

## Overview on recent photovoltaic module cooling methods: advances PVT systems

Nurul Shahirah Binti Rukman<sup>1</sup>, Ahmad Fudholi<sup>2</sup>, Ivan Taslim<sup>3</sup>, Merita Ayu Indrianti<sup>4</sup>,  
Intan Noviantari Manyoe<sup>5</sup>

<sup>1,2</sup>Solar Energy Research Institute, Universiti Kebangsaan Malaysia, Malaysia

<sup>3,4</sup>Universitas Muhammadiyah Gorontalo, Indonesia

<sup>5</sup>Universitas Negeri Gorontalo, Indonesia

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### ABSTRACT

Renewable energy had been monopolized the research area in these past decade up till nowadays, due to its reliability and future in global production of electrical and thermal energy. Narrowing down the scope to the photovoltaic thermal (PVT) system, lots of improvements had been implied both theoretically and experimentally. One of the most attractive applications of PVT water or air-based collectors is building integrated photovoltaic thermal (BIPVT) system, which has undergone rapid developments in recent years. This review paper comprises the research findings on the improvements that had been integrated by PVT systems as well as well as personal and cited remarks on advancements on cooling techniques on PVT system.

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### Corresponding Author:

Ivan Taslim,

Universitas Muhammadiyah Gorontalo,

Email: ivantaslim@umgo.ac.id

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## 1. INTRODUCTION

The dependence of human on technologies and augmented living ideals certainly lead to the rise of energy needs. Hence, as the energy demands needs to be fulfilled, consumption of fossil fuels is growing, resulting lots of climate and environmental issues [1-5]. The necessitate today kept flowing, expanding 2.4% annually, interest in renewable technologies which are growing fast [6]. In addition, rising concerns over climate change, environmental sustainability and security of supply have exerted pressure towards initiating reformation in the energy sector. Global efforts had focused on a transition towards sustainable energy provision. A substantial change in the global perceptions of renewable energy has been observed since 2004 and it has shown that their potential is achievable. Renewable energies had been improving and many technologies are at par with conventional energy generation technologies. There are lots of studies had been conducted on the energy demands which can be concluded in order to recognize on how the demands had contributed to the society, surroundings and the economy of one self's country. Solar energy is one of the sustainable energy which promises clean energy production. Regarding to limited conventional fuels, the implementation of solar technology is going into great advancement as one used to produce electrical energy using photovoltaic (PV) solar system. Furthermore, thermal energy can be generated which by utilizing working fluids in an integrated cooling system of PV; known as photovoltaic thermal (PVT) system. PV solar panel is a PV power generation system composes with series of silicon cells, interconnected and then joining together forming a circuit. PV solar panel results higher power output as the higher solar irradiances relatively absorbed. However, cloudy days will contribute to a decrease in sunlight absorption. It is because the clouds reflect some of the rays of sunlight and limit the sun absorption by the panels. An issue involving higher solar absorption which will also results to high temperature of solar panel itself,

resulting the efficiency of the panel in generating energy to decrease. This problem of efficiency's deficiency led to the improvement of solar energy technology, which the PVT solar panel had been introduced which had been advantaged as the one that can produce hot water with the same time as electricity as the system's operation is at lower temperature. The PVT system had improved the electrical deficiency of the PV system as heat from the panel had been extracted. The studies on PVT system had been anticipated by lots of researchers which intended to study on how it can contribute its performances in generating both electrical and heat energy [7-26].

Further theoretical approaches had been done such for the use of nanofluids as coolants as had been carried out by Mustafa *et al* [27] which a theoretical model was performed to evaluate system's performance while studied numerically a new configuration of the PVT system which includes the collector tube and working fluid. In this writing, it will be focusing on the advancements of cooling techniques with the employment of nanofluid, phase-change material (PCM) and heat pipe in PVT system.

## 2. CLASSIFICATION ON PV COOLING METHODS

These past years had discovered lots of researches on the advancements in the technology of solar energy in order to establish reliable energy source. The focuses in the studies can be classified into on how the improvements had been worked on the cooling system design and the working fluid used as the coolants for the systems of PVT solar collector.

By recognizing the abilities and contributions of PV system to one's country, tremendous research and study had been conducted in order to attain most advancement which may produce reliable and sustainable PVT system. The cooling system's design referred to the design of the absorber which mostly focused on water and air PVT solar system. Foremost, for air-based system had been developed through different absorber configurations, the air flow mode and using single or double pass design [28]. An optimization on single and double pass PVT system had been designed by Sopian *et al.* [29] which the performances had been analyzed for both the cases with varied flow rate of air as well as packing factor, collector length and duct depth. The study had concluded that the thermal efficiency generated by double-pass system was higher by 8% as it produced 32-34% compared to single-pass which produced 24-28% while the combined efficiency for double-pass also higher than the single-pass system, producing 30-35% and 40-45%.

As shown in Figure 1, PV cooling methods can be categorised into two types are: (i) base on cooling system's design, and (ii) base on type of coolants. PV cooling method using fluid such air, water, bifluid (air+water) known as conventional photovoltaic thermal (PVT) systems. PV cooling method using phase change material (PCM), nanofluid and heat pipe known as advances PVT systems.

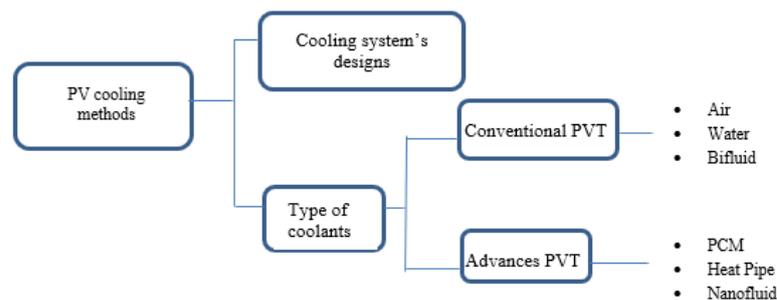


Figure 1. Classifications of PV cooling methods

## 3. PVT SYSTEM WITH PCM

The integration of phase change material (PCM) to the PVT system often related to the employment of it along nanofluids which acted as coolants. PCM acts to store heat energy. It absorbs sensible heat sensibly until it reaches melting temperature [30]. PCM has been engaged with nanofluid-based PVT to control heat capacitance of the system. This purposed to maintain electrical efficiency and to increase the overall efficiency in the same operation time. Higher efficiency had been attained by employing nanofluid due to the establishment of high thermal conductivity [31].

Delisle and Kummert [32] also stated the validation in assuming that more improvement of the PVT systems can be done by applying different design structures besides employing various materials. However,

in the same time, they must be within an acceptable amount as to avoid cause poor costs of energy or extended pay-back periods. Beforehand, there were also more advance research in applying PCM as the coolant for PVT system. There were lots previous and current study on preparation, characterization, properties and applications of nanofluids. One had been conducted by Devinderan and Amir [33] where focusing on preparation of metal, metal oxides nanofluids and hybrid nanofluids as well as the methods applied in studying the features of them, both physically and chemically.

An outlook had been conducted which focused on the uses of PCM for PV module thermal regulation and electrical efficiency improvement. Throughout the research, it can be described that the system may not be practicable in economical term to enhance PV conversion efficiency as the main requirement [34]. Beforehand, an indoor analysis as well as computational study had been carried out by Jay *et al.* [35] which focusing on the performance of PV-PCM system. A honeycomb structure made up of aluminum was used to capsule the PCM which purposed to boost heat conduction. From the study, it was reported that there was improvement of about 18% in electrical efficiency compared to the stand alone PV panel.

An experimental study had been done by Huang *et al.* [36] which validated numerical model of PV/PCM. The analyzed system designed by with and without fins, integrating with RT25 and paraffin wax used as PCM. It was confirmed that, the employment of designing fins to the system was significant on thermal management of PV/PCM. Meanwhile, the effect of PCM thickness on the temperature reduction of the panel module by Indartono *et al.* [37] had led to an observation of attaining optimum PCM thickness based on CFD simulation results among three PCM thickness. The optimum thickness was 80 mm among the three thickness variables which were considered.

#### 4. PVT SYSTEM WITH NANOFLUID FLOW

A theoretical study had been conducted by Tyagi *et al.* [38] with the presence of aluminum/water nanofluids had been implied on direct absorption solar collector and the performance of it was being compared to conventional flat plate solar collector. The studied system involved enclosed space of fluid channel which in the same time, the bottom surface was perfectly isolated. It was also equipped with a transparent glass and it was concluded that small amount of solar irradiance, lost by scattering or transmission through the glass cover. Meanwhile, the major amount of it absorbed by the nanoparticles and converted into useful heat.

A research on direct absorption solar collector by utilizing nanofluids made from different nanoparticles also had been investigated by Otanicar *et al.* [39] in which they were carbon nanotubes, graphite, and silver. This had resulted an improvement in the collector efficiency up to 5% by utilizing nanofluids as coolants and in the meantime, the using nanofluids has a reduced reflectance as it acted as volumetric based absorption medium. Hence, the absorbance of heat had been increased which was higher paralleled to the surface based absorption.

Besides, thermal performance of a densely packed PV cells cooled by  $\text{Al}_2\text{O}_3$ /water nanofluid based cooling system also had been conducted by Xu *et al.* [40]. Lee *et al.* [41] proposed a theoretical study on the feasibility of using plasmonic nanoparticles in which it was suspended in water of direct absorption solar collector in order to improve broad-band solar thermal absorption. Khanjari *et al.* [42] also had presented a theoretical study on the performance of PVT system, focusing to the effects of utilizing Ag/water and Alumina/water nanofluids as working fluids. The results had been shown that the thermal efficiency and the heat transfer coefficient improved by increasing volume fraction of the nanoparticles. By comparing to the pure water, 12% and 43% of maximum increment of heat transfer coefficients for alumina/water and Ag/water nanofluids were obtained.

Sardarabadi *et al.* [43] also had investigated and compared the effects of using purewater and silica/water nanofluids on PVT units. Two different concentrations had been prepared and tested at constant optimum mass flow rate, with a tilt angle of  $32^\circ$ . Through economical assessment on both of nanofluids preparation and silica/water nanofluid suspension, PVT system's performances and exergy assessment of system had been improved. A study by Yun and Qunzhi [44] had employed film of Magnesium Oxide (MgO)/water nanofluid of different concentrations on top of PV cells. The evaluation of the system proved that the thickness of the film had influenced the system's output. Both energy efficiencies had been decreased at fixed light irradiance when thicker film had been used.

#### 5. PVT SYSTEM WITH HEAT PIPE

Integration of heat pipe guaranteed high thermal conduction, allowing transfer of heat almost without any temperature drop. Gang *et al.* [45] had investigated on heat pipe PVT system which this system

can be applied in cold states without worrying that it may freeze compared to the conventional water-based PVT system. Beforehand, a study in 1995 had confirmed that the thermal efficiency of a heat-pipe collector is comparable with that of a water based solar collector [46]. The implementation of heat pipes in solar collectors had preventing the freezing and backflow of the working fluid during night time. Hence, more stable operating conditions had been achieved [47].

Yang *et al.* [48] conducted a study of heat pipe which sodium was used as coolant. It had been concluded that the inclination angle and heat input influenced the thermal performance. The system had been able to exhibit good temperature uniformity and excellent thermal conductivity. Beforehand, in an investigation conducted by Boo *et al.* [49] on loop heat pipes filled with different ratios of sodium. They concluded that the fill ratio has an effect on thermal resistance, effective thermal conductivity, startup time and as well as isothermal characteristics.

Xia *et al.* [50] probed the impacts of the PVT module size on its performance in heating dominated residential building. The ideal PVT collector size for conducted research had been persisted through an economic analysis. The high initial investment caused the short-term economics even increasing the significance of the system's main design parameters optimization. Recent advance study on this heat pipe implementation had been carried out by focusing on designing optimization plan for ground source heat pump systems which was integrated with the PVT collectors. The study gap on the design optimization of hybrid ground source heat pump systems had been governed and computationally comprehensive [51].

## 6. CONCLUSION

PVT solar system had been such a demand during this recent years. Though, it can still be assumed that, the commercialization of this technology in being employed by the industries and communities, are still in trial stage. There are also much factors and main point that can be discussed such as the classification of solar collectors and as well as the gap or some boundaries to the implementation of them in the PVT solar system. By focusing on employment of nanofluids, PCM and heat pipe, even they promised better performances of PVT system, the advancements are still in the mid of lacking in discovery and cost of technology it self. As had been recommended and concluded for upcoming study on PVT, the first is to emphasize its thermal insulation and assess this improvement with the conventional model and by further studies alongside with the sensitivity analysis. Lastly, the PVT's operation in pairing with a liquid to liquid heat pump need to be focused on and by that, potential of PVT module in generating energy can be assessed.

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## BIOGRAPHIES OF AUTHORS



**Nurul Shahirah binti Rukman**, graduated in bachelor degree of Applied Physics from Universiti Sains Islam Malaysia (USIM) 2017. Focusing on PVT energy generation during her final year study had influenced her to further the study of PVT technology system. Currently, has been under supervision of Dr Ahmad Fudholi for her Master degree (Renewable Energy), on exergy-environmental-economic analysis of bi-fluid PVT system.



**Ahmad Fudholi, Ph.D, M.Sc** obtained his S.Si (2002) in physics. He was born in 1980 in Pekanbaru, Indonesia. He served as was the Head of the Physics Department at Rab University Pekanbaru, Riau, Indonesia, for four years (2004–2008). A. Fudholi started his master course in Energy Technology (2005–2007) at Universiti Kebangsaan Malaysia (UKM). After obtaining his Master's, he became a research assistant at UKM until. After his Ph.D (2012) in renewable energy, he became postdoctoral in the Solar Energy Research Institute (SERI) UKM until 2013. He joined the SERI as a lecturer in 2014. He received more than USD 400,000 worth of research grant (16 grant/project) in 2014–2018. He supervised and completed more than 30 M.Sc projects. To date, he has managed to supervise nine Ph.D (seven as main supervisors and two as co-supervisor), one Master's student by research mode and one Master's student by coursework mode. He was also an examiner (five Ph.D and one M.Sc). His current research focus is renewable energy, particularly solar energy technology, micropower systems, solar drying systems and advanced solar thermal systems (solar-assisted drying, solar heat pumps, PVT systems). He has published more than 120 peer-reviewed papers, of which 37 papers are in the ISI index (more than 25 Q1, impact factor more than 4) and more than 80 papers are in the Scopus index. He has published more than 80 papers in international conferences. He has a total citations of 1225 and a h-index of 17 in Scopus (Author ID: 57195432490). He has a total citations of

1684 and a h-index of 21 in Google Scholar. He has been appointed as reviewer of high-impact (Q1) journals. He has also been appointed as editor of journals. He has received several international awards. He has also been invited as speaker in the Workshop of Scientific Journal Writing: Writing Scientific Papers Steps Towards Successful Publish in High Impact (Q1) Journals. He owns one patent and two copyrights.



**Ivan Taslim, S.Si, M.T** from South Sulawesi, Indonesia. He graduated with the M.T in Geology Engineering from University of Hasanuddin in 2014. In 2015, he joined as lecturer at the Department of Geography, Faculty of Science and Technology, University of Muhammadiyah Gorontalo. His main areas of research interest are Management Risk Disaster, Geospatial Data Science and Climate Change with no limited to Renewable Energy. He is currently one of the researchers from USAID SHERA who focuses on developing and using renewable energy in Indonesia. Currently, he is entrusted to work with the Gorontalo Regional Government as a staff in the field of Climate Change and Disaster Mitigation.



**Merita Ayu Indrianti, S.P., M.P** from Banjarmasin South Borneo, Indonesia. She graduated in Agriculture from University of Hasanuddin in 2016. She has working as a lecturer at the Department of Agriculture University of Muhammadiyah Gorontalo since 2014. Her main areas of research interest are Socio-Economic in Agriculture, Biomass and Biogas energy and Integrated Farming System for Food Security. In her career, she had served as secretary of the Agricultural Study Center (2015) and secretary of the Agribusiness study program (2016) in Department of Agriculture.



**Intan Noviantari Manyoe, S.Si, M.T** from Gorontalo, Indonesia. She was born in 1982, and graduate from University of Hasanuddin with a degree in Geophysics and have a masters in Geology Engineering in 2014. She is working as a lecture at the Department of Geology also Head of Geology Engineering Laboratory at University State of Gorontalo. Her main areas of research interest are Geophysics, Tectonic, Volcano and Geothermal.