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Design and CFD Analysis of Photovoltaic/Thermal (PV/T) Air Collector with Straight Fins

Amrizal[a)], Amrul[b)], Abdurrahman Firmansyah[c)], Joko Prasetyo[d)], and Ahmad Yonanda[e)]

Mechanical Engineering Department, University of Lampung, Bandarlampung 35145 Indonesia

[a)] *Corresponding author: amrizal@eng.unila.ac.id*
[b)] *amrulh@yahoo.com*
[c)] *rahmandwi1@gmail.com*
[d)] *jokoprasetyo210997@gmail.com*
[e)] *amrizal@eng.unila.ac.id*

Abstract. The electrical efficiency of a PV/T solar collector decrease as its operating temperature increases. The use of fins can reduce the operating temperature of the PV/T collector due to the addition of a heat transfer area. Meanwhile, straight fins are most widely used because of their simplification in manufacturing. This study aims to simulate numerically the performances of PV/T air collectors using the CFD method. Furthermore, the inlet fluid temperature applied in this work was based on the climate in Bandar Lampung, Indonesia. Additionally, the mass flow rates and solar radiation are varied from 0.01 to 0.05 kg/s and 500 to 1250 W/m^2, respectively. The surface of the PV/T collector is joined together with four straight fins. The fins length, height, thickness, and spacing were selected 500 mm, 25 mm, 1 mm, and 50 mm respectively. The results showed that with the increased air mass flow rate, the operating temperature of the PV/T collector tends to decrease and conversely the pressure drop tends to increase. Furthermore, the lowest values of PV/T surface temperature and outlet fluid temperature are found to be 33.65ºC and 30.66ºC respectively at solar radiation of 500 W/m^2 and a mass flow rate of 0.048 kg/s. In addition, the highest value of pressure drop obtained from this work is about 18,82 Pa at a mass flow rate of 0.048 kg/s.

INTRODUCTION

The abundant availability of solar energy in every part of the world can be used as a source of renewable energy. Using PV/T collectors is one of the methods to produce electrical and thermal energy simultaneously. This type of collector generally implements water [1-2] and air [3] as a working fluid that can absorb unused waste heat from the PV collector. The water-coolant PV/T system has higher electrical efficiency than the system with air as the coolant [4]. Besides, the hot fluid produced can be used as a water heater or a dryer for agricultural products [5]. Further studies based on the dynamic testing methods for the performance of PV/T collectors are also carried out both thermally and electrically [6-7].

The cooling process on the PV/T collector can provide benefits to increase the electrical efficiency by 0.5% for every 1 ºC decrease in operating temperature [8]. Furthermore, to improve the performance of a PV/T collector, various preliminary studies related to the use of fins have been extensively reviewed [9].

In general, the fins act as extended surfaces that can increase the rate of heat transfer as in the case of the staggered heat exchanger [10]. Moreover, the use of fins on PV/T collectors has also been investigated by several previous researchers including design, simulation, and experimental processes.

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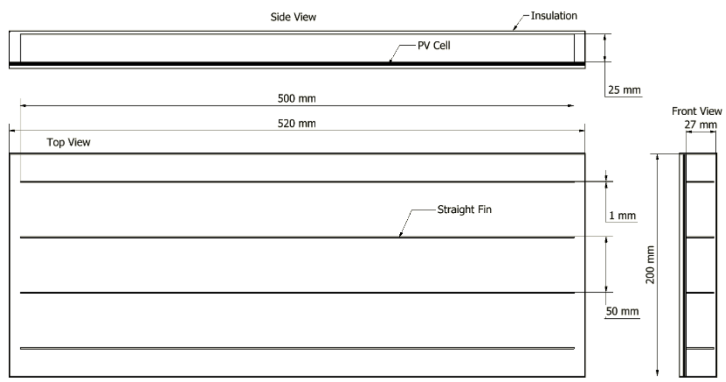
Meanwhile, Abbas et al. conducted an experiment to determine the effect of fin spacing on the thermal efficiency of PV/T with air as a working fluid under natural convection conditions [11]. Rectangular plate-fin absorber of PV/T air solar collector has also been investigated with double pass flow [12] otherwise the inclined fins type has been modeled by Bootan et al. with air as the working fluid [13].

From the literature review, the use of fins may increase the performance of the PV/T collector. However, the references concerning the characteristic of PV/T collectors with fins especially under tropical climates is still limited. In the present study, further developments need to be made regarding the use of straight fins since they are easy and simple in manufacturing. This research was conducted by simulation using the CFD method to determine the characteristics of the PV/T collector with an inlet fluid temperature based on the tropical climate in Bandarlampung.

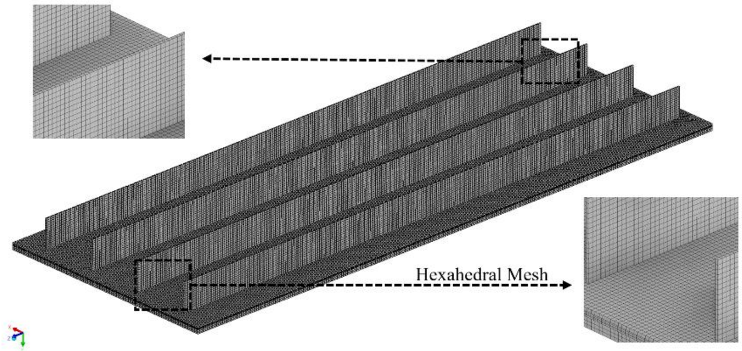
METHOD

A prototype of the PV/T collector with a surface area of 520 mm x 200 mm is presented in Figure 1. Four straight fins are attached underneath the surface of the PV/T collector. The performances of the PV/T collector are then simulated using the CFD method which has the advantages of easier technical procedures at relatively lower cost, the ease of providing a variety of parameters, and less time-consuming. The meshing process is generated with a properly sized structure. The mesh contained in a geometric object affects the accuracy of the analysis in which the smaller the mesh used, the more accurate the analysis will be. In Figure 1b, the hexahedral mesh is applied in this work with the number of nodes and number of elements being 1598993 and 1213316 respectively.

Furthermore, several things must be considered related to the determination of boundary conditions in the CFD method. In this process, the iteration process or algorithm and numerical calculations are carried out by the program until convergence occurs. A more detailed flowchart of the simulation procedure can be seen in Figure 2.



(a)



(b)

FIGURE 1. PVT collector design (a) Top, side, front of views (b) Mesh structure

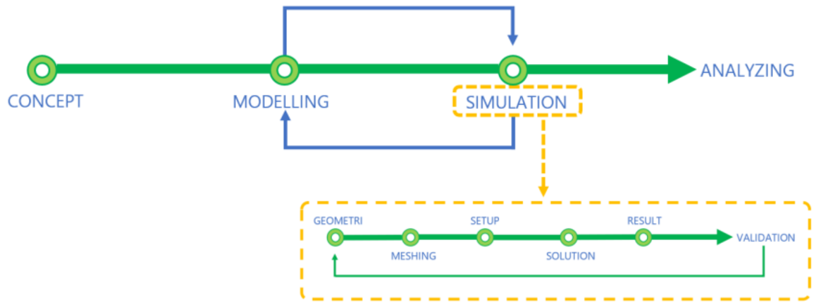
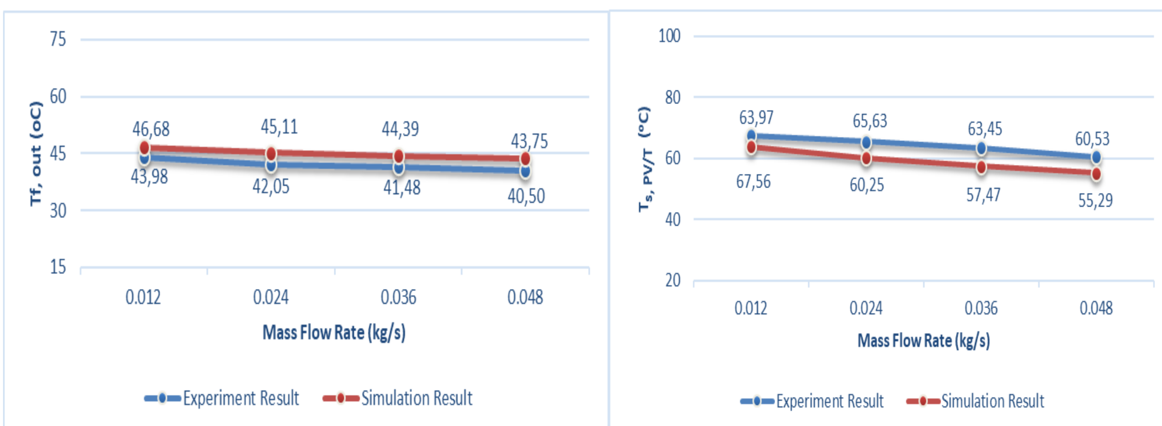


FIGURE 2. Flowchart for simulation process

Validation

Validation was carried out by comparing results between experimental [12] and simulation data. In Figure 3 especially in outlet fluid temperature and the surface temperature, the comparison results have an error of 6-8%. It can be said that the comparison results are in good agreement between the two data. Hence, the use of the Ansys program in the present study may reflect the actual conditions due to relatively similar tendencies. On the other hand, the simulation result in this work is capable of conducting further research development.



(a) (b)

FIGURE 3. Comparison results of simulation with experimental data (a) Outlet fluid temperature and (b) PV/T collector surface temperature

Furthermore, the thermal model used in this study is shown in the following equation [14]

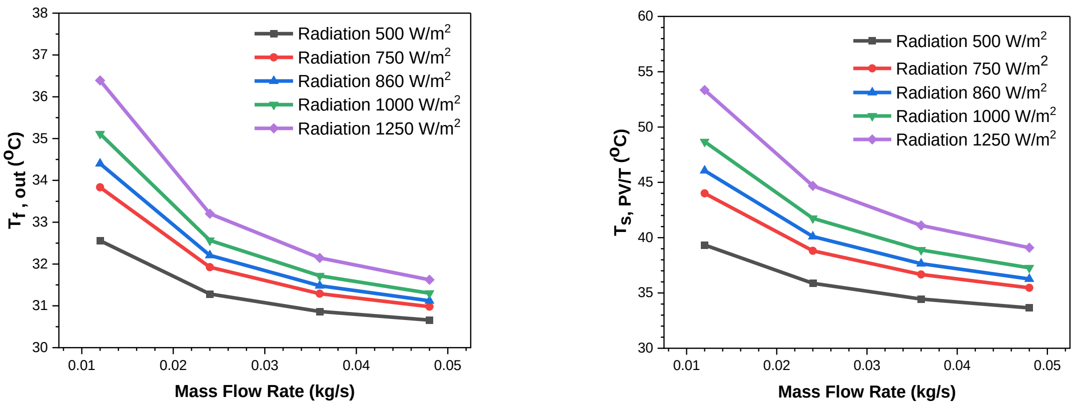
$$Q_u = A\left[(\tau\alpha)G - U_L\left(T_{pm} - T_a\right)\right] \quad (1)$$

where η_{th} is thermal efficiency, Q_u is heat useful (W), G is solar radiation (W/m^2), $\tau\alpha$ is efficiency factor, U_L is overall heat transfer coefficient (W/m^{2}°C), T_a is the ambient temperature (°C), T_{pm} is the mean temperature of the surface (°C), and A is collector area (m^2).

RESULTS AND DISCUSSION

Performance of PV/T collector for several variations of working fluid mass flow rate and solar radiation level has been carried out extensively. Mass flow rates and solar radiation were varied from 0.01 to 0.05 kg/s and 500 to 1250 W/m^2, respectively by applying an inlet fluid temperature of 30 ºC concerning the tropical climate in Bandarlampung. In the following figures, the simulation results of the thermal performance and pressure drop of the PV/T collectors with straight-fin can be observed.

Thermal Performance of Thermal PV/T Collector

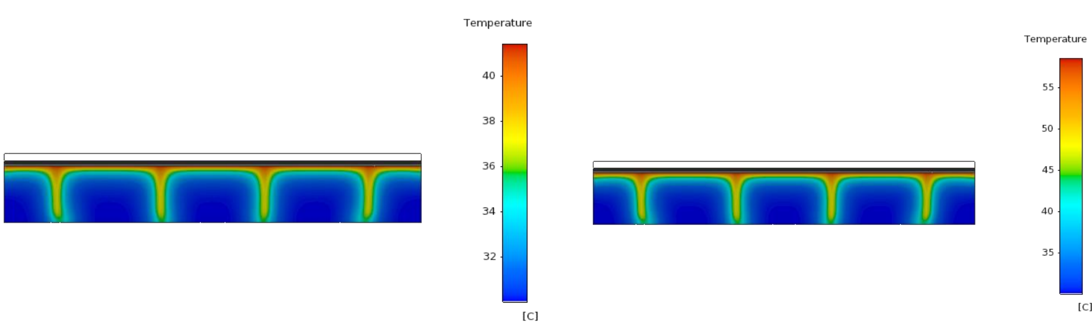


(a) (b)

FIGURE 4. Effect of the air mass flow rate and solar radiation level on (a) the outlet fluid temperature and (b) the surface temperature

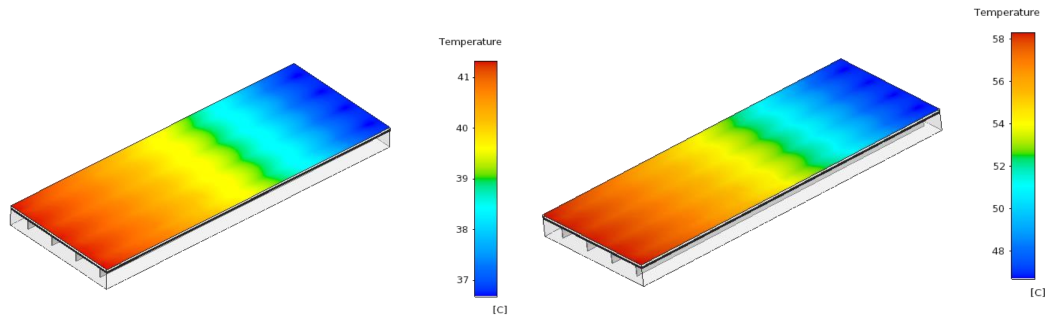
The simulation results of the effect of mass flow rate on the outlet fluid temperature and the surface temperature can be depicted in Figure 4a-b. In general, it can be explained that an increase in the mass flow rate of the working fluid will decrease both the outlet fluid temperature and the PV/T surface temperature, respectively. Meanwhile, the increase in solar irradiation causes the outlet fluid temperature and the surface temperature of the PV/T collector to increase.

If the mass flow rate of the working fluid is doubled, therefore the outlet fluid temperature is decreased by 3.9% from the initial condition. Furthermore, if the mass flow rate is increased by four times (the maximum mass flow rate) in this study, the outlet fluid temperature is decreased by 5.8%. The temperature contour that occurs at the outlet fluid temperature and the surface of the PV/T collector can be observed in Figures 5-6 below.



(a) (b)

FIGURE 5. Outlet fluid temperature contour for solar irradiation level (a) 500 W/m^2 and (b) 1250 W/m^2



(a) (b)

FIGURE 6. Surface temperature contour for solar radiation level (a) 500 W/m^2 and (b) 1250 W/m^2

Figure 5a-b shows the contour of outlet fluid temperature ($T_{f,out}$) under different levels of solar radiation. The color difference shows the temperature distribution where the red color indicates the high temperature at the area closer to the fin surface, and conversely, the low temperature is indicated by the blue color at the outer region of the fin surface.

The high temperatures illustrated in Figure 5 are due to the convective heat transfer process which is more dominant at the area closer to the fins. Furthermore, the solar radiation variation in Figure 6 gives a significant difference in working fluid temperature with the lowest and highest average outlet fluid temperatures of 32.5^{o}C for 500 W/m2 solar radiation and 36.5^{o}C for 1250 W/m2 solar radiation, respectively at a mass flow rate of 0.012 kg/s. If the solar radiation increases from 500 W/m^2 to 750 W/m^2, therefore the outlet fluid temperature increases about 3.77% from initial conditions. Then if the solar radiation is increased up to 1250 W/m^2, the fluid outlet temperature increases about 10.53% at the same flow rate conditions.

Meanwhile, Figure 6 also shows the contour of the surface temperature based on solar radiation levels of 500 W/m^2 and 1250 W/m^2, respectively. If the irradiation level increases from 500 W/m2 to 750 W/m^2, the surface temperature increases about 10.6%. Then if the solar radiation value is increased up to 1250 W/m^2, therefore the surface temperature is increased by 26.25% at the same flow rate conditions.

Pressure drops of PV/T Collector

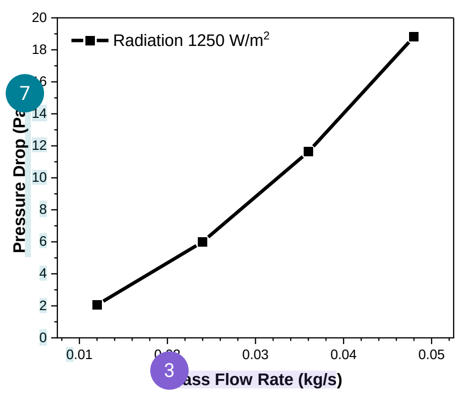


FIGURE 7. Effect of the air mass flow rate on pressure drop of the PV/T collector

The last phenomenon observed in this study is the pressure drop parameter which has a maximum value of 18,817 Pa at a radiation level of 1250 W/m^2 and a mass flow rate of 0.048 kg/s. In Figure 7 it can be seen that the increase in the mass flow rate contributes a significant difference in the value of pressure drop in comparison with the initial condition.

However, in the present study, the simulation results of pressure drop do not provide a significant effect on pumping power. Thus, it may not require a large pumping power to circulate the working fluid due to the low value of pressure drop. This may be the straight fins applied in this study provide a slight frictional resistance to fluid flow that passes through the fins and channels.

CONCLUSION

The numerical simulations of PV/T air solar collectors with the addition of straight fins using the CFD method have been carried out extensively. The Ansys CFD program can be relied upon to predict the characteristics of thermal performance and pressure drop of the PV/T collectors. Furthermore, increasing both mass flow rate and solar radiation affects the working fluid outlet temperature and the operating temperature of the PV/T collector. Meanwhile, the pressure drop value is more dominantly influenced by variations in the mass flow rate. Based on the simulation results obtained from this study, the lowest PV/T panel surface temperature is found to be 33.65 C at 500 W/m^2 radiation and a mass flow rate of 0.048 kg/s. Meanwhile, the lowest outlet fluid temperature and highest pressure drop are found to be 30.66 C and 18,82 Pa respectively. Additionally, the straight fins of PV/T collectors have the advantage of being easy and simple to manufacture, reducing significantly the operating temperature of PV/T collectors concerning tropical climates, producing a low-pressure drop, so they need to be further developed for different operating conditions and geometries.

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