Thermal Properties Characteristics of MWCNT-OH Based Nanofluids in Mixture of Ethylene Glycol and Deionized Water

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ABSTRACT

Conventional fluids have lower thermal properties. Moreover, the low freezing and high boiling point of water are another issues have made limitation occurred. Therefore, inclusion of MWCNT-OH nanoparticles in mixture of ethylene glycol and deionized water is an alternative way to solve these problems. Then, two-step method is used in nanofluids synthesizing through homogenized and sonicated all materials together such as MWCNT-OH nanoparticles (0.1 wt% to 1.0 wt%) and PVP surfactant (0.01 wt%) in mixture of ethylene glycol to deionized water (20:80) for five minutes. The nanofluids were tested in thermal conductivity test, heat transfer coefficient test and specific heat test. Thus, the thermal conductivity results show positive enhancement for all concentrations and 0.9 wt% of MWCNT-OH based nanofluids have the highest thermal conductivity. It is followed by 0.3 wt% and 0.6 wt% of MWCNT-OH based nanofluids. The percentage enhancement of thermal conductivity is about 0.812% to 17.0%. Whilst, high heat transfer coefficient has given increment of nanofluids Nusselt number. However,

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specific heat test have decrement values with increment of weight loading even though has high thermal conductivity values. This thermal properties results are affected by dispersion and suspensions of nanoparticles possess higher thermal conductivity. In addition, functionalized group attached on nanoparticles, quantity of surfactant, ultrasonication process and nanofluids stability are factors which influenced the thermal conductivity. Moreover, heat absorption and capacity of nanofluids and as well as temperature are another factors that capable to enhance the thermal conductivity. The small size and high surface area of nanoparticles, low surface roughness, nanoparticles concentration, temperature and nanoparticles interaction are others influenced factors in these test. Whilst, lower specific heat value on nanoparticles and agglomeration form affected in specific heat test. In conclusion, addition of MWCNT-OH nanoparticles in mixture of base fluids is capable to improve thermal properties of nanofluids.

Keywords: *Thermal Conductivity, Heat Transfer Coefficient, Specific Heat Nanofluids.*

Introduction

Water, organic liquid (ethylene glycol, oil, biological liquids, etc) and polymer solutions are commonly used as conventional fluids in cooling or heating system applications. However, these fluids have low thermal conductivity which affected the thermal applications such as car radiator, electronic system and so on. Therefore, a new generation of heat transfer fluid known as nanofluids is a technology advancement in nanotechnology field. In 1995, Choi is the first researcher that introduced nanofluids in the world of science [1,2]. A nanofluids is defined as a suspension of nano-sized particles where the particles size is about 1 nm to 100 nm into a conventional base fluid [1,3]. Many applications have use nanofluids in their system as to improve thermal management system. For example, nanofluids is used in absorption refrigeration, micro electromechanical systems, lubrication of automotive systems, manufacture of advanced miniature camera lenses, machining coolant, automobile radiator cooling, personal computers, heat exchangers and in several aerospace applications [4]. In addition, there are two types of nanofluids which are metallic and non-metallic nanofluids. Metallic nanofluids are dispersion process of nanoparticles that are made from metals (i.e. aluminium, copper,nickel etc.) and whilst non-metallic nanofluids are made by dispersing non-metals nanoparticles (i.e. metal oxides, graphene, CNT etc.) in the fluids [1].

In addition, seeding of nanoparticles has reputation in enhancing the thermal properties of fluids such as thermal conductivity, heat transfer coefficient and specific heat. This statement is supported by researchers which stated that, an addition of nano-sized particles in the fluids capable to improve fluid's thermal conductivity because of characteristics of nanoparticles that have higher thermal conductivity [5,6]. Thus, carbon nanotube (CNT) is an example of nanoparticles that commonly used in the making of nanofluids which fall under non-metallic nanofluids particles category. Previous research has stated that CNT has higher thermal conductivity compared to metallic or oxide nanoparticles where the thermal conductivity value of CNT is about 1800 W/m.K to 2000 W/m.K [7]. Therefore, inclusion of CNT in the conventional fluids or base fluids is an alternative method to produce nanofluids with higher thermal properties. This fact is supported by researcher which found that, thermal conductivity enhancement for CNT based nanofluids reaches 22.31% at temperature 45°C and 12.7% at 1.0 vol% CNT [8,9]. Whilst, mixture of ethylene glycol and water in MWCNT based nanofluid has 72% thermal conductivity enhancement at 0.4 wt% [10].

Besides, thermal conductivity has strong relationship with heat transfer coefficient where good thermal conductivity contributed in high heat transfer coefficient. In 2007 [11], convective heat transfer coefficient is about 350% at 0.5 wt% CNT based nanofluids. Others researcher revealed that,enhancement of convective heat transfer at 3.5 vol% of amorphous carbonic nanofluids shows 8% enhancement for laminar flow and no enahncement for turbulent flow [12]. Whilst, for the specific heat property shows the decrement value when the volumetric concentration increases. This fact is proved by investigation on Al_2O_3, SiO_2 and ZnO nanofluids on 60:40; ethylene glycol: water mixture at 2 vol% to 10 vol%. Those results show the decrement of specific heat occured as concentration increases [13].

Nevertheless, inclusion of nanoparticles in conventional base fluids result in agglomeration and affected the stability of nanofluids where it remains as a major problem among researchers [14]. The literature on nonstable nanofluids has highlighted several factors influenced this phenomena are Van Der Waals attractive force (repulsion, polarization and dispersion forces), hydrophobic nature of nanoparticles, high surface area and surface activity of nanoparticles in nanofluids [1-5]. Previous literature also stated that, stable nanofluids without supernatant or agglomeration is vital factor that can optimized thermal property performance of nanofluids [15,16]. Therefore, to overcome this problem the researchers have used surfactant or stabilizer because of the outstanding function of surfactant to improve stability of nanofluids. Usually, gemini, gum arabic (GA), sodium dodecylbenzene sulfonate (SDBS) and polyvinylpyrrolidone (PVP) are used as surfactant in the preparation of nanofluids. Previously published studies on the effect of surfactant in nanofluids found out SDBS surfactant is the main factor in maintaining stability of two water-based nanofluids (water-Al_2O_3 and water-Cu) and inclusion of PVP in nanofluids exhibit better stability than nanofluids without surfactant [3,17]. In addition, inclusion of surfactant has enhanced the thermal conductivity about 22.2% at 0.01 wt% of PVP surfactant for 0.5 wt%

of MWCNT water based nanofluids. Meanwhile, at 40°C, SDBS surfactant has increased the thermal conductivity by 19.73% at 0.45 vol.% of ethylene glycol and water mixtureMWCNT based nanofluids [3,18]. Another limitation of conventional fluids (especially deionized water) in cooling system application is their low boiling point and high freezing point.

Hence, antifreeze additive such as ethylene glycol and methanol can be used to overwhelm this problem by mixing the antifreeze additive in deionized water. In nanotechnology, researches on mixture of fluids as base fluid in nanofluids is still lack or rarely study among researchers. In 2016, at 20°C, a researcher has found out, the enhancement of thermal conductivity for mixture of ethylene glycol and water is increased to 33.84% at weight loading 1.0 vol% SiC [19]. Meanwhile, nanofluids's thermal conductivity enhancement for formulation 60:40 (ethylene glycol/deionized water) is 6.67% to 10.47% and 53.81% for 0.5 vol% SiC nanofluids (water/ethylene glycol) at 50°C [20,21]. Therefore, in this work, we have investigated the thermal conductivity, heat transfer coefficient and specific heat of ethylene glycol and deionized water mixture at formulation ratio of 20:80 with inclusion hydroxyl functionalized multiwalled carbon nanotube (MWCNT-OH). The addition of MWCNT-OH as nanoparticles in the conventional base fluids was performed with intention to fill the research gap in nanotechnology field.

Methodology

Material Selection

Hydroxyl functionalized multiwalled carbon nanotube (MWCNT-OH) is selected as nanoparticles in this work. The MWCNT-OH was purchased from Nanostructures & Amorphous Material, Inc. Physical and chemical properties of MWCNT-OH are shown in Table 1 and Table 2. PVP surfactant used as stabilizer was purchased from Sigma Aldrich, Co. The density value of PVP is 1.6 g/cm^3 and an average mol. wt is about 1000. Ethylene glycol and deionized water are used as base fluid in making the nanofluids and specifications of base fluid include in Table 3 and Table 4.

Table 1: MWCNT-OH specification

CNT properties	Specification
Outer diameter	10-30 nm
Inner diameter	5-10 nm
Length	10-30 μm
Density	2.1 g/cm^3
Surface area	40-300 cm^3/g
Melting point	3652-3697°C

Table 2: Elements composition in MWCNT-OH

CNT properties	Contents (%)
Multiwalled carbon nanotubes (excluding –OH)	> 90
-OH	2.36-2.60
Al	4.21
Fe	0.18
Ni	0.97
S	0.16

Table 3: Ethylene glycol specification

Properties	Specification
Chemical name	Ethylene glycol
Other name	Acetic acid ethyl ester; acetic ether
Chemical formula	$C_2H_6O_2$
Molecular mass	62
Purity	Minimum 99%
Melting point	-13°C
Boiling point	198°C
Flash point	111°C
Density	1.11 g/cm^3

Table 4: Deionized water specification

Properties	Specification
Chemical name	DI
Resisitivity	18.2 megohm
Chemical formula	H_2O
Density	1.00 g/cm^3

Preparation of Nanofluids

Two-step method is the most popular and economic method used by researcher in preparation of nanofluids [1,14]. Therefore, in this work, two-step method is used by mixing all materials which are MWCNT-OH nanoparticles, PVP surfactant at 0.01 wt% and base fluids at ratio 20:80 for ethylene glycol to deionized water mixture. The weight percentage loading of MWCNT-OH is varied from 0.1 wt% to 1.0 wt%. Formulation of nanofluids is calculated by using Equation (1)[22]. The mixture is filled up in a clear sampling glass bottle for 40 ml and then homogenized and sonicated for five minutes by using Wise Tis HG-15D homogenizer at 10000 rpm and Branson 8510DTH Ultrasonic Cleaner at 40 kHz. Dispersion and stability of nanofluids are monitored more than 100 hours of aging nanofluids by using stability test rig (STR) unit and ZEISS inverted microscope. The stable nanofluids without any agglomeration or sedimentation form are further tested in thermal conductivity test, heat transfer coefficient test and specific heat test by using TC-KD2 Pro thermal analyser, Pico Data Logger and calorimeter bomb.

$$Volume = \frac{Weight\ percentage}{Density} \tag{1}$$

Result and Discussions

Thermal Conductivity Test

TC-KD2 Pro thermal analyser of Decagon Device, Inc is used in nanofluids's thermal conductivity test. This equipment is verified by ASTM D5334-14 and IEEE 422-03 standards. In addition, the equipment consists of controller and sensor where KS-1 sensor is used to measure the nanofluids's thermal conductivity. The accuracy of KS-1 sensor is about ±0.01 W/m.K.. Thermal conductivity analysis is tested at three various temperatures (6°C, 25°C and 40°C) and controlled by refrigerated water bath. The samples of nanofluids are placed in the refrigerated water bath until the desired temperature is achieved. Then, KS-1 sensor is inserted inside the nanofluids in perpendicular position as to avoid high error during taking the thermal conductivity reading. The position of sensor may influence the reading of thermal conductivity values, therefore three reading were taken with 15 minutes gap before each measurements to surpass error.

The thermal conductivity test is started with comparison between standard base fluids data and American Society of Heating, Refrigerating and Air Conditioning (ASHRAE) as to ensure standard data values is aligned with ASHRAE standard. Then, the results is shown in Figure 1.

Figure 1 shows the thermal conductivity comparison on standard base fuids and ASHRAE standard. The results revealed that the standard base fluids is aligned with ASHRAE standard. Even the standard base fluids results presented lower thermal conductivity values than the ASHRAE standard, the thermal conductivity still increases with increment temperatures. The thermal conductivity of standard base fluids at three temperatures (6°C, 25°C and 40°C) are 0.4440 W/m.K, 0.4556 W/m.K and 0.4600 W/m.K. These values are used in thermal conductivity enhancement calculations.

Whilst, Figure 2 shows the thermal conductivity of ethylene glycol and water mixture MWCNT-OH based nanofluids at three different temperatures.

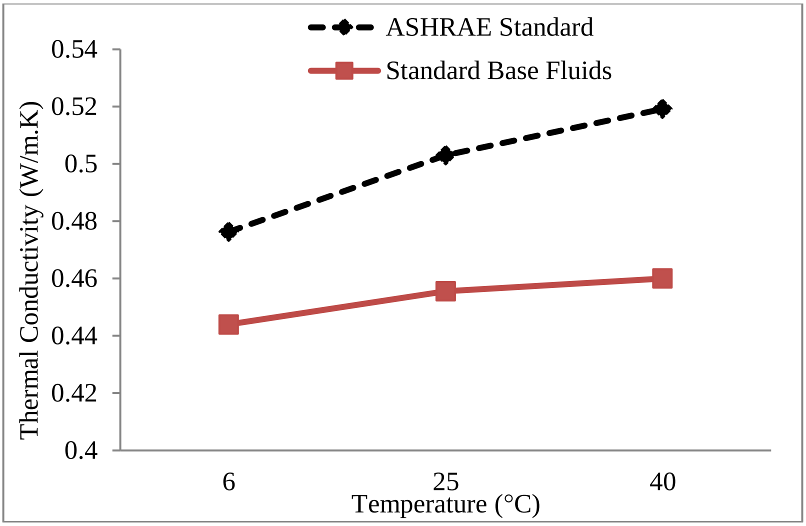

Figure 1: Thermal conductivity comparison between standard base fluids and ASHRAE standard.

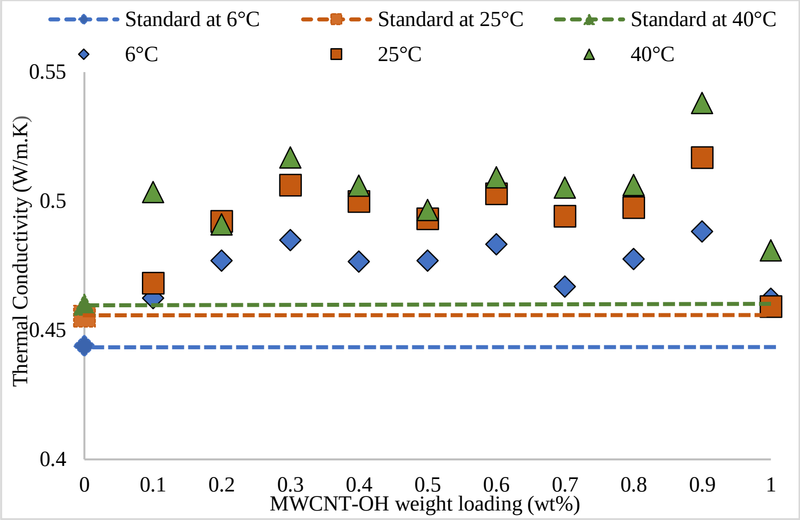

Figure 2: Thermal conductivity of MWCNT-OH based nanofluids

The results presented MWCNT-OH based nanofluids (20:80; water: ethylene glycol) are higher than the standard base fluids data. The highest thermal conductivity data is on 0.9 wt% with value given is 0.5380 W/m.K (40°C), 0.5170 W/m.K (25°C) and 0.4883 W/m.K (6°C). Then, it is followed by weight loading 0.3wt% where thermal conductivity data are 0.5170 W/m.K (40°C), 0.5063 W/m.K (25°C) and 0.4850 W/m.K (6°C). Normally, thermal conductivity increases with an increment of weight loading [23]. However, maximum weight loading which is 1.0 wt% does not shows high thermal conductivity values compared to other weight loading and it is still higher than the standard data. In addition, based on Figure 1,it shows the trend of the graph is fluctuated. This phenomena is happened due to speed of nanoparticles clustering in condensed nanofluids, surfactant and as well as aspect ratios of nanoparticles used [24, 25]. Literatures stated that, Fe based nanofluids and CNF based nanofluids thermal conductivity test reported same result where the thermal conductivity increases nonlinearly with increment of volume fraction [25, 26]. In addition, the literature mentioned, the lower weight loading has much greater thermal conductivity data compared to high weight loading [27].

Table 5 presented the percentage enhancement of thermal conductivity for all samples MWCNT-OH based nanofluids. The values of percentage enhancement is calculated based on Equation (2).

$$Enhancement\ of\ T.C(\%) = \left| \frac{T.C\ of\ B.F - T.C\ of\ Nanofluids}{T.C\ of\ B.F} \right| \times 100\% \qquad (2)$$

Where; T.C is thermal conductivity and B.F is base fluids.

Table 5: Percentage (%) Enhancement of Thermal Conductivity

Weight Loading of MWCNT-OH (wt%)	Percentage (%) Enhancement of Thermal Conductivity (W/m.K) at Three Different Temperatures (°C)		
	6	**25**	**40**
0.1	4.17	2.79	9.48
0.2	7.43	8.05	6.74
0.3	9.23	11.1	12.4
0.4	7.34	9.75	10.0
0.5	7.43	8.27	7.96
0.6	8.85	10.4	10.7
0.7	5.18	8.49	9.85
0.8	7.57	9.22	10.1
0.9	9.98	11.2	17.0
1.0	4.12	0.812	4.56

As mentioned earlier, weight loading 0.9 wt% of MWCNT-OH based nanofluids has the highest thermal conductivity. Hence, necessarily the highest percentage enhancement of thermal conductivity occurred on weight loading 0.9 wt% concentration where the enhancement is 17% , 11.2% and 9.98% at 6°C, 25°C and 40°C. Moreover, 0.3 wt% concentration where the second highest of thermal conductivity has enhancement from 9.23% to 12.4% and whilst 0.6 wt% concentration has positive enhancement from 8.85% to 10.7%. Meanwhile, the lowest percentage enhancement is 0.812% which occurred on 1.0 wt% of MWCNT-OH based nanofluids at temperature 25°C. In summary, all samples of MWCNT-OH based nanofluids presented positive percentage enhancement even though some of samples concentrations only shows slightly enhancement.

Based on our results above, there are several factors that may influenced thermal conductivity fluids containing nanoparticles. Dispersion and suspension of nanoparticles in the base fluid did play the major roles on the thermal conductivity characteristic as agreed by many researchers [28]. Poor dispersion of nanoparticles in conventional base fluids may results in agglomeration and less stability which appear as the limiting factor in the effectiveness of their thermal properties. To overcome these issues, the use of functionalized carbon nanotubes, addition of surfactant, nanoparticles size and ultrasonication have shown some good promising results.

Besides, another factor that influenced thermal conductivity is functionalized group of nanoparticle. Higher amount of functionalized group attached on nanoparticles surface will give high thermal conductivity and homogeneous solution of nanofluids [29, 30]. Therefore, the hydroxyl group (-OH) is a functionalized group that was included in nanoparticles. Moreover, the quantity of surfactant used in synthesized of nanofluids also can influences the thermal conductivity value. Decrement of thermal conductivity occurred when quantity of surfactant is high [31]. As mentioned earlier in methodology section, a lower weight percentage of PVP surfactant (0.01 wt%) was selected in this present study. Moreover, surfactant also adept to enhance the repulsive force of nanoparticles and can overcome the agglomeration or sedimentation to form in nanofluids [3]. Others factor is a larger heat absorption and capacity by nanoparticles are resulting in higher thermal conductivity value [32]. This is because the small size and large surface area of MWCNT-OH which has 10 nm to 30 nm for outer diameter and 5 nm to 10 nm for inner diameter. This fact is supported by literature where small nanoparticles resulting in high thermal conductivity due to high surface area [33]. Moreover, as mentioned earlier thermal conductivity of MWCNT-OH based nanofluids is increased with the increment of temperature. This fact shows nanofluids is dependent on temperature. It is because of high temperature make the nanoparticles become more active and collided to each other more often and tend to conduct energy well.

Heat Transfer Coefficient

Heat transfer coefficient is tested by using Pico Data Logger to measure the temperature inlet (T_{in}) and temperature oulet (T_{out}) at three temperatures (6°C, 25°C and 40°C). The three best samples from thermal conductivity test which are 0.3 wt%, 0.6 wt% and 0.9 wt% are selected to undergo heat transfer coefficient test. The condition of nanofluids is assumed as laminar flow and Reynolds number value is less than 2300. Based on Table 6, it shows the data on some variables in this test.

Table 6: Data on heat transfer coefficient test

Variables	Values
Specific heat of water, C_p	4187 J/kg.K
Length of copper coil	2.063 m
Inner diameter of coil	0.0048 m
Outer diameter of coil	0.0064 m
Thickness	0.0016 m
Area of copper coil, $A = \pi D_i L$	0.03111 m^2

The accuracy of Pico Data Logger in measuring the temperature is about ±0.5°C and ±0.2%. Whilst, thermocouple type K used as it has wide temperature range from -270°C to 1260°C which suitable to be used in heat transfer coefficient test. Refer to Figure 3, it shows the heat transfer coefficient schematic diagram.

Then, heat transfer coefficient is calculated by Equation (3) as below.

$$h = \frac{mC_p \Delta T_1}{A \Delta T_2} \tag{3}$$

where;
m = mass of water (kg)
C_p = Specific heat of water (J/kg.K)
ΔT_1 = Temperature difference between water bath and surface ($T_{wb} - T_s$)
ΔT_2 = Logaritmic mean temperature
A = Area of copper coil (m^2)
h = Heat transfer coefficient ($W/m^2.K$)

Refer to Figure 4, it shows the heat transfer coefficient results on three different weight loading at 6°C, 25°C and 40°C.

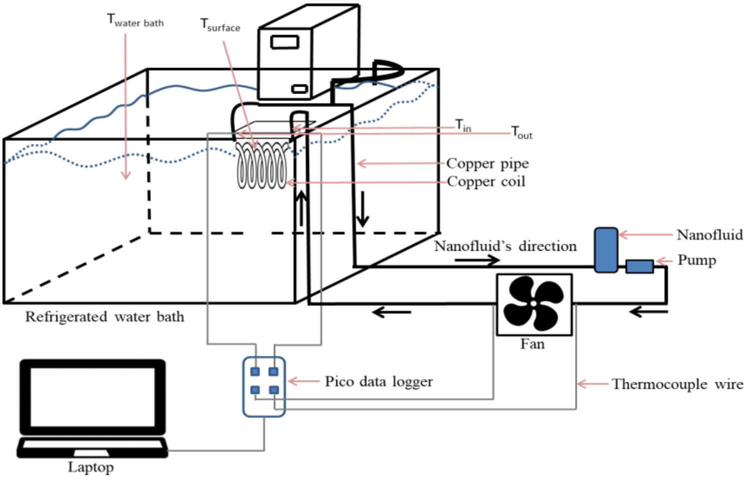

Figure 3: Schematic diagram of heat transfer coeffcient test

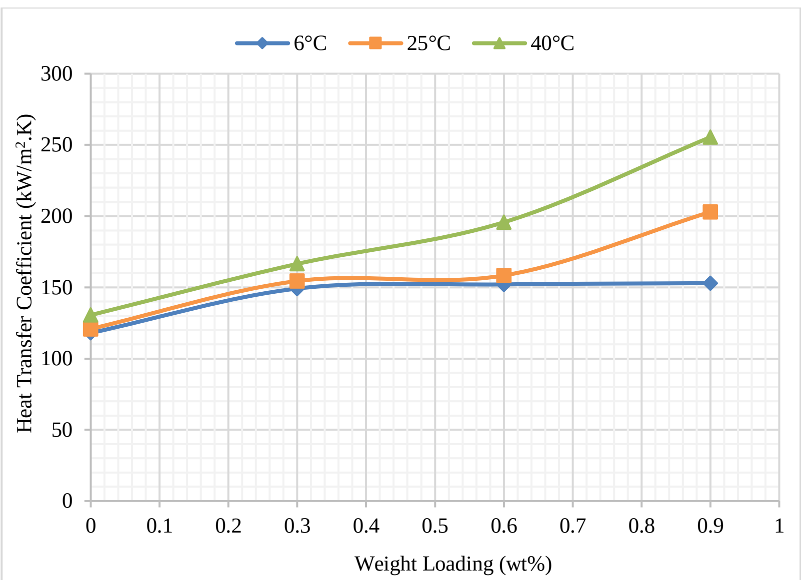

Figure 4: Heat transfer coefficient on MWCNT-OH based nanofluids

On 0 wt% is the result for standard heat transfer coefficient for base fluids which has values 117.99 kW/m^2.K, 120.85 kW/m^2.K and 130.54

kW/m^2.K at 6°C, 25°C and 40°C. Refer to Figure 3, all samples show positive results where higher than the standard base fluids. The highest heat transfer coefficient is occured on 0.9 wt% and followed by 0.6 wt% and 0.3 wt% for all temperatures. It can be simplify as the heat transfer coefficient increases with increment of weight loading and temperatures.

Nusselt numbers

The heat transfer coefficient values are then used in calculating the Nusselt number as in Equation (4). The enhancement of heat transfer coeffcient can be measured by Nusselt number where high Nusselt number represent the effective convection of heat transfer coeffcient. Table 7 shows the Nusselt number for 0.3 wt%, 0.6 wt% and 0.9 wt% of MWCNT-OH based nanofluids at three different temperatures.

$$Nusselt\ number, Nu\ =\ \frac{h\ D}{k} \tag{4}$$

Table 7: Nusselt number for MWCNT-OH based nanofluids

Weight loading (wt%)	Nusselt Number		
	6°C	25°C	40°C
Standard	1275.57	1273.22	1362.16
0.3	1476.22	1464.27	1545.65
0.6	1510.42	1511.00	1844.23
0.9	1503.50	1884.26	2278.93

Refer to Table 7, the Nusselt number of MWCNT-OH based nanofluids is higher than the standard base fluids Nusselt number. It can be summarized, seeding of MWCNT-OH nanoparticles in base fluids has capability in enhancing the Nusselt number and as well as the thermal properties of fluids.

Heat transfer coeffient and Nusselt number has strong relation with each other where Nusselt number increase with the high heat transfer coefficient values. Then, high values of heat transfer coefficient and Nusselt number are due to small size and high surface area of MWCNT-OH nanoparticles [34]. The solid surface roughness on pipe which has low roughness due to smooth surface also gave results in enhancing the heat transfer coefficient and Nusselt number [35]. Other factors that affecting the heat transfer coefficients are temperature and weight loading of nanoparticles. Researchers have mentioned that high temperatures and weight loading has increased the CNF based nanofluids [26]. Moreover, heat transfer property also can be enhanced by the interaction of nanoparticles in fluids from the collision which make energy transport occured [36].

Specific Heat

In specific heat test, three best samples of MWCNT-OH based nanofluids which are 0.3 wt%, 0.6 wt% and 0.9 wt% are measured by calorimeter bomb. Specific heat is measured when nanofluids is burned in the device and nanofluids energy is absorbed by calorimeter bomb. Futhermore, the calorimeter bomb is operated on room temperature and qualified by DIN 51900, ASTM D4809 and ISO 1928.

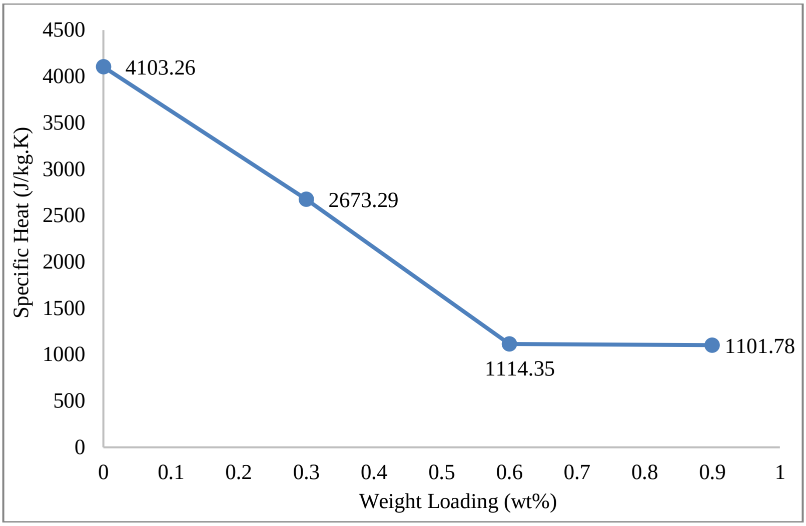

Figure 5: Specific heat of MWCNT-OH based nanofluids

Figure 5 shows the outcome of MWCNT-OH based nanofluids on specific heat property. The specific heat value for standard ethylene glycol water mixture at 20:80 ratio is 4103.26 J/kg.K. All the nanofluids samples have negative results where the specific heat of nanofluids are lower than the standard based fluids. It means that the amount of heat required to raise the temperature of nanofluids is lower than the base fluids. The specific heat is decreased with the increment of weight loading.

This results is same as other researchers which reported that nanofluids have lower specific heat when compared to base fluids. Researchers in ethylene glycol based nanofluids and water alumina nanofluids investigation have reported that nanofluids have low specific heat even their thermal conductivity is high [37, 38]. In addition, at 2 vol% to 10 vol% of Al_2O_3, SiO_2 and ZnO based nanofluids on 60:40; ethylene glycol: water mixture also have low specific heat. The specific heat is decreased with the weight loading and temperatures increment [13]. This phenomena is explained by the thermal property of MWCNT-OH nanoparticles which have lower specific heat value. In addition, supernatant or agglomeration form in nanofluids also has affected the specific heat values [39]. In thermal property of nanofluids, there are still insufficient or limited experimental data and explanation in specific heat property of nanofluids [40].

Conclusions

In summary, inclusion of MWCNT-OH nanoparticles in mixture of ethylene glycol to deionized water (20:80) resulting the increment of thermal conductivity value compared to base fluids at all temperatures (6°C, 25°C and 40°C). 0.9 wt% of MWCNT-OH based nanofluids have the highest thermal conductivity values at all temperatures compared to other samples which have enhancement of thermal conductivity from 9.98% to 17.0%. Whereas, 0.3 wt% of MWCNT-OH based nanofluids is second highest of thermal conductivity which have 9.23% to12.4% enhancement and followed by 0.6 wt% which have 8.85% to 10.7% enhancement of thermal conductivity. Several factors that influenced the thermal conductivity test are dispersion of nanoparticles that have higher thermal conductivity values, functionalized group, temperature and surfactant quantity and ultrasonication process.In addition, stability, small size and larger surface area of nanoparticles are also affected the results in term of sedimentation form and larger heat absorption and capacity by nanoparticles. The sedimentation can decrease the thermal conductivity, while the larger heat absorption and capacity by nanoparticles can enhance the thermal conductivity. Besides, heat transfer coefficient test and Nusselt number on 0.3 wt%, 0.6 wt% and 0.9 wt% are related to each other where high heat transfer coefficient increase the Nusselt number. Positive results from this test is affected by size, surface area, solid surface roughness, weight loading, temperature and interaction between nanoparticles by collision. Whilst, in specific heat test, the nanofluids have lower specific heat values than the base fluids. This phenomena is due to lower specific heat on nanoparticles and supernatant form in nanofluids. There are still lacking explanation on specific heat of nanofluids among researchers. Therefore, researchers are encouraged to do more investigation on specific heat based nanofluid in future studies.

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