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Thermal Properties Investigation of Nanocellulose for Liquid Cooling

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ABSTRACT

It is convinced by numerous researchers that nanofluid may enhance heat transfer especially in those heat related engineering applications that acquire quick thermal responses such as in a Central Processing Unit (CPU) liquid cooling system. The main purpose of this research is to measure thermophysical properties of nanofluid with different concentration ratios but at constant weightage ratio of 7.4 %. Thermal conductivity is the thermophysical property that was measured within a certain range of temperatures in order to determine how it was affected by the variation in temperatures. KD2 Pro thermal analyzer was used to measure thermal conductivity of nanocellulose from 30 - 60°C. The main nanofluid used was nanocellulose from Blue Goose Biorefineries INC. The nanocellulose was mixed with distilled water with a concentration of 0.1 - 1.3 %. With a better enhancement in the thermal conductivity compared to that of the base fluid when it existed alone, thus this nanofluid is believed to contribute for a better heat transfer rate as a coolant, so that it can be applied in a CPU liquid cooling system.

1. Introduction

In a fast pace technological era where each and every technology is undergoing innovation so as to make each of them perform better at a higher responsive time, this includes the usage of daily devices such as mobile phones, laptops and computers. These devices not only perform better from time to time but are also becoming smaller in size as researchers found a way developing and compressing a tiny microchip into a CPU of a computer, for example [8]. Due to this cramping of electric circuits inside a small compartment the circuits can generate an excessive heat when run at a full capacity. The conventional cooling system of CPU which uses fan will not be able to sufficiently cool down a high-performance gaming CPU, running at full overclock. Thus, to tackle this problem, liquid cooling was presented. Basically, liquid cooling has been popularly used in radiators of motor vehicles. It has been proven to be able to dissipate heat more efficiently compared to that with air

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cooling [9]. However, conventional liquid-cooled system uses water or liquid chemical as the coolant. These types of chemical coolant can be harmful, dangerous and bad for the environment.

To further enhance this technology, instead of using plain distilled water or chemical coolant, the usage of nanofluid was introduced. Whereby nanofluid has a higher heat capacity than water thus being much more efficient in cooling the CPU [10]. This could be a breakthrough for a new cooling technology in CPU cooling as more and more advance CPU will be invented in the future, this could be the key to the cooling solution.

Nanofluid was first coined by Choi *et al.,* [1] who were the pioneers among researchers to perform investigation on this new type of engineered fluid. They believed that it could provide efficient heat transfer enhancement compared to that provided by the conventional fluid. In simpler meaning, nanofluid can be justified as the dispersion of metallic or non-metallic with size less than 100 nm into a base liquid and it may contribute to effective flow of mixing and higher thermal conductivity compared to conventional fluid [2]. The enhancement in heat transfer properties was due to the considerable improvement in thermal conductivity. The thermal conductivity of nanofluid increases due to addition of higher thermal conductivity nanoparticles and due to Brownian motion of nanoparticles in the base fluid [3].

From past decades, investigations on nanofluids have been made in many engineering applications such as electrical equipment, domestic refrigerator, grinding, vehicle brake fluids and heat exchanger. However, many fields which are related with this novel nanotechnology acquire more effective engineered fluid in order to match with their corresponding implementation area. Nanofluids now are also applied as coolant in many purposes such as in solar panels and in CPU.

2. Literature Review

The term of nanofluid is nothing but familiar with heat transfer researchers nowadays. This is because this fluid has been used in numerous studies and applications in order to replace conventional heat transfer fluid such as water, oil and ethylene glycol due to its better heat transfer and flow characteristics. Choi *et al.,* [1] introduced an advanced fluid that is believed to offer us its ability by exhibiting high thermal conductivity compared to those of currently used heat transfer fluids. It is called nanofluid whereas an extension of nanotechnology, are fluids obtained by dispersing solid nanoparticles into base fluid.

In past decades, with more desirable demands for effective heat transfer performance, newly types of nanofluid have been investigated by researchers. The fluid is proven to have better thermal conductivity and heat transfer performance than both mono nanofluid and base fluid. By dispersing two different types of nanoparticles into base fluid, "Hybrid nanofluid" is produced in which the dispersed nanoparticles are combined with both physical and chemical properties and presented in a homogenous phase [4].

With the success result of the investigation on nanofluid characteristics, it has been widely used in many engineering applications such as electronic cooling, engine cooling/vehicle thermal management, generator cooling, coolant in machining, welding, nuclear system cooling, lubrication, thermal storage, solar heating, cooling and heating in buildings, transformer cooling, biomedical, drug reduction, heat pipe, refrigeration, space, defense and ships. Nevertheless, limited research is conducted on hybrid nanofluid as the new type of fluid is currently in its development phase of performance evaluation.

Cellulose is one of the sustainable raw materials and natural polymers as it can be found abundantly in biomass products. Nanocellulose is classified as cellulosic materials in the nanometer range with at least one dimension [8]. Despite being a green material, it also has a large surface area, high strength and low-density extensive chemical modification. Nanocellulose is one of the nanoparticles that can be dispersed in base fluid for heat transfer application. One of the usages is in liquid cooling of CPU. Therefore, this work aimed to investigate the stability of nanocellulose in base fluid and its thermal performance for heat transfer application.

2.1 Stability Enhancer

Stability of nanofluid is very important for the reason of practicality of the substance. If the solution is not stable, sedimentation will form after being left for a period of time. This can cause much trouble when applying this unstable nanofluid as a coolant as it can damage the cooling system by clogging the pathway. In order to achieve a better stability of nanocellulose fluid, surfactant shall be added to the solution. As for this study, Triton X-100 was used as the main surfactant. According to study by Menlik *et al.*, [6] the presence of surfactant Triton X-100 can increase the stability of nanofluid. However, there is no research done yet to prove that surfactant Triton X-100 can increase the stability of nanocellulose. Therefore, in this study two sets of nanocellulose were prepared to analyze the differences of stability between absence of surfactant and the presence of surfactant.

2.2 Thermophysical Properties

In order to carry out the simulations for nanofluid, the effective thermophysical properties of nanofluids [5] must be calculated first. In this case, the nanocellulose being used was cellulose nanocrystal. Basically the required properties for simulations are effective thermal conductivity (kefs), effective dynamic viscosity (Heff), effective mass density and effective specific heat. Regarding these, the effective properties of mass density, specific heat, thermal conductivity and viscosity are calculated according to the mixing theory.

3. Methodology

Background problem of this research was identified and the literature review was thoroughly analyzed in order to find the best methodology proposed by previous researchers. Methodology of nanofluid sample preparation, thermophysical properties measurements and data analyses were obtained from previous researches.

The Figure 1 summarized the methodology flow chart of the research. A sample of cellulose nanocrystals from Blue Goose Biorefineries INC. with a weight concentration of 7.4 % in the form of aqueous suspension was mixed with distilled water to produce the nanofluid. It was further used to investigate the stability and thermophysical properties of those samples.

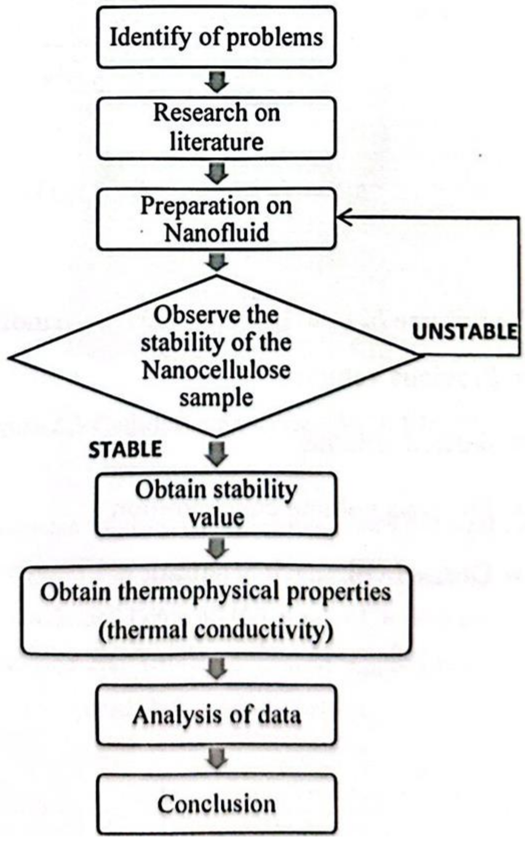


Fig. 1. Methodology flow chart

3.1 Preparation of Nanofluid

At the first stage of nanofluid preparation experiment, samples of cellulose nanocrystal with 7.4 % weightage concentration was prepared. The nanofluid was set using a two-step method [7] process as in Figure 2. Dilution method was used to reduce the concentration of the nanofluid to several lower values. The dilution process was then calculated.

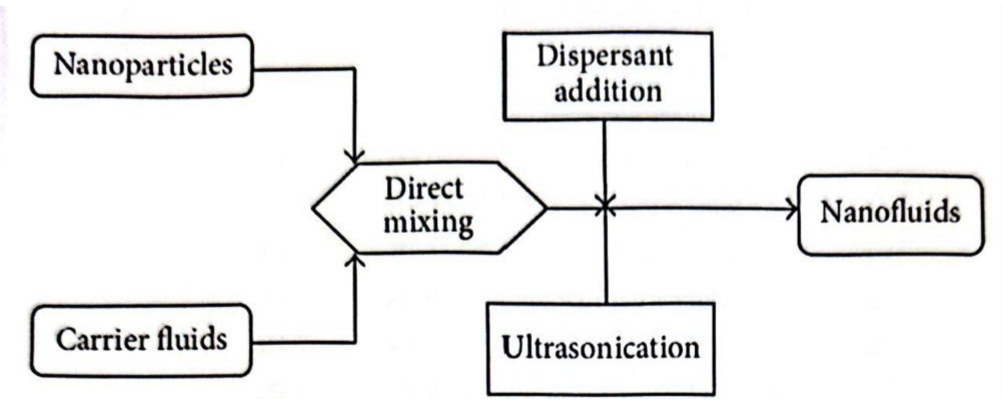


Fig. 2. Typical two-step method process

In the second stage, cellulose nanocrystal was prepared with 4 different concentrations which were each at 0.1 %, 0.5 %, 0.9 % and 1.3 % with no surfactant. The other 4 samples with stated concentration with added surfactant Triton X-100 at ratio 1 %. The selected samples were the one that is stable and can withstand against agglomeration within three weeks observation period. Samples prepared were labelled as in Table 1.

Table 1
Samples of nanofluid prepared

Sample	Nanofluid	Concentration (%)	Wt (%)
1	Nanocellulose	0.1	7.4
2	Nanocellulose	0.5	7.4
3	Nanocellulose	0.9	7.4
4	Nanocellulose	1.3	7.4
5	Nanocellulose with Triton	0.1	7.4
6	Nanocellulose with Triton	0.5	7.4
7	Nanocellulose with Triton	0.9	7.4
8	Nanocellulose with Triton	1.3	7.4

3.2 Tools and Platforms

The following figures below are the apparatuses that are used to prepare the nanofluids. Average time taken to prepare for one sample of nanofluid was approximately around three hours. Magnetic stirrer is an equipment used to stir the nanocellulose and the base fluid to produce a nanofluid solution. The operation consists of timer and speed settings. For each of the sample preparation, base fluid was stirred for 10 mins at a speed of 300 rpm. After that, nanocellulose was added into the base fluid and stirred for 30 mins or longer at an increased speed of 450 rpm or higher, depending on the viscosity of the nanofluid prepared.

After the nanocellulose was well-stirred, the next process is subjecting the samples to ultrasonic vibration using the ultrasonic homogenizer for 2 hours which generates ultrasonic waves of 400 W at 24 kHz in order to obtain a uniform suspension of particles in the base fluid. Ultrasonic Bath Elmasonic S100H was applied to perform sonication process in order to homogenize the sample. The minimum homogenizer sonication time required for the nanofluid was 2 hours. The samples were then ready to be tested for further evaluation.

3.3 Experimental Setup

The experiment started after completing the nanocellulose samples preparation as in Figure 3. A total of 8 samples were to be tested for stability evaluation with the comparison of nanocellulose without surfactant and with the presence of surfactant Triton X-100. After collecting results for stability evaluation, the samples with better stability were tested in thermal conductivity evaluation. The samples were then compared with distilled water to study its thermal conductivity at temperatures ranging from 30 - 70°C.

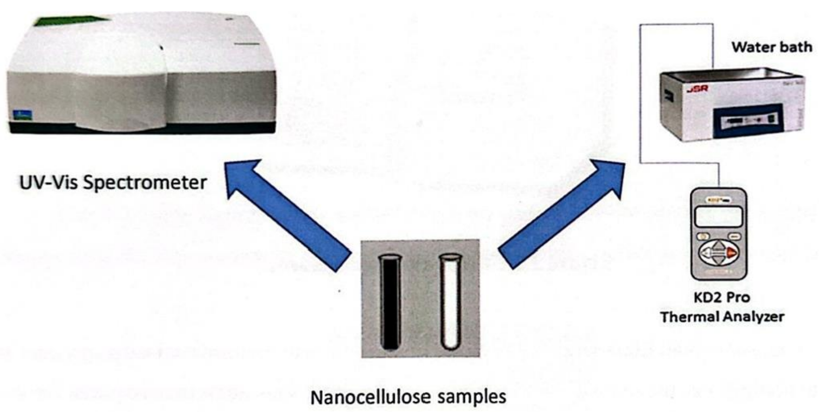


Fig. 3. Experimental setup

3.4 Stability Observation and Measurement

Observation on the stability of those nanofluids was to be recorded within a 2 - 3 weeks duration. For the preparation of the nanofluid, four samples of cellulose nanocrystal were added in four different concentrations of 0.1 %, 0.5 %, 0.9 % and 1.3 % respectively, and another 4 samples with Triton X-100. Presence of sedimentation will be recorded to identify which concentration is the best for the nanofluid.

3.5 Absorbance Drop Analysis

Stability test was conducted by using spectrophotometry method's absorbance drop evaluation [10-14]. Samples that were selected to be tested on this equipment are the one that have passed stability test observation. To out carry this analysis, ultraviolet-visible (UV-Vis) spectrophotometry equipment was needed. Analysis could not be done in MJIIT because equipment was unavailable. Therefore, analysis were done at Sunway University in Advanced Nano-Materials & Energy Research lab. The absorbance drop was calculated using formula in Eq. (1),

(Absorbance day, n / Absorbance day, 0) or (Cn/CO) (1)

3.6 Thermal Conductivity

Figure 4 shows the KD2 Pro thermal analyzer which operates on modified transient hot wire equipment was used by most of the researchers. It uses the transient line heat source method to measure thermal conductivity, resistivity, diffusivity and specific heat. The KD2 equipment consists of a handheld controller and needle like sensors which acts as sensor and heat source that can be inserted into the medium to be measured. The controller waits for 30s after pressing the start button to ensure temperature stability and then heats the probe for 30s. It then monitors the cooling rate for 30s. Finally, the controller computes the thermal conductivity using the change in temperature [11].

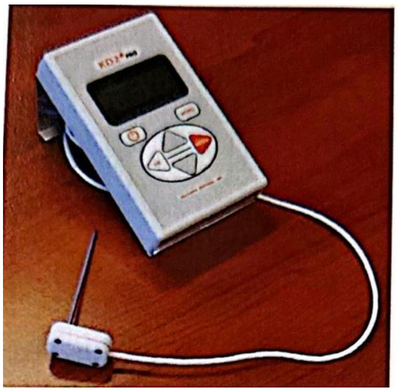


Fig. 4. KD2 Pro thermal analyzer and KS-1 sensor

Reading of thermal conductivity of samples 1, 4, 5, 6, 8 and 9 were taken from 30 - 60°C by using water bath to do the heating process for the samples as in Figure 5. It is to investigate the effect of different temperature on the thermal conductivity. Sample of base fluid was measured together in order to investigate the enhancement in terms of thermal conductivity of nanofluid compared to conventional fluid. The reading was taken for three times to gain the average value of the thermal conductivity with controlled errors. KS-1 sensor was applied to take the reading of those samples.

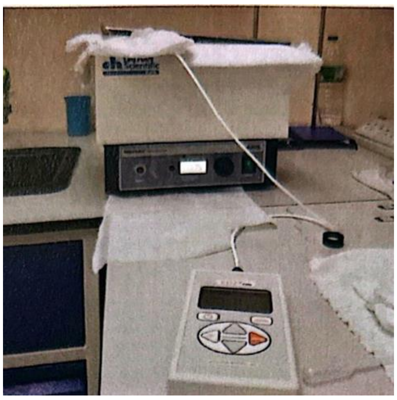


Fig. 5. Thermal conductivity measurement setup

4. Results and Discussion

4.1 Stability Result

From the data collected, it was found that using surfactant Triton X-100 proves that it can increase the stability on nanocellulose in water. So, for the thermal conductivity test, only nanocellulose with added surfactant will be tested as it has a stable property compared to nanocellulose without surfactant as depicted in Figure 6.

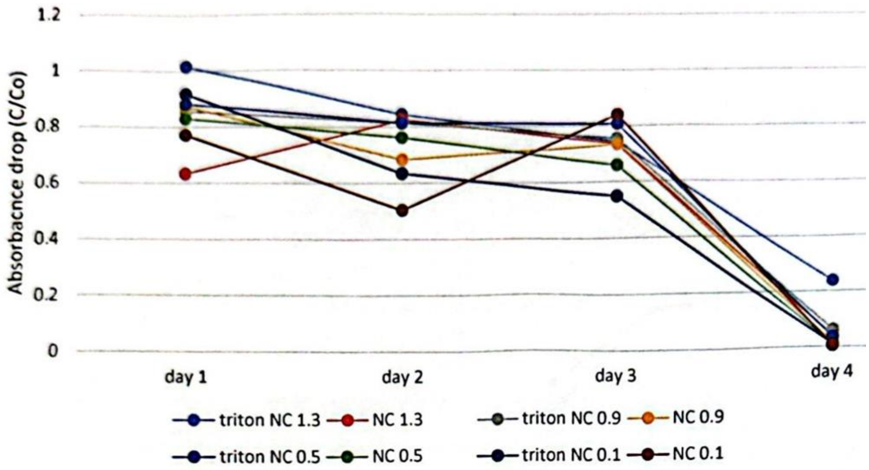
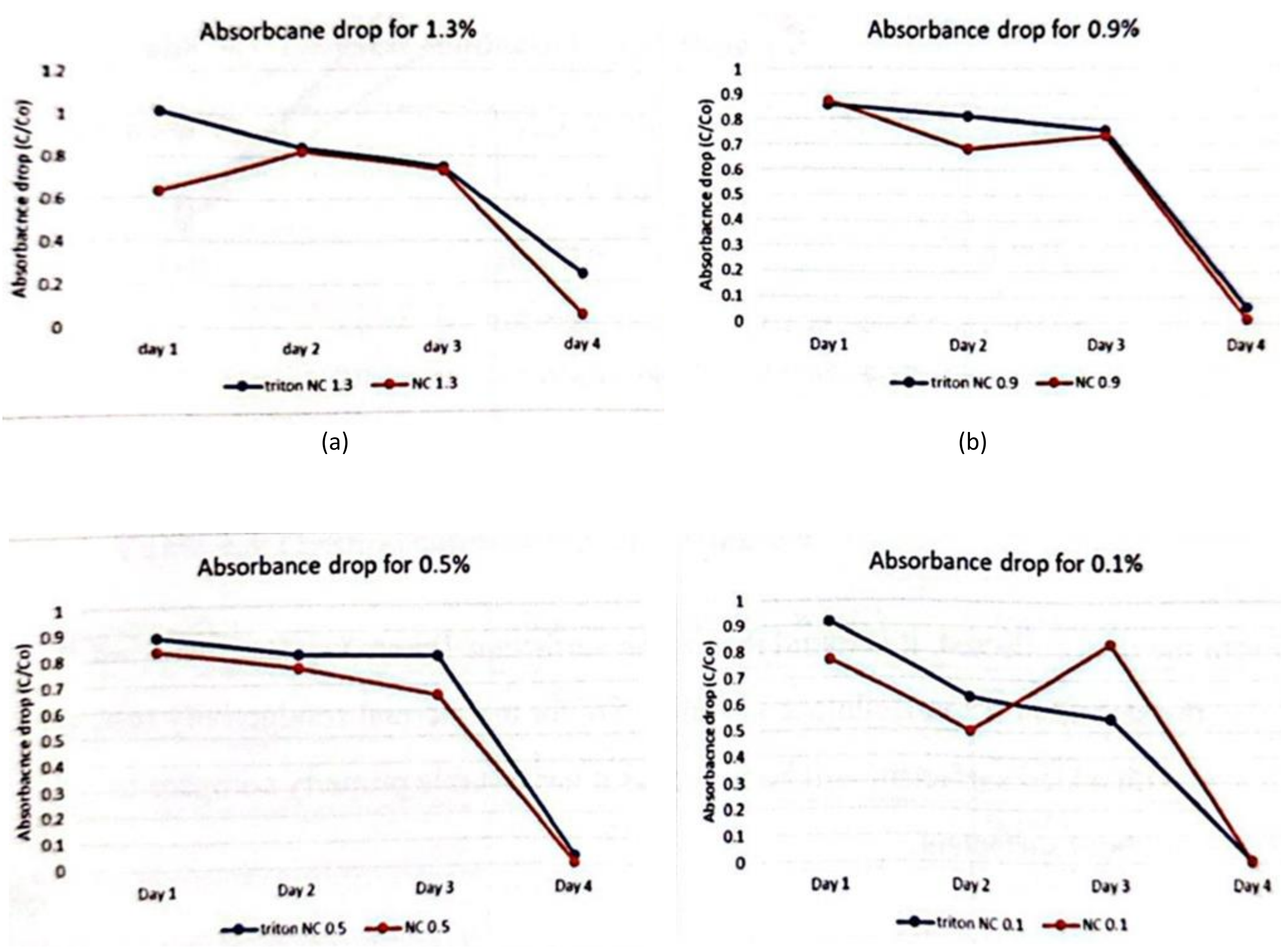


Fig. 6. Summary graph for absorbance drop

From the graphs shown in Figure 7, it was found that all samples with added Trition X-100 as surfactant showed a lower absorbance drop ratio compared to samples with no surfactant added. Exception for graph d) which shows a spike for NC at day 3 which may due to error in reading. But in day 4 the graph falls below the Trition X-100 level.



(a) (b)

(c) (d)

Fig. 7. Absorbance drop of nanocelullose with (Triton X-100) and without (NC) surfactant across 4 days duration (a) 1.3 % concentration (b) 0.9 % concentration (c) 0.5 % concentration and (d) 0.1 % concentration

4.2 Thermal Conductivity

In this test, nanocellulose with added surfactant Triton X-100 was tested and were compared with distilled water. Thermal conductivity of every sample was measured at temperatures 30°C, 40°C, 50°C, 60°C and 70°C using KD2 Pro. Table 2 to 6 are the results from this investigation.

Table 2
Thermal conductivity of distilled water

Temperature (°C)	Thermal Conductivity (W / mK)	Average Error
30	0.7663	0.0189
40	0.9405714	0.0429
50	1.25425	0.4320
60	0.998	0.7628
70	1.230	0.4990

Table 3
Thermal conductivity of Triton 1.3

Temperature ($°C$)	Thermal Conductivity (W / mK)	Average Error
30	0.51733333	0.0126
40	0.83775	0.0268
50	1.047	0.0516
60	0.552625	0.0862
70	0.8671429	0.2428

Table 4
Thermal conductivity of Trition 0.9

Temperature ($°C$)	Thermal Conductivity (W / mK)	Average Error
30	0.7966	0.0245
40	1.1163636	0.0360
50	1.1593333	0.2801
60	0.9045714	0.4219
70	0.6258333	0.2820

Table 5
Thermal conductivity of Trition 0.5

Temperature ($°C$)	Thermal Conductivity (W / mK)	Average Error
30	0.7641	0.02012
40	1.2445833	0.06545
50	0.90175	0.04086
60	1.00443	0.0380
70	0.807	0.5833

Table 6
Thermal conductivity of Trition 0.1

Temperature ($°C$)	Thermal Conductivity (W / mK)	Average Error
30	0.757	0.0165
40	0.972	0.0367
50	1.193	0.0956
60	0.953	0.4519
70	0.935	0.8370

Based on the experiment findings as seen in Figure 8, it is found that nanocellulose of concentration 0.1 %, 0.5 % and 0.9 % has a higher thermal conductivity reading than water at 30°C and 40°C. Above 50°C, distilled water shows a higher reading compare to all other samples.

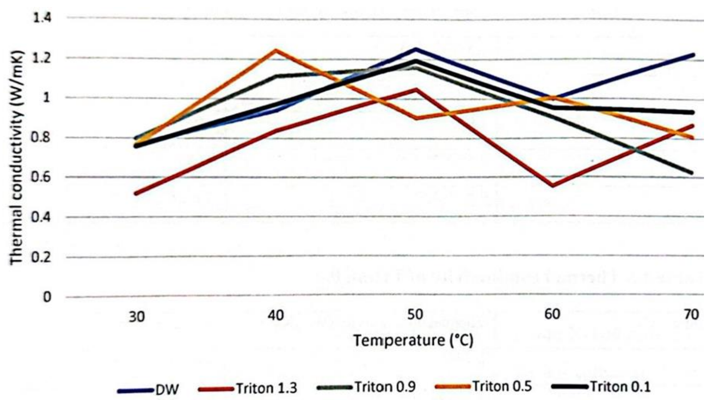


Fig. 8. Summary graph for thermal conductivity between all samples across various temperatures

5. Conclusions

All the plant-based nanofluid samples were prepared, each using nanocellulose was extracted from natural products. Both two sets of the nanofluid samples were prepared, one set were added with surfactant Triton X-100 while the other set were without any addition, were then analyzed to determine the stability of the nanocellulose. From the analysis, it was concluded that in order to create a stable nanocellulose, surfactant Triton X-100 was needed. The nanocellulose became more stable and less visible sedimentation was spotted after a period of time.

Based on the experimental data obtained, it was found that nanocellulose with concentrations 0.9 % and lower, has a higher thermal conductivity than that of water. However, the reading only showed higher readings at 30°C and 40°C only. At temperatures above these two stated values, the distilled water has shown to give higher readings of thermal conductivity. The absolute reasoning behind this is still unknown although based on research by Hilo *et al*., [14] their theory shows that at higher concentration and temperature, the thermal conductivity was higher. These discrepancies may be due to some experimental errors or the surfactant in nanocellulose that were degraded due to high temperature, of which a possible cause was found in a research done by Xian *et al*., [15].

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