Prediction of Thermal Characteristics For Solar Water Heater

Dr. Saad T. Hamidi ***Mohamaad A. Fayath***

University of Technology
Iraq-Baghdad
Received on : 8/6/2010 ***Accepted on : 15/10/2011***

ABSTRACT.

The research studies the prediction of thermal characteristics for open designer shape of solar collector of flat plate of area 2.34m^2, connected to water tank of 85 liter capacity . Mathematical model was represented and made the system of private accounts, transactions and through the creation of mathematical equations and solved numerically using the method of Finite Difference Method (FDM).The results of research is to obtain hot water at average temperatures up to 52^0C at mid-day during February month, as the water temperature is at its lowest value in this month in Baghdad city, with an average efficiency of the system up to 53.6% .This predictive study is compared with a previous measurement work and confirmed that the results match well.

Keyword: Solar energy, Solar heater, Thermal collector, Type collector, Efficiency.

1. INTRODUCTION.

The earliest work on solar water heating systems focused more on establishing the technical feasibility using different configurations. This is evidenced by the large number of patents filed in the USA and Japan in the early 20th century. These early systems tested, basically of the integrated collector storage (ICS) type, were soon discovered to suffer substantially from heat losses to ambient, particularly at night and during periods when solar heating is not going on. This was due to their constructions which comprised simply of exposed tanks left out to warm in the sun . More detailed description of the early SHWS is given in Refs. [1,2].

The technical and economic feasibilities of solar hot water systems (SHWSs) are well established and they have found domestic and commercial applications. These systems use solar energy to generate hot water. The technology employed has been reasonably developed and can be easily implemented at a low cost. Several configurations exist for this purpose. These configurations may be grouped into two, namely, the passive solar hot water system (PSHWS) and the active SHWS. The solar collectors employed in these configurations could be flat plate, concentrating, or evacuated tube types. However, the flat-plate-type solar collector appears to be the most commonly used. Its low cost and ease of design and construction are basically responsible for this. They are often used for low and medium temperature applications but may be applied on high load situation by using more than one collector, connected in series. The concentrating and evacuated tube collectors are used for industrial or commercial applications where high load temperatures of up to 100°C are required. In this work we review the current works on SHWSs with a view to bringing into focus their expected specific applications, cost, and ranges of performance.

The PSHWSs generally transfer heat by natural circulation as a result of buoyancy due to temperature difference between two regimes; hence they do not require pumps to function. They are the most commonly used solar water heaters for domestic application and have been designed and investigated by different researchers [3-7]. They could either be open loop (direct) or closed loop (indirect) in operation. The open loop systems circulate service water through the collector while the closed loop systems use a heat-transfer fluid to pick up solar energy from the solar collector and subsequently transfer it to the storage tank containing the service water. Natural circulation flow rate is often controlled by the insolation level. The thermosyphon systems and the integrated collector storage (ICS) systems generally fall within this category. However, the open and closed loop types can only be applied to the thermosyphon system.

Many other successfully studied the thermosyphon solar water heater. Shariah and Shalab [8] reported on the optimal design for a thermosyphon solar water heater. They used the TRNSYS, a transient simulation program, to determine the optimized design parameters for thermosyphon solar water heaters installed in Amman and Aqaba, Jordan. Shariah and Löf [9] reported the effect of auxiliary heater on annual performance of thermosyphon solar water heater under variable operating conditions. Michaelides and Wilson [10] reported on the optimum design criteria for SHWSs. In their work, they used the TRNSYS transient analysis program to perform optimization of some design criteria of SHWSs intended for residential and hotel applications .In general, technical advances in SHWS have been very rapid in the past 50 years and these advances are mainly on flat plate solar collectors. From some of the previous works in SHWS reported in Refs.[11,12], their technical feasibility, designs, and method of sizing for specific applications have been well established. However, some of these works are dedicated to a particular type of SHWS and even when and where all the types are considered, the emphasis is usually on their designs, sizing, and construction. There is therefore the need to outline factors considered for selection of each type of SHWS for particular application, field testing experiences, prospects, and economic problems affecting their popularization, and possible solutions and also determine their level of acceptability.

In the present study is prediction of thermal characteristics for solar water heater especially passive hot solar depends on Iraq weather conditions. This theoretically studied is compared with the available measurement work.

2. DESIGN CONSIDERATIONS.

The performance of all solar energy systems depends on the weather and it cause in successful application of solar heating systems. In a solar heating systems, both the energy collected and energy demanded (i.e. the heating load) are functions of the solar radiation, the ambient temperature, and other meteorological variables. The weather may be viewed as a set of time-dependent forcing functions imposed upon solar energy systems.

A flat-plate collector is the most common choice for domestic heat and hot water from solar energy, which is widely used for water heating in many parts of the world. The flat-plate collector absorbs as much as possible of the incident solar energy that falls upon it. Since the collector is normally fixed in position, the plate is close to perpendicular to the beam of sunlight (and therefore maximum absorption) for only part of the time, and the level of energy received therefore varies more strongly with time and season than does the actual intensity of the solar radiation is shown in **Fig.(1)** . A flat plate collector, shown in **Fig.(2)**, is designed for applications at moderate temperatures up to 100 ºC. They use both beam and diffuse solar radiation. It does not require any tracking of the sun .

A flat plate collector is always mounted in a stationary position (typically on a roof) and the orientation is set to the best operating position. There is also a portable flat-plate collector that can be oriented in any position. **Fig.(3)** shows the cross section of a basic flat-plate collector solar collector. It consists of the following items:

Heat transfer to the fluid depends on the thermal conductivity of the plate material and on the distance between fluid passageways. **Fig.(4)** showed the instantaneous efficiency of solar collector with different material [14] . High thermal conductivities such as copper, aluminum and stainless steel can be economically used in plate and tubes.

3. MATHEMATICAL MODEL.

The mathematical model of solar collector consists of external energy balance of absorber and internal energy balance of absorber . Model solves the energy balance of solar collector under steady-state condition were taken into considerations:

- the regular flow and in case stability in the pipeline.
- there is no energy stored in the glass cover and absorber plate.
- the neglect of the temperature difference through the glass cover.
- the properties of the fluid constant.

According to principle Hottel-Whillier [15] the useful energy output of collector can be represented as :

$$Q_{Coll} = A_c F_R \left(S - U_L \left(T_{f,i} - T_a\right)\right) \tag{1}$$

Where;

T_a : is the air temperature.

Assuming that there is no thermal loss from connecting pipes, the heat stored in the storage tank can be expressed as :

$$Q_{Coll} - Q_{Load} - Q_{SLoss} = m_s C_p \frac{dT_s}{dt} \tag{2}$$

Using eq. (1) , eq. (2) yields

$$A_c F_R \left(S - U_L \left(T_{f,i} - T_a\right)\right) - Q_{Load} - Q_{SLoss} = m_s C_p \frac{\mathrm{dT_s}}{\mathrm{dt}} \tag{3}$$

The absorbed solar radiation by solar collector can be expressed as:

$$S = H R(\tau\alpha)(1-d)(1-Z) \tag{4}$$

$$R = K_b R_b + K_d \left(1 + \frac{\cos(s)}{2}\right) + \rho_r \left(\frac{1-\cos(s)}{2}\right) \tag{5}$$

$$R_b = \frac{H_{bT}}{H_b} = \frac{H_n \cos\theta_T}{H_n \cos\theta_Z} = \frac{\cos\theta_T}{\cos\theta_Z}$$

$$\cos\theta_T = \cos(\phi - s)\cos\delta\cos\omega + \sin(\phi - s)\sin\delta$$

$$\cos\theta_Z = \sin\delta\sin\phi + \cos\delta\cos\phi\cos\omega$$

$$\delta = 23.45 \sin\left(360\left(\frac{284+\tilde{n}}{365}\right)\right)$$

$$; \ \omega_2 = \frac{180}{12}(12 - I) \ ; \ \omega = (\omega_1 + \omega_2)/2 \quad \omega_1 = \omega_2 + \frac{180}{12}$$

Where,

d is the factor takes into account the impact of dust on the glass cover.
z factor effect of the compound the edge of the solar collector on the absorber plate.
Kb, kd represent the proportion of the beam radiation to total radiation and the proportion of scattered radiation to total radiation respectively, and their values in winter as:
Kd=30%

Kb=70%

ϕ = (33°)

S= (17°)

(ω1,ω2) are beginning and end hour.

Emissivity coefficient is [15]

$$\tau\alpha = (\tau_1 \times \tau_2 \times .....\tau_n) \times \alpha_P \times (0.395) \quad (6)$$

For the purpose of calculating the overall heat loss coefficient of the solar collector the following equation is used:

$$U_L = U_t + U_b + U_e \quad (7)$$

To calculate the coefficient heat loss from the upper surface of the solar collector the following formula is used [16] :

$$U_t(s) = (1 - (s - 45)(0.00259 - 0.00144\,\varepsilon_P))U_t(45) \quad (8)$$

$$U_t = \left(\frac{N}{(344/T_P)[(T_P - T_a)/(N+f)]^{0.31}} + \frac{1}{h_w}\right)^{-1} + \frac{\sigma(T_P + T_a)(T_P^2 + T_a^2)}{[\varepsilon_P + 0.0425\,N(1-\varepsilon_P)]^{-1} + [(2N + f - 1)/\varepsilon_g] - N} \quad (9)$$

$$f = (1.0 - 0.04h_w + 5.0\times10^{-4}h_w^2)(1 + 0.058N)$$

$$h_w = 5.7 + 3.8V$$

To calculate the coefficient of thermal losses from the lower surface and sides of solar collector, as the sides of solar collector isolated the same material, Ub, Ue becomes

$$U_b = \frac{K}{L} \tag{10}$$

To calculate the energy drawn from the heat tank and the thermal heat losses from the tank ,the following equations are used:

$$Q_{Load} = \dot{m}_L C_p \left(\frac{T_{s1} + T_{s2}}{2} - T_r \right) \tag{11}$$

$$Q_{SLoss} = (UA)_s \left(\frac{T_{s1} + T_{s2}}{2} - T_a \right) \tag{12}$$

the solar energy in storage tank is calculated by using the following equation:

$$q_{Stor} = m_s C_p (T_{s2} - T_{s1}) \tag{13}$$

Average heat losses from the solar collector is calculated from the following equation:

$$q_{CLoss} = U_L (T_{s1} - T_a) \tag{14}$$

The temperature of water exits from solar collector is calculated from following equation:

$$T_{f,o} = T_{f,i} + \left(\frac{F_R A_c}{\dot{m}_c C_p} \right) \left(S - U_L (T_{f,i} - T_a) \right) \tag{15}$$

the mean fluid temperature can be expressed as:

$$T_{f,m} = T_{s1} + \frac{Q_{Coll} A_c}{U_L F_R} \left(1 - \frac{F_R}{F1} \right) \tag{16}$$

The collector heat removal factor is [17]:

$$F_R = \frac{G\, C_p}{U_L} \left[1 - e^{-\frac{U_L F1}{G\, C_p}} \right] \tag{17}$$

Where;
Cp : specific heat at constant pressure.
G : flow rate per unit area of collector.
The collector efficiency factor (F1) is constant for any collector design and fluid flow rate.
The collector efficiency factor can be determined by:

$$F1 = \frac{\frac{1}{U_L}}{W\left[\frac{1}{U_L\left[D+(W-D)F\right]}+\frac{1}{hi\,Ai}+\frac{1}{C_b}\right]} \quad (18)$$

Where;
hi : internal heat transfer coefficient of water inside risers.
Cb : bond conductance.
W, D are explained in **Fig.(5)**.

The welding thermal conductivity is calculated by:

$$C_b = \frac{K_b b}{\gamma} \quad (19)$$

Where,
b = is the thickness of welding line
K_b= conductivity thermal coefficient (400kW/m.°C)
The mean temperature of absorber plate is calculated by :

$$T_{p,m} = T_{f,m} + Q_{Coll} R_{p\_f} \quad (20)$$

And:

$$R_{p\_f} = \frac{1}{\pi D_i n L h_{f,i}}$$

Solar collector efficiency is the ratio of the useful energy output of collector to the incident solar energy and can be expressed as :

$$\eta_{Coll} = (\frac{Q_{Coll}}{HRA_c})100\% \quad (21)$$

The specification of the flat plate collector are summarized in **Table (1)**.

4. RESULTS AND DISCUSSION.

Fig.(6) shows the variation of the average solar radiation at a horizontal surface which was estimated in the day of 12th of February as recommended by Iraq weather center and note that the maximum value of average intensity solar radiation on a horizontal surface between (12-14) p.m. .February was chosen in our research in order to lower the amount of solar energy falling and overload heating is required in this month.

In Fig. (7) shows the flowing mention :

The change and behavior of the temperature of water tank during heating process of the solar collector during daylight hours in the event does not have a load of water from tank assembly during daylight hours (L=0) . We note from the figure a gradual rise of temperature of the water tank as a result of solar heating of water through the collector solar to reach a value higher at (14) o'clock in the afternoon and then begin the temperature of the water tank down and by the lack of solar radiation falling on the collector solar and a shadow effect of the grooves the surface absorber collector solar due to a decrease of energy collected and to increase thermal losses from the solar collector and the thermal reservoir .

- Where noted the possibility estimated in the day of 12^{th} of February to get (85) liters of hot water average temperature maximum 52^0C at 14 o'clock in the afternoon (end time solar heating) , this represents an increase of the water tank temperature about (33^0C) from temperature water which is supplied directly from individual reservoir at 19 C^0 in the mooring .

- Mathematical Model simulation results compared with experimental results for the purpose of speculation and convergence results were acceptable. Also shows that the maximum temperature of the water tank after heating in the practical side reach to 43^0C at 14 o'clock in the afternoon and this means that there is an increase in the temperature of the water tank 24^0C compared to the temperature of the individual reservoir at 19^0C in the mooring.

- Each run, where water passes through the solar collector temperature rise between (2^0-6^0) C and action depends on the size of the solar collector may increase up to (10^0-20^0) to provide the required quantities of hot water.

- The difference between theoretical simulation model and the experimental findings is that the conditions used in theoretical calculations is the best compared with , which depends on the quality of workmanship and materials for thermal insulation solar collector and accuracy of solar radiation incident on the surface of the collector .

Fig.(8) shows that the surface temperature of the absorber solar collector increases to reach the highest value (54.5^0C) at (14) o'clock in the afternoon because of the increased amount of radiation falling on the solar collector and then begins to decrease as a result of decreasing the amount of solar radiation falling on the solar collector and a shadow effect of the surface grooves of the collector solar absorber, that the rise in temperature inside the collector solar heat causes the water heating when passing through the pipes of the collector solar. Also that the amount and rate of flow of water to the solar collector depends on the difference between the temperature lowland water from the reservoir and the high temperature of the surface of the absorber as a result of solar heating which leads to an increase in difference density of water between the entrance and exit of the collector, and thus to increase the rate of flow of water from the reservoir to the collector.

Fig.(9) shows the efficiency of the solar collector during daylight hours. It is noted that a gradual increase in efficiency due to cold water at the beginning of the day, causing a gradual increase of the heat gain until twelve o'clock noon for theoretical result about 53.6% and for practical result about 48.4% . After it starts to decrease gradually to reach a minimum value when the gradual rise of water temperature influence of solar heating and increased emission of radiation infrared as a result of high surface temperature of the absorber solar collector and increasing loss of heat from solar collector to the higher temperature of the absorber surface, causing falling efficiency of the solar collector.

Fig.(10) shows the effect load of water during daylight hours on the energy gained. Start load was 10 liters / hour from the hot tank water at the end of 12 o'clock noon, where we note increased energy gained as a result of the difference made in the temperature between the plate absorption and cold water Provider of solar heating , improve the efficiency of the system during the process of loading, also requires limited of the water load according to require temperature . Increased energy gained and the efficiency of the solar heater with the increase in the rate of discharge of hot water from the tank water at the expense of temperature, so that the discharge rate of the heater with a certain size must be determined according to the required temperature and the efficiency of assembly.

- Mathematical simulation model can predict the performance of the solar heater to an acceptable level.
- A solar heater that works in a natural circulation of water for household use can be used due to its simplicity, where no water pump is needed there is no need for a control, a self-employed without relying on electricity and almost no need for maintenance .

6. REFERENCES.

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7. NOMENCLATURE.

Symbols	Definition	Units
A_c	Area of solar collector	m^2
C_b	Welding thermal conductivity	W/m.°C
C_p	Specific heat of water	J/kg.°C
D	External diameter of tube	m
D_i	Internal diameter of tube	m
F_R	Removal factor of solar collector	-
F'	Efficiency factor of solar collector	-
G	Mass flow per unit area	$kg/sec.m^2$
h_w	Wind heat transfer coefficient	$W/m^2.°C$
h	Heat transfer coefficient between fluid and internal tube wall	$W/m^2.°C$
H	solar radiation incident on horizontal surface	W/m^2
H_T	solar radiation incident on the solar collector	W/m^2

K	Thermal conductivity	W/m.°C
L	Riser length	m
$\dot{m}$	Mass flow rate of water	kg/sec
$\dot{m}_c$	Mass flow rate of water passing through the solar collector	kg/sec
$\dot{m}_L$	Load water flow rate	kg/sec
m_s	Mass of water in the tank	kg/m^2
N	Number of glass covers	-
n	Number of risers	-
Q_{Coll}	Solar energy collector	W
Q_{Load}	Thermal energy drawn from the thermal tank	W
Q_{CLoss}	Energy lost from the solar collector to the environment	W
Q_{Stor}	Energy stored in the tank	W
R	Ratio of total solar radiation	-
S	Solar energy absorbed	W
s	Inclination angle of the solar collector	degree
t	Time	hr
T_a	Air temperature	°C
$T_{f,i}$	Inlet water temperature tor solar collector	°C
$T_{f,o}$	Outlet water temperature from solar collector	°C
$T_{f,m}$	Mean external temperature from solar collector	°C
$T_{p,m}$	absorber plate mean temperature	°C
T_P	Temperature of absorbed plate	°C
T_s	Temperature of water tank	°C
T_{s1}	Temperature of water tank at the beginning of hour	°C
T_{s2}	Temperature of water tank at the end of hour	°C
$(UA)_s$	Coefficient of thermal losses from heater tank	W/°C
U_L	Coefficient of thermal losses from solar collector	$W/m^2.°C$
U_t, U_b, U_e	Coefficient of thermal losses from the upper and lower surface and behind solar collector	$W/m^2.°C$
V	Wind energy	m/sec
V_{st}	Size of heater tank	m^3
W	Distance between centers of two tubes	M
γ	Thickness of the welding line	M
δ	Angular position of the sun at the time of the back of the level of the equator	egree
ε	Emissivity coefficient	-
η_{Coll}	Efficiency of solar collector	%
η_{DColl}	Efficiency daily of solar collector	%
θ	Fall angle of solar radiation	Degree
ρ_r	Reflection coefficient	-
τ	Emission factor	-
ϕ	Angle of latitude	Degree
ω	Hour angle	Degree

Table (1): Specification of flat plate solar collector.

Items	Dimensions and specifications
Glass cover	Glass Jerry glass cover Permeability coefficient: 0.96 Refractive index: 1.52 The number of covers (N) = 2 Thickness: 4 mm Air space between covers = 9.5mm Air space between inner cover and absorber plate = 42mm
Absorber collector	galvanized iron plate absorber Coefficient of thermal conductivity °C: 66.99 W / m. Type of coating: black chrome Absorptive coefficient: 0.95 Emission factor: 0.1 Inner tube diameter: 10 mm Outer tube diameter: 12.5 mm The number of rises tubes (n)=13
Insulation	glass wool insulation Coefficient of thermal conductivity°C: 0.038 W / m. Thickness of the insulating material (C): 8.9 mm Metal Type: Stainless steel structure of the solar collector
Area of collector system	Gross = 2.74 m^2 Aperture = 2.34 m^2 Inclination angle of the solar collector is $32^{0.}$ Collector system tiled at an angle within the range of latitude 45^{o} south direction to Baghdad city,. February month. Mass flow rate in the mooring : 48.87 kg/h

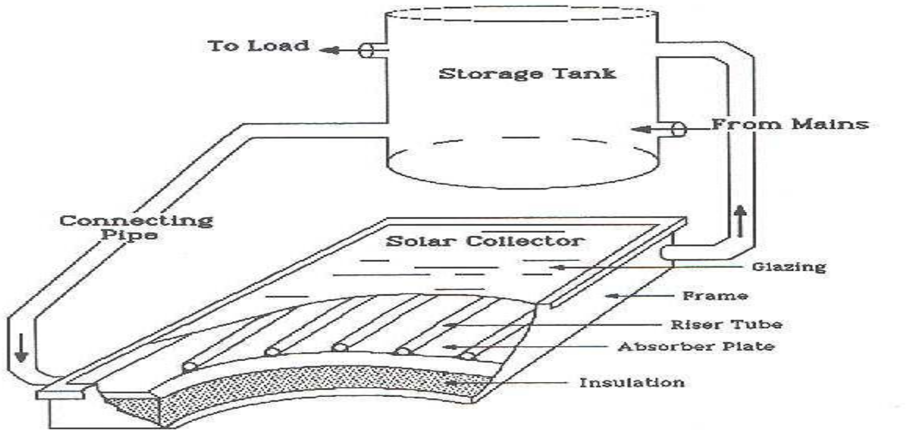

Figure (1): solar system showing flat plate collector cross section.

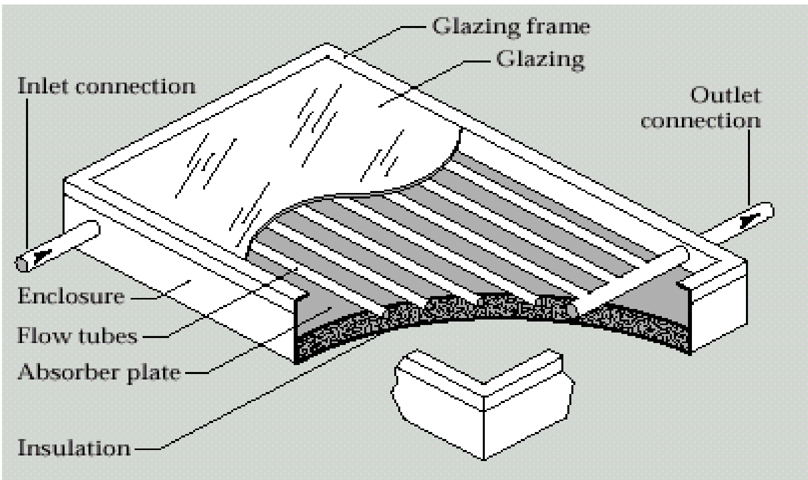

Figure (2): flat plate collector [13].

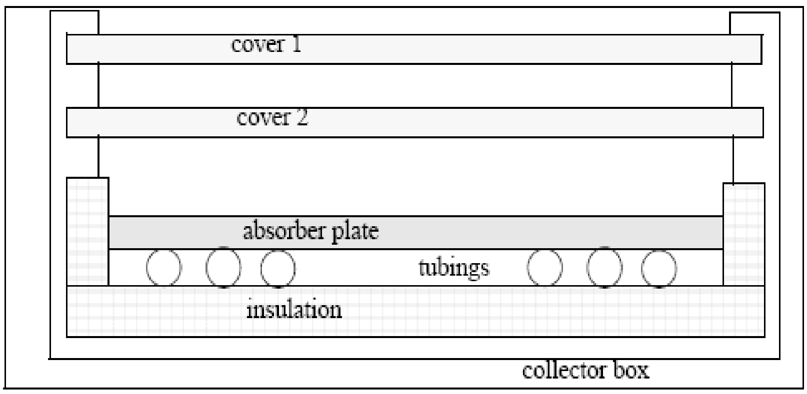

Figure (3): Cross section of a flat plate collector.

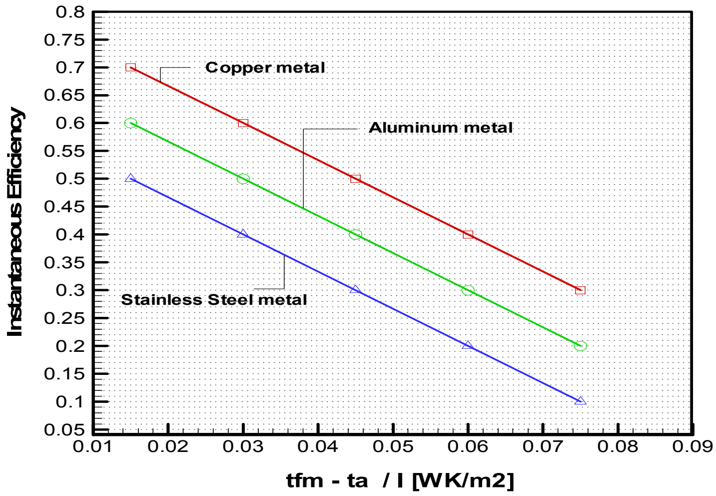

Figure (4): Instantaneous efficiency of solar collector with different material [14].

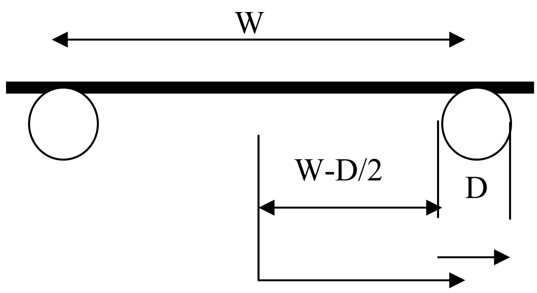

Figure (5): Explain the distance and diameter of tubes.

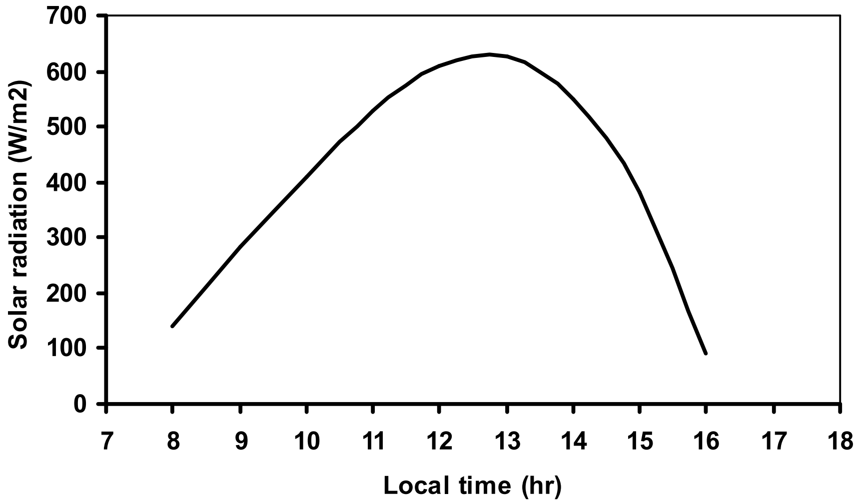

Figure (6): History of average solar radiation for Baghdad city at February month.

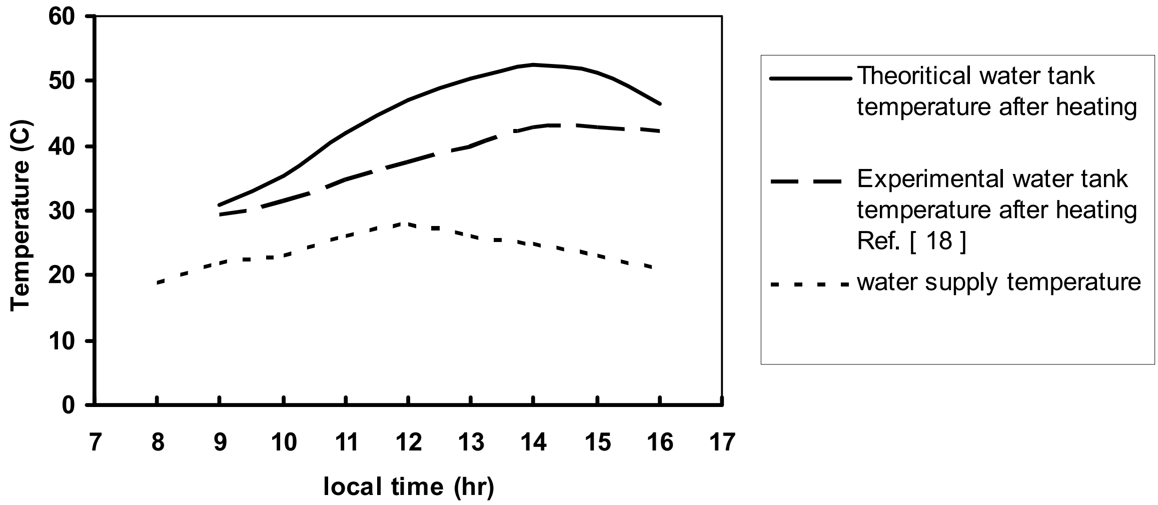

Figure (7): Variation between temperature and local time.

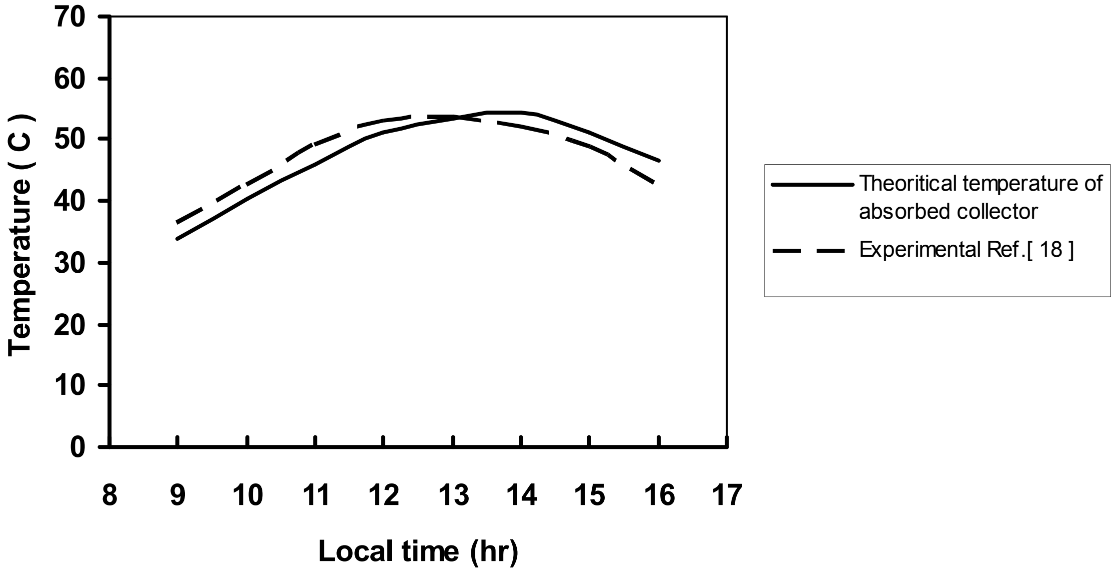

Figure (8): Variation between temperature of absorbed collector and local time.

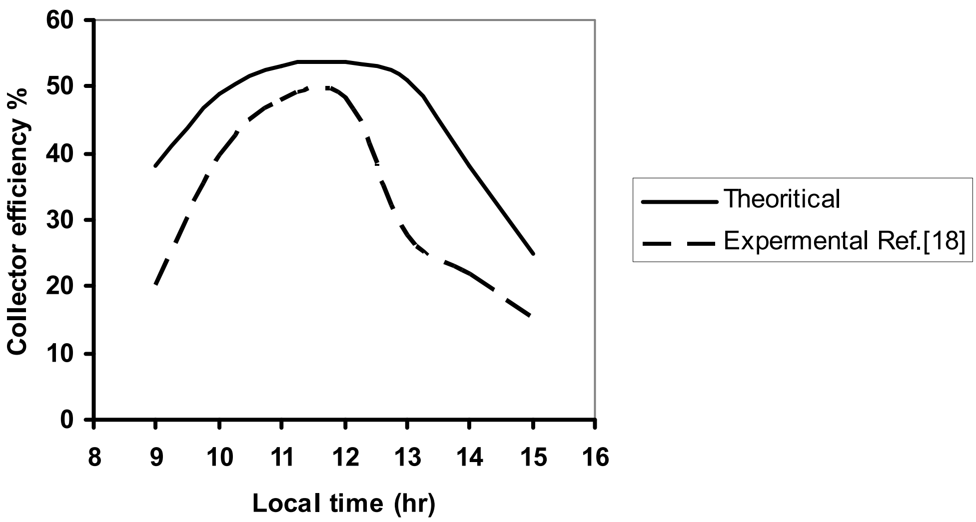

Figure (9): Variation of efficiency of solar collector system with local time.

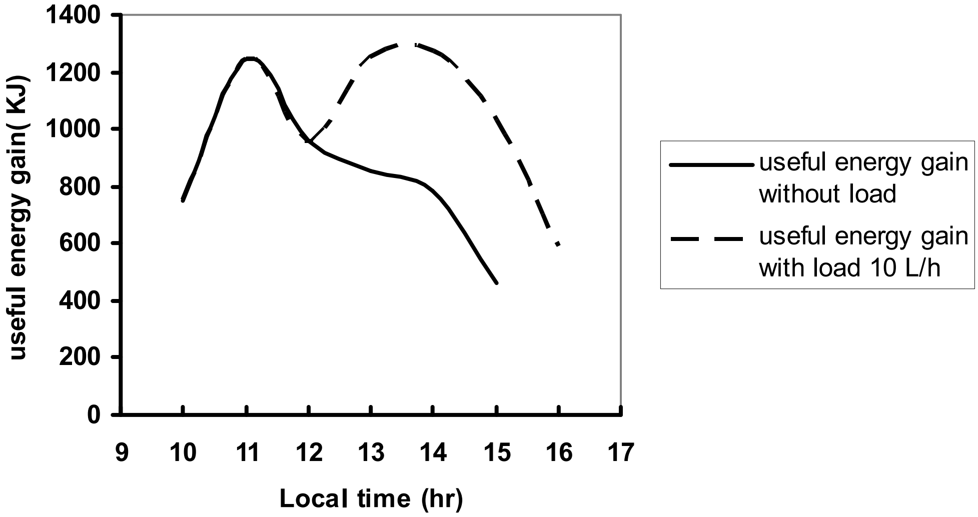

Figure (10): Variation of useful energy gain without load from water tank and with load 10 liter per hour from storage water tang at afternoon of local time .

تخمين الخصائص الحرارية لسخان الماء الشمسي

د . سعد طامي حميدي م. محمد علي فياض

مركز بحوث الوقود والطاقة

الجامعة التكنولوجية

العراق / بغداد

الخلاصــــة.

البحث درس تخمين الخصائص الحرارية لسخان ماء شمسي مفتوح من نوع اللوح المستوي مساحته 2.34م^2 موصل بخزان ماء سعته 85 لتر. تم تمثيل موديل رياضي واجراء الحسابات الخاصة بالمنظومة من خلال ايجاد المعاملات والمعادلات الرياضية وحلها عدديا بأستخدام طريقة الفروق المحددة البينية (FDM) . بينت نتائج البحث الحصول على ماء ساخن بدرجة حرارة بحدود 52^0 مئوية عند الساعة الثانية بعد الظهر خلال شهر شباط على اعتبار إن درجة حرارة الجو في هذا الشهر تمثل أدنى درجات الحرارة خلال السنة في مدينة بغداد ، مع معدل كفاءة عمل المنظومة تصل لغاية 53.6 % . تقيم الدراسة تم مقارنتها مع قياسات ونتائج عملية سابقة واكدت تلك النتائج تطابق جيد .

كلمات رئيسية : طاقة شمسية ، سخان شمسي ، جامع حراري ، كفاءة الحرارية .