Design and Fabrication of evacuated tube solar thermal collector for domestic hot water

Dr. Alaa H. Shneishil

Al-Mustansiriyah University, College of Education, Physics Department

ABSTRACT

The objective of this research is to design and fabricate solar water heating system by Investment defective materials in Iraq for domestic sector applications in order to encourage national industry. Defective neon light tube with length 120 Cm and diameter 3 Cm has been used as an outer pipe. Copper pipe with length 125 Cm and diameter 1 Cm is placed inside the glass tube and close the space between them by circular shell that is used as an inner absorber material after painting it by black non brightness coating. The space between the outer glass tube and the inner copper pipe is evacuated by using small compressor. The evacuated tubes are connected from the upper side with insulated storage tank and from lower side with circulation pump. The evacuated tubes are placed in the focal line of reflective surfaces. The efficiency of the fabricated solar collector has been measured and compared with uninsulated storage tank which put in the same conditions. These measurements are done with and without reflective surfaces. The results indicated that the temperature of water in the evacuated tube with reflective surfaces reach to 59.5 °C while in the evacuated tube without reflective surfaces reaches to 44.3 °C. The temperature of water in the evacuated tube without circulation pump reach to maximum value which about 85.3 ^{o}C. This value is greater than that of the case with circulation pump.

Keywords : solar thermal collector, evacuated tube solar collector, solar collector with reflective surfaces

تصميم وتصنيع مجمع الطاقة الشمسية الحرارية ذات الأنابيب المفرغة لتسخين الماء في المنازل

د. علاء حسين شنيشل
الجامعة المستنصرية ، كلية التربية ، قسم الفيزياء

الخلاصة

الهدف من هذا البحث هو تصميم وتصنيع نظام الطاقة الشمسية لتسخين المياه باستثمار المواد التالفة في العراق لتطبيقات القطاع المحلي من أجل تشجيع الصناعة الوطنية .وقد استخدم أنبوب ضوء نيون تالف بطول ١٢٠ سم وقطر ٣ سم كأنبوب الخارجي .وتم وضع أنابيب النحاس بطول ١٢٥ سم وقطرها ١ سم داخل الأنبوب الزجاجي وإغلاق المسافة التي تفصل بينهما بواسطة حلقة دائرية والتي يتم استخدامه كمادة امتصاص داخلية بعد طلاءه بمادة سوداء غير عاكسة. تم تفريغ المنطقة بين أنبوب الزجاج الخارجي وأنبوب النحاس الداخلي باستخدام ضاغط صغير .تم توصيل الأنابيب المفرغة من الجانب العلوي مع خزان معزول ومن الجانب السفلي مع مضخة التدوير .وضعت الأنابيب المفرغة في الخط البؤري للسطوح العاكسة .وقد تم قياس كفاءة مجمع الطاقة الشمسية المصنع ومقارنته مع خزان غير معزول موضوع في نفس الظروف .وتم هذا القياس مع وبدون السطوح العاكسة .أشارت النتائج إلى أن درجة حرارة المياه في الأنابيب المفرغة مع السطوح العاكسة تصل إلى ٥٩.٥ °C بينما الانبوب بدون السطوح العاكسة تصل إلى ٤٤.٣ °C .درجة حرارة المياه في الأنابيب المفرغة بدون مضخة التدوير تصل إلى القيمة القصوى حوالي ٨٥.٣ °C .هذه القيمة أكبر من حالة وجود مضخة التدوير.

كلمات البحث :مجمع الطاقة الشمسية الحرارية، مجمع الطاقة الشمسية ذات الانابيب المفرغة، مجمع الطاقة الشمسية مع الالواح العاكسة

1. INTRODUCTION

The global energy consumption increases continuously and the fossil fuels are eventually non-renewable and therefore will essentially run out. The rate of solar energy that received by the earth is about thousand times larger than the amount of energy consumed by the modern solar collectors' technologies [1]. The radiation from the sun contains large amount of possible energy with extended wavelengths for most applications in the life of humans. The average efficiency of solar thermal collectors is about 4-5 times that of PV, and is therefore, much cheaper per unit of energy produced. Thermal energy can be used to passively heat the water by using of certain building materials. Solar water heaters are now a viable supplement of alternative to electric or gas hot water. The use of renewable energy can help to reduce adoption of fossil fuels in producing energy, and therefore directly reducing the emission of CO_2. The installation of solar collector in the house helps to reduce emissions of CO_2 by about 20% [2]. Heat energy also forms a large fraction of the total energy consumption in the industrial process heat as well as for household, such as food processing, washing, bathing, etc. This heat is often supplied as hot water in the range from 20 to 60 ^oC [3]. The solar water heating system may be easily coupled with electric geyser. The hybrid system will conserve electricity and result in overall economy. Feasibility studies carried in this respect show that about 50% of electrical energy consumed in the geyser can easily be saved by integration of solar water heater with electric geyser [4]. The evacuated tube solar thermal collectors (ETC) have better efficiency in comparison to flat plate solar collectors, in particular for high temperature operations. The mechanism of this type of solar water heating system is driven by natural circulation of fluid in the collector and the storage tank. It consists of all-glass vacuum tubes, inserted directly into a storage tank, with water in direct contact with the absorber surface. The limitation of this concept is that it can only be used for a low-pressure system, as the tubes can only withstand a few meters of water head [5]. Evacuated tube solar collector has been commercially available for over 25 years. Since 2000, the evacuated tube solar collector has had a significant impact on the solar water heating market. In 2008, ETC constituted more than 30% of the total sales, in 2009, there were 61 MNRE approved ETC suppliers and manufacturers. A solar powered air heating system using one ended evacuated tubes with surface area of about 4.44 m^2 was experimentally investigated by avadhesh et al in 2011. It was observed that down flow configuration is more effective than up-flow condition at all flow rates due to lesser losses in down-flow. Aed et al in 2014 experimentally tested the thermal losses in solar water heaters with (32) evacuated tubes and tank capacity (263 liters) that have used for heating a hall of specified area in Baghdad-Iraq, The results indicated that the average energy losses were about (24743KJ). Dmitri et al in 2015 presented the experiments of measuring the performance of evacuated tube (ETC) and flat plate solar collectors (FPC) in Nordic climate conditions. According to the results, during sunny days FPC produced 21-37% more thermal energy than ETC. On partly cloudy days when the weather was changing FPC produced 8-23% more thermal energy, while, during rainy and cloudy days ETC produced 21-64% more. The main aim of this project is to reduce the electricity consumption along with making it Iraqis human friendly by ridding the environment of waste and Investment defective materials for making useful Devices. This paper analyzes and discusses the performance results of homemade evacuated tube solar collector from defective materials. The design was fabricated by manufacturer and installed at Baghdad,-Yusufiyah.

2. EVACUATED-TUBE SOLAR COLLECTOR

In the preceding decades the evacuated-tube solar collector represent the most popular design to heat the water. Each evacuated tube consists of two glass tubes made from extremely strong borosilicate glass. The outer tube is transparent that allowing solar rays to pass through with minimal reflection, while the inner tube is painted by a special selective material which has excellent absorption to solar radiation and minimal reflection properties. The two glass tubes are fused together and the air contained in the space between them two is pumped out, forming a vacuum. A vacuum represents an excellent insulator versus heat loss, and so evacuated tubes are able to operate very efficiently when there is a large difference between the inner tube and the outside ambient air, figure 1 shows evacuated tube solar collector. The evacuated-tube solar collector has better thermal efficiencies at higher temperatures than the conventional flat-plate solar collector and they are suitable for applications at the temperature of above 80 ^{o}C [3]. The whole system is placed in a tilted position, depending upon the place latitude and directed towards the south direction. The maximum temperature of water in winters is 60-70 degree Celsius [4]. The heat energy is converted into thermal energy of water in the pipes, as [6]:

$$Q = \dot{m}\, C_p \left(T_{fo} - T_{fi}\right) \qquad (1)$$

Where $\dot{m}$ is the mass flow rate of hot water (kg/s), C_p is the specific heat capacity of water and T_{fo} is the outlet hot water temperature T_{fi} is the inlet cold water temperature. The efficiency of solar water heating system can be calculated by using the following equation [7]:

$$\eta = \frac{Q}{A\, I} \qquad (2)$$

Where A is the solar collector area, Q is the daily required energy to heat the water, η solar collector efficiency, I solar radiation.

Figure 1: Evacuated tube solar thermal collector [6]

3. EXPERIMENTAL PART

Homemade solar water heating system has been fabricated from some simple useless materials and other materials are bought from local market with cheap price in order to encourage national industry. After the fabrication process has been completed many measurements are made to show the efficiency and activity of the system. The following paragraphs illustrate the fabrication and measurement processes, in addition to the feasibility study of made some parts of the system such as evacuated tube and reflective surfaces.

3.1 THE FABRICATION OF EVACUATED TUBES

Neon light tubes have been used as an outer pipes. Each one is a glass tube with length 120 Cm and diameter 3 Cm. It is made a hole from the two sides and remove the coating material from the inner side of the tube. Copper pipes with length 125 Cm and diameters 1 Cm is used as an inner absorber material after painting it by black non brightness coating. The copper pipe is placed inside the glass tube and close the space between them by circular shell to perform two concentric cylinders. Small copper pipe with diameter 3 mm and length 5 Cm is fixed in the glass tube to evacuate the air from the space between outer glass tube and inner copper pipe by using small compressor and the pipe is closed. On the other hand, other type of fabricated evacuated tube consists of two glass tubes with different diameters. In this type the fluid has black color to absorb large amount of solar radiation.

3.2 THE FABRICATION OF REFLECTIVE SURFACES

Plastic pipe with 115 Cm length and 7.5 Cm diameter has been cut from its longitude into two equity parts, each part represent half cylinder and the inner surface is coated by silifon material which perform a trough reflective surface similar to trough mirror with focal length of 1.8 Cm as shown in figure 2. The evacuated tube is placed in the focal line of trough reflective surface. There are eight reflective surfaces connected parallel to wood frame. The distance between each center of surface and the other is 10 Cm to perform the primary collector surface. There is another surface with diameter 10 cm and length 30 cm that made for laboratory experiment.

Figure 2: Trough reflective surface

3.3 THE FABRICATION OF COLLECTION PIPE

The collection pipes are fabricated from plastic pipe with inner diameter 1.8 Cm and length 90 Cm and make eight holes with diameter 1 Cm, the distance between each hole and other is 10 Cm. This pipe is closed from one side and open from other side.

3.4 THE FABRICATION OF STORAGE TANK

Plastic tank is placed inside carton box and the space between them is filled with foam which represent as insulator for storage tank from ambient temperature. There are two holes, one in the upper side which represent outlet side and the other in the lower side which represent the inlet side of storage tank. The circulation pump is an electrical device which connects between storage tank and the solar heating unit.

3.5 THE COLLECTION OF THE SYSTEM

The evacuated tubes are connected to collection pipes from the upper and lower side, the copper pipes are entered into the holes of collection pipes and put adhesive material to prevent the water emerging from the pores. The upper collection pipe is connected with the upper side of insulated storage tank and the lower collection pipe with circulation pump. All pipes are insulated with foam. The evacuated tubes are placed in the focal line of reflective surfaces, see figure 3.

(a) (b)

Figure 3: Fabricated solar collector (a) without reflective surface (b) with reflective surface

3.6 MEASUREMENTS

Many measurements are done to study the efficiency of fabricated solar collector for heating the water, study the effects of evacuated tubes on the heat losses, the effect of reflective surfaces on the efficiency. The efficiency of the fabricated solar collector has been measured and compared with uninsulated storage tank which put in the same conditions. The solar collector is faced to the south and fixed at 45^o tilt angle. The quantity of water in the storage tank of fabricated solar collector is the same as in the uninsulated tank. These measurements are done with and without reflective surfaces. The evacuated tube and non-evacuated tube that have the same quantity of water have been compared in laboratory by using electrical heater source, the two tubes are placed at equal distance from the source as shown in figure 4. After the temperature in these tubes reach to maximum value the electrical heater source is turned off and the temperature is measured as a function of time in order to evaluate the heat loss coefficient of the tubes and the feasibility of insulate the tube from ambient temperature. Figure 4 shows the laboratory setup of this experiment.

Figure 4: Laboratory setup for comparison between evacuated and non-evacuated tubes

4. RESULTS AND DISCUSSIONS

4.1 ASSESS THE FABRICATED SOLAR COLLECTOR PERFORMANCE

The study of the relationship between the temperature of water inside the insulated storage tank which associated the fabricated solar collector with time in comparison with uninsulated storage tank has been done in 08/04/2015 on the roof of a house in the city of Baghdad, Yusufiyah, starting from the seven o'clock in the morning to the seventh o'clock in the evening. Figure 5 shows the results of the measurements for this experiment. It can be seen from this figure that the water temperature inside the two heat reservoirs is about 24 °C in the beginning of measurements, and then increase over time for both reservoirs under the effect of solar radiation but the amount of increasing in temperature for the insulated reservoir is larger than the other. The maximum value of water temperature is get at 1:00 pm which about 56 °C for the insulated reservoir and 41 °C for the second reservoir. After that the temperature begin to decrease due to heat losses because of drop the value of solar radiation and decrease in ambient temperature.

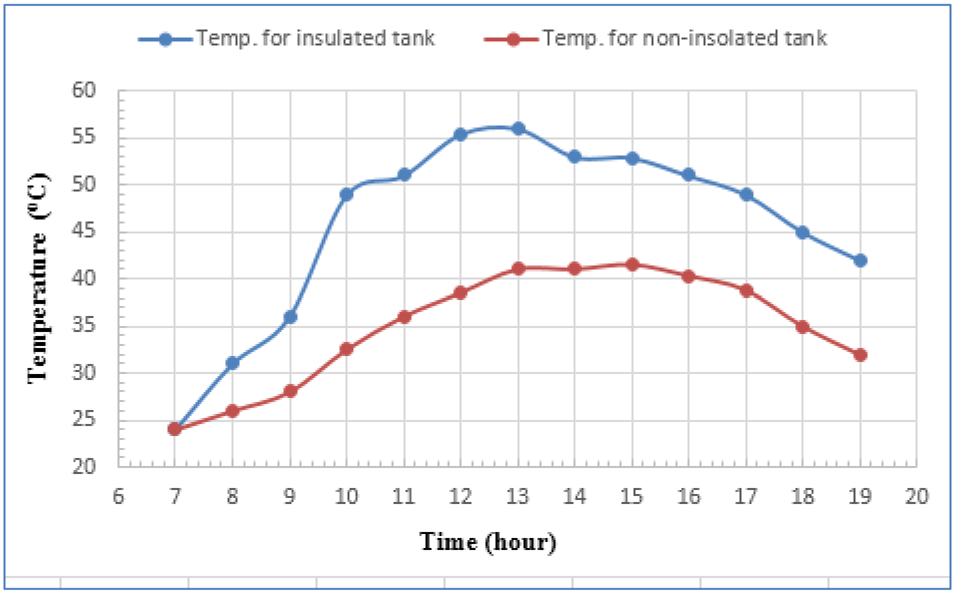

Figure 5: The temperature variation of the insolated tank connected with fabricated solar collector and non-insolated tank with time

4.2 THE EFFECT OF REFLECTIVE SURFACES ON THE PERFORMANCE OF THE SYSTEM

Figure 6 shows the results of the measurements for solar collector with reflective surfaces. This experiment conducted in 10/04/2015. It is observed from this figure that the temperature starting from 24.5 °C, which represents the starting degree water temperature inside the heat reservoirs and then begin to increase over time under the impact of solar radiation, but the amount of increase in the degree of the reservoir associated with the reflective surfaces are larger than the other, where the greatest value is about 64 °C for the first tank and to 34.3 °C for the second tank then the curve begins to decrease in temperature due to heat loss, the decline of solar radiation and decrease in ambient temperature value.

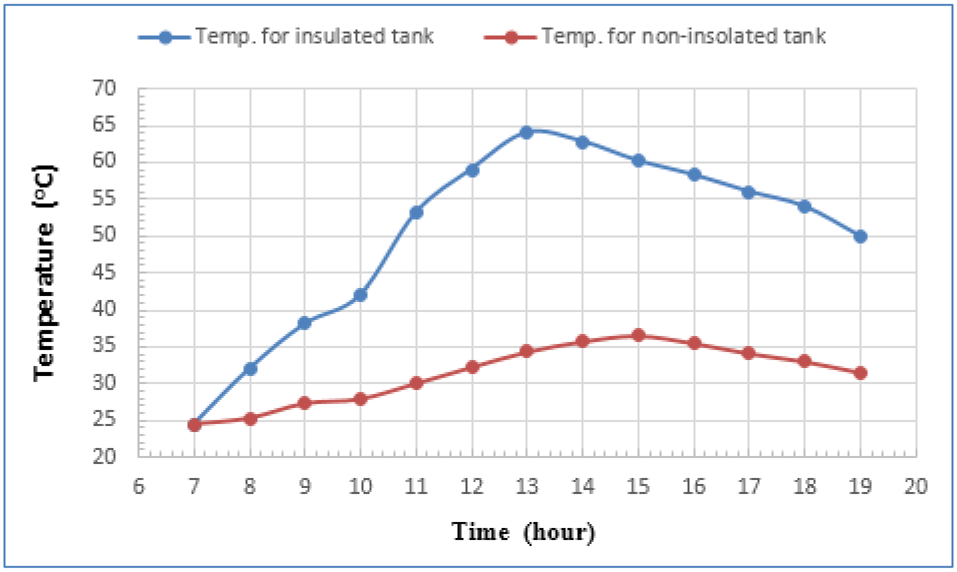

Figure 6: The temperature variation of the insulated tank connected with fabricated solar collector provided with reflective surfaces and uninsulated tank with time.

4.3 COMPARISON BETWEEN EVACUATED TUBE AND NON-EVACUATED TUBE

Figures 7 and 8 illustrate the heat gain and heat losses of two tubes conducted in the laboratory. Evacuated and non-evacuated tubes are placed at equal distance from electrical heater where the temperature in the two tubes at the beginning of measurements is 30 °C. It is obvious from figure 7 that the heat begins to increase over time, but the amount of increase in the temperature of the evacuated tube to be lower than a few degree of the non-evacuated tube where the temperature reaches the highest value in the evacuated tube 44.3 °C after 50 minutes while other tube up to such a degree after 40 minutes, and almost the two curves to be Compatible one over the other because of the vacuum does not affect the thermal acquisition of tube because most thermal power reaches to tubes are in the form of thermal radiation and no acquire by conduction or convection.

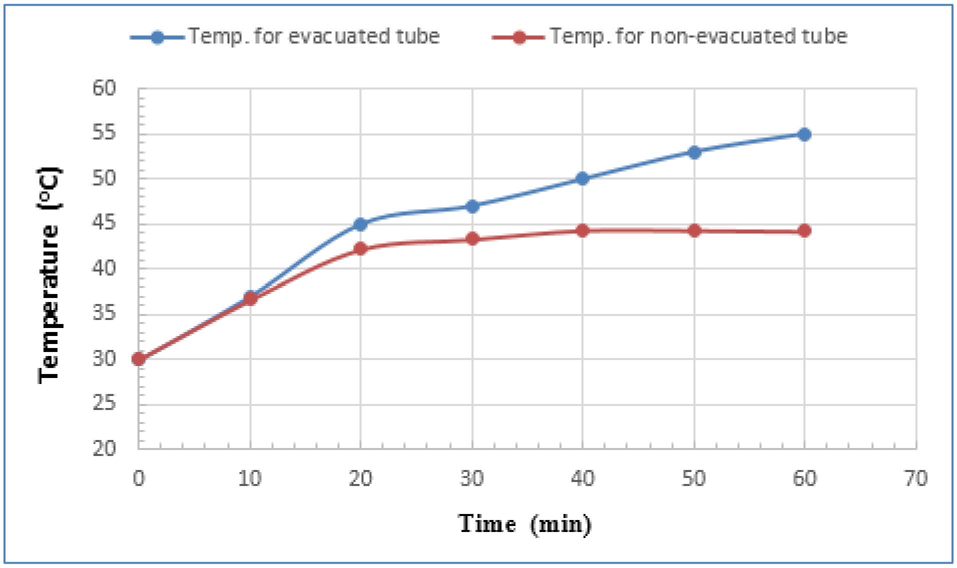

Figure 7: The temperature variation (heat gain) of the evacuated tube and non-evacuated tube with time

After the temperature of the two tubes reaches to maximum value (44.3 °C) the electrical heater is turn off in order to study the heat losses. The heat begins to go down over time for both tubes under the impact of radiation emitted from the evacuated tube and radiation and convection of non-evacuated tube, but the amount of drop in the temperature of the first tube is less than the other by about 3 °C as shown in figure 8. The reason of this difference is the heat insulation quotient of the space in the evacuated tube which prevents the convection losses.

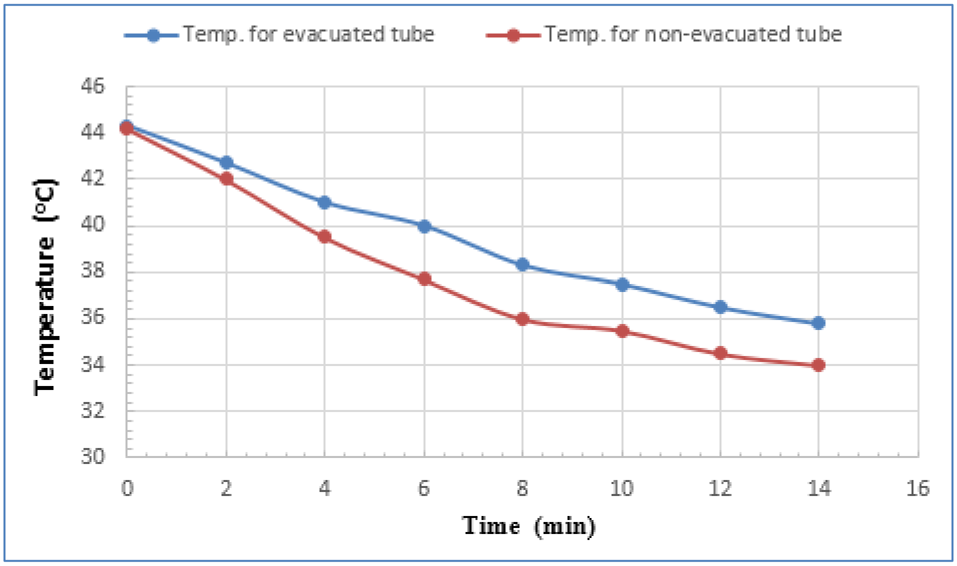

Figure 8: The temperature variation (heat losses) of the evacuated tube and non-evacuated tube with time

4.4 THE EFFECT OF REFLECTIVE SURFACES ON VACUUM TUBES

As illustrated in Figure 9 the results of the measurements made during the laboratory by using electrical stove for two evacuated tubes one connected with reflective surface and the other without reflective surface indicated that the amount of increase in the existing water temperature in the first tube greater than that of the increase in the degree of existing water temperature in the second tube. It can be seen that the temperature of the first tube reach to 52.5 ° C after 10 minutes and then change the shape of the curve and increase the temperature relatively slower rate and up to a higher value, which is 59.5 ° C. The evacuated tube without reflective surface does not much affected by the passage of time and the temperature reach to maximum value which about 44.3 °C. The reason for the difference in temperature between the tubes which about 15 °C is the effect of reflective surface.

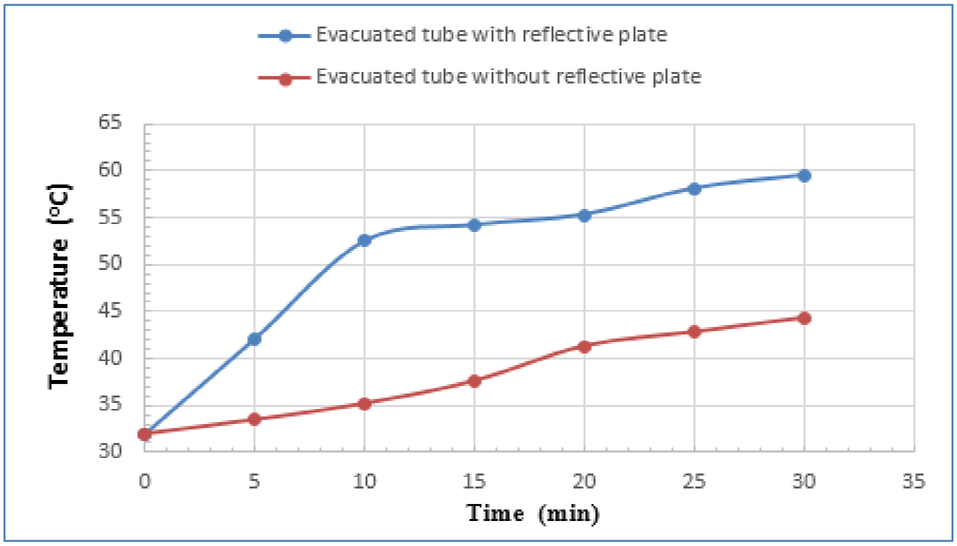

Figure 9: The temperature variation of water in the evacuated tube with reflective surface and evacuated tube without evacuated surface with time

4.5 NATURAL HEAT TRANSFER (WITHOUT CIRCULATION PUMP)

Figure 10 shows the result of measurements for the temperature variation of water in the evacuated tube without circulation pump. It can be seen from figure that the temperature reaches to maximum value which about 85.3 ^{o}C. This value is greater than that of the case with circulation pump.

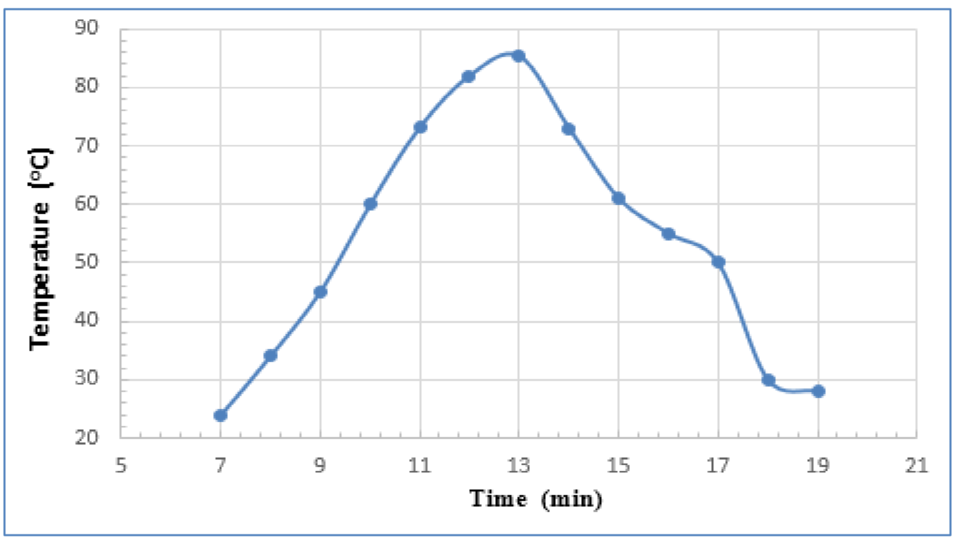

Figure 10: The temperature variation of water in the evacuated tube without circulation pump (natural heat transfer) with time

5. CONCLUSION

1. It must stop the circulation pump and isolate the storage tank from the evacuated tubes in order to prevent heat losses in the afternoon.
2. The reflective surfaces are important for increasing heat gain by solar collector.
3. Any family in Iraq can make solar collector by simple way in their house in order to decrease the using of electric heater.

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