Experimental Study of Solar Photovoltaic/Thermal Energy System Assisted with PCM and Nanofluid for Enhanced Power Generation in Oman

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Introduction

The development of renewable energy sources has accelerated in recent times, primarily due to the concerning climatic changes resulting from the depletion of traditional fuel reserves. In recent times, solar photovoltaic technology has garnered significant attention among various clean energy sources, primarily due to the lower cost of solar cells compared to alternative clean energy options. Solar photovoltaic is projected to be the most significant renewable energy source globally. In line with Oman Vision 2040, solar photovoltaic systems have been growing in the country. Increased cell temperatures, which reduce solar PV efficiency, are the primary cause of performance degradation in solar photovoltaic systems.

Research aim and objectives

This research main objectives are:

1. To study the performance of solar PV/thermal system in Al Seeb's climate.
2. To investigate factors affecting solar PV/thermal system in Al Seeb Oman.
3. To study water flow effects of cooling on the PVT system.
4. To investigate the effects of PCM on the PVT system's performance.

Literature Review (Summary of recent studies)

1- Factors affecting solar energy

Environmental factors, tilt angle, and temperature variations all affect solar cells (Adeeb et al., 2019). External factors reduce the light transmittance on solar panel surfaces, which causes a decrease in the efficiency of the solar panels in generating energy. Solar panels were set up at angles of 0, 15, 30, 45, and 60 for a month (Elshazly et al., 2021). The declines in energy production were 17%, 10%, 25%, 27%, and 30%, respectively. An excessive amount of heat can significantly lower efficiency (Chala et al., 2024).

2- Effect of manual cleaning on photovoltaic panel

Climate and human cleaning practices are the main factors influencing solar panel performance, as they can cause chips and scratches to accumulate on the panels' surface (Khalid et al., 2023). The panels generate 18% more energy than a manually cleaned panel. The surface corrosion of PV modules is typically made worse by environmental problems. The process of converting air gas into molecules on cell surfaces and building membranes is carried out by fungi and algae (Toth et al., 2018).

3- Use of SiO2 as a nano-photovoltaic material

SiO2 was used as a nano-photovoltaic material in an experiment on the surface of PV solar cells since it is a hydrophobic substance (Alamri et al., 2020). It raised the overall percentage of energy-covered panels by up to 15% and 5% as compared to panels that have accumulated dust.

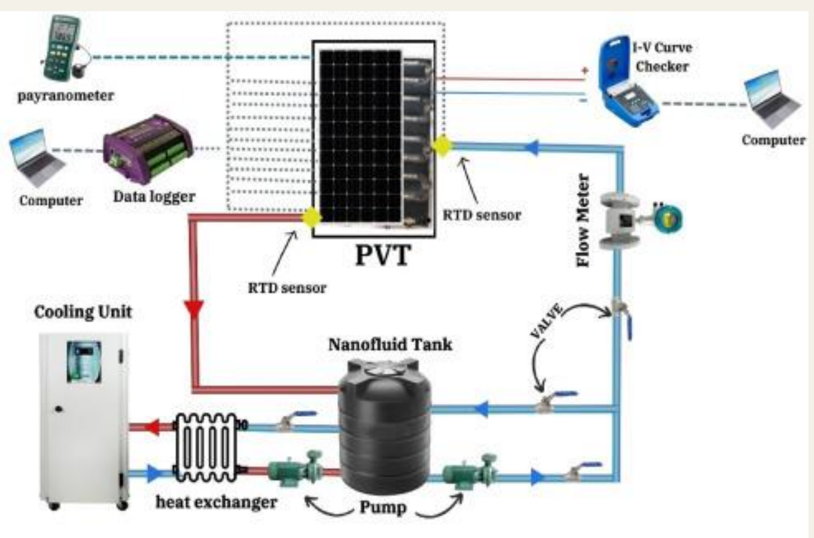

Figure 1: Solar PV Thermal System

4- Using photovoltaic energy to produce green hydrogen

Ahsan et al., 2021 studied the financial and technological ramifications of producing green hydrogen in the Sultanate of Oman using solar photovoltaic electricity. The study covers fifteen distinct locations in Oman with sizable (2000 kW) solar facilities. Thumrait is the most efficient place to produce green hydrogen, according to the study, with the chosen solar power plant generating 62,557 kg annually.

Methodology

This research investigates how PCM and nanofluids may enhance the performance of PV/thermal energy systems using an experimental methodology. Photovoltaic and solar thermal are combined as a co-generation system as the setup is developed. Phase change material are incorporated into the design of the experimental system to store energy.

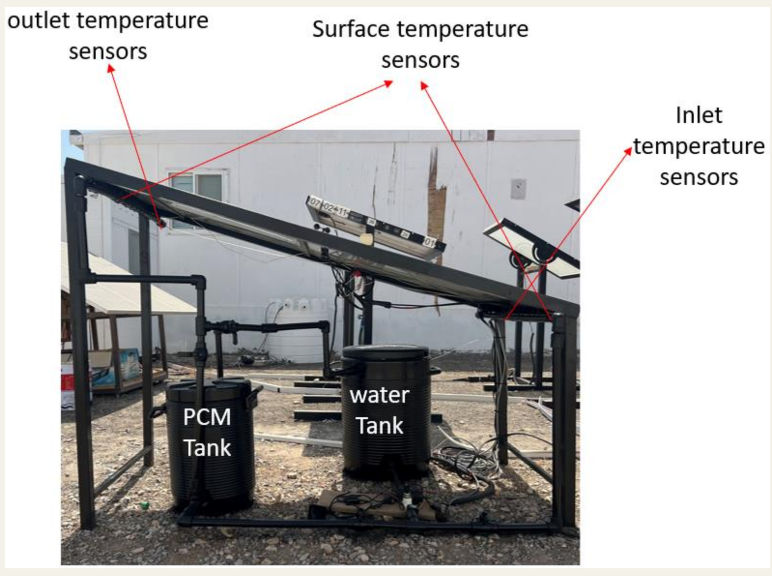

Figure 2:The PVT experimental setup from the front, displaying the pipe and tank configuration.

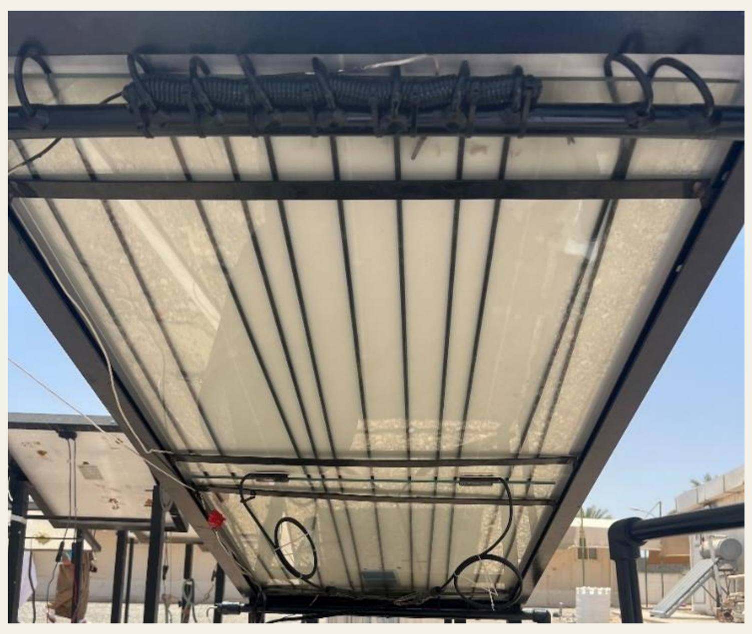

Figure 3: Flow Pipe Layer with Glass Covering (Behind PV Panel)

Formulas Used

a) temperature-adjusted efficiency

$$\eta_{(T)} = \eta_{ref} \times \left[1 - \beta \times (T - T_{ref})\right]$$

b) Efficiency Calculation at Standard Test Conditions (STC):

$$\eta_{ref} = \frac{P_{max}}{G \times A} \times 100$$

Table 1: Specification of solar panels

Parameter	Value
Maximum Power (Pmax)	280W
Maximum Power Current (Imp)	12.95A
Maximum Power Voltage (Vmp)	21.63V
Open Circuit Voltage (Voc)	25.82V
Short Circuit Current (Isc)	14.00A
Max Series Fuse	25A
Max System Voltage	1500V
area of the solar panel	6. m^2

RESULTS AND DISCUSSION

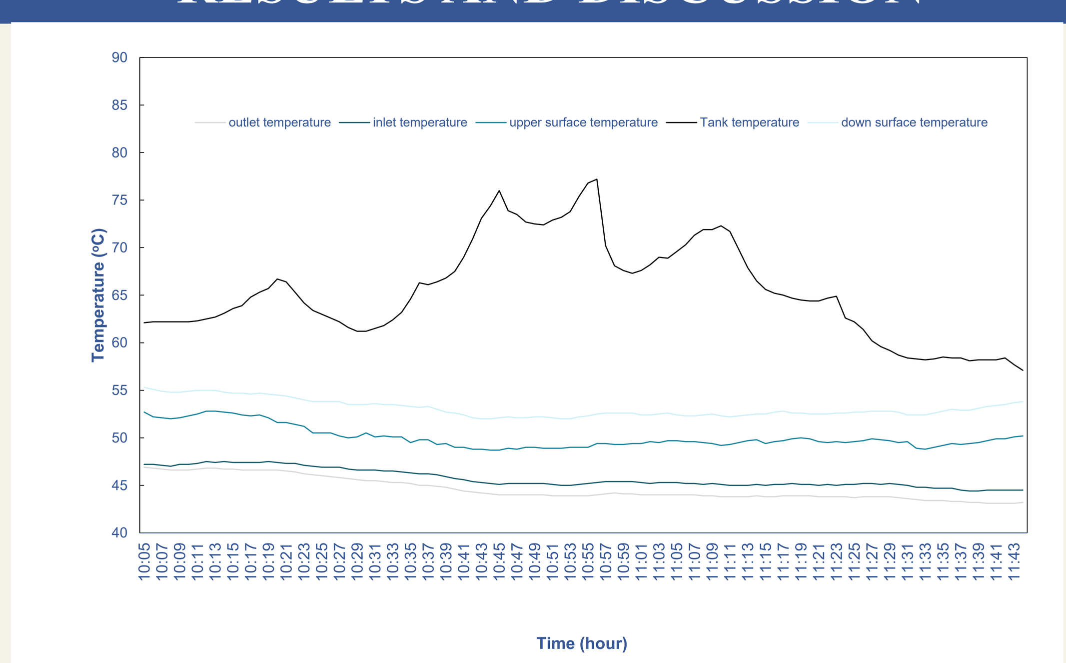

Figure 4: Temperature distribution (PV, tank, inlet, outlet) under no flow condition.

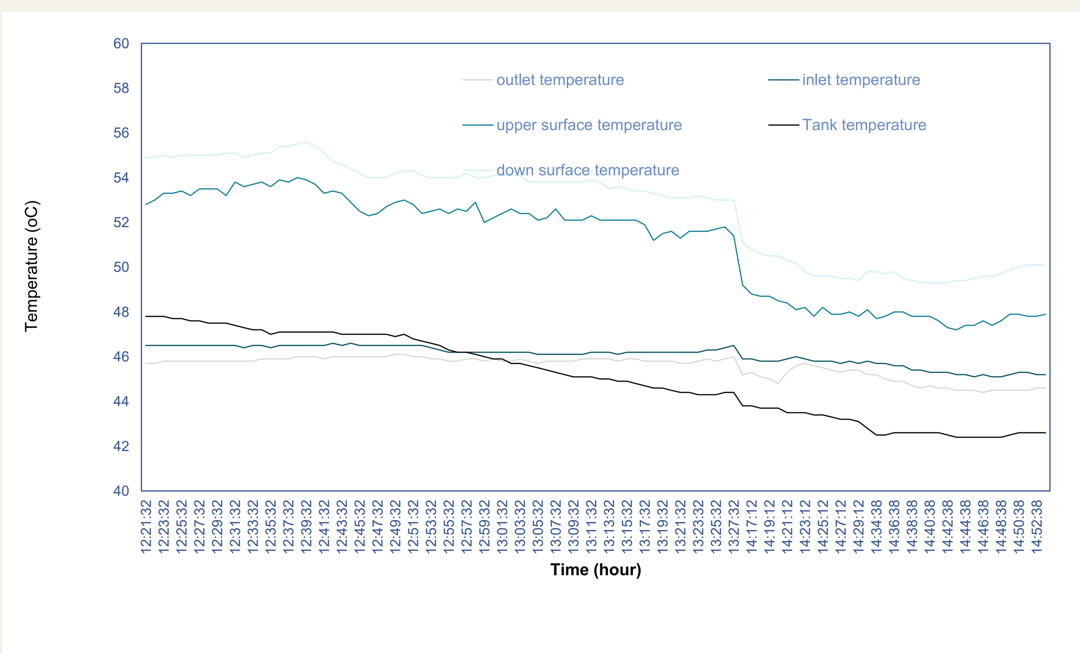

Figure 5: Temperature distribution (PV, tank, inlet, outlet) under Water Flow with Full PCM Tank

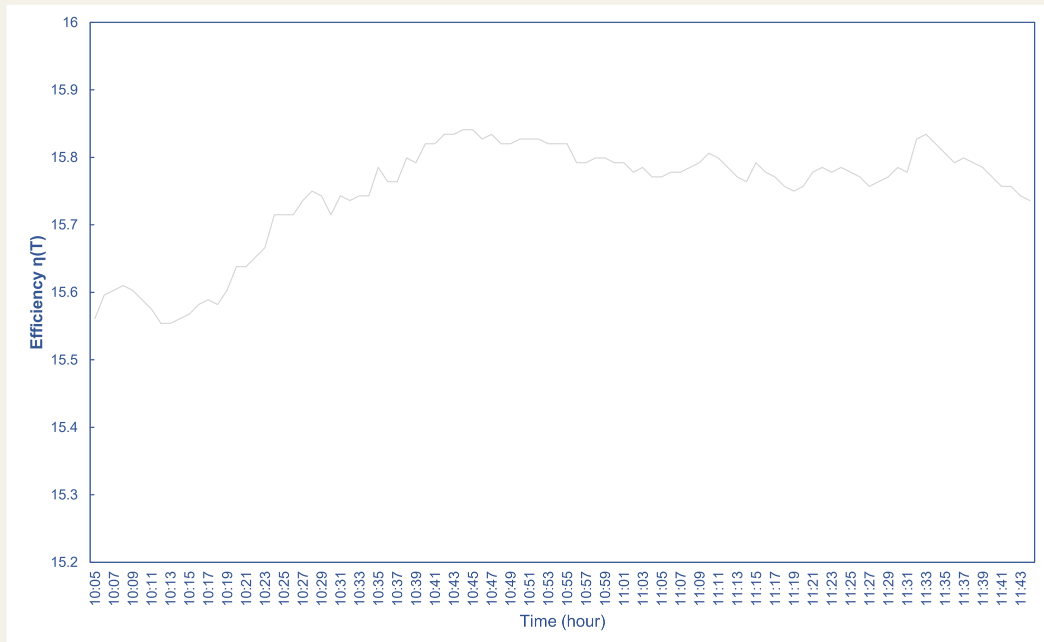

Figure 6: Efficiency vs Time for PV - Case 1: No fluid flow

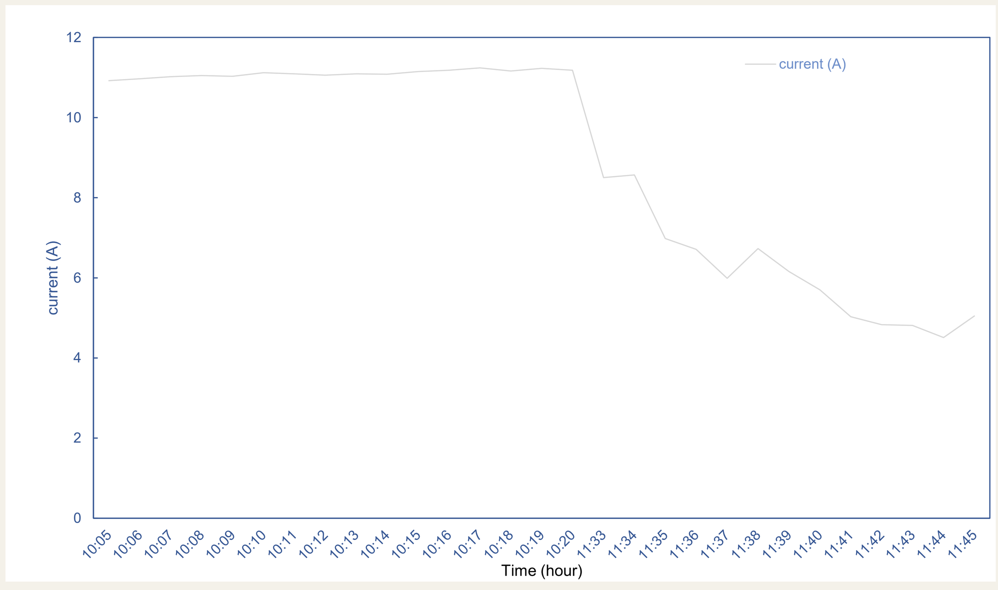

Figure 7:Current (A) changes over time in the absence of flow.

Table 2: Average observed Efficiency

Case	Cooling Method	Observed Efficiency Trend
Case 1	No Flow	Decreasing
Case 2	Water Flow	Slightly stable
Case 3	Water Flow + Limited PCM	Stable, moderate improvement
Case 4	Water Flow + Full PCM	High and stable

Conclusion

In conclusion, the incorporation of nanofluids and phase change materials (PCMs) in Photovoltaic Thermal (PVT) cells signifies a groundbreaking approach to enhancing solar energy conversion and thermal management systems. By exploiting the unique properties of nanofluids to improve heat transfer efficiency and leveraging the energy storage capabilities of PCMs, significant strides can be made in optimizing the performance of PVT technology. This innovative synergy not only enhances the conversion of solar energy into electricity but also facilitates efficient thermal regulation within the system. The integration of nanofluids and PCMs in PVT cells represents a promising strategy for achieving enhanced energy efficiency, increased power generation, and improved sustainability in solar energy applications. As research in this field progresses, the practical implementation of these advanced materials holds immense potential for revolutionizing PVT technology, paving the way for more efficient and sustainable solar energy utilization.

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