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Feasibility of using Solar PV Waste Heat to Regenerate Liquid Desiccant in Solar Liquid Desiccant Air Conditioning System

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ABSTRACT

(Hybrid Photovoltaic (PV) units are systems that produce both electrical and thermal energy in a single unit. The purpose of this research is to investigate the feasibility of using PV solar waste heat to regenerate liquid desiccant in the solar air conditioning system. A typical liquid desiccant regenerator requires a temperature range between 50˚C and 60˚C. Thus, the heat recovery system is designed on a 50W solar PV that focuses on recovering, delivering, and transferring of heat from panel PV to heat the circulating water. This paper also discusses the comparison of output power and efficiency between heat recovered and a standard solar photovoltaic panel. The calculated maximum output power for heat recovered and standard solar PV system was 52.20W and 40.15W, with an efficiency of 11.72% and 9.65% respectively. The maximum temperature for the heat recovered system was 55.10˚C at 1.00 pm and the standard system was found at 62.30˚C. The experiment results show that stored water temperature in the reservoir able to reach 55˚C, within the range of a preferred liquid desiccant regenerator. Thus, it is possible to utilise the solar PV waste heat for desiccant solution regeneration and simultaneously benefit from the added benefit of improved efficiency.

Keywords:
PV Temperature, Liquid desiccants, Waste heat, Solar panel, Cooling system

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1. Introduction

Numerous researches have been done to reduce the operating temperature of a solar PV to increase its efficiency and energy output. Proper cooling can improve the electrical efficiency, and decrease the rate of cell degradation over time, resulting in maximisation of the life span of photovoltaic modules. Usually, the heat removed from the solar panel is treated as waste heat and is rejected to the environment or is used on secondary applications such as for water heating. Solar air-conditioning using a liquid desiccant system is a possible application for solar PV waste heat utilisation. This system consists of a liquid desiccant dehumidifier unit and an evaporative cooling unit. Driving the fans pumping and regenerating desiccant throughout the regeneration process is the only energy used in this technique.

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Liquid desiccants require lower regenerating temperature, mostly in the range of 40-900C (Kassem & Alisaimy, 2013; Ghafoor & Munir, 2015). Utilising solar energy for the desiccant regeneration process can save primary energy in the operation of a desiccant air cooling system. Thermal energy, at a temperature as low as 40–500C required for regenerating of the liquid desiccant can efficiently be obtained using a flat plate collector (Nesreen, Kamel & Antoine, 2003). Low-grade energy sources can be utilised for regeneration (about 65–80°C). A solar desiccant cooling system can work with lower heat source temperatures from 60-70°C and have thermal COP over 1 (Fong & Chow, 2010). Solar desiccant cooling systems have the lowest heat source temperature and the highest thermal COP (Guo & Lin, 2017). A solar desiccant cooling prototype able to supply air temperatures as low as 11-12°C using heat source temperatures of 60-70°C provided by solar evacuated tube collectors (George & Gerald, 1988).

Several researchers (Fesharaki & Dehghani, 2011; Borkar & Prayagi, 2014; Fontenault, 2012; Sobhan, 2015) reported that the rise in PV cell temperature decreases its efficiency. Thus, solar cooling systems have been proposed (Krauters, 2004; Royne & Dey, 2005; Daghigh & Ruslan, 2011). There were many cooling techniques had been proposed from past research to overcome this overheating issue. Irwan (Irwan & Leow, 2015) tested the PV panel performance of an air-cooled solar PV and standard solar PV using DC brushless fan. The temperature of the PV panel with a DC brushless fan decrease 6.1 °C compared to the PV panel without a cooling system. While, the voltage, current and power had increased by 3.47%, 29.55% and 32.23% respectively. Catalin (Catalin & Sebastian, 2016) presented a numerical approach for temperature reduction of PV panel by using air-cooled heat sinks. The numerical model was analysed using ANSYS Fluent software for turbulent flow, and results are presented for the average temperature of the PV panel. Sobhan (Sobhan, 2015) designed and experimented with a hybrid photovoltaic/thermal (PV/T). The authors designed a parallel array of ducts with an inlet/outlet manifold for uniform airflow distribution. With the cooling mechanism, the temperature dropped significantly, leads to an increase in efficiency from 12% to 14%. It has been demonstrated that the solar PV module with the cooling system produces more energy than the non-cooling system. By using water, the temperature of the solar cells dropped by 8°C and the efficiency of the solar PV module increased by 3%. Naturally, the water cooling system has good potential in providing electricity and produce higher power output than the air cooling system (Ahmad, 2010; Colt, 2016; Sreejith & Rajesh, 2016). It shows that with the cooling system, it enhances the power generated.

The objective of this study is to investigate the probability of using solar waste heat to regenerate liquid desiccant in a solar air conditioning system thru the heating of circulated water and its effect on solar PV performance

2. Methodology

In this paper, a standard commercial PV module is converted to a hybrid PV system by adding a heat exchanger unit at its backside. This heat exchanger was designed and fabricated using copper tubes. Copper tubes are used for the fabrication of the device due to its better thermal conductivity and ease in fabrication. The copper heat exchangers are used as the waste heat recovery method to increase the temperature of water in the reservoir to a designated temperature. The components of the system include a water pump, piping, pipe insulation, copper tube, and a tank. The assembly of the copper heat exchanger on the solar PV back surface was simple and good contact was ensured to maximise heat transfer. Figure 1 shows the schematic drawing of the PV module and copper tubes assembly functioned as waste heat recovery from the solar panel.

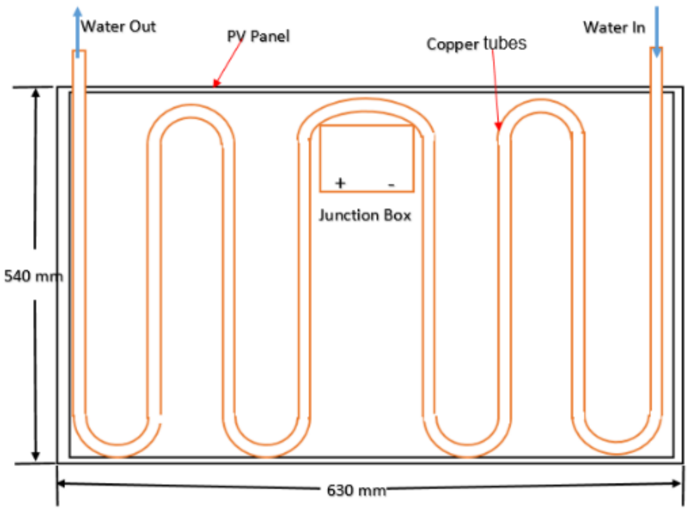


Fig. 1. Solar Panel with Cooper Pipe System

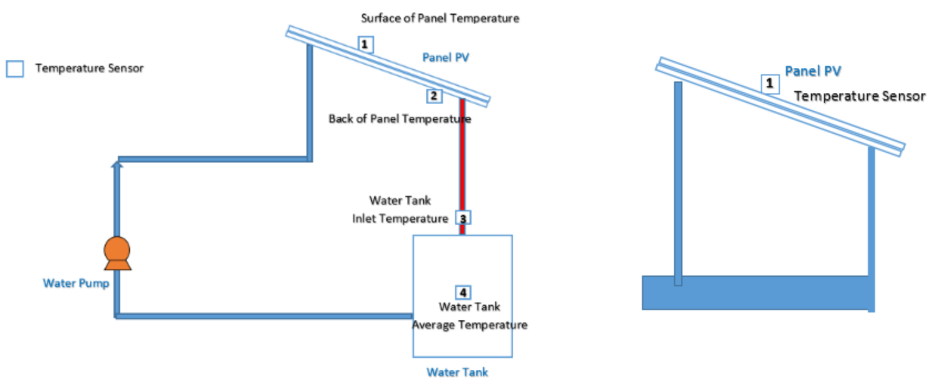
In this experiment, the PV module used was the PVM-50 (mono-crystalline silicon) with maximum power (Pmp) 50 WP, open-circuit voltage (Voc) 21.6 V, maximum power voltage (Vmp) 18 V, maximum system voltage DC 1000 V, maximum power current 2.8 A, (Imp) 2.78 A, short circuit current (Isc) 3.1 A, collector area 0.4288 m2 and size 630 mm X 540 mm x 18mm. A 20W (water flow of 0.042 Kg/sec) water pump was used to circulate the water to the tank. The water flows to the heat collector, absorbing heat from the solar PV module and produces warm water which is measured using thermocouples. Solar PV power output and efficiencies were calculated using the following equation.

The power output for PV, $P_{out} = V_{oc} \times I_{sc}$ (1)

Electrical efficiency $\eta = I_m * V_m / Apvt * G$ (2)

Thermal efficiency $\eta = \dot{m} * C_p * (T_o - T_i) / Apvt * G$ (3)

The experiment was conducted in Universiti Malaysia Sabah, Kota Kinabalu at a location of 6.0367°N, 116.1186°E (Sukarno & Abd Hamid, 2015; Sukarno & Abd Hamid, 2017). The measurement was taken for two days which was on the 26th and 28th of August 2020, from 10.00 am to 3.00 pm period. The corresponding maximum global solar radiation was 1052.9 W/m^2 on 26th August 2020 at 2 pm whereas the highest hourly average was 970.17 W/m2 at 1 pm. A 50 W mono-crystalline photovoltaic panel module PVM-50 was used in this research. RTD-PT100 thermocouple was used to measure the temperature of the solar PV module, and a 5-in-1 environmental meter was used to measure the environment temperature. All readings were recorded manually for peak PV powerpoint. Readings of the inlet and outlet temperatures, water flow rate flowing through the heat exchanger were collected, which were further used to calculate the thermal power, PV efficiency, and performance ratio of the hybrid system. The heat exchanger comprises of 12 mm diameter copper tube, 8.5 meters in length and the pitch between two consecutive tubes was set at 75 mm. In this experiment, the measurement was taken to calculate the electrical power generated and thermal energy transferred to compare the effect of heat recovery on solar PV performance and water temperature. The tilt angle for the solar panel was inclined at the 15° facing to the southern hemisphere. A similar experiment was performed simultaneously without heat recovery systems for comparison purposes as shown in Figure 2. Whereas Figure 3 shows actual experimental work done to test the waste heat recovery system.



(a) (b)

Fig. 2. Experimental Set-up of (a) Waste-heat recovery and (b) Standard System

Fig. 3. Experimental Work on Waste-heat recovery system

3. Results and Discussion

3.1 Experimental Result

The study investigates the possibility of using a solar PV waste heat to regenerate liquid desiccant in a solar air conditioning system by observing the temperature of water in the tank, inlet water tank temperature and surface panel temperature. The measure and calculated experimental data are as shown in Table 1.

Table 1
Production of Solar Panel

Technical parameters	**Performance of PV (standard solar PV)**			**Performance of PV (heat recovered solar PV)**		
	Average	**Max**	**Min**	**Average**	**Max**	**Min**
Voltage (V)	18.16	19.12	15.60	19.34	20.53	18.00
Current (A)	2.02	2.10	2.00	2.09	2.36	2.08
PV power (W)	36.68	40.15	31.20	42.36	52.20	37.44
PV Efficiency (%)	10.11	13.18	8.49	12.24	15.22	11.06
Thermal efficiency (%)				21.95	33.77	20.68
Water Tank Average Temperature (°C) #4				50.23	55.50	40.10
Top module temperature (°C) #1	53.70	62.30	43.00	46.70	55.10	38.10

3.2 Thermal Behaviour

The surface temperature of both panels gradually increased and peaked at 1.00 pm as shown in Figure 4. International Journal of Renewable Energy Research Comparing the average surface temperature of these two setups also shows the cooler surface temperature of the solar PV with a heat recovery system. The maximum temperature for the cooling system (top surface) was found 55.10˚C at 1.00 pm while the temperature for the standard (top surface) system was 62.30˚C. This shows that with the heat recovery system, it can lead to an increase in conversion efficiency and power output of PV cells due to the reduction of the panel temperature.

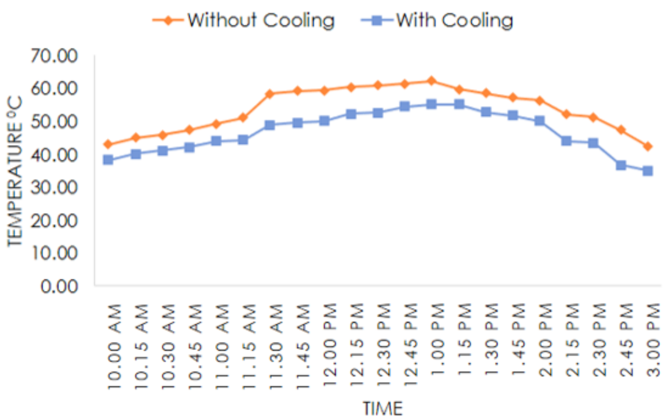


Fig. 4. Surface Temperature of Solar PV

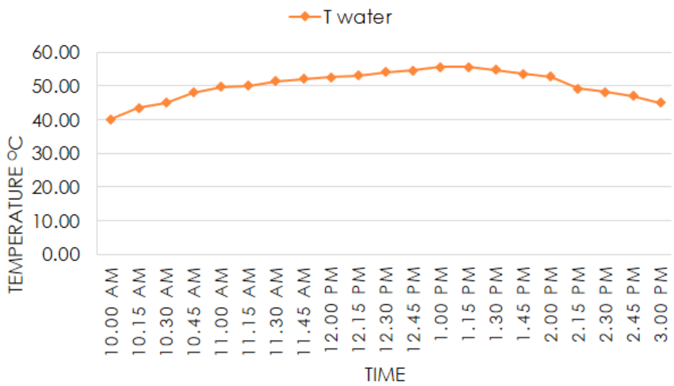


Fig. 5. Water Temperature in The Tank

The temperature in the tank is as shown in Figure 5. The water temperature inside the reservoir initially starts at 40.10˚C early in the day and gradually increases to 55.5˚C. This is the result of heat recovery from the solar PV waste heat and it shows a stable profile before going down towards the afternoon. The average thermal efficiency for the heat exchangers was calculated at around 21.95%. The temperature achieves indicates that the waste heat recovery from a solar PV system is capable of being used to regenerate the liquid desiccant solution in a liquid desiccant air conditioning system.

3.3 Electrical Performance

Measured power output shows both panels generate power gradually in the morning and decrease in the afternoon due to the variance of solar radiation as shown in Figure 7. The power generated by the solar PV system with a waste heat recovery system produces better power output compared to the standard configuration and thus better efficiency as shown in Figure 8. This is expected as the cooler surface temperature would translate to better efficiency with maximum efficiency recorded at 15.22%. The total power produced by the system with a cooling PV panel is 261.43 Wh/d and a non-cooling PV panel is 212.76 Wh/d.

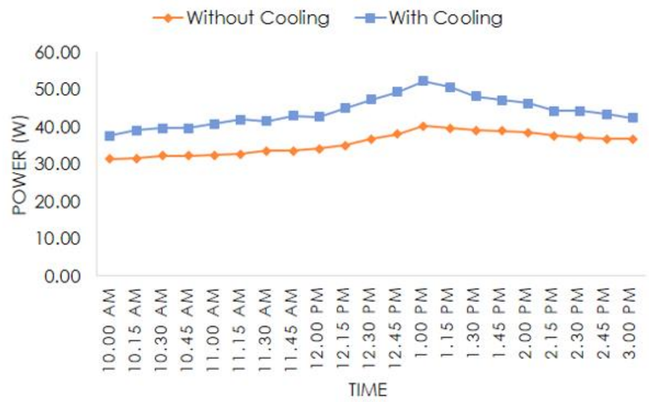


Fig. 7. Power Output of Solar PV System

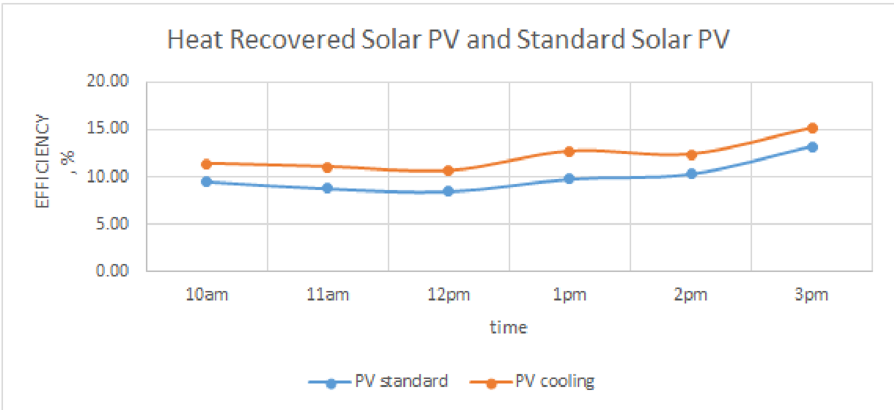


Fig. 8. Efficiency of Solar PV system

4. Conclusion and Recommendation

In this study, a waste heat recovery system for a 50Watt solar PV was designed, fabricated and experimentally analysed. The experimental result shows that waste heat from solar PV was able to increase the temperature of the circulated water by 15.50°C and remain stable at 55.50°C. The temperature gained indicates that it is possible to use this setup to regenerate liquid desiccant solution for solar air conditioning system, which requires a minimum temperature of 40°C - 70°C to function effectively.

Waste heat recovery on solar PV also reduces the average operating temperature of the solar PV resulting and improvement in efficiency and power output. The maximum power output for the solar PV with heat recovery was 52.20 W while the standard solar PV was able to achieve 40.15W. Furthermore, this will benefit the system in terms of improved longevity and durability of the system.

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