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Studies on Photovoltaic Thermal System Utilising Titanium Oxide Nano Fluid Experimentally

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Abstract*: The present study was designed to experimentally investigate the performance of a solar water heater consisting of a flattened tube absorber with spiral configuration. The analysis is carried out by using water as the working fluid adopting forced circulation for various flow rates of 0.05 kg/s, 0.1 kg/s, 0.15 kg/s, 0.2 kg/s and 0.3 kg/s. The effect of mass flow rate on the flatness of the tube and spiral configuration of the absorber is investigated. The instantaneous efficiency, outlet fluid temperature, Reynolds number, Nusselt number, and heat transfer coefficient, friction factor, and Dean number are investigated. The results presented indicate higher instantaneous efficiency of a flattened tube absorber and a highest outlet temperature was obtained for a mass flow rate of 0.1 kg/s. The removed energy parameter FRUL increases by 3.5% and the absorbed energy parameter FR(τα) increases by 2% for every increase in a flow rate of 0.05 kg/s. The values of the Nusselt number, friction factor and dean number obtained experimentally were compared with numerical correlation and the deviation was found to be. within limits. The Dean number was calculated for different curvature ratio of κ1 ¼ 0:141, κ2 ¼ 0:070and κ3 ¼ 0:047 increase dean number with the increase in curvature ratio was found resulting in an increased Nusselt number better heat transfer was obtained.*

Keywords: Flattened tube; spiral configuration; flow rate; heat transfer; Nusselt number; curvature ratio; Dean number

I. INTRODUCTION

Solar energy is the widely utilized renewable energy resource and the solar water heater is its significant application in which solar energy can be harvested directly and it has drawn awesome consideration among scientists in this field. Solar energy can be obtained by passing water through an absorber coated with a selective coating. (Jamar et al. 2016) defined the solar water heating system as the system in which continuous circulation of water through the absorber raises the temperature. Garcia, Martin, and Perez-Garcia (2013) investigated experimentally and determined that the utilization of wire-coil inserts improves the heat transfer in water heater, and the increase in efficiency was found to be 14% to 31%.

The performance of the solar water heater using concrete structures with three different conditions is evaluated by Krishnavel, Karthick, and Murugavel (2014). Hossain et al. (2011) and Sakhrieh and Al-Ghandoor (2013) conducted experiments on five different types of collectors and the effi ciency was calculated in each case. The improvement in the performance is obtained using a corrugated absorber surface as an absorber in a solar water heater, which was analyzed by Kumar and Rosen (2010). Anvari et al. (2011) analyzed a horizontal tube with convergent and divergent conical struc tures, which showed that the divergent conical form has better performance. The presence of honeycomb structures with a different air gap in the collector gives better performance results compared to the plain collector was experimentally analyzed by Abdullah, Abou-Ziyan, and Ghoneim (2003).

Ho and Chen (2008, 2006) showed that the implementation of recycle effect improves collector the efficiency. The attachment of internal fins attached to the tubes also shows a considerable increase in the efficiency of the collectors at the same flow rate. An analysis was performed to investigate the flow structure and heat transfer mechanism to improve heat transfer due to the presence of V-finned tape inside the tested duct by Noothong et al. (2015). Hobbi and Siddiqui (2009) demonstrated the improved performance of a solar collector using enhancement devices. The effect of a heat

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exchanger placed diagonally in the storage tank has been analyzed experimentally and validated using theoretical results by Koffi et al. (2008).

Hussain Al-Madani (2008) constructed solar water which was cylindrical in shape and determined that the maximum value of efficiency was found to be 41.8%. Balaji and Iniyan 2016 experimentally investigated the enhancement in the transfer and pumping power due to the presence, using enhancers in absorber tube. Apart from using heat enhancement devices for enhancing the efficiency of the solar collec tor, a significant amount of research has been carried out using alternate fluids, mostly nanofluids in the collector. Nanofluids are fluids composed of particles of nanosizesus pended in the base fluid. The nanofluids have higher heat transfer properties compared to water. Experiments were con ducted using Al2O3-water nanofluid by Said et al. (2011) and using TiO2-H2O nanofluid (Said et al. 2015) on the solar water heater and the improvement in the exergy and exergy efficiency compared to that of water were noted. The effi ciency of a collector using Al2O3-water nanofluid and gra phene oxide (GO) nanofluid as the working fluid was investigated experimentally for different flowrates using forced circulation by Yousefia et al. (2012) and AninVincely and Natarajan (2016). Michael and Iniyan (2015) investigated the enhancement in efficiency under natural flow compared to forced circulation for CuO-water nanofluid. Faizal et al. (2013) estimated the cost and energy savings for solar collectors using various nanofluids. Saida et al. (2014) investigated the performance of a solar collector operated with SWCNT-based nanofluids. Higher efficiency could be seen in a solar collector using Al2O3/water nanofluid with volume fraction of 4% at a constant mass flow rate as studied by Mahian et al. (2014). Ahmadi, Ganji, and Jafarkazemi (2016) tested the effect of nanofluids using graphene on a solar collector. The experimental analysis of using Al2O3/distilled nanofluid on an evacuated tube solar collector was carried out by Ghaderian, Azwadi, and Sidik (2017). Qinbo, Zeng, and Wang (2015) proved that the efficiency of a collector increases by using nanofluids. The impact on the absorptance and emittance of the selective coating on reducing heat loss coeffi cients is evaluated by Roberts and Forbes (2012). Kaichun et al. (2015) proved that solar water heater with elliptical tube shows better heat transfer and flow characteristics. Cheng, Qian, and Wang (2017) reported that experimental results show improved heat transfer using twisted oval tube compared to a plain tube. From the experimental results obtained by Abdolbaqi et al. (2017) and Vajjha, Das, and Ray (2015), it has been determined that the heat transfer and friction factor in flat tubes in turbulent flow condition leads to increase in Nusselt number which leads to improvement in heat transfer. From the wide range of literature of the analysis presented,

it could be noted that efforts have been made to improve the efficiency of a solar water heater by introducing various heat transfer enhancement devices and different working fluids, but the basic structure of the water heater which consists of header and riser tube remains the same. Moreover, it is noteworthy that the flat tubes display a better heat transfer compared to plain tubes. In this work, a flattened tube solar water heater with a spiral configuration is presented replacing the conventional absorber which is composed of header and riser tubes. The analysis was performed to determine the effect of the flat tube and the influence of spiral configuration for mass flow rates of 0.05 kg/s, 0.1 kg/s, 0.15 kg/s, 0.2 kg/s, and 0.3 kg/s on heat transfer, Reynolds number, Nusselt number and friction factor.

II. METHODOLOGY

The experiment was conducted by fabricating the absorber and analyzing the performance of the absorber using different flow rates.

2.1. Fabrication of the absorber

The major focus of this work is to increase the efficiency of the collector by reducing the area of the collector. In order to reduce the area of the collector in this work, an alternative design of absorber is proposed and this replaces the conventional absorber with header and riser arrangement.

Flattened tube spiral flow absorber made of copper is used to extract the solar energy. For a solar thermal system, increasing the heat transfer area can increase the output temperature of the system. Flattened tube absorber is being considered as it allows more contact area compared to other types of absorbers. Flat tube is a light and compact design which can reduce the design space and is economical for fabrication processes. The heat transfer characteristics of a flat tube are higher. The heat transfer coefficients of flat tubes are higher compared to elliptic and circular tubes. As per the geometry of the flattened tube, the top and bottom of the wall are closer to each other. Consequently, the tempera ture distribution is flat and better compared to the circular tubes resulting in better heat transfer characteristics than a circular tube. The spiral flow configuration enhances the heat transfer to the fluid and hence, as a result, a higher outlet temperature of the water could be obtained. The entire pro cess of fabrication of the absorber is shown in Figure 1. The absorber was fabricated from the single copper sheet using a welding process. A copper sheet of thickness 18 gauges was purchased which was then cut and welded to form a flattened tube and then bent to form a spiral configuration. The absor ber is then coated with the black coating and placed in a wooden box with insulation between the absorber and the box. Water enters into the absorber, it passes through the whole length of the absorber and reaches the outlet. The length of the absorber is 4.5 m. The storage tank was constructed having a capacity of 50 litres. The dimensions of the absorber are displayed in Figure 2.

Figure 1.Fabrication process of the system. (a) Copper Sheet of Dimension .(b) Absorber through welding process. (c) Absorber after welding process is complete. (d) Black coated absorber. (e) Wooden box with insulation. (f) Storage tank with heat exchanger.

2.2. Description of the system

The collector was placed at an inclination angle of 23o on the terrace of the building on a horizontal plane. Experiments were conducted at Anna University at its regional campus located at Tirunelveli. The latitude and longitude of the test location are 8°73′N and 77°7′ E, respectively. The experimental setup is placed facing south as the test location is located in the northern hemi sphere. The experimental setup consists of the flattened tube spiral absorber with a storage tank, a utility water storage tank, a rotameter, manometer, a pump, and a data acquisition system for monitoring the temperature values. The detailed specification of the system is listed in Table 1.

The temperature of the fluid at various instances was measured using RTD PT-100 sensors radiation using Tenmars TM-207 solar power meter. A circulation pump and a rotameter were used for maintaining a constant flow rate by means of forced circulation. The water from the storage tank is pumped back again by means of a booster pump. The tests were conducted with water as the absorber fluid during February to April 2017 between 10 a.m. and 4 p.m. on sunny days. The schematic layout and view of the experimental set up have been given in Figure 3. Water pumped from the inlet passes through the absorber passing through a number of bends and it reaches the outlet which is connected to the storage tank. The process is a closed loop process. The flow rate is controlled by valves. The pressure drops at the inlet and the outlet are measured using a mercury U-tube manometer. The experiment was performed using forced circulation for various flow rates of 0.05 kg/s, 0.1 kg/s, 0.15 kg/s, 0.2 kg/s, and 0.3 kg/s.

Figure 2.Experimental setup.

Table 1. Details of experimental set up.

S.No	Description	Values
1	Collector size	Length-1250mm,breadth −500mm
2	Thermal absorber	Flattened tube Spiral flow absorber
3	Copper tube – spiral	Effective diameter −28mmWidth −100mm thickness-1mm
4	Bends and Joint	Gas welding
5	Glazing	Quantity −1,width 5mm thickened glass cover
6	Bottom thermal insulation	50mm Thick polystyrene
7	Side thermal insulation	50mm Thick polystyrene

2.3. Efficiency calculations

The useful energy and the thermal efficiency of a flat plate solar collector may be acquired primarily based on the equations given by Duffie and Beckman (2006) in the following form as presented in Equation (1). The heat gained by the fluid is dependent on mass flow rate specific heat of the fluid and the difference between inlet and outlet fluid temperatures. The heat gained by the fluid expressed as a function of heat removed by the absorber and the heat lost by the fluid is given by Hottel – Whiller – Bliss Equation (2).

$Q = \dot{m}\, Cp(To-Ti)$ (1)

$Q = AsFr[Gt(\tau\alpha) - UL(Ti - Ta)]$ (2)

Where FR is the heat removal factor, ULthe overall loss coefficient. The instantaneous collector efficiency can be given by Equation (3) or Equation (4).

$\eta = Q\ mCp(To-Ti)/AsGt$ (3)

$\eta i = Fr(\tau\alpha) - Fr\ UL/(Ti - Ta)/Gt$ (4)

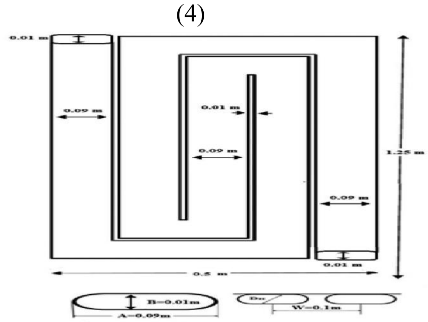

Figure 3.Dimensions of the absorber.

2.4. Uncertainty analysis

Uncertainty analysis is used to determine the goodness of experimental results. It determines the deviation of the experi mental values with true values. The efficiency of the solar water heater depends on mass flow rate, specific heat of the heat, area, and incident solar radiation falling on the solar collector. Therefore, the uncertainty in the measurement of efficiency id calculated based on equations suggested by Moffat (1985)

Table 2. Thermo physical properties of water.

Parameter	Values
Density (kg/m3)	995
Dynamic Viscosity (Ns/m2) 10−3	0.83
Thermal conductivity (W/mK)	0.6
Specific heat (kJ/kgK)	4180

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III. RESULT AND DISCUSSION

3.1. Effect of fluid flow rate on outlet temperature

The experimental data was obtained for every half an hour. Out of the several days for which the experimental analysis was carried out the consistent experimental data when the daily average solar radiation varied between 600 and 650 W/ m2 has been chosen and presented here. The experimental results were influenced by several factors pertaining to environmental conditions. The solar collector was tested with various flow rates, solar isolation, and ambient temperature.

Table 3. Uncertainty of experimental quantities.

S.No	Parameter	Instrument used	Range
1	Length	Measuring tape	L = 1600 mm
2	Temperature	RTD	0 to 250°C
3	Radiation	Solar Power Meter	0–2000 W/m2
4	Wind speed	Anemometer	0–45 m/s
5	Mass flow rate (manual)	Rotameter	0 to 250 lit/hr
6	Pressure drop	Manometer	Limb difference 25cm

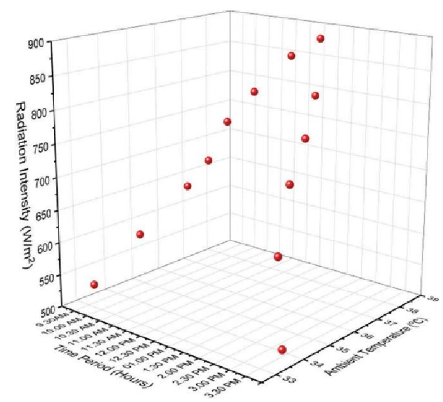

Figure 4.Variation of hourly solar radiation intensity with ambient temperature for a typical day.

variation of solar radiation intensity with ambient tempera ture for every half an hour on a typical sunny day is displayed in Figure 4. The maximum intensity is obtained in the noon and thereafter the intensity goes on decreasing. The experi ment is started with an initial temperature of 40°C at 9.00 a.m. till 4.00 p.m. The variation of the outlet fluid temperature with the changes in the ambient temperature and solar inten sity at various mass flow rates is shown in Figure 5. The outlet temperature of the fluid increases consistently with time. The temperature difference between the initial inlet temperature and the outlet temperature attains a maximum value when the solar intensity and the ambient temperature are at the highest and decreases thereafter. The highest outlet temperature of 64°C was obtained at a mass flow rate of 0.05 kg/s and a minimum temperature of 54 oC was obtained at 0.3 kg/s. The outlet temperature varies from 1.15% to 2.5% for every increase in mass flow rate. There is a 12.8% increase in the outlet temperature as the flow rate varies from 0.05 kg/s to 0.3 kg/s. The fluid produces lower outlet temperature is higher at lower flow rates mainly due to the minimal contact time with the absorber. The fluid passes rapidly and as a result, it is not able to absorb more amount of heat from the absorber.

3.2. Effect of fluid flow rate on storage tank temperature

The temperature of the tank had been one of the important aspects in the solar collector system as it was found to be correlated in terms of mass flow rate. The average tank tem perature is determined at the end of the day. The variation of the average tank temperature with mass flow rate is displayed in Figure 6. The experiment was initiated with an initial storage tank temperature of 36°Cthe overall increment in temperature of the tank varies from about 15°C to 27°C depending on the mass flow rate. Besides, the attainment of useful energy was determined from the raise of the tank temperature over a daytime as well as the mass of working fluid inside the tank and the absorber. The temperature of the water in the thermal storage tank depends on the effectiveness of the heat exchanger and the temperature difference between the outlet and inlet fluid. The data presented in Figure 6, which showed that by using a lower mass flow, the average temperature of the tank was higher. The tank temperature decreased by 7% as the flow rate increases from 0.05 kg/s to 0.3 kg/s. Moreover, as mentioned previously, the heat exchange time between the working fluid inside the collector and the fluid in the storage tank increased, and as a result of this, the heat exchanger performed better.

3.3. Instantaneous thermal efficiency

The experimental results are introduced depicting collector efficiency against a reduced temperature parameter (Ti – Ta)/GT. Figure 7 shows the variation of the collector efficiency with the fluid flow rate of water. The efficiency of the collector increases with an increase in mass flow rate. The removed energy parameter, FRUL, is the slope of the curve fit line of the measured data. For fluid flow rates of 0.05 kg/s and 0.03 kg/s, the values of this parameter, FRUL were estimated to be 4.1188 and 4.6274, respectively. For a flow rate of 0.05 kg/s, the absorbed energy parameter FR(τα), which is the point of intersection of the curve fit line of the data plotted for the corresponding flow rate on the ordinate, was determined to be 0.7853. For the highest flow rate of 0.3 kg/s, this value was found to be 0.8217. The values of the removed energy para meter FRUL, the absorbed energy parameter FR(τα), and the regression coefficient (R2) value of the curve fit lines for the experimentally measured values are listed Table 4. The enhancement in the absorbed energy parameter FR(τα) for the base fluid with a flow rate of 0.05 kg/s, when compared to the corresponding values at 0.3 kg/s, was found to be 4.5%,and the removed energy parameter FRUL was 10.9%. The values of the removed energy parameter FRUL and absorbed energy parameter FR(τα) obtained through experimental ana lysis as listed in table are compared with the theoretical values determined to be within 10% to 15 %.

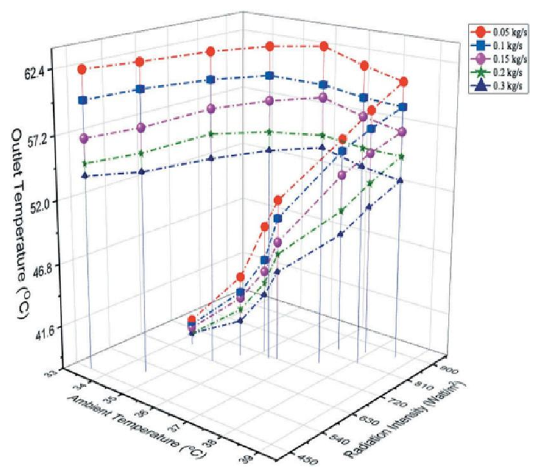

Figure 5.Variation of outlet temperature with ambient temperature and radiation intensity.

3.4. Influence of flatness

In flat tubes as the distance from the centre of tubes varies peripherally and hence the value the local heat transfer coefficient and local wall shear stress are not the same and varies peripherally. Figure 8 shows the variation of mass flow rate on heat transfer coefficient and Nusselt number and Figure 5 shows the variation heat transfer coefficient and Nusselt number with Reynolds number. Increase in Reynolds number is followed by an increase in Nusselt number. Increase in Nusslet number is due to enhancement in heat transfer coefficient due to larger turbulence. A similar increase in values can also be noted for mass flow rate. The increase Reynolds number at higher flow rates creates turbulence inside the absorber tube and hence the convective heat transfer coefficient gets increased. At the center of the flat tube, the maximum flow is achieved and on the walls and the flow gets reduced. The bends of the spiral absorber act as a nozzle, and as a result, there is an increase in temperature and decrease in pressure because of which the turbulence gets increased. The increment in the value of Nusselt number and heat transfer coefficient with Reynolds number is linear with an increase in flow rate. It follows a similar pattern of variation as that of heat transfer coefficient. Nusselt number depends on heat transfer coefficient, diameter, and thermal conductivity. Since thermal conductivity and hydraulic diameter of the absorber were maintained constant the profile for Nusselt number is similar to that of heat transfer coefficient. The value of Nusselt number obtained by means of experimental analysis from equation is validated using the correlations recommended by Dittus–Boelter and Gnielinski for turbulent flow region (Incropera et al. 2007).

3.5. Influence of spiral flow

The nature of flow through the absorber is spiral this flow is achieved by flattened tubes which are connected to form U bends both at the top and the bottom ends of the absorber. The U-bend structures generate turbulence enhancing the heat transfer process. The two parameters that affect flow turbulence are Reynolds number and the Dean number. Water entering the absorber passes through three U-bends of varying curvatures. The radius of curvatures of the U-bends is represented as R1, R2, R3 respectively according to increas ing order of magnitude. The flow in a curved duct was first investigated by Dean based on which the Dean number is derived (Yalin et al. 2016). The Dean number acts as the control parameter in analyzing flow through curved ducts (Dean 1927)

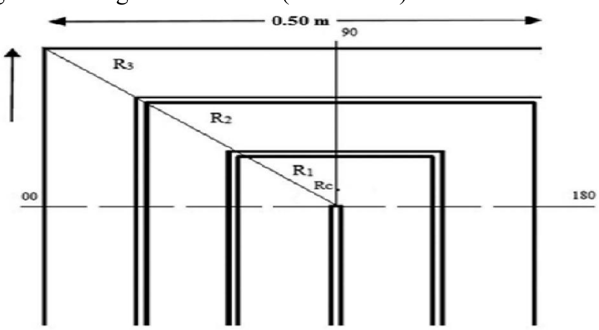

Figure 6.Sectional view of absorber with increasing radius of curvature.

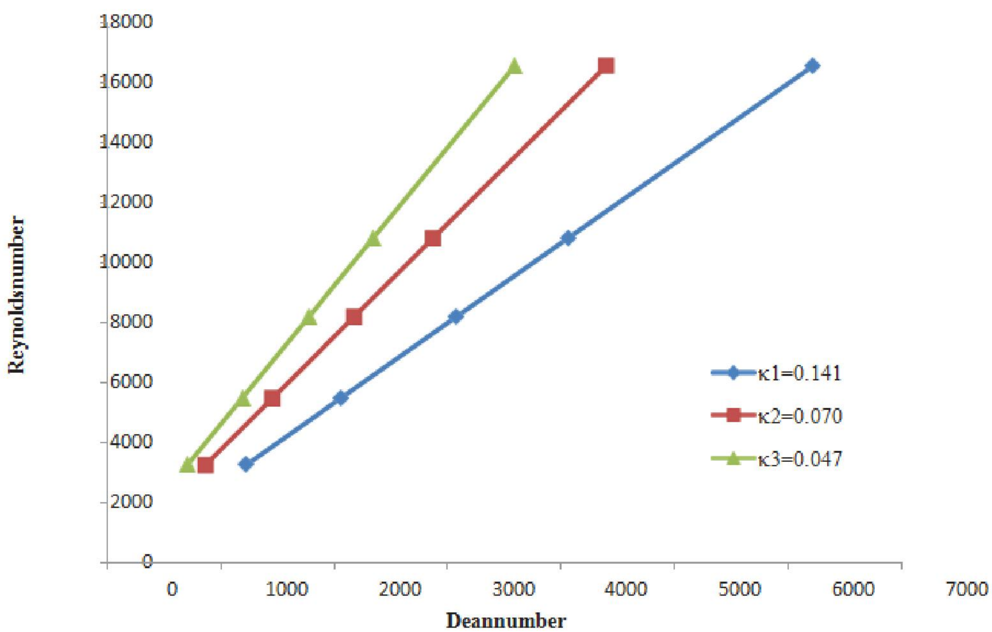

Figure 7. Variation of Dean numbers at various curvature ratios with Reynolds number.

IV.CONCLUSION

The performance of a solar water heater with flattened tube spiral absorber was experimentally analyzed. The following conclusions are derived from the experimental analysis. The outlet temperature and storage tank temperature increases with time. The increase in the mass flow rate results in an increase in Reynolds number in the turbulent flow region and causes an increase in heat transfer coefficient and Nusselt number. Even though the more heat transfer is experienced at higher flow rates of 0.2 and 0.3 kg/s the maximum tem perature attained is lesser compared to flow rates of 0.1 kg/s and 0.15 kg/s due to the minimum contact time of the fluid with the absorber. There is a steady increase in the absorbed energy parameter as the flow rate increase from 0.05 kg/s to 2 kg/s. The value of absorbed energy parameter increases by 3.5% and removed energy parameter increases by 10% for a flow rate of 0.2 kg/s compared to flow rate of 0.05 kg/s which states that the collector efficiency increases with mass flow rate. The average maximum temperature attained storage tank is 60°C for flow rate of 0.1 kg/s higher temperature could be obtained if a direct contact type storage tank was used. The flat tubes have higher value of Nusselt number for the same.

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