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Design Analysis Of Water Cooling System For A Photovoltaic Modules

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Abstract: Photovoltaic cells otherwise known as solar panel, converts irradiance into electrical energy. During this process of conversion, the temperature of the PVC increased as it absorbs solar irradiance leads to a reduction in its output power. This problem affects the performance of the PVC especially in the hotter regions of the world. In this research, a water cooling system was designed for photovoltaic module in order to reduce its temperature. The objective of this research is to carryout design analysis of the system for possible fabrication and performance evaluation. The system components were analyzed using 80 watts solar panel and the required dimensions obtained through designed calculations. The design analysis results shows an insulator thickness of 5.5 mm and a theoretical water temperature of 62.3°C was attained, which implies a 5.2°C reduction in Photovoltaic module temperature

Keywords*: PV Module, Pressurized Fluid, Flow rate, Heat exchanger, Cooling*

NOMENCLATURE

$\dot{m}$-The mass flow rate
C_p - Specific heat
T_0 - Outlet temperature of working fluid.
T_i - Inlet temperature of working fluid.
A_p - Area of the absorber plate
F_R - Heat removal factor
T_a - Ambient temperature
U_I - Overall heat loss coefficient
I_T - Incident solar radiation
$\tau\alpha$ - The transmittance absorptance product
F' - Collector efficiency factor
Q - Heat transfer rate (kJ/h)

A - Heat transfer area (m^2);
U - Overall heat transfer coefficient (kJ/h.m^2.°C)
ΔTm - Log mean temperature difference (°C)
T1 - Inlet tube side fluid temperature;
t2 - Outlet shell side fluid temperature;
T2 - Outlet tube side fluid temperature;
t1 - Inlet shell side fluid temperature.

INTRODUCTION

The use of solar photovoltaic (PV) electric systems is growing rapidly in the sustainable renewable energy market and is expected to play an important role in the future sustainable energy mix (Saira, *et al*, 2018). On the other hand, the initial capital cost of the PV modules and systems has always been a major barrier to the widespread use of this technology over the globe. The initial price of solar PV systems can be reduced by producing more power with the same PV module. The PV module's power output can be increased by increasing the incident solar radiation falling on a PV module according to the inherent characteristics of the PV cells. The distribution of solar radiation is not constant throughout a day. Photovoltaic panels absorb incident solar energy converting directly a small part of it into electrical energy. A limited wavelength of the incoming irradiation on the PV cells is converted into electrical energy with an electrical efficiency of 15 %–20 %, while the remaining energy is wasted as thermal energy causing the major problem of heating of PV modules, consequently increasing its surface temperature and thus decreasing the electrical efficiency (Huan-Liang, 2014).The efficiency of the energy conversion depends strongly on the type of the solar cell and its technology, as well as the operating and environmental conditions such as surface temperature of PV panel, solar irradiation intensity, air temperature and its humidity, air dust, and mass flow rate of cooling fluids (Chandra, *et al*, 2015).

The development of new technologies of the PV panels and the improvement of existing available ones are necessary to increase the panel electrical efficiency by decreasing its high surface temperature utilizing appropriate cooling techniques. The reduction in the electrical power of the PV module is 0.65% per 1 deg of temperature increase within the range from 22℃ to70℃ (Arjyadhara & Bhagbat, 2017). In addition, the conversion efficiency and power output of the PV panel decrease by 0.08 % and 0.65 %, respectively, per 1 deg of temperature increment up to 80℃ (Swar, *et al*, 2017). Cooling of PV panels can be achieved by either passive or active cooling systems. Active and passive cooling systems may coexist in order to obtain better efficiency. The passive cooling system of the PV panels that is achieved by three basic heat transfer mechanisms such as free convection, conduction, and radiation depends on the buoyancy-driven flow of the working cooling fluid in a duct. The drawbacks of the passive cooling system are dependent on the environmental conditions, its low heat transfer rate, low thermal conductivity, and hence limited temperature reduction. The active cooling system that is performed using liquid or air is comprised of a supplementary device, such as pump to circulate liquids or fan to force air to the panels to extract heat away from the system (Kasaeian, A.,2017). Generally, the active cooling system is used for both increasing the electrical power output of the PV/T module and supplying available heat to nearby users. Mainly, there are three fundamental working fluids that are employed for the combined PV/T active cooling system: air, water, and refrigerant. The advantages of the water cooling are availability, reliability, low cost, no environmental impact, high thermal conductivity and higher heat transfer rate, and higher temperature reduction for the Photovoltaic (PV) module temperature. Solar energy is one of the most abundant renewable energy resources, but is it characterized with very low conversion efficiency. Another major problem of energy from PV modules is the larger percentage of the solar radiation that incident on the solar panel is converted to heat energy. This research is aimed at is to carryout design analysis of the system for possible fabrication and performance evaluation of a water cooling system for a solar panel. Hoping that, this will cool the solar panel thereby improving its electricity conversion efficiency and also harvesting the excess heat to heat up a water for domestic use.

(Bahaidarah, *et al*, 2013), investigated the thermal behavior of a PV panel integrated with a water cooling system by producing a 3D models of the PV panels without and with water cooling system and simulated them using ANSYSCFX. The thermal performances of the PV panels without and with water cooling system has been compared and the effect of the inlet water temperature in the cooling case has also been studied detail in method section. A water pump of 373 Watts was used to pump the water flow over the surface of the PV panel from an insulated tank. The experimental measurement of the PV panel with cooling system shows a temperature reduction 7.3 °C in as compared to that without cooling system. This leads to the electrical efficiency of the PV panel with water cooling system has increased 9 %, with a reduction in temperature.

Similarly, Abiola-Ogedengbe (2016) applied a water-closed circulation to the PV panel to overcome the overheating issues. But in this research work a water pump drained water on the surface of the PV panels and hot water has flowed back into the water tank and circle continues in that manner. The result obtained shows that the PV panel with cooling system has increased an additional 11.6 % of the output power from the PV panel without the cooling system by reducing the temperature of the PV panel. Photovoltaic (PV) panel is directly converted solar irradiance into electrical energy. The temperature of the PV panel increased as it absorbs solar irradiance lead to a reduction in its output power (Leow *et al.*, 2019).This undesired impact can be prevented through the use of a cooling system with PV panel (Leow, *et al*., 2019), designed a water cooling system for a PV panel, so as to reduce its temperature (Saira Iqbal, etal 2016) investigated the effect of water cooling of the energy conversion efficiency of PV cell inclined at 45^o using Polycrystalline solar panel having area of 1.2m^2 36 x 27 cm^2 of area and a power of 12watt (12v and 0.68A), a battery, a 5L water tank. A knob connected to a hose were used to regulate the water flow. Sponge was used to absorb the water flowing over the panel. Pyranometer was used to monitor water temperature and that of solar panel. The voltage and current from the solar panel were measured with the used of voltmeter and ammeter. A 8 Watt bulb was used to load and discharge the battery used for the study. The result obtained are 0.50 V and 0.10 A. The efficiency of solar panel against mass flow rate in used ranges between 7% - 12% and the highest PV temperature recorded was 48^o.

MATERIALS AND METHODS

2.1 Materials

The Materials used and their specifications are listed in Table-1.

Table-1 List of Materials Used.

S/No	Materials	Specification
1	Solar Panel	80 W
2	Insulated Tank	20 Litres
3	DC Pump	12V, 3-6 W
4	Stand	Mild steel
5	Robber Hose	12.7mm

2.1 Model Description

Fig. 1, shows the layout of the system been designed for cooling a solar panel, so as to improve its thermal efficiency. The 3/8″ copper tube were attached to the solar panel at the back and insulated to reduce the heat loss to the environment. The solar panel collector is now connected to a heat exchanger that will harvest the heat from the back of the solar panel. A DC Pump was used to pump the hot water from the copper tube to the heat exchanger tank, there by cools the solar panel. The PV module with coiled copper is then connected with the heat exchanger via an insulated hose, so as t minimized heat loss to the environment.

When the solar panel with coiled copper absorb heat from the PV module, the hot water is circulate intermittently between the hot copper tube and the heat exchanger tank.

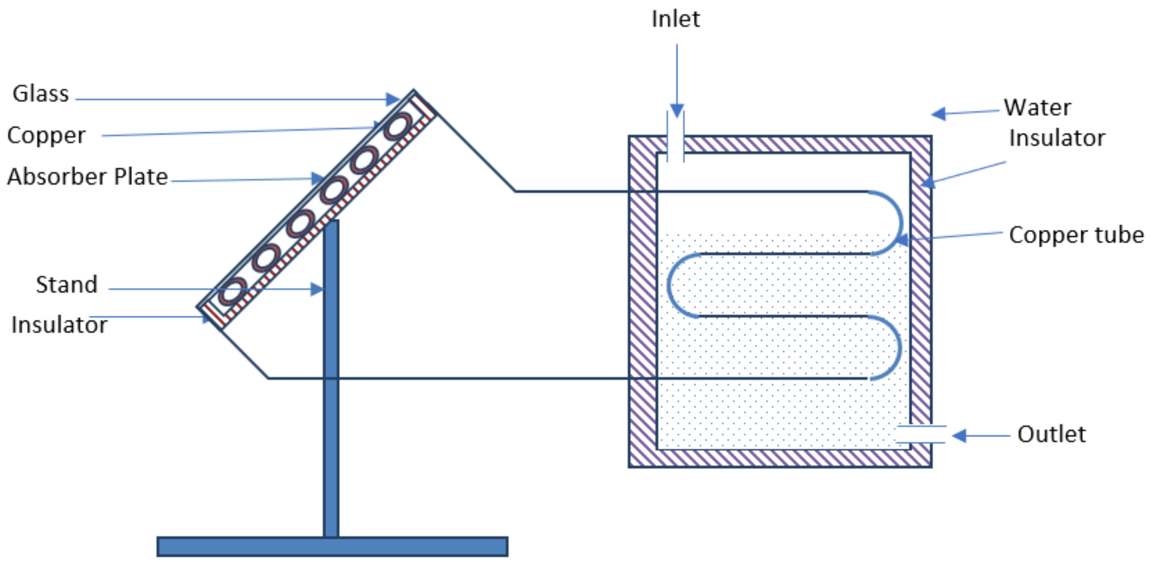

Fig.1 Schematic of the PVC Cooling system

2.2 Solar Collector Design

The solar collector converts the solar energy to heat energy, for other useful purposes. The collector is comprising of the absorber plate, the glass, the insulator cover, the fluid tubes and the frame (See Fig. 1). The design analysis of the collector requires the determination of the amount of heat absorbed through radiation by the solar panel into the copper tubes and the insulator thickness required for maximum retention of the absorbed heat. The useful heat gain from working fluid from the environment is given by equation 1(Kartini, *et al*, 2017),

$$Q = mC_p(T_o - T_i) \quad (1)$$

The Hottel-Whiller equation for the useful heat gain from solar collector is given by equation 2.

$$Q_U = A_P F_R[I_R(\tau\alpha) - U_L](T_o - T_i) \quad (2)$$

Heat removal factor in equation 2 is defined by equation 3;

$$F_R = \frac{\dot{m}C_p}{U_L A_p}\left[1 - exp\left(-\frac{F U_L A_p}{\dot{m}C_p}\right)\right] \quad (3)$$

And the thermal efficiency of solar collector is calculated from equation 3.8;

$$\eta_e = \frac{Q_U}{I_T A_p} \quad (4)$$

2.3 Heat Exchanger Design

The function of the heat exchanger in this system is to absorb heat from the solar panel and discharge the heat into reservoir tanks via copper pipe. According to Jaya (2019), "The temperature difference (ΔT) is not constant throughout the heat exchanger it varies with the length of heat exchanger." The rate of heat transfer in a heat exchanger was expressed by equation 5 (Efstratios, 2015);

$$Q = UA\Delta T_m \quad (5)$$

$$\Delta T_m = \frac{(T_1-T_2)-(T_2-t_1)}{ln\frac{T_1-t_2}{T_2-t_1}} \quad (6)$$

Where the mean temperature difference (ΔTm) between the hot and cold stream is obtained by using equation 7.

$$T_m = \frac{DT_o-DT_L}{\ln\left({DT_o}/{DT_L}\right)} \quad (7)$$

The overall heat transfer coefficient (U) for the heat exchanger based on the heat exchanger tube outside surface was obtained using equation 8,

$$U_o = \frac{1/A_0}{\frac{1}{h_iA_i}+\frac{ln^{d_o}/d_i}{2K_wL}+\frac{1}{h_oA_o}} \quad (8)$$

When designing a vapor absorption air conditioning system there is a need of mass flow rate at each point to be determined. According to tubular exchange manufactures association (TEMA) the following specifications are used in the design of a heat exchanger.

0.0666 < (Shell diameter/Tube length) < 0.2
1.25 < Pitch/Outer diameter of tube < 1.5

$$\text{Number of tubes} = \frac{\pi CTP.D^2}{4CL.P^2} \quad (9)$$

RESULTS AND DISCUSSION

This design study has demonstrated the opportunity for cost-effective cooling by using copper pipes, heat exchanger and active water cooling. According to Peter (2019), Water cooling proves to be the most effective at lowering operating cell temperature and should be pursued under the following circumstances, in a hot environment where water is easily accessible and stored. The result of the design analysis of water cooling system for a PV module are presented in shown in Table 2. The best insulator thickness, collector area required and the amount of heat absorbed by the PV module and extracted by the copper tubes are all shown in Table-2.

Table-2 Design Analysis Results.

S/N	Quantity	Value	Unit
1.	Amount of heat absorbed, Q	351.74	W/m^3
2.	Insulation thickness	5.5	Mm
3.	Efficiency thermal	66.8%	
4.	Area of collector, A_C	0.0855	m^2
5.	Area of copper tube, A_c	0.0339	m^2
6.	Number of coil copper tube, n	9	
7.	Shell diameter/Tube length	0.18	
8.	Reduction in PV Module Temperature	5.2	^oC

The results of the design analysis shown in Table-2, reveals that for an 80 watt PV module with an area 0.0855 m^2, nine (9) lines of 3/8" copper tubes are required to effectively absorbed all the heat generated. The Shell diameter/Tube length ratio falls with the accepted design region.

The thermal efficiency obtained is 66.8% leading to 5.2°C reduction in PV module temperature and this is closed to the result obtained by (Pravesh, 2018).

CONTRIBUTION TO KNOWLEDGE

PV module generate heat during the process of converting solar energy into electricity. This heat tends to lower the conversion efficiency of the PV module, therefore, design a water cooling system with 66.8% efficiency promise a better conversion efficiency of a PV modules.

CONCLUSION

The design analysis of a water cooling system to determine its effect of the performance of a solar panel output was conducted. The system are made of copper tubes laid behind the PVC and water runs through it, with the aid of a heat exchanger. The design analysis result gives the dimension for the fabrication of the PVC water cooling system. The system was designed using an 80 watt solar panel and a 20 liters water tank/heat exchanger. The PV module and the heat exchanger insulator thickness was determine to be 5.5 mm and a theoretical water temperature of 62.3°C was attained, which implies a 5.2°C reduce in PVC temperature.

CONFLICT OF INTEREST

There is no conflict of interest for this research work.

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