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LIQUID COOLING TECHNIQUES OF PHOTOVOLTAIC CELLS: A BRIEF REVIEW

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Abstract

The main issue with solar panels is their efficiency; while being a sustainable energy source, its diminishing efficiency significantly impacts its advantages. As the surface temperature of the PV panel rises, its efficiency falls. Absorbed sunlight converts to heat, resulting in a rise in temperature on the panel's surface. As a result, the solar panel's power output it's energy productivity, and life expectancy is decreased. Many scholars across the world are experimenting with various cooling solutions to solve this problem. Liquid cooling and air cooling are the two most common cooling methods. This paper covers advanced and efficient liquid cooling methods to provide a better understanding and to aid researchers who wish to pursue, develop, or optimize any form of liquid cooling technology.

Keywords: Advance PV cooling methods, Liquid cooling, Immersion cooling, nanofluid, forced water circulation, heat pipe, heat exchanger, hybrid cooling;

1. Introduction

The use of renewable energy during this increase of human population and environmental problems becomes well known. The most essential source of non-conventional energy, many researchers have an interest around the world to use this source. This solar energy generates two types of energy: electrical energy used for electricity and thermal energy which is the loss of heat. The Photovoltaic cells are used to produce or generate electrical energy. These PV panels directly transformed the small solar irradiance into electrical energy, which is most effective, viable, and harmless to the environment, and the rest of the solar incident transformed into heat energy which is the most essential reason of rising in temperature of panel and decrease the effectiveness and performance of the solar panel. For this reason, the present study looks at reviewing factors affecting the PV module's efficiency and the types of cooling methods (active and passive cooling) to take out the heat from the PV panels and increase the performance and effectiveness of PV modules.

Modes of cooling:

Active cooling: - The technologies that rely on an external device to improve the heat transfer are known as active cooling. Active cooling necessitates the use of a coolant, such as air or water, as well as the use of fan or pump power.

Passive cooling: - In this cooling is done without the use of any external devices, naturally heat transfer is achieved. It relies on the natural convection process to remove the heat from PV cells.

2. Types of Liquid cooling methods:

I. Water Spray Method:

Water spray falls under a functioning cooling strategy. Nizetic et al. [1] assessed the impact of water spray cooling on the exhibition of a PV board in a high sun-oriented illumination condition in a testing climate. A sum of twenty spouts, ten on each side, we're utilized to cool the two sides of the PV board simultaneously. The discoveries were contrasted with a non-cooling case for three elective cooling cases: front side cooling, backside cooling, and the two sides joined. As indicated by the discoveries, water splash cooling decidedly affects PV board execution. The most ideal situation is synchronous cooling of the front and back sides of the PV board. At long last, the water shower cooling framework impacted the PV board execution.

Abdolzadeh et al. [2] explored the impact of water spray cooling on the exhibition of photovoltaic water siphoning in a test set. In the test, two modules with 25 lit/h/module water shower were assigned the case, sometimes three modules with 5 lit/h/module and 25 lit/h/module water splash were known as the case 'B1' and case 'B2,' separately. The module temperature was decreased in cases A and B1, with case A seeing a more noteworthy drop than case B1. The testing discoveries showed that showering water on the PV module impressively expanded framework execution.

Irwan et al. [3] utilized a water-cooling way to deal with exploring the presentation of a PV board. A sunlight-based test system with twenty 500 W halogen bulbs was utilized to lead within the test. The test was directed utilizing two 50W monocrystalline PV boards. The front surface of one of the boards was connected to a DC water siphon, and the other board was filled in as a baseboard. The working temperature of the PV board with the water-cooling framework was diminished by 5-23°C, while the power creation rose by 9-22 percent, as indicated by the testing information.

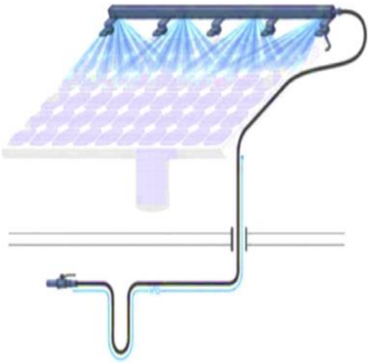

Figure 1 Perspective of water spray on PV panel [4]

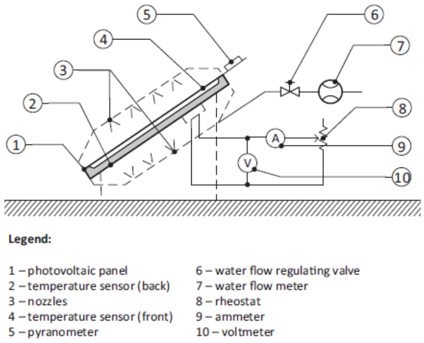

Figure 2 Schematic asyout of the specified experimental setup [1]

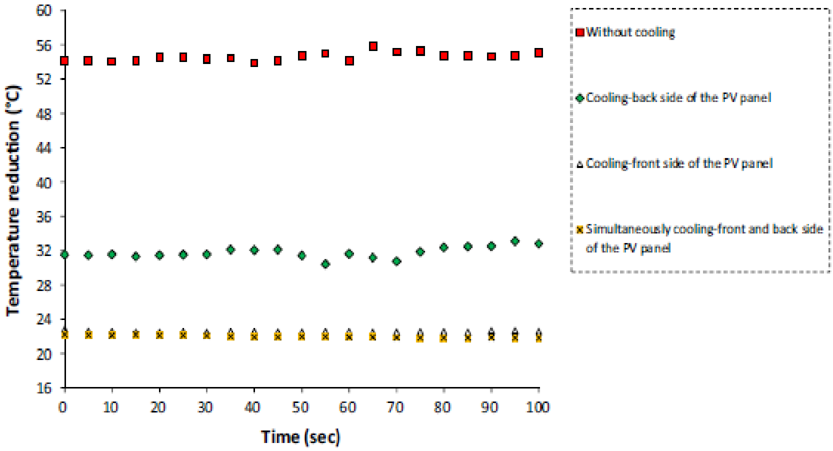

Figure 3 PV panel temperature reduction (difference) for different coolingregimes in the period of highest solar irradiation levels [1]

Table 1: Summary of water spray cooling technique [1]

Researcher	**Type of cooling system**	**Cell temperature**	**Electrical parameters**	**Key findings**
Nizetic et al.	water spray cooling	Average panel temp. recorded= 24.7 °C	Effective increase in power output = 6.6 % and increase in electrical efficiency by 3.6%	The panel temperature was reduced from 52°C to 24°C
Abdolzadeh et al.	Water spray with water pumping system	Panel temp reduced to 11.7°C	Effective increase in power output = 12.35 % and increase in electrical efficiency by 5.11%	Panel temp decreased and efficiency is increased
Moharram et al.	Spraying with minimum water	An average of 2.4°C drops per minute is noted	--	Average cooling rate 2.4°C/min

Forced water circulation:

The review [5] proposes a heat pipe PV/T cross breed framework. This crossbreed framework's general thermal, electrical, and exergy efficiencies have been determined to explore its thermal-electric transformation execution. The general thermal, electrical, and exergy efficiency of a heat pipe PV/T half breed framework, as indicated by the discoveries, could be just about as high as 63.65 percent, 8.45 percent, and 10.26 percent, separately. A solar cell's working temperature on a solar PV panel differs by under 2.5 degrees Celsius. The complete thermal, electrical, and exergy efficiency of the heat pipe PV/T crossover framework have been investigated long regarding different factors. As per a parametric report, the thermal efficiency of a heat pipe PV/T framework might be improved by expanding water mass flow rate and lessening intake water temperature, solar cell packing factor, and heat loss coefficient in the PV/T framework. The impacts of fluctuating inlet water temperature and solar cell packing factor on the by and large exergy efficiency of the heat pipe PV/T cross breed framework are unmistakable, specifically, higher inlet water temperature and solar cell packing factor lead to altogether higher framework exergy efficiency, while more modest impacts of water mass flow rate and heat loss coefficient on the general exergy efficiency have been acquired, even though the generally speaking exergy efficiency increments as the inlet water temperature and packing factor of solar cell increment.

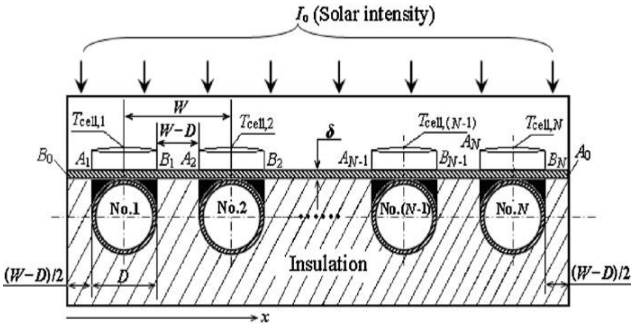

Figure 4 The Calculation model of het pipe PV/T system.[5]

Immersion cooling:

The utilization of an immersion cooling approach prompts the establishment of photovoltaic modules submerged. Heat retention by water from the PV boards creates high-proficiency improvement results. The presentation of the module can be expanded by inundating it in water. For instance, Mehrotra et al. [6] exhibit that profundity of 1 cm can bring about a 17.8% expansion in electrical proficiency. To battle the warming of the solar cell surface, water immersion cooling innovation might be utilized for example it tends to be lowered in water to protect its surface temperature and give further developed proficiency at serious temperatures. In this work, the electrical qualities of solar cells were resolved which showed that the cooling factor assumes a vital part in the electrical effectiveness increment. The temperature of a solar cell drenched in water was estimated under certifiable settings, and the cell surface temperature was directed somewhere in the range of 31 and 39 degrees Celsius. The electrical exhibition of the cell improves altogether. As indicated by the discoveries, the board proficiency has improved by 17.8% at a water severity of 1cm. The review can help the Concentrated Photovoltaic System by inundating solar cells in different liquids.

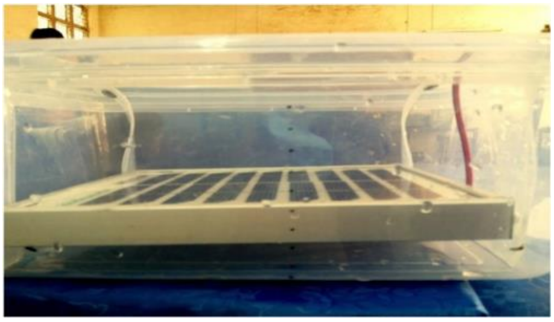

Figure 5 PV Panel immersion in water

II. Heat Exchanger:

A Heat Exchanger is a technique of transferring the heat from one or more fluids to another, thereby resulting in overall heating/cooling of the system. This technique is used in P.V panels as a significant improvement in efficiency is achieved at higher working temperatures of panels, as stated by Pushpendu Dwivedi [7] Numerous experiments have been performed to investigate the performance of the PV cells by using a heat exchanger as a cooling technique.

Hussein et al [9] used a micro channeled plate heat exchanger with water as a cooling medium to derive the changes in the performance of PV panels. It was concluded that at a flow rate of about 3L/min the P.V module experienced the maximum drop of 15^{0}C which resulted in around 14% power improvement.

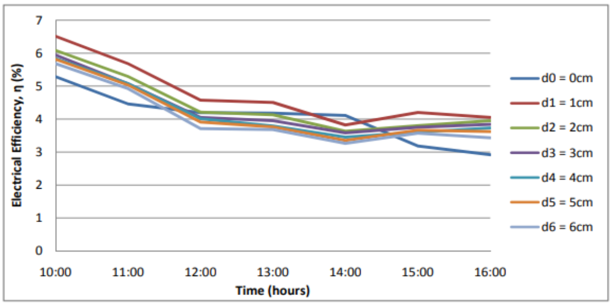

Figure 6 Variation of electrical efficiency of solar panel ith time at different submersion depths of water [6]

An investigation on the performance of P.V panels with rectangular heat exchanger cooling (RGX) attached to the back of panels was conducted by Bahaidarah [10] A heat exchanger was connected to the back of the PV panels to enhance the performance of the PV panel for the climate of Dhahran, Saudi Arabia. The hybrid PV-water cooled system consisted of a 230 W mono-crystalline type, a cooling panel (heat exchanger) was connected to the backside of the PV module, and an insulated tank to store the cooling water. From the experimentation, it was concluded that the operating temperature was reduced by 20% and electrical efficiency jumped by 9%. On top of that, the energy collection capacity quadrupled with the use of this system. M.U Siddiqui [12] has carried out experimentation for the design and selection process for a heat exchanger which yielded maximum efficiency. He presented about 12 designs of heat exchangers, by varying different parameters such as the Intake manifold, exit manifold, Inlet position, Outlet position, Number of channels subjected to multiple modifications to evaluate their impact on PV panels. Following were the conclusion made:

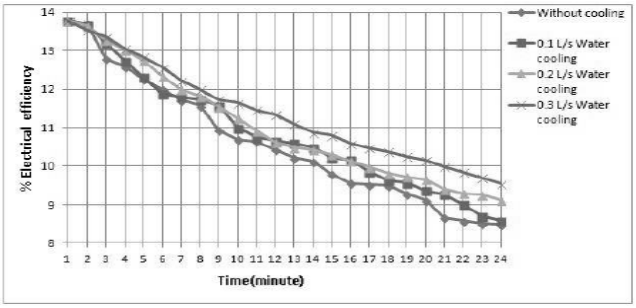

Figure 7 Effects of water mas flow rate on electrical ffficiency of the PV panel [8]

- By varying the number of channels the performance of the heat exchanger was unaffected; however, as the number of channels incremented significant increase in pressure loss, was observed.
- Variation in header width was the most significant design parameter, with a wider header resulting in inflow uniformity, eventually leading to the uniform temperature distribution.
- Inlet and outlet ports present in corners lead to less flow in the middle channel, which can be optimized by designing the channel's layout to the middle of the manifold.

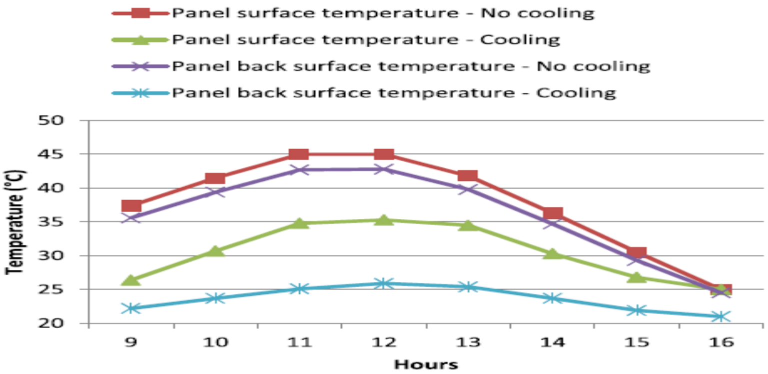

Figure 8 Figure 8 Conversion Efficiency variation for PV with jet cooling, RHX cooling and an uncooled panel.[11]

Liquid Jet Impingement Cooling:

Liquid Jet Impingement Cooling is very simple to implement as compared to other methods as it offers low thermal resistance as well as high heat fluxes. Liquid jets can be made using a straight tube or a contracting nozzle. These are used in industrial applications such as Metal hardening and quenching, cooling of turbine blades, tempering of glass, and in electronic components as it involves rough surfaces. These rough surfaces play a significant role in heat transfer. Often in this situation, we must maintain a minimum temperature or temperature difference within the system making liquid jet impingement attractive in these situations.

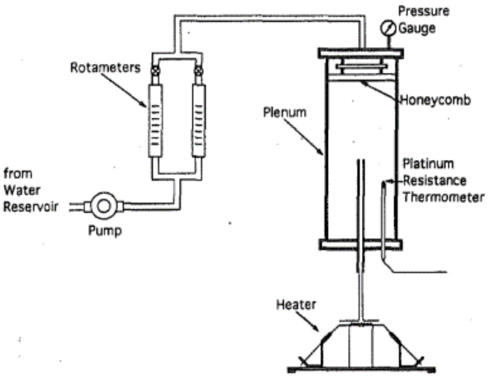

Figure 10 Figure 9 Experimental arrangement [16]

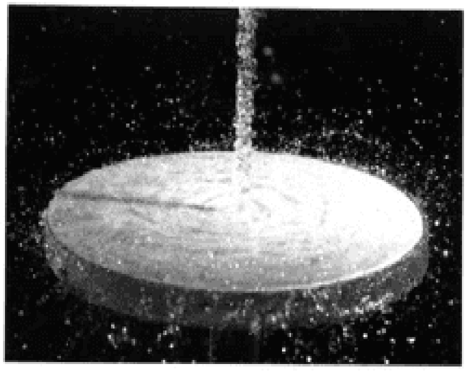

Figure 9 Figure 10 Splattering turbulent jet [17]

Nanofluids:

In these cooling systems various metallic and non-metallic particles are mixed with base fluids to create nano-fluids. Then nano-fluids is used to cool the P.V. panel by increasing the thermal performance. The commonly used metallic, non-metallic nanoparticles and multiwalled carbon nanotubes are MgO2 (Magnesium peroxide), Al2O3 (Aluminium oxide), TiO2 (Titanium oxide), CuO (Copper oxide), SiC (Silicone carbide), Fe3O4 (Iron oxide black). These are then mixed with some common base liquids such as Water, Ethylene glycol, and Oil to form the desired nano-fluid.

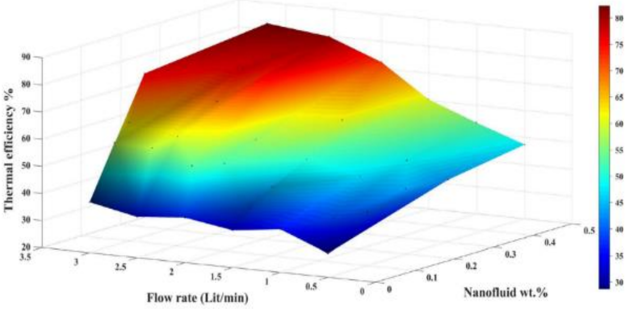

Figure 12 Temperature changes of the coolant flowing versus nano-fluid in the half-pipe concentration for different flow rates [24]

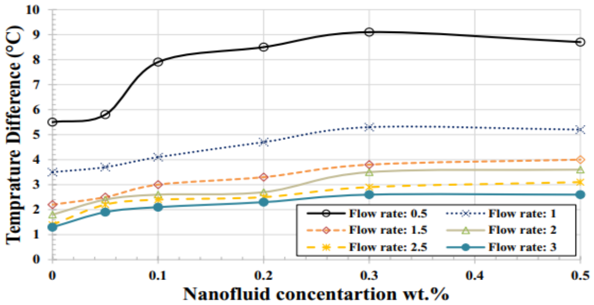

Figure 11 3D plot of thermal efficiency versus nano-fluid in various concventrations and flow rate of coolant [25]

Table 2: Summary of Nanofluid based Cooling

Sr. No.	Nanofluid	Method	Advantages
1	Transformer oil +C nanoparticle suspension	Cu nanoparticles are mixed with the transformer oil. Oleic acid is used as the dispersant to stabilize the suspension	The heat transfer coefficient has been improved.
2	Water + Cu nanoparticles suspension	A suspension is created using water and 5% Cu nanoparticles. As a stabilizer, laurate salt is used.	The heat transfer coefficient has been improved.
3	Al2O3 and CuO in water	Al2O3 and CuO nanoparticles were produced by gas condensation. The nanoparticles were thoroughly mixed with water.	The heat transfer coefficient has been improved.10% and 12% increase in thermal conductivity for Al2O3 and CuO, respectively, were observed.
4	Al2O3 in water and ethylene glycol	Alumina nanoparticles were dispersed in ethylene glycol.	Enhanced heat transfer coefficient. An 18% increase in thermal conductivity for Al2O3 was observed.

3. Conclusions

We aimed to compare various kinds of liquid cooling techniques and these cooling systems affect different kinds of aspects such as their efficiency and desired output. Among the techniques discussed some are widely acceptable and show sudden changes inefficiency. We found these are more ideal in applications such as restaurants, hotels, and process industries. Furthermore, the water used in the P.V. module can be recovered and reused for agricultural purposes preventing unnecessary wastage of water. Active water cooling is the simplest and most effective cooling approach however, it is not always feasible for active water cooling to be worthwhile, the environment must have a consistent supply of cool water, and the cooling array must be large enough to offset the energy usage.

i. Water-based cooling systems are better suited for applications that require both hot water and energy, such as restaurants, hotels, and process industries.
ii. Another advantage of this system is that it cleans the PV module of dust accumulation. Furthermore, it can be used in agriculture, the water used for cleaning can be restored and used to water crops
iii. Water spray cooling has a significant impact on the PV cell working and also even at low water flow rates, systems performance improves dramatically.
iv. In water immersion cooling, when the accurate depth is used, PV module temperature drops and boosted the efficiency successfully. Furthermore, ionized water exposure also has a pretentious electrical efficiency over a period.
v. As passive cooling relies on natural convection, its efficiency may be below.
vi. Where a large amount of cooling is to be required active cooling techniques are used, as active cooling is achieved by forced circulation.
vii. Using the Heat exchanger as a cooling technique, a maximum temperature drop of 15°C and an increase of around 14% in power improvement at a flow rate of about 3L/min can be achieved.

References

[1] S. Nizˇetic´ a,⇑ , D. Cˇoko b, A. Yadav c, F. Grubišic´ -Cˇabo a, Water spray cooling technique applied on a photovoltaic panel: The performance response, Energy Conversion, and Management, http://dx.doi.org/10.1016/j.enconman.2015.10.079

[2] M. Abdolzadeh, M. Ameri, M.A. Mehrabian, Energ. Source, (2011) 10.1080/15567036.2010.499416 (Water spray 2nd para + source table 2)

[3] Y.M. Irwan, W.Z. Leow, M. Irwanto, M. Fareq, A.R. Ameliaa, N. Gomesha, I. Safwati, Energ. Procedia, 79 (2015) (Water spray 3rd para)

[4] K.A. S Moharrama, H. Abd-Elhadyb, M.S. Kandila, A.H. El-Sherif, Enhancing the performance of photovoltaic panels by water cooling, Ain Shams Eng. J. 4 (2013) 869–877.

[5] S.Y. A Wu, Q.L. Zhang, L.X. Xiao, F.H. Guo, A heat pipe photovoltaic/thermal (PV/T) hybrid system and its performance evaluation, Energy Build. 43 (2011) 3558–3567.

[6] S. Mehrotra S, P. Rawat, M. Debbarma, K. Sudhakar, Performance of a solar panel with water immersion cooling technique, Int. J. Sci. Environ. Technol. 3 (2014) 1161–1172.

[7] Pushpendu Dwivedi, K. Sudhakar, Archana Soni, E Solomin, I Kirpichnikova,

[8] Swar A. Zubeer, H.A. Mohammed, and Mustafa Ilkan, A review of photovoltaic cell cooling techniques. DOI: 10.1051/e3sconf/20172200205ASEE17

[9] H.A. Hussien, A.H. Numan, A.R. Abdulmunem, Mater. Sci. Eng. 78 (2015)

[10] H.M.S. Bahaidarah, IEEE, (2015)

[11] H. Bahaidarah, A. Subhan, P. Gandhidasan, S. Rehman, Energ. 59 (2013)

[12] M.U. Siddiqui A novel heat exchanger design procedure for photovoltaic panel cooling application: An analytical and experimental evaluation

[13] Ali Hassan, Abdul Wahab, Muhammad Arslan Qasim, Muhammad Mansoor Janjua, Muhammad Aon Ali, Hafiz Muhammad Ali, Tufail Rehman Jadoon, Ejaz Ali, Ahsan Raza, Noshairwan Javaid, Thermal management and uniform temperature regulation of photovoltaic modules using hybrid phase change materials-nanofluids system, Renew. Energy 145 (2020) 282–293, https://doi.org/10.1016/j.renene.2019.05.130.

[14] N. Karami, M. Rahimi, Heat transfer enhancement in a hybrid microchannel-photovoltaic cell using Boehmite nano-fluid, Int. Commun. Heat Mass Tran. 55 (2014) 45–52.

[15] M. Lucas, F. Aguilar, J. Ruiz, C. Cutillas, A. Kaiser, P. Vicente, Photovoltaic Evaporative Chimney as a new alternative to enhance solar cooling, Renew. Energy 111 (2017) 26–37.

[16] Gabour, L. A.; Lienhard, J. H. (1994). Wall Roughness Effects on Stagnation-Point Heat Transfer Beneath an Impinging Liquid Jet. Journal of Heat Transfer, 116(1), 81–.
DOI: https://doi.org/10.1115/1.2910887

[17] X. Liu and J.H. Lienhard V, 1989, "Liquid Jet Impingement Heat Transfer on Uniform Heat Flux Surface," Heat Transfer Phenomena in Radiation, Combustion, and Fires, ASME HTD, Vol.106, pp.523- 530. (26th ASME/AIChE National Heat Transfer Conference, Philadelphia, Aug. 6-9, 1989)

[18] Heat Transfer by Impingement of Circular Free-Surface Liquid Jets

[19] X. Liu, J.H. Lienhard V, and J.S. Lombara, 1991, "Convective Heat Transfer by Impingement of Circular Liquid Jets," J. Heat Transfer, Vol. 113, No. 3, pp. 571-582.

[20] (Reference for table)-Advanced cooling techniques of P.V. modules: A state of arthttps://doi.org/10.1016/j.csite.2020.100674.

[21] X. Tang, Z. Quan, Y. Zhao, Experimental investigation of solar panel cooling by a novel micro heat pipe array, Energy Power Eng. 2 (2010) 171–174. doi:10.4236/epe.2010.23025

[22] Hossein Alizadeh, Roghayeh Ghasempour, Mohammad Behshad Shafii, Mohammad Hossein Ahmadi, Wei-Mon Yan, Mohammad Alhuyi Nazari, Numerical simulation of P.V. cooling by using single turn pulsating heat pipe, Int. J. Heat Mass Tran. 127 (2018) 203–208, https://doi.org/10.1016/j. ijheatmasstransfer.2018.06.108.

[23] Laith Jaafer Habeeb, Dheya Ghanim Mutasher, Faez Abid Muslim Abd Ali, Cooling photovoltaic thermal solar panel by using heat pipe at Baghdad climate, Int. J. Mech. Mechatron. Eng. 17 (6) (2017) 171–185

[24] [Sardarabadi M, Hosseinzadeh M, Kazemian A, Passandideh-Fard M. Experimental investigation of the effects of using metal-oxides/water nanofluids on a photovoltaic thermal system (PVT) from energy and exergy viewpoints. Energy 2017;138:682–95.]DOI: 10.1002/ese3.1067

[25] Chapter 14 - Scale-Up Technologies for Advanced Nanomaterials for Green Energy: Feasibilities and Challengeshttps://doi.org/10.1016/B978-0-12-813731-4.00014-X