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Design of photovoltaic/thermal (PV/T) with heat pipes as a heat transfer medium used for water heater

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Abstract

One of the main obstacles for developers and users of photovoltaic (PV) modules is that the module temperature is too high due to high solar radiation and a higher ambient temperature, which reduces PV efficiency. A photovoltaic/thermal (PV/T) system is a technique developed for absorbing heat, that combines PV with a solar thermal collector (STC). In this research, heat pipes are used as the heat transfer medium. This paper aims to design a PV/T system for water heating and examines the thermal performance and water temperature that can be achieved by PV/T. In designing PV/T, the method used is to estimate the intensity of solar radiation and determine the size of the thermal collector, thermal insulation, type of working fluid, and heat pipe filling ratio. The PV/T thermal performance is also tested after the system design has been built. The design parameters that have been obtained are the PV area of 0.67 m^2 and the volume of heated water of 20 liters. This design proposes water as the working fluid of the heat pipe with a filling ratio of 10%. The system performance indicates that PV/T could heat the water to 50.9 °C with energy absorbed by the water of 1.85 MJ, and the maximum thermal efficiency of PV/T is 27.14%. The results show that PV/T has a very promising future in terms of its ability to use heat energy and can be further developed for future research so that it can encourage people to use environmentally friendly renewable energy.

Keywords: photovoltaic/thermal; heat pipe; solar water heater; PV/T; solar energy.

1 Introduction

The growth of technology in various sectors including residential and industrial has contrived energy as a basic necessity with a very high usage rate. However, the fulfillment of these energy needs is still largely dependent (up to 80 %) on fossil energy, which is unsustainable and exacerbates the effects of greenhouse gases [1]–[3]. In order to meet the demand and adress these energy challenges, the use of renewable energy will be expanded and accelerated [4],[5]. Among various sources and methods for renewable energy harvesting, solar energy technology attracts the attention of researchers, universities, and the government to expand its utilization due to its accessibility, renewability, immense potential, and environmental friendliness [6]–[8].

However, the substantial challenges associated with collecting and storing this free and pure energy severely limit its industrial potential. Solar energy is scarce at night, therefore it needs to be efficiently absorbed, transferred, and stored [9]. In this situation, solar collectors take on a significant role in a solar-powered system that has the lowest operating and maintenance expenses compared to other solar energy applications [10].

In particular, photovoltaic (PV) technology is attractive due to the direct conversion of the absorbed solar radiation into electricity and the use of mild and clean technology. However, the high temperature of PV modules caused by increased solar radiation and ambient temperature is one of the main challenges facing solar PV module manufacturers and users [11]. The efficiency and power output of the solar module is greatly reduced with increasing temperature [12]. Several specialists and analysts who examined the use of PV modules under various climatic conditions found an inverse relationship between PV efficiency and PV module temperature [11]. In order to increase the electrical efficiency, the PV module should be cooled by somehow removing the extra heat from the cell assembly. The module must be equipped with a heat exchange system that uses a fluid stream, such as air or water, either at its front or back surface. This hybrid system is called photovoltaic thermal (PV/T).

The photovoltaic thermal (PV/T) collector is a hybrid device that uses solar photovoltaic (PV) and solar thermal collectors (STC) to produce electricity and heat concurrently. Such systems can boost the usage of solar energy more effectively and produce more energy per unit area than solar PV or solar thermal systems alone [13]. This innovative technology is expected to considerably improve the efficiency of complete solar energy usage and expand the service life of photovoltaic modules, which will address the issues of low PV electrical efficiency and thermal failure caused by high cell temperatures [14].

In terms of heat absorption of PV/T systems, the use of heat pipes is quite promising due to their high heat transfer rate. Heat Pipes are generally used to carry heat using the principle of evaporation and condensation without the use of external power. The working fluid in the evaporator section takes heat from the surrounding system and is converted into the vapor phase, the steam then flows into the condenser section due to the pressure difference through the adiabatic section. Through the use of capillary action, the steam in the condenser section releases its heat, transforms into a liquid, and then returns to the evaporator [15]. Heat pipes that work under gravity with a condenser above the evaporator do not require external power or a capillary structure to return the heat transfer fluid to the evaporator, so they are often called wickless heat pipes [16].

Several designs of PV/T systems with flat plates equipped with heat pipes as heat exchangers used for electric generation and water heating have been carried out previously [17][18][19][20][21], but there are still few studies discussing how to design this systems. The novelty of PV/T in this study are using wickless heat pipes as a heat transfer medium of the system, optimizing the required area and thermal insulation of the collector, designing the type of cover and plate absorber, and choosing the best type and filling ratio of the working fluid. Fig. 1 shows a PV/T scheme using a flat plate collector with a heat pipe tube as a heat transfer medium placed under the absorber plate and a PV module which is the basic reference in designing Heat Pipes PV/T.

This paper aims to design a PV/T system for water heating and observes the thermal performance and water temperature that can be achieved by PV/T. In designing PV/T, the method used is to estimate the intensity of solar radiation and determine the size of the thermal collector, thermal insulation, type of working fluid, and heat pipe filling ratio. The PV/T thermal performance is also tested after the system design has been built.

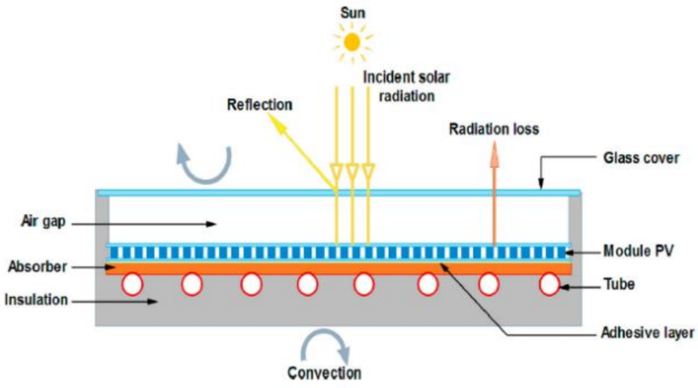

Fig. 1. Basic design of PV/T with Flat Plate Collector [22]

The results of this study are expected to be a contribution to the development of solar energy that can be used as heat and electricity so that it can encourage people to use more environmentally friendly renewable energy.

2 Research Methods

The PV panel, absorber plate, and copper heat pipe absorber tubes made up the system design. The PV was attached to an alumunium plate, and the alumunium plate was attached with copper heat pipe tubes. To minimize heat loss from the bottom and edges, thermal insulation was placed at the bottom and edges of the PVT absorber tube. The absorber collector helps reduce PV module temperature, -to be then employed to heat up the water as cooling. In this study, monocrystalline PV has been used with maximum output energy of 120 Wp (Watt peak).

There are numerous ways and processes utilized in the design of PV/T employing a flat plate solar collector with heat pipe media as a heat absorbing medium used for this water heater. The process for choosing the solar collector's dimension and materials, the type of working fluid for heat pipes, the method for filling working fluid into heat pipes till they are vacuumed, and the selection of the heat pipe filling ratio are some of the factors that must be taken into account.

The procedure for designing a Heat pipes PV/T system is carried out with the following steps: (1) Estimating the Intensity of Incident Solar Radiation. (2) Determine the volume and temperature of water to be achieved. (3) Calculate the energy needed to raise the temperature of the water. (4) Calculate the thermal energy absorbed by the solar collector and transferred to the water by the heat pipes. (5) Determine the heat pipes working fluid filling method and selection of the heat pipes filling ratio. (6) Determine the dimensions and materials of solar thermal collectors and the heat pipes needed. (7) Validate the design results with thermal performance testing to ensure the design results are as expected.

2.1 Evaluation of solar radiation

In order to gather information for resource evaluation, solar system monitoring, and the creation or validation of radiative models, the solar renewable energy community has long relied on solar radiation measurements. Data on measured solar radiation have varied widely in both quantity and quality. Generally, there are three main sources of regular solar radiation data: (i) solar monitoring sites, which typically have low-cost, automated instrumentation to provide local data quickly and at the lowest cost; (ii) traditional long-term measurements, typically by national weather services, based on "proven" techniques and instruments with few incentives for innovation; and (iii) research sites—such as those from the Atmospheric Radiation Measurement (ARM) program [23].

Ground-based measurements of solar radiation are the most direct way of measuring solar radiation at the Earth's surface [24]. In predicting the performance of solar collectors requires information from solar energy absorbed by the collector absorber plate. When measurements of incident solar radiation (I_t) are available, the solar energy incident on a tilt angle surface can be found by Eq. 1 [25]:

$$S = I_t(\tau\alpha) \qquad (1)$$

where τ glass cover transmissivity and α absorber plate absorptivity.

The intensity of incident solar radiation used in the design is used by measuring the intensity of incident solar radiation every minute on a selected number of days in sunny weather conditions with solar power meter. The district selected during the measurement was in Pekanbaru City, Indonesia on March 2022 which is shown in table 1.

Table 1. Incident solar radiation was used as the design reference

Time	**Incident Solar Radiation (W/m^2)**							
	18th March	**19th March**	**21st March**	**22nd March**	**23rd March**	**24th March**	**26th March**	**27th March**
08:00	122	303	163	214	218	203	304	203
08:30	180	521	201	389	554	303	370	245
09:00	253	560	190	493	329	167	453	564
09:30	367	674	237	641	616	249	701	644
10:00	431	788	361	755	650	382	771	748
10:30	501	871	327	587	610	254	194	824
11:00	554	913	538	921	734	317	864	891
11:30	666	945	675	931	543	457	938	940
12:00	643	947	319	997	1143	888	845	957
12:30	877	929	469	1035	1021	294	902	967
13:00	907	811	636	981	223	329	268	447
13:30	538	793	976	966	250	246	254	809
14:00	752	850	881	1024	241	619	254	861
14:30	438	755	629	241	185	832	556	784
15:00	357	741	920	155	737	365	753	728
15:30	519	162	449	82	599	711	568	698
16:00	609	425	255	126	453	113	273	403
Average	**516**	**744**	**525**	**560**	**561**	**526**	**554**	**736**

2.2 Energy Balance in Solar Thermal Collectors for PV/T

The energy absorbed by the water in terms of the temperature increase of the water in the storage tank can be calculated by the Eq. 2 [26]:

$$Q_w = M_w C_{p,w}(T_{w,2} - T_{w,1}) \qquad (2)$$

where M_w is the mass of water (kg), Cpw is the specific heat of water (4200 J/kg.°C), Tw_1 is the initial temperature of the water (°C), and Tw_2 is the final temperature of the water (°C).

Photovoltaic/Thermal (PV/T) is designed by attaching a heat absorber plate to the back of the photovoltaic, causing the temperature of the absorber plate to have the same temperature as the photovoltaic cell temperature. The solar radiation absorbed by the collector per unit area of the absorber S is equal to the difference between the solar radiation incident and the heat loss. Heat transfer variation in the solar thermal collectors is shown in Fig 2.

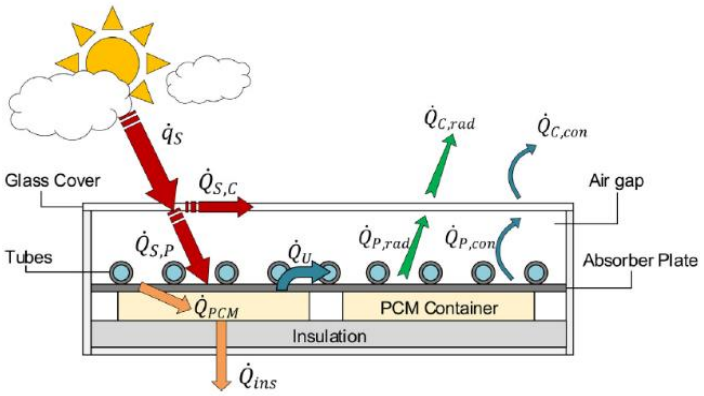

Fig. 2. Heat transfer variation in solar thermal collectors [28]

The energy that can be absorbed by solar collectors is proposed by the Eq. 3 [27]:

$$Q_u = A_c[S - U_L(T_p - T_a)] \qquad (3)$$

where A_c is the surface area of the solar collector (m^2), S is the intensity of solar radiation (W/m^2), U_L is the coefficient of heat loss (W/m^{2}K), Tp is the temperature of the plate absorber (°C), and Ta is the ambient temperature (°C).

When a certain amount of solar radiation falls on the surface of the collector, most of it is absorbed and sent to the transport fluid and is carried away as useful energy. However, as in all thermal systems, heat loss to the environment by various modes of heat transfer is unavoidable. The thermal network for a single-cover flat plate solar collector in conduction, convection, and radiation and the thermal resistance are shown in Fig. 3.

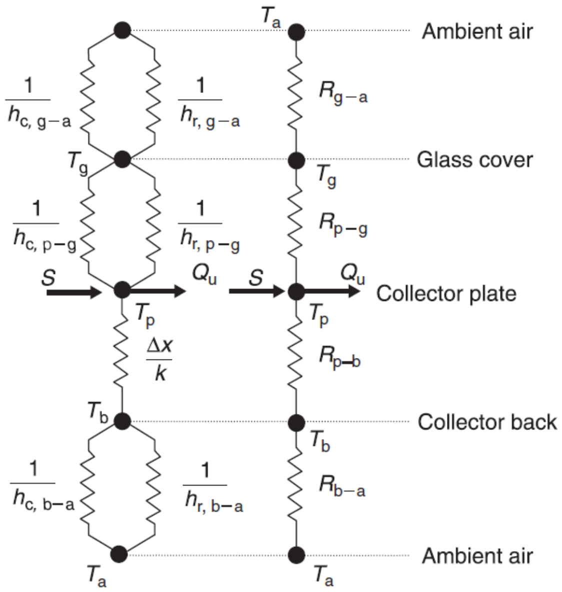

Fig. 3. Thermal network and resistance of Solar Collector with Single glass Cover [25]

The various heat losses from the collector can be combined into a simple resistance (R_L) so that the energy losses (Q_{loss}) from the collector can be written by the Eq. 4 [25]:

$$Q_{loss} = \frac{T_p - T_a}{R_L} = U_L A_c (T_p - T_a) \qquad (4)$$

from the relation, it is obtained by Eq. 5

$$R_L = \frac{1}{A_c U_L} \qquad (5)$$

In designing, keep heat losses to a minimum by making proper insulation. This is done on the side and bottom. The section is determined by the number and thickness of the most appropriate glass cover so that heat can be absorbed optimally.

2.3 Solar Thermal Collector Heat Transfer Modelling

The thermal energy lost from the collector by conduction, convection, and radiation is expressed as the heat loss coefficient U_L [W/m^2.K]. The value of the heat loss coefficient is the sum of the heat losses from the top, bottom, and edge side of the collector can be written as Eq. 6 [27]:

$$U_L = U_t + U_b + U_e \qquad (6)$$

The convection heat transfer coefficient $h_{c,p-g}$ [W/m^2.^{0}C] is obtained by calculating the Rayleigh number and other data can be seen in the air properties table. For tilt angles up to 60°, the convection heat transfer coefficient, $h_{c,p-g}$, (Eq. 7-8) [29]:

$$Nu = \frac{h_{c,p-g}\, L}{k} \qquad (7)$$

$$Nu = 1 + 1.44\left[1 - \frac{1708(\sin 1.8\beta)^{1,6}}{Ra\cos\beta}\right]\left[1 - \frac{1708}{Ra\cos\beta}\right]^{+} + \left[\left(\frac{Ra\cos\beta}{5830}\right)^{1/3} - 1\right]^{+} \qquad (8)$$

where β is the angle of inclination of the collector, and the *Rayleigh* number is obtained from the Eq. 9:

$$Ra = \frac{g\beta' Pr}{v^2}(T_p - T_a)L^3 \qquad (9)$$

where g is gravitational constant, (9.81 m^2/s), $\beta'$is volumetric coefficient of expansion, Pr is Prandtl number, L is absorber to glass cover distance (m), v is kinetic viscosity (m^2/s).

From the equation, get the convection heat transfer coefficient (Eq. 10):

$$h_{c,p-g} = \frac{Nu.k}{L} \qquad (10)$$

The radiation heat transfer coefficient is given in the following Eq. 11:

$$h_{r,p-g} = \frac{\sigma(T_p + T_g)(T_p^2 + T_g^2)}{\frac{1}{\varepsilon p} + \frac{1}{\varepsilon g} - 1} \qquad (11)$$

so, the thermal resistance of the absorber to the glass cover is (Eq. 12)

$$R_{p-g} = \frac{1}{A_c(h_{c,p-g} + h_{r,p-g})} \qquad (12)$$

The convection heat transfer coefficient from the cover glass to the environment is influenced by the wind speed in the environment so that the value of $h_{c,g-a}$ is also written as h_w which is obtained from the Eq. 13 [30]:

$$h_w = 5{,}7 + 3{,}8V \qquad (13)$$

where V is wind velocity (m/s).

For the radiation heat transfer coefficient from the cover glass to the surroundings $h_{r,g-a}$ is described in the following Eq. 14:

$$h_{r,p-g} = \varepsilon_g \sigma (T_g + T_a)(T_g^2 + T_a^2) \quad (14)$$

then the thermal resistance of the glass cover to the environment is (Eq. 15)

$$R_{g-a} = \frac{1}{A_c(h_w + h_{r,g-a})} \quad (15)$$

Since the Thermal Resistance R_{p-g} and R_{g-a} are in series (Eq. 16):

$$R_{g-a} = R_{p-g} + R_{g-a} = \frac{1}{A_c U_t} \quad (16)$$

Then the value of the top heat loss coefficient U_T (Eq. 17-18):

$$\frac{1}{A_c U_t} = \frac{1}{A_c(h_{c,p-g} + h_{r,p-g})} + \frac{1}{A_c(h_w + h_{r,g-a})} \quad (17)$$

$$U_t = \left[\frac{1}{(h_{c,p-g} + h_{r,p-g})} + \frac{1}{(h_w + h_{r,g-a})}\right]^{-1} \quad (18)$$

Heat Loss from the bottom of the collector that has been insulated causes the temperature of the bottom of the collector to be low so that the radiation value can be ignored, so that the coefficient of heat loss at the bottom U_b (Eq. 19):

$$U_b = \frac{1}{\frac{t_b}{k_b} + \frac{1}{h_w}} \quad (19)$$

where t_b is the back insulation thickness (m) and k_b is the back insulation conductivity (W/m.K).

The edge heat loss coefficient U_e is (Eq. 20):

$$U_e = \frac{1}{\frac{te}{ke} + \frac{1}{h_w}} \quad (20)$$

where t_b is the thickness of the side insulation (m) and k_b the conductivity of the side insulation (W/m.K).

2.4 Heat Transferred by The Heat Pipe as Fins

The thermal energy received by the water is obtained by transferring the energy contained in the collector with a heat removal factor (Eq. 21) [27].

$$Q_w = F_R A_c [S - U_L (T_p - T_a)] \quad (21)$$

where F_R is the heat removal factor.

In this design the heat transfer system from the solar collector to the heated fluid uses a heat pipe, so we assume that the heat pipe works as a fin which will determine the value of the Fin Efficiency Factor (F). The arrangement of the heat pipe as fins on the solar collector is shown in Fig 4. To calculate the value of the heat removal factor (F_R), it must calculate the collector efficiency factor and the collector flow factor obtained using the equation proposed by Duffie and Beckman (1991)

$$F_R = F' \, x \, F'' \quad (22)$$

where F' is the collector efficiency factor, and F" is the collector flow factor.

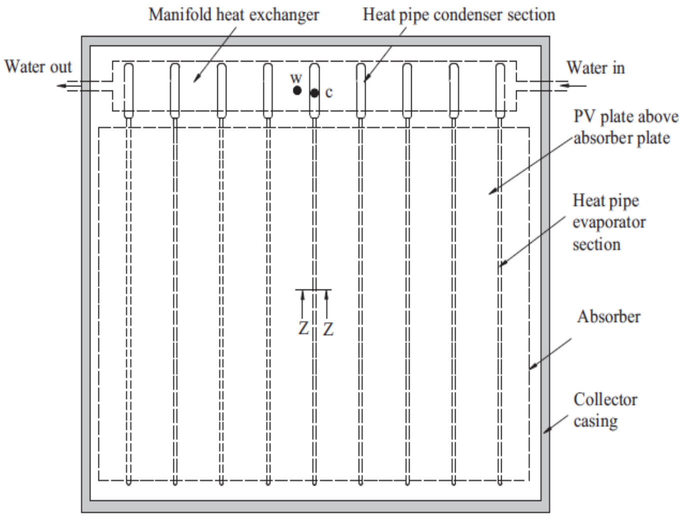

Fig. 4. Solar collector design for Heat Pipe PV/T [31]

The collector fin efficiency factor (F') is obtained by using the Eq. 23:

$$F' = \frac{1/U_L}{W\left[\frac{1}{U_L\,[D + (W-D)F]} + \frac{1}{C_b} + \frac{1}{\pi D_i h_{fi}}\right]} \quad (23)$$

where W is the distance between the heat pipes (m), Di is the inner diameter of the heat pipe (m), h_{fi} is the heat transfer coefficient in the heat pipe (W/m^2.K), and F is the Fin efficiency factor. Fig. 5 depicts the design of plate absorber and heat pipe cross-section.

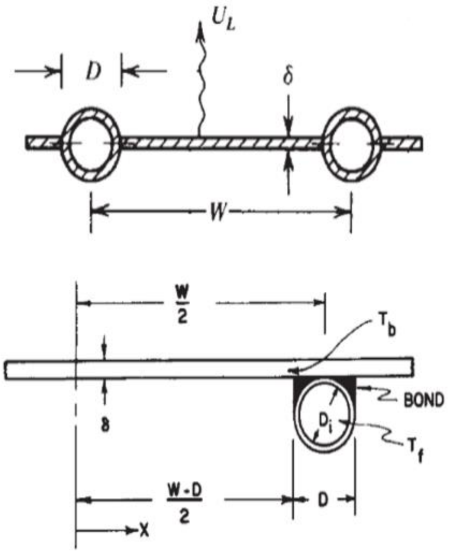

Fig. 5. Design of plate absorber and heat pipe cross-section [27]

To calculate the value of the fin efficiency factor (F) used the equation offered by Duffie and Beckman (1991) is used (Eq. 24-25).

$$F = \frac{\tanh[m(W-D)/2]}{m(W-D)/2} \quad (24)$$

$$m = \sqrt{\frac{U_L}{k\delta}} \quad (25)$$

where k is the thermal conductivity of the plate absorber (W/mK), and δ is the thickness of the plate absorber (m), and to calculate the collector flow factor (F"), the equation offered by Duffie and Beckman (1991) is used (Eq. 26).

$$F'' = \frac{\dot{m}\ x\ C_p}{A_c\ x\ U_L\ x\ F'}\ x\ [1 - \exp(-\frac{A_c\ x\ U_L\ x\ F'}{\dot{m}\ x\ C_p})] \quad (26)$$

where is the mass flow rate of the heated fluid (kg/s) and C_p is the specific heat of the fluid at the working temperature (J/kg.K).

2.5 Working Fluid Filling Method and Selection of Heat Pipe Filling Ratio

The method used in filling the working fluid in this study is Filling by Evaporation of The Working Fluid. In this filling method by calculating the total weight of the heat pipe. The schematic of filling with the evaporation of working fluid is shown in Fig. 6 The basic principles of this method are [32]: (1) Verify the weight of the heat pipe when it is empty, calculate the total volume of the heat pipe and determine the amount of working fluid to be filled. (2) Fill the tube with a syringe at a higher value than required. (3) Verify the weight after filling. The difference in weight before and after is the amount of working medium in the tube. (4) Evaporate the working fluid in the heat pipe using an external heat source until the working fluid mass is reduced to the required fluid weight. After that, lock/close the heat pipe tube. (5) When the steam in the tube condenses as the heat pipe temperature decreases, the pressure in the heat pipe will decrease so that it becomes a vacuum.

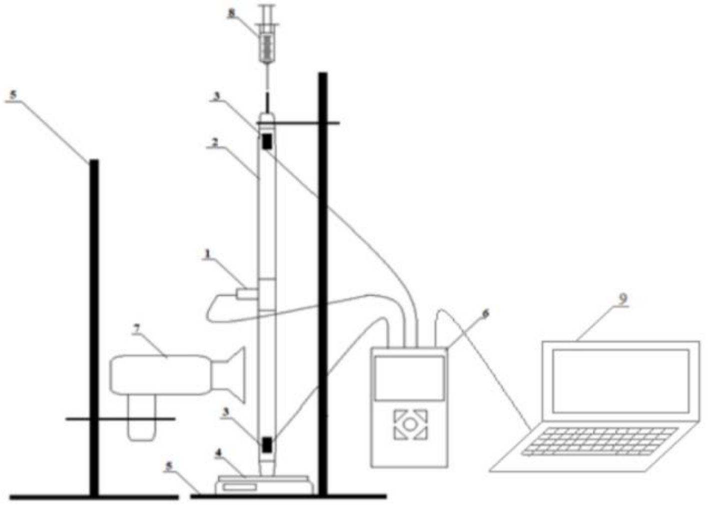

Fig. 6. Schematic of filling with the evaporation of working fluid [32]

The heat pipes are designed using a Schrader valve at the top near the condenser so that after heating occurs and the steam has filled the heat pipe, the heat pipe can be locked immediately. After the heat pipe is locked, the vaporized working fluid will immediately condense due to a decrease in temperature and cause a vacuum condition on the inside of the heat pipes. The vacuum pressure value obtained by the vacuum pressure gauge after the tests carried out in this method was -60 cmHg (20 kPa) with an 80% vacuum percentage. The heat pipe working fluid filling process shows in Fig 7.

After the working fluid filling process is done, a test is carried out to see if the heat pipe can work properly. After the test is carried out and the heat pipe is working, then the heat pipe is installed on the heat exchanger and solar thermal collector. The process of testing the response of the heat pipe for heat transfer is carried out with several different fluid filling ratios and is carried out with the previous working fluid filling method. The procedures carried out are as follows: (1) The heat pipe which has been filled with working fluid is enforced using a buffer, then heat is given using a hot air gun to the heat pipe with an air temperature of 250 ºC. (2) The temperature on the side of the evaporator and condenser is measured with a thermocouple thermometer, to determine the temperature rise. (3) Calculate the time required for the condenser to reach the specified temperature of 50ºC. Measurement results are compared to get the best filling ratio.

3 Results and Discussion

The previously mentioned procedure is used to carry out the design. The first step is to select the appropriate working fluid filling ratio for the particular heat pipe being used. Additionally, the heat pipe will be mounted on the solar thermal collector of PV/T so that the thermal energy from photovoltaic can be absorbed by the solar thermal collector and delivered to the water through the heat pipe. The heat pipe has been vacuum tested with the proper working fluid filling ratio.

In this research, there are several limitations used. The design process only assumes that the temperature of the PV cell is the same as the temperature of the absorber plate and the heat pipes act like the fins of the absorber plate. In the testing process, it was carried out in 8 days with certain weather conditions in Pekanbaru City, Indonesia. Useful thermal energy is only seen from the temperature rise of the heated water at 8 hours of measurement.

3.1 Design of The Heat Pipes

3.1.1 Heat Pipe Working Fluid

In order to attain the best heat pipe performance, numerous studies have been done on the choice of the working fluid. Since it has a significant impact on the heat pipe's operation and performance, the choice of working fluid is crucial. Some of the previous research that has been done shown in table 2.

From several studies in table 2., the use of water as a heat pipe working fluid is one of the most widely used applications and has good performance. Therefore, in this study, water was used as the designed working fluid. Furthermore, after determining the working fluid used, the design of the working fluid filling ratio on the heat pipe is carried out so that the heat pipe has the best performance.

3.2 Heat Pipe Working Fluid Filling Ratio

The heat pipe works with the working fluid under vacuum pressure so that the evaporation and condensation processes occur at a lower temperature than the saturation temperature at standard conditions (1 atm). Therefore, during the working fluid filling process, it must be made so that the working fluid in the heat pipe is in vacuum pressure. Fig. 7 shows the heat pipe working fluid filling process.

(a) (b) (c)

(d)

Fig. 7. Heat pipe working fluid filling process (a) Weighing the mass of the empty heat pipe (b) Filling the heat pipe with working fluid (c) Heating the heat pipe evaporator (d) Measuring the vacuum of the heat pipe

Table 2. Previous research as a reference in selecting heat pipe working fluid

Reference	Description	Working Fluid	Result
Ersöz, 2016 [33].	Evaluation of energy and exergy performance of heat pipe working fluid at different solar working fluid mass flow rates.	Chloroform, Hexane, Methanol, Petroleum Ether, Acetone, and Ethanol.	Among the different working fluids, Acetone has the best energy efficiency (65%) for medium flow rates (2–3 m/s).
Arab & Abbas, 2013 [34].	Analyze the performance of heat pipe working fluid during operational days based on thermal resistance and critical heat flux.	Methanol, Ammonia, Water, Acetone, dan Pentane	From a technical and economical point of view, water is the best working fluid with an efficiency of 84%.
Kabeel et al., 2017 [35].	Investigate the effect of several parameters such as the working fluid of hot pipes, charging ratios, and slope angle.	R22 dan R 134a	•The best performance is obtained at a 30% filling ratio for mass flow rates of 0.0051 and 0.0062 kg/s. •Optimum performance occurs at a filling ratio of 40% for mass flow rates of 0.007 and 0.009 kg/s. •The optimum slope angle at a mass flow rate of 0.009 kg/s occurs at 20°.
Wei et al., 2013 [36].	Ethanol was used as the working fluid and the filling ratio was 50%. For the low boiling point of ethanol, the heat pipe can work easily at low temperatures.	Ethanol	The maximum collector efficiency can reach 66%, while the water temperature of 200 kg in the storage tank increases by about 25 °C in the end.
Jahanbakhsh et al., 2015 [37].	HPSC experimental evaluation at different heat pipe filling ratios and tilt angles.	Ethanol	Collectors with 50% and 75% ethanol concentrations have the best performance among all other concentrations.
Elmosbahi et al., 2012 [38].	Measuring the temperature of different parts of the heat pipe at different fill ratios.	Methanol	•Optimum performance occurs at a 66% filling ratio. •Lower temperature difference between evaporator and condenser results in better thermal performance.
Chaudhry et al., 2012 [39].	Studying the Merit Number variation with increasing intermediate operating temperature for various heat pipe working fluids.	Heptane, Water, Ammonia, Pentane, and Acetone.	•Water exhibits a significantly superior Merit Number compared to other candidate fluids in the operating temperature range, thereby confirming its historical dominance as the primary working fluid in most heat pipe applications.

In this investigation, working fluid filling was carried out utilizing six working fluid filling ratios: 5%, 10%, 20%, 30%, 40%, and 50%. After filling the working fluid in the heat pipe, then testing the response of the fluid for heat transfer to the six types of working fluid filling ratio. In this test, a heat source is given to the evaporator section and then the time required for the heat to reach the condenser section is given at a certain temperature which in this study was determined to be 50 °C. The vacuum pressure at each filling ratio is set to be the same at -60 cmHg. The process of testing the response of the heat pipe in transferring heat and the result of the response of the heat pipe for heat transfer are shown in fig 8 and table 3.

Fig. 8. The process of testing the response of the heat pipe in transferring heat

Table 3. Response of the heat pipe for heat transfer

Filling Ratio (%)	Heat Pipe Response Speed to Reach 50 °C (second)	Negative Vacuum Pressure (cm Hg)	Vacuum Percentage
5	212	-60	80 %
10	220	-60	80 %
20	230	-60	80 %
30	378	-60	80 %
40	431	-60	80 %
50	655	-60	80 %

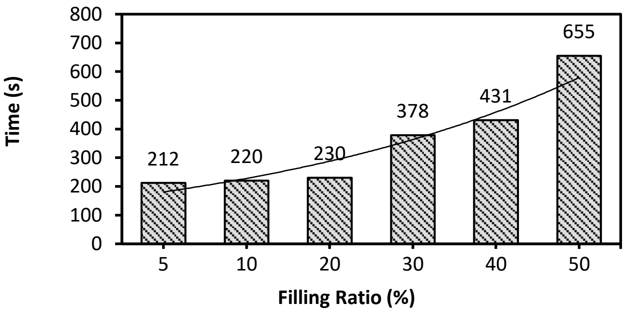

Fig. 9. Comparison of heat pipe response speed in transferring heat to reach 50 °C from several filling ratios

The test results show that the response of the fluid for heat transfer at a filling ratio of 5%, 10%, and 20% has a better response speed. Of the three, a filling ratio of 10% was chosen so that there was no dryness of the working fluid in the heat pipe due to too little working fluid and also under conditions of a small heat source, the heat pipe can still work in transferring heat because the energy required to evaporate the working fluid is less. The greater the filling ratio means the mass of the working fluid is greater and more thermal energy is required to evaporate the fluid so that the response speed of the heat pipe will be longer. Fig. 9 compares the heat pipe response speed in transmitting heat to attain 50 °C from various filling ratios.

3.3 Design of Solar Collector for PV/T

Solar collector is a special type of heat exchanger that can collect and absorb incoming solar thermal energy, then heat energy will be utilized and transfer it to the working fluid. The working fluid then carries the collected solar energy either to the load or to a thermal energy storage tank to be used for daily, night or overcast periods.

The solar collector is designed to absorb the heat in the PV module so that it has better efficiency. The absorbed heat is then reused to heat water. This research was conducted by designing PV/T from the previously introduced method. The design results that have been obtained will be made. After the PV/T system is built, the PV/T thermal performance will be tested in several days.

With the methodology proposed in the previous section, the design results of the photovoltaic/thermal system are obtained as shown in fig. 10 and table 4. The results of the PV/T that have been made are shown in the fig. 11.

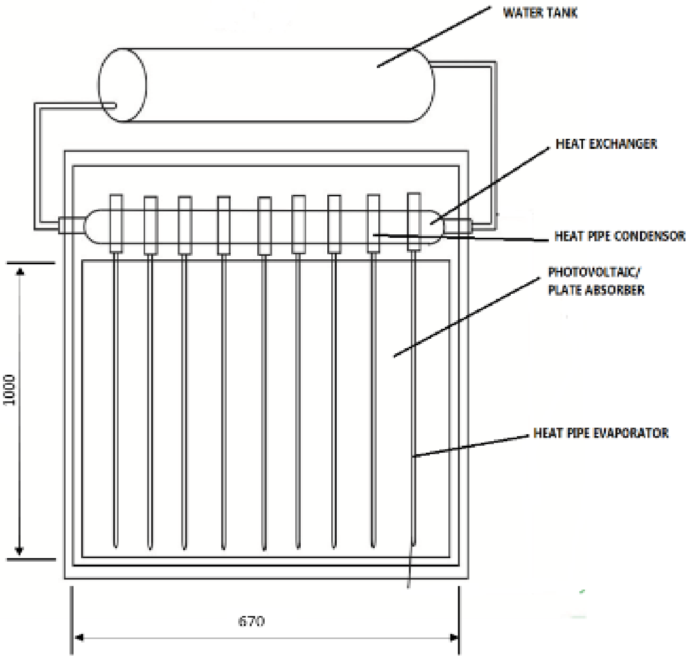

Fig. 10. Design result of solar collector for PV/T

Table 4. Design characteristics of the solar thermal collector and the heat pipe for PV/T

Parameter of design	Value
Collector area, Ac	0,67 m^2
Collector tilt angle, β	60°
Number of the glass cover	1
Glass cover thickness	5 mm
Plate absorber thickness, δ	1 mm
Plate absorber conductivity, k	237 W/m.K (Aluminium)
Plate absorber emissivity, ε_p	0.98
Glass cover emissivity, ε_g	0.88

Insulation of collector	*Styrofoam* = 2 cm, k = 0,036 W/m.K *Rockwoll* = 5 cm, k = 0,042 W/m.K
Number of the heat pipe	6
Distance between heat pipe, W	100 mm
Diameter of the heat pipe, D	10 mm
Diameter of heat exchanger	25 mm
Type of heat pipe	Wickless
The initial temperature of the water	28 °C
The final temperature of the water	50 °C
The capacity of water heated	20 Liters

(a) (b)

Fig. 11. Experiment setup of PV/T (a) Back side of PV/T (b) Experiment set up of PV/T

3.4 Thermal performance of PV/T

As already mentioned, the useful thermal power of the collector at the site design conditions for heating 20 liters of water from 28 to 50 °C is 1.848 MJ. The collector power and performance profiles are calculated for several days of testing to see how well it performs in minute intervals of 8 hours of test time per day. Fig. 9 shows available and generated solar power and thermal power generated over several days of testing. Due to the high solar radiation value and low angle of incidence, as well as the peak energy demand, the daytime is when the most energy is produced. Thermal energy and water temperature obtained during several days of PV/T testing are shown in Fig. 12.

Based on tests that were conducted on several days in March 2022 at Pekanbaru City, Riau, Indonesia, on collectors that were constructed from collector designs designed for PV/T. The test starts from 08.00 to 16.00 WIB. The range of useful thermal energy for water heating is 1.21 to 1.85 MJ. The range of hot water temperatures that can be reached is 43.9 to 50.9 °C. The amount of incoming solar energy is also calculated during the test so that we can calculate the thermal efficiency and see the quality of the energy produced by the PV/T. The range of thermal efficiency of PV/T is 17.40 to 27.14%. The amount of incoming solar energy and thermal efficiency of PV/T are shown in Fig. 13.

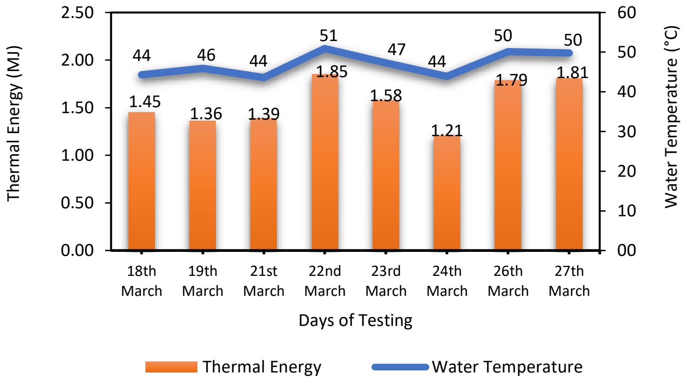

Fig. 12. Thermal energy and water temperature were obtained during several days of PV/T testing.

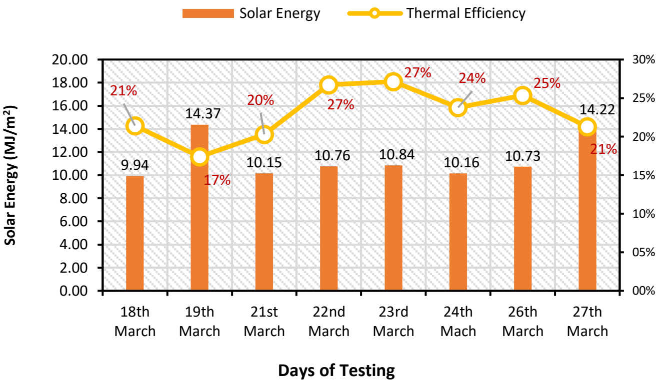

Fig. 13. Incoming solar energy and thermal efficiency of PV/T during several days of testing

The test's findings show that the PV/T design actually produces outcomes that are consistent with the design. This demonstrates how effectively and promisingly thermal energy may be used from the heat produced by photovoltaic panels. The results also show that the utilization of solar energy can be more efficient and can produce a higher amount of energy per unit area with this hybrid system and is expected to overcome the problem of low PV electricity efficiency due to the high temperature of the PV module.

It is clear from the data discussed above that PV/T as a water heater has good development potential. It may also be thought of as using improved methods to capture heat from solar energy. Future study can also take into account the economic viability of using PV/T as a water heater.

4 Conclusions

In this article, the author has designed a photovoltaic/thermal (PV/T) which is system that utilizes solar energy as heat energy and electrical energy simultaneously. Heat pipe technology is used to absorb heat from PV which is then used as a water heater. This gives an advantage in solving the problem of decreasing the efficiency of solar cells (Photovoltaic) as the temperature of the cell increases. The design is completed by designing the dimensions and materials of the solar thermal collector needed, the type and ratio of the heat pipe working fluid filling used, and testing the PV/T that has been built from the design. The result of the design is PV/T with an area of 0.67 m2 using a wickless heat pipe with water working fluid with a working fluid filling ratio of 10%. The test results in this research shows that PV/T with heat pipe as heat transfer medium performance in absorbing thermal energy from the photovoltaic module which is able to heat 20 liters of water up to 50.9 °C with energy absorbed by water of 1.85 MJ. The maximum thermal efficiency of PV/T is up to 27.14%. This demonstrates that the outcomes are consistent with the design, and it also suggests that PV/T has a very promising future in terms of its ability to use thermal energy.

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