Theoretical Technique for Studying the Effecting Factors for Loss Coefficients in Solar Collectors

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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.

Keywords*—Solar collector parameters, losses coffiecents, theoritical technoque*

I. INTRODUCTION

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: non-concentrating or stationary and concentrating [1]. A non-concentrating 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 absorptions 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. 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 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 considered the heat loss and the collector efficiency under different conditions, Hottel and Woertz analyzed the estimation of energy transferred to the glass cover and after that Tabor has modified the equation of Hottel .Klein used the modified equation . Mullick SC, Samdarshi SK improved technique for computing the top heat loss factor of flat-plate collector with a single glazing, Malhotra A, Garg HP, Palit A. evaluation of the heat loss of flat-plate solar collectors, Pillar and Agarwal 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 [2-5].

II. 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:

- 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 [6].

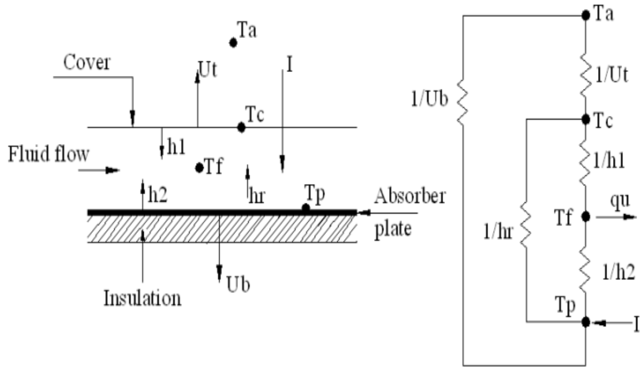

Fig. 1 Thermal network for single glass cover flat plate collector

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 heats 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 [7-11].

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 [12-13]. 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 [14].

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 [14-18].

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

From energy 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:

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

Compensation equation (1) in equation (2) yields

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

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

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

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

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

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

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

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

$$\omega_1 = \omega_2 + \frac{180}{12}$$

$$\omega_2 = \frac{180}{12}(12 - I)$$

$$\omega = (\omega_1 + \omega_2)/2$$

Where:

d = 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.

K_b, K_d 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:

K_d = 30% , K_b = 70% , ϕ = (33°) , S= (17°)

(ω1,ω2) are beginning and end hour.

Emissive coefficient is:

$$\tau\alpha = \left(\tau_1 \times \tau_2 \times .....\tau_n\right) \times \alpha_p \times (0.395) \qquad (6)$$

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

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

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 [19]:

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

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

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

The top loss coefficient of the collector by using empirical correlation Malhorta method:

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

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

$$h_w = 5.7 + 3.8V$$

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

To calculate the energy drawn from the heat tank and the thermal heat losses from the tank is by using the two equations respectively [20]:

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

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

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

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

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

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

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:

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

The collector heat removal factor is:

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

Where;

C_p = 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:

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

(18)

Where:

hi = internal heat transfer coefficient of water inside risers.

C_b = bond conductance.

W, D are explained in Fig. (3), the welding thermal conductivity is calculated by [21-22]:

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

Where,

b = is the thickness of welding line

K_b= conductivity thermal coefficient (400kW/m.°C)

III. 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/m^2.K) with increasing in absorber plate temperature of solar collector until ambient temperature 50 C increasing exponentially (3.8 – 4.4 W/m^2.K) with increasing in absorber plate temperature of solar collector.

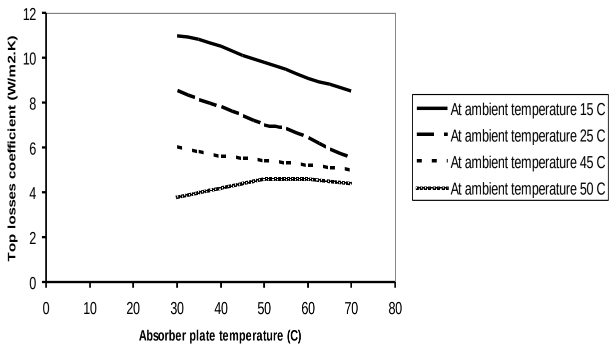

Fig. 2 correlation between losses coefficient with Absorber plate temperature for solar collector

Figure 3 indicate 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.

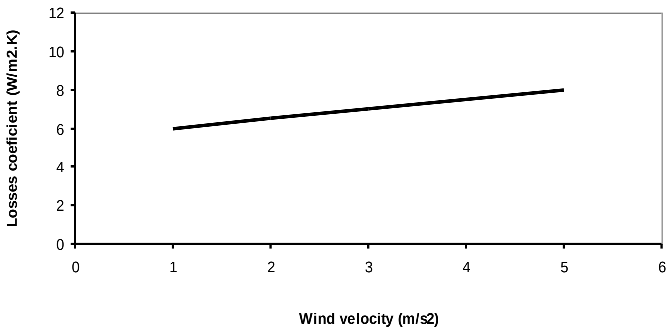

Fig. 3 Relation between losses coefficient with wind velocity over solar collector

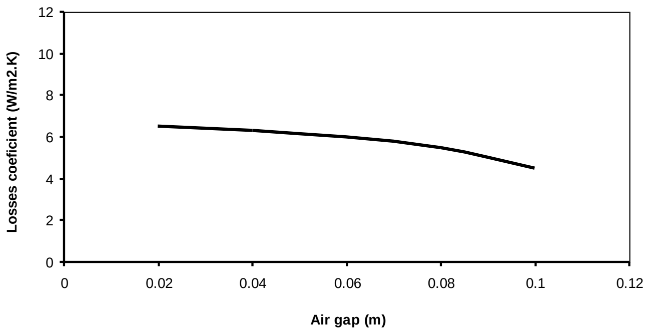

Fig. 4 Relation between losses coefficient with air gap spacing between the absorber plate and the glassing cover of solar collector

Figurer 4 note the influence of the air gap spacing between the absorber plate and the glassing cover (0.02 - 0.10 m) which indicate that losses coefficient of solar collector dcreases with increasing air gap spacing (6.5-4.5 w/m^2.k) so that required to optimiz this gap to reduces convective heat losses from the absorber plate to the glassing cover.

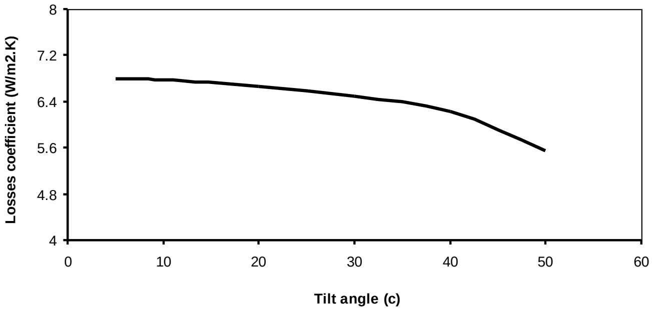

Fig. 5 Relation between losses coefficient with Tilt angle of solar collector

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 $W/m^2.K$) with higher values of tilt angle .

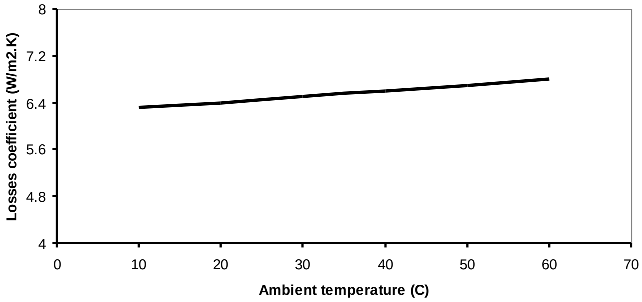

Fig. 6 Relation between losses coefficient with ambient temperature of solar collector

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 $W/m^2.K$) 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.

CONCLUSION

Theoretical analysis was performed on a flat plate collector with a single glass cover. The values of loses coefficient predicted according to empirical correlation of Malhorta laid between (4.5-11.2 $W/m^2.K$) for different parameters. 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 flat plate collector.

LIST OF SYMBOLS

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
$m^{\cdot}$	Mass flow rate of water	kg/sec
$m^{\cdot}_t$	Mass flow rate of water passing through the solar collector	kg/sec
$m^{\cdot}_L$	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	Degree
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^o
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

References

[1] M. T. Chaichan, K. I. Abaas, "Performance amelioration of a Trombe wall by using phase change material (PCM)," International Advanced Research Journal in Science, Engineering and Technology, vol. 2, No. 4, pp. 1-6, 2015.

[2] Moafaq K.S. Al-Ghezi, "The Global and Scattered Radiation Evaluation for a Horizontal Surface in Baghdad City," International Journal of Computation and Applied Sciences IJOCAAS, vol. 3, No. 1, pp. 153-158, 2017.

[3] Roshen T. Ahmed, "Design a position control of the blade pitch angle for variable speed wind turbine generators", Engineering and Technology Journal, vol. 27, issue 1681-6900, University of Technology, 2009.

[4] Abbass Z. Salman, ―The aerodynamical and structural analysis of wind turbine blade for fatigue prediction‖, Journal of Natural Sciences Research, vol. 7, no. 8, pp. 1-15, 2017.

[5] Bhatt M.K. Gaderia S.N. and Channiwala S.A. Experimental Investigations on Top Loss Coefficients of Solar Flat Plate Collector at Different Tilt Angle. Journal of World Academy of Science, Engineering and Technology, Vol. 79, Pp 432 – 436, 2011.

[6] H. A. Kazem and M. T. Chaichan, "The impact of using solar colored filters to cover the PV panel on its outcomes," Bulletin Journal, vol. 2, No. 7, pp. 464-469, DOI: 10.21276/sb.2016.2.7.5, 2016

[7] Roshen Tariq Ahmed, "Solar cell system simulation using Matlab-Simulink", Kurdistan Journal of Applied Research (KJAR) | Print-ISSN: 2411-7684–Electronic-ISSN: 2411-7706, kjar.spu.edu.iq,Volume2 , Issue1, DOI:10.24017/science.2017.1.4, June2017.

[8] Moafaq K.S. Al-Ghezi, "Calculate the Reflected Hourly Solar Radiation by Mirror Surfaces of Solar Concentrators Parabolic Trough," International Journal of Computation and Applied Sciences IJOCAAS, vol. 3, No. 3, pp. 256-260, 2017.

[9] Abbas Zghair Salman, Roshen Tariq Ahmed, "Numerical Technique of Flow Heat through Various Configurations of Steel Shapes", International Research Journal of Advanced Engineering and Science, Volume 3, Issue:2455-9024,Pages:247-252, 2018.

[10] M.T. Chaichan, K. I. Abaas, H. A. Kazem, H. S. Al Jibori, U. Abdul Hussain, " Novel design of solar receiver in concentrated power system" International J. of Multidispl. Research & Advcs. in Eng.(IJMRAE), vol. 5, No. 1, 211-226, 2013.

[11] Mahdi A. Abdul-Hussain and Roshen T. Ahmed, "Connect the wind farms to the electrical grid and indicate their effect on improving the characteristics of the network", International Research Journal of advanced Engineering and Science, vol. 3, issue 1, pp. 45-48, 2018.

[12] S. T. Ahmed & M. T. Chaichan, "A study of free convection in a solar chimney sample," Engineering and Technology J, vol. 29, No. 14, pp. 2986-2997, 2011.

[13] Dr. Abbass. Z. Salman, "Experimental and Theoretical Study to Invest Solar Energy for Operating Water Coolers", Advances in Physics Theories and Applications, vol. 63, issue:2225-0638, PP: 1-9, www.iiste.org, 2017.

[14] Shawn Husami, "Energy Crisis in Kurdistan and the impact of Renewable Energy", MSc thesis, university of Strathclyde, 2007.

[15] Trin Trong Chuong, ―Effect of wind generation in voltage dip‖, International Symposium on Electrical & Electronics Engineering, HCM City, Vietnam, 2007 - Oct 24 2007.

[16] P. J. Bansod, S. B. Thakre, N. A. Wankhade, "Solar chimney power plant-A review," International Journal of Modern Engineering Research (IJMER), vol. 4, no.11, pp. 18-34, 2014.

[17] Mahdi A. Abdul-Hussain, Eman Ali Ehsan, Roshen T. Ahmed, and Salah M. Ali, ―The feasibility of linking the fuel cells with public electrical grid on the voltage level: A simulation study‖, International Journal of Computation and Applied Sciences (IJOCAAS), vol. 3, issue 2, pp. 207-211, October 2017.

[18] H. A. Kazem, H. S. Aljibori, F. N. Hasoon and M. T. Chaichan, "Design and testing of solar water heaters with its calculation of energy," Int. J. of Mechanical Computational and Manufacturing Research, vol. 1. No. 2, pp. 62-66, 2012.

[19] Abbass Z. Salman, Roshen Tariq Ahmed, "The compration analysis of fixed pitch angle wind turbine that of a double output induction generator", National Renewable Energies Conference and Their Applications, pp. 96-107, University of Technology, Baghdad, IRAQ, 2013.

[20]] H. A. Kazem, M. T. Chaichan, A. H. Alwaeli, K. Mani, Effect of shadows on the performance of solar photovoltaic, Mediterranean Green Buildings & Renewable Energy, Springer Cham , pp. 379-385, 2017.

[21] K. Lovegrove, M. Dennis, "Solar thermal energy systems in Australia," International Journal of Environmental Studies, vol. 63, no. 6, pp. 791-802, 2006.

[22] H. A. Kazem, T Khatib, K. Sopian and W. Elmenreich, "Performance and feasibility assessment of a 1.4kW roof top gridconnected photovoltaic power system under desertic weather conditions", Energy and Building, Netherlands, vol. 82, pp. 123- 129, 2014.