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Simulation of Heat Transfer Enhancement using Nanofluids as Cooling Media for Flat Solar Panel

A.H.Y.Lau[1], **T.W.Ting**[2], **T.S.Y.Moh**[3]

School of Engineering & Technology, University College of Technology Sarawak, Sibu, Sarawak, Malaysia[1,2,3]

Abstract: PV solar panel has been widely used as a source of electricity generation. Heat irradiance from sunlight will increase the temperature of the PV solar panel which leads to the increase in its resistance to electricity being generated. Different types of nanofluids including CuO-H_2O, TiO_2-H_2O, Al_2O_3-H_2O have been simulated and show positive effect on reducing the maximum temperature of the surface of PV solar panel. However the results show no significant differences on temperature reduction among different nanofluids even though we can notice a slightly more drops on PV solar panel using CuO-H_2O nanofluids. However, by varying different parameters such as the nanoparticles concentration in the nanofluids, the results may vary. The present study has been performed by setting the coordinates of UCTS in ANSYS Fluent with the time being set at 12.00pm to simulate the solar heat irradiance at that particular time and location.

Keywords: Nanofluids; convection cooling; Solar Panels.

I. INTRODUCTION

PV solar system produces heat energy during the electric generation process. The heat produced will reduce the efficiency of the power output from the PV solar system. Moh and Ting [1] and some other research group [2-3] demonstrated the idea of immersing the PV solar panel in the cooling media to keep the temperature to less than 45℃ in order to maximise or enhance the energy conversion [1]. However, it is not practical when the PV solar panel is installed at the rooftop. Therefore, in this project, we explore the possibility of having fluidic channel filled with nanofluids to further cool the PV by exploiting the enhanced thermo-physical properties of nanomaterials. We also explore if the cooling efficiency is higher than the immerse technique.

Our Contributions: This paper provides understandings towards the properties of nanofluids. The simulation of heat transfer on a flat solar panel using nanofluids as cooling media is expected to increase in solar panel efficiency.

Paper Organisation: We provide a brief review of the existing work, which can be related to different phases of our systematic approach. In Section III, we illustrate the design of our set-up modules. Section IV shows the results and discussion from the simulations.

Nanofluids are fluids with the mixture of nanoparticles and base fluids with nanometer-sized (1-100 nm in one dimension) [4,5]. These nanoparticles can be produced naturally or man-made. An example of natural occurring nanoparticles is volcanic ash. Nanofluids is chosen because of its larger surface area to volume ratio as more surface area of nanoparticles are exposed to the surrounding due to its smaller size. The concept of larger surface area to volume ratio could be explained as figure below.

(a) (b)

Fig 1: Comparisons between similar volume with different surface areas exposed particles. (a) Surface area exposed of larger particles; (b) Surface area exposed of smaller particles [6,7]

From figure 1(a) shown above, the total surface area exposed is 5cm x 5cm x 6 faces =150 cm^2. However, from figure 1(b), the surface area exposed increases to 2.5cm x 2.5cm x 6 faces x 6particles = 225 cm^2 which is much larger than figure 1(a). This increases the total surface area to volume ratio.

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II. LITERATURE REVIEW

There are three modes of heat transfer, namely the conduction, the convection and the radiation [4,6,8]. Conduction heat transfer is due to the vibration of molecules which transfer energy from the faster moving molecules, with higher thermal energy, to the slower molecules. Hence, the cooler molecules with slower movement will gain thermal energy [8]. Another type of heat transfer is convection and it happens in liquid and gases [8]. When heated, the particles of gases and liquids vibrate more rigorously and hence the density decreases. On the other hand, it becomes denser when it is being cooled. Heat is therefore transferred due to the convection current created. It is a kind of energy transfer through fluid motion. There are two types of convection which are the forced convection and the natural convection. Radiation heat transfer is due to the emission of energy by an object which is at temperature above absolute zero. Radiation is energy transfer in the form of electromagnetic waves and no medium is needed for radiation heat transfer [9].

Nanofluids can be prepared from two methods , namely the one-step method and the two-step method [10-17]. Since the technique of nanopowder synthesise is already up to scale of production in industries, two-step method is therefore more economical compared to one-step method [17]. Therefore, two step method is employed in the present study. However, there is an issue on the stability of nanofluid due to the strong Van der Waals forces of attraction among the nanoparticles which causes the nanopowders to aggregate [18]. Two step preparation of nanofluids can be shown in Figure 2 below:

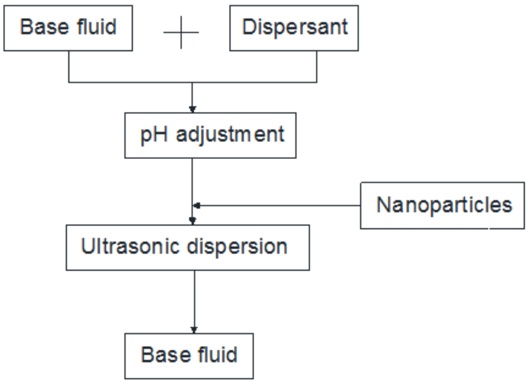


Fig 2: Two-step method in nanofluids preparation [13]

One-step method is developed by continuously producing and dispersing nanoparticles in basefluids [13, 17]. In one-step method nanofluid can be prepared through direct evaporation method or laser ablation method. Direct evaporation is a process of solidification of the nanoparticles from gaseous state. This method is developed by Akoh et al. [19] to produce nanoparticles but it is difficult to separate nanoparticles from the fluids in order to produce dry nanoparticles [19,20]. The stability of nanofluids are important in order for the applications to operate in optimal condition for a longer period of time. In order to achieve the stability, one of the methods used is by using the pH value adjustment which gives good dispersion of nanofluids [15, 21]. Bose et al. [22] reported that the stability of nanofluids is also determined by zeta potential. As the name implied, zeta potential is a potential difference which is produced between the surfaces of a solid particle when being immersed in nanofluids which is conductive. Zeta potential affects the stability of nanofluids as illustrated in Table 1 [15, 21-24].

Table 1: Zeta potential values and its respective stability [22,24]Stability behaviour of colloid	Zeta potential range (mV)
Coagulate rapidly	-5 to 5
Incipient coagulation	±10 to ±30
Moderate Stability	±30 to ±40
Good Stability	from ±40 to ±60
Excellent stability	more than ±61

Huang et al. [16] demonstrates the stability changes by measuring the zeta potential values (mV) Al_2O_3-H_2O and CuO-H_2O nanofluids with different pH valure. The study demonstrates that Al_2O_3-H_2O requires pH values of 8.0 whereas CuO-H_2O requires pH values of 9.5 in order to obtain a good dispersion of nanoparticles in the basefluids. The study also states that these optimised pH values of the respective nanofluids causes the increases in surface charge of nanoparticles due to a more frequent attack of hydroxide ion and hydrogen ion to the surfaces of hydroxyl-groups and phenyl sulfonic group [16]. This leads to the increase in the stability of colloidal particles.

In the present study, the cooling of flat PV panels with and without pumping are being studied. Jin Huang et al. [16] states that when Reynolds number increases, the friction factor decreases. There is insignificant effect for nanoparticle concentration on friction factor which makes nanofluid as a suitable candidate for coolant because it does not lead to extra pumping power to the system [16]. Jeng et al. [25] demonstrates the Mpemba effect which shows that warmer fluid tends to cool down faster comparing to cooler fluid. Pumping of fluid brings the warmer fluids to the channel surface which increases the rate of cooling. Channana et al. [26] states that flowing fluids enhances the convection which increases the heat transfer rate.

In the existing literature, nanoparticles with different materials such as TiO_2 [12,21,27-30] , Al_2O_3 [6, 12, 15, 28, 30,31] and CuO [30,31] are being investigated. Hamid et al. [32] investigate the concentration of nanoparticle on the pressure drop.The experiment is performed for temperature with 50℃ and 70℃ by using. TiO_2-H_2O. The study shows that the increases of pressure drop is not significant in nanofluid. Besides, the increase of temperature from 50℃ to 70℃ causes a reduction of pressure drop and nanofluid viscosity. Therefore, insignificant amount of extra pumping power is needed for nanofluid. The study also reports that the thermal conductivity is the lowest for water-EG mixture. By increasing the volume fraction of TiO_2, the thermal conductivity increases and therefore, TiO_2 is a suitable material for cooling purposes. Hasan et al. [31] investigate numerically the effects of using Cu-H_2O and Al_2O_3-H_2O nanofluids on the performance of a counter flow micro channel heat exchanger. The study shows an enhancement of counter flow microchannel heat exchanger by using nanofluids without causing extra rises in the pressure drop. Besides, the heat transfer rate of Cu-H_2O and Al_2O_3-H_2O enhances with the increasing volume fraction. The study reported that a higher thermal conductivity characteristic of Cu-H_2O nanofluids leads to a higher heat transfer rate when compared with Al_2O_3-H_2O nanofluids. Moreover, the ratio of heat transfer rate to pumping power increases with the increasing volume fraction.

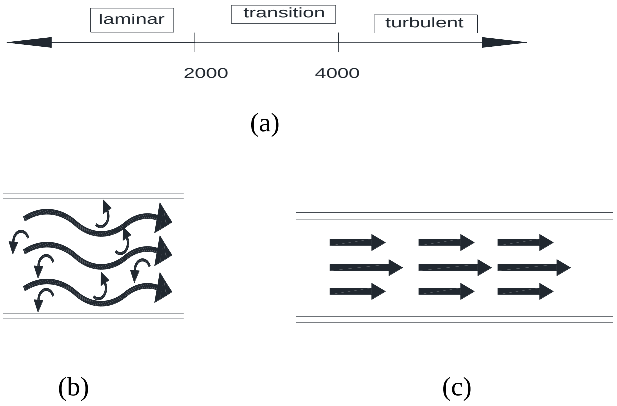
There are two types of flow, namely the laminar flow and the turbulent flow [33], which can be determined by using Reynolds number as defined in Eq. (1).

$$\text{Reynold number} = \frac{\text{Inertial forces}}{\text{Viscous forces}} \qquad (1)$$

$$= \frac{\rho\, V\, L}{\mu}\text{ ,where}$$

ρ = density of the fluid, V = velocity of the fluid, μ = viscosity of fluid, L = characteristic length of the flow

Figure 3 shows the range of Reynold number corresponding to the respective fluid flow types. When Reynold number is below 2000, as the flow is a laminar flow. When it is above 4000, as the flow is a turbulent flow. In between, the flow is known as a transition flow.



(a)

(b) (c)

Figure 3: Reynolds number and its respective types of fluid flow (a) Reynold number (b) Turbulent flow; (c) Laminar flow [33,34]

III. SIMULATIONS

1) Without pumping

ANSYS simulation is carried out to justify the hypothesis which predict that the nanofluids would enhance the performance of PV solar panel through reduction of temperature. Figure 4 illustrates the simulation model without pumping (natural convection) whereas Figure 5 shows the model with pumping (forced convection) featuring one to three channels which yield different cooling effects as per simulated.

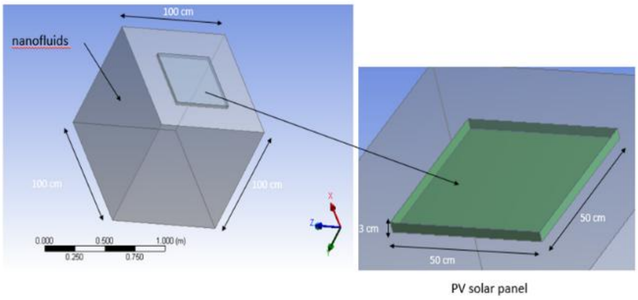


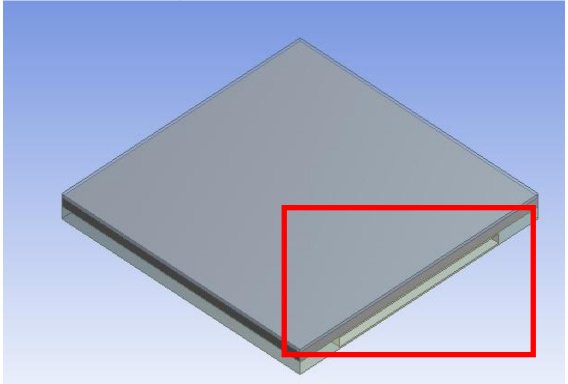
Fig 4: Simulation model for natural convection in ANSYS

Table 2: Thermo-physical properties of nanofluids

	TiO_2-EG-H_2O	CuO-H_2O	Al_2O_3 -H_2O	H_2O	EG-H_2O
Thermal conductivity (W/(m.k))	0.432 – 0.501	0.616 – 0.744	0.661 – 0.739	0.643	0.428 – 0.438
Viscosity (kg/m.s)	0.00125 – 0.00164	0.000612 - 0.000672	0.000612 – 0.000672	0.000595	0.00111 – 0.00157
Density (kg/m3)	1049.35 – 1093.12	1061 – 1378	1007.4 – 1112.2	981.3	1033.37 – 1045.35
Specific heat (J/(kg.k))	3463.3 – 3511.7	3998 – 4150.9	4017.8 – 4154.7	4189	3596 – 3636
References	[12, 21, 27, 28-30]	[6, 12, 15, 28, 30, 31]	[30, 31]	[30, 31]	[6,12,,14, 15, 27 28, 35]

2) With pumping

In the case with pumping, different sizes and quantity of channels are simulated to investigate the nanofluid cooling capability in forced convection as illustrated in Figure 5.



(a)

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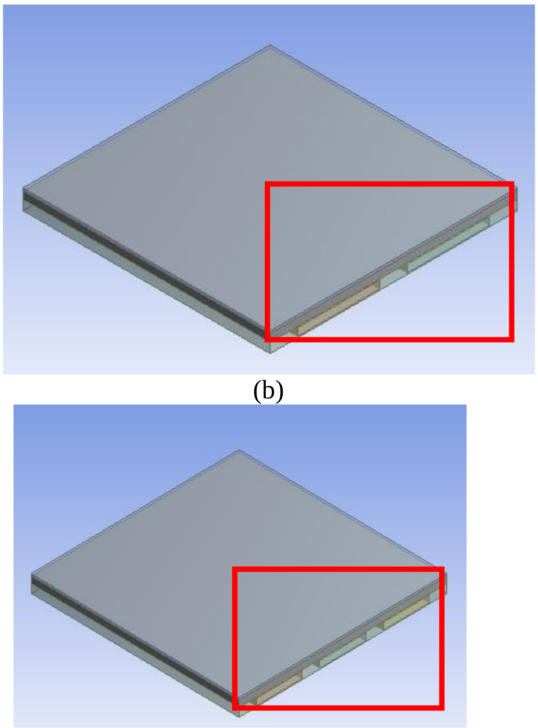

(b)

(c)

Fig 5: Simulation models for forced convection in ANSYS with (a) one channel, (b) two channels and (c) three channels, respectively (highlighted in the red-colour boxes).

IV. RESULTS & DISCUSSIONS

For the case without pumping, the fluids remain stationary while the solar panel is cooled with different types of nanofluids which properties are shown in Table 2. For the case with pumping, the velocity at the inlet is set to 0.01m/s whereby the number of channel is varied to study the effect of the number of channel on the enhancement of cooling effect.

1) Without pumping

Figure 6 depicts the results of temperature contours of the PV panel. It is apparent that water-based nanofluids with the suspension of Al_2O_3 and CuO induce lower temperature on the surface of the solar panel. This is justified by Table 3 which shows that CuO-H_2O has the highest cooling performance. Ethylene Glycol (EG) has lower cooling performance comparing to water which when added with water in a ratio of 40(EG):60(H_2O). Moh et.al [36] states that a PV solar panel works best when the temperature is maintained below 45°C (318 K). Therefore, further investigation is needed to enhance the solar panel efficiency by using nanofluids as coolant. In particular, the effect of nanoparticle concentration can be further studies as the present study fixes the nanoparticle concentration at 1%.

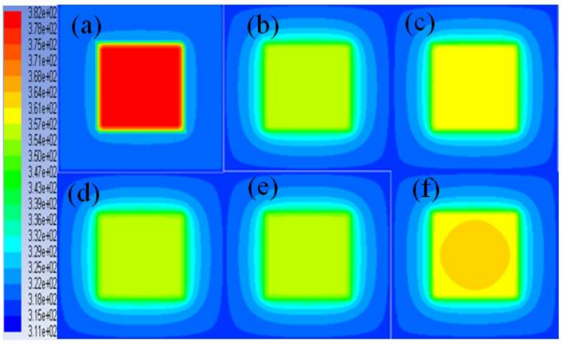

Fig 6: Temperature contour on the surface of the solar panel with different fluids of (a) Air, (b) $\mathrm{H_2O}$, (c) $\mathrm{TiO_2 - EG - H_2O}$ nanofluid, (d) $\mathrm{CuO - H_2O}$ nanofluid, (e) $\mathrm{Al_2O_3 - H_2O}$ nanofluid, and (f) $\mathrm{EG - H_2O}$.

Table 3: Tabulation results (without pumping) for nanofluids with 1% concentration.

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Medium	Air	H_2O	EG-H_2O	TiO_2-EG -H_2O	Al_2O_3-H_2O	CuO - H_2O
Temp, K	382.1268	356.3672	360.7464	360.1804	355.0725	355.0586
% based on Air	-	6.74	6.00	6.08	7.51	7.62

2) With pumping

For the case with pumping, the flow is directed towards the positive X-direction as shown in Figure 7. Figure 8 - 12 show the temperature contours of the coolants.

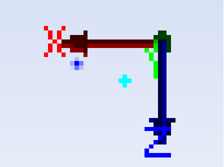

Fig 7: The pumping direction is in positive X-direction.

i) H_2O

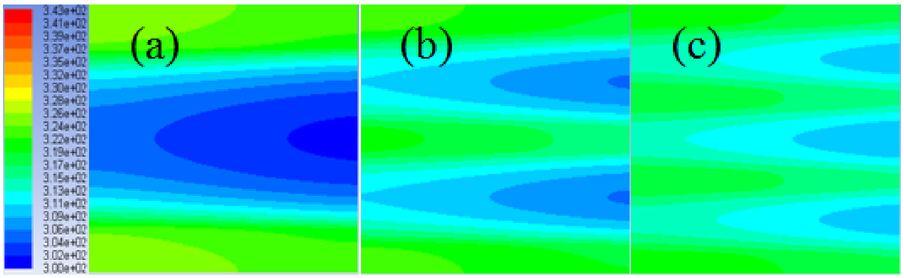

Fig 8: Temperature contours of H_2O for forced convection with (a) one channel, (b) two channels and (c) three channels respectively.

ii) TiO_2-EG-H_2O

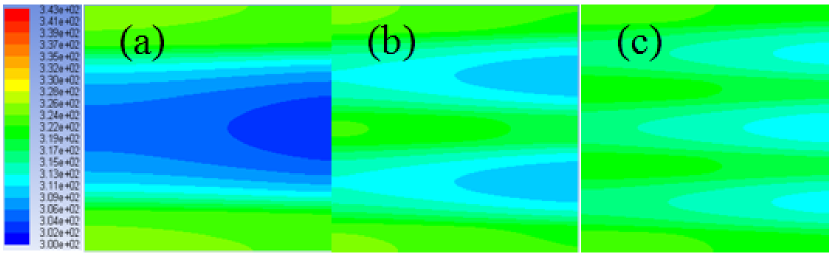

Fig 9: Temperature contours of TiO_2-EG-H_2O for forced convection with (a) one channel, (b) two channels and (c) three channels respectively.

iii) CuO -H_2O

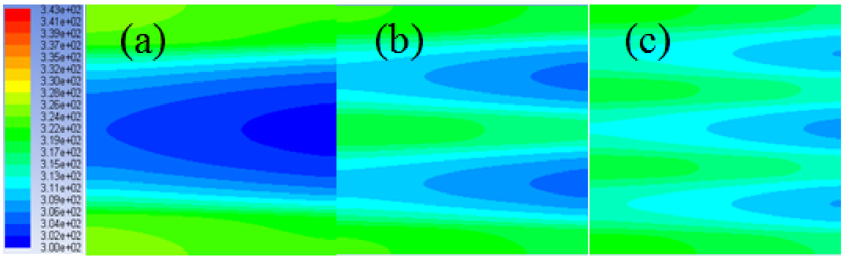

Fig 10: Temperature contours of CuO-H_2O for forced convection with (a) one channel, (b) two channels and (c) three channels respectively.

iv) Al_2O_3-H_2O

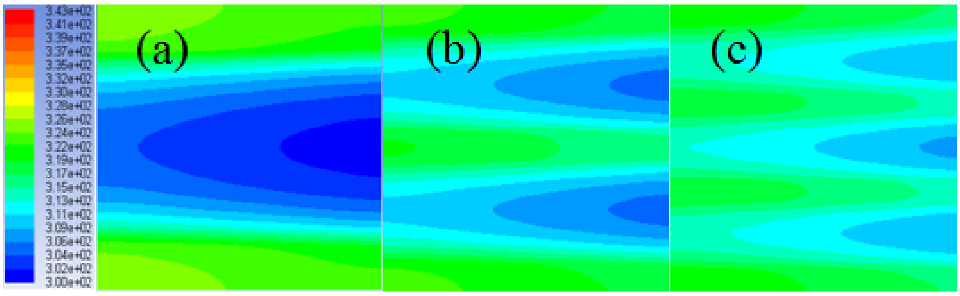

Fig 11: Temperature contours of Al_2O_3-H_2O for forced convection with (a) one channel, (b) two channels and (c) three channels respectively.

v) EG-H_2O

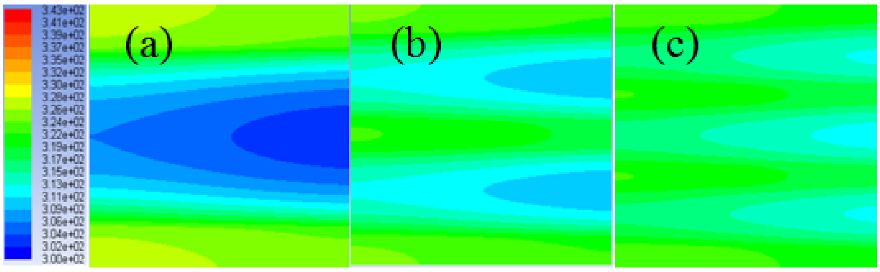

Fig 12: Temperature contours of EG-H_2O for forced convection with (a) one channel, (b) two channels and (c) three channels respectively.

The velocity of coolant is fixed at 0.01m/s. As depicted by Table 4, the temperature on the panel surface decreases as number of channel increases. This is because more heat is absorbed by the coolants when the number of channel increases as illustrated by Fig. 8 to Fig 12. From Table 4, it is depicted that as the number of channel increases from one channel to three channels, the temperature on the solar panel drops for approximately 3ºC, except for TiO_2-EG-H_2O which shows a temperature reduction of 1.61ºC. On the other hand, with the suspension of nanoparticle, the temperature of the panel can be further reduced, concurring with the case of natural convection.

Table 4: Temperature on the solar panel surface for the case with pumping for nanofluids with 1% concentration.

Medium	H_2O	EG-H_2O	TiO_2-EG-H_2O	Al_2O_3-H_2O	CuO-H_2O
Temp, K (1 channel)	322.4220	324.8257	322.9052	321.9688	321.8196
Temp, K (2 channel)	320.3584	322.4865	322.3962	319.889	319.7296
Temp, K (3 channel)	319.2181	321.6953	321.2959	318.7371	318.5662
Δ, Max, K	3.20	3.13	1.61	3.23	3.25

V. CONCLUSION

In the present study, the cooling capability of several nanofluids on PV solar panel is investigated by using ANSYS. Both natural convection and forced convection are studied. From the simulation, it can be concluded that the temperature of PV solar panel could be reduced with the suspension of nanoparticle for both cases. For the case without pumping, the maximum temperature reduction by using nanofluid as coolant is as much as 7%. Besides, CuO-H_2O nanofluids demonstrates the highest cooling capability. For the case with pumping, the temperature reduces as the number of channel increases, while the suspension of nanoparticles would further decreases the PV solar panel temperature. This study demonstrates the potential of applying nanofluids in the cooling of solar panel to enhance the efficiency of the panel.

REFERENCES

[1] Moh, T. and E. Ting (2016). "Efficiency Improvement Based on Cooling Effect via Immersion Technique in a PV Solar Panel: Tropical and Cloudy Weather Setting." International Journal of Innovative Research in Electrical, Electronics, Instrumentation and Control Engineering 4(10): 1-6.
[2] S. Mehrotra, P. Rawat, M. Debbarma, and K. Sudhakar, "Performance of a solar panel with water immersion cooling technique," International Journal Science Environ Technology, vol. 3, pp. 1161-1162, 2014.
[3] L. Zhu, R. F. Boehm, Y. Wang, C. Halford, and Y. Sun, "Water immersion cooling of PV cells in a high concentration system," Solar Energy Materials and Solar Cells, vol. 95, pp. 538-545, 2011/02/01/ 2011.
[4] [4] A. Kasaeian, A. T. Eshghi, and M. Sameti, "A review on the applications of nanofluids in solar energy systems," Renewable and Sustainable Energy Reviews, vol. 43, pp. 584-598, 3// 2015.
[5] [5] H. Setia, R. Gupta, R. Wanchoo, S. Tripathi, K. Dharamvir, R. Kumar, et al., "Thermophysical Properties of TiO 2-Water Based Nanofluids," in AIP Conference Proceedings, 2011, pp. 267-268.
[6] H. Setia, R. Gupta, R. Wanchoo, S. Tripathi, K. Dharamvir, R. Kumar, et al., "Thermophysical Properties of TiO 2-Water Based Nanofluids," in AIP Conference Proceedings, 2011, pp. 267-268.
[7] A. N. Al-Shamani, M. H. Yazdi, M. A. Alghoul, A. M. Abed, M. H. Ruslan, S. Mat, et al., "Nanofluids for improved efficiency in cooling solar collectors – A review," Renewable and Sustainable Energy Reviews, vol. 38, pp. 348-367, 10// 2014.
[8] A. N. Al-Shamani, M. H. Yazdi, M. A. Alghoul, A. M. Abed, M. H. Ruslan, S. Mat, et al., "Nanofluids for improved efficiency in cooling solar collectors – A review," Renewable and Sustainable Energy Reviews, vol. 38, pp. 348-367, 10// 2014.
[9] P. Mukesh Kumar, J. Kumar, R. Tamilarasan, S. Sendhilnathan, S. Suresh, P. Praserthdam, et al., "Review on nanofluids theoretical thermal conductivity models," Engineering Journal, vol. 19, 2015.Available: https://www.youtube.com/watch?v=Gyj444FK0zs
[10] DoodleScience. (2013). Heat Transfer - Conductive and Convective.
[11] F. S. Javadi, R. Saidur, and M. Kamalisarvestani, "Investigating performance improvement of solar collectors by using nanofluids," Renewable and Sustainable Energy Reviews, vol. 28, pp. 232-245, 12// 2013.
[12] K. Y. Leong, H. C. Ong, N. H. Amer, M. J. Norazrina, M. S. Risby, and K. Z. Ku Ahmad, "An overview on current application of nanofluids in solar thermal collector and its challenges," Renewable and Sustainable Energy Reviews, vol. 53, pp. 1092-1105, 1// 2016.
[13] T. T. Baby and S. Ramaprabhu, "Enhanced convective heat transfer using graphene dispersed nanofluids," Nanoscale Research Letters, vol. 6, p. 289, 2011.
[14] M. Babajani, B. Ghasemi, and A. Raisi, "Numerical study on mixed convection cooling of solar cells with nanofluid," Alexandria Engineering Journal.
[15] W. Yu and H. Xie, "A Review on Nanofluids: Preparation, Stability Mechanisms, and Applications," Journal of Nanomaterials, vol. 2012, p. 17, 2012.
[16] V. Sridhara and L. N. Satapathy, "Al2O3-based nanofluids: a review," Nanoscale Research Letters, vol. 6, p. 456, 2011.
[17] L. Yang and K. Du, "A comprehensive review on heat transfer characteristics of TiO2 nanofluids," International Journal of Heat and Mass Transfer, vol. 108, Part A, pp. 11-31, 5// 2017.
[18] J. Huang, X. Wang, Q. Long, X. Wen, Y. Zhou, and L. Li, "Influence of pH on the stability characteristics of nanofluids," in Photonics and Optoelectronics, 2009. SOPO 2009. Symposium on, 2009, pp. 1-4.
[19] S. Witharana, I. Palabiyik, Z. Musina, and Y. Ding, "Stability of glycol nanofluids—the theory and experiment," Powder technology, vol. 239, pp. 72-77, 2013
[20] J. A. Eastman, S. Choi, S. Li, W. Yu, and L. Thompson, "Anomalously increased effective thermal conductivities of ethylene glycol-based nanofluids containing copper nanoparticles," Applied physics letters, vol. 78, pp. 718-720, 2001.
[21] H. Akoh, Y. Tsukasaki, S. Yatsuya, and A. Tasaki, "Magnetic properties of ferromagnetic ultrafine particles prepared by vacuum evaporation on running oil substrate," Journal of Crystal Growth, vol. 45, pp. 495-500, 1978/12/01/ 1978.
[22] D. K. Devendiran and V. A. Amirtham, "A review on preparation, characterization, properties and applications of nanofluids," Renewable and Sustainable Energy Reviews, vol. 60, pp. 21-40, 7// 2016.
[23] A. Ghadimi and I. H. Metselaar, "The influence of surfactant and ultrasonic processing on improvement of stability, thermal conductivity and viscosity of titania nanofluid," Experimental Thermal and Fluid Science, vol. 51, pp. 1-9, 2013.
[24] A. Bose. (2016). Zeta Potential for measurement of stability of nanoparticles. Available: http://www.pharmainfo.net/book/emerging-trends-nanotechnology-pharmacy-physicochemical-charaterization-nanoparticles/zeta
[25] K. Wager, T. Chui, and S. Adem, "Effect of pH on the stability of gold nanoparticles and their application for melamine detection in infant formula," IOSR-JAC, vol. 7, p. 8, 2014.
[26] S. Honary and F. Zahir, "Effect of zeta potential on the properties of nano-drug delivery systems-a review (Part 2)," Tropical Journal of Pharmaceutical Research, vol. 12, pp. 265-273, 2013.
[27] M. Jeng, "The Mpemba effect: When can hot water freeze faster than cold?," American Journal of Physics, vol. 74, pp. 514-522, 2006.
[28] T. Chanchana, "Fluid velocity measurement using convective heat transfer coefficient measuring system," in 2007 IEEE/NIH Life Science Systems and Applications Workshop, 2007, pp. 81-84.
[29] A. H. Khamisah and U. NA, "Effect of titanium oxide nanofluid concentration on pressure drop," Journal of Engineering and Applied Sciences, vol. 10, pp. 7815-7820, 2015.
[30] M. Hatami and D. Jing, "Evaluation of wavy direct absorption solar collector (DASC) performance using different nanofluids," Journal of Molecular Liquids, vol. 229, pp. 203-211, 3// 2017.
[31] C.-Y. Lee, C.-L. Chang, Y.-N. Wang, and L.-M. Fu, "Microfluidic Mixing: A Review," International Journal of Molecular Sciences, vol. 12, pp. 3263-3287, 05/18
[32] W. Qu and J. Feng, "Method comparison and measurement accuracy of thermal conductivity for several nanofluids," in Nano/Micro Engineered and Molecular Systems (NEMS), 2010 5th IEEE International Conference on, 2010, pp. 492-496.
[33] M. I. Hasan, A. M. A. R. Rageb, and M. Yaghoubi, "Investigation of a Counter Flow Microchannel Heat Exchanger Performance with Using Nanofluid as a Coolant," Journal of Electronics Cooling and Thermal Control, vol. Vol.02No.03, p. 10, 2012.
[34] A. H. Khamisah and U. NA, "Effect of titanium oxide nanofluid concentration on pressure drop," Journal of Engineering and Applied Sciences, vol. 10, pp. 7815-7820, 2015.
[35] B. Zohuri and P. McDaniel, Thermodynamics in nuclear power plant systems: Springer, 2015.
[36] S. Adam-Day. Fluid Flow. Available: http://alevelnotes.com/#/?id=112&tree=3o1
[37] A. Turgut and E. Elbasan, "Nanofluids for electronics cooling," in 2014 IEEE 20th International Symposium for Design and Technology in Electronic Packaging (SIITME), 2014, pp. 35-37.

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BIOGRAPHIES

A.H.Y.Lau received his STPM from SMK Methodist back in 2012/2013. Then, he continued his tertiary education in University College of Technology Sarawak, Sibu pursuing Bachelor of Engineering Technology (HONS) in Electrical & Electronic.

T.W. Ting received his engineering degree (with Honours) from Multimedia University Malaysia in Mechanical Engineering in 2011. Subsequently, he joined Monash University Malaysia and completed his PhD degree in 2015. Now he is a senior lecturer at University College of Technology Sarawak, Sibu, Malaysia.

T.S.Y. Moh received his engineering degree (with Honours) from University Technology of Malaysia in Electrical Engineering in 2005. A year later, he received his Master of Engineering from the same university. Later, he obtained his Master of Science degree in bio-photonics from École Normale Supérieure de Cachan, Paris, France in 2008. Subsequently, he joined Microsystems Lab at Royal Institute of Technology Stockholm, KTH, Sweden to work on fabrication and packaging of microfluidics for European FP6 project. In 2013, he received his PhD from Delft University of Technology, The Netherlands in the fabrication of Silicon Nanowires Transistor for biosensing application. Now he is an Associate Professor in University College of Technology Sarawak, Sibu, Malaysia.

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