The study of affecting parameters on thermal loss coefficients in solar collector

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Abstract

Thermal loss coefficients of flat plate collector are mainly influenced by a large number of parameters. These parameters could be classified as design, operational and environmental, In this work the effects of some of these will considered, ambient temperature, wind velocity, tilt angle, air gap and absorber plate temperature. The results showed that values of losses coefficient using empirical correlation of Malhorta from (4.1- 12.2 $W/m^2.K$) for ambient temperature at absorber plate temperature (25 and 70 °C), the loss coefficient was observed to increasing gradually (7.2 – 8.9) with increasing wind velocity at (1-5m/s), also the losses coefficient decreases (7.5- 5.5 $W/m^2.K$) as the air gap spacing increasing (0.02- 0.1m), the losses factor progressively drops from (7.8-6.55 $W/m^2.K$) with higher values of tilt angle (5-50 degree) and the results indicates that the losses coefficient increasing (7.32-7.8 $W/m^2.K$) as the ambient temperature (10-60 °C) also increases.

1. NTRODUCTION

Solar energy collectors are special kind of heat exchangers that transform solar radiation energy to internal energy of the transport medium. The major component of any solar system is the solar collector. This is a device which absorbs the incoming solar radiation, converts it into heat, and transfers this heat to a fluid (usually air, water, or oil) flowing through the collector. The solar energy thus collected is carried from the circulating fluid either directly to the hot water or space conditioning equipment, or to a thermal energy storage tank from which can be drawn for use at night and/or cloudy days. There are basically two types of solar collectors: nonconcentrating or stationary and concentrating. A nonconcentrating collector has the same area for intercepting and for absorbing solar radiation, whereas a sun-tracking concentrating solar collector usually has concave reflecting surfaces to intercept and focus the sun's beam radiation to a smaller receiving area, thereby increasing the radiation flux. A large number of solar collectors are available in the market. An energy efficient solar collector should absorb incident solar radiation, convert it to thermal energy and deliver the thermal energy to a heat transfer medium with minimum losses at each step. It is possible to use several different design principles and physical mechanisms in order to create a selective solar absorbing surface. Solar absorbers are based on two layers with different optical properties, which are referred as tandem absorbers. A semiconducting or dielectric coating with high solar absorptance and high infrared transmittance on top of a non-selective highly reflecting material such as metal constitutes one type of tandem absorber. Another alternative is to coat a nonselective highly absorbing material with a heat mirror having a high solar transmittance and high infrared reflectance [1]. Reduction of heat loss from the absorber can be accomplished either by a selective surface to reduce radiative heat transfer or by suppressing convection. Francia [2] showed that a honeycomb made of transparent material, placed in the airspace between the glazing and the absorber, was beneficial. Many researchers studies parameters which increasing the performance of solar collector ,Gary and Rani [3] considered the heat loss and the collector efficiency under different conditions, Hottel and Woertz [4] analyzed the estimation of energy transferred to the glass cover and after that Tabor [5] has modified the equation of Hottel .Klein [6,7] used the modified equation . Mullick SC, Samdarshi SK [8] improved technique for computing the top heat loss factor of flat-plate collector with a single glazing, Malhotra A, Garg HP, Palit A.[9] evaluation of the heat loss of flat-plate solar collectors, Pillar and Agarwal [10] had reported on the optical and thermal analysis for optimizing a set of α and ε values for solar energy applications.

The objective of the present work is to evaluate loss coefficient under some different parameters such as ambient temperature, wind velocity, tilt angle, air gap and absorber plate temperature by using empirical correlation Malhorta method.

2. ANALYTICAL APPROACH

Figure 1 shows schematically the cross sectional views and the thermal network of the solar collector investigated in the present work. The following analysis is based on energy balance at various components of the collector models, along with the different heat transfer coefficients at their surfaces. The assumptions made are [11]:

- Heat transfer is steady and one dimensional
- The temperatures of the glass, absorber and bottom plates vary only along the x-direction of the air flow
- There is no leakage from the smooth flow channels

- The absorption of solar radiation in the cover is neglected insofar as it affects loss from the collector
- Heat losses through the front and back of collector are to the same ambient temperature

Heat losses from any solar water heating system take the three modes of heat transfer (radiation, convection conduction). The radiation losses occur from the absorber plate due to the plate temperature. The convection heat losses take place from the absorber plate to the glazing cover and can be reduce by evacuating the space between the absorber palte and the glazing cover and by optimizing the gap between them. The conduction heat losses occur from sides and the back of the collector plate. **Figurer 1** shows the heat loss pattern in a typical flat-plate collector. The heat losses from the transparent cover to the ambient air are due to radiative and convective exchanges with are affected by the wind velocity, ground surrounding condition and by long wave radiation from the sky.

The major of heat loss from the collector is from the bottom loss coefficient Ub and sides loss coefficient Us are evaluated by considering only the conduction losses from the absorber plate in the downward direction. the top loss coefficient Ut is evaluated by considering convection and re-radiation losses from the absorber plate in the upward direction. It is assumed that the transparent cover and the absorber plate constitute a system of infinite parallel surfaces, heat flow is steady and in one dimension. It is also assumed that the temperature drop across the thickness of the cover is negligible such that the interaction between the incoming solar radiation and the outgoing radiation is negligible [12]. It is assumed that the thickness of insulation material is such that the thermal resistance associated with conduction dominates over the convective loss. Thus, neglecting the convective resistance, the heat flow becomes steady and in one dimension.

The heat loss coefficient is a function of different parameters which include the ambient temperature ,tilt angle, wind speed, humidity, glass cover, air gap, temperature of the absorber plate, emissivity of absorber and glass cover, thermal conductivity of insulation material and its thickness and others parameters

The overall heat loss coefficient is a complicated function of the collector construction and its operating conditions, given by the following expression:

From nergy balance of the solar collector under steady-state conditions useful energy output of collector can be represented as :

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

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 :

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

The compensation equation (1) in equation (2) yields

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

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

$$S = H\, R(\tau\alpha)(1-d)(1-Z) \quad (4)$$

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

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

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

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

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

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

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^o)

(ω1,ω2) are beginning and end hour.

Emissivity coefficient is [9]

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

The overall heat loss coefficient is a complicated function of the collector construction and its operating conditions, given by the following expression:

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

The energy loss from the bottom of the collector is first conducted through the insulation and then by a combined convection and infrared radiation transferred to the surrounding ambient air. Because the temperature of the bottom part of the casing is low, the radiation term (*hr,b-a*) can be neglected; thus the energy loss is given by [13]:

$$U_b = \frac{1}{\frac{t_b}{K_b} + \frac{1}{h_{c,b}}} \qquad (8)$$

In a similar way, the heat transfer coefficient for the heat loss from the collector edges can be obtained from [13]:

$$U_e = \frac{1}{\frac{t_e}{K_e} + \frac{1}{h_{c,e}}} \qquad (9)$$

The top loss coefficient of the collector by using empirical correlation Malhorta method [14]

$$U_t = \frac{1}{\dfrac{N}{\dfrac{C}{T_p}\left[\dfrac{T_p - T_a}{N+f}\right]^{0.252} + \dfrac{1}{h_w}}} + \frac{\sigma(T_p^2 + T_a^2)(T_p + T_a)}{\dfrac{1}{\varepsilon_p + 0.0425N(1-\varepsilon_p)} + \dfrac{2N+f-1}{\varepsilon_g} - N} \qquad (10)$$

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

$$h_w = 5.7 + 3.8V$$

$$U_t(s) = \left(1 - (s-45)(0.00259 - 0.00144\varepsilon_P)\right)U_t(45)$$

To calculate the energy drawn from the heat tank and the thermal heat losses from the tank is by using the two equations respectively, the following:

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

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

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

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

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

$$q_{CLoss} = U_L \left(T_{s1} - T_a\right) \quad (14)$$

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

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

the mean fluid temperature can be expressed as: (16)

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

The collector heat removal factor is [10]:

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

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 determining 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.(3):

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)

3. RESULTS AND DISSCUSION

- **Figurer 2** show the relation between top losses coefficient with absorber plate temperature of solar collector under different ambient temperatures (15, 25, 45 and 50 C). Top loss coefficients decreases linearly (11.2 - 4.9 W/m2.K) with increasing in absorber plate temperature of solar collector until ambient temperature 50 C increasing exponentially (3.8 – 4.4 W/m2.K) with increasing in absorber plate temperature of solar collector .

Figure 3 indicat the effect of the wind velocity on the overall heat-loss coefficient of the flat plate solar collector (1-5 m/s) on the losses coefficient, was observed increasing gradually from (6.1 – 7.9) with increasing wind velocity due to increased convective and radiative losses from the glasing cover to the surrounding.

- **Figurer 4** note the influence of the air gap spacing between the absorber plate and the glassing cover (0.02 - 0.10 m) wich indicat that losses coefficient of solar collector dcreases with increasing air gap spacing (6.5-4.5 w/m2.k) so that required to optimiz this gap to reduces convective heat losses from the absorber plate to the glassing cover.

- **Figurer 5** effect of the collector tilt angle was observed that it the losses coefficient is insignificantly affected by variation in tilt angle (5-50 degree C) ,the losses coefficient progressively drops (6.8-6.32 W/m2.K) with higher values of tilt angle .

- **Figurer 6** correlation between the over all heat losses coeficient and the ambient temperature srounding solar collector , the result indicates that the losses coefficient increasing (7.32-7.8 W/m2.K) as the ambient temperature (10-60 C) also increases, from figurer observed that for a 10 C rise in the ambient temperature ,the losses coefficient increases about 0.07, this trend that the collector losses will be minimum in morning.

4. CONCLUSION

- Theortical analysis was performed on a flat plate collector with a single glass cover.The values of loses coefficient predicted according to emperical correlation of Malhorta laid between (4.5-11.2 W/m2.K) for different paramerts.
- The degree of the effect of these parameter on the collector performance as has been shows is a strong guide for designers and users for optimization of the system design and its operation of solar flate plate collector

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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

Smbols	Definition	Unit
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 range for different parameters

Variable	Range
Wind speed	1-5 m/s
Ambient temperature	25-70 C
Tilt angle for collector	5-50 degree
Air gap	0.02- 0.10 m
Absorber plate temperature	25,45,65 C
Absorber plate emittance	0.96
Glass cover emittance	0.94
Dimension	1.5*0.8 m

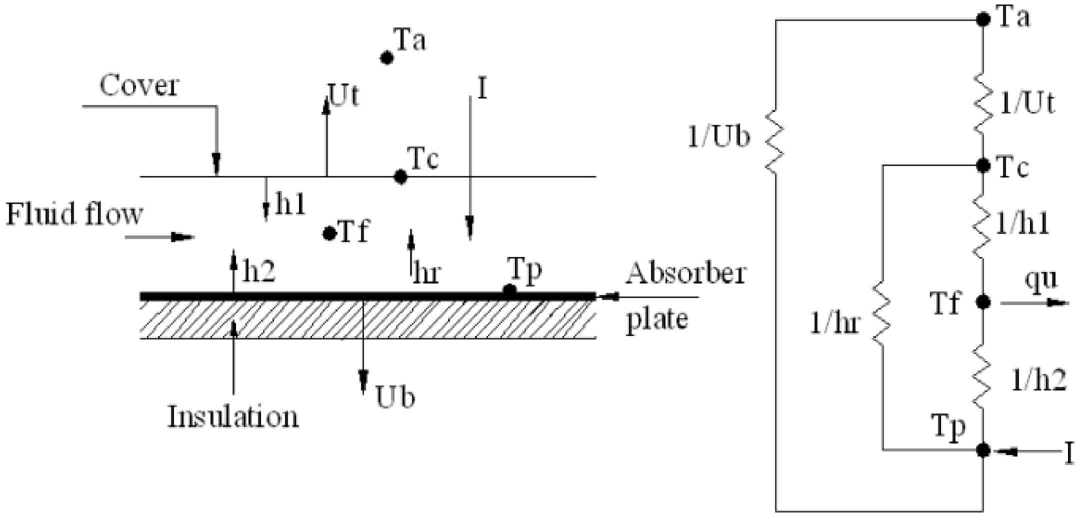


Figure 1 Thermal network for single glass cover flat plate collector

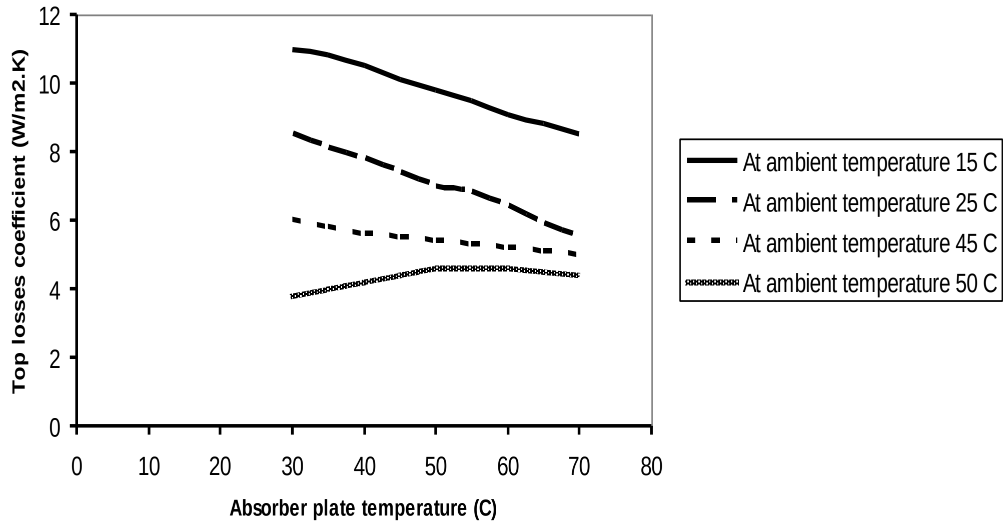


Figure 2 correlation between losses coefficient with Absorber plate temperature for solar collector

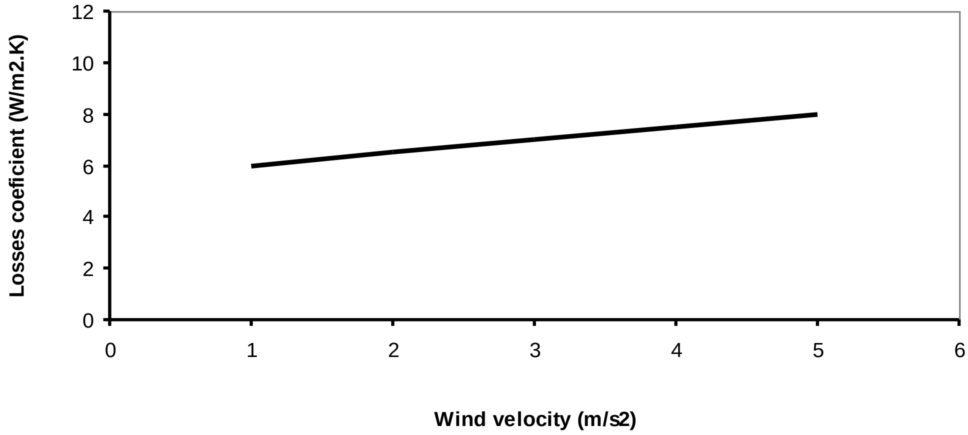


Figure 3 Relation between losses coefficient with wind velocity over solar collector

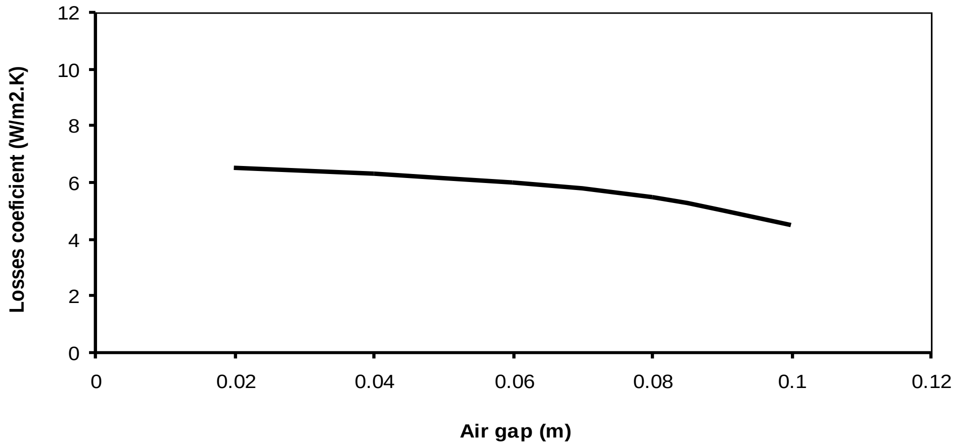
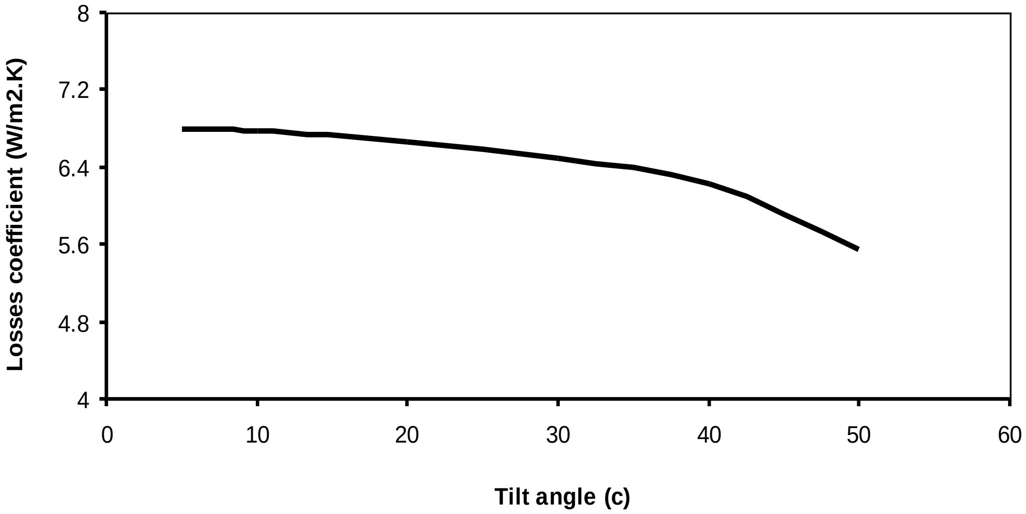


Figure 4 Relation between losses coefficient with air gap spacing between the absorber plate and the glassing cover of solar collector



of solar collector **Figure 5** Relation between losses coefficient with Tilt angle

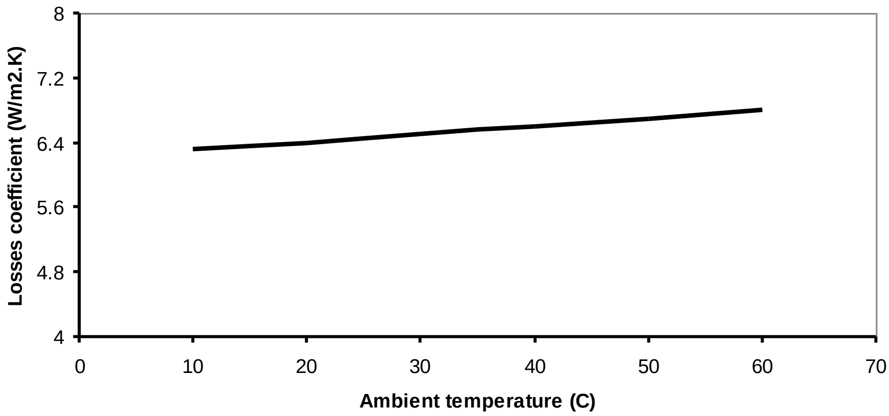


Figure 6 Relation between losses coefficient with ambient temperature of solar collector

دراسة العوامل المؤثرة على معاملات الفقد الحراري للمجمع الشمسي

الخلاصة

تم في هذا البحث دراسة العوامل المؤثرة على معاملات الفقد الحراري للمجمع الشمسي حيث يتأثر الفقد للمعاملات الحرارية للمجمع الشمسي بصورة اساسية بعدد كبير من العوامل. و يمكن تصنيف هذه العوامل على اساس التصميم و التشغيل والبيئة. في هذا البحث تم الاخذ بنظر الاعتبار تأثير بعض هذه العوامل مثل درجة حرارة المحيطية, سرعة الرياح, زاوية الميل, الفجوة الهوائية ودرجة اللوح الامتصاصي.

وبينت النتائج قيم المعاملات المفقودة باستخدام معاملات تصحيحات مالهورتا من (4.1- 12.2 W/m^2.K) لدرجة حرارة المحيط عند درجة حرارة لوحة الامتصاص من (25 and 70 °C), حيث لوحظ ان الفقدان كان بزيادة تدرجية من (7.2 -9.8) مع زيادة سرعة رياح عند (1-5m/s), وايضا لوحظ انخفاض معامل الفقدان من 7.5- (5.5 W/m^2.K) وكذلك زيادة فجوة الهواء من (0.02- 0.1m).

وبينت النتائج انه مع قيم عالية لزاوية الميل من (5-50 degree) هبوط ملحوظ لمعامل الفقدان من (7.8-6.55 W/m^2.K) مع زيادة لمعامل الفقدان من (7.32-7.8 W/m^2.K) وزيادة لدرجة الحرارة المحيطية من (10-60 °C)ايضا.