Experimental Investigation of a Water Based PV/T System with Energy and Exergy Analysis

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Abstract

As the surface temperature of solar photovoltaic (PV) panels rises, the efficiency with which they convert sunlight into usable energy drops. Consequently, reducing its surface temperature is the most alluring strategy for improving its performance. This paper presents an experimental study of back surface Pv cooling technique with Cu tubes. Results revealed that the cool panel has got better performance than the non-cooled panel. This is confirmed from the exergy analysis that the average exergy efficiency is 2.91% and 12.96% for the non-cooled and cooled panel respectively.

1. Introduction

Tebaldi et al. [1] look into the permanent consequences of fossil fuels on environment and come to the conclusion that as extreme weather events occur more frequently around the world, these effects become more apparent. Since renewable energy sources are often pollution-free and ecologically benign, they present practical options. Photovoltaic (PV) systems, which convert direct sunlight radiation to electricity, are one of the most well-known and commonly utilised technologies for renewable energy generation. According to Yu et al. [2], PV energy has a number of benefits, including a high-power density, low maintenance costs, cheap operating expenses, and minimal effects on climate change. PV technology has significant advantages, but it is vulnerable to environmental factors. Researchers Sanaz et al. [3] looked into the effects of dust, and Swapnil et al. [4] looked into the effect of temperature variation on PV performance. Low sun irradiation has a substantial effect on the power quality of the output of the PV module, as was found by researchers Mekhilef et al. [5] and Yildirim et al. [6] who studied the negative effects of humidity on PV cells. Both the experimental and theoretical studies show that temperature has a disproportionately large impact on the performance of PV panels. The efficiency of the electrical conversion decreases as the operating temperature rises. This means that according to the energy conservation law, not all of the sun's rays are turned into usable electricity, and some of it is instead transformed into usable heat. According to Heba [7], a 0.45-0.65% drop in efficiency is seen for every degree Celsius if PV panels are heated to over their optimum operating temperature.

Researchers have tried a variety of methods to reduce the detrimental effects of heat on solar modules.

Performance evaluation of PV panel surfaces with hydraulic cooling was examined by Bhakre et al. [8]. They discovered that running water constantly over the top cleaned and cooled the PV panel. As a result, the PV panel's optical efficiency improves.

Duan [9] investigated the charging procedure of porous systems including phase change materials (PCMs) with a cooling effect of PV panels for the cavities at various inclinations. Since the mild natural convection of liquid PCM exists, the results demonstrate that the smaller the porosity of metal foam, i.e., 14 85% or 90%, the weaker the effect on the inclination angle during the charging process. Weak convection is found to increase the time required to cool the panel and decrease the charging time of the PCM-porous system. Bayrak et al. [10] looked into the various approaches taken to cooling PV modules. Fins made of aluminium, thermoelectric (TE) technology, and the phase change material (PCM) are all taken into account.

The findings show that power generation was maximised by the PV with the fin system and minimised by the PCM and TEM. Three-dimensional physical and mathematical models of a water-cooled PV/T system with a cooling channel above the PV panel surface were reported by Wu et al. [11].

This model is useful for analysing the cooling channel's heat transfer characteristics and the overall system's efficiency. Several factors, including mass flow rate, cooling channel height, inlet water temperature, and solar radiation intensity, were investigated. Thermal efficiency is improved over conventional PV/T systems, as demonstrated by the tests conducted for this research. While electric energy production is reduced due to water above the PV panel, overall energy efficiency is enhanced under all circumstances. The best way to improve the performance of PV panels and generate hot water is with a solar thermal absorber collector system. The authors also discovered that compared to a conventional PV system, a hybrid PV cooling system significantly reduces atmospheric CO2 emissions.

In a comprehensive study pa- per, Nizetic et al. [12] explored and evaluated experimentally different PV/T systems combining with PCMs. According to the data, the electrical efficiency of the investigated PV/T-PCM systems is often around 20%, while the thermal efficiency improvement ranges from 40% to 70%. Since PCM materials are expensive per unit, the authors recommend more research to find flexible economic options. An accurate predictive thermal model of a PV panel in an integrated irrigation system and an intermittent irrigation cycle was created by Osma- Pinto [13]. The estimated error was less than 6%. Examining how PV panels are watered in hot climates helps validate the model (Bucaramanga, Colombia).

The thermoelectric cooler modules (TEC) and PV panels were studied by Moshfegh et al. [14] using numerical analysis under different circumstances of operation. Solar photovoltaic (PV) modules were used to power the TEC units, which draw power from the outside. It has been shown that by using a combination of TEC modules and forced air, a higher level of cooling efficiency can be achieved. Experimental research into the effect of a pulsing heat pipe (PHP) mounted on the back of a photovoltaic (PV) module was conducted by Benuel et al. [15]. In PHP, acetone flooded the pipes and PV modules went on for miles. DC fans are mounted to the expanded portion of pipes to facilitate forced convection of heat out of the pipes. A series of experiments were carried out to measure the voltage produced by various PV module combinations. Without the aid of a cooler or concentrator, the output voltage may be adjusted to 21.03 V, and the operating temperature can be maintained at 31.08 C. Maximum output voltage for the same module with concentrator and no cooler was 23.03 V, while maximum operating temperature was 34.32 C. The authors also discovered that the PV module with concentrator and cooler can achieve a maximum output voltage of 22.23 V at a maximum operating temperature

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of 30.32 C. Cooling PV modules by water spraying was the subject of experimental and numerical research by Moharram et al. [16]. Six PV modules, each with a max output of 185 W, and 120 water nozzles are used in this experiment. As such, the authors aim to reduce the quantity of water and power required to cool the PV modules. They limit the modules to a maximum temperature of 45 degrees Celsius, with a reduction of up to 10 degrees Celsius. After only five minutes of using the proposed technology, solar cells' temperatures drop by 10 degrees Celsius and their efficiencies rise by 12.5%. A cross-fined channel box was developed by Mohamed R.G. et al. [17] for use in the PV/T setup. Using industry-standard analysis tools, the authors compared the functionality of cross-fined channel boxes with thicknesses of 3 mm and 15 mm. Different levels of solar irradiation are compared with respect to the 0.008e0.066 kg/s flow rates. They found that under high radiation (1000 W/m2) and with the output water temperature at 38.95 C, the optimal flow rate for both cross-fined chan- nel boxes was 0.05 kg/s.

By affixing a cooling panel to the module's back, Bahaidarah et al. [18] conducted an experimental study of PV -a monocrystalline-module by back surface water cooling and compared their findings to those of their numerical model. According to the findings, when the module is cooled, its front surface reaches a maximum temperature of 35 degrees Celsius, while the back surface reaches a maximum temperature of 25.9 degrees Celsius. The highest temperatures recorded on the uncooled module were 45 degrees Celsius at the front and 42.8 degrees Celsius at the back. There was a 10% boost in the module's power output. Using fins attached a duct put under the panel and a direct current blower to improve heat transfer, Teo et al. [19] presented research on a cooling PV panel. The results suggest that the non-cooled panel can reach temperatures of 68 degrees Celsius, with a subsequent decrease in electrical efficiency to 8.6 percent. The module's optimal operating temperature is maintained with the help of a fan, which is kept at 38 degrees Celsius. An airflow rate of 0.055 kg/s is utilised in the experiment, and this is determined to be adequate for removing all of the excess heat produced by the PV panel. An absorber strategy was developed by Jurcevic et al. [20-22] for a hybrid PV/T idea. A water-flowing aluminium absorber denotes the active cooling side of the system, while pork fat acts as the organic PCM on the passive cooling side.

Therefore, it is crucial to thoroughly investigate methods for cooling the PV modules. The authors made an effort to lessen the temperature's detrimental effects on the PV module. The literature review demonstrates the use of numerous methods. It has been determined that cooling technologies that utilise water are the most effective. The proposed solutions for water-based PV/T systems typically achieve an electrical efficiency of around 10.77% and a thermal efficiency of around 50.35%. The main problems with the systems are their low thermal and electrical conversion efficiency, high implementation costs, and complicated geometries.

Therefore, in order to maximize thermal and electrical conversion efficiencies and reduce manufacturing costs, further analytical and experimental study is required.

2. Experimental Set Up

In this study, we present a PV/T setup that uses water as a cooling medium. As can be seen in Figure 1, a heat exchanger made of copper tubes has been mounted to the rear of the PV panel. Copper's capacity to efficiently transfer both electrical and thermal currents is only one of many valuable features it possesses. This takes place because the metal's internal, delocalized electrons are free to move about in the lattice. These would improve the metals' ability to conduct heat and electricity.

Figure 1. Back View of the PV/T (cooled) System

Information about this experiment has been recorded every 15 minutes using a data logger manufactured by Everon Energy Pvt Ltd. This is linked to the internet wirelessly so that data can be saved in the cloud and tracked in real time on a laptop.

This data logger features an IoT controller and a 32-bit Micro Controller. A Pyranometer is an actinometer used to detect sun irradiation on a flat surface. The Apogee S-110-SS pyranometer is a battery-free option that features an analogue sensor with a reading range of 0–400 mV.

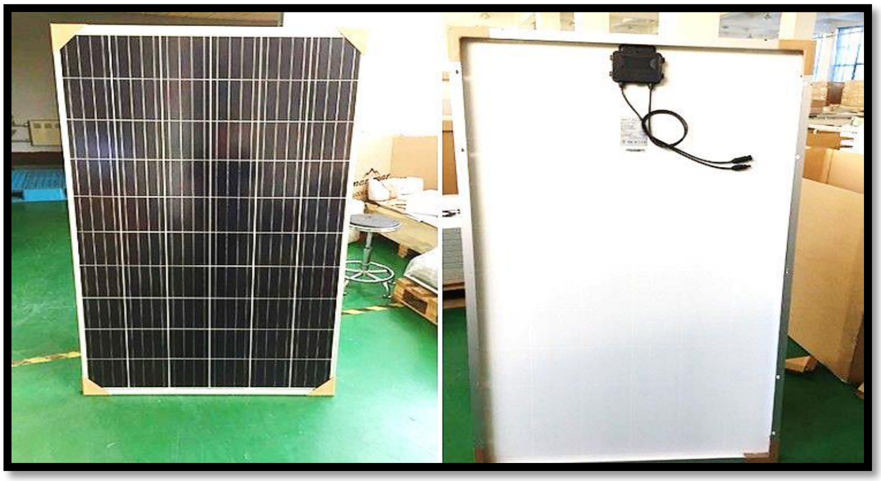

Figure 2. Front and Back View of the Non-Cooled PV Panel

Figure 3: Instruments Used

3. Methodology

All of the tests have been done during the summer. Four different water flow rates have been tested in advance of the experiment to determine the optimal one. For 30 minutes, a panel has received water at 2 l/min, 2.5 l/min, 3 l/min, and 4 l/min. Their voltage, current, power, and temperature have all been compared.

Figure 4: Experimental Setup

Parallel experiments have been conducted using cooled and uncooled panels on a sunny day, with both receiving the same amount of irradiation and being exposed to the same ambient temperature. There has been round-the-clock laptop monitoring of the logs.

4. Results and Discussions

Experiment outcomes have been sorted into categories and discussed. Recovering the data logged from the data logger. Photovoltaic panel types and their respective output values are tabulated. As well as the measured data, this section also displays certain estimated values, such as the electrical efficiency, thermal efficiency, total efficiency, energy saving efficiency, and exergy values. Connections between the variables have also been determined. Parameters are presented graphically in the discussion section to further illustrate the outcomes.

4.1 Determining Water Flow Rate

Water absorbs heat as it moves across the surfaces of PV panels. The temperature of the discharged water increases as a result. A higher collected temperature means greater thermal efficiency. To be clear, this has no bearing on the electricity efficiency. When water mass increases, the panel cools down. The panel's cooling helps to increase its electrical efficiency.

Maximum total efficiency is 74.06% at a mass flow rate of 3 LPM.

In spite of the fact that a water flow rate of 3 LPM yields the best results, a rate of 2.5 LPM has been proposed for future research and evaluation due to the possibility of water savings. When it comes to electricity usage, there isn't much of a distinction between 2.5 LMP and 3 LPM.

Front and back temperatures of 62.2°C and 76°C were measured by the non-cooling panel, respectively. For a cooled solar panel, the smallest temperature differential between the front and back surfaces was discovered.

The day's highs reach 21.2V, while the lows dip to 19.1V at peak hours. Cooled panel voltages have been measured to be higher than ever before, while non-cooled panel voltages have been seen to be at their lowest ever.

The variance of global irradiation over time is shown in Figure 5 for the day of experiment.

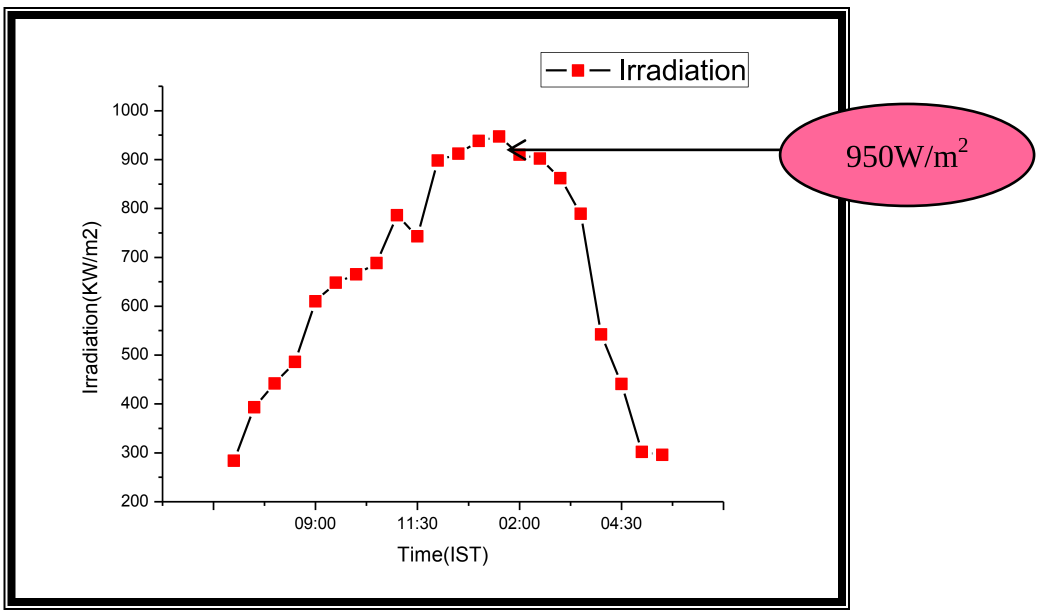

Figure 5: Irradiation Fluctuations Throughout the Day

4.2 Electrical Parameters of PV/T and PV with 2.5 LPM Mass Flow Rate

The electrical output parameters including voltage, current, and fill factor for 2.5 LPM are listed in Table 1.

The panel is cooled by the incoming water, which absorbs the panel's heat. As a result, the water being released gets heated. The highest input water temperature is 31 degrees Celsius, while the highest output water temperature is 47 degrees Celsius.

Table 1: Electrical Parameters of PV/T and PV

Time	Global Radiation (W/m^2)	Ambient Temp(^{o}C)	Wind Velocity (m/s)	Mass Flow Rate	Water Temp IN	Water Temp OUT	(PV/T) V_o	(PV/T) I_{sc}	(PV/T) FF
10:00	875	34	0.15	2.5LPM	23	40	19.32	1.712	0.701
11:00	907	33.5	0.73	2.5LPM	24	42	19.14	1.804	0.687
12:00	1020	35.2	0.6	2.5LPM	25	43	18.95	2.014	0.678
13:00	1050	38.4	0.46	2.5LPM	27	45	18.84	2.06	0.666
14:00	966	35.5	0.33	2.5LPM	29	47	18.89	1.936	0.668
15:00	800	36.7	0.86	2.5LPM	31	46	19.38*	1.552	0.706
16:00	685	38.1	0.15	2.5LPM	30	44	19.1	1.186	0.724
17:00	250	35.2	0.1	2.5LPM	29	36	18.78	0.265	0.772

*Maximum voltage attained by PVT

As an added bonus, both the incoming and outgoing water temps are included. In its highest setting, it measures 19.38V and 2.06A. The values have been computed using the Fill factor formula. The table below includes both PV and PVT temperatures for easy comparison.

There is a difference of 18 degrees Celsius between the arriving and outgoing water temperatures around 2 in the afternoon. Table 2 shows the thermal and electrical efficiency as well as the overall efficiency with a water flow rate of 2.5 LPM.

These numbers, electrical characteristics for PV system, have been displayed as well, facilitating comparison between panels with and without cooling. The following table displays the input and output exergies as well as the exergy efficiency.

PV has an electrical efficiency of 7.612, and PVT is at 8.254. The PV system's peak voltage was measured to be 19.58V. When combined, PV and PVT can achieve an electrical efficiency of up to 1.8%. In the best-case scenario, the fill factor is 0.765%.

Table 2: Efficiency of PV/T and PV

Thermal Efficiency of PV/T	Electrical Efficiency of PV/T	Overall Efficiency of PV/T	(PV) Voc	(PV) Isc	(PV) FF	Electrical Efficiency (PV)	Exergy IN	Exergy OUT	Exergy Efficiency
50.841	8.254*	8.316	19.45	1.682	0.714	7.612**	310.09	35.103	11.320
51.932	8.147	8.353	19.29	1.791	0.704	7.547	321.47	42.066	13.085
46.179	7.903	8.024	19.06	1.995	0.691	7.103	361.37	47.367	13.107
44.859	7.668	8.016	18.9	2.02	0.687	6.858	371.70	47.163	12.688
48.760	7.878	8.057	19.04	1.88	0.698	6.182	342.21	44.247	12.929
49.065	8.269	8.36	19.58	1.525	0.719	5.566	283.32	33.531	11.834
53.482	7.458	7.458	19.21	1.167	0.727	6.363	242.51	24.392	10.058
73.271	4.787	4.787	18.75	0.249	0.765	4.453	88.57	4.505	5.086

*Maximum electrical efficiency of the PVT system

**Maximum Electrical efficiency of the PV system.

The front and back temperatures of PV and PVT systems are compared in Table 3. Maximum frontal temperatures for PVT systems are reached at 70.7°C, whereas PV systems achieve 71.4°C. When compared to the temperatures at the back, the PV panel may reach 72 degrees Celsius without cooling and 49 degrees Celsius with it. The highest possible percentage of energy saved is 73.397%.

Table 3: Temperature Values of PV/T and PV

S. No.	Front Temp of PV/T (^oC)	Back Temp of PV/T (^oC)	Front Temp of PV (^oC)	Back Temp of PV (^oC)	Energy Saving Efficiency
1.	51.1	41	54.8	59	51.058
2.	56.2	44.6	58.8	64.6	52.146
3.	69.8	49.4	64.2	69.4	46.387
4.	70.4	49.8*	71.4	72.2*	45.061
5.	65.6	48.4	67.2	68.8	48.967
6.	55.6	49.6	58.2	60.8	49.283
7.	55.8	49.8	55.2	59.4	53.678
8.	35.6	36.8	36.8	40.2	73.397

*The difference between back temperatures of the PV and PVT system is 22.4^oC.

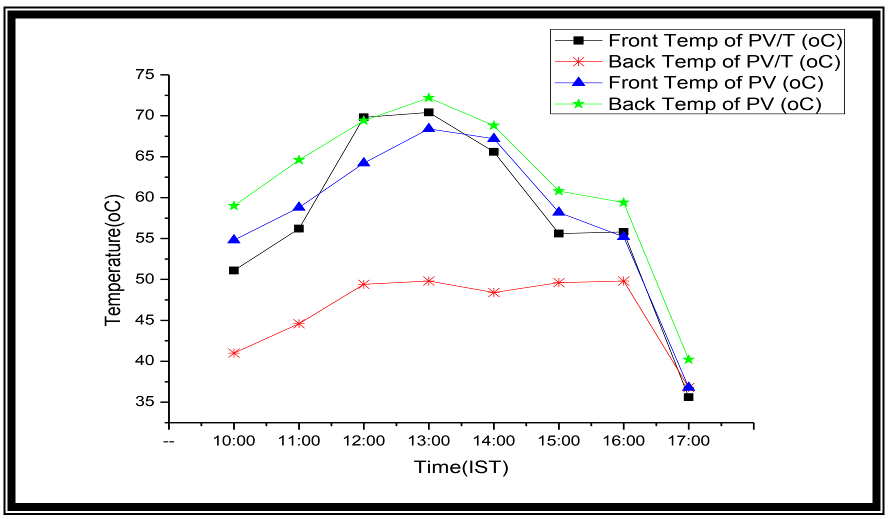

Figure 4.16: Front and Back Temperatures for PV and PVT system

The front temperatures of various cooling and non-cooling panel types are graphically represented in Figure 4.17.

The changes in temperature between the front and back PV ad PV/T panels are shown in Figure 4.16. Solar panels lose some of their energy to heat as they transfer heat to the moving water, so PV/T is less than PV.

The PV panel's rear side temperature reaches up to 72^oC, while the PV/T rear side is up to

49.8°C.

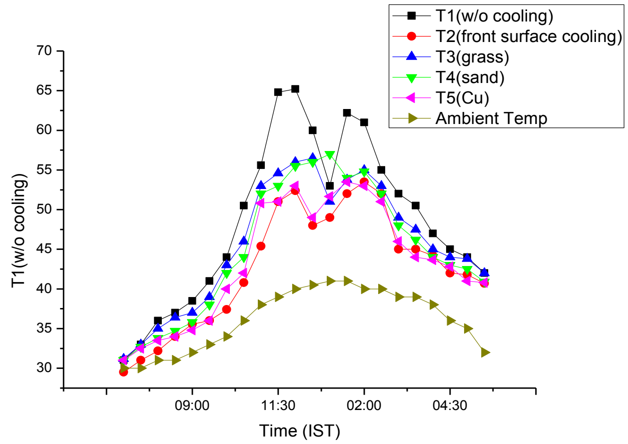

Figure 4.17: Evaluation of Front Surface Temperature for All Types of Panels

The temperature of the drain water has increased due to heat transfer from the PV/T panel. Figure 4.18 shows the difference in temperature between the arriving and departing waters.

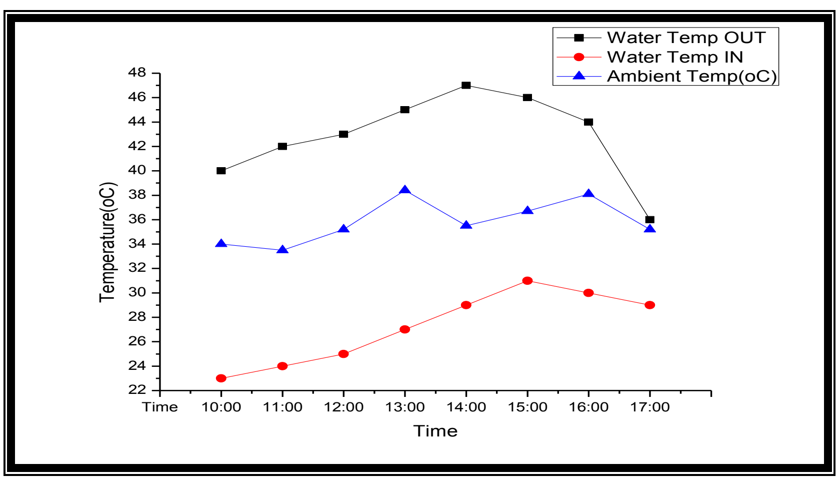

Figure 4.18: Water Temperature Varying from Inlet to Outlet

In order to increase efficiency, the input water temperature should be lowered. The intake water temperature is 29 degrees Celsius, and the final product is 47 degrees Celsius. Electrical, thermal, and cumulative efficiency of PVT are shown as a function of time in Figure 4.19. In terms of electricity, heat, and overall performance, efficiency is around 70%.

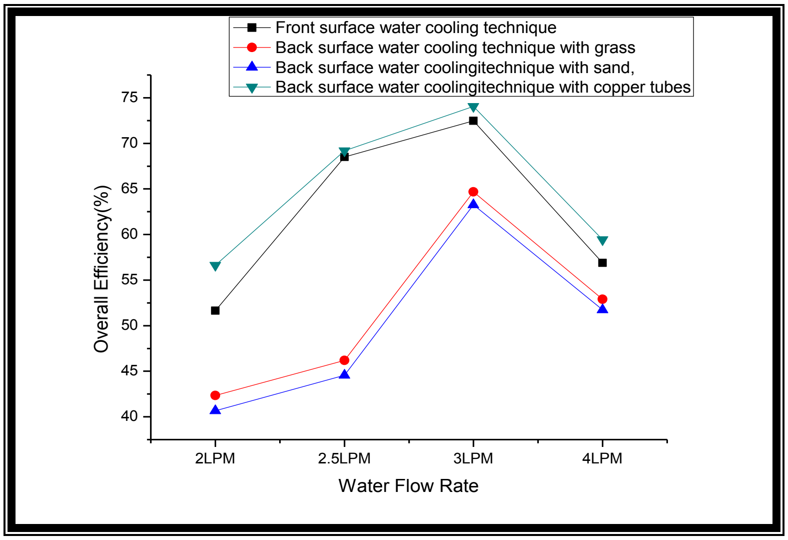

Figure 4.19: Overall Efficiency of PV/T

4.9 Conclusion

The temperature of the PV panels has a significant effect on the system's efficiency. Solar PV/T technology completely gets rid of the heat produced by solar panels. This article proposes a hybrid solar PV/T collector technique to boost energy efficiency per square foot. The experimental results show that the electrical performance of the PV module has been greatly improved by using the PV/T technology. The findings showed that the PV/T system generates more power and heat than PV alone.

What we learn from the experiments is as follows:

1) Experiments have been conducted in the open air with beginning water temperatures ranging from 2 to 4 degrees Celsius and mass flow rates ranging from 2 to 4 LPM. 2.5 LPM is the optimal mass flow rate for a PV/T collector.

2) The average PV/T efficiency is between 47% and 77% at a mass flow rate of 2.5 LPM. Maximum achievable average PV/T efficiency is 67.16% while monitoring a total mass flow rate of 2 LPM.

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