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Experimental and Theoretical Calculation of Efficiency for Flat Plate Solar Collectors in Erbil City

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ABSTRACT

Solar plate collectors are utilized to heat up water or a mixture of water and glycol by capturing solar radiation and transfer this heat to the collector fluid. In this study, the efficiency of solar plate collector during 19th, 20th and 21st of February, was investigated experimentally. The time of day, plate collector mean temperature, solar intensity and external air temperature can effect on the efficiency of solar collector. And the effect of incidence angle on solar irradiation has been studied; as a result, the solar irradiance will be decreased as the angle of incidence increased. A method presented can be used to calculate hour angle, diffuse solar radiation and total solar radiation at various temperatures in this paper its MATLAB programs.

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1. Introduction

Nowadays, the solar flat plate collector is widely used to transfer as well as absorb solar energy radiation for working in low-temperature (up to 60℃) or medium temperature (up to 100◦C). The solar thermal energy has increased and become a significant source of renewable energy, because of increase in the effect of the environmental as well as rising cost of fuels type (i.e., oil or gas, such as the heating of the global, greenhouse effects, the pollution of the air, reduction of the ozone layer. The solar thermal systems, photovoltaic (PV), as well as designing passive solar are a principal input for solar thermal energy application of solar radiation data for optimization, designing and evaluation of the efficiency of solar technologies for any position, a reliable as well as readily available data is needed. Due to unable to afford the techniques involved and measuring equipment, the measurements of solar radiation is difficult for various developing countries. To evaluate the amount of solar energy radiation on the horizontal plane surface, many models have been invented by utilizing the climatic parameters, minimum and maximum the temperature of the ambient, humidity, sunshine duration and the speed of the wind [1-6]. For appropriate designing of solar energy systems, as well as a great evaluation of thermal energy surrounding within buildings, the acknowledge of the local solar radiation is important for that purpose [7-11]. Solar thermal energy collector is a type of heat exchanger that converts solar radiation energy which is coming from the sun into internal energy [12]. Solar collector absorbs the solar radiation energy and transforms it into heat then this heat is transferred to a fluid that passes through the collector, where the absolute performances of various material such as collector absorbing, glazing materials, as well as utilized fluids are used to estimate these conversions.

Mongre and Gupta [13] experimentally studied the solar collector efficiency by combining the system of the solar collector water heater with a circulating pump and utilizing of aluminum tube. As a result, by increasing the glazing area the efficiency of the system was increased by 55.24%. The solar plate collector performance has been calculated experimentally under specified outdoor and indoor test procedures [14, 15]. Weitbrecht et al. [16] investigated solar flat plate collector experimentally. The distribution of fluid flow pass through the collector has been observed. Hammad [17] reported that the solar plate collector performance which is cooled by a set of heat pipes, manufactured and designed to operate at low-temperature conditions. As a results, the efficiency of the system was fulfilled about 60%, where the value of this efficiency was equal to that of the water cooled collector. Miguel et al. correlation [18, 19] have been implemented to determine the hourly values of diffuse as well beam components of solar irradiance from global total solar irradiance. Rasmussen and Svendsen [20] performed a simulation program SOLEFF, for determining the efficiency of solar flat plate collectors. Merriam et al.[21] investigated that for high-temperature outputs, the solar flat plate collectors are not frequently used. The solar flat plate collector suffers from the losses of the heat because of convection, conduction. The losses of heat increase with the working fluid temperature [22]. The present aim of this paper is to experimentally calculate the efficiency of solar plate collector on 19th, 20th, and 21st February for various water temperatures.

2. Experimental method procedures

The analysis of the thermal solar collector flat plate which is made of copper plate was performed experimentally. To absorb solar energy radiation, the absorber of the black solar flat plate collector which is covered with a double glass of 6 mm. The material of mineral wool of thickness 4.6 cm was utilized to insulate the bottom of the solar collector to minimize the loss of the heat through the absorber plate which is occurred by conduction. The earth rotates about its axis in every 24 hours, this revolution gives 15° for every 1 hour. A water reservoir was made of aluminum with a capacity of 196 liters, thickness 5 mm, and thermal conductivity of 204.2 W/(m.K) was used to supply water to the collector. The experiments were conducted with coordinates (36.2063° N, 44.0089° E) on 19th, 20th and 21st February 2015. The temperatures were taken through a thermocouple every 30 min during daylight from 8:30 am to 2:30 pm and with changing the sun position, the position of the solar plate collector was changed as well. Regarding the diffuse radiation as well as direct radiation, the location of the solar collector was oriented to receive both of them. The solar plate collectors are influenced extremely by the angle of inclination [23, 24]. The maximum value of solar plate collector was achieved with 45° of inclination angle from a horizontal surface. The water is circulated due to density difference; the discharges of water and the temperature of the ambient were 1.89 liter/min and 31℃, respectively. By utilizing the thermocouple, the input and outlet water temperature were measured. Figure 1 shows the solar flat plate collector components.

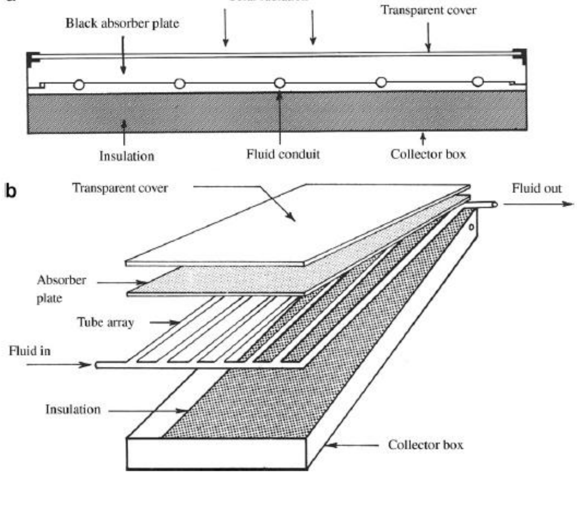

Fig. 1 Solar collector components. [25]

3. Mathematical Modeling

The δ can be calculated from equation of [26].

$$\delta = 23.45 sin\left(360\frac{284+n}{365}\right) \tag{1}$$

Where n is the day of the year and obtained from [30]. Thus, $1 < n < 365$.

$$B = (n-1)\frac{360}{365} \tag{2}$$

The beam incidence angle radiation on a surface θ can be calculated as;

$$cos\theta = sin\delta\ sin\emptyset\ cos\beta - sin\delta\ cos\emptyset\ sin\beta\ cos\gamma + cos\delta\ cos\emptyset\ cos\beta\ cos\omega + cos\delta\ sin\emptyset\ sin\beta\ cos\omega \tag{4}$$

The sun zenith angle, θ_z can be calculated as;

$$cos\theta_z = cos\delta\ cos\emptyset\ \ cos\omega + sin\emptyset\ sin\delta \tag{5}$$

The solar time and standard time can be calculated according to:

$$Solar\ time - standard\ time = 4(L_{st} - L_{1oc}) + E \tag{6}$$

The equation of time and can be calculated from

$$E = 229.2(0.000075 + 0.001868\ cosB - 0.032077\ sinB - 0.014615\ cos2B - 0.04089\ sin2B) \tag{7}$$

The solar plate collector thermal energy lost can be find from the following equation.

$$\mathrm{Q_u} = F_R * \mathrm{A_c}\left[G_{sc} * \tau * \alpha - \mathrm{U_L}\left(\mathrm{T_{pm}} - \mathrm{T_a}\right)\right] \tag{8}$$

Where A_c is the Collector area, G_{sc} Solar constant, τ the transmittance, α the Absorptance.

Equation (8) which is known as the "Hottel-Whillier-Bliss equation" is commonly utilized relationship for measuring collector energy. The value of F_R can be calculated as:

$$F_R = \frac{\dot{m}C_p}{A_cU_L}\left[1 - exp\left(-\frac{A_cU_LF'}{\dot{m}C_p}\right)\right] \tag{9}$$

Where F' can be taken as 0.841[27]

The collector solar radiation received is determined by:

$$(\mathrm{Q_i}) = G_{sc} * \mathrm{A_c} \tag{10}$$

Where the value of G_{sc} is $1367(W/m^2)$.

A collection efficiency cab be found from equation:

$$\eta = \frac{\mathrm{Q_u}}{\mathrm{Q_i}} \tag{11}$$

Substitute eq. (10) in eq. (11) we get:

$$\eta = \frac{\mathrm{Q_u}}{G_{sc} * \mathrm{A_c}} \tag{12}$$

$$\eta = \frac{F_R * \mathrm{A_c}\left[G_{sc} * \tau * \alpha - \mathrm{U_L}\left(\mathrm{T_{pm}} - \mathrm{T_a}\right)\right]}{G_{sc} * \mathrm{A_c}} \tag{13}$$

$$\eta = F_R * \tau * \alpha - F_R * \mathrm{U_L}\left(\frac{\mathrm{T_{pm}} - \mathrm{T_a}}{G_{sc} *}\right) \tag{14}$$

The direct irradiance of solar rays can be expressed as [281]:

$$\mathrm{I_{DN}} = \mathrm{A}\exp\left(-\frac{\mathrm{B}}{\mathrm{sina}}\right) \tag{15}$$

Where (a) is the solar altitude, A is the apparent solar irradiance at zero air mass, and B is the extinction coefficient. $For\ 21\ February\ A = 1215(W/m^2)\ , B = 0.144(W/m^2)\ and\ C = 0.06(W/m^2)$[29]:

The solar elevation angle can be determined from

$$\mathrm{sina} = \cos\emptyset\ \cos\delta\ \cos\omega + \sin\emptyset\ \sin\delta \tag{16}$$

Diffuse radiation from the sky

$$\mathrm{I_d} = \mathrm{C} * \mathrm{I_{DN}} * \mathrm{F_{ws}} \tag{17}$$

F_{ws} view factor is given by

$$F_{ws} = \frac{1 + \cos\beta}{2} \quad (18)$$

The value of β for horizontal is 0° and for vertical surface is 90°. Also, the reflected shortwave (solar) radiation can be expressed as:

$$I_r = (I_{DN} + I_d) * \rho g * F_{wg} \quad (19)$$

Where $\rho g = 0.6$ is the reflectivity of the ground, and F_{wg} is the view factor between the surface and earth, is calculated by:

$$F_{wg} = \frac{1 - cos\beta}{2} \quad (20)$$

The total solar irradiance I_T (W/m^2) of a surface of any orientation can be calculated according to this formula.

$$I_T = I_{DN} * cos\theta + I_d + I_r \quad (21)$$

4. Discussion and Results

The experimental test was performed to evaluate the efficiency of the solar plate collector in environmental conditions. The data of temperatures were taken during 13 hours from 8:30 am to 2:30 pm and translate it into MATLAB program and the following results were obtained.

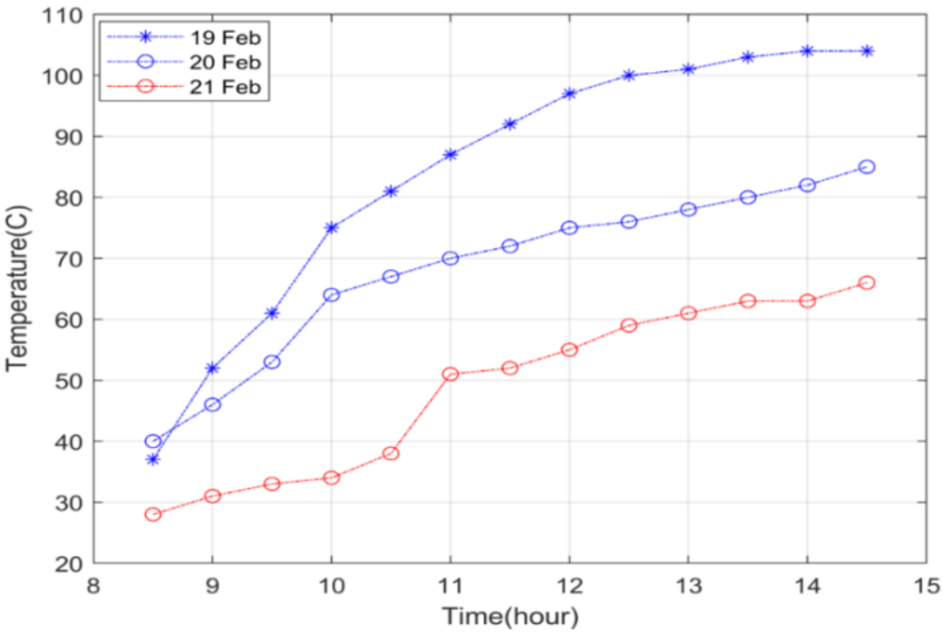

Fig. 2 The temperature of the water variation with solar time on 19th, 20th and 21st February

Figure 2 presents the temperature of the water variation with time in a sunny day of 19th, 20th, and 21th February 2018. The temperature of the water increases as the time increases from 8:30 to 14:30. It is seen that the maximum water temperature at 2:30 pm occurred. The maximum possible water temperature of solar collector on 19th, 20th and 21st was achieved as104°C, 85°C and 66°C, respectively. Figure 3 depicts the variation of solar collector efficiency with hourly time. It is clear that as time increased the collector efficiency is decreasing gradually. It can be easily observed that, the solar plate collector on 21st February gives maximum efficiency is of 74.8% at the beginning of the day. The diffuse irradiance $I_d$was calculated based on equation (17) for various values of the angle of incidence θ for (36.2063° N latitude, 44.0089° E longitude). Figure 4 illustrates the relationship between diffuse irradiance I_d and incidence angle θ at tilt angle 40°. The results show that as the angle of incidence increases the diffuse irradiance decreases. It is also noticed that on 19th, 20th, and 21st February there is a few differences between the value of diffuse irradiance I_d. As shown in Figure 5 the total solar irradiance (I_T) which is calculated from Eq. (21) is plotted against the hourly time. The maximum value of solar energy irradiation (I_T) occurs at solar noon and reached about $170\,W/m^2$ on

19th February. After 12 pm it started to decrease until reached115 W/m^2. The curve of the solar irradiance (I_T) is smooth that means there is no effect of atmospheric conditions such as cloud cover.

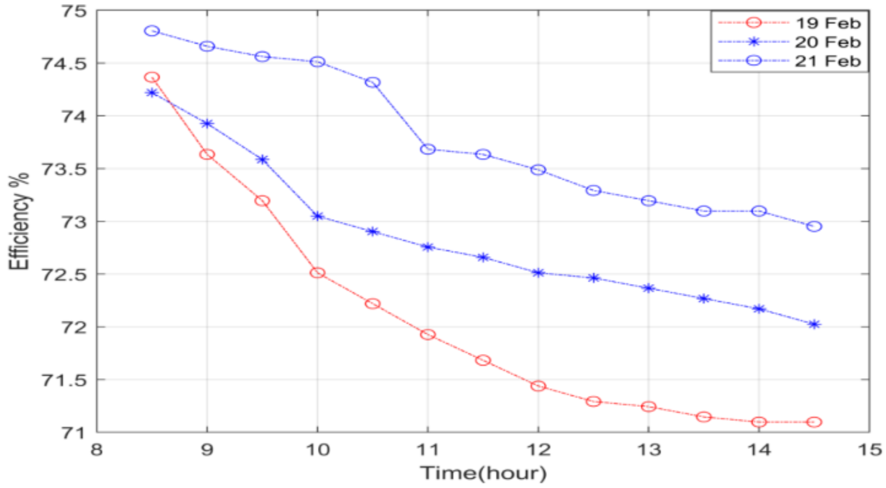

Fig. 3 The collector efficiency variation with a solar time on 19th, 20th and 21st February

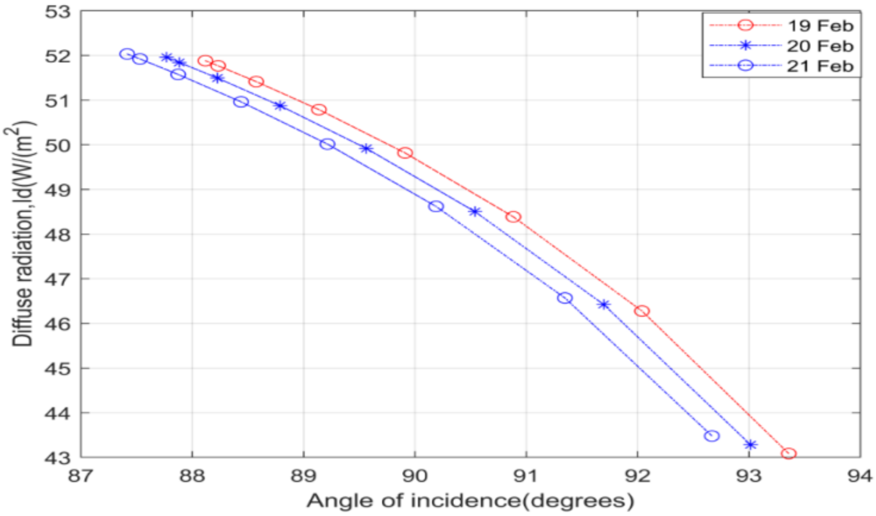

Fig. 4 The diffuse radiation variation with solar time

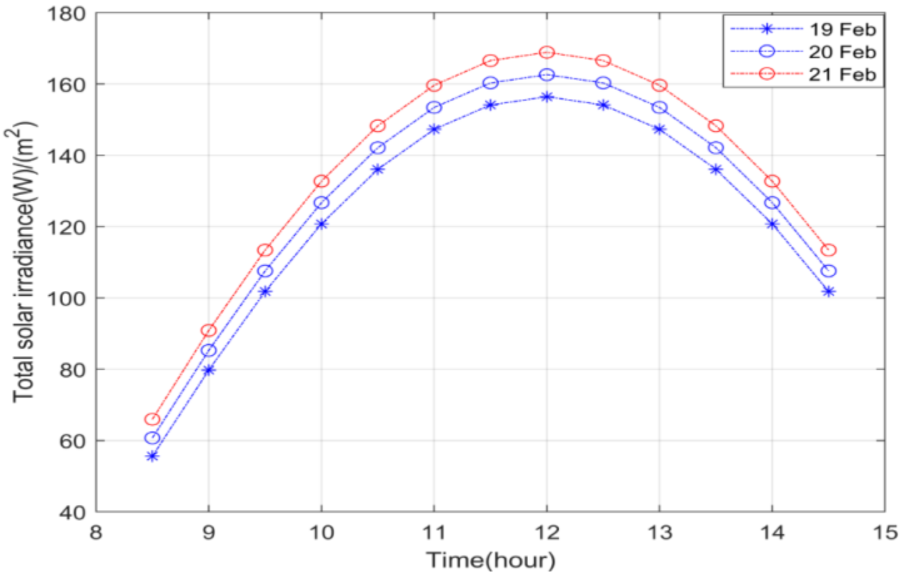

Fig. 5 Daily changes of total solar energy irradiation

5. Conclusion

The main objective of this paper was a determination efficiency of solar plate collector which is the ratio of the thermal energy useful over incident solar energy. The efficiencies of solar plate collectors are strongly depending on solar radiation as well the temperature of the external air. The efficiency of solar collector decreased as time increased conversely, the temperature of water outlet increased with time. For an ambient temperature of 31℃, the maximum value of solar collector efficiency on 19th, 20th, and 21st was achieved as 74.4%, 74.3%, and 74.8%. On the other hand, the measured data were utilized to determine the relationship between incidence angle with a diffuse radiation, and total solar irradiance with hourly time, the results show that the diffuse radiation inversely changed with incidence angle and the highest possible value of solar irradiance can be achieved at solar noon.

Nomenclature

A_c	Collector area(m^2)	I_d	Diffuse radiation (W/m^2)
T_a	Ambient temperature(℃)	θ	Angle of incidence, degrees
C_P	Specific heat (kj/$kg.K$)	I_r	Reflected radiation (W/m^2)
U_L	Heat transfer coefficient(W/m^2K)	ρg	Reflectivity of the ground
E	Energy, equation of time	I_T	Total solar irradiance (W/m^2)
α	Absorptance	τ	Transmittance
F_R	Collector heat removal factor	$\dot{m}$	Mass flow rate (kg/s)
β	Tilt angle, degrees	∅	Latitude, degrees
F'	Collector efficiency factor	Q_u	Thermal energy lost(W)
γ	Surface azimuth angle, degrees	ω	Hour angle, degrees
G_{sc}	Solar constant, (W/m^2)	S	radiation absorbed flux(W/m^2)
δ	Declination, degrees	α	Absorptance
I_{DN}	Direct solar irradiance (W/m^2)	T_{pm}	absorber plate temperature(℃)
η	Efficiency %	a	Solar altitude

L_{st} standard meridian
L_{1oc} longitude of the location

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