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AN EXPERIMENTAL INVESTIGATION OF EVACUATED TUBE SOLAR COLLECTOR UNDER AL-HILLA CLIMATE CONDITION

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ABSTRACT

There has been a shift in our concern for energy towards renewable energy sources as a result of the increasing demand for energy and the decreasing supply of fossil fuels. Solar energy is, without a shadow of a doubt, the most environmentally friendly and beneficial alternative among all of the other sources that are now available. In today's world, many people harvest energy from the sun using a variety of various kinds of solar collectors. It has been discovered that the efficiency of the solar collector is reliant on the properties of the working fluid, which is responsible for the collection of solar energy in solar collectors. In this study, the experimental findings of using deionized water as the working fluid for heat pipe evacuated tube solar collectors are presented. During the course of the experiment, a solar collector, a closed working fluid system, and measurement devices will be utilized (flow meter, thermocouples, temperature meter and digital solar power meter). The results of the present work can be used efficiently to improve the perfomance of solar collector in the place of study (Babylon City) in Iraq. This will save the energy and make the work of the collector better and increase its efficiency. From the another hand it fill the gap in the experimental studies related to ETSC in the middle east general and Iraq specially. When the solar irradiance was approximately 494 W/m^2, the solar collector had a maximum temperature differential of 15.5 oC between its outlet and its inlet. The average energy efficiency reached was 67.3%.

Keywords: *Solar collector, heat pipe evacuated tube solar collector, performance.*

1. INTRODUCTION

Over the top utilization of petroleum derivatives has brought about various issues, including the arrival of CO_2, CO, and NOx into the air and the subsequent repercussions on our current circumstance. It tends to be changed if we lessen our dependence on petroleum products by using elective sustainable power sources (Baharoon *et al*.,2015). Due to its low ecological impact, sun-based energy is one of the most engaging choices for meeting the world's growing energy interest, with a few applications in the industry(Villicana-Ortiz *et al*.,2015). Sun-powered energy is a huge existing wellspring of environmentally friendly power on Earth, as the planet retains a large number of watts of energy consistently from sun-based radiation. Be that as it may, just a little part of it is utilized as daylighting and photosynthesis 33% is reflected once again into space by the regular world, while the rest of consumed by seas, mists, and land (Gaur *et al*., 2017). Therefore, it is incredibly sensible to gather sun-based energy and use it effectively to create electric power, hotness, and cooling reasonably. Since sun-based energy creates no hurtful toxins, its effect on the climate is low. Besides ecological mindfulness, the consumption of existing energy sources positions sun-powered energy as the most satisfactory energy source to meet the world's growing energy interest. Specialists have inspected and proposed frameworks for reaping sun-powered energy to serve people, and they are as yet considering innovations to boost the assortment and use of sun-oriented energy and the utilization of sun-based energy (Wei, 2010). It is a difficult undertaking with many obstacles for effective sun-based energy assortment and capacity, yet it is free and non-draining. Since sun-based radiation is just present during the day, the energy should be accumulated in a viable way to benefit as much as possible from the light hours and afterward put away.

These sun-oriented warm gatherers are the promptly accessible stuff for catching sun-based radiation, which is then changed over to nuclear power and conveyed to a functioning liquid. Thus, sun-powered authorities are the most significant and significant parts of any nearby planet group(Singh *et al*.,2013) . There are two kinds of authorities: fixed gatherers and following gatherers(Kalogirou,2004) . Different kinds of authority geographies can assist with accomplishing a wide temperature range, for instance, a level plate gatherer (FPSC) (Sharma and Diaz, 2011) has a working temperature scope of 20-80°C, and an emptied tube sunlight-based gatherer (ETSC) has a working temperature scope of 50-200°C (Kalogirou,2013; Tyagi *et al*.,2012).

Sun-powered water warmers are progressively being utilized all over the planet, and the cleared cylinder models are the most widely recognized in light of their adaptability and generally speaking better execution over their level plate models, particularly in helpless climate conditions. A few cleared cylinder plans have been created and are being utilized among which, because of its minimal expense and simple assembling and establishment methods, the water-in-glass configuration is extremely normal. The design utilizes a moderate liquid hotness pipe framework used to bring the hotness from the warming components to the tank. During this case, as it is being gone all over, the functioning liquid goes through a stage shift process(Hayek *et al*.,2011). Evacuated tube sun powered authority is a framework used to supply heat at generally high temperatures for different applications including water warming, cooling, and so on Because of the joined impacts of exceptionally particular surface covering and vacuum protection, this authority can arrive at temperatures over 120 ºC (Harding,1985) . ETSC utilizes ease changes in fluid fume materials to move heat at high productivity. Such authorities highlight a hotness pipe that is a profoundly successful warm guide inside a cylinder that is fixed with a vacuum. The attachment, which is a fixed copper plug, is then associated with a cylinder (safeguard plate) filled dark copper balance. A metal tip

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connected to the fixed line juts from the highest point of each channel. The hotness pipe contains a little volume of liquid (e.g., methanol) going through a course of dissipation buildup. Sun powered hotness dissipates the fluid during this interaction, and the fume goes to the district of the hotness sink where it gathers and deliveries its idle hotness (Saxena and Gaur, 2018). The consolidated liquid re-visitations of the sun oriented authority and rehashes the cycle. When such cylinders are mounted the metal tips up to a hotness exchanger (complex). Water goes through the line, or glycol, and takes up heat from the cylinders, Shows in figure 1.

Figure 2. shows the schematics of an emptied U-tube sunlight based authority; this comprises of an outer glass tube, an inner glass tube, a copper or aluminum fine, and a copper tube molded in U. The occurrence sunlight based radiation is passed to the inward glass tube and is consumed by the blade on the external surface of the external glass tube. The energy that the balance retains is moved to the U-tube through conduction, and from that point to the functioning liquid that streams by convection inside the U-tube (Kalogirou,2004).

The most popular evacuated tube solar collectors ,The most common type is all-glass evacuated tubes for transferring the Solar energy is transferred directly to the fluid circulating in it.(Morrison *et al*.,2004) investigated the performance of a water-in-glass evacuated tube solar preheater in Asia and Europe using the International Standard test method ISO 9459-2. Based on their numerical simulation of water circulation through long single-ended thermosyphon tubes, they demonstrated the existence of an inactive region near the sealed end of the tube.

Morrison *et al*.(2005)in Another study numerically and experimentally assessed the characteristics of water-inglass evacuated tube solar water heaters, including the circulation rate through single-ended tubes(Ong and Chow ,2003), conducted an experiment with evacuated tubes. collectors (U-shaped tube and heat-pipe design) (U-shaped tube and heat-pipe design). They according to reports, the evacuated tube collector with heat-pipe ,The design is more efficient and has a lower temperature drop. throughout the night(Sabat,1982)

Rittidech *et al*.(2003) ,looked into the A closed-end oscillating heat pipe's thermal performance experimentally. They used R123, ethanol, and water as solvents. the working fluids with a 50% filling ratio Their The results of the experiment revealed that the correlation equation could forecast the heat flux and the operation map Calculate the operational range and inner diameter.

Sharafeldin and Grof (2018),fully investigated the impact of CeO_2/water nanofluid on the effectiveness of ETSC with a concentration of 0.035% and mass flux rate of 0.017 kg/s.m^2. They noticed that, the temperature difference, heat removable factor and useful heat gain were increased by increasing volume concentration and mass flux rates. Also, they concluded that, the maximum increase in temperature difference, heat removable factor, heat gain was respectively (37.3%, 34.66% and 42.3%) at (φ=0.035% and $\dot{m}$=0.017 kg/s.m2) compared with the pure water.

Kim *et al*.(2017), investigated experimentally the efficiency of (UTSC) by using (Al_2O_3 /water) nanofluid at different concentration, mass flow rate and nanoparticles size. It was found that, the thermal conductivity of (Al2O3) increased by increasing concentration of nanoparticles. Also, they concluded that the efficiency of (UTSC) increased by increasing mass flow rates and decreasing nanoparticles size. It was attained its maximum value (i.e.,72.4%) at highest mass flow rate and concentration equals to (1.0 vol.%).

Sharafeldin *et al*.(2019), investigated experimentally the thermal efficiency of (ETSC) by using (Cu/water) nanofluid at different volume concentrations and volume flow rates. The mean diameter of (Cu) nanoparticle was considered as (50nm). It was found that, the thermal efficiency of (ETSC) was increased by increasing volume concentrations and volume flow rates. Also, they concluded that absorbed and the removal energy parameters attained respectively their maximum values (i.e., 0.83 and 21.66) at the highest value of volume concentrations of the nanofluid.

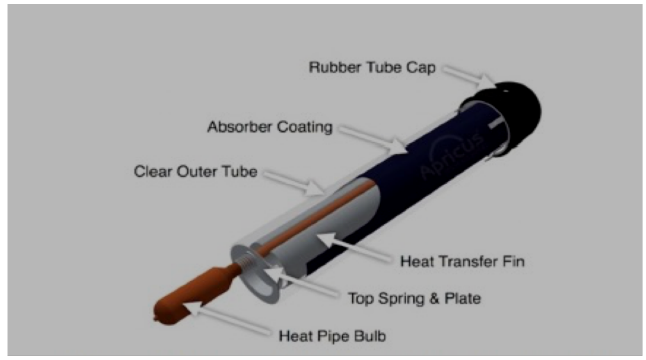

Fig. 1. Evacuated tube with heat pipe (Wei ,2011)

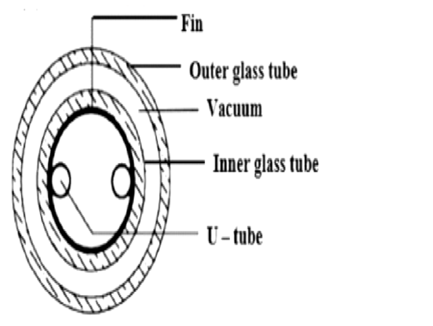

Fig. 2. Schematic of evacuated U- tube solar collector (Kalogirou, 2004)

2. EXPERIMENTAL WORK

The purpose of this work is to investigate the efficiencies of a heat pipe evacuated tube solar collector employing Deionized Water working fluid at various flow rates ranging from 1 to 3 L/min. The experimentation system was a commercial evacuated tube solar collector (ETSC) with an aperture area of 1.128 m^2. Each heat pipe is put in the center of the pipe and supported by an aluminum fin to maximize the area of absorption. Figure 3. depicts the ETSC setup utilized to conduct the current studies which installed in Hilla city (32°28'59.99" N 44°25'59.99" E), whereas figure 4. depicts a schematic diagram of the system. Table 1 lists the collector specifications. The tank has a capacity of 100 L and is connected to the collector by a coil heat exchanger, forming a closed loop for the working fluid.

To minimize the distance traveled by the working fluid, the system tank is situated near the collector. CPVC(Chlorinated polyvinyl chloride) tubing with insulation are used to link the collection and the tank. Before and after the collector, control (on/off) valves were employed to manage the flow of the fluid in the system if necessary. The system is comprised of four thermocouple sensors of type K with an accuracy of (∓0.4 degrees Celsius) and a reading range of (-40 degrees Celsius to 150 degrees Celsius), each of which is connected to a readout. For both the collector and the tank, thermocouples are employed to measure the temperatures at the entrance and exit of both the collector and the tank. A flow meter was used to determine the rate at which the fluid was flowing. The ETSC was operated by turning on the pump to allow for deionized water to circulation between 9:00 a.m. to 4:00 p.m.

The use of energy balance equations serves as the foundation for the thermodynamic modeling of an ETSC's energy system. Kalogirou and colleagues(Naik and Muthukumar, 2019)compiled the equations for an ETSC in steady state for the purpose of calculating energy.

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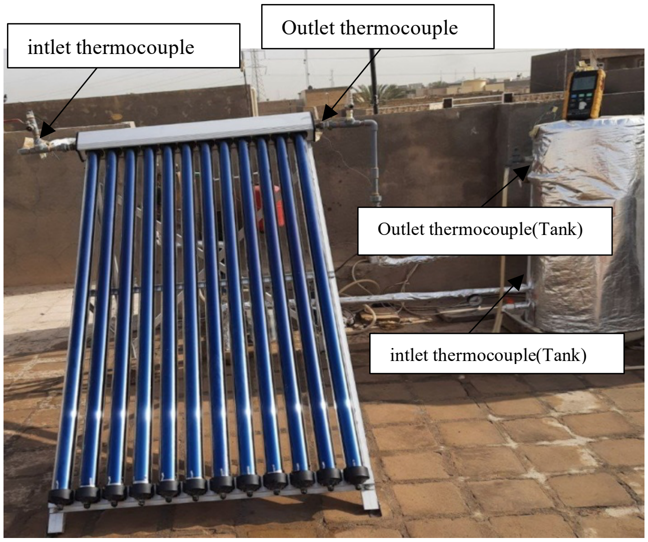

Fig. 3.Photogragh of evacuated tube solar collector used

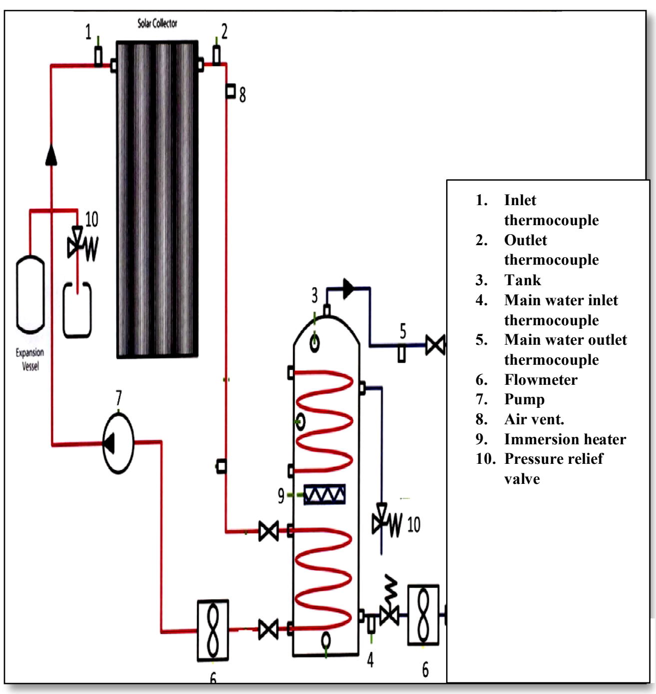

Fig. 4. Sensors locations in evacuated tube solar collector

Table 1 Heat pipe evacuated tube solar collector specification

Specification	*Dimension*
Active Area	1.128 m^2
Glass Transmissivity	$\tau \geq 92\%$
Absorber Emissivity	$\varepsilon \leq 8\,\%$
Absorber Coating Emissivity	$\varepsilon \leq 5\,\%$
Absorber Absorptivity	$\alpha \geq 92\%$
No. of Evacuated Tubes	12
Tube Length	180 cm
Heat Pipe	Material: High purity copper Thermal conductivity: 401 W/m.k Inner diameter: 12mm Outer diameter: 14mm
Outer Glass Tube	Diameter 58 mm Transmissivity $\tau \geq 92\%$ Emissivity $\varepsilon \leq 90\%$ Thickness 2 mm
Inner Glass Tube	Diameter 47 mm Outward Emissivity $\varepsilon \leq 35\%$ Inward Emissivity $\varepsilon \leq 8\%$ Thickness 2 mm
Manifold Insulation Thermal Conductivity	Ki = 0.043 W/m. K

3. CALCULATIONS

3.1. Energy Efficiency

The balance equation of energy is given by

$$\dot{Q}_u = \dot{Q}_{Abs} - \dot{Q}_{loss} \tag{1}$$

$$\dot{Q}_{loss} = U_L A_C (T_M - T_{amb}) \tag{2}$$

It's difficult to employ TM when the collector's temperature isn't uniform; this can be remedied by using the heat removal factor (FR). Calculating the heat removal factor

$$F_R = \frac{\dot{m}C_p(T_{out}-T_{in})}{A_C[I_T(\alpha\tau)-U_L(T_{in}-T_{amb})]} \tag{3}$$

The useful energy is given by

$$\dot{Q}_u = F_R A_C [I_T(\alpha\tau) - U_L(T_{in} - T_{amb})] \tag{4}$$

The thermal efficiency of the collector is given by

$$\eta = \frac{\dot{Q}_u}{A_C I_T} = F_R[I_T(\alpha\tau) - U_L(T_{in} - T_{amb})] \tag{5}$$

3.2.1. Overall Heat Loss Coefficient For ETSC

Ref. (Kalogirou ,2009) can be used to derive the overall heat loss coefficient for ETSC, which is separated into losses by the header tube edge and losses by the absorber tube with ambient air:

$$U_L = U_t + U_e \tag{6}$$

$$U_e = \frac{(UA)_P}{A_s} \tag{7}$$

$$U_t = \frac{1}{\frac{1}{h_{ga}}+\frac{1}{h_{pg}}} \tag{8}$$

$$h_{pg} = h_{pgc} + h_{pgd} \qquad \text{(Tong } et\ al.\text{, 2015)} \tag{9}$$

$$h_{pgd} = \frac{\sigma\varepsilon_p}{1+\frac{\varepsilon_{pd}}{\varepsilon_{gdg}}(1-\varepsilon_p)}(T_p^2 + T_g^2)(T_p + T_g) \tag{10}$$

Tian(2007) concluded that (Ul) is not a constant number but it is a function of the ambient temperature and tube temperature as shown in Eq. (11)

$$U_l = \begin{bmatrix} 0.0025009 \times (T_p - T_a) + 0.70032 & 263°K \le T_a \le 273°K \\ 0.0025418 \times (T_p - T_a) + 0.74336 & 273°K \le T_a \le 283°K \\ 0.0025764 \times (T_p - T_a) + 0.78825 & 283°K \le T_a \le 293°K \\ 0.0024599 \times (T_p - T_a) + 0.85418 & 293°K \le T_a \le 208°K \end{bmatrix} \quad (11)$$

4. UNCERTAINTY ANALYSIS

The error evaluation of the experiment is necessary for faith in the observed results. Uncertainty analysis is used to address the range of uncertainty associated with test results. The general form equation for the uncertainty analysis is provided by:

$$U_y^2 = \sum_{i=1}^{n} U_{xi}^2 \quad (12)$$

Where, Uy is the total uncertainty calculated parameter and Uxi is the uncertainty of each parameter measured.
Input temperature (T_{in}), exit temperature (T_{out}), flow rate ($\dot{m}$), and solar intensity (I) are the observed parameters of the experiments, with minimal errors in specific heat (C_P) and collector area (Ac). As a result, the total uncertainty is as follows:

$$U_y = \eta \times \sqrt{\left(\frac{U_{\dot{m}}}{\dot{m}}\right)^2 + \left(\frac{U_I}{I}\right)^2 + \left(\frac{U_{Tin}}{T_{in}}\right)^2 + \left(\frac{U_{Tout}}{T_{out}}\right)^2} \quad (13)$$

Where, Um ˙ is the uncertainty for the mass flow rate, measured by flow meter (YF–S201) with uncertainty of 0.05 L/min, U_I is the uncertainty for solar radiation, measured by solar radiation sensor PYR 1307 with uncertainty of 10 W/m^2 while, U_{Tin} and U_{Tout} are the uncertainties for the inlet and outlet temperatures respectively, measured by thermocouples type K with uncertainty of 0.4 ◦C. The total uncertainty for the efficiency of the collector is about 5%.

Table 2 shows the uncertainty test for each source.

Parameter	*Uncertainty*
Solar intensity	±1%
Flow rate	±1.5%
Temperature difference	±1.3%

5. RESULTS AND DISCUSSION

An investigation into the effect of using deionized water as the working fluid with three different flow rates on the temperature difference between the collector's inlet and outlet was carried out in January 2022. The working fluid was pumped through the apparatus at three different flow rates from 9 AM to 4 PM (1,2,3 Lpm). Every 120 seconds, the temperatures at the inlet, outlet, and throughout the system were recorded. As an average over two-minute intervals, the solar radiation intensity was recorded.

5.1. Incident Solar Radiation Results

The data of the incident solar radiation was measured directly for eight hours (9 AM – 4 PM)from the weather at the selected experiments days as Fig. 5 showed.It can be noticed that the solar radiation during the interval time are fluctuate since some days witnessed a few clouds although that the tests days were selected based on the weather conditions as the clear sky.

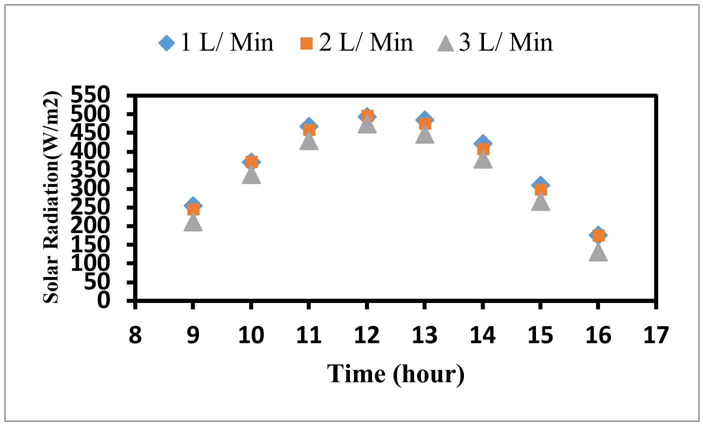

Fig. 5. The incident solar radiation variation with time

5.2.Temperature Difference Results

The results of the temperature difference experiments show that the mass flow rate of the fluid flow and the characteristics of the fluid affect the temperature difference between the outlet and the inlet of the solar collector working fluid. This topic will be discussed in more detail in the following paragraphs. The influence of the mass flow rate of fluid on the temperature differential of deionized water was investigated:
As shown in Figure 6, the difference in temperature between the outlet and the inlet of the deionized water experiments conducted with three different flow rates decreased as the mass flow rate increased. This was because the increase in mass flow rate caused an increase in fluid velocity, which in turn reduced the amount of solar energy that was consumed during the same amount of time.

In contrast, when the flow rate was low, the fluid stayed in the collector for a longer period of time, which resulted in a greater amount of solar energy being absorbed and consequently a higher temperature rise. This was easily observed in the figure that compared flow rate in liters per minute to temperature difference in degrees Celsius.

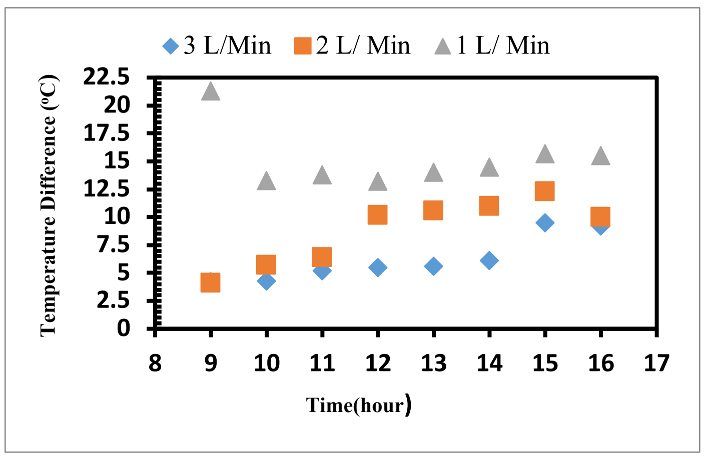

Fig. 6.The outlet-inlet temperature difference of deionized water for three flow rates variation with time

5.3. Energy Analysis Results

Regarding the energy efficiency, the effect of the flow rate of the base fluid, which was deionized water, was investigated, and the results are shown in figure (7-9), which compares three different flow rates. The increase in flow rate brings about an improvement in the collector's efficiency about 42.55% because a higher flow rate brings about a higher Reynolds number, which in turn brings about an improvement in heat transfer (Mintsa *et al.,* 2013).

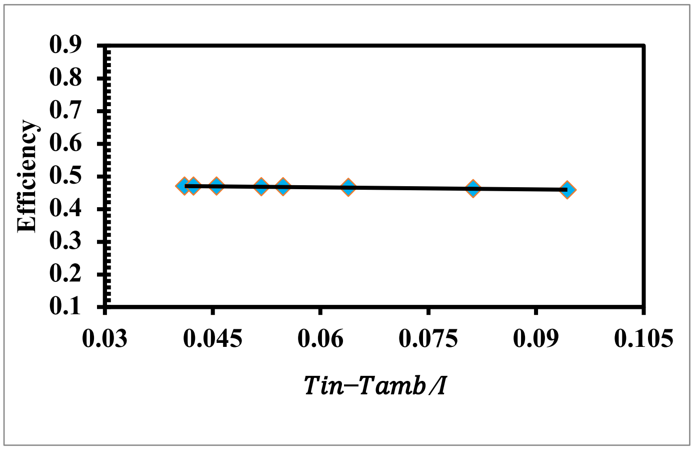

Fig. 7.Efficiency of evacuated tube solar collector for 1 L/ Min of deionized water

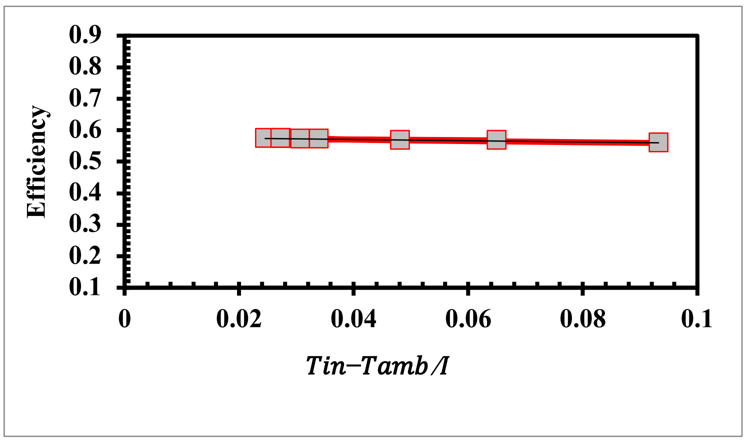

Fig. 8. Efficiency of evacuated tube solar collector for 2 L/ Min of deionized water

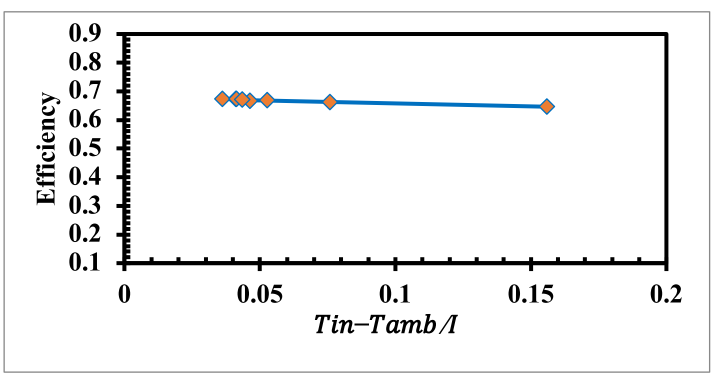

Fig. 9. Efficiency of evacuated tube solar collector for 3 L/ Min of deionized water

6. CONCLUSION

An investigation into the effect of varying volumetric flow rates with distilled water was the subject of an experiment that was conducted for the purpose of determining the energy efficiency of evacuated tube solar collectors .It is possible to draw the conclusion that:

1.when using water as the working fluid, the temperature differences between the outlet and the inlet decreased as the mass flow rate increased.
2.The maximum temperature difference between the outlet and the inlet was attained when the flow rate was low, whereas the smallest temperature difference was attained when the flow rate was high.
3.Furthermore, the intensity of the solar radiation has been measured so that its effect on the solar collector can be observed and recorded.

NOMENCLATURE

A	Area (m^2)
C_p	Specific heat capacity ($J/kg.K$)
d	Outer diameter of the glass (mm)
F_R	Heat Removal Factor
h	Heat transfer coefficient ($W/m^2.K$)
I_T	Total radiation (W/m^2)
k	Thermal conductivity ($W/m.K$)
$\dot{m}$	Mass flow rate (kg/s)
$\dot{Q}$	Heat transfer rate (W)
T	Temperature (°C)
U	Overall heat transfer coefficient ($W/m^2.K$)
$(UA)_P$	Overall heat loss coefficient for the pipe
Greek Symbols	
ε	Emissivity
ρ	Density (kg/m^3)
α	Collector absorptivity
η	Thermal efficiency of the collector
σ	Stefan –Boltzmann constant ($W/m^2.k^4$)
τ	Glass transmissivity
Subscript	
Abs	Absorbed by the collector absorber surface
loss	Loss to the ambient
u	Useful gain
c	Collector
s	Outer surface
M	Mean plate
amb	Ambient
g	Outer glass
in	Inlet fluid
out	Outlet fluid
p	Absorber plate
L	Over all
e	Edge of the header tube
t	Between the ambient and absorber tube
ga	The outer glass and environment
pgc	The glass tube and absorber tube
pgd	Across the thermal conductivity
Abbreviation	
FPSC	Flat plate solar collector
ETSC	Evacuated tube solar collector

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