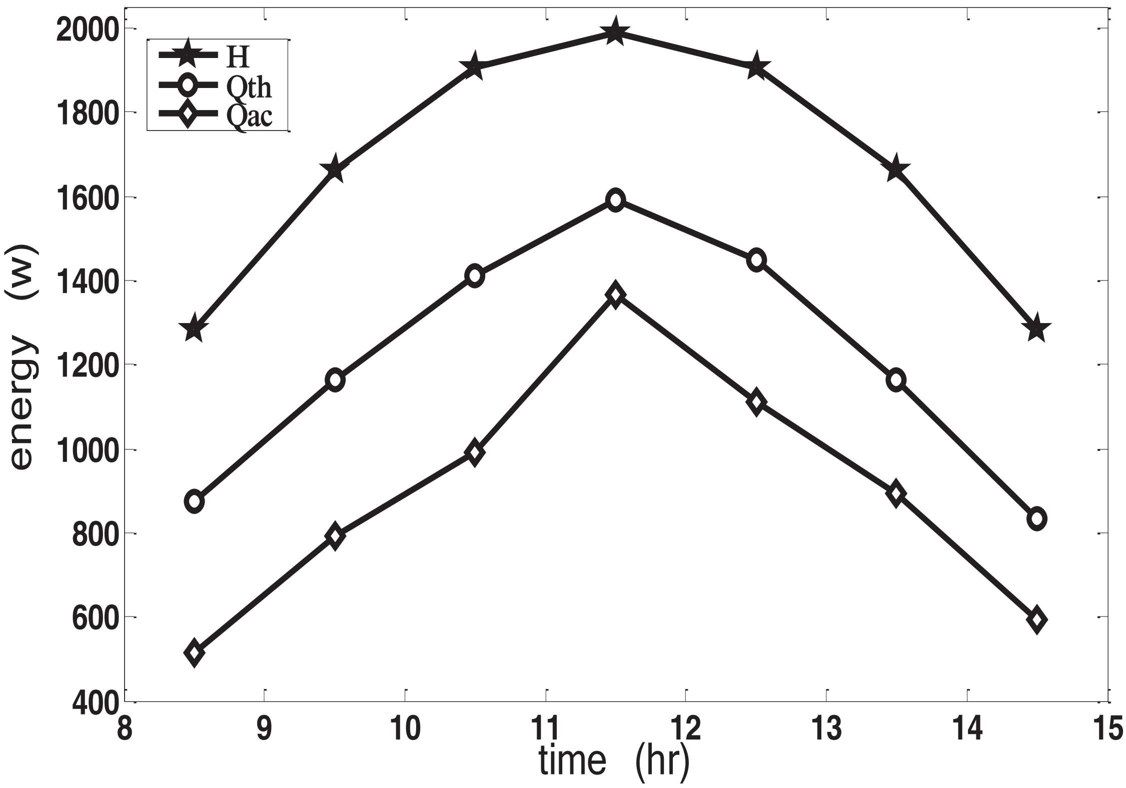

Figure 3, Variation of solar radiation and heat gained on 15/9/2007

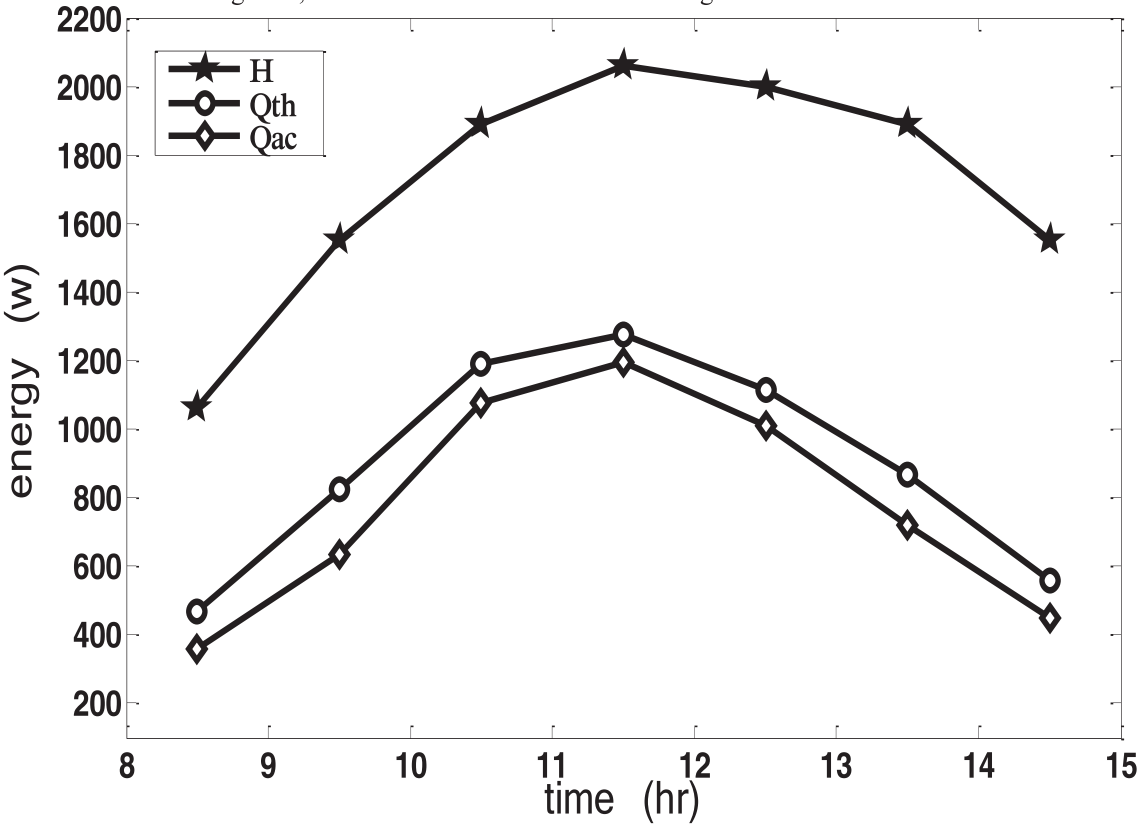

Figure 4, Variation of solar radiation and heat gained on 12/12/2007

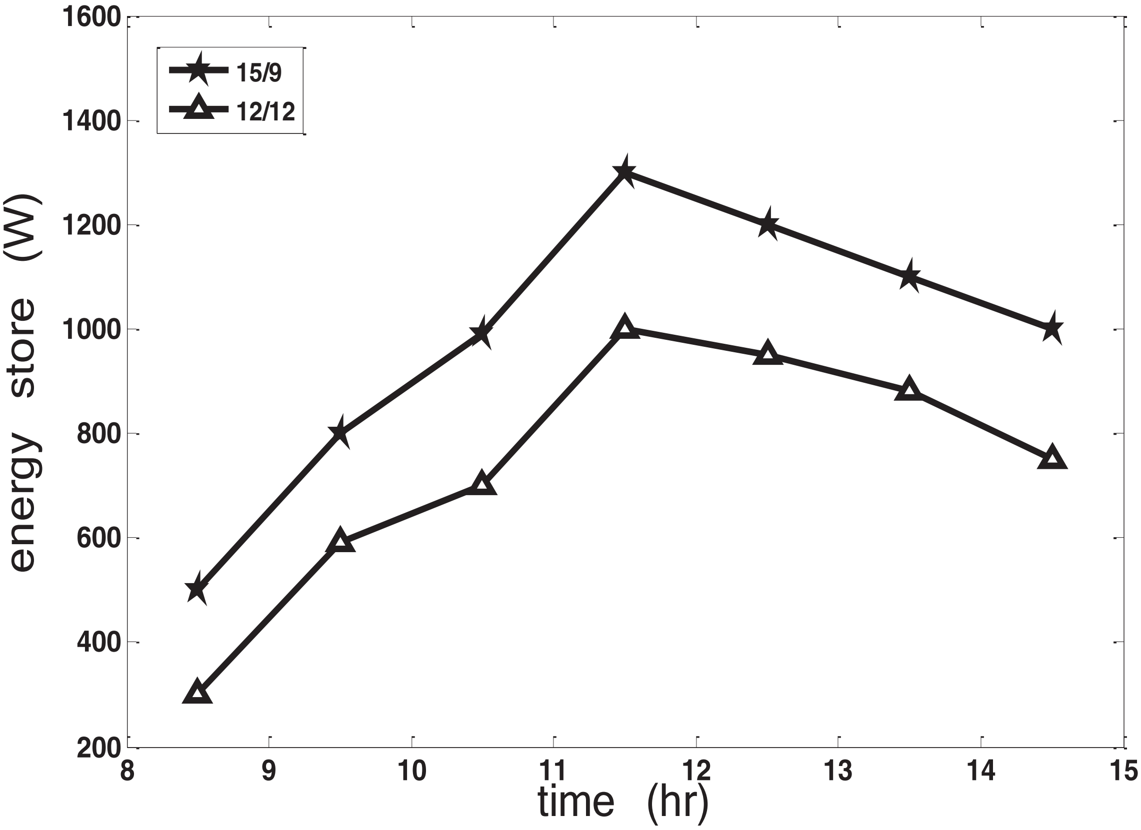

Figure 5, Variation of energy storage

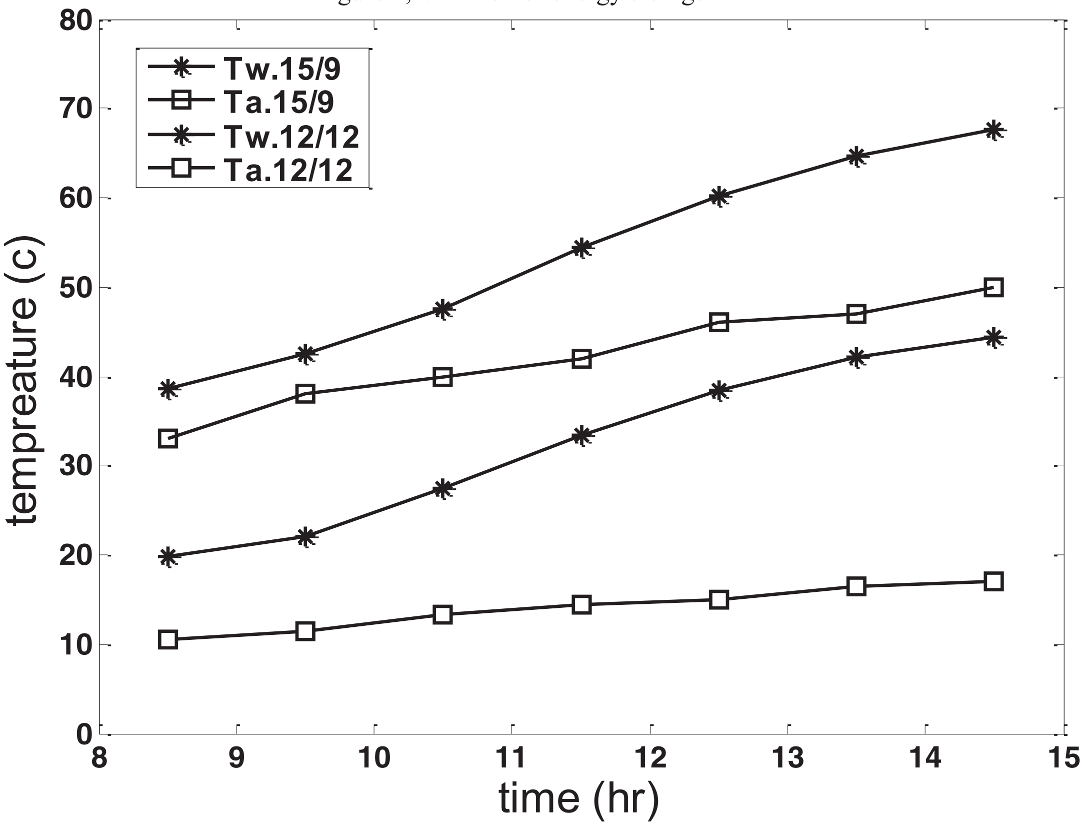

Figure 6, Variation of water temperature (Tw) and ambient air temperature (Ta)

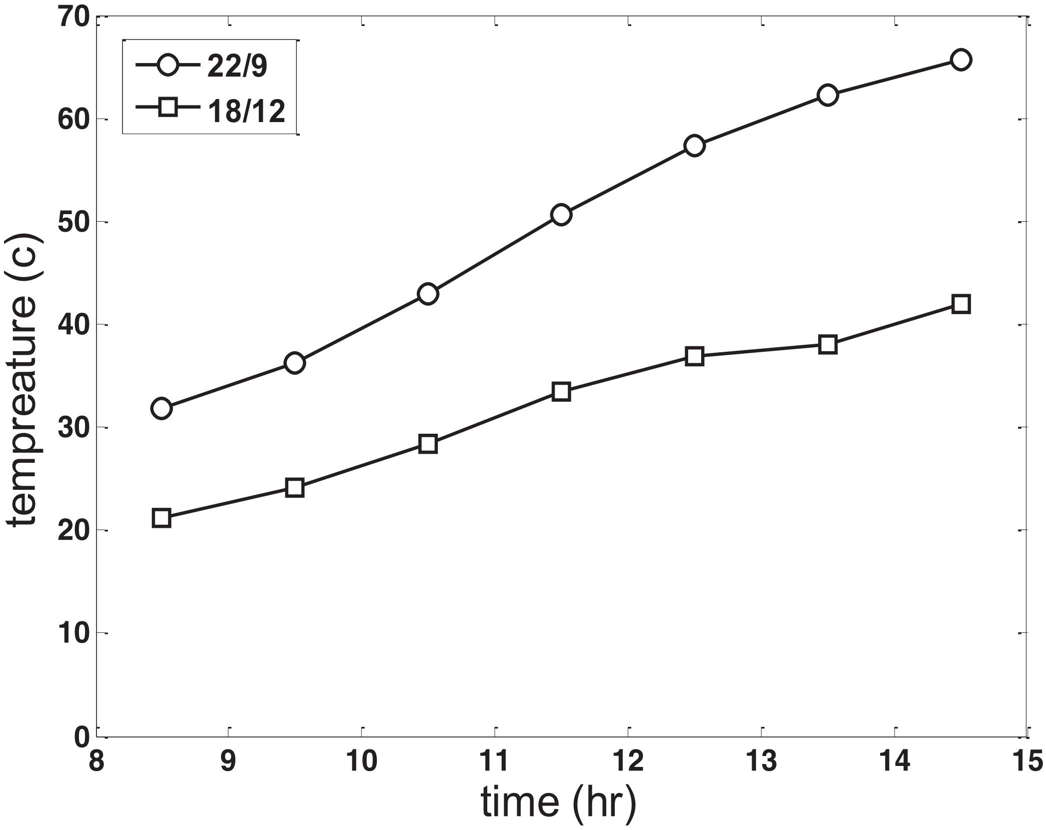

Figure 7, Variation of maximum water temperature in the tank

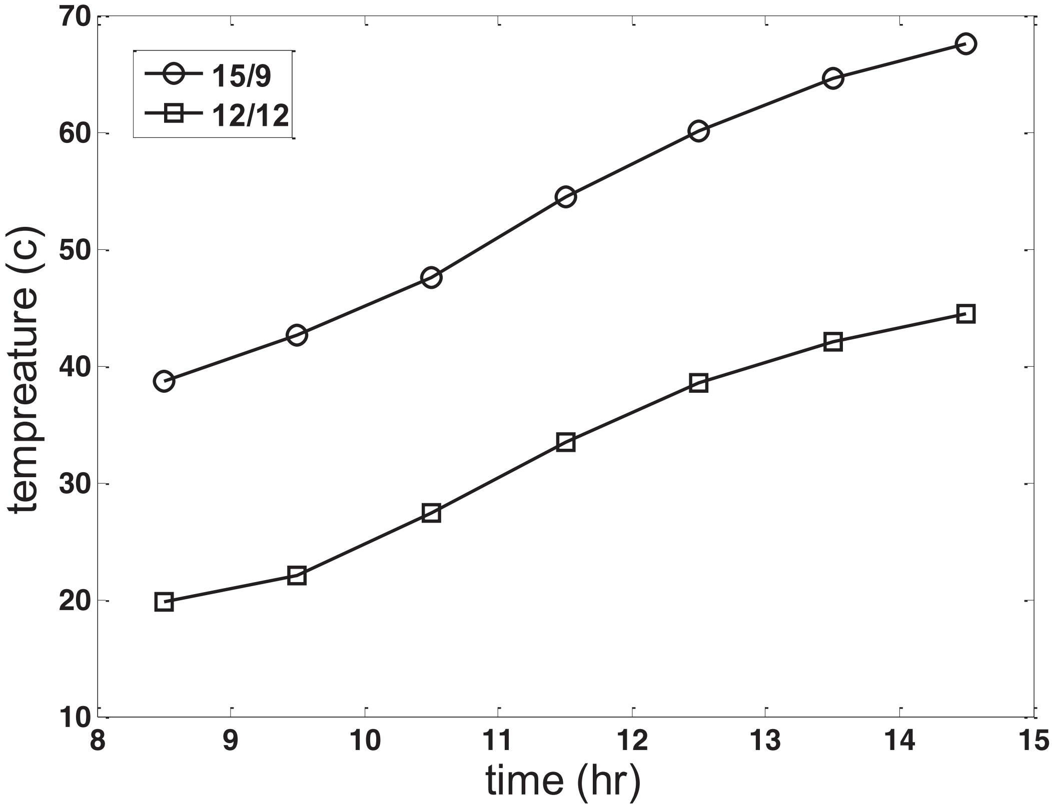

Figure 8, Variation of minimum water temperature in the tank

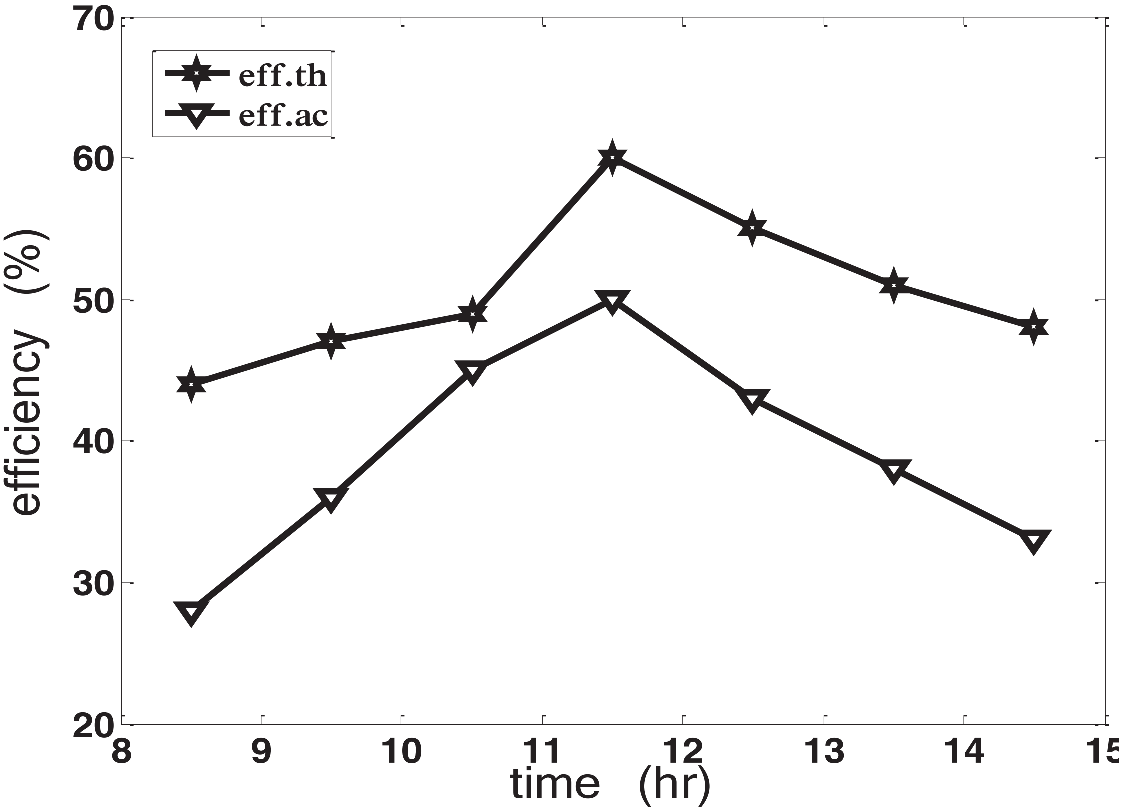

Figure 9, Variation of solar collector efficiency on 18/12/2007

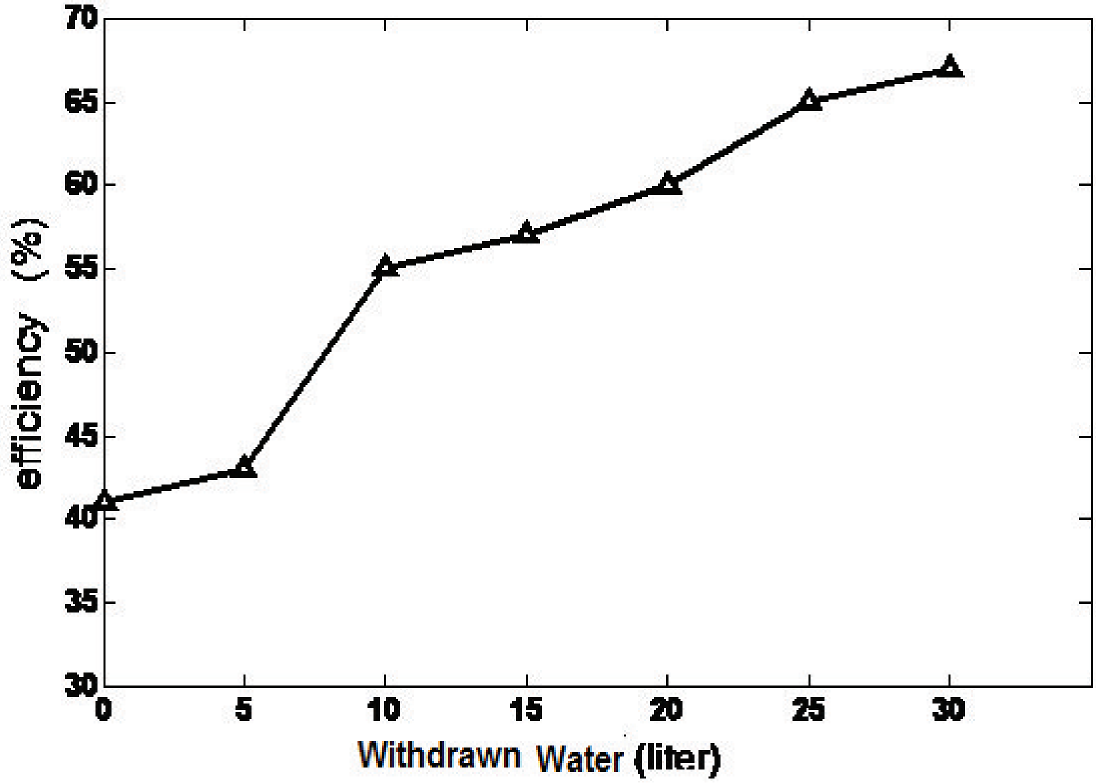

Figure 10, Variation of withdrawn water on the efficiency

6. Conclusions

In the current design, a thermal gradient of heat gained is satisfied since the density difference gives the possibility of withdrawing the required heat from the hot part of the tubes, and add other quantity of new water for part cold from the reservoir and that is what makes solar collector works efficiently. The temperature of the water is an important variable in determining the solar collector efficiency and the amount of stored. It is noticed that the maximum temperature of the water in winter could reach (43^{o}C). Hence, the using of the offered collector is reliable and applicable to supply domestic hot water in conjugation with auxiliary heater.

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