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A Simulation Study on Performance of Photovoltaic Thermal Water (PVTW) Collector Under Different Loading of Mass Flow Rate Using ANSYS Fluent

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ABSTRACT

The renewable energy has been a widely grown field fascinated by the researchers and scientist from the public and private sector. Solar energy is considered as the most abundant energy in the present world. The purpose of this research is to determine the performance of photovoltaic thermal water collector under different design of absorber tube in steady state condition. The computational fluid dynamics (CFD) simulation is carried out by using ANSYS Fluent software. This study used the geometry drawn in computer-aided design (CAD) software SolidWorks. The model drawn are spiral, horizontal serpentine and vertical serpentine absorber tube. The model drawn in SolidWorks software is then imported into ANSYS Fluent model to obtain the meshed model. The photovoltaic panel used in this project is silicon-based photovoltaic cell. The performance of photovoltaic thermal water collector is determined with the summation of electrical performance from the photovoltaic panel and thermal performance from the solar collector under 0.001 kg/s to 0.005 kg/s with intervals 0.001 kg/s. The relationship between water mass flow rate and solar irradiance intensity on performance photovoltaic thermal system was determined. At 1000 W/m^2, spiral absorber photovoltaic thermal water collector has the highest overall performance of 34.96% followed by vertical serpentine absorber of 34.07% while horizontal serpentine absorber has the lowest overall performance of 33.59%. Recommendations are proposed to improve the overall performance of the photovoltaic thermal water collector system.

Keywords: CFD, ANSYS Fluent, photovoltaic thermal collector, total efficiency

1. INTRODUCTION

In recent years, the increase in demand of energy usage creates another option on choosing renewable energy resources such as solar, wind, hidro, biomass and also geothermal energy [1]. Solar energy is the one of the best options due to its availability and its ready in market to use. However, the recent technology on solar energy still considered as expensive and the long return of payback period. Thus, a lot of research work being progress by researcher in this field. One of the most potential research work in solar engery is the solar photovoltaic thermal (PVT) technology. Solar thermal system is a device that use the solar radiation to heat up water. The thermal performance of the solar thermal system is depending on the temperature and the mechanism they deliver heat [2]. Recent advancement in solar photovoltaic thermal (PVT) technology has been reviewed by Abdullah et al. [4]. In solar PV cell, the solar irradiances converted to into thermal energy. This thermal energy raises the temperature of PV cells which lead to the reduction of efficiency and power generation [5-6]. One of the best method to solve this issue is by removing heat generated by the PV cells. The solar photovoltaic thermal (PVT) system are used to carry out the accessive heat generated by the PV cell. By removing this heat,

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will allowed the PV cells working under lower temperatures and thus increasing the efficiency [6-8]. Heat carriers in the PVT system based on the air and liquid. Various type heat carriers were used by previous researchers [9] to enhance and improve the mechanism of heat transfer between cooling fluid and PV module. Some of the research work focus on the mass flow rate of working fluid, type of working fluid in order to achieve better thermal effieciency of the PVT system.

Instead of type and mass flow rate of working fluid, the deisgn of the absorbers also could improved the thermal efficiency. Different types of absorber in the thermal solar system contribute different thermal performance. Various design of absorbers such as spiral, serpentine, parallel and horizontal, and others custom design. Rosli et al conducted a study on different deisgn of absorber tubes and its shows that different shapes of absorber will affected the thermal efficincy of the PVT system [10]. According to the previous researcher, the spiral shapes and arrangement give the best efficiency compared to the others type. The spiral design is more efficient in term of heat carrier and remover and this lead for better total efficiency of PVT system [11, 12, 13]. Studies also shows the shapes of absorber tubes give better performance in terms of heat remover. Round absorber tubes found to be more effective compared to the rectangular shapes. Round shapes allow better flow of working fluid eventhough rectangular shapes have better contact area with the absorber plate [11,13].

Fudholi et al. [14] perfomed an experimental analysis on the PVTW collector focus on the electrical and the thermal efficiency. The solar radiation used in his research works are 500, 600, 700 and 800 W/m^2. The water flow rates of 0.011, 0.024, 0.032 and 0.041 kg/s are given to each of the solar radiation level respectively. The experimental result shows that at solar radiation of 800 *W/m^2* with water flow rate of 0.041 *kg/s*, the spiral flow absorber of PVTW collector has the highest performance. The spiral flow absorber has the overall efficiency of 68.4 %, an electrical efficiency of 13.8 % and a thermal efficiency of 54.6 %. At water flow rate from 0.0011 to 0.041 *kg/s*, a primary-energy saving efficiency is also produced ranging from 79 % to 91 % [14]. The electrical performance of photovoltaic system varies on different materials of the photovoltaic module, different amount of irradiance receives by the photovoltaic module, and the operating temperature of the photovoltaic system [15].

Photovoltaic thermal system is the hybrid technology of photovoltaic system and solar thermal system. This hybrid technology basically improves the overall performance over the two-individual system. The performance for the hybrid system is evaluated by many of researcher with the help of Computer-aided design (CAD) software and Computational Fluid Dynamics (CFD) simulation software [16]. Water is chosen as the working fluid of photovoltaic thermal system collector as energy transfer in air is not as efficient as a water collector with focused on the spiral, horizontal serpentine and vertical serpentine absorber [17]. To simulate the flow of the PVTW collector, CFD software ANSYS Fluent is used. The simulation flow is conducted under steady state condition and assuming no heat is loss to the surroundings due to the insulation at the bottom of the absorber [18].

The initial study on the previous researcher was on the photovoltaic thermal system of air-based and water based. Different geometry of the absorber contributed to different performance of the photovoltaic thermal system. Many experiments and modelling simulation were carried out to improve the efficiency of the PVT collector system. In this study, the length of the absorber is fixed at 4 m. The mass flow rate of inlet flow is ranging from 0.001 kg/s to 0.005 kg/s with intervals 0.001 kg/s. The solar irradiance is set to 600 W/m^2, 800 W/m^2 and 1000 W/m^2. The inlet temperature of the absorber collector tube is set to 27°C. Silicon-based photovoltaic panel is used in the PVTW system. The outlet temperature of the absorber tube, average surface temperature of the photovoltaic panel is obtained from the results of the simulation of flow of the PVTW system [19]. The temperature difference, thermal efficiency, electrical efficiency and total efficiency of different type of absorber PVTW system is then evaluated [14].

2. MATERIAL AND METHODOLOGY

2.1 Geometry Modelling

The methodology used to simulate the flow of spiral, horizontal serpentine and vertical serpentine absorber PVTW system is simulation. The CFD software used in this project is ANSYS Fluent. It is difficult to solve the heat transfer equation based on the heat flow [20]. Therefore, the ANSYS Fluent is used to overcome the problems by simulating the fluid flow upon the manipulated conditions to obtain the result with higher accuracy. Figure 1 shows the geometry of spiral absorber PVTW system drawn in SolidWorks software. Table 1 shows the dimensions for the spiral PVTW system.

Table 1 Dimensions for spiral absorber PVTW

PVTW Components	Dimensions (L x W x H; m^3)
Top cover	1.0 x 0.5 x 0.003
Encapsulant of PV	1.0 x 0.5 x 0.0008
PV panel	1.0 x 0.5 x 0.0001
Backsheet	1.0 x 0.5 x 0.00005
Thermal Paste	1.0 x 0.5 x 0.0003

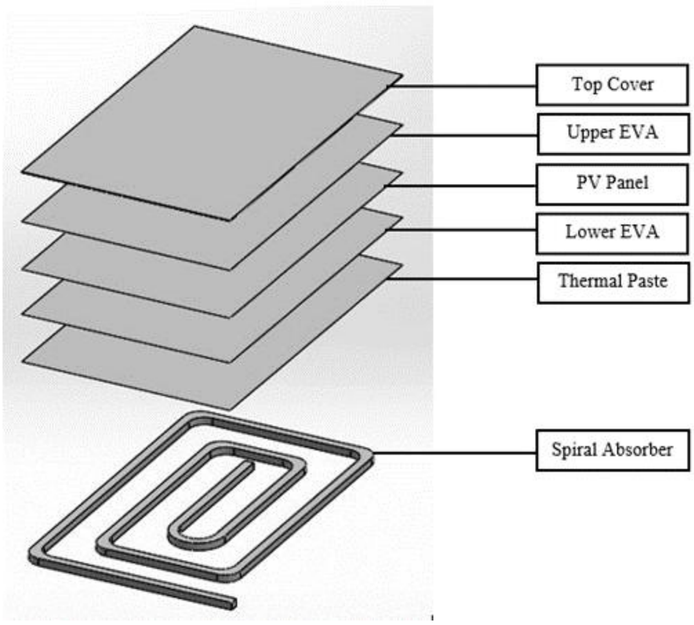
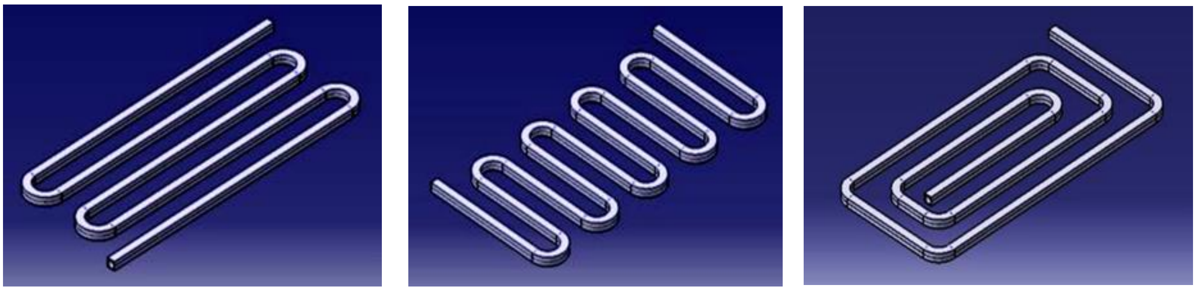


Figure 1. Spiral absorber PVTW system.



(a) (b) (c)

Figure 2. Type of absorber (a) Horizontal serpentine (b) Vertical serpentine (c) Spiral.

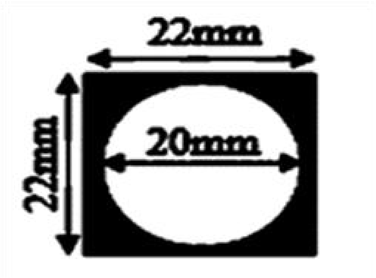
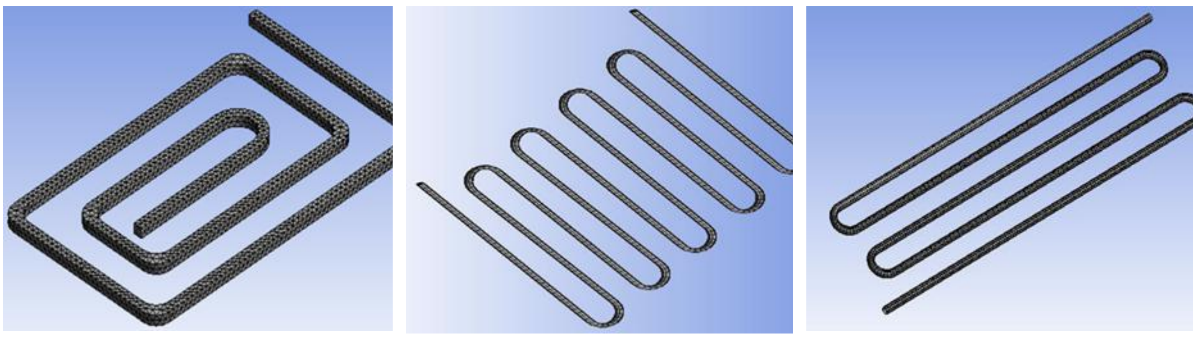


Figure 3. Cross section for different absorbers.

2.2 Geometry Meshing

Meshing is the process to divide a whole component into certain manipulated number of elements and nodes. Higher accuracy result is obtained for smaller meshed cells with longer time taken for the meshing. The geometry drawn is then transfer to the ANSYS Fluent Workbench to perform meshing and post processing to obtain the results. The spiral PVTW is meshed with medium relevance center, high smoothing and medium span angle. The meshed spiral absorber has 5863 nodes and 9768 elements. The vertical serpentine absorber is meshed with medium relevance center, high smoothing and medium span angle. The meshed vertical serpentine absorber has 8957 nodes and 4167 elements. The horizontal serpentine absorber is meshed with fine relevance center, high smoothing and fine span angle. The meshed horizontal serpentine absorber has 9418 nodes and 13257 elements. Figure 4 shows the meshed (a) spiral absorber, (b) vertical serpentine absorber, and (c) horizontal serpentine absorber.



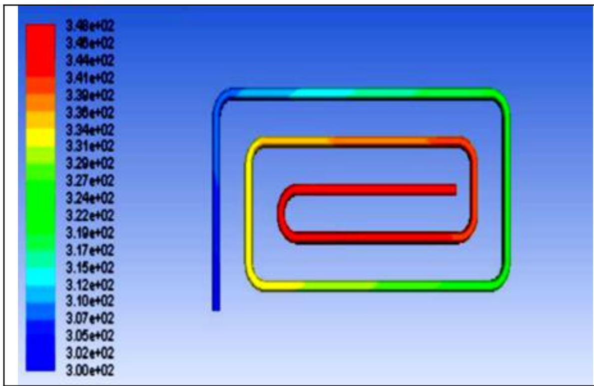
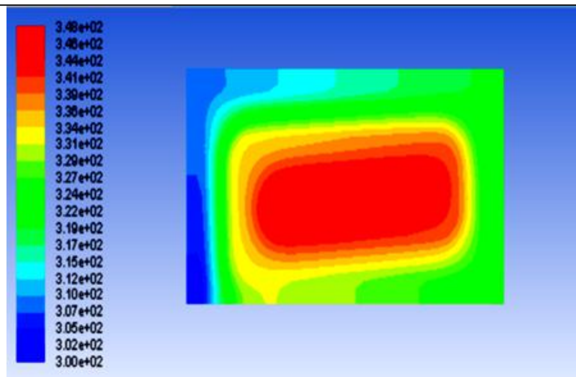
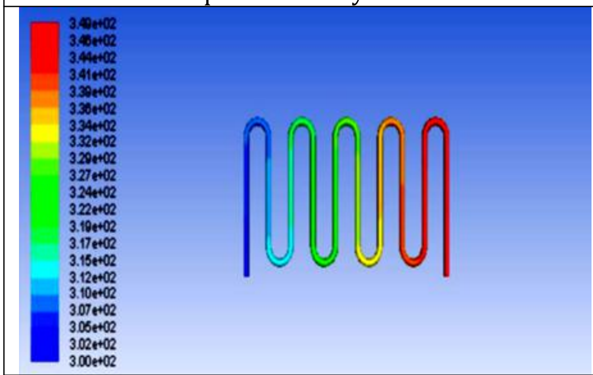
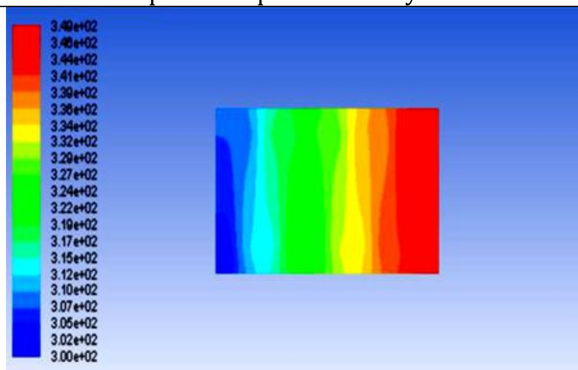
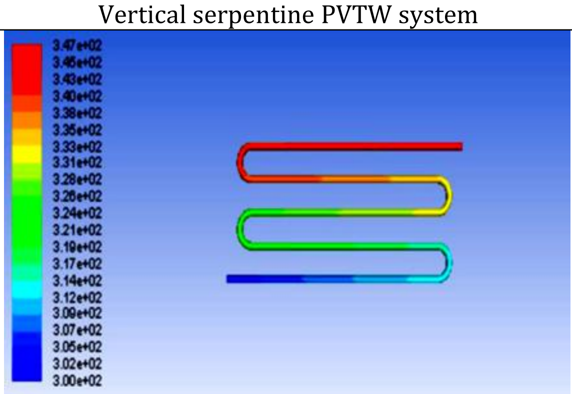
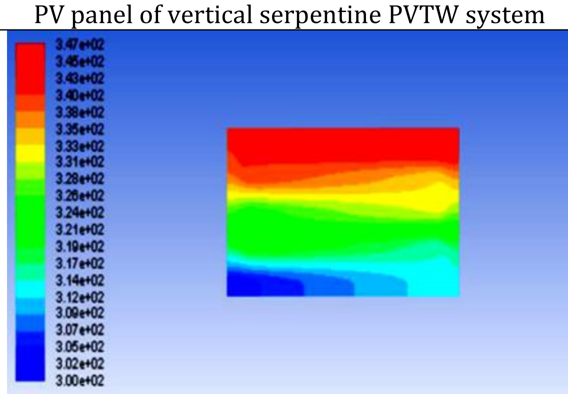
(a) (b) (c)

Figure 4. Meshed absorber (a) Spiral (b) Vertical serpentine (c) Horizontal serpentine.

2.3 Post Processing and Mathematical Calculations

The contour diagram for different absorber tube and photovoltaic panel under mass flow rate of 0.001 kg/s to 0.005 kg/s, solar irradiance of 600 W/m^2, 800 W/m^2 and 1000 W/m^2 can be obtained from the results of simulation. From the contour diagrams, the outlet water temperatures for different absorbers and average surface temperatures for different photovoltaic panel are reviewed as tabulated. Table 2 shows contour diagram of different absorber and photovoltaic panel PVTW system at 0.001 kg/s under 1000 W/m^2.

Table 2 Contour diagram of different absorber and photovoltaic panel PVTW system at 0.001 kg/s under 1000 W/m^2

	
Spiral PVTW system	PV panel of spiral PVTW system
	
Vertical serpentine PVTW system	PV panel of vertical serpentine PVTW system
	
Horizontal serpentine PVTW system	PV panel of horizontal serpentine PVTW system

The outlet water temperatures of different geometry absorber tubes are used to find the thermal efficiency and the average surface temperatures of photovoltaic panel are used to find the electrical efficiency. The total efficiency of PVTW system is obtained from the summation of thermal efficiency contributed by the absorber solar thermal system and electrical efficiency contributed by the photovoltaic module system [21].

The thermal efficiency of a solar thermal system is expressed as:

$$n_{th} = \frac{\dot{m}c_p\,(T_o - T_i)}{IA_c} \quad (1)$$

where ṁ is the water flow rate, c_p = 4180 J/kg °C is the specific heat capacity of water, T_o is the water outlet temperature of the absorber tube under specific heat flux, T_i is the water inlet temperature of 27°C, I is the heat flux and A_c is area of collector. Since ṁ of different geometry absorber under specific heat flux, c_p, T_o, T_i, I and A_c is determined, n_{th}, thermal efficiency of absorber tube can be evaluated.

The electrical efficiency of a photovoltaic module system is expressed as:

$$n_{el} = n_{ref}\,[1 - ß_{ref}\,(T_c - T_{ref})] \quad (2)$$

where T_{ref} = 25°C, the n_{ref} and $ß_{ref}$ of silicon-based PV panel are 0.0045 °C^{-1} and 0.12 respectively. T_c is the cell temperature or photovoltaic panel average surface temperature obtained from the simulation. Since T_{ref}, n_{ref} and $ß_{ref}$ is determined, n_{el}, electrical efficiency of photovoltaic panel can be evaluated.

The total efficiency of a PVTW system is expressed as:

$$n_{Total} = n_{th} + n_{el} \quad (3)$$

where the total efficiency of PVTW system, n_{Total} is the summation of n_{th}, thermal efficiency of absorber tube solar thermal system and the n_{el}, electrical efficiency of photovoltaic panel photovoltaic module system.

3. RESULTS AND DISCUSSIONS

3.1 Thermal Efficiency of Absorber Tube

The water outlet temperatures, thermal efficiencies of spiral, horizontal serpentine and vertical serpentine absorber tube for mass flow rate ranging from 0.001 kg/s to 0.005 kg/s under 600 W/m^2, 800 W/m^2 and 1000 W/m^2 is evaluated and the graph of changes in outlet temperature and thermal efficiency with various mass flow rate under 600 W/m^2, 800 W/m^2 and 1000 W/m^2 is plotted.

Figure 5 shows the changes in water outlet temperature and thermal efficiency with various mass flow rate under 600 W/m^2. Figure 6 shows the changes in water outlet temperature and thermal efficiency with various mass flow rate under 800 W/m^2. Figure 7 shows the changes in water outlet temperature and thermal efficiency with various mass flow rate under 1000 W/m^2.

Figure 5, Figure 6 and Figure 7 show that with increasing water flow rate, the water outlet temperature of the absorber tube is decreased and the thermal efficiency of the solar collector is increased. The effect of the mass flow rate on the outlet temperature for various solar irradiance due to the higher water flow rate increased the velocity of water inside the absorber tube. This lead to the heat absorbed by the water is decreased and the outlet water temperature of absorber tube decreased. This resulted in smaller temperature difference and higher thermal efficiency of the system.

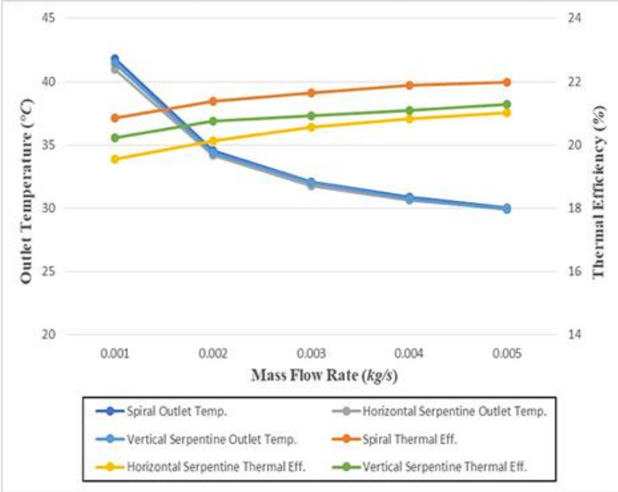


Figure 5. Water outlet temperature, thermal efficiency and mass flow rate at 600 W/m^2.

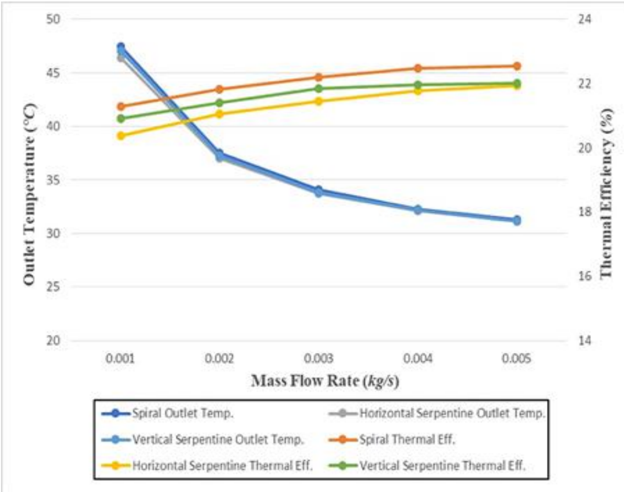


Figure 6. Water outlet temperature, thermal efficiency and mass flow rate at 800 W/m^2.

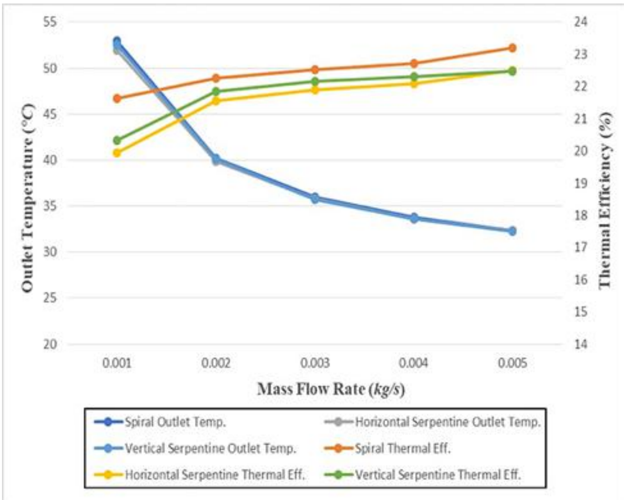


Figure 7. Water outlet temperature, thermal efficiency and mass flow rate at 1000 W/m^2.

3.2 Electrical Efficiency of Photovoltaic Panel

The average PV panel surface temperatures, electrical efficiencies of photovoltaic panel with respect to spiral, horizontal serpentine and vertical absorber for mass flow rate ranging from 0.001 kg/s to 0.005 kg/s under 600 W/m^2, 800 W/m^2 and 1000 W/m^2 is evaluated and the graph of changes in PV temperature and electrical efficiency with various mass flow rate under 600 / ^{2}, 800 W/m^2 and 1000 W/m^2 is plotted.

Figure 8, 9 and 10 shows the changes in PV temperature and electrical efficiency with various mass flow rate under 600 W/m^2, 800 W/m^2 and 1000 W/m^2. Similar trends show on all various solar irradiances. The PV temperature decreased with the increased of mass flow rate while the electrical efficiency increased with the increased of the mass flow rate.

The decreased and increased trend happened on the PV temperature and electrical efficiency due to higher water flow rate applied to the system, the velocity of water inside the absorber tube increased, thus more heat can be carried by the faster flowing water to cool down the photovoltaic panel as heat is dissipated from photovoltaic panel to absorber tube. As more heat is dissipated, the average surface temperature of the photovoltaic panel is lowered and the electrical efficiency of the system is increased. These results also support the results obtained in Figure 8-10 where, the effect of mass flow rate on the water outlet temperature and thermal efficiency.

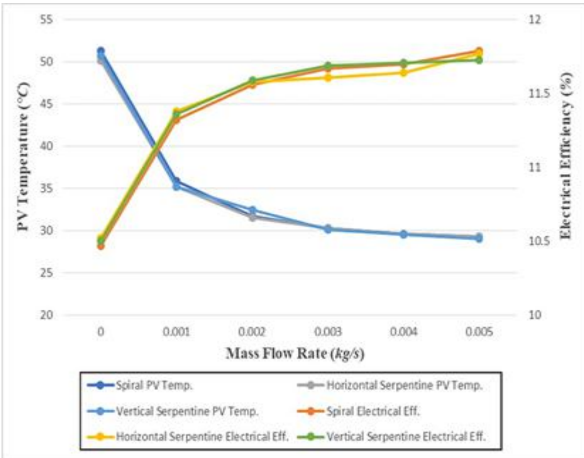


Figure 8. PV temperature, electrical efficiency, mass flow rate at 600 W/m^2.

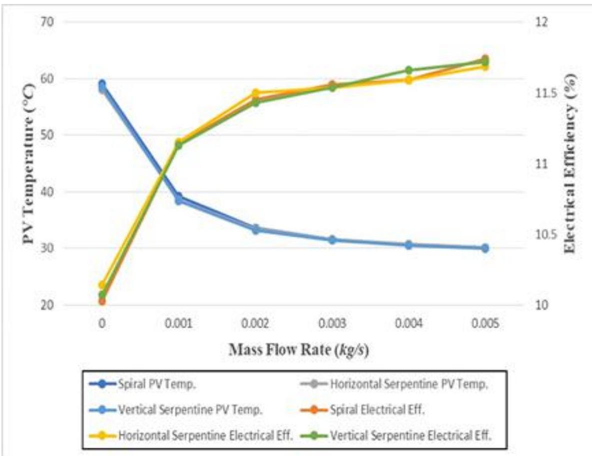


Figure 9. PV temperature, electrical efficiency, mass flow rate at 800 W/m^2.

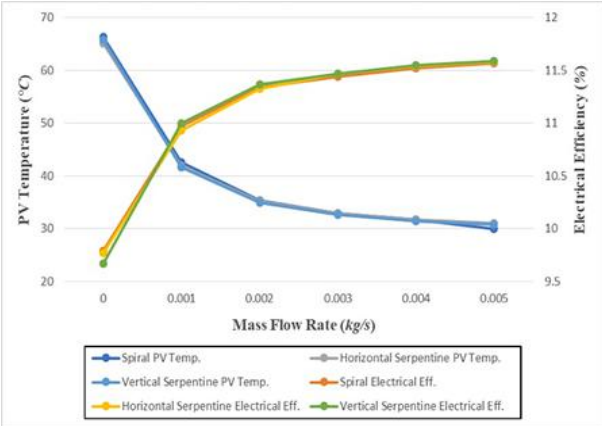


Figure 10. PV temperature, electrical efficiency, mass flow rate at 1000 W/m^2.

3.3 Total Efficiency of Different Absorber PVTW System

Figure 11, 12 and 13 shows the total efficiency of the spiral absorber PVTW, vertical serpentine absorber PVTW and the horizontal serpentine absorber PVTW system under 600 W/m^2, 800 W/m^2 and 1000 W/m^2.

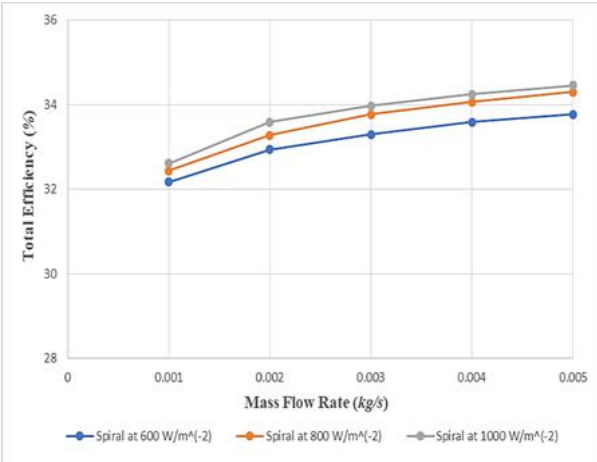


Figure 11. Total efficiency of spiral PVTW system.

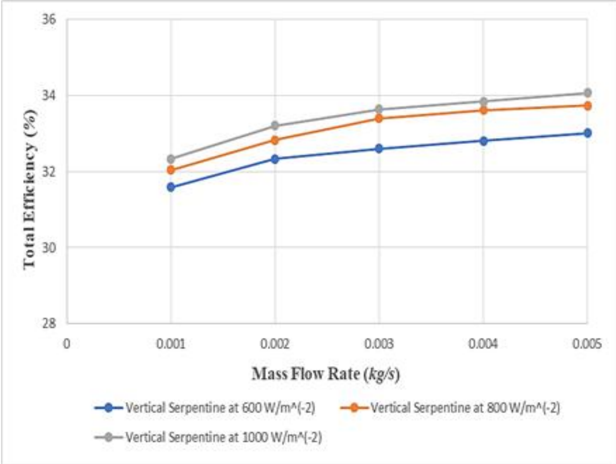


Figure 12. Total efficiency of vertical serpentine PVTW system.

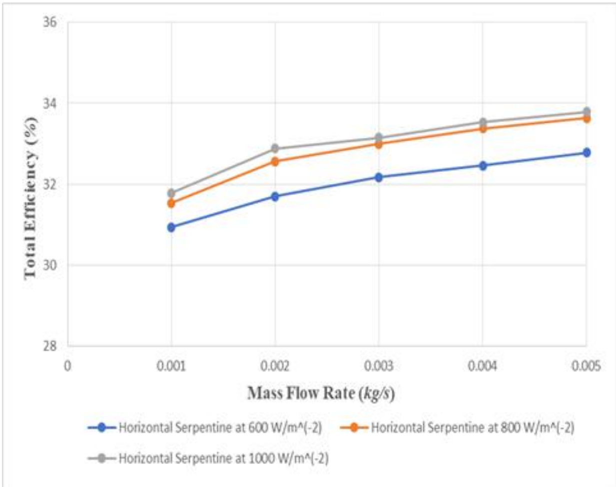


Figure 13. Total efficiency of horizontal serpentine PVTW system.

From the graph in Figure 11, Figure 12 and Figure 13, the comparison of performance of different absorber PVTW system exhibits that the spiral type absorber has the highest overall performance (32.17% to 34.96%) followed by vertical serpentine type absorber (31.59% to 34.07%) while the horizontal type absorber has the lowest overall performance (30.93% to 33.59%). According to Zarzoor et. al [22], the spiral type absorber gives a higher performance than the serpentine absorber at all solar radiation levels.

4. CONCLUSIONS

The total efficiency of photovoltaic thermal water collector with different design of absorber tube at 0.001 kg/s to 0.005 kg/s under solar irradiance of 600 W/m^2, 800 W/m^2 and 1000 W/m^2 is determined in steady state condition. The CFD simulation is carried out by using ANSYS Fluent software. The geometry drawn are spiral, horizontal serpentine and vertical serpentine absorber tube. The relationship between water flow rate and solar irradiance intensity on performance photovoltaic thermal system was determined. In this study, the thermal efficiency, electrical efficiency and the total efficiency of different type of PVTW collector absorber were determined. The higher the mass flow rate, gives the higher the total efficiency of the PVTW. Besides, the increased in solar irradiance will caused the increased in thermal efficiency but decreased in electrical efficiency of the PVTW system. The total efficiency also increased when the increment in thermal efficiency is larger than the decrement in electrical efficiency. At 1000 W/m^2, spiral absorber photovoltaic thermal water collector has the highest overall performance of 34.96% followed by vertical serpentine absorber of 34.07% while horizontal serpentine absorber has the lowest overall performance of 33.59%. In overall, the highest performance of the PVTW collector system is a spiral type absorber followed by vertical serpentine type absorber while the horizontal type absorber has the lowest overall performance.

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