Experimental Study of Solar Hot Water System Design

Muhannad Sahib Ali

Mech. Eng. Dept.

College of Engineering

Thi-Qar University

Abstract

This paper investigates the design of flat-plate solar collector system experimentally. The production amount of hot water depends on the type and size of the system, the amount of sun rays available at the site, proper installation, and the tilt angle and orientation of the collectors with respect to the south direction. The results show that the amount of the energy collected by the thermal fluid and the absorber plate are inversely proportional to that thickness and diameter of both riser and drum tubes, and it decreases when the air gab between glasses layer increases (prevents the sun rays and the solar effect). The intensity of the mean sun rays daily per hour is an important factor to the energy absorbed by the collector. This study used aluminum as an absorber plate because its thermal conductivity is high more than copper and mild steel, its price is cheap.

دراسة عملية لتصميم منظومة سخان شمسي

المستخلص

في هذا البحث تم دراسة عملية لتصميم سخان شمسي نوع الصفيحة المستوية يستخدم لتسخين المياه. حيث أن كمية الماء الساخن المحصلة من استخدام السخان الشمسي تعتمد على نوع وحجم السخان المستخدم، كمية الإشعاع الشمسي المتوفر في موقع العمل، الربط المناسب زاوية واتجاه المجمعات الشمسية بالنسبة للاتجاه الجنوبي. النتائج أوضحت أن كمية الطاقة الحرارية الممتصة من قبل الصفيحة الماصة والماء الساخن تتناسب عكسياً مع سمك وقطر الأنابيب سواء كانت المجمعة أو الصاعدة ، كما إن الطاقة الممتصة تزداد بزيادة عدد الأغطية الشفافة الزجاجية ألا أنها تقل بزيادة المسافة بين الأغطية الزجاجية لأنها تمنع أو تقلل من تأثير أشعة الشمس. أن شدة معدل الإشعاع اليومي للشمس في الساعة تلعب دوراً أساسيا في كمية الطاقة الممتصة. في هذا البحث تم استخدام الألمنيوم كصفيحة ماصة للحرارة كونه موصل جيد للحرارة كما أن الألمنيوم متوفر في الأسواق المحلية وثمنه ارخص.

1. Introduction

Solar energy is radiant energy that is produced by the sun. Every day the sun radiates, or sends out, an enormous amount of energy. The sun radiates more energy in one second than people have used since the beginning of time.

The sun is a big ball of gases mostly hydrogen and helium atoms. The hydrogen atoms in the sun’s core combine to form helium and generate energy in a process called nuclear fusion.

It takes millions of years for the energy in the sun’s core to make its way to the solar surface, and then just a little over eight minutes to travel the 93 million miles to earth. The solar energy travels to the earth at a speed of 186,000 miles per second, the speed of light.

Only a small portion of the energy radiated by the sun into space strikes the earth, one part in two billion. About 15 percent of the sun’s energy that hits the ear this reflected back into space. Another 30 percent is used to evaporate water, which, lifted into the atmosphere, produces rainfall. Solar energy also is absorbed by plants, the land, and the oceans. The rest could be used to supply our energy needs.

More than 100 years ago, a scientist used heat from a solar collector to make steam to drive a steam engine[1]. In the beginning of this century, scientists and engineers began researching ways to use solar energy in ear nest. One important development was a remark ably efficient solar boiler invented 1936. The public and world governments remained largely indifferent to the possibilities of solar energy until the oil shortages of the 1970.

May be more important for the purposes of collecting solar energy to heat water is that the sun comes to us in three different forms: (1) direct parallel rays; (2) diffuse radiation, which comes to us from all directions after being glanced off clouds, dust or moisture particles in the air; and (3) reflected radiation, which has been bounced straight off some surface[2,3].

Today there are more than 30 million m^2 of solar collectors installed around the globe. Hundreds of thousands of modern solar water heaters, are in use in countries such as China, India, Germany, Japan, Australia and Greece. In fact, in some countries the law actually requires that solar water heaters be installed with any new residential construction project. People use solar energy to heat buildings and water and to generate electricity[4,5].

In spite of the aforementioned work for the hot water solar system, there is a gap in the heat transfer literature for the system design and the equation and factors depends in design. The object of the present study is to fill this gap and provide a basis for the validity of the approximate analysis presented by other researchers [6,7,8]. Further gives the behavior of the temperature of the hot water inside the storage tank with difference in any member of constructions.

2. Governing equations

$$Q_E = Q_L + Q_I \quad (1)$$

$$Q_E = I_h \times f \times HT \times A \quad (2)$$

$$Q_L = U_f \times HT \times A \times \Delta T \quad (3)$$

$$Q_I = \sigma \times C\left(t_{f,e} - t_{f,i}\right) \quad (4)$$

$$t_{f,e} = t_{f,i} + \left(T_p - t_{f,i}\right)\left[1 - \exp(-H/\sigma \times C)\right] \quad (5)$$

$$C = G_m \times C_m + g \times C_w \quad (6)$$

$$f = A_f . T_{rf} \quad (7)$$

$$\frac{(t_{f,e} - t_{f,i})}{Q_E} = \frac{1}{\sigma * C}\left|1 + \frac{U_c}{\sigma \times C\left[1 - \exp\left(-\frac{H}{\sigma * C}\right)\right]}\right|^{-1}\left[1 - \frac{U_c\left(t_{f,i} - t_a\right)}{Q_E}\right] \quad (8)$$

$$I_{daily} = S \int_{t1}^{t2} e^{-\tau/\cos z} \cos\theta \, dt \quad (9)$$

$$T_m = t_a + \left(t_{f,e} - t_a\right)\exp\left(-\overline{U}_L \times L/m \times c\right) \quad (10)$$

$$m_{fuel} = Q_I \times HT \times 320/H_0 \quad (11)$$

3. System configuration

A schematic diagram of the solar system modeled is shown in Figure (1). Flat solar collector is a very simple. It consists of an insulated rectangular box. It contains a metal plate that has been painted black, with a pipe at each end (called headers) that are connected to small tubes (called risers) also made from pipe. Water is first heated in the risers and then returns to the storage tank. The entire box is covered with a special glass that is hail resistant. The storage tank contains water that accumulates heat obtained from the hot water. The cold water enters the storage tank at the bottom, and the supply hot water exits from the top.

3.1. Flat collectors with glass cover

A flat-plate collector Figure(2) consists of an absorber, a transparent glass cover, a frame, and insulation material. Usually an iron-poor solar safety glass is used as a transparent cover, as it transmits a great amount of the short-wave light spectrum. Simultaneously, only very little of the heat emitted by the absorber escapes the cover (greenhouse effect). In addition, the transparent cover prevents wind and breezes from carrying the collected heat away (convection) and also prevent the accumulation of dirt on top of the absorber surface. The insulation on the back of the absorber and on the side walls lessens the heat loss through conduction, generally frame made from wood with dimensions (1×2)m and height 0.1m, it is covered with aluminum plate to protect it and the aluminum is very good to resist the corrosion.

3.2.The absorber

The heart of a solar collector is the absorber. Absorber was made from aluminum plate (1×2)m and painted black, as dark surfaces demonstrate a particularly high degree of light absorption. As the absorber warms up to a temperature higher than the ambient temperature, it gives off a great part of the accumulated solar energy in form of long-wave heat rays. The ratio of absorbed energy to emitted heat is indicated by the degree of emission. In order to reduce energy loss through heat emission, the most efficient absorbers have a selective surface coating. This coating enables the conversion of a high proportion of the solar radiation into heat, simultaneously reducing the emission of heat. The selective coatings provide a degree of absorption up to 90%.

3.3. Hot water storage tank

The purpose of the hot water storage tank is to stockpile energy for days with less solar radiation. Its volume capacity should be larger than the daily hot water consumption, to avoid a lack of hot water, when there is less sun. Good solar storage tanks have a slim, cylindrical form in order to develop a layering of temperature in the tank. This allows for optimal usage of the heated potable water in the upper storage region, thus the entire contents of the tank don't need to be heated to the desired temperature.

Because heat tends to rise, insulation does the most good above the heat source. Any extra material should be put at the top of the tank. Another way to insulate a tank very well is to build a ply wood box around the tank and fill it with insulation Figure(3).

Insulation fills all the nooks and crannies around the tank, and it's just a matter of mixing two liquids together and pouring them into the box. The mixture will expand, foam and bubble like a witch's brew, and work its way into all the spaces between the tank and the plywood.

4. Results and discussion

A thermo siphon system relies on warm water rising, a phenomenon known as natural convection, to circulate water through the collectors and to the tank. In this type of installation, the tank must be placed above the collector. As water in the collector heats, it becomes lighter and rises naturally into the tank above. Meanwhile, cooler water in the tank flows down pipes to the bottom of the collector, causing circulation throughout the system. The storage tank is attached to the top of the collector so that thermo siphoning can occur.

4.1. Solar energy

There are four factors that affect the amount of heat captured by a flat plate collector: (1) the solar intensity (2) the collector's orientation toward the sun, usually to the south,(3) the temperature of the air surrounding the collector call the ambient air and (4) the materials used in the collector itself, specifically the quality of the glazing and the material selected for the key component, the absorber plate.

Equation $\{G=(D-t)\times k\}$ shows that the effect of the thickness of the pipes (riser, drum) on the heat transfer energy. Figure(4) shows that any increasing in the thickness causes decreasing in the temperature of hot water in storage tank because the bigger thermal resistance and much time to the same temperature.

The continuity equation and Figure(5 and 6) show that the opposite relation between the heat energy and diameter to both riser and drum pipes, when the diameter increase the area and the flow rate is greater due to that no enough time to heated fluid pass through pipes so the absorbed energy relative to the mass flow rate.

The important job of the glass cover is to reduce the energy losses and allow to the sun rays absorbed by the dark plate. We must decrease thickness of the glass cover to increase the permeability and due to that absorbed energy increasing Figure(7).

This paper studies the effect of the glasses cover number, glass heat transfer coefficient increase when the gap between glasses layer decrease and Figure(8) shows that when glasses heat transfer coefficient increasing the temperature decrease because the gap between glasses layer prevent the sun rays deflected to the atmosphere and reduce the energy losses by conduction and convection, the effect of two glasses layer more better than one glass cover.

Figure(9) shows that any increase in the mean daily average of the sun rays cause increase in the heat energy.

In this paper examined many metal (aluminum, copper and mild steel) to made black plate, from Figure(10) shows that the aluminum is the best metal to absorbed energy and any increasing in metal thickness decrease in temperature because the plate must be in a thermal balance then the heat transfer from it to the pipes and this is need more time.

The experimental result for the temperature is shown in Table (1); the absorbed amount of the sun rays is higher with the angle of the solar collector orientation is equal to 45 degree and to the south.

Table (1). Measured temperature .

$T_{\text{dark plate}}$	$T_{\text{out of collector}}$	$T_{\text{inside collector}}$	Orientation
76°C	58°C	22°C	
81°C	65°C	21°C	
82°C	71°C	23°C	45°
80°C	69°C	25°C	
51°C	46°C	25°C	
55°C	47°C	24°C	
78°C	58°C	24°C	30°
77°C	48°C	23°C	
77°C	59°C	23°C	

4.2. Economic benefits

This paper analysis illustrates that the initial installed cost of the solar water heater ($700), it is higher than that of a gas water heater ($350 to $450) or an electric water heater ($150 to $350). The costs vary from region to region. Depending on the price of fuel sources, the solar water heater can be more economical over the lifetime of the system than heating water with electricity, fuel oil, propane, or even natural gas because the fuel (sunshine) is free. To determine the simple payback of a solar water heater by determining the net cost of the system then calculate the annual fuel savings and divide the net investment by this number to determine the simple payback. This study expected a simple payback of 4 years.

5. Validation of the results

In order to check the validity of the present study, a comparison is made with a Delfin Sili Salcines. A comparison of the heat energy calculation with the experimental data table 2 shown it seam that, the result have good agreement and the average error is (1%).

Table (2)

Experimental heat energy	Delfin Sili Salcines
366.976	364.886
352.585	350.225
330.998	328.564

6. Conclusions

Passive systems move household water or a heat-transfer fluid through the system without pumps. Passive systems have no electric components to break. This makes them generally more reliable, easier to maintain, and possibly longer ages and economical.

1. To maximize the amount of solar energy collected in a passive solar system you can increase the size of the solar collector, and ensure that the position of the tank and system get optimum sunlight.
2. Concentrates the sun's rays on the collector (glass cover number), which maximizes the heat energy transferred to the water.
3. Use black absorbs light because it has no color to reflect.
4. Use materials (Aluminum) to further focus the sun's energy; insulate the collecting tank, check the sun's angle at different times of the year; use a thermal mass under and around the collector etc.
5. Some limitations are hot water storage at night, when the sun is not available (good insulation would be required).
6. Sunlight has no cost; oil supplies will not be depleted so fast, if solar energy is part of our energy mix; energy bills would be less; less pollution would be emitted.

Figure (1). A thermo siphon solar water heater uses a free-circulating panel.

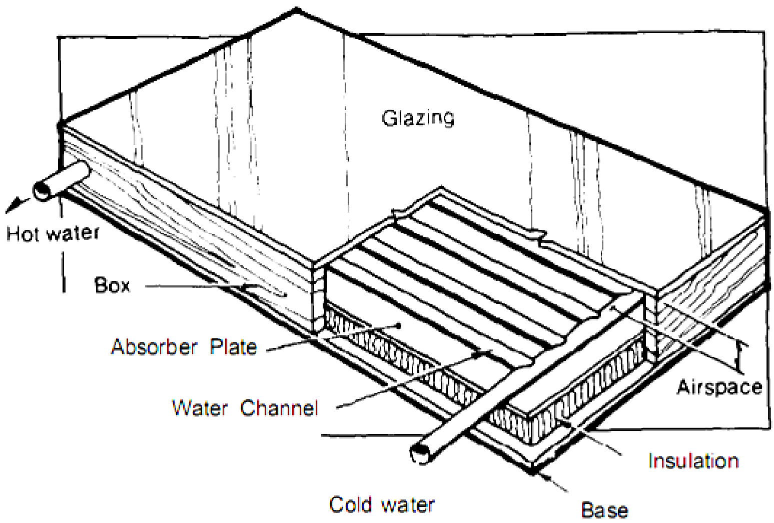

Figure (2). Flat plate solar collector.

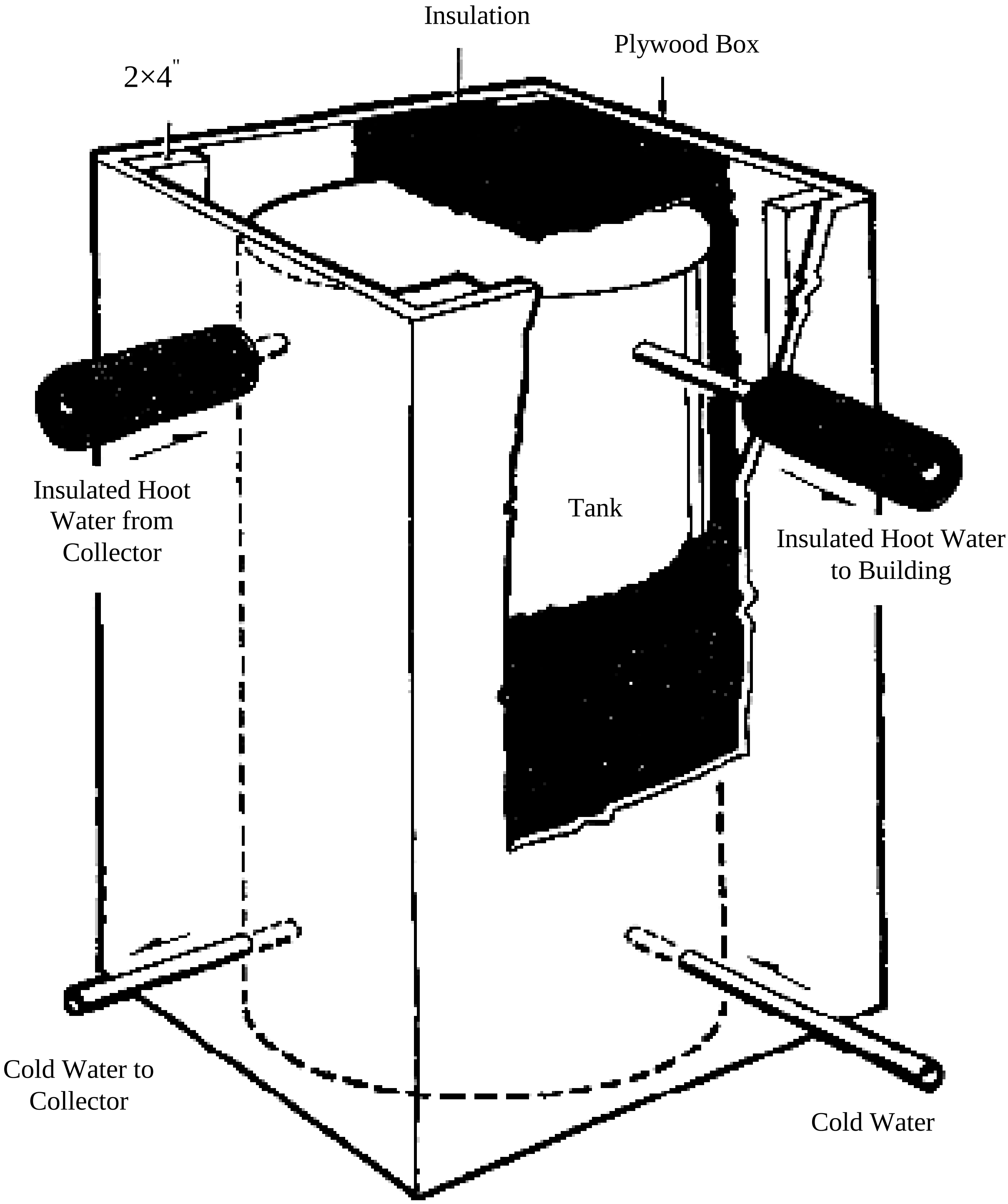

Figure (3) .Solar hot water tank.

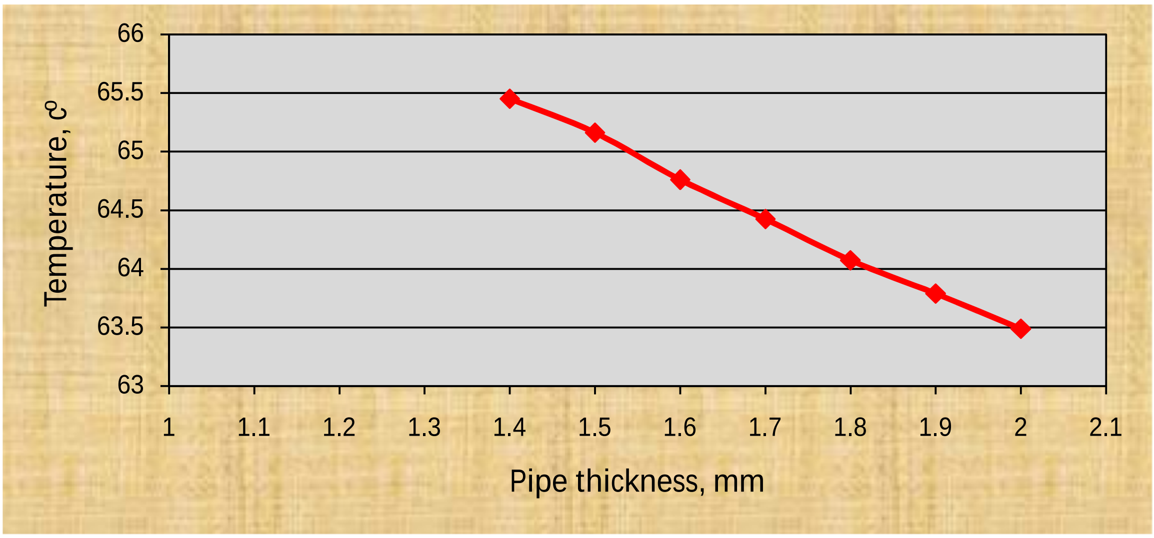

Figure (4). Pipe thickness effect.

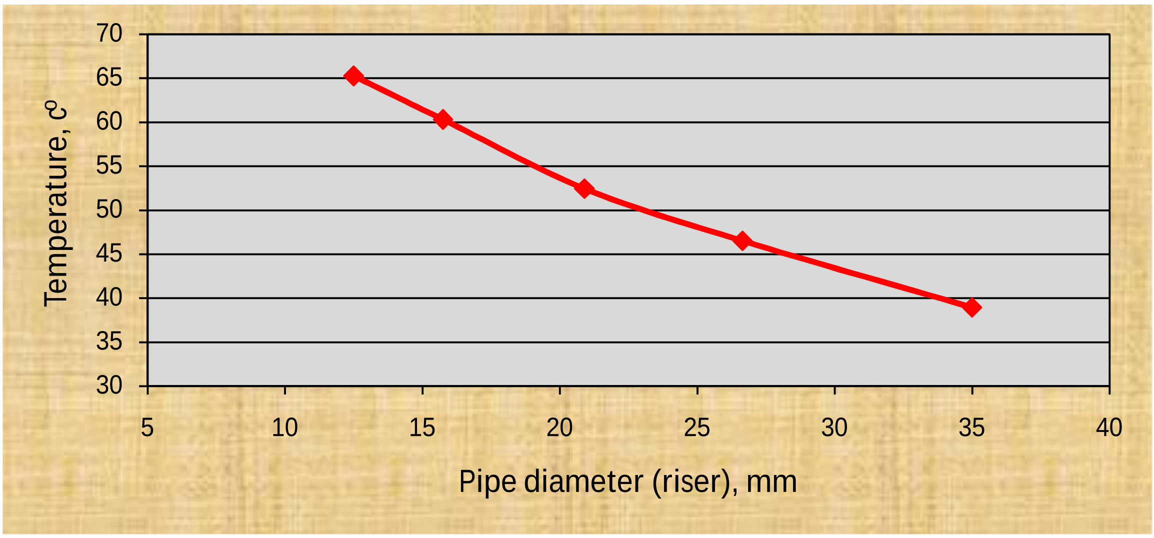

Figure (5). Pipe diameter (riser) effect.

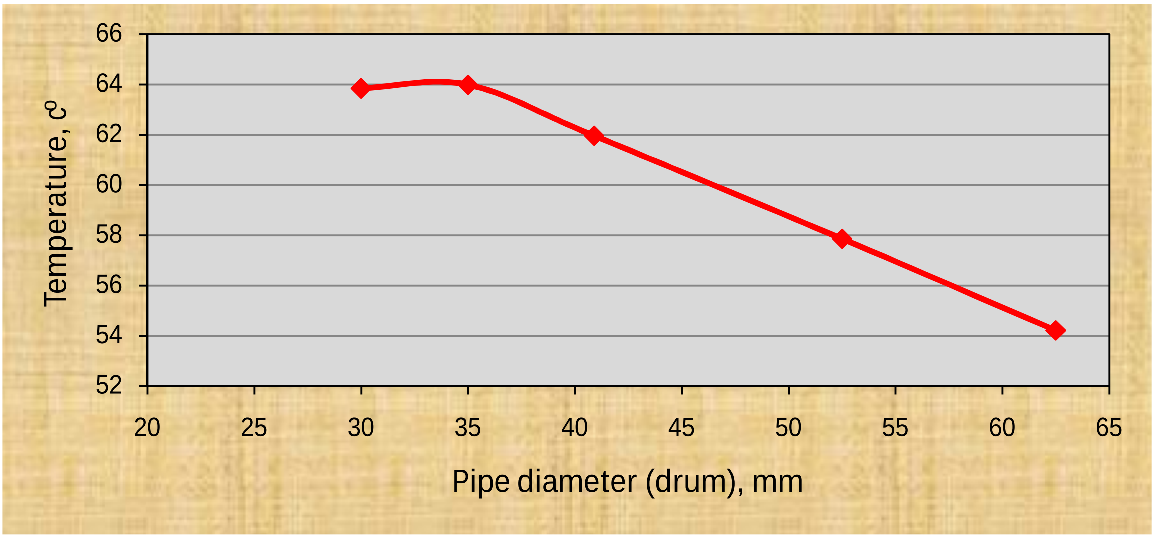

Figure (6). Pipe diameter (drum) effect .

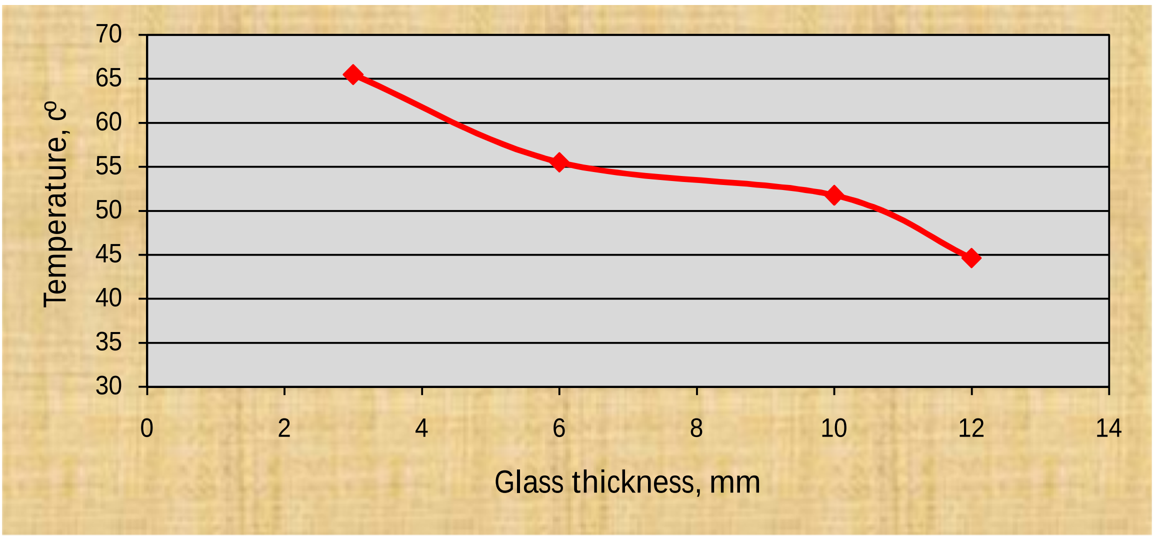

Figure (7). Glass thickness effect.

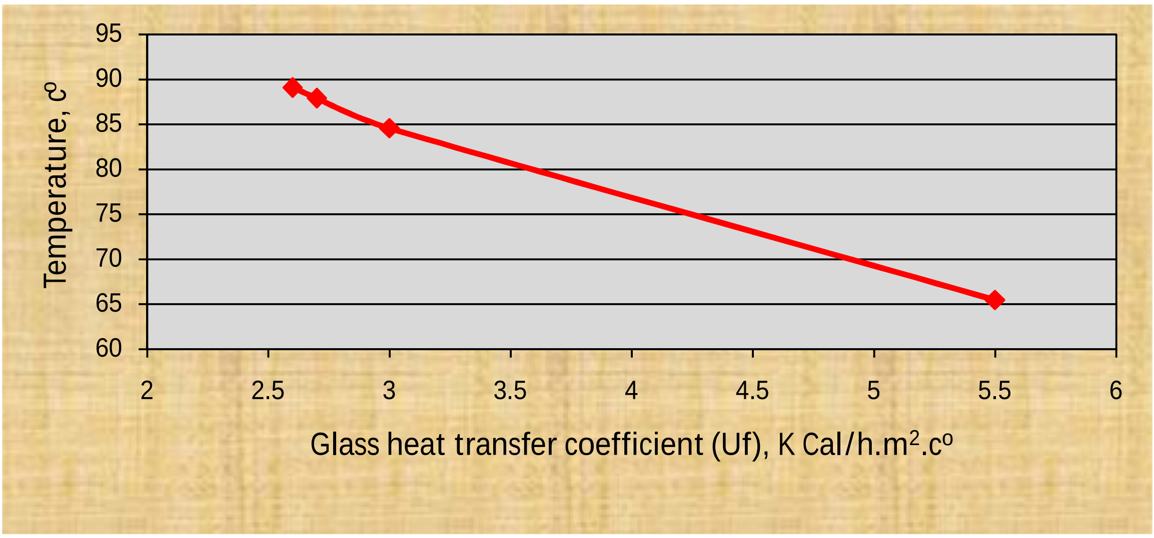

Figure (8). Glasses number effect.

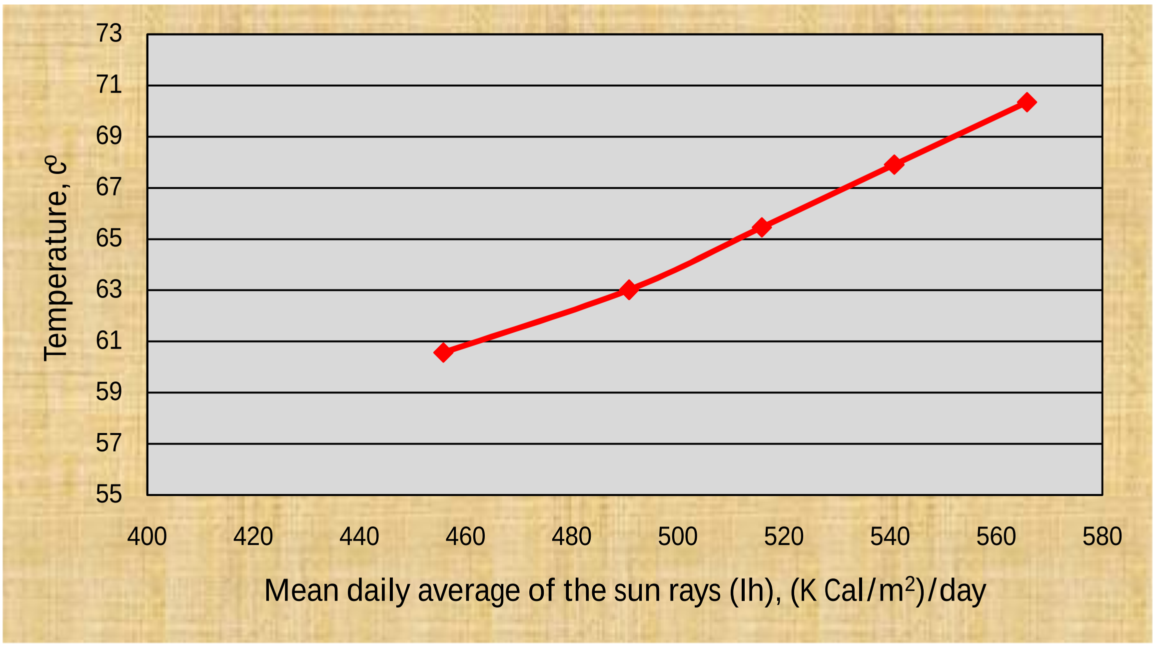

Figure (9). Mean daily average of the sun rays effect.

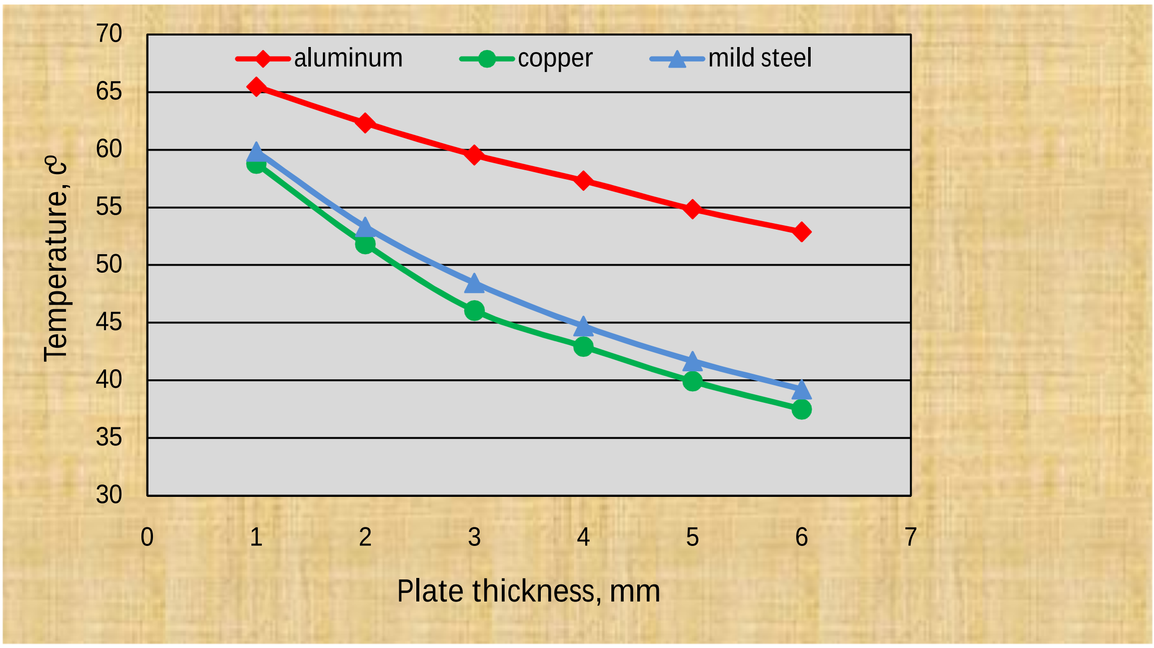

Figure (10). Plate thickness effect.

7. References

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8. Nomenclature

$\overline{U}_L$= losses longitudinal heat transfer coefficient

A_f=absorption glass coefficient

m_{fuel}= The annual fuel savings

T_p= plate temperature

T_{rf}= permeability glass coefficient

U_c= losses heat transfer coefficient

$\dot{\sigma}$ = average flow rate

A = solar collector area

Af= glass absorber coefficient

C = solar collector thermal capacity

D = pipe diameter

g_m = capacity of the pipe metal mass

Gm = weight of the metal mass for absorber plate and pipe

H = heat transfer coefficient

H_o= oil thermal capacity

HT = the daily average of the sun rays time

Iday = the daily average of the sun rays

L= pipe length

QE = solar energy per hour land on the solar collector

QI = solar energy per hour absorbed by the solar collector

QL = solar energy per hour losses by the solar collector

t = thickness

T= temperature

Tf = glass permeability coefficient

$t_{f,e}$ = hot water temperature

$t_{f,i}$ = cold water temperature

t_a= ambient temperature

Tm = hot water temperature in storage tank

U_f = glass heat transfer coefficient

θ= acceptance angle

ρ= density