Theoretical and Experimental Analysis of Flat Plate Collector

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Abstract

In this work a flat plate collector was designed and manufactured with dimension of (100cm×160cm×20cm) and analyzed experimentally and theoretically. The designed FPC consist of Nine pipes with (2.223cm in diameter with 140cm long) welded above the plate to act as heat removal fluid passage ways. The flow inside the pipes can takes place by forced convection. However, certain energy absorbed by the plate is lost to atmosphere due to higher temperature of the plate. Effect of plate temperature on efficiency and top loss coefficient studied for different wind velocities and different air temperature. Effect of emissivity of absorber plate on top loss coefficient was estimated.

The obtained result showed that the efficiency of FPC increase by 3% with the increase in ambient temperature by 8˚C, the efficiency decrease with the increase in plate temperature and the top loss coefficient increase when the emissivity of absorber plate increase and when wind velocity increase. The comparison of result showed a good agreement.

المستخلص

في هذا العمل تم تصميم وبناء مجمع شمسي نوع الوسادة بابعاد (100cm×160cm×20cm) وتم تحليل المنظومة عمليا و نظريا. المجمع الشمسي يتكون من تسع انابيب تمتلك قطر 2.223cm وطول 140cm تكون هذه الانابيب ملحومة على صفيحة لتقوم بتحويل الحرارة الممتصة الى المائع الذي يجري في الانابيب. ان جريان المائع في الانابيب يكون من خلال الحمل القسري. قسم من الحرارة الممتصة سوف تنتقل الى المحيط بسبب ارتفاع درجة حرارة الصفيحة و الانابيب. تم دراسة تاثير درجة حرارة صفيحة الامتصاص على كفاءة المنظومة وعلى معامل فقدان الحرارة العلوي وتم دراسة تاثير انبعاثية صفيحة الامتصاص كذلك.

بينت النتائج التي تم الحصول عليها ان كفاءة المجمع الشمسي تزداد بمقدار 3% بزيادة درجة حرارة الهواء بمقدار 8 مْ وتنخفض الكفاءة مع زيادة درجة حرارة صفيحة الامتصاص ويزداد معامل فقدان الحرارة العلوي مع زيادة انبعاثية صفيحة الامتصاص ومع زيادة سرعة الرياح.

مقارنة النتائج اظهرت تقارب جيد.

1. Introduction

Solar power is the result of converting sunlight into heat. Sunlight can be converted directly to heat using Flat–Plate Collectors. The flat plate collectors are based on two important principles: a black base that absorbs the solar radiation better than any other color and a glass lid that is needed to keep the heat in. A typical flat–plate solar collector is shown in Figure (1). When solar radiation passes through a transparent cover and impinges on the blackened absorber surface of high absorptivity, a large portion of this energy is absorbed by the plate and transferred to the transport medium in the fluid tube carried a way for storage or use. The underside of the absorber plate and the two sides are wall insulated to reduce conduction losses. The liquid tubes can be welded to the absorbing plate or they can be an integral part of the plate. The liquid tubes are connected at both ends by large diameter header tubes. The header and riser collector are the typical design for flat–plate collectors.

When a certain amount of solar radiation falls on the surface of a collector, most of it is absorbed and delivered to the transport fluid, and it is carried away as useful energy. However, as in all thermal systems, heat losses to the environment by various modes of heat transfer are inevitable. The thermal network for a single-cover, flat-plate collector in terms of conduction, convection, and radiation is shown in Figure (2-a) and in terms of the resistance between plates in Figure (2-b).

The advantages of flat–plate collectors are that they are inexpensive to manufacture they collect both beam and diffuse radiation and they are permanently fixed in position so no tracking of the sun is required.

In 2005 Christoph trink l and et l ,[1] Studied the performance of flat plate and evacuated tube collectors and they found that both collectors are considered to be suitable for solar heating in Central European Climates. The vacuum tube collector, however, does not reach the additional energy yield expected.

In 2006, O.A. Ogunwole [2] presented a mathematical model and experimental test for Flat Plate Collector Solar Cooker and found that the temperature to which the cooker could be raised depended on the solar energy intensity and the period of sunshine.

In 2008, Fabio Struckmann . [3] developed a mathematical model to simulate the performance of flat plate collector. The most important measure is the collector efficiency. A more precise and detailed analysis should include the fact, that the overall heat loss coefficient and other factors as the heat removal factor are not constant values.

In 2009 Y. Raja Sekhar and etl., [4] analyze theoretically and experimentally a flat plate collector with a single glass cover. They conclude that the emissivity of the absorber plate has a significant impact on the top loss coefficient and consequently on the efficiency of the Flat plate collector.

The objective of the present work is to evaluate the heat loss coefficients and calculate the efficiency of designed flat plate collector for AL-Basra city in Iraq.

2. Experimental setup

The schematic of the experimental setup is shown in Figure (3). One sheet of Glass used with 7mm thickness to cover solar collector above a plate of iron (80cm×146cm) coated with black to maximize the energy collection. Nine pipes (2.223cm in diameter with 140 cm long) welded above the plate to act as heat removal fluid passage ways. A water tank of iron with (17cm×17cm×70cm) used as storage tank. In order to minimize the heat loss from the back and side of the collector the insulation of wall with 3.81cm thickness was used. The case of aluminum used surrounds the aforementioned components and protects them from dust, moisture, and any after material. To measure the temperature of water at inlet and outlet, two thermocouples located inside the pipes as shown in Figure (3). One of the thermocouples is placed on the center of plate to measure the plate temperature.

3. Analysis

Assuming one-dimensional heat flow, under steady state conditions. In a steady state, the rate of useful energy collected from a collector of area A_c can be obtained from [5]:

$$Q_u = \dot{m}\, c_p\, (T_o - Ti) \qquad (1)$$

The thermal energy lost from the collector to the surroundings by conduction, convection, and infrared radiation is represented by:

$$Q_l = U_L\, A_c\, (T_P - T_a) \qquad (2)$$

Where: U_L: The overall heat loss coefficient

The overall heat loss coefficient is a complicated function of the collector construction and its operating conditions, given by the following expression [5]:

$$U_L = U_t + U_b + U_e \qquad (3)$$

The overall top heat loss coefficient is a function of various parameters which include the temperature of the absorber plate, glass cover and ambient, emissivity of absorber and glass cover, spacing between the absorber and glass cover L, tilt angle of the collector β, number of glass covers, etc given by[4]:

$$U_t = \frac{1}{\frac{N_g}{\frac{C}{T_P}\left[\frac{T_P-T_a}{N_g+f}\right]^{0.33}+\frac{1}{h_w}}} + \frac{\sigma(T_P^2+T_a^2)(T_P+T_a)}{\frac{1}{\epsilon_P+0.05N_g(1-\epsilon_P)}+\frac{2N_g+f-1}{\epsilon_g}-N_g} \qquad (4)$$

$$f = (1 - 0.04h_w + 0.0005h_w^2)(1 + 0.091N_g)$$

$$C = 365.9(1 - 0.00883\beta + 0.0001298\beta^2)$$

$$h_w = \frac{8.6V^{0.6}}{L^{0.4}}$$

The energy loss from the bottom of the collector is first conducted through the insulation and then by a combined convection and infrared radiation transfer to the surrounding ambient air; because the temperature of the bottom part of the casing is low the radiation term can be neglected thus the energy loss is given by:

$$U_b = \frac{1}{\frac{t_b}{k_b}+\frac{t_c}{k_c}+\frac{1}{h_{c,b-a}}} \qquad (5)$$

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

$$U_e = \frac{1}{\frac{t_e}{k_e}+\frac{t_c}{k_c}+\frac{1}{h_{c,e-a}}}$$

Efficiency of FPC can be calculated from:

$$\eta = \frac{Q_u}{Q_u + Q_l}$$

4. Results and discussions

Comparison of efficiency of designed FPC with that obtained by [4] shows in Figure (5). The effect of ambient temperature on the efficiency of the FPC is shown in Figure (6). The efficiency is increase with the increase in ambient temperature due to reduction in heat loss from the system and the efficiency is decrease with the increase of absorber plate temperature due to the increase of losses from absorber plate. The effect of wind velocity on top loss coefficient is shown in Figure (7). As the wind velocity increase the top loss coefficient increase due to increasing in amount of heat rejected to atmosphere. The variation of top loss coefficient with absorber plate temperature is shown in Figure (8). As the emissivity of absorber plate increases the top loss coefficient increases.

From the obtained result it can be included that the efficiency of FPC increase by 3% with the increase in ambient temperature by 8° C, the efficiency of FPC decrease with the increase in absorber plate temperature and the top loss coefficient increase when the emissivity of absorber plate increase and when wind velocity increase.

5. Conclusion and recommendation

The experimental and theoretical analysis of FPC has been described. The efficiency of FPC collector increase with the increase in ambient temperature and decrease with the increase in absorber plate temperature. The top loss coefficient increase when the emissivity of absorber plate increase and when wind velocity increase.

The future work may be include study the effect of collector tilt angle, number of glass cover and use glass solar concentrator on efficiency of FPC.

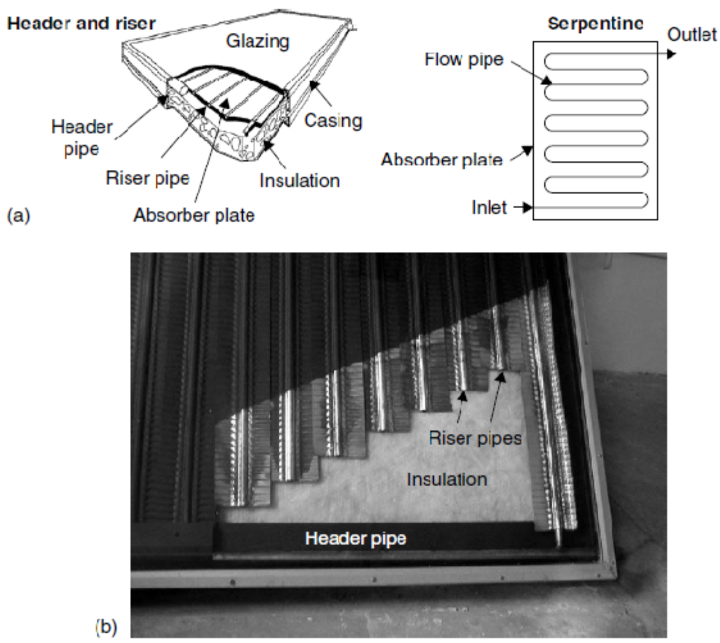


Figure (1) . Typical flat-plate collector. (a) Pictorial view of a flat-plate collector. (b) Photograph of a cut header and riser flat-plate collector.[5]

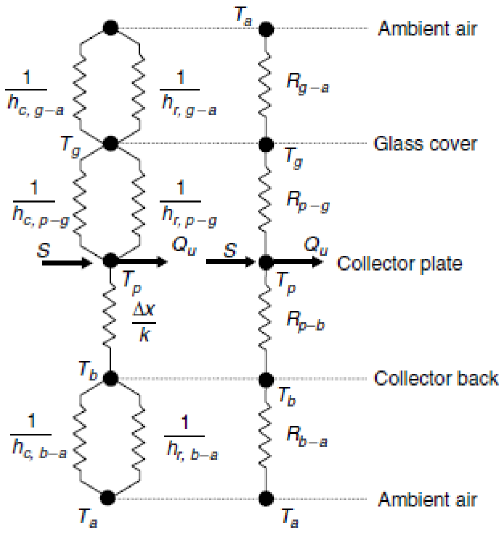
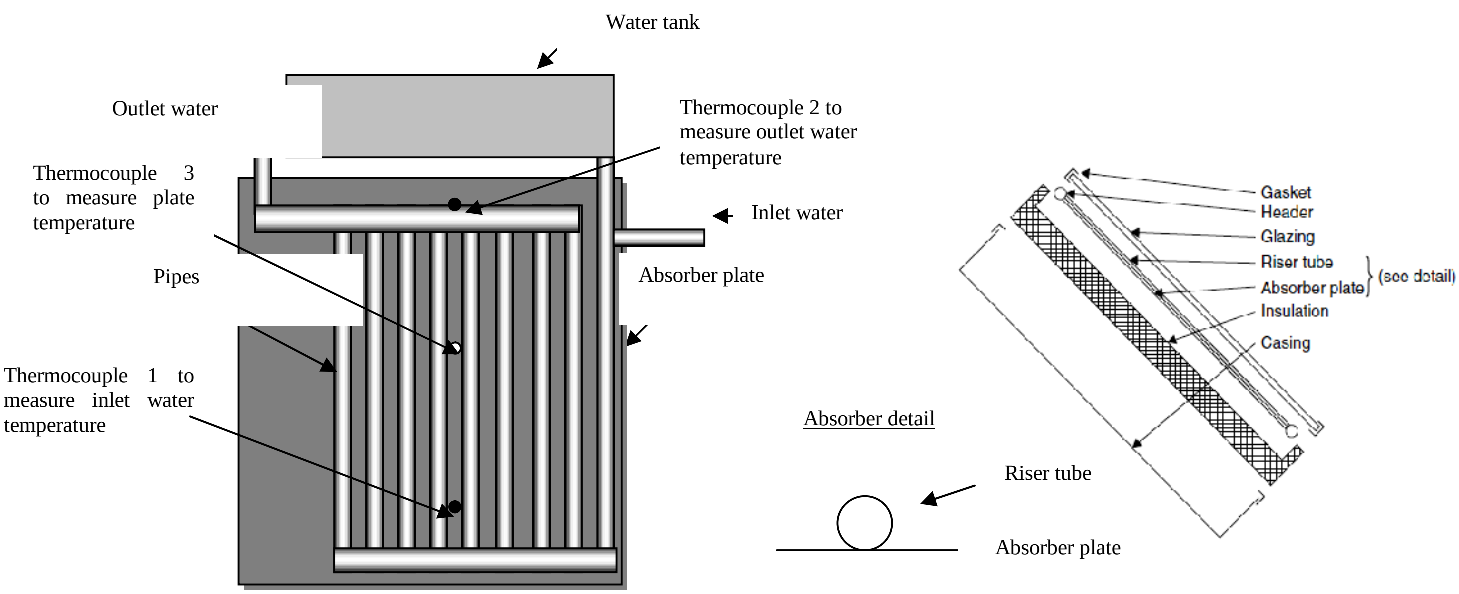


Figure (2). The thermal network for a single-cover, flat-plate collector. (a)In terms of conduction, convection, and radiation (b)In terms of the resistance between plates.



a) Front view of flat plate collector

b) exploded view of flat plate collector and absorber details.

Figure (3). Schematic diagram for flat plate collector.

Figure(4). Different photograph view for the Manufactured Flat-Plate Collector.

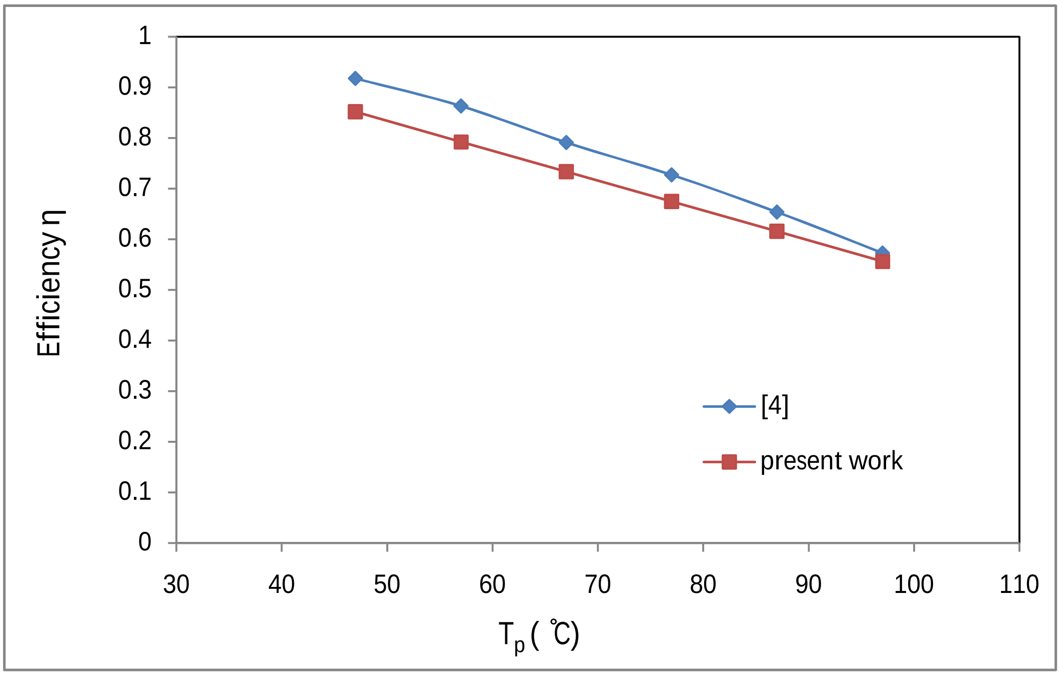


Figure (5) . Comparison of efficiency obtained by [4] with present work.

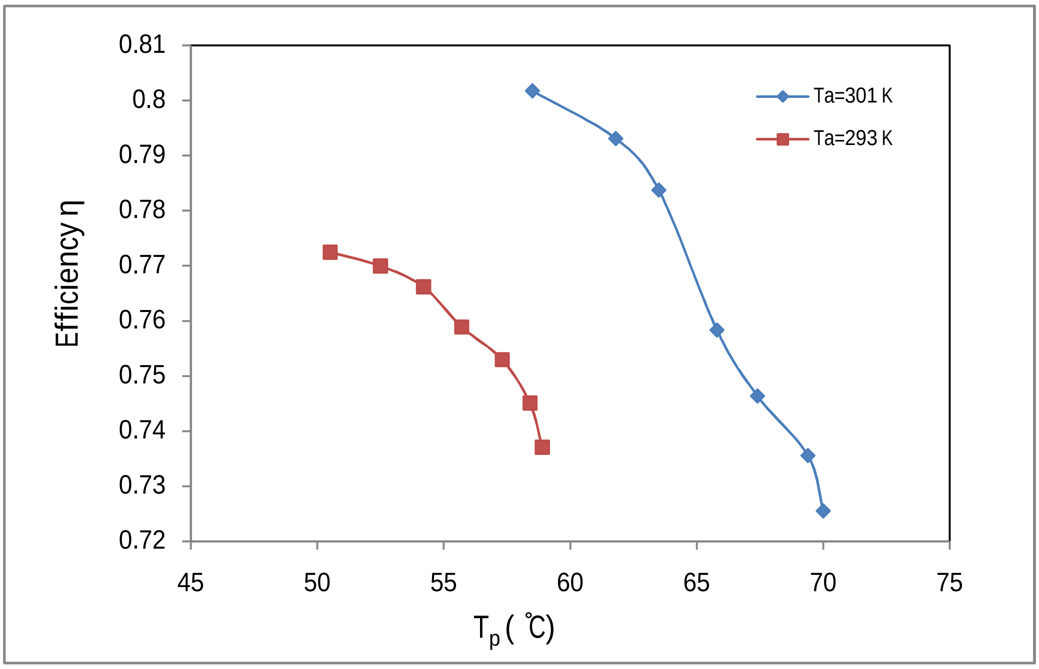


Figure (6) . Effect of absorber plate temperature on efficiency of FPC for two different ambient temperature.

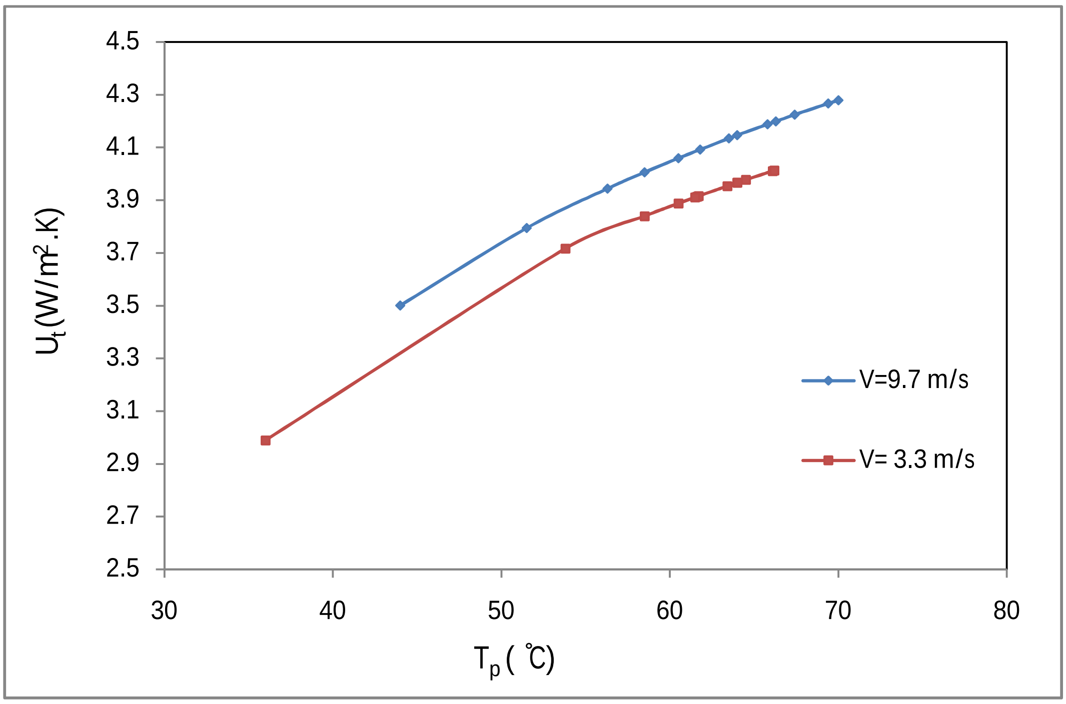


Figure (7). Effect of absorber plate temperature on top loss coefficient for different wind velocity.

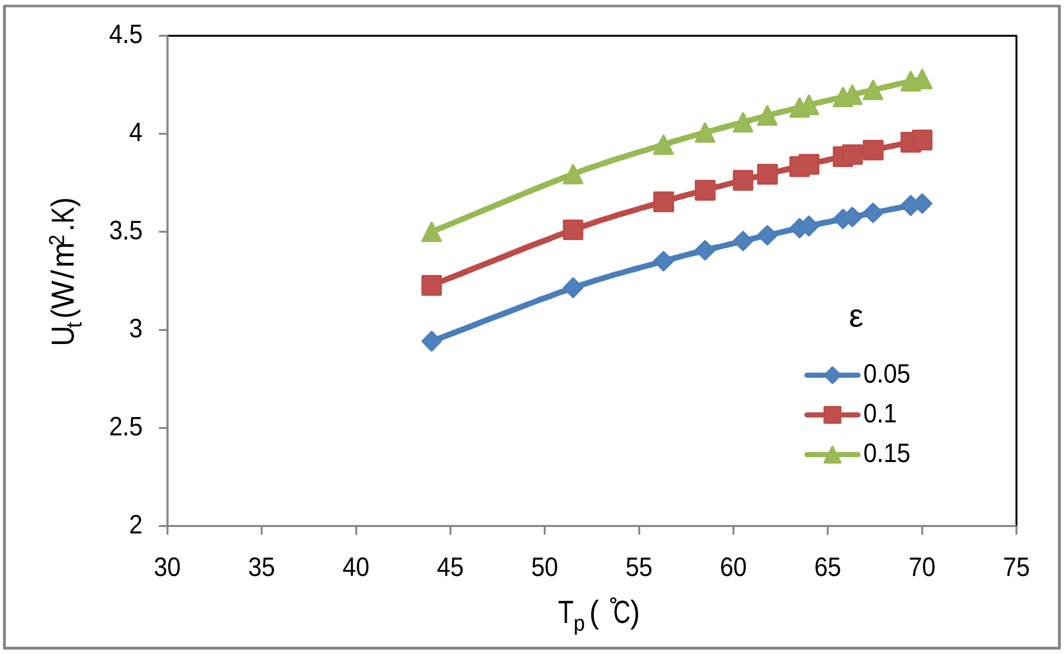


Figure (8). Effect of absorber plate temperature on top loss coefficient for different value of (ϵ_p).

6. References

[1] Christoph Trinkl and etl., "Performance of Vacuum Tube and Flat Plate Collectors Concerning Domestic Hot Water Preparation and Room Heating", 2nd European Solar Thermal Energy Conference, 2005.

[2] O.A. Ogunwole, " Flat Plate Collector Solar Cooker ", Department of Mechanical Engineering, Federal University of Technology, Nigeria 2006.

[3] Fabio Struokmann, "Analysis of a Flat-plate Solar Collector ", Dept. of Energy Science, Faculty of Engineering, Lund University, Project Report, Sweden, 2008.

[4] Y. Raja Sekhar, K. V. Sharma and M. Basaveswara Rao, "Evaluation of Heat Loss Coefficients in Splar Flat Plate Collectors", ARPN Journal of Engineering and Applied Sciences, Vol. 4, No. 5, JULY 2009.

[5] Soteris Kalogirou, "Solar Energy Engineering: Processes and Systems", Elsevier's Science & Technology, United States of America, 2009.

7. Nomenclature

A Area, m^2

h convection heat transfer coefficient, $W\ m^{-2}\ K^{-1}$

h_w wind loss coefficient, $W\ m^{-2}\ K^{-1}$

k conductivity $W\ m^{-1}\ K^{-1}$

N number of glass cover

L length of absorber pipes, m

Q Energy, W

T Temperature, ℃

t Thickness, m

U_l Overall loss coefficient, $W\ m^{-2}\ K^{-1}$

U_t Overall top loss coefficient, $W\ m^{-2}\ K^{-1}$

U_b Overall loss coefficient for the heat loss from back to ambient, $W\ m^{-2}\ K^{-1}$

U_e Overall loss coefficient for the heat loss from edge to ambient, $W\ m^{-2}\ K^{-1}$

Greek symbols

ε Emissivity

σ Stefan-Boltzman constant, $W\ m^{-2}\ K^{-4}$

β Collector tilt angle

Sub scripts

a ambient

b back

c collector

e edge

p absorber plate

g glass cover

u useful

l lost

o out

i in