Performance an Experimental Study of Dual Fluids (Air-Water) Flat Plate Solar Heater

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Abstract

In this study, a flat plate solar (air- water) heaters are analyzed experimentally. The collector consists of two pipes with (12m) long, diameter (0.01905m) and a (5.54m) long air duct with a (0.01)m^2 cross-sectional area. The air duct consists of four channels which the water pipes fixed parallel to the air duct in a serpentine configuration on the absorber plate. This work was performed under the weather conditions of Hilla city-Iraq with (long.44.25° E, lat.32.3° N) where the study is conducted during eight months (from July 2018 to March 2019) with different tilt angles. The performance and the effect of the mass flow rate on the collector is studied. Air, water and absorber temperatures, pressure drop and air speed are measured. Thermocouples type (K) are used to measure the temperature as this type covers the range of the studied system. A temperature data logger devices are used to display the values of the temperature. The pressure drop and air speed are measured by a U tube manometer and a digital anemometer respectively. The results show that as the mass flow rate for air and water increases the temperature for air ,water and absorber temperatures will decrease, while the efficiency of collector increase.

Keywords: Flat plat collector, Solar energy, Renewable energy, Absorber plate

NOMENCLATURE

Symbol	Definition	Units
A_{ap}	Aperture area of the collector	m^2
A_c	Cross-sectional area of the flow	m^2
C_{Pa}	Specific heat at constant pressure of air	J/kg.°C
C_{Pw}	Specific heat at constant pressure of water	J/kg.°C
f_c	Efficiency function	m^2.°C/W
I_T	Total incident solar radiation	W/m^2
$\dot{m}_a$	Mass flow rate of air	Kg/s
$\dot{m}_w$	Mass flow rate of water	Kg/s
P	Pressure	N/m^2
Q_{ga}	Rate of heat gain	W
T_{amb}	Ambient temperature	°C
T_a	Air temperature	°C
T_w	Water temperature	°C
T_{in}	Inlet air temperature	°C
T_{out}	Outlet air temperature	°C
T_m	Mean temperature	°C
U_L	Collector heat loss coefficient	W/°C.m^2
V	Velocity of air	m/s

GREEK SYMBOLS		
Symbol	Definition	Units
α	Absorptivity of the absorber plate	—
η	Thermal efficiency	—
ρ	Density	kg/m^3
τ	Transmissivity of the transparent cover	—

1- Introduction

The energy crisis is currently one of the most serious crises in the world today. Technology development has greatly increased the process of energy consumption so that traditional energy sources are threatened by depletion. In addition, the planet is exposed to environmental pollution caused by the emission of carbon dioxide and other gases resulting mainly from the combustion of fossil fuels, which led to global warming. So many countries in the world have resorted to the exploitation of renewable energy sources (solar energy and wind power.....etc.). Several researches and studies have been carried out in this field, and some of these countries have moved from research and study to the manufacturing of components and systems for the use of renewable energy. The use of solar and wind energy systems began gradually spreading until it reached the commercial stage, and many countries have depended on these systems to provide a significant part of their electrical, thermal and mechanical energy needs.

[1] design, constructed and tested a flat plate solar air heater in Hilla city- Iraq. The length of the duct was (4.5m) and its cross sectional area (10x10)cm and the tilt angle was 45°. The glass cover condition and the effect on the collector performance were studied. [2] studied the effect of duct configuration and stuffing on the thermal performance of solar air heater under climatic conditions of Hilla city-Iraq with (45°, 30°, and 60°) tilt angles. The cross-sectional area and the length were (20×5)cm and (4.5m) respectively. [3] studied the thermal performance evaluation of the solar heater with different configurations (cylindrical-conical duct, circular duct and rectangular duct) with natural and forced convection. Two types of heaters were tested by turning it on auxiliary power by halogen tube mode (300W) inside the inlet and outlet ducts. [4]studied experimentally and theoretically the performance of a double pass air solar heater in INENCO, Universidad Nacional de Salta, Argentina. The collector area was 2m2, and height of channel was 0.025m. Collector tilt angle was 40° facing north, in order to maximize the intensity of solar radiation during the winter. [5] investigated experimentally the solar air heater performance with different configurations. The configurations included testing the single- and double-pass solar collectors with a natural and perforated covers and with wire mesh layers instead of an absorber plate. [6] tested two types of collectors with sensible heat storage (SHS) with copper strips (copper tubes with extended copper fins on both sides). The impact of this novel design on the performance of the SAH was studied. The results were compared with another collector without (SHS) which is a conventional SAH of similar dimensions. Experiments were carried out on both the SAHs at the same location and identical testing conditions such as the surrounding environment of the experimental setup and amount of solar radiation received. [7] studied a conventional and advanced exergy analyzes of a simple flat plate collector (SFPC) and a flat plate collector with thin metal sheet (CTMS). The mathematical models were designed using the equations of energy that have been developed for each component. The effect of channel depth, Reynolds number and intensity of radiation on the exergy annihilation for each component and process was studied using conventional exergy analysis. [8] studied the benefits of using an unglazed solar air collector (UTC) with a perforated absorbable plate (PAP) experimentally and theoretically. This work was done at Ramadi city in Iraq. The collector was tilted at 90o with the horizontal so that it can be easily placed on the wall of the building and reduce cost and weight. The benefits of using an unglazed perforated solar air collector are that it is simple to set up on the exterior walls of the buildings. [9] investigated experimentally thermal performance of thermosyphon flat-plate solar water heater. The experimental system consists of a 2m2 flat-plate collector directed to the south with a tilt angle of 25° with insulated water horizontal cylindrical storage tank with a capacity of 0.18m3. [10] studied the comparison of total loss coefficient of the collector under different numbers and kinds of class covers on flat plate solar water heater. The study focused on an evaluation of the effect of the absorber emissivity on the heat transfer process. This work was done in Morocco. [11] examined the dynamic simulation of the collector of solar thermal water heaters in view of weather conditions of a city in north of Iran. Simulation was conducted for clear and partly cloudy days. The useful energy, the efficiency diagrams, the inlet and the outlet of collector, center of the absorber and center of the glass cover temperatures, were studied. [12] studied condensation control in flat plate solar water heaters. The collector consists of (1.8m2) area. This collector was tilted at an angle of 37° to the horizontal. The

height of the collector (above surface) was (2m) and the thickness of insulation plate was (0.03m). [13] tested two collectors, an enhanced collector with wire-coil insert (EC), and a standard collector (SC) under the same weather and operating (inlet fluid temperature and mass flow rate) conditions. This work was done in Cartagena, south eastern Spain. [14] studied the efficiency of solar heating system for greenhouses to make it suitable for agricultural objective through the coldest period of the year (December–April). Experimental tests were carried out in the Laboratory of Energetic and the Thermal Processes(LEPT) of the Technology and Research Center in Bourj Cedria, Tunisia (latitude 36°48` N, latitude 10°10`).

2- Experimental Setup

The collector consists of two pipes with (12 m) long, diameter (0.01905 m) and a (5.54 m) long air duct with a (0.01) m2 cross-sectional area. The air duct consists of four channels which the water pipes fixed parallel to the air duct in a serpentine configuration on the absorber plate. A lower plate with a dimension (1.44×1.34×0.002) m is welded to the air duct, which made from the same material as the absorber plate. The paint is made from local materials [1] with high absorptivity of (0.95). The base of the collector is made from a wooden sheet with a dimension of (1.65x1.54x0.015) cm. The sides of the collector consists of three layers (wood- insulating foam- wood). The insulation is used to minimize heat losses through the sides and bottom of the collector. The air duct and water pipes on the wooden base by using (M10) bolts. A glass cover with (4 mm) thickness is fixed at (4 cm) above the air duct. The purpose of glass cover is to reduce heat losses from the absorber by convection and radiation and preventing rain and dust from coming in contact with the absorber. The glass cover is fixed on the wooden box by using aluminum tapes which are fixed by screws to the sides of the wooden box. The gap between the glass and the box side is filled with rubber-sponge tapes while on the sides of the aluminum tapes are filled with silicon-rubber to prevent air leakage and heat losses to the environment. The collector is then fixed on a steel frame which has a protractor to adjust the desired tilt angles. An air blower with variable air speed is connected to the inlet of the air duct by using a flexible duct with (10 cm) diameter and (3 m) long and water pipes are connect to flow meter. The mass flow rates are varied in order to study their effect on the collector performance. The test rig is shown in Fig. (1).

Thermocouples type (K) is used to measure the temperatures of air, water and absorber plate. Two points for the lower and upper plate are measured. All thermocouples are connected to data logger device to record the temperature values. The air speed is measured by using anemometer device. The pressure difference between the inlet and outlet air is measured by a U tube manometer. Fig. (2) shows the measurement devices.

Fig. (1) The Test Rig

Fig. (2) The Measurement Devices

3- Experimental Procedure

The collector is directed to the south-east direction since it delivers the highest absorbed radiation. Calculated optimum monthly tilt angle is used (11.5 º, 19.4 º, 31.08 º , 43.3 º , 53 º, 57.3 º, 55 º and 47.4 º). The blowers are operated from (9:00 AM to 2:00 PM) for all the testing days. The glass covers for both collectors are cleaned every day before the tests so that the highest amount of incident solar radiation can reach the absorbers. The tests are conducted in Hilla city – Iraq (Latitude equal to 32.30º N and Longitude equal to 44.25º E). The data loggers are set to record the temperature values every 10 minutes. The velocity of the air is measured at the start of each test. The water and air flow rate are fixed for each test.

4- Collector Performance Calculations

The instantaneous thermal efficiency of the collector is calculated as [15].

$$\eta = \frac{Q_{ga}}{A_{ap}\,.\,I_T} \qquad (1)$$

Where (A_{ap}) is the aperture area of the collector, (I_T) is the total incident solar radiation and (Q_{ga}) is the heat gained by the air and water and:

$$Q_{ga})_{total} = Q_{ga})_a + Q_{ga})_w \qquad (2)$$

$$Q_{ga})_a = \dot{m}_a . C_{Pa} . [Ta)_{out} - Ta)_{in}] \qquad (3)$$

$$Q_{ga})_w = \dot{m}_w . C_{pw} . [Tw)_{out} - Tw)_{in}] \qquad (4)$$

$$\dot{m} = \rho\, V\, A_C \qquad (5)$$

$where: duct\ cross\ sectional\ area\ A_C = 0.01 m^2$

$$\rho_a = 1.2\ kg/s\ and\ \rho_w = 1000\ kg/s$$

The collector performance curve is the relationship between the collector efficiency (η) and the efficiency function (f_c). This variable taken from reference [16]is:

$$\eta = \tau\alpha - U_L \frac{(T_m - T_{amb})}{I_T} \qquad (6)$$

$$f_c = \frac{(T_m - T_{amb})}{I_T} \quad where \quad T_m = \frac{Ta)_{out} + Tw)_{out}}{2} \qquad (7)$$

U_L is the collector heat loss coefficient. The product of transparent cover transmissivity (τ) and the absorber absorptivity (α) is referred to as the optical efficiency. The values of $(\tau\alpha)$ and (U_L) are (0.8 and 5.22) respectively.

5- Results and Discussion

The results show the effect of various parameters such as (mass flow rate for air and water and test conditions) on the performance of the solar (Air-Water) heater. Fig. (3) shows the variation of the absorber plate temperature, outlet air and water temperatures and the ambient air temperature for the Collector during the day. The absorber plate temperature is measured from two points which are (1 m) from the inlet and (1 m) from the exit for both collectors. By investigating the specific points of the absorber plate temperature for collector, it can be observed that the temperature of point (1) near the inlet is less than the point (2) near the outlet. This is due to lower inlet temperature of both fluids which mean the larger temperature difference between fluids and absorber plate which means more heat transfer at inlet than at the exit.

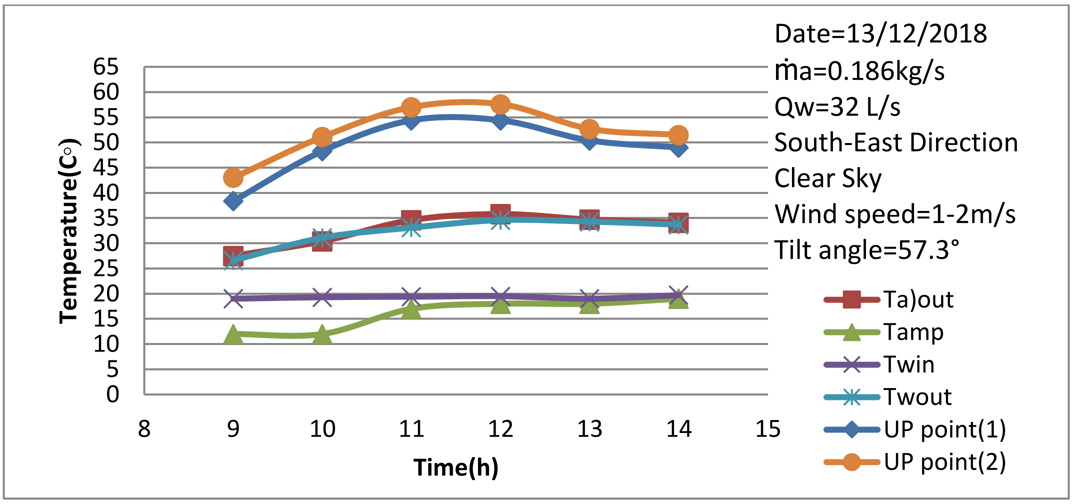

Fig. (3) Variation of Temperatures with Time for Clear Sky Condition

The effect of weather condition is shown in Figs. (4, 5 & 6). Figs (4 & 5) are for cloudy and partly cloudy weather while Fig. (6) is for misty weather. These Figures show lower exit temperature of both fluids compared to clear sky due to lower incident radiation.

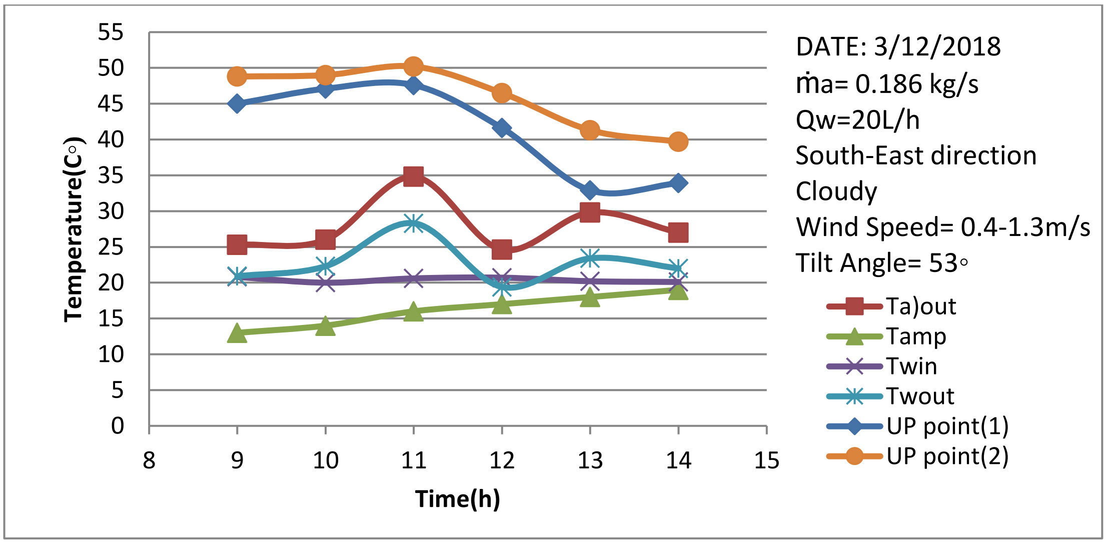

Fig. (4) Variation of Temperatures with Time for Cloudy Condition

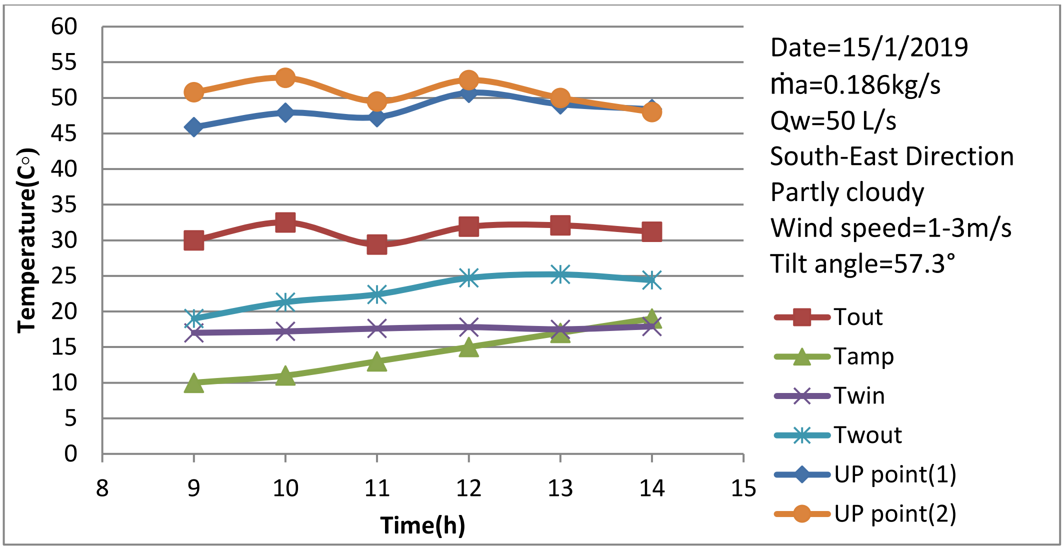

Fig. (5) Variation of Temperatures with Time for Partly Cloudy Condition

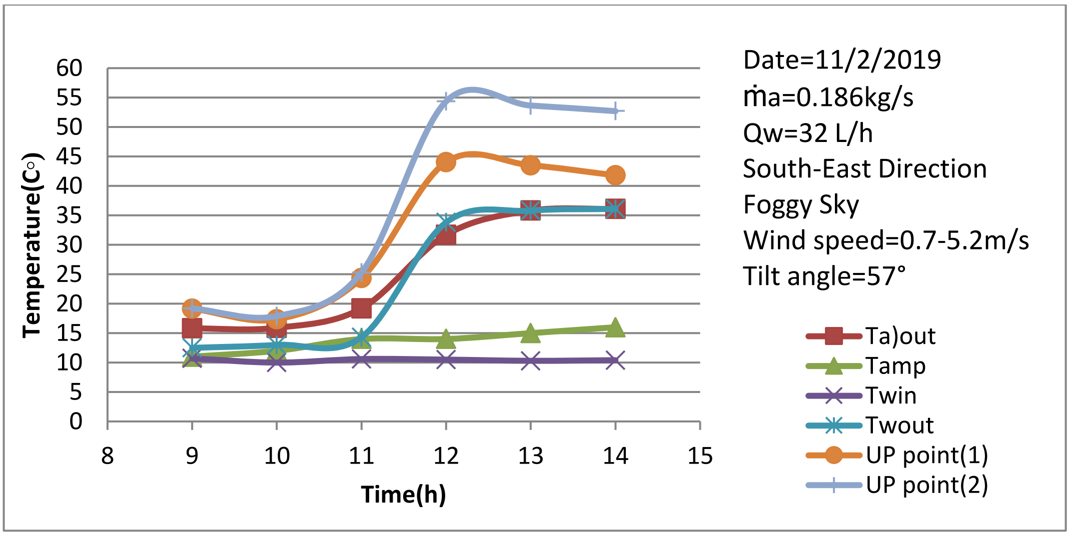

Fig. (6) Variation of Temperatures with Time for Foggy (misty) Sky

Fig.(7) shows the effect of air and the water mass flow rate on exit temperature. It is clear that as the flow rate increases the exit temperature for both fluids decreases because ΔT is inversely proportional with mass for same heat input. Also the air temperature increase more speedily than water due to difference in specific heats. The fig. also shows that the total temperature rise of air is larger than that for water for same weather conditions and time. However the temperature of water reaches a maximum value and decrease in the afternoon.

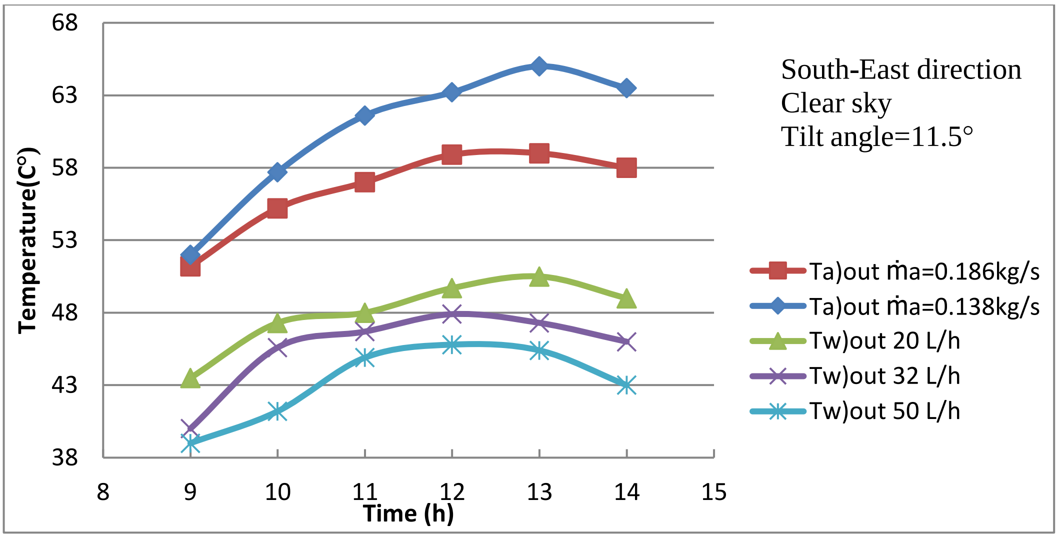

Fig (7) effect of flow rate on outlet (air & water) temperatures

Fig (8) displays the growth of the air temperatures, as it flows through the air duct for two air mass flow rates . The Fig shows that as the mass flow rate increases the air temperature decreases. The reduction is due to the increase in the velocity of air, which affects the heat transfer between the absorber plate and air.

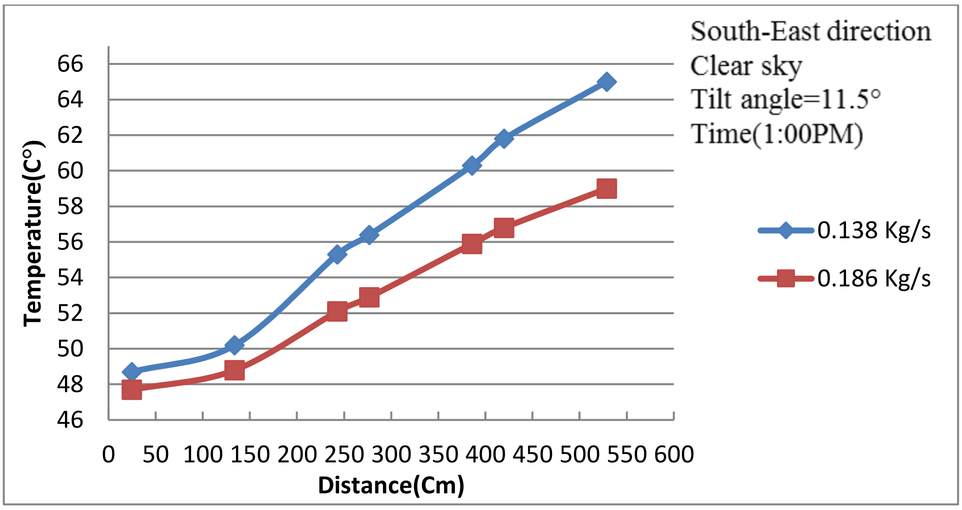

Fig (8) Mass Flow Rate Effect on the Air Temperature

Fig (9) shows the variations in thermal efficiency of the collector with the time for maximum and minimum mass flow rate. The efficiency values of this figure are calculated from equation (1). It can be observed that the thermal efficiency of the collector increases with an increase in the mass flow rate during the day.

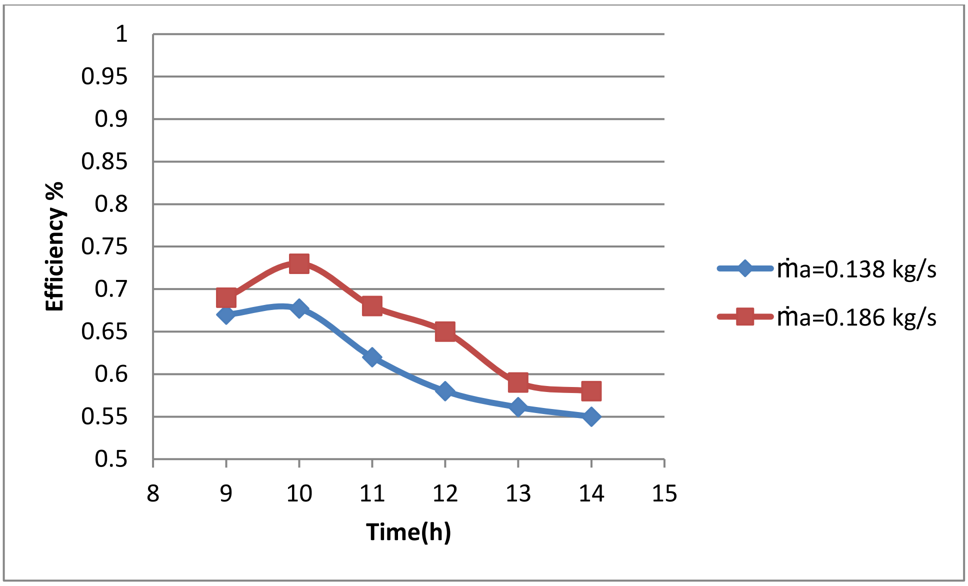

Fig (9) Effect of Mass Flow Rate on the Efficiency of the Collector

Fig (10) shows the performance curve for the collector. From equation (6) the efficiency values of this curve are calculated. The maximum collection efficiency found when the intersection happens with the y-axis and results when (Tm or Tabs=Tamb), this makes $f_c = 0$ and the heat transfer between the ambient air and the absorber stops, while the intersection with the x-axis occurs when the fluid flow through the collector stops.

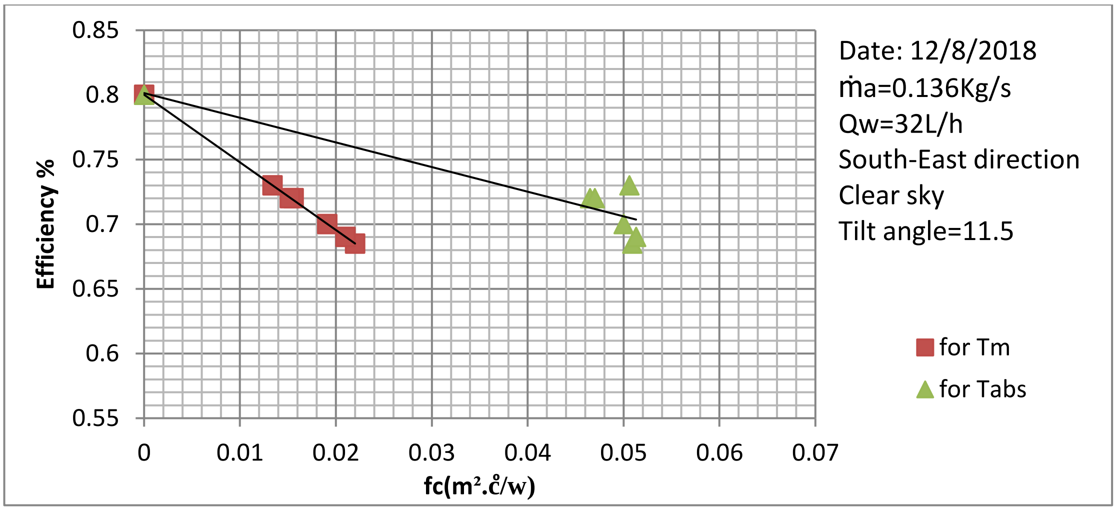

Fig (10) Performance Curve of the Collector

6- Conclusions

The following conclusions can drown from this work

1- The outlet temperature of air and water and the absorber plate temperature are all increase with time until the solar radiation reached its maximum value, after that the temperature start decreasing.
2- Increasing the mass flow rate of air causes a decrease in the outlet air and plate temperatures.
3- The outlet water temperature decrease as the mass flow rate of the water increases.
4-The air temperature rises increase gradually by increasing the distance along the duct.
5-The efficiency of the collector increases with the increase in the mass flow rate of air and water.
7- A maximum temperature of 87.4°C for the absorbing plate was obtained at tilt angle 11.5° in the south-east direction at summer.

CONFLICT OF INTERESTS.

- There are no conflicts of interest.

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دراسة تجريبية لاداء السخان الشمسي المسطح المزدوج المائع(ماء-هواء)

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الخلاصة

في هذه الدراسة، يتم تحليل سخانات الطاقة الشمسية المسطحة (الهواء – الماء) بشكل تجريبي. يتكون المجمع من أنبوبين بطول (12m)وقطر (0.01905m) وقناة هواء طويلة (5.54m) مع مساحة عرضية ($0.01m^2$) .يتكون مجرى الهواء من أربع قنوات يتم فيها تثبيت أنابيب المياه موازية لقناة الهواء ذهابا وايابا على صفيحة الامتصاص. تم تنفيذ هذا العمل في ظل الظروف الجوية لمدينة الحلة – العراق باستخدام (lat.32.3° N, long.44.25° E)حيث أجريت الدراسة خلال ثمانية أشهر (من يوليو 2018 إلى مارس 2019) بزوايا ميل مختلفة. تتم دراسة أداء وتأثير معدل التدفق الشامل على المجمع. يتم قياس درجات حرارة الهواء والماء والامتصاص وانخفاض الضغط وسرعة الهواء. يستخدم الثرموكبل النوع المزدوج (K) لقياس درجة الحرارة لأن هذا النوع يغطي نطاق النظام المدروس. يتم استخدام أجهزة تسجيل بيانات درجة الحرارة لعرض قيم درجة الحرارة. يتم قياس انخفاض الضغط وسرعة الهواء بواسطة مقياس ضغط أنبوب U ومقياس شدة رقمي على التوالي. أظهرت النتائج أنه مع زيادة معدل تدفق الكتلة للهواء والماء، تنخفض درجة حرارة الهواء والماء وامتصاص درجات الحرارة، بينما تزيد كفاءة المجمع.

الكلمات الدالة: جامع لوحة مسطحة، طاقة شمسية، طاقة متجددة، لوح ماص.