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Recent Review on Preparation Method, Mixing Ratio, and Heat Transfer Application Using Hybrid Nanofluid

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ABSTRACT

Hybrid nanofluid is the extension from nanofluid that had been recently discovered, which can enhance heat transfer performance of heat transfer application. However, there were limited reviews had been done on the effect of surfactant on thermal conductivity and the mixing ratio of hybrid nanofluid. These reviews are critical to giving a detailed insight into the factors that affect the heat transfer enhancement of hybrid nanofluid. Furthermore, a recent review on the hybrid nanofluid in heat transfer application is done to update any new findings in heat transfer enhancement. The review results showed that there were limited studies had been done on the optimisation of surfactants based on thermal conductivity. This optimisation is essential to ensure the prepared hybrid nanofluid has high stability without affecting the high thermal conductivity properties. Furthermore, there were no studies done by any researchers on the comprehensive optimisation of the mixing ratio hybrid nanofluid. All of the studies used the One Factor at a Time (OFAT) method with the selected mixing ratio. Next, based on the review of hybrid nanofluid in heat transfer application, there were limited studies compared with mono-nanofluid. Furthermore, the idea of hybridising different nanoparticles was to achieve high stability and high thermal conductivity working fluid. Several drawbacks were highlighted from the studies: pressure drop, pumping power, lower velocity flow, and high friction factor.

1. Introduction

Nanofluid is defined as a fluid with nano-sized particles dispersed in a base fluid. There are three types of nanoparticles: metal nanoparticles, carbon-based nanoparticles, and oxide nanoparticles [1,2]. Carbon-based nanoparticles consist of Carbon Nanotubes (CNTs) and graphene. Oxide nanoparticles consist of aluminium oxide (Al_2O_3) nanoparticles, titanium oxide (TiO_2) nanoparticles, copper oxide (CuO) nanoparticles, silica (SiO_2) nanoparticles, diamond nanoparticles, gold nanoparticles, and many more. These nanoparticles have better thermal properties than conventional heat transfer fluid such as water and ethylene glycol. Many research had proved that the addition of nanoparticles in the based fluid increases the thermal properties of the based fluid

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and increases the heat transfer performance in heat transfer applications. Kakaç and Pramuanjaroenkij [3] studied convective heat transfer enhancement with nanofluids shows that nanofluids significantly improve the heat transfer performance of conventional heat transfer fluids such as oil or water suspending nanoparticles in these base liquids. They recommended conducting additional theoretical and experimental studies on effective thermal conductivity to establish nanofluids' potential for forced convection enhancement fully.

Furthermore, Raja *et al.,* [4] studied nanofluids characterisation, heat transfer characteristics, and applications showing that nanoparticles' addition in the based fluid increases viscosity and thermal conductivity. Furthermore, nanofluid's convective heat transfer behaviour was found superior to based fluid based on numerical and experimental works done by other researchers. Recommendation action suggests doing more research on different thermal applications.

The nano-sized particle used to prepare nanofluid plays a significant role to ensure the suitability for nanofluid to be used as a coolant in heat transfer applications. From the past practice, micron-sized particles were mixed with a based fluid to enhance the heat transfer performance. However, the downside of micron-sized nanoparticles is their lack of stability due to particle agglomeration. This issue can lead to sedimentation, clogging of the channel, and increased pumping power required to cool a cooling system [5]. Therefore, nano-sized particles were used to overcome this problem. The dispersion of nano-sized particles in a base fluid is expected to stay stable for a y period with a proper method of nanofluid preparation. Furthermore, the sustainability of the enhanced thermal conductivity depends on the stability of the nanofluid. Research by Nasiri *et al.,* [6] showed that the thermal conductivity of the studied nanofluid decreases with time. Rapidly decrease for the first 50 hours and constant for the rest 400 hours Other than that, research from Haghighi *et al.,* [7] shows only a slight reduction of the thermal conductivity after a period with a standard deviation 0.003W/m.K. Therefore, proper nanofluid preparation is needed to ensure the sustainability of thermal conductivity enhancement.

Despite the enhancement of thermal properties of nanofluids, many actual times applications demand trade-offs among several characteristics/properties of nanofluids. Such example, metal oxide nanoparticle exhibits good chemical inertness and stability. In contrast, metallic nanoparticles like aluminum, copper, silver possess higher thermal conductivities but are chemically reactive and unstable [8]. Therefore, hybridising two different nanoparticles with different properties introduces a new nanofluid extension called hybrid nanofluid. Hybrid nanofluid is the dispersion of two different nanoparticles in the base fluid. The idea of hybrid nanofluid is to improve thermal properties compared to based fluid and mono-nanofluid due to synergistic effect [9]. For heat transfer applications, hybrid nanofluid is expected to improve the heat transfer performance, pressure drop, and stability by trade-off the advantages and disadvantages of the nanoparticles used. Based on a review on hybrid nanofluid done by Idris *et al.,* [9], proper hybridisation of hybrid nanofluid is likely for heat transfer enhancement. Further work is recommended in preparation and stability, characterisation, and applications to address long-term stability, increased pressure drop or pumping power, high viscosity, and unavailability of a suitable thermal conductivity model [10].

The preparation method and thermophysical properties analysis of hybrid nanofluid are similar to mono-nanofluid. The literature review from Idris *et al.,* [9] and Sidik *et al.,* [11] indicated hybrid nanofluid could be prepared using similar methods with mono-nanofluid, which are one-step and two-step methods. However, most of the literature used the two-step method than the one-step method because the method is cheaper for mass production than the one-step method. The one-step method is suitable for small-scale production with a high power supply and many chemical processes. For the two-step method, the simple chemical alteration and physical dispersion method are suitable to be used to prepare a hybrid nanofluid such as addition of surcfactant and ultrasonication method respectively.

2. Preparation Method of Hybrid Nanofluid

The hybrid nanofluid is considered to have good stability if there is no agglomeration with each nanoparticle and sedimentation within a short period. Idris *et al.,* [9] and Sidik *et al.,* [11] mentioned that maintaining the stability of hybrid nanofluid is the biggest challenge to be solved. This agglomeration of nanoparticles suspended causes the settlement and clogging in micro heat transfer devices. The agglomeration between nanoparticles is due to the strong Vander Waal forces and high surface areas among the nano-sized powder. Then, sedimentation of nanoparticles occurs due to the density difference between the nanoparticles and base fluid. Based on the research done by Nine *et al.,* [12], unstable nanoparticles cause unwanted deposition on heat transfer surfaces, raising clogging and corrosion issues. Furthermore, the thermal conductivity of nanofluid changed as the stability of nanofluid decreased.

2.1 Surfactant

Surfactant is one of the exciting methods to increase the stability of nanofluids. Surfactant or dispersant is a popular and economical method to enhance the stability of two-phase nanofluids by affecting the surface characteristics of the mixture. Surfactants act as barriers and reduce the interfacial tension between suspended particles and the based fluid. It makes the suspension more stable by increasing the repulsive forces and the zeta potential. The dispersant consists typically of two portions; one is the hydrophobic tail portion, usually long-chain hydrocarbon, and the second is the hydrophilic polar head portion. Surfactant is responsible for converting nanoparticles' hydrophobic surfaces to hydrophilic and vice versa to increase the solubility of aqueous and non–aqueous solutions. Surfactants also increase the wettability, which is the interface conjunction of two materials and introduces a degree of continuity between the two-phase systems. Despite the surfactant's ability, the disadvantages of surfactant for the application at high temperature [13]. At high temperatures above 60°C, the bonding between surfactant and nanoparticle can damage, resulting in the nanofluid losing its stability and changing its thermal physical properties and nanoparticle concentration due to sedimentation and agglomeration [14].

Next, the addition of surfactant in a based fluid can decrease its thermal conductivity. Baek *et al.,* [15] found that the addition of SDBS in distilled water decreased thermal conductivity by 2.1%. Therefore, exceeding the amount of surfactant dispersed in the nanofluid decreased its thermal conductivity, not suitable for cooling performance. This problem is due to the low thermal conductivity of surfactant used in the nanofluid, which reduces its thermal conductivity. Other than that, a higher amount of surfactant can cause higher viscosity, increasing the power needed for a pump in a cooling system to flow the coolant to all parts of the cooling system and could cause clogging. Therefore, only an optimised amount of surfactant is needed to have good nanofluid stability while having good thermal conductivity and viscosity for heat transfer applications.

A review of the influence of surfactants on the thermal conductivity of nanofluid was conducted to investigate the surfactant's behaviour in nanofluid other than stability enhancement. Few studies examined the optimal amount of surfactant in the prepared nanofluid. Thermal conductivity prepared by Tilak and Patil [16] increases to 0.5 %wt. Beyond 0.5 %wt, the thermal conductivity decreases due to the nanoparticles being surrounded by cationic chitosan surfactant, which lowers the interface layer thermal conductivity and decreases the thermal conductivity of the nanofluid.

Other than that, Krishnakumar *et al.,* [17] had done a more comprehensive study by comparing the thermal conductivity of Al_2O_3/water nanofluid with three different surfactants, which are SDBS, PVP, and GA at their optimum surfactant concentrations. This method shows an accurate comparison of the performance of various surfactants on the thermal conductivity of nanofluid. Other than that, Altun *et al.,* [18] investigate the thermal conductivity enhancement of Al_2O_3/water nanofluid compared to based fluid after measuring the thermal conductivity of the nanofluid with the optimum amount of surfactant. This method also accurately compared thermal conductivity enhancement after adding a surfactant to the nanofluid.

Ma *et al.,* [19] had investigated the effect of surfactant concentration on the thermal conductivity of hybrid nanofluid. Despite the excellent stability of hybrid nanofluid, the thermal conductivity of hybrid nanofluid decrease after the optimised amount of surfactant. As the amount of surfactant added increases, the number of micelles increases, aggregating the surfactant molecules and nanoparticles into large clusters. Therefore, the Brownian motion and micro-convection weaken, resulting in decreased thermal conductivity enhancement. It is worth noting that the optimum value of the surfactant is called the critical micelle concentration (CMC). At this specific concentration, the colloidal system is relatively stable, and all of the estimated parameters can reach the optimum performance. Li *et al.,* [20] measured the effect of surfactant on the thermal conductivity of based fluid first, then with nanofluid. The results show similar behaviour of the effect of surfactant on the thermal conductivity between the based fluid and nanofluid. The highest thermal conductivity of SDBS/water is at 0.02 wt%, while the thermal conductivity ratio decreases slowly as SDBS concentration increases from 0.02 wt% to 0.10 wt% in 0.1 wt% of Cu/water.

Research by Kim *et al.,* [21] shows that the addition of SDBS decreased the enhancement at the initial stage of the experiment compared to without surfactant. However, the presence of surfactant sustains the thermal conductivity enhancement better than without surfactant for some time. Other findings by Mare *et al.,* [22] mentioned that there was no significant effect of surfactant on thermal conductivity at low concentration (<0.1 vol%). However, a further discussion needs to be done to uncover the result shown from the research.

2.2 Ultrasonic Vibration

An ultrasonic vibration is a powerful tool for breaking down the agglomeration of the nanoparticles in a based fluid. There is another method to break down the agglomeration, such as magnetic and high shear stirrer. However, ultrasonic vibration is a much more popular method used by other researchers compared to other methods. A review done by Idris *et al.,* [9] showed most of the preparation with mechanical method uses ultrasonication method. Stability enhancement of nanofluid using ultrasonic vibration is due to supersonic waves travelling longitudinally within the liquid medium and causing alternate positive and negative pressure waves in the liquid [23]. Thus, increasing the particle dispersion in the nanofluid. The stability of nanofluid is based on the duration and the intensity of the ultrasonication. However, there is an optimised duration of ultrasonication. Exceeding the duration can cause more severe stability problems such as agglomeration and fast sedimentation, or no significant effect can be observed [24]. Mahbubul *et al.,* [25] had studied the influence of ultrasonication time on the stability of nanoparticle dispersant in the based fluid. Al_2O_3 nanoparticle was used in the preparation. A 0.5% vol% of Al_2O_3 nanofluid was ultrasonicated for a period of 0 to 5 hours. As the sonication time increased, better dispersion and lower viscosity were observed. Recommended further work from an overview paper done by Afzal *et al.,* [26] suggested that to determine as many sonication parameters as possible such as durations, amplitudes, pulses, probe tip diameter, and sonication types.

Table 1
Table of findings the effect of surfactant on the thermal conductivity of nanofluid

References	Hybrid/Mono Nanofluid	Surfactant	Stability	Effect on Thermal Conductivity
Tilak and Patil [16]	Al_2O_3 - CNT/water	Chitosan	zeta potential = 55.32mV. increase in surfactant concentration beyond 0.25% wt, the stability of the nanofluid decreases	Thermal conductivity ratio increases till 0.5 wt%, decreases with an increase in surfactant concentration after 0.5 wt% concentration. Beyond 0.5 wt%. the nanoparticles are surrounded by cationic chitosan surfactant, which lowers the interface layer thermal conductivity (ki) and decreases the thermal conductivity of the nanofluid.
Krishnakumar *et al.,* [17]	Al_2O_3/water	SDBS, PVP, GA		The optimum value of the volume fraction of SDBS is found to be 1. A similar trend is observed for GA surfactants. However, Alumina nanofluid of 13 nm requires only a 0.5% volume fraction of PVP to obtain maximum enhancement. The maximum enhancement in thermal conductivity is obtained for nanofluids added with PVP surfactant.
Altun *et al.,* [18]	Al_2O_3/water	Tween 80 or NP-10	up to 10th day	Surfactants at optimum concentrations have positive effects on the thermal conductivity of nanofluids. A maximum enhancement of approximately 5% was provided by nanofluid prepared using 1.1 vol% by volume particle ratio and no surfactant. The highest thermal conductivity improvement was 7.5% when utilising 0.2 wt% Tween 80 and 1.1 vol% particle concentration.
Kim *et al.,* [21]	Al_2O_3/water	Sodium Dodecyl Benzene Sulfonate (SDBS)		Heat transfer enhancement for the nanofluid without SDBS, the addition of SDBS decreased the enhancement at the initial stage of the experiment, but it could retard the reduction of convection heat transfer with time lapse.
Mare *et al.,* [22]	Multi-walled carbon nanotubes (MWCNT)	SDBS		No significant effect to thermal conductivity at low concentration (<0.1 vol%).
Ma *et al.,* [19]	Al_2O_3-CuO/Water, Al_2O_3-TiO_2/Water	SDS, CTAB, and PVP	Up to 25 days	Thermal conductivity drops after the optimised concentration of surfactant.
Li *et al*., [20]	Cu/water	SDBS		The thermal conductivity ratio decreases slowly as SDBS concentration increases from 0.02 wt% to 0.10 wt% and then decreases very quickly with an increase in the SDBS concentration in 0.1 wt% of Cu/water.

3. Hybrid Nanofluid Mixing Ratio

Typically, the thermophysical properties of nanofluids depend on the dispersed nanoparticle type, size, shape, concentration, base fluid, operating temperature, and surfactant addition [27-30]. On the other hand, the synergetic effect of hybrid nanofluid is dependent on the mixing ratio [8,9,31]. A good synergetic effect of hybrid nanofluid is significant to enhance the thermal properties of the prepared hybrid nanofluid. Therefore, the synergetic effect of hybrid nanofluid can be determined by optimising the mixing ratio of the nanoparticles. Therefore, a systematic literature review is done to study the method to investigate the mixing ratio of hybrid nanofluid.

Various nanoparticles had been used with different based fluid had been reviewed. The best synergetic effect of the hybrid nanofluid was determined based on the best results of respective responses. Most researchers use the One factor at a time (OFAT) method to determine the best mixing ratio of hybrid nanofluid. OFAT method is a method of designing experiments involving the testing of factors, or causes, one at a time instead of multiple factors simultaneously. The traditional OFAT approach for optimisation has three serious downsides, which are (a) leading to an unnecessarily large number of experimental runs, (b) unable to study interactions among the factors, (c) time consuming to conduct a large number of experiments [32-34].

Therefore, the best response value from the selected mixing ratio shows the best mixing ratio for the respective hybrid nanofluid. Wanatasanapan *et al.,* [35] had prepared TiO_2-Al_2O_3 hybrid nanofluid with several mixing ratios, which are 0:80, 40:60, 50:50, 60:40, 80:20, and fixed volume concentration of 1.0 % to study the optimised mixing ratio. The response for the optimisation is thermal conductivity and dynamic viscosity, respectively. The results show that the 50:50 mixing ratio is the best for the thermal conductivity response, while 80:20 is the best mixing ratio for viscosity. However, the optimal mixing ratio result was unrelated to the others and was unique to each response. Therefore, further analysis needs to be done to find the best mixing ratio by relating both responses. The mixing ratio's best value needs to be studied by considering both responses. Similar work was done by Kumar and Sarkar [36,37] to study the optimised mixing ratio for Al_2O_3-MWCNT/water based on two responses, which were heat transfer coefficient and pressure drop. However, this study's performance evaluation criteria (PEC) connect the two responses, maximum heat transfer coefficient to pressure drop ratio, for the optimised mixing ratio. Therefore, the optimised mixing ratio, which is 3:2, is achieved by relating the two responses analyses by PEC.

Furthermore, based on the review, the optimised mixing ratio found is limited with the mixing ratio selected in the respective experiments. Malika and Sonawane [38] investigated the optimised mixing ratio based on the thermal conductivity of the hybrid nanofluid. Eleven samples of 0.6vol% were prepared with various mixing ratios of 100:0 to 0:100. Therefore, many experiments need to be done for eleven samples, and the results are only limited to the sample studied only. Zhang *et al.,* [39] studied the effect of the mixing ratio of hybrid nanofluid on lubrication performance. Six samples were used, which are two respective mono-nanofluid, Mix(1:1), Mix(1:2), Mix(2:1), and Mix(1:3), in three experiments. Other work done by Çiftçi [40] study only 25:75, 50:50, and 75:25 mixing ratios on the thermal characteristics of the heat pipe. The optimum ratio achieved is 50:50 based on the three ratios used only. This study also shows that many experiments need to be done to investigate the mixing ratio, and only limited mixing ratios have been used. Xie *et al.,* [41] also used three mixing ratios only. This study shows the limited result of the mixing ratio to the thermal characteristic of the heat pipe. Next, Siddiqui *et al.,* [42] experimented with five mixing ratios based on net evaporation rate. However, the result for the mixing ratio is only limited to the mixing ratio selected. In this case, the optimisation ratio can quickly determine where the lowest amount of Ag in the mixing ratio is the best mixing ratio without further analysis.

From this review, the OFAT approach shows limited results to study hybrid nanofluid's mixing ratio. The OFAT approach is only limited to the mixing ratio used in the experiment. The mixing ratio between the experimented mixing ratio needs to be studied to achieve the best synergetic effect of hybrid nanofluid. A better design experiment approach is needed to study all the mixing ratios, including the experiment mixing ratio and the experimented ratio. Design of experiment using a statistical tool such as full-factorial design or Response Surface Methodology (RSM) is suggested to optimise the mixing ratio of hybrid nanofluid, which requires a minimum set of experiments and provides optimum condition settings for maximum yield. This method formulates a mathematical matrix and considers multiple variables and their interactions to develop an equation based on the factors and responses. Therefore, various studies successfully validated the experimental results without any assumptions [38,43].

Based on the reviewed literature, the mixing ratio investigation had been done by using a single concentration only. Çiftçi [40] fixed 2 vol% concentration and Triton X-100 surfactant concentration at the rate of 0.5% to study mixing ratio of 25:75, 50:50, and 75:25. Next, Wanatasanapan *et al.,* [35] fixed 1.0 vol% to investigate optimized ratio of 0:80, 40:60, 50:50, 60:40, 80:20. Next, Xie *et al.,* [41] fixed 1 wt% to optimise three mixing ratios. Zhang *et al.,* [39] fixed 4% mass concentration to study the effect of mixing ratio on lubrication performance. After finding the optimised ratio, the effect of concentration on lubrication performance is done using the optimised mixing ratio. Malika *et al.,* [38] fixed to 0.6 vol% concentration to study 100:0 to 0:100 mixing ratio. Then, the optimised mixing ratio is used to study the effect of concentration using RSM.

Table 2
Findings for the method of optimisation

References	Hybrid nanofluid	Method for optimisation	Responses
Malika *et al.,* [38]	Fe_2O_3-SiC/water	One factor at a time	Thermal conductivity ratio
Çiftçi [40]	AlN-ZnO/water	One factor at a time	Efficiency and thermal resistance
Wanatasanapan *et al.,* [35]	TiO_2-Al_2O_3/water	One factor at a time	Thermal conductivity, dynamic viscosity
Siddiqui *et al.,* [42]	AG-GNP/water	One factor at a time	Net evaporation rate
Kumar and Sarkar [36]	Al_2O_3-MWCNT/water	One factor at a time	Heat transfer coefficient and pressure drop
Kumar and Sarkar [37]	Al_2O_3-MWCNT/water	One factor at a time	Heat transfer coefficient and pressure drop
Siddiqui *et al.,* [43]	Cu-Al_2O_3/water	One factor at a time	Thermal conductivity and stability
Xie *et al.,* [41]	SiO_2-MoS_2/engine oil	One factor at a time	The friction coefficient and wear volume
Zhang *et al.,* [39]	MoS_2-CNT/synthetic lipids	One factor at a time	Coefficient of friction and Surface roughness

4. Conclusions

This research aims to prepare a novel working fluid called hybrid nanofluid, an advanced development from nanofluid for CPU liquid cooling systems. Only limited research was using hybrid nanofluid in a computer liquid cooling system. It is expected that the prepared hybrid nanofluid has better heat transfer enhancement compared to the conventional working fluid, which is water or distilled water. Based on the literature review, high thermal conductivity dispersed in a based fluid enhanced the thermal conductivity of the based fluid, suitable for heat transfer applications. Furthermore, the presence of nano-sized particles dispersed in the based fluid increases the nanofluid and hybrid nanofluid stability. Good nanofluid and hybrid nanofluid stability are essential to prevent clogging in heat transfer devices and deteriorate the fluid's thermal conductivity properties. Two main preparation methods for stable hybrid nanofluid were reviewed: using surfactant and ultrasonic vibration. The surfactant is one of the effective methods to enhance the stability of nanofluids. However, there were limited studies on optimising the amount of surfactant based on the thermal conductivity of nanofluid. It is crucial to ensure the prepared nanofluid has good stability without affecting the thermal conductivity.

Furthermore, good optimisation of the amount of surfactant in nanofluid increases the accuracy of comparing the thermal conductivity of nanofluid with the based fluid. Due to the importance of optimising surfactants, the present study analysed this issue comprehensively. Besides that, an adequate period of ultrasonic vibration is a powerful tool for breaking down the agglomeration of the nanoparticles in a based fluid.

Next, the idea of hybridising different nanofluids is to have a better-working fluid for respective heat transfer applications by trade-off the advantages and disadvantages of the nanoparticles used. Most of the studies hybridising nanoparticles were to have high stability and thermal conductivity of hybrid nanofluid. Next, the study on the mixing ratio of hybrid nanofluid is critical as the synergetic effect of hybrid nanofluid is dependent on the mixing ratio. A good synergetic effect of hybrid nanofluid is significant to enhance the thermal properties of the prepared hybrid nanofluid. Therefore, the synergetic effect of hybrid nanofluid can be determined by optimising the mixing ratio of the nanoparticles. However, all of the studies reviewed used the OFAT method to study the optimum mixing ratio of the hybrid nanofluid. This method only shows the optimised mixing ratio limited with the selected ratio used in the respective experiments. Furthermore, more experiments need to be done to study the mixing ratio if using this method comprehensively. There were no studies that comprehensively researched the optimal mixing ratios by analysing all the possible mixing ratios within the range despite the selected mixing ratio only.

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References

[1] Singh, Virendra, Daeha Joung, Lei Zhai, Soumen Das, Saiful I. Khondaker, and Sudipta Seal. "Graphene based materials: past, present and future." *Progress in Materials Science* 56, no. 8 (2011): 1178-1271. https://doi.org/10.1016/j.pmatsci.2011.03.003

[2] Poplaski, Leonard M., Steven P. Benn, and Amir Faghri. "Thermal performance of heat pipes using nanofluids." *International Journal of Heat and Mass Transfer* 107 (2017): 358-371. https://doi.org/10.1016/j.ijheatmasstransfer.2016.10.111

[3] Kakaç, Sadik, and Anchasa Pramuanjaroenkij. "Review of convective heat transfer enhancement with nanofluids." *International Journal of Heat and Mass Transfer* 52, no. 13-14 (2009): 3187-3196. https://doi.org/10.1016/j.ijheatmasstransfer.2009.02.006

[4] Raja, M., R. Vijayan, P. Dineshkumar, and M. Venkatesan. "Review on nanofluids characterization, heat transfer characteristics and applications." *Renewable and Sustainable Energy Reviews* 64 (2016): 163-173. https://doi.org/10.1016/j.rser.2016.05.079

[5] Sezer, Nurettin, Muataz A. Atieh, and Muammer Koç. "A comprehensive review on synthesis, stability, thermophysical properties, and characterization of nanofluids." *Powder Technology* 344 (2019): 404-431. https://doi.org/10.1016/j.powtec.2018.12.016

[6] Nasiri, Aida, Mojtaba Shariaty-Niasar, Alimorad Rashidi, Azadeh Amrollahi, and Ramin Khodafarin. "Effect of dispersion method on thermal conductivity and stability of nanofluid." *Experimental Thermal and Fluid Science* 35, no. 4 (2011): 717-723. https://doi.org/10.1016/j.expthermflusci.2011.01.006

[7] Haghighi, E. B., Nader Nikkam, Mohsin Saleemi, Mohammadreza Behi, Seyed Aliakbar Mirmohammadi, H. Poth, Rahmatollah Khodabandeh, Muhammet S. Toprak, Mamoun Muhammed, and Björn Palm. "Shelf stability of nanofluids and its effect on thermal conductivity and viscosity." *Measurement Science and Technology* 24, no. 10 (2013): 105301. https://doi.org/10.1088/0957-0233/24/10/105301

[8] Babu, J. A. Ranga, K. Kiran Kumar, and S. Srinivasa Rao. "State-of-art review on hybrid nanofluids." *Renewable and Sustainable Energy Reviews* 77 (2017): 551-565. https://doi.org/10.1016/j.rser.2017.04.040

[9] Idris, Muhammad Syafiq, Irnie Azlin Zakaria, and Wan Azmi Wan Hamzah. "Heat transfer and pressure drop of water based hybrid Al_2O_3: SiO_2 nanofluids in cooling plate of PEMFC." *Journal of Advanced Research in Numerical Heat Transfer* 4, no. 1 (2021): 1-13. https://doi.org/10.37934/arfmts.88.3.96109

[10] Sidik, Nor Azwadi Che, H. A. Mohammed, Omer A. Alawi, and S. Samion. "A review on preparation methods and challenges of nanofluids." *International Communications in Heat and Mass Transfer* 54 (2014): 115-125. https://doi.org/10.1016/j.icheatmasstransfer.2014.03.002

[11] Sidik, Nor Azwadi Che, Muhammad Mahmud Jamil, Wan Mohd Arif Aziz Japar, and Isa Muhammad Adamu. "A review on preparation methods, stability and applications of hybrid nanofluids." *Renewable and Sustainable Energy Reviews* 80 (2017): 1112-1122. https://doi.org/10.1016/j.rser.2017.05.221

[12] Nine, Md J., Hanshik Chung, Md Riyad Tanshen, NAB Abu Osman, and Hyomin Jeong. "Is metal nanofluid reliable as heat carrier?." *Journal of Hazardous Materials* 273 (2014): 183-191. https://doi.org/10.1016/j.jhazmat.2014.03.055

[13] Wlazlak, Agnieszka, Bartosz Zajaczkowski, Michal Woluntarski, and Matthias H. Buschmann. "Influence of graphene oxide nanofluids and surfactant on thermal behaviour of the thermosyphon." *Journal of Thermal Analysis and Calorimetry* 136, no. 2 (2019): 843-855. https://doi.org/10.1007/s10973-018-7632-x

[14] Assael, M. J., I. N. Metaxa, J. Arvanitidis, D. Christofilos, and Christos Lioutas. "Thermal conductivity enhancement in aqueous suspensions of carbon multi-walled and double-walled nanotubes in the presence of two different dispersants." *International Journal of Thermophysics* 26, no. 3 (2005): 647-664. https://doi.org/10.1007/s10765-005-5569-3

[15] Baek, Seungyeop, Dongwook Shin, Jungpil Noh, Byeongkeun Choi, Sunchul Huh, Hyomin Jeong, and Yonmo Sung. "Influence of surfactants on thermal performance of Al_2O_3/water nanofluids in a two-phase closed thermosyphon." *Case Studies in Thermal Engineering* 28 (2021): 101586. https://doi.org/10.1016/j.csite.2021.101586

[16] Tilak, Abhilash K., and Ranjit S. Patil. "Effect of chitosan surfactant concentration on the thermal conductivity and viscosity of Al_2O_3+ CNT Hybrid Nanofluid." In *Journal of Physics: Conference Series*, vol. 1455, no. 1, p. 012004. IOP Publishing, 2020. https://doi.org/10.1088/1742-6596/1455/1/012004

[17] Krishnakumar, T. S., S. P. Viswanath, and Sajin Mathew Varghese. "Experimental studies on thermal and rheological properties of Al_2O_3-ethylene glycol nanofluid." *International Journal of Refrigeration* 89 (2018): 122-130. https://doi.org/10.1016/j.ijrefrig.2018.03.008

[18] Altun, Aycan, Osman Nuri Şara, and Barış Şimşek. "A comprehensive statistical approach for determining the effect of two non-ionic surfactants on thermal conductivity and density of Al_2O_3-water-based nanofluids." *Colloids and Surfaces A: Physicochemical and Engineering Aspects* 626 (2021): 127099. https://doi.org/10.1016/j.colsurfa.2021.127099

[19] Ma, Mingyan, Yuling Zhai, Peitao Yao, Yanhua Li, and Hua Wang. "Effect of surfactant on the rheological behavior and thermophysical properties of hybrid nanofluids." *Powder Technology* 379 (2021): 373-383. https://doi.org/10.1016/j.powtec.2020.10.089

[20] Li, X. F., D. S. Zhu, X. J. Wang, N. Wang, J. W. Gao, and H. Li. "Thermal conductivity enhancement dependent pH and chemical surfactant for Cu-H_2O nanofluids." *Thermochimica Acta* 469, no. 1-2 (2008): 98-103. https://doi.org/10.1016/j.tca.2008.01.008

[21] Kim, Man Bae, Hong Gen Park, and Chang Yong Park. "Change of thermal conductivity and cooling performance for water based Al_2O_3-surfactant nanofluid with time lapse." *International Journal of Air-Conditioning and Refrigeration* 26, no. 01 (2018): 1850009. https://doi.org/10.1142/S2010132518500098

[22] Mare, Thierry, Patrice Estelle, Salma Halelfadl, and Normah Mohd Ghazali. "Consideration of carbon nanotube-based nanofluid in thermal transfer." *Jurnal Teknologi* 78, no. 8-4 (2016). https://doi.org/10.11113/jt.v78.9583

[23] Lin, Cherng-Yuan, Jung-Chang Wang, and Teng-Chieh Chen. "Analysis of suspension and heat transfer characteristics of Al_2O_3 nanofluids prepared through ultrasonic vibration." *Applied Energy* 88, no. 12 (2011): 4527-4533. https://doi.org/10.1016/j.apenergy.2011.05.035

[24] Ghadimi, A., Rahman Saidur, and H. S. C. Metselaar. "A review of nanofluid stability properties and characterization in stationary conditions." *International Journal of Heat and Mass Transfer* 54, no. 17-18 (2011): 4051-4068. https://doi.org/10.1016/j.ijheatmasstransfer.2011.04.014

[25] Mahbubul, I. M., Rr Saidur, M. A. Amalina, and M. E. Niza. "Influence of ultrasonication duration on rheological properties of nanofluid: an experimental study with alumina-water nanofluid." *International Communications in Heat and Mass Transfer* 76 (2016): 33-40. https://doi.org/10.1016/j.icheatmasstransfer.2016.05.014

[26] Afzal, Asif, Ibrahim Nawfal, I. M. Mahbubul, and Sunil Siddalingappa Kumbar. "An overview on the effect of ultrasonication duration on different properties of nanofluids." *Journal of Thermal Analysis and Calorimetry* 135, no. 1 (2019): 393-418. https://doi.org/10.1007/s10973-018-7144-8

[27] Elfaghi, Abdulhafid M. A., Alhadi A. Abosbaia, Munir F. A. Alkbir, and Abdoulhdi A. B. Omran. "CFD Simulation of Forced Convection Heat Transfer Enhancement in Pipe Using Al_2O_3/Water Nanofluid." *Journal of Advanced Research in Numerical Heat Transfer* 8, no. 1 (2022): 44-49.

[28] Thirupathi, G., K. Govardhan, and G. Narender. "Radiative Magnetohydrodynamics Casson Nanofluid Flow and Heat and Mass Transfer past on Nonlinear Stretching Surface." *Journal of Advanced Research in Numerical Heat Transfer* 6, no. 1 (2021): 1-21. https://doi.org/10.3762/bxiv.2021.65.v1

[29] Farahani, Somayeh Davoodabadi, Mahdi Alibeigi, and Hamed Hossienabadi Farahani. "The Uniform Magnetic Field Efficacy on Heat Transfer of Nanofluid Flow in A Flat Tube." *Journal of Advanced Research in Numerical Heat Transfer* 5, no. 1 (2021): 9-27.

[30] Das, Pritam Kumar, Nurul Islam, Apurba Kumar Santra, and Ranjan Ganguly. "Experimental investigation of thermophysical properties of Al_2O_3-water nanofluid: Role of surfactants." *Journal of Molecular Liquids* 237 (2017): 304-312. https://doi.org/10.1016/j.molliq.2017.04.099

[31] Ma, Mingyan, Yuling Zhai, Peitao Yao, Yanhua Li, and Hua Wang. "Synergistic mechanism of thermal conductivity enhancement and economic analysis of hybrid nanofluids." *Powder Technology* 373 (2020): 702-715. https://doi.org/10.1016/j.powtec.2020.07.020

[32] Czitrom, Veronica. "One-factor-at-a-time versus designed experiments." *The American Statistician* 53, no. 2 (1999): 126-131. https://doi.org/10.1080/00031305.1999.10474445

[33] Singh, Santosh K., Sanjay K. Singh, Vinayak R. Tripathi, Sunil K. Khare, and Satyendra K. Garg. "Comparative one-factor-at-a-time, response surface (statistical) and bench-scale bioreactor level optimization of thermoalkaline protease production from a psychrotrophic Pseudomonas putida SKG-1 isolate." *Microbial Cell Factories* 10, no. 1 (2011): 1-13. https://doi.org/10.1186/1475-2859-10-114

[34] Mutalik, Snehal R., Bhalchandra K. Vaidya, Renuka M. Joshi, Kiran M. Desai, and Sanjay N. Nene. "Use of response surface optimization for the production of biosurfactant from Rhodococcus spp. MTCC 2574." *Bioresource Technology* 99, no. 16 (2008): 7875-7880. https://doi.org/10.1016/j.biortech.2008.02.027

[35] Wanatasanapan, V. Vicki, M. Z. Abdullah, and P. Gunnasegaran. "Effect of TiO_2- Al_2O_3 nanoparticle mixing ratio on the thermal conductivity, rheological properties, and dynamic viscosity of water-based hybrid nanofluid." *Journal of Materials Research and Technology* 9, no. 6 (2020): 13781-13792. https://doi.org/10.1016/j.jmrt.2020.09.127

[36] Kumar, Vivek, and Jahar Sarkar. "Particle ratio optimization of Al_2O_3-MWCNT hybrid nanofluid in minichannel heat sink for best hydrothermal performance." *Applied Thermal Engineering* 165 (2020): 114546. https://doi.org/10.1016/j.applthermaleng.2019.114546

[37] Kumar, Vivek, and Jahar Sarkar. "Experimental hydrothermal behavior of hybrid nanofluid for various particle ratios and comparison with other fluids in minichannel heat sink." *International Communications in Heat and Mass Transfer* 110 (2020): 104397. https://doi.org/10.1016/j.icheatmasstransfer.2019.104397

[38] Malika, Manjakuppam, and Shriram S. Sonawane. "Application of RSM and ANN for the prediction and optimization of thermal conductivity ratio of water based Fe_2O_3 coated SiC hybrid nanofluid." *International Communications in Heat and Mass Transfer* 126 (2021): 105354. https://doi.org/10.1016/j.icheatmasstransfer.2021.105354

[39] Zhang, Yanbin, Changhe Li, Dongzhou Jia, Dongkun Zhang, and Xiaowei Zhang. "Experimental evaluation of the lubrication performance of MoS_2/CNT nanofluid for minimal quantity lubrication in Ni-based alloy grinding." *International Journal of Machine Tools and Manufacture* 99 (2015): 19-33. https://doi.org/10.1016/j.ijmachtools.2015.09.003

[40] Çiftçi, Erdem. "Distilled water-based AlN+ ZnO binary hybrid nanofluid utilization in a heat pipe and investigation of its effects on performance." *International Journal of Thermophysics* 42, no. 3 (2021): 1-21. https://doi.org/10.1007/s10765-021-02792-2

[41] Xie, Hongmei, Bin Jiang, Bo Liu, Qinghang Wang, Junyao Xu, and Fusheng Pan. "An investigation on the tribological performances of the SiO_2/MoS_2 hybrid nanofluids for magnesium alloy-steel contacts." *Nanoscale Research Letters* 11, no. 1 (2016): 1-17. https://doi.org/10.1186/s11671-016-1546-y

[42] Siddiqui, Farooq Riaz, Chi Yan Tso, Sau Chung Fu, H. H. Qiu, and Christopher YH Chao. "Evaporation and wetting behavior of silver-graphene hybrid nanofluid droplet on its porous residue surface for various mixing ratios." *International Journal of Heat and Mass Transfer* 153 (2020): 119618. https://doi.org/10.1016/j.ijheatmasstransfer.2020.119618

[43] Siddiqui, Farooq Riaz, C. Y. Tso, Ka Chung Chan, Sau Chung Fu, and Christopher YH Chao. "On trade-off for dispersion stability and thermal transport of Cu- Al_2O_3 hybrid nanofluid for various mixing ratios." *International Journal of Heat and Mass Transfer* 132 (2019): 1200-1216. https://doi.org/10.1016/j.ijheatmasstransfer.2018.12.094

[44] Nasirzadehroshenin, Fatemeh, Heydar Maddah, and Hossein Sakhaeinia. "Experimental and theoretical investigation of thermophysical properties of synthesized hybrid nanofluid developed by modeling approaches." *Arabian Journal for Science and Engineering* 45, no. 9 (2020): 7205-7218. https://doi.org/10.1007/s13369-020-04352-6