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Experimental Investigation on the Effect of Inclination Angle of Flat Plate Solar Collector Using Gravity Assisted Heat Pipes

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ABSTRACT

The high cost of traditional fuel leads the scientists to look at new sources of energy. Solar energy is the best renewable source of energy as it is free of running cost and has no pollution of the environment. So, solar distillation is a cheap way to produce fresh water. In this work, the design, construction, and performance evaluation of flat plate solar collector (FPSC) using gravity assisted heat pipes (Thermosyphon) and using acetone as a working fluid is presented. Two systems are designed, the first system is a flow water heat exchanger connected with FPSC welded with 11 thermosyphon, Effect of tilt angle of FPSC was performed from 12°, 17°, 20°, 25° and 30° with filling ratio of thermosyphon was 80% of the evaporator volume. Measuring was conducted in August and September 2021 at Faculty of Engineering, Menoufia University, Shebin El-Kom, Egypt, latitude 30.5° N and Longitude 31° E. The results were as follows, average effectiveness all over the day of measurements was 73% at 12°. The other average effectiveness was 69.35% for 17°, 62.47% for 20°, 67.14% for 25° and 66.68% for 30°. So, the results showed that the best angle performance was 12° with absorber maximum temperature of 70.36 °C at 12:30 PM, and adiabatic section temperature of 60.35 °C, and condensing section temperature of 42.46 °C. The second system is the same FPSC welded with 11 thermosyphon but the condensing section was immersed in the basin of shaded conventional solar distiller as a thermal storage tank and the experiments was conducted with 12° tilt for FPSC. The results of the experimental work showed that maximum value of the instantaneous effectiveness is 51.7% at noon, daily accumulated stored energy of 0.937 MJ and the maximum heat transfer coefficient is 187.82 W/m^2. K. This means a better performance for solar still with thermosyphon if compared with conventional solar still.

Keywords: *Solar energy; Flat Plate solar Collector; Thermosyphon; Thermal Storage; effectiveness.*

1. Introduction

The great increase of population tends to increase the demand of water for humans, animals, and agriculture [1]. Potable water may not be available in all places on the ground while salt water may be in hand but not suitable for drinking or irrigation. So, it is important to produce distilled water from salt water for these purposes. The distillation of water may be achieved by different methods [2]. Solar energy is a promising alternative to serve the fast-growing energy demand in an efficient, clean, and reliable way [3]. The utilization of a small portion of the solar resource can easily meet energy requirements of humankind [4]. Using solar energy for desalination is important because of the high cost of using traditional energy. Fortunately, solar radiation covers a great area on the land and could be used for numerous applications. Heat pipes are an effective tool for transferring heat as they use the phenomena of evaporation and condensation of a fluid to transfer heat from one place where the evaporating portion is settled to another place where the condensing section is settled. There are a lot of types of heat pipes according to what the inner domain looks like. The most common two types are smooth inner with wick material for capillary action and the other is called thermosyphon which means gravity assisted heat pipe and the inner domain is smooth without any wicks. Using thermosyphon will be beneficial for solar still as it helps for increasing distilled water after attenuation of solar radiation because it is used for water heating storage. Many researchers have been focused on using thermosyphon for different purposes [5-8]. Other focused on thermosyphon flat plate solar collector.

Hussein et al. evaluated the usage of solar collectors with heat pipes with 3 various cross-sections experimentally [9]. 3 different pure water filling percentages were applied to the pipes: 10%, 20%, and 35%. The outcomes of the experiments indicated that wickless elliptical cross section HPFPSC has superior performance vs circulars when water filling percentages are low. For wickless elliptical cross section HPFPSC, the best water filling ratio is about 10%, and is very near to 20% for the circular one. Azad [10] did a comparison study on 3 different solar collectors that used heat pipes. They were installed concurrently and evaluated under identical operating conditions. The first type of performance was more efficient across the entire lowered temperature range of parameters, while the other two were adequate. Ahmet and Adnan [11] presented an experimental evaluation of single-phase and two-phase closed thermosyphon solar water heater (SWH) systems. For the traditional single-phase system, the working fluid of two-phase system is water, working fluid was R-134a. The experimental results demonstrated that the redesigned two-phase systems have a 42% better efficiency than the conventional system.

An experimental and theoretical assessment of the impact of integrating HP to conventional FPC was conducted as a means of energy withdrawal devices by Allouhi et al. [12]. There was a high level of agreement between theoretical and experimental studies. The outcomes demonstrated that the solar water heating technology was able to maintain thermal efficiencies up to 33% with a daily solar component greater than 58% in Fez, Morocco during the coldest month of the year. Roshan and Kiran [13] studied experimentally the influence of working fluid on heat pipe thermal resistance and the effect of Bond number which is a dimensionless number involved with working fluid characteristics and geometry of the HP and it is defined as the working fluid's buoyancy force divided by its surface tension force. Also, as thermal resistance decreases, Bond number increases and better performance for the working fluid. Rudresha et al. [14] investigated the influence of filling ratio on heat pipe thermal resistance and thermal performance experimentally. It is concluded that 55% filling percentage has the most effective performance as it has the smallest resistance of thermal (0.136 °C/W). The heat source was 600 W, and the temperature in the evaporator area was 181.57 degrees Celsius, the temperature of the condenser SECTION was 41.06 degrees Celsius, and the coefficient of heat transmission was 526.45 $W/m^2.°C$.

Srikrishna Parthasarathi et al. [15] carried out an experimental investigation on the influence of the bending radius, insulation on the adiabatic sections and the inclination angle for heat transfer. Two working fluids were used (water and methanol). Electrical source was used for heat input. The result showed that water turned out to work better than methanol. The impact of bend radius for methanol is less than that for water because a dynamic viscosity is much less for methanol. Thermal resistance has been found to be reducing with a heat load increases because of the higher flow velocity at a greater heat load. The greatest effect of insulating the adiabatic section was found to extend the convective range of each of the tested working fluids. Rudresha et al. [16] added Al_2O_3 and SiO_2 to distilled water charged in heat pipes with different concentrations. They indicated that adding nanofluids enhanced the rate of heat transfer and reduces the thermal resistance of heat pipes. Allouhi and Benzakour [17] studied numerically the performance of HPFPSC operating with nanofluids. A 1-dimensional transient heat transfer model was performed and indicated mathematical formulation under a 1-dimensional transient heat transfer model was indicated for this. The spatio-temporal temperature variation of each mosque for a sunny day in Fez and Morocco was calculated and CuO, Al2O3 and TiO2 nanofluids were used for various geometries. CuO was the best performer as the energetic enhancement was 2.7% when compared with base fluid (water) and it made a highest increase in a pressure drop across the absorber with a value of 13.26% which expected for a 3% nanoparticle loading. There are other researchers also focused on CFD analysis for the heat pipes, [18-21].

Mousa et al. [22] conducted an experimental and a theoretical investigation of the performance of heat pipes embedded in SWH for heat transfer, from collector plate to a tank of water, using 2-working fluids (Ethanol & Acetone) and various numbers of a heat pipes. The mathematical study was performed for predicting a performance of a SWH. A collector plate temperature and a temperature of a water storage tank were observed during daytime and solar radiation intensity was measured. There was a good compatibility between the experimental and mathematical results. An experimental max-temperatures were about 66 °C for conventional system and 67.8 °C and 64.6 °C for modified systems that used ethanol and acetone respectively, while theoretical temperatures were about 69.2 °C, 69 °C and 69.3 °C, sequentially. The experimental max-efficiency of conv-system is ranged between about 47~53% while that of mathematical calculation was between about 50~53%. Al-Mashat and Hasan [23] investigated the efficiency of an evacuated well tube solar collector (ETC) which consisting of sixteen evacuated tubes with an aqueous/Al2O3 nanofluids. It was found that the performance of the ETC was significantly to the volumetric concentration of the nanofluids. Also, an efficiency was enhanced by about 7.08% and 16.9% with a using of a curved plate reflector and a flat plate reflector, sequentially. Tong and Cho [24] carried out an experimental and mathematical study of the thermal performance of U-tube and heat-tube evacuated solar collectors. There is a good acceptance between the theoretical and experimental work. It has been found that a U-tube-type was less efficient than a heat pipe-type during the hotter day, While the U-tube type showed more stable and better performance when the weather is cloudy. Teles et al. [25] investigated the performance of an ETSC with and without a system of a solar tracking. The tube consisted of an absorbent copper tube inserted eccentrically inside a clear glass cover tube with a reflective film on its inner surface and the eccentric annular space was discharged. Also, an effect of a tracking systems and a tilt angle were calculated. The results showed that, maximum and minimum daily efficiencies of the absorber of about 73% and 42%, sequentially. The efficiency of this collector was calculated annually as 61.5% for the city of São Luís, Brazil.

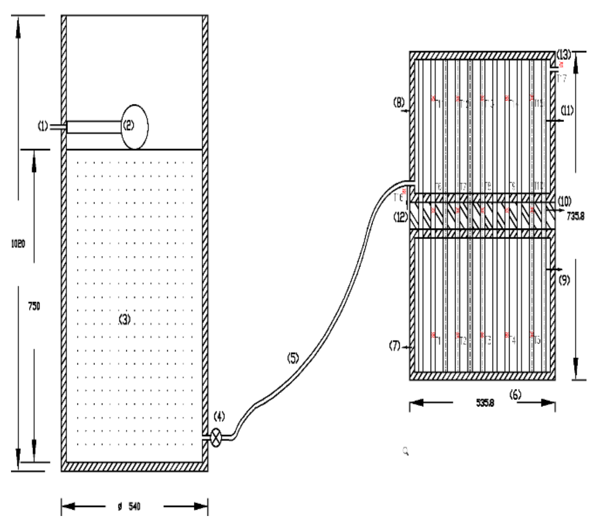
There are two main objectives of that work. First, is to study the flow water heat exchanger performance which connected with FPSC welded with 11 thermosyphon at different inclination angles and finding the best angle performance. The second objective is to use a heat released from a section of condenser for thermal storage at a beast angle. The solar intensity and temperatures were measured all over the day every 30 minutes to evaluate a performance.

2. Methodology:

2.1. Experimental Setup:

The experimental apparatus on which the experimental study has been conducted consists as shown in Figures 1 and 2 of two solar heating systems. The first one, as demonstrated in Fig. 1, includes a water supply tank having 150 liters volume and a thermosyphon heat exchanger. The tank is equipped with a water level controller to maintain a constant level and ensure constant water flow rate. The flow rate of water was controlled by a valve. The thermosyphon consists of 11 pipes with inner diameters of 16 mm, exterior diameters of 18 mm, and lengths of 670 mm. The thermal storage system, as shown in Fig. 2, includes a thermosyphon with flat plate collector. The thermosyphon condensing section was soaked in basin water of conventional solar distiller shaped tank as a thermal storage tank and the evaporating section was welded to FPSC. The thermal storage tank is made of three layers from inside to outside; steel plate of 1.25 mm thickness, glass wool of 254 mm and wooden frame of 4 mm thickness. The tank has a base of 300×500 mm, two sides with vertical edges 150 and 290 mm and a glass cover with inclination angle of 25°. The tank was filled with 12.875 kg of water. The glass cover was shaded to not receive any solar radiation during the experiment.

The thermosyphon pipes were closed at their two ends. They were evacuated and charged with acetone as a working medium. The charging pressure was 1.013 bar that corresponds to boiling temperature of 55 °C for acetone. The thermosyphon pipes were separated into three sections, section of evaporator (300 mm), section of adiabatic (70 mm) and section of condenser (300 mm). The evaporator section was welded with a copper metal sheet that was considered as a flat plate collector of dimensions 300 mm×500 mm. The adiabatic section was insulated with 25.4 mm thickness glass wool of thermal conductivity. The condenser was immersed in cuboid of 300 mm×500mm×40 mm as a heat exchanger, see Fig. 3.



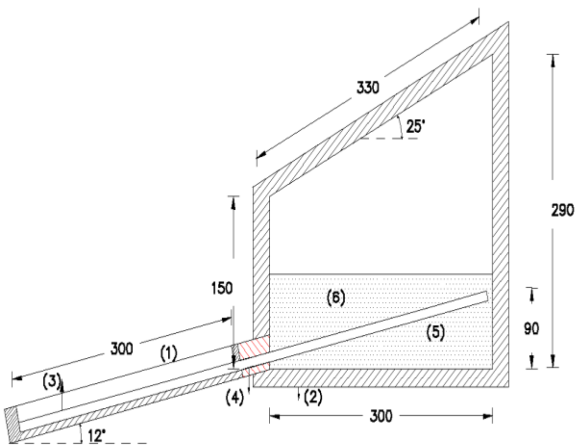
1-Water source	2-Water level controller
3-Water tank	4-Valve
5-Water hose	6-FPSC with thermosyphon
7-Insulation	8-Heat exchanger
9-Evaporating section	10-Adiabatic section
11-Condensing section	12-Inlet water
13-Outlet water	

(Dim. in mm)

(1.a)

(1.b)

Fig. 1: Experimental apparatus: (a) Layout (b) Experimental.



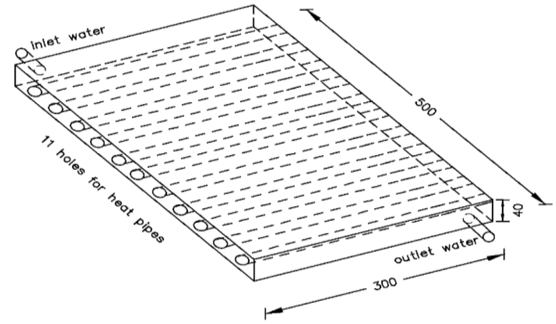
1 Glass cover
2 Glass wool with wooden frame as insulation
3 The heat pipe's evaporating section
4 Adiabatic section of the heat pipe
5 The heat pipes' condensing section
6 Water basin

(Dim. in mm)

(2.a)

(2.b)

Fig. 2: Thermosyphon with flat plate collector used for thermal storage: (a) Layout (b) Experimental.



(Dim. in mm)

Fig. 3: Lay out of the Heat exchanger.

2.2. Measuring procedure:

An experimental investigation was performed in the solar energy laboratory of Division of Mechanical Power Engineering (MPE), The University of Menoufia, Shebin El-Kom (30° 6' N latitude and 30° 98' E longitude), Egypt under actual weather conditions for different days in August and September 2021. The tests were carried out in two stages. During the initial stage, a flow water heat exchanger connected with FPSC welded with 11 thermosyphon, effect of tilt angle of FPSC was performed at different angles 12°, 17°, 20°, 25° and 30° with filling ratio of thermosyphon was 80% of the evaporator volume. For all the days, the measurements were taken from 8:00 AM to 16:00 PM with step time of half an hour. Temperatures T and solar radiation intensities *I(t)* were the most crucial variables to be measured. For the second stage, the same FPSC welded with 11 thermosyphon but the condensing section was immersed in the basin of shaded conventional solar distiller as a thermal storage tank and the experiments was conducted with 12° tilt for FPSC. The same procedure of measurements was taken for the second system to make thermal analysis of it.

2.3. Uncertainty and error analysis.

First, the radiation intensity was measured every day of experiments with a step time of half an hour. The measuring was carried out with EPPLEY PSP Pyranometer, which has a range of (0 to 2000 W/m^2) and ±20 W/m^2 mistake. Second measuring was the temperature which was measured by calibrated copper-constantan thermocouples (type T) with a range of (-200:200 °C). The thermocouples were attached to NI cDAQ-9174 data Acquisition with an error of ±0.05 °C. The data acquisition was connected to laptop for reading and saving the measurements. The measurements were conducted at steady state condition. The flow rate of water that enters the condenser section was also measured; it was measured by an amount of water in a certain time by using Calibrated Flask with a range of 0:600 ml and an error of ±1 ml. Time was measured by stopwatch with an error of ±1 msec. All measuring were conducted at different tilt angles to obtain the influence of direction on flow water heat exchanger performance connected with FPSC, then the thermal analysis of thermal storage system.

3. Thermal analysis:

3.1. Flow water heat exchanger connected with thermosyphon-FPSC.

The main parameter of the system to be calculated is the effectiveness which can be calculated by the following eq.:

$$\varepsilon = \frac{Q_{w.out.}}{Q_{in.}} \tag{1}$$

Where $Q_{w.out.}$ is the Output energy, heat released from condensing section which can be calculated from eq.

$$Q_{w.out.} = \dot{m} \times Cp \times \Delta T \times t \tag{2}$$

Where $\dot{m}$ is the circulating water mass flow rate that was maintained at about 0.0032 Kg/s and

$$\Delta T = T_{out} - T_{in} \tag{3}$$

Where T_{out} and T_{in} are the temperatures of the exit and inlet water, respectively.

$Q_{in.}$ is the Input energy, solar radiation energy,

$$Q_{in.} = I(t) \times A_{abs} \times t \tag{4}$$

Where $I(t)$ is the amount of solar radiation and A_{abs} is the absorber copper sheet area which was 0.15 m^2.

3.2. Thermosyphon-FPSC for storing energy.

For this system, effectiveness is the main parameter which can be calculated by the relation,

$$\varepsilon = \frac{Q_{w.heated.}}{Q_{in.}} \tag{5}$$

Where $Q_{w.heated.}$ is the heat stored in the water during step time of the measurements which was 30 minutes and can be calculated from,

$$Q_{w.heated.} = m \times Cp \times \Delta T \tag{6}$$

Where ΔT is the difference between the temperature at the end of time step and at the beginning, by the following eq.:

$$\Delta T = T_2 - T_1 \tag{7}$$

And Q_{in} is the Input energy, solar radiation energy, eqn. (4).

The second important parameter is the accumulated stored energy which can be calculated by,

$$SE_{acc} = \sum_{t_{start}}^{t_{finish}} (SE) \tag{8}$$

Where SE is the stored energy within certain amount of water mass which was 12.875 kg and can be determined using the following formula:

$$SE = m \times Cp \times \Delta T \tag{9}$$

The third parameter is the coefficient of heat transfer for the natural convection process which can be calculated by,

$$h = (Q_{w.heated.}/t) / (A_{lat} \times (T_s - T_\infty)) \tag{10}$$

Where A_{lat} is the lateral area of the thermosyphon's condensing section and can be calculated by

$$A_{lat} = \pi \times n \times d_o \times L \tag{11}$$

T_s is the surface Condensing section temperature and T_∞ is the temperature of the water inside the thermal storage far away of the condensing section surface.

4. Results and Discussions.

4.1 Solar intensity distribution.

The solar intensity was measured every day of experiments to evaluate the performance of a heat exchanger. Fig. 4 indicates a distribution solar energy in various days and different flat plate tilt angles (FPTA). Fig. 5 indicates the same distribution on September 20, 2021, for 12° inclination angle. The 2 figures show that the solar intensity increases until it reaches a max value at solar noon and after that, it decreases again.

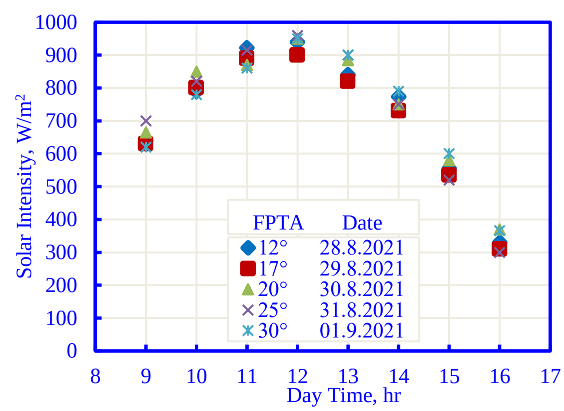


Fig. 4: Hourly variation of experimental solar radiation intensity for different inclination angles.

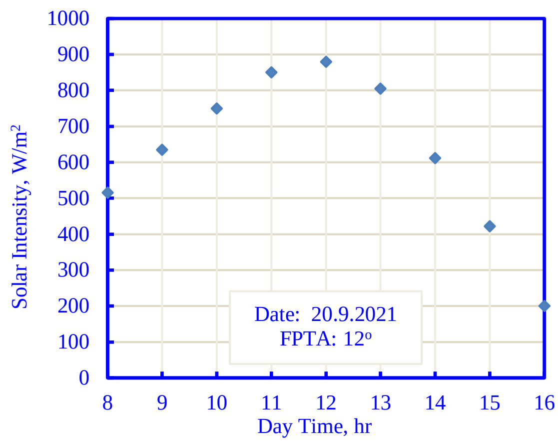
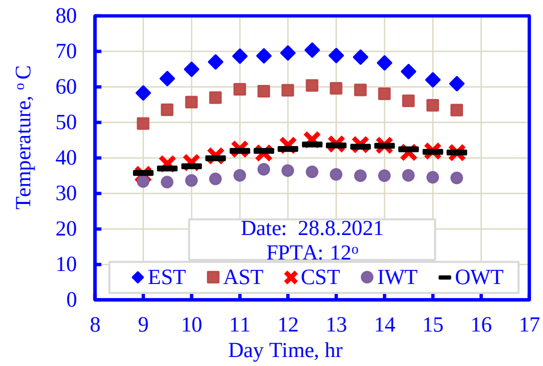


Fig. 5: Hourly variation of experimental solar radiation intensity for 12° inclination angle.

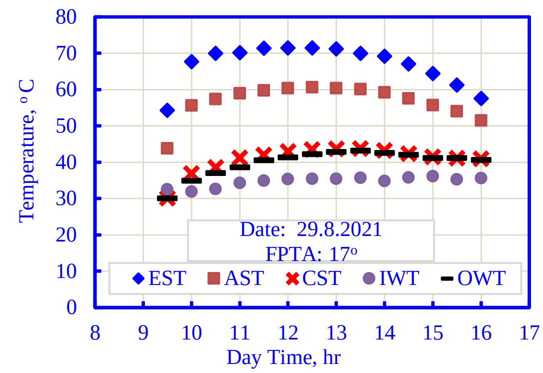
4.2 Temperature distribution:

The temperature was measured along the heat pipes for water inlet and outlet of heat exchanger for five days and illustrated in Fig. 6.

From the figures, it's shown that the evaporating section has the highest values of temperature (EST) because of the welding with flat plate collector which oriented to face the sun by facing south direction. The adiabatic (AST) one followed by the condensing section (CST) which immersed in the heat exchanger to heat the flowing water has less temperatures than it. and it should be hinted that condensing section temperature (CST) was more than outlet water temperature (OWT). There is a clear rise in the temperature of flowing water from inlet to outlet. It also can be seen that the increasing of temperature slightly until noon, because of the highest solar intensity, after which it goes down due to the decrease of solar intensity. The output energy from the system mainly depends on the difference between the inlet (IWT) and outlet (OWT) temperatures of the water. It is recorded that the maximum difference of these temperatures at around 14:00 PM at all days and this is due to the release of stored heat in the materials of thermosyphon and flat plate collector absorber after the attenuation of the solar intensity. The maximum difference was found to be 8.5 °C on 28.8.2021 at inclination 12°.



(6.a)



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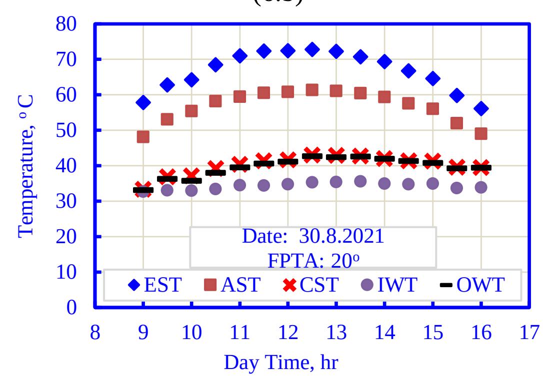
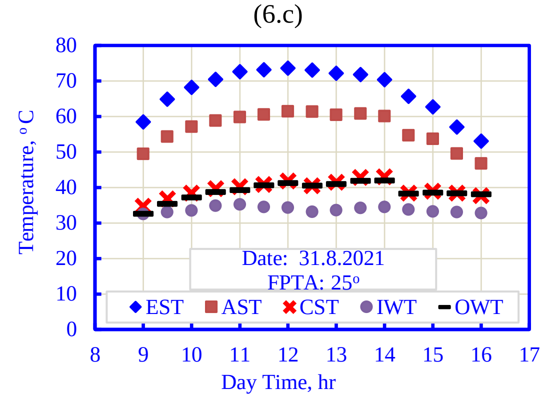
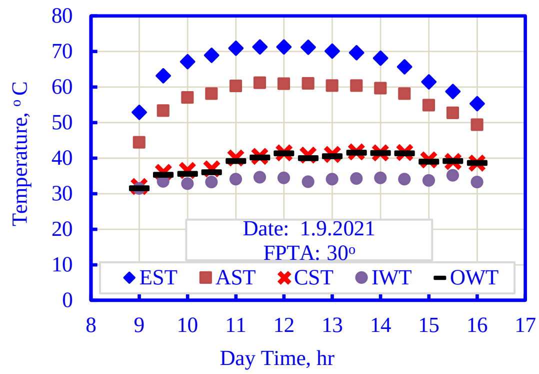


(6.c)



(6.d)



(6.e)

Fig. 6: Comparison between different inclination angles experimental results of temperature distribution along heat pipes, water inlet and for different angles.

Fig. 7 shows the daily average effectiveness for different angles. The maximum effectiveness was achieved at angle 12° because of the effect of gravity force on working fluid movement inside the thermosyphon although the highest solar radiation was for the angles near latitude angle of the local area. The weather conditions should be taken into consideration.

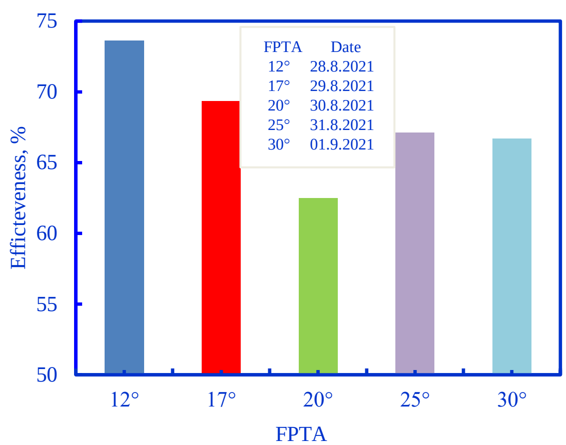


Fig. 7: Daily effectiveness for thermosyphon at different angles.

Fig. 8 shows the variation of instantaneous effectiveness of thermosyphon at different angles. The trend is the same for all angles with slight difference because of weather conditions. It is found that the instantaneous effectiveness of thermosyphon increases with daytime till it has a value more than 100% after 15:00 PM because of heat storage by the thermosyphon materials as the heat by radiation is distributed to three Parts, heating water (output energy), lost within ambient and the last was stored by the materials of thermosyphon and flat plate collector absorber. So, at small solar radiation before sunset the stored energy comes back to aid in heating water and then the effectiveness becomes more than 100%. Also, at inclination 12°, the instantaneous effectiveness was higher than the rest except around noon where the 25° and 30° takes the lead as the solar intensity has its maximum value and then high effect on the performance.

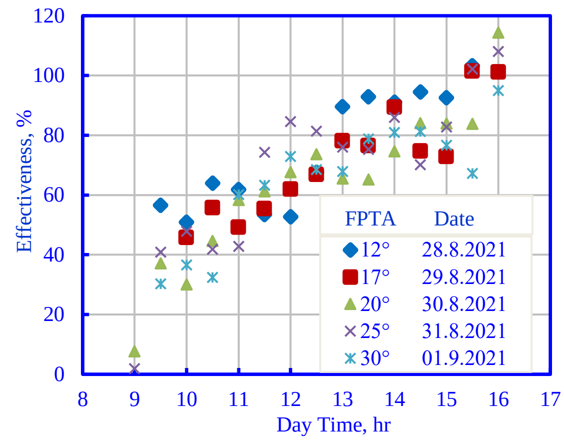


Fig. 8: Instantaneous effectiveness for thermosyphon at different angles.

Fig. 9 indicates the input and output energy through the period 9:30 AM to 15:30 PM. It is shown from the figure that the input energy increases till it reaches its maximum value at 12:30 PM then it decreases again till sunset. The output energy follows the same trend, but it has its maximum value at 13:00 PM and 13:30 PM. It is shown that the effectiveness has a value lower than 100% until 15:00 PM then the effectiveness increases over 100% because of the same reason as fig. 8 which was heat storage by the thermosyphon materials. The heat by radiation is distributed to three Parts, heating water (output energy), lost within ambient and the last was stored by the materials of thermosyphon and flat plate collector absorber so at small solar radiation before sunset the stored energy comes back to aid in heating water and then the effectiveness becomes more than 100%.

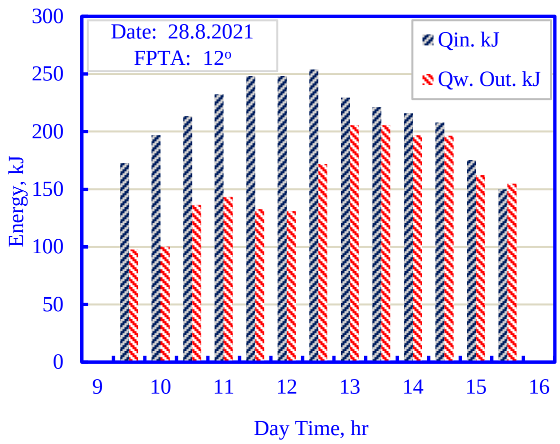


Fig. 9: Input and Output energy for 12° inclination angle.

Fig. 10 shows a heat transfer coefficient variation along a condenser section for a thermosyphon with daytime. It is indicated that the coefficient of heat transfer increases significantly from early morning until it has its maximum value at 13:00 PM. This is because of solar radiation absorption by the evaporating section of thermosyphon and working fluid evaporation-condensation phenomena, Also, because of a high temperature difference between a surface temperature of a thermosyphon tube and water. After that, a coefficient of heat transfer reduces till sun set. A maximum value of heat transfer coefficient attained was 187.8 W/m^2. K at 13:00 PM.

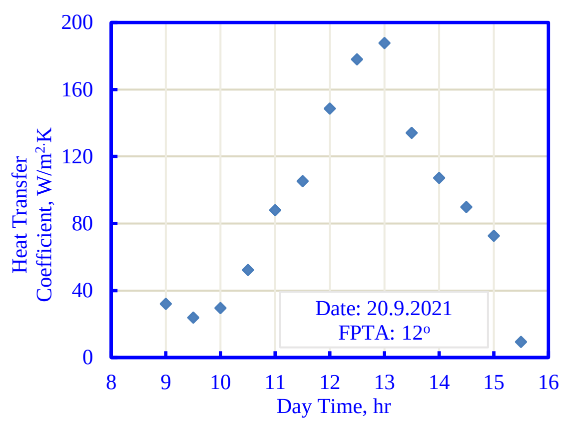


Fig. 10: Variation of a convection coefficient of heat transfer along a condenser section of the thermosyphon.

Fig. 11 presents an instantaneous effectiveness variation of a thermosyphon with daytime. It is found that the effectiveness has small value in the morning (about 23%) then it increases with increasing solar intensity till it has maximum value of 51.7% at noon. After that it decreases because the losses to surroundings have large effect on effectiveness as the ambient temperature goes down and no sufficient incoming energy to recompense those losses.

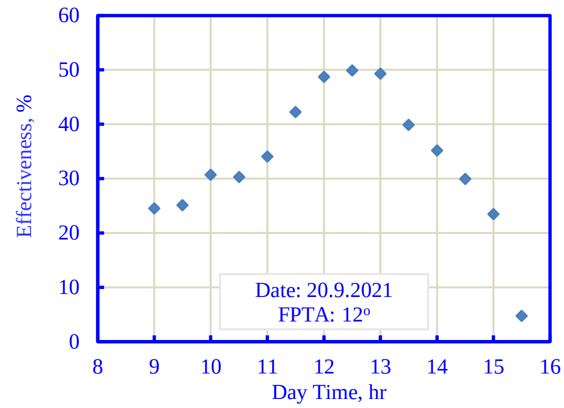


Fig. 11: Variation of instantaneous effectiveness for thermosyphon.

Fig. 12 indicates the increase of accumulated stored energy with daytime. It still increases as there was a difference between the thermosyphon tube and water. The value was 0.953 MJ at the end of the positive measurements at 15:30 PM after that, there was no accumulation.

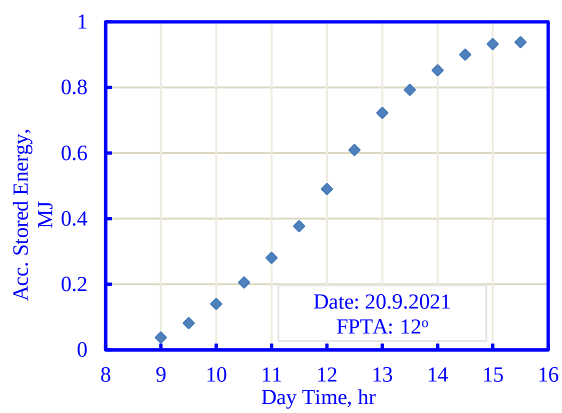


Fig. 12: Accumulated stored energy of the thermosyphon with flat plate collector during daytime.

5. Conclusion:

The aim of this work is to study the performance of a flow water heat exchanger connected with FPSC welded with 11 thermosyphon at different inclination angles and finding the best angle performance. Then using this inclination angle for thermal storage system which use the basin of conventional still as a water heating storage system by immersing the condensing section inside the basin of conventional still and the current research can lead to the following conclusion:

1. The maximum radiation is for tilt angle equal to Latitude for the location where the experiment was done but there is another important parameter to enhance the efficiency of the solar thermosyphon which is gravity force effect. The movement of the evaporated acetone is easier for lower inclination angles than latitude angle so from this study it is obvious that the best effectiveness was at inclination angle 12° which was 73% of a daily basis.
2. For instantaneous effectiveness, it was recorded that there was an increase with time. And it increased more than 100% after 15 PM for all FPTAs, because of heat storage during sunshine earlier. The radiation energy divided into three items (rising water outlet temperature as a useful energy, stored into materials of the system and lost energy to the environment) stored energy is the base of that the instantaneous effectiveness was more than 100% as it reached 103.2% at 15:30 PM for FPTA 12°.
3. For the thermal storage system, the heat transfer coefficient and instantaneous effectiveness have a similar trend as a solar radiation model and there were 187.82 W/m^2.K and 51.1% respectively at 13 PM.
4. Total accumulated stored energy all over the day was 0.953 MJ and this means more energy stored inside solar still and more productivity as a modification.

Nomenclature:

A: Area, m^2.
A_{abs}: Absorber Area, m^2.
A_{lat}: Lateral area, m^2.
C_p: Specific heat capacity, kJ/ kg. K.
d: Diameter of the heat pipe, m.
h: Convective heat transfer coefficient, W/m^2. K.
$I\ (t)$: Solar radiation intensity W/m^2.
L: Height, m.
m : Water basin mass, kg.
$\dot{m}$: Water mass flow rate, kg/s.
n: Number of heat pipes connected with flat plat collector.
$Q_{in.}$: Input energy, solar radiation energy.
$Q_{w.heated.}$: The heat stored in the water during step time of the measurements.
$Q_{w.out.}$: Output energy, heat released from condensing section.
SE: Stored energy.
SE_{acc} : Accumulated stored energy, MJ.
T : Temperature, K.
T_s: Condensing section average temperature.
$T\infty$: Far away water temperature inside basin.
t: Time, s.

Abbreviations:

AST: Adiabatic section temperature.
CST: Condensing section temperature.
EST: Evaporating section temperature.
ETSC: Evacuated tube solar collector.
FPC: Flat plate collector.
FPSC: Flat plate solar collector.
FPTA: Flat plate tilt angle.
HP: Heat pipe.
HPFPSC: Heat pipe flat plate solar collector.
IWT: Inlet water temperature.
OWT: Outlet water temperature.

Subscripts:

abs: Absorber.
c: Condenser.
in: Inlet.
o: Outlet, outside.
out: Outlet.

References:

[1] Mahmoud S. El-Sebaey et al., "Experimental Analysis and CFD Modeling for Conventional Basin-Type Solar Still", Energies, MDPI, Vol. 13 (2020), Issue 21, 5734.

[2] Mahmoud S. El-Sebaey, Ahmed Hegazy, Asko Ellman and Tarek Ghonim, "Experimental and CFD Study on Single Slope Double Basin Solar Still", ERJ, 44 (2021), 21-32.

[3] A. Allouhi, "Management of photovoltaic excess electricity generation via the power to hydrogen concept: a year-round dynamic assessment using artificial neural networks", Int. J. Hydrogen Energy, 45 (2020), 21024–21039.

[4] A. Kumar, M. Sharma, P. Thakur, V.K. Thakur, S.S. Rahatekar, R. Kumar, "A review on exergy

analysis of solar parabolic collectors", Sol. Energy, 197 (2020), 411–432.

[5] Xu RJ, Zhang XH, Wang RX, Xu SH, Wang HS., "Experimental investigation of a solar collector integrated with a pulsating heat pipe and a compound parabolic concentrator", Energy Conversion and Management, 148 (2017), 68–77.

[6] Verma SK, Tiwari AK, Chauhan DS., "Experimental evaluation of flat plate solar collector using nanofluids", Energy Convers Management, 134 (2017), 103-115.

[7] Mosleh HJ, Mamouri SJ, Shafii MB, Sima AH., "A new desalination system using a combination of heat pipe, evacuated tube and parabolic trough collector", Energy Convers Management, 99 (2015), 141-150.

[8] Ozsoy A, Corumlu V., "Thermal performance of a thermosyphon heat pipe evacuated tube solar collector using silver-water nanofluid for commercial applications", Renewable Energy, 122 (2018), 26-34.

[9] Hussein H. M. S., El-Ghetany H. H., and Nada S. A., "Performance of Wickless Heat Pipe Flat Plate Solar Collectors Having Different Pipes Cross Sections Geometries and Filling Ratios", Energy Conversion and Management, 47(2006), 1539–1549.

[10] Azad E. "Assessment of three types of heat pipe solar collectors", Renew. And Sustainable Energy Rev., 16 (2012), 2833-2838.

[11] Ahmet S. and Adnan B., "Experimental Investigation of Single-Phase and Two-Phase Closed Thermosyphon Solar Water Heater Systems", Scientific Research and Essay, 6 (2011), 688-693.

[12] Allouhi et al., "Forced-circulation solar water heating system using heat pipe-flat plate collectors: Energy and exergy analysis", Energy, 180(2019), 429-443.

[13] Roshan D. Bhagat and Prof. Kiran M. Watt, "Effect of Bond Number, Working Fluid and Operating Temperature on Thermal Performance of Closed Loop Pulsating Heat Pipe", International Conference on Electrical, Electronics, and Optimization Techniques (ICEEOT) – 2016.

[14] S. Rudresha, E. R. Babu, R. Thejaraju, "Experimental investigation and influence of filling ratio on heat transfer performance of a pulsating heat pipe", Thermal Science and Engineering Progress, 38 (2023).

[15] Srikrishna Parthasarathi,Siddharth Nagarajan, Shambhavi Desai, S. Umamaheswara Reddy, G. S. V. L. Narasimham. "Effect of bend radius and insulation on adiabatic section on the performance of a single closed loop pulsating heat pipe: experimental study and heat transfer correlation", Heat and Mass Transfer, 57(2021) 1871–1892.

[16] S. Rudresha, V. Kumar, "CFD analysis and experimental investigation on thermal performance of closed loop pulsating heat pipe using different nano fluids", Int. J. Adv. Res., 2, (2014) 753–760.

[17] A. Allouhi and M. Benzakour Amine, "Heat pipe flat plate solar collectors operating with nanofluids", Solar Energy Materials & Solar Cells, 219 (2021).

[18] Bandar Fadhl et al., "CFD modelling of a two-phase closed thermosyphon charged with R134a and R404a", Applied Thermal Engineering, 78 (2015), 482-490.

[19] Asghar Alizadehdakhel et al., "CFD modeling of flow and heat transfer in a thermosyphon", International Communications in Heat and Mass Transfer, 37 (2010), 312–318.

[20] Xiaoyuan Wang et al., "A combined CFD/visualization investigation of heat transfer behaviors during geyser boiling in two-phase closed thermosyphon", International Journal of Heat and Mass Transfer, 121(2018), 703–714.

[21] H. El Mghari et al., "Annular Condensation CFD Models for the Water-Steam in the Heat Pipe Systems", J. Mater. Environ. Sci., 8 (2017) 763-771.

[22] Mousa M. Mohamed, Mostafa A. Abdel-Baky, Tarek A. Ghonim and Karima A. Soliman, "Experimental and Theoretical Study of the Performance of Solar Water Heaters with

Gravity-Assisted Heat Pipes", Engineering Research Journal, 43 (2020) 51-61.

[23] Al-Mashat SMS, Hasan AA. "Evaluation of convective heat transfer and natural circulation in an evacuated tube solar collector". Journal of Engineering (May 2013),19.

[24] Tong Y. and Cho H., "Comparative Study on the Thermal Performance of Evacuated Solar Collectors with UTubes and Heat Pipes", International Journal of Air-Conditioning and Refrigeration, 23(2015).

[25] M. de P.R. Teles, K.A.R. Ismail, A. Arabkoohsar, "A new version of a low concentration evacuated tube solar collector: optical and thermal investigation", Sol. Energy, 180 (2019) 324–339.