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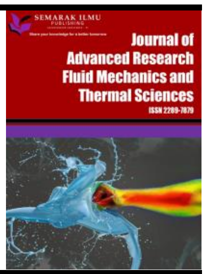

Thermal Conductivity-Based Optimisation of Surfactant on Hybrid Nanofluid

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ABSTRACT

A surfactant is an efficient approach for increasing the stability of nanofluids. However, excessive surfactant degrades the hybrid nanofluid's outstanding thermal conductivity. Additionally, there was only a little research on optimising the amount of surfactant used in nanofluids depending on their thermal conductivity. As a result, it is critical to ensure that the created nanofluid is stable without impairing thermal conductivity. The optimisation was carried out in this study utilising Design Expert 11. Surfactant ratios and the mixing ratio of hybrid nanofluid were employed as variables, while thermal conductivity was used as the response. Additionally, the concentration and temperature of the hybrid nanofluid remained constant at 0.5 vol% and 40 °C, respectively. The results indicate that a 1:10 ratio of surfactant to TiO2 is the optimal proportion for the generated TiO_2-GNP hybrid nanofluid. The correct amount of surfactant results in a hybrid nanofluid with high thermal conductivity and good stability.

1. Introduction

Surfactant is one of a method to improve the stability of a nanofluid. Surfactant or dispersant is a popular and economical method to enhance nanofluids' stability by affecting the mixture's surface characteristics [1-3]. 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 typically consists of the hydrophobic tail, usually long-chain hydrocarbon, and 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 [4]. Surfactants also increase wettability, which is the interface conjunction of two materials, introducing a degree of continuity between the two-phase systems [5]. Apart from their capability, surfactants have several downsides when used at high temperatures [6]. At high temperatures above 60 ^oC, the bonding between surfactant and

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nanoparticle can damage [7,8], resulting in the nanofluid losing its stability and changing its thermal physical properties and nanoparticle concentration due to sedimentation and agglomeration [8].

Next, the addition of surfactant in a based fluid can decrease its thermal conductivity. Baek *et al.,* [9] found that the addition of SDBS in distilled water decreased thermal conductivity by 2.1%. Thus, exceeding the amount of surfactant dispersed in the nanofluid reduces its thermal conductivity, making it unsuitable for cooling due to the surfactant's low 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. Mingzheng *et al.,* [10] also mentioned that viscosity of polyvinylpyrrolidone (PVP) solution at 4.0 wt.% is about twice than that of water. 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. High thermal conductivity with low viscosity will give the best heat transfer performance of nanofluid and hybrid nanofluid [11-13].

Few pieces of research investigated the optimum amount of surfactant for the prepared nanofluid. The thermal conductivity of nanofluid prepared by Tilak *et al.,* [14] 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.,* [15] 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. Zhai *et al.,* [16] found that the prepared nanofluids with PVP surfactant provide the best stable suspensions due to polymeric chain interaction. With the increase in PVP surfactant concentration, both viscosity and thermal conductivity firstly increase up to a maximum value, after which, it decreases. Ghadimi *et al.,* [17] done optimization of nanofluid parameter according to the thermal conductivity based on surfactant and duration of ultrasonic vibration. The results showed that 3 hours of ultrasonic bath procedure with 0.1 wt.% surfactant addition can provide the most stable suspension with the best thermal conductivity for subsequent applications within 1 month. 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.

It is vital to ensure the prepared hybrid nanofluid is stable for an extended period and does not significantly affect the thermal conductivity. The present study objective is to evaluate the stability of the hybrid nanofluid effect on thermal conductivity.

2. Methodology

2.1 Preparation of Hybrid Nanofluid

A two-step method was used to produce the hybrid nanofluid using Eq. (1). First, a balance is used, AS 310.R2 PLUS Analytical Balance, to prepare the hybrid nanofluid as show in Figure 1. The concentration used for this experiment is 0.5 vol% only with different ratios of TiO_2 and GNP, which were 1:9 up to 9:1 dispersed in distilled water. This concentration is expected to be the highest concentration used in this study. Therefore, if good stability of the hybrid nanofluid can be achieved using this concentration, the stability of the lower concentration is good.

$$\emptyset = \frac{\omega \rho_{bf}}{\left(1-\frac{\omega}{100}\right)\rho_{np} + \frac{\omega}{100}\rho_{bf}} \tag{1}$$

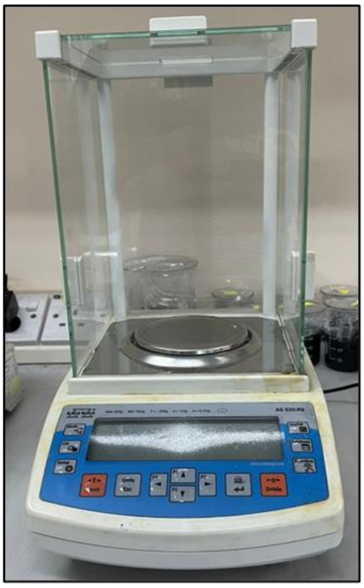

Fig. 1. Analytics balance

Furthermore, the amount of surfactant utilised was based on the weight ratio with TiO_2, which was 1:10 up to 1:1. The ratio of 1:10 was used as the based parameter based in the study by Das *et al.,* [19], where the prepared TiO_2-water nanofluid has good stability for more than 500 hours using 1:10 of CTAB. Then, samples with good stability will be used for the thermal conductivity measurement.

Firstly, the required amount of surfactant was mixed with distilled water until it dissolved completely in water using a magnetic stirrer. The colour of the solution becomes apparent as the surfactant is completely dissolved. After that, the required amount of TiO_2 and GNP was mixed and let the solution stir for 15 minutes. The presence of surfactant dissolved in the distilled water help the nanoparticles and distilled water become homogeneous. However, using the magnetic stirrer was not enough to make the solution homogeneous. Therefore, the mixture was mixed using Ultrasonic Probe (FS-1200 N, frequency: 20 kHz, power output: 1200 W, 18mm probe) for 90 minutes to achieve a better homogeneous solution. The setup for the ultrasonic probe is shown in Figure 2.

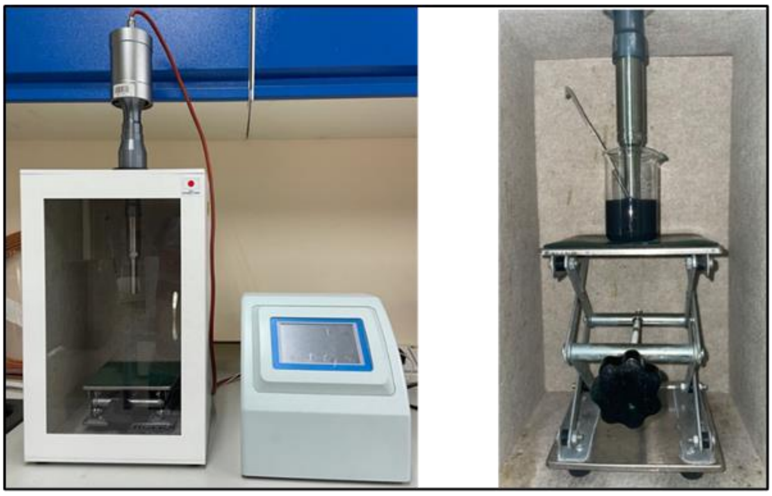

Fig. 2. Ultrasonic probe

2.2 Stability Analysis

After the preparation of the samples, the stability analysis was done using the sedimentation observation method. The sample was left for 30 minutes, and any sedimentation or physical changes were examined to ensure that the solutions were stable. This analysis was essential to ensure the accurate reading of the thermal conductivity measurement of the hybrid nanofluid. The low stability of the hybrid nanofluid can cause a high error reading during thermal conductivity measurement.

2.3 Thermal Conductivity Measurement

A design of experiment (DOE) was developed using Design Expert 11 software for 0.5 vol% hybrid nanofluid, at 40 ^oC, 1:9 to 9:1 (TiO_2 : Graphene) ratio with center point, and the amount of surfactant with two-level based on the results from the stability analysis. Therefore, this study prepared only three mixing ratios of hybrid nanofluid, which are 1:9, 1:1, and 9:1. The thermal conductivity of nanofluid was measured using KD2 Pro, which was a transient hot-wire method. In this study, a KS1 sensor was used, and it had an uncertainty of ±10.0% as it was the most suitable sensor for liquid analysis. Regarding equipment validation, the KS1 sensor was tested using a glycerin sample at a temperature of 20 ^oC provided by the supplier. The result was accurate to within a 2% error. Before starting the thermal conductivity measurement, the sample was put in an ultrasonic bath (Elmasonic S100H) to ensure that the sample was homogeneous to have an accurate measurement. Three replication and random run were set to increase the accuracy of results and avoid bias. The thermal conductivity setup is shown in Figure 3.

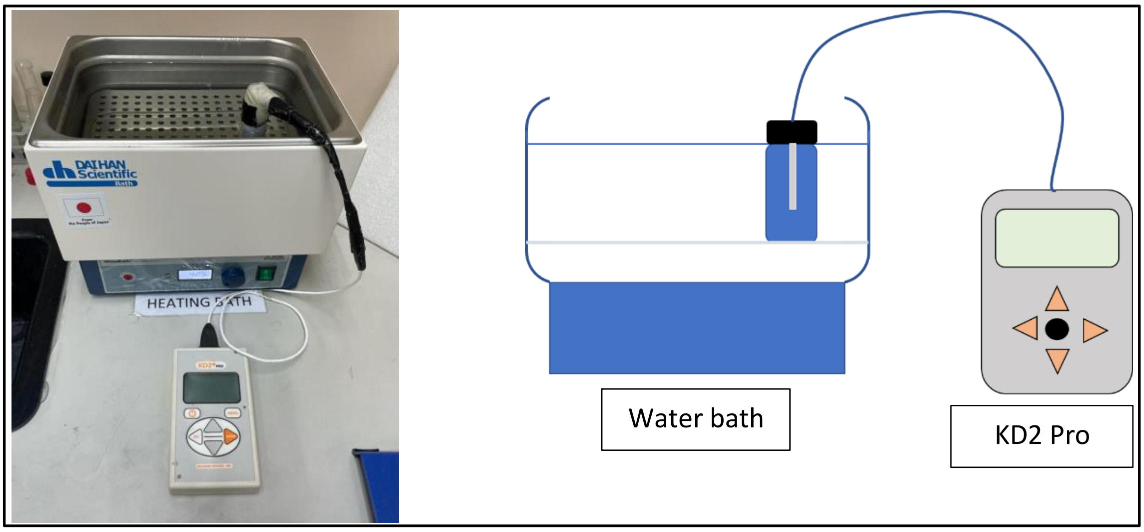

Fig. 3. Thermal conductivity measurement setup

3. Results and Discussions

3.1 Stability Analysis

Several samples of the hybrid nanofluid had been prepared with different amounts of surfactant to determine the optimised amount of surfactant for the prepared hybrid nanofluid. Figure 4 shows the stability analysis for the samples with a 1:1 amount of surfactant. Sample 1:1 surfactant (TiO_2) and 1:1 surfactant (GNP) was mono-nanofluid samples. After preparation, the samples looked homogeneous. However, after 30 minutes, a noticeable amount of nanoparticles sediment was visible for samples 1:1 surfactant (TiO_2) and 1:1 surfactant (9:1 hybrid nanofluid ratio). However,

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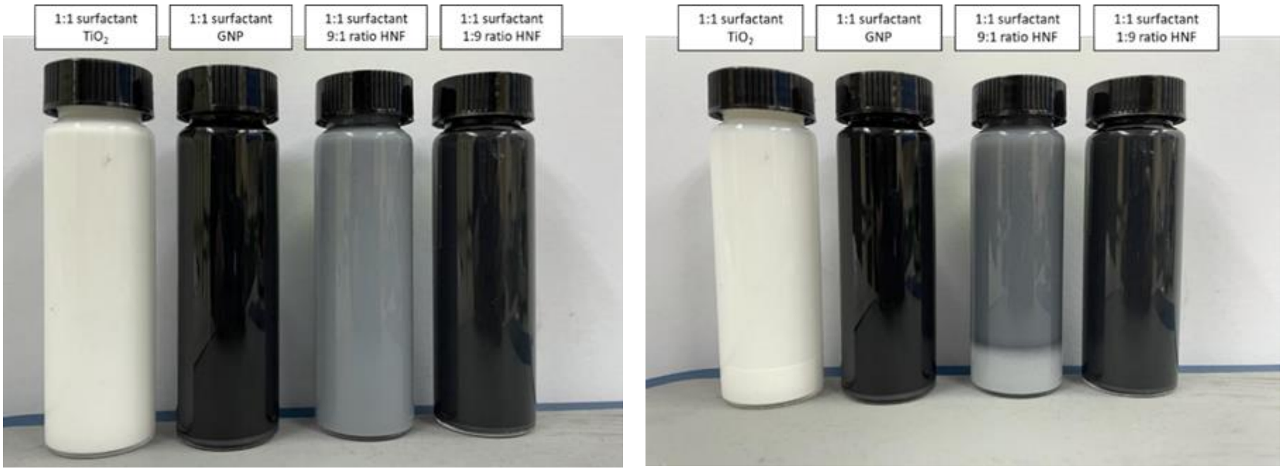
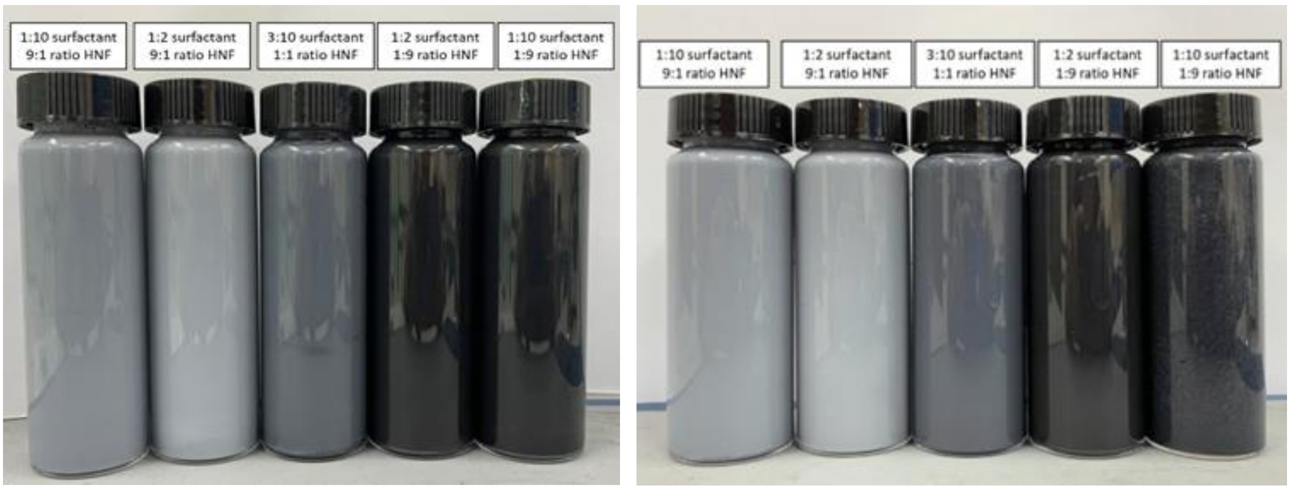
other samples did not show any significant sedimentation because the surfactant has a higher impact on the TiO_2 than GNP. Furthermore, an excessive amount of surfactant disrupts nanoparticle suspension stability in the hybrid nanofluid. Therefore, a lower amount of surfactant was used, which was 1:2.



(a) (b)

Fig. 4. Sedimentation analysis for 1:1 surfactant (a) 0 min (b) 30 minutes

Next, optimisation analysis includes three samples with a surfactant amount of 1:2 as maximum, 1:10 as a minimum, and 3:10 as the centre point for optimisation. Figure 5 shows that the prepared samples had no significant sedimentation visible after 30 minutes. Therefore, the samples prepared were stable to measure the thermal conductivity.



(a) (b)

Fig. 5. Sedimentation analysis for 1:2, 1:10, and 3:10 surfactant (a) 0 min (b) 30 minutes

3.2 Analysis of Variance (ANOVA)

After conducting the thermal conductivity measurement for full factorial design, the response collected is shown in Table 1. All available terms are selected for the ANOVA analysis at the half-normal plot: A – TiO_2, B – Surfactant Ratio, and AB. The terms are selected from the largest effect to the lowest effect. The sequence is A>B>AB, as shown in Figure 6. Before proceeding to ANOVA analysis, the presence of curvature is checked to make sure the factorial model generated is accurate.

If the curvature test is significant, a quadratic or higher-order model is required to model the relationship between the factors and the response. If the curvature test is not significant, it is okay to assume that the linear model fits in the middle of the design space. If the curvature is significant, augmenting the design to a response surface design is recommended to generate a better model. However, based on Table 2, proceeding with the analysis is acceptable.

ANOVA table is commonly used to summarise the test for significance of the regression model, test for significance on individual model coefficients, and test for lack-of-fit. Based on the input and the output value from Table 1, Table 2 demonstrates the ANOVA for thermal conductivity.

Table 1
Design of Experiment

Run	TiO_2 / Mixing ratio		Surfactant Ratio (%)	Thermal Conductivity (W/mK)
	TiO_2 (g)	Mixing ratio		
1	0.793719	9:1	0.1	0.8401
2	0.793719	9:1	0.5	0.815
3	0.440955	1:1	0.3	0.8417
4	0.793719	9:1	0.5	0.792
5	0.088191	1:9	0.1	0.9389
6	0.793719	9:1	0.5	0.8019
7	0.440955	1:1	0.3	0.8484
8	0.088191	1:9	0.5	0.8824
9	0.793719	9:1	0.1	0.8215
10	0.088191	1:9	0.5	0.8918
11	0.440955	1:1	0.3	0.8771
12	0.088191	1:9	0.1	0.8963
13	0.088191	1:9	0.5	0.8663
14	0.793719	9:1	0.1	0.8303
15	0.088191	1:9	0.1	0.9098

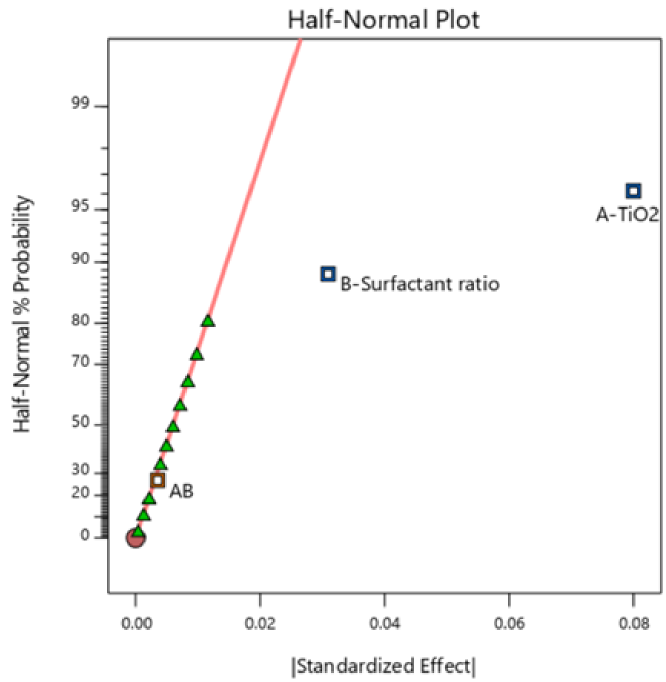


Fig. 6. Half-Normal plot

Table 2
ANOVA table for thermal conductivity measurement

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	0.0225	3	0.0075	30.96	< 0.0001	significant
A-TiO_2	0.0196	1	0.0196	80.66	< 0.0001	
B-Surfactant ratio	0.0029	1	0.0029	12.07	0.0060	
AB	0.0000	1	0.0000	0.1587	0.6987	
Curvature	5.104E-06	1	5.104E-06	0.0210	0.8876	
Pure Error	0.0024	10	0.0002			
Cor Total	0.0250	14				

After gathering all of the data, the analysis continued by analysing the generated ANOVA table for the test for significance of the regression model, test for significance on individual model coefficients, and test for the lack-of-fit. Based on Table 2, the p-value for the model is less than 0.05, which indicates that the model is significant. Next, P-values less than 0.0500 indicate model terms are significant. Therefore, A and B are significant model terms, while AB and curvature are not significant. Therefore, these not significant terms can be removed to improve the model. The new ANOVA table is generated as shown in Table 3. The Predicted R^2 is in reasonable agreement with the Adjusted R^2, which has a difference of less than 0.2. Therefore, these models can be used to navigate the design space. After analysing the ANOVA table, the final empirical models for thermal conductivity with mixing ratio and surfactant ratio for 0.5 vol% at 40 ^oC are shown in Eq. (2).

$$Thermal\ conductivity\ = 0.8569 - 0.0404A - 0.0156B \quad (2)$$

Table 3
New ANOVA table for selected factorial model (response: thermal conductivity measurement)

ANOVA						
Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	0.0225	2	0.0113	54.66	< 0.0001	significant
A-TiO_2	0.0196	1	0.0196	95.09	< 0.0001	
B-Surfactant ratio	0.0029	1	0.0029	14.23	0.0027	
Residual	0.0025	12	0.0002			
Lack of Fit	0.0000	2	0.0000	0.0899	0.9148	not significant
Pure Error	0.0024	10	0.0002			
Cor Total	0.0250	14				
Fit Statistics						
R^2	0.9011					
Adjusted R^2	0.8846					
Predicted R^2	0.8475					
Adeq Precision	17.4585					

3.3 Effect of Surfactant on The Thermal Conductivity of Hybrid Nanofluid

Figure 7 shows the effect of surfactant on the thermal conductivity based on Eq. (2) and the actual average results from Table 1. As the amount of surfactants increases, the thermal conductivity measurements decrease because low thermal conductivity surfactants affect the thermal conductivity of the prepared hybrid nanofluid. Therefore, the higher the amount of surfactant, the lower the thermal conductivity of the prepared hybrid nanofluid. Furthermore, the presence of surfactants surrounding the suspended nanoparticles decreases the interface layer thermal conductivity of the suspended nanoparticles. Therefore, the heat transfer between the particles and Brownian motion decreases. These findings were supported by the previous study on the optimisation of the amount of surfactant based on thermal conductivity of nanofluid by Tilak *et al.,* [14] and Ma *et al.,* [20]. Therefore, from this study, the best amount of surfactant is 1:10.

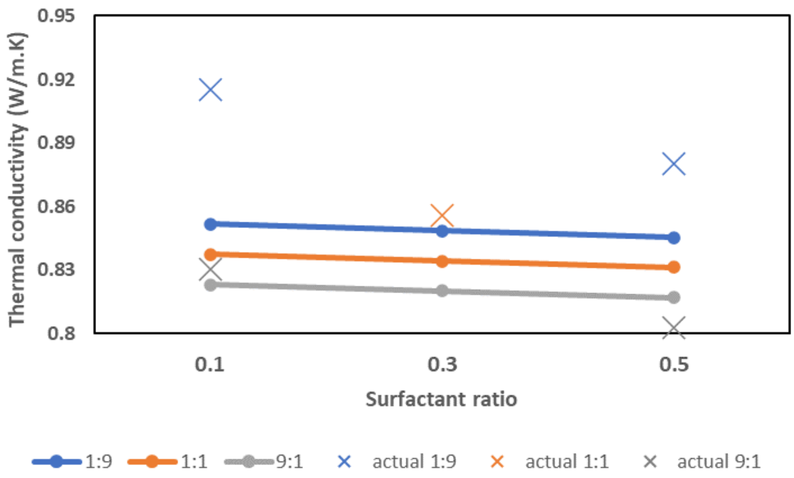


Fig. 7. Effect of surfactant ratio on thermal conductivity

4. Conclusions

This research aims to evaluate the effect of surfactants on the thermal conductivity of hybrid nanofluid. The results showed that the prepared hybrid nanofluid was stable for 30 minutes using surfactant and ultrasonic vibration. Next, an experiment on the effect of the amount of surfactant on the thermal conductivity using Design Expert 11 for the design of the experiment showed that as the amount of surfactants increases, the thermal conductivity decreases. Therefore, the optimum value for surfactant is a 1:10 ratio.

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