Effect of Multi-Walled Carbon Nanotubes Concentrations on Heat Transfer in Nanofluid

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Abstract

Nanofluids are being widely used in many applications due to their ability to increase heat transfer in the fluids. The present study is aimed to investigate the potential of multi-walled carbon nanotubes (MWCNT) in the based fluid as a coolant for battery application. Nanofluids based on MWCNT and pure distilled water was prepared in the experimental work. Different volume percentage (vol %) of MWCNT was used to prepare the nanofluids; 0.1%, 0.2%, 0.3%, 0.4% and 0.5% vol%. Analysis was done experimentally and through simulation using ANSYS Workbench to identify the best composition of nanoparticles required in nanofluid to enhance heat transfer. Experimental data on the heat transfer coefficient show an enhancement from 11.5% to 30.2% for 0.1 vol% MWCNT and 0.5 vol% MWCNT, respectively. From the simulation of the nanofluid, it was found that 0.5 vol% MWCNT nanofluid provides the highest heat transfer enhancement. This is contrary to the experimental result where the highest heat transfer coefficient enhancement percentage is shown by 0.4 vol% MWCNT nanofluids by the value of 35%. Reduction in heat transfer coefficient for 0.5 vol% MWCNT nanofluid in the experimental work is due the high viscosity which influenced the flow rate of the nanofluids.

Keywords: multi-walled carbon nanotubes, nanofluids, thermal conductivity

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Introduction

In liquid based cooling system, it is obvious that all conventional liquid coolants in used today exhibit rather poor thermal conductivity when compared to solid metals based on their thermal properties. Despite obvious improvement over air based cooling system, several methods have been proposed to further enhance the thermal conductivity of liquid coolants [1]. One way is to disperse nano-sized solid particles with high thermal conductivity into a liquid coolant to improve thermal properties of heat transfer fluids known as nanofluids. Nanofluids has since emerged as a new class of heat transfer fluids and has been the subject of significant contemporary research [1-3]. Nanofluids demonstrated great potential applications in many engineering applications such as automobiles cooling, heat pipes car radiators, electronic cooling, heat exchanger, solar heating and also in medical applications. Figure 1 shows examples of common applications of nanofluids [4-5].

Nanofluids are being widely used in many applications due to their thermal properties which are better compared to just using conventional base fluids. It was reported that by dispersing some nanoparticles into conventional base fluids, this leads to increase in thermal properties and improve heat transfer characteristics of base fluid. Used of nanoparticles increase the surface contact of the particles and the heated body, thus the heat transfer of the nanofluids will be increased if compared to micron-sized particles [2, 3].

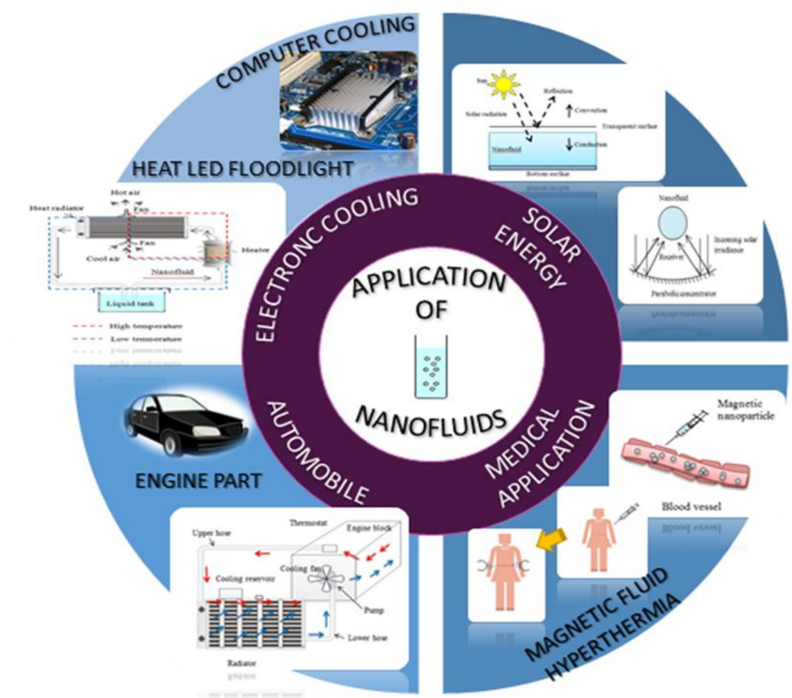


Figure 1. Some common applications of the nanofluids

Previous works investigated on the performance of several types of nanofluids. For example, few types of metallic nanoparticles and oxide nanoparticles were used as additives in the nanofluids. Additives such as Alumina (Al_2O_3), Gold (Au), Copper (Cu), Silver (Ag) and Boron Nitride (BN) are the most commonly added in nanofluids [6, 7]. High thermal conductivity, lightweight, high stability and the availability of different shapes have elicited research interest in synthesizing nanosize particles from carbon such as single-walled carbon nanotubes (SWCTs), multi-walled carbon nanotubes (MWCNTs), graphene nanoplatelets (GNPs) and diamond [8]. Table 1 lists various type materials with thermal conductive values which can be considered as an additive in nanofluids. Carbon nanotubes (CNTs) for example have the capability to conduct electricity and heat efficiently and can act like metals or semiconductors. CNTs are tubular in shape as they are composed of cylindrical sheet form with carbon which is rolled up in a tube like structure with the appearance of lattice work fence. Table 2 summarizes recent works on nanofluids using MWCNT, SiO_2 and TiO_2. If compared thermal conductivity of water in Table 1 than those of thermal conductivities of nanoparticles in Table 2, it is apparent that the addition of nanoparticles only increased 4-23% of nanofluids thermal conductivity. Addition of high thermal conductivity nanoparticles such as CNT is not significantly influenced thermal conductivity values of the nanofluids. This is due to many factors which influence thermal conductivity of the nanofluids for example nanoparticles dipersion, stability, amount of nanoparticles and size of nanoparticles.

The present study is aimed to investigate heat transfer performance of MWCNT /Distilled water nanofluids in a circular mini-tube tube (D_{in} = 0.8mm). The flow was assumed as fully laminar flow (Re = 112) with initial temperatures at all channels were maintained at 50°C as uniform heat flux was applied to the outer surface of the mini-tube. MWCNT with volume percentage of 0.1%, 0.2%, 0.3%, 0.4% and 0.5 vol% were used to prepare the nanofluids. The heat transfer performance was measured experimentally and through simulation using ANSYS Workbench. The visual observation were carried out for day 0, day 1 until day 4 counting from the nanofuid preparation.

Materials and Methods

Materials

The MWCNTs used were synthesized via catalytic chemical vapour deposition (CCVD) process by a group of researcher from School of Chemical Engineering, Universiti Sains Malaysia, Penang. The MWCNT was purchased from USAINS Holding Berhad. The filler with 80% purity has average diameter of 10 nm and average length of 1-5 μm.

Sample preparation

Nanofluids were prepared based on 0.1, 0.2, 0.3, 0.4 and 0.5 vol% of MWCNT in distilled water. The distilled water acts as the base fluid of the suspension. Then, the nanofluid was dispersed using ultrasonic for 20 minutes in order to break down the agglomeration of nanoparticles. The prepared nanofluids have been kept under visual surveillance for 4 days for visual observation on the stability of the samples.

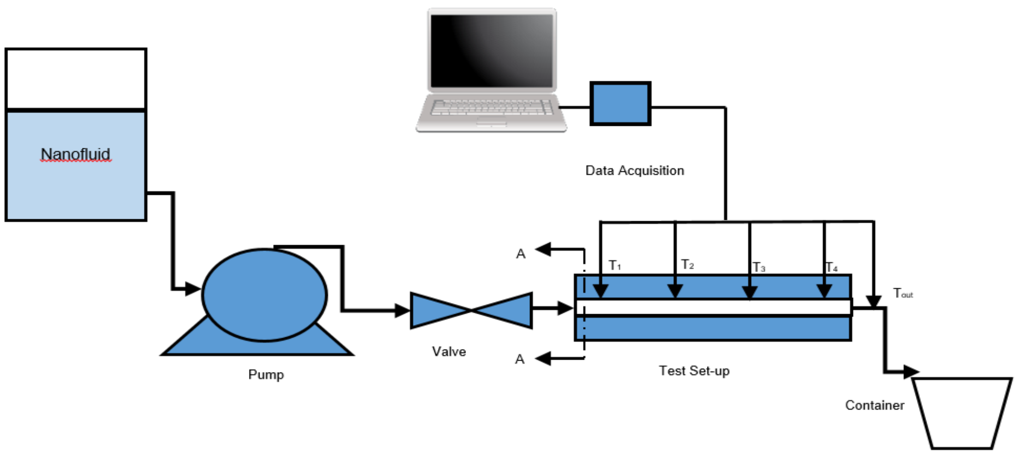
Table 1. A selection of thermal conductivities of solid particles and working fluids [9-14]

Material		**Thermal conductivity at 25 ºC (W/mK)**
Metals		
	Gold	315
	Silver	424
	Copper	398
	Aluminum	273
	Iron	80
	Steel	46
	Stainless Steel	16
Ceramic		
	Boron nitride (BN)	280
	Beryllium oxide (BeO)	250-300
	Aluminum nitride (AlN)	170-220
	Silicon dioxide (SiO_2)	1.4
	Silicon carbide (SiC)	150
	Alumina (Al_2O_3)	20-30
	Titanium dioxide (TiO_2)	12
Carbons		
	Diamond	5000
	Carbon Nanotubes	3000-5000
	Graphite	100-400
	Graphene	3000-5000
Working Fluids		
	Water	0.608
	Ethylene Glycol	0.257

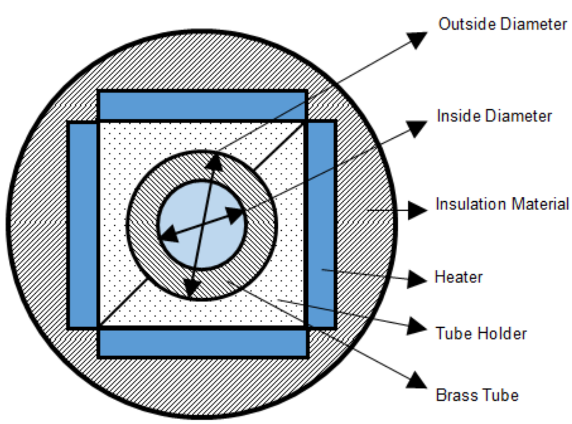
Table 2. Previous works on distilled water based nanofluids

Nanofluid particle	**Dispersion technique**	**Thermal conductivity (W/m.K)**	**Ref.**
MWCNT (outer diameter= 10-20 nm, length=30 µm)	Mechanical mill &Ultrasonic	0.63 W/m.K for 0.48 vol% of MWCNT	[15]
SiO_2 (diameter range= 40-50 nm)	Magnetic stirrer	0.68 W/m.K for 0.3 vol% of SiO_2	[16]
TiO_2 (diameter range= 30 to 60 nm)	Ultrasonic	0.75 W/m.K for 0.3 vol% of TiO_2	[17]
MWCNT (outer diameter= 40-60 nm, length=5-15 µm)	Ultrasonic	0.63 W/m.K for 1.5 wt% of MWCNT	[18]

Figure 2 (a) shows the schematic diagram of the mini tube flow loop and (b) cross sectional area of test section at A-A section. The mini tube flow loop setup which consist of a reservoir at one end and an empty beaker at the other end was used determine the heat transfer coefficient of the working fluids. A long tube was used to connect the test section and the reservoir. The tubing pump (Cole-Parmer, USA) was used to pump the working fluids from the reservoir to the test section through the tube at a low flow rate. The test section consisted of a brass mini-tube covered by a stainless steel holder. Four electrical flat heaters were held at the edge of the mini-tube holder and insulated by a thick layer of woven fiberglass to prevent heat loss. The heaters were connected to the voltage supply to provide constant heat flux to the tube. The inner diameter, outer diameter and length of the mini-tube are 0.8, 1.5 and 300 mm, respectively. The experimental setup is based on previous work by Hussien et al. [11].



(a)



(b)

Figure 2. (a) The schematic diagram of experimental setup, (b) Front View Cross Sectional Area of Test Section

Five K-type thermocouples were used to measure the desired temperatures, one thermocouple was used to measure the outlet temperature, whereas the others were attached to the outer surface of the mini-tube to measure the surface wall temperatures at different axial locations from the inlet (Channels 1 - 4 (T_1-T_4) with distance from inlet (Z) = 41, 125, 207, 250 mm, respectively). The inlet temperature was taken as the room temperature (T_{in}= 23 °C). The thermocouples were connected to a portable Data Acquisition (DAQ) module (Advantech Co., Ltd, Taiwan) which was connected to a desktop computer. The contact areas between the thermocouples and the mini-tube were insulated with thermal compound to prevent any heat loss.

Data Analysis

In the simulation study, the tube was designed with temperature of outer surface of 50 °C and inner surface of rod acting as fluid domain. The whole simulation is done using ANSYS Workbench. The boundary conditions were set on the model to ensure the simulation is run according to the situation. Inlet velocity is set to be 0.13 m/s on inlet selection that had been made earlier. Temperature of outer and inner tube wall was then set with temperature of 50 °C.

For experimental work, the thermophysical properties of nanofluids are important parameters for calculating the heat transfer enhancement. The density, or more precisely, the volumetric mass density of a fluid is its mass per unit volume. The specific heat capacity of a fluid is the amount of energy needed to change the temperature of 1 kg of the fluid by 1°C. Both densities and specific heat capacities of nanofluids were determined using a well-known mixture model was shown in Equations (1) and (2) respectively:

$$\rho_{nf} = \phi_v \rho_p + (1 - \phi_v)\rho_{bf} \qquad (1)$$

$$c_{nf} = \frac{\phi_v \rho_p c_p + (1-\phi_v)\rho_{bf} c_{bf}}{\rho_{nf}} \qquad (2)$$

The relationship between the volume concentration, ϕ_v and weight concentration, ϕ_w of nanoparticles was obtained from Equation (3);

$$\phi_v = \frac{\phi_w \rho_{bf}}{\rho_p + \phi_w \rho_{bf} - \phi_w \rho_p} \qquad (3)$$

The dynamic viscosity of working fluids is a significant parameter to study the forced convective heat transfer. Dynamic viscosity is defined as the measurement of the fluid's internal resistance to flow and was estimated from the Einstein’s viscosity equation for dilute suspension ($\phi \leq$ 2vol%), as showed by Equation (4):

$$\mu = \mu_0(1 + 2.5\phi_v) \qquad (4)$$

The thermal conductivity of nanofluids is predicted by adopting the Hamilton and Crosser model as shown by Equation (5):

$$k_{nf} = k_{bf} \frac{k_p + (n-1)k_{bf} + (n-1)(k_p - k_{bf})\phi_v}{k_p + (n-1)k_{bf} - (k_p - k_{bf})\phi_v} \qquad (5)$$

Where n is the shape factor is considered in terms of sphericity factor (ψ). The value given as n = 3/ψ, where n = 6 for cylindrical particles and n = 3 for spherical particles.

The morphology of MWCNT was characterized using field emission scanning electron microscopy (FESEM, Zeiss SUPRA 35 VP).

Results and Discussion

SEM photomicrographs in Figure 3 show the morphology of MWCNT fiber at 15kx and 25kx magnifications. Microstructure of the MWCNT fiber showing the MWCNT bundles are entangled to each other. Based on Figure 3(b), the diameter of the fiber is obviously less than 100 nm, and this confirms the claim made by the supplier where the diameter of MWCNT is 10 nm.

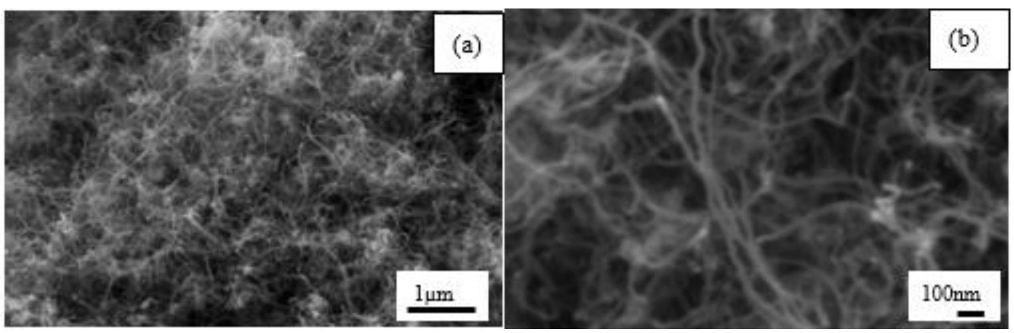


Figure 3. SEM Micrograph of MWCNT at the magnification of (a) 15kx and (b) 25kx

Figure 4 shows the comparison the visual analysis of different concentrations of MWCNT at different time intervals (until four days). All the MWCNT nanofluids with different concentrations showed good stability on the first day of experiment. The sedimentation slowly happened after 24 hours and second day for 0.1 vol% of nanofluids compared to the others concentrations. On the third day, it is visually observed that the nanofluids with 0.1, 0.2, 0.3, 0.4 and 0.5 vol% of MWCNT showed the presence of clear water or gap at the top of the nanofluids which are around 1.4, 0.3, 1.2, 0.2 and 0.5 cm, respectively. Apparently, it can be seen that all nanofluids exhibits flocculated sedimentation behaviour. After four days, the sample showed considerable sedimentation with the gap around 1.6, 0.4, 1.3, 0.3 and 0.7 cm for 0.1, 0.2, 0.3, 0.4 and 0.5 vol% of MWCNT. As MWCNT known to be hydrophobic, dispersion of MWCNT in distilled water are not able to produce a stabilized suspended solution. The experiment was initially run using MWCNTs nanofluids. The inlet temperature of all samples were fixed at 23 ℃ before taking the measurement values. Measurements were taken at steady state conditions. The reported values are the average of at least three repeated trials.

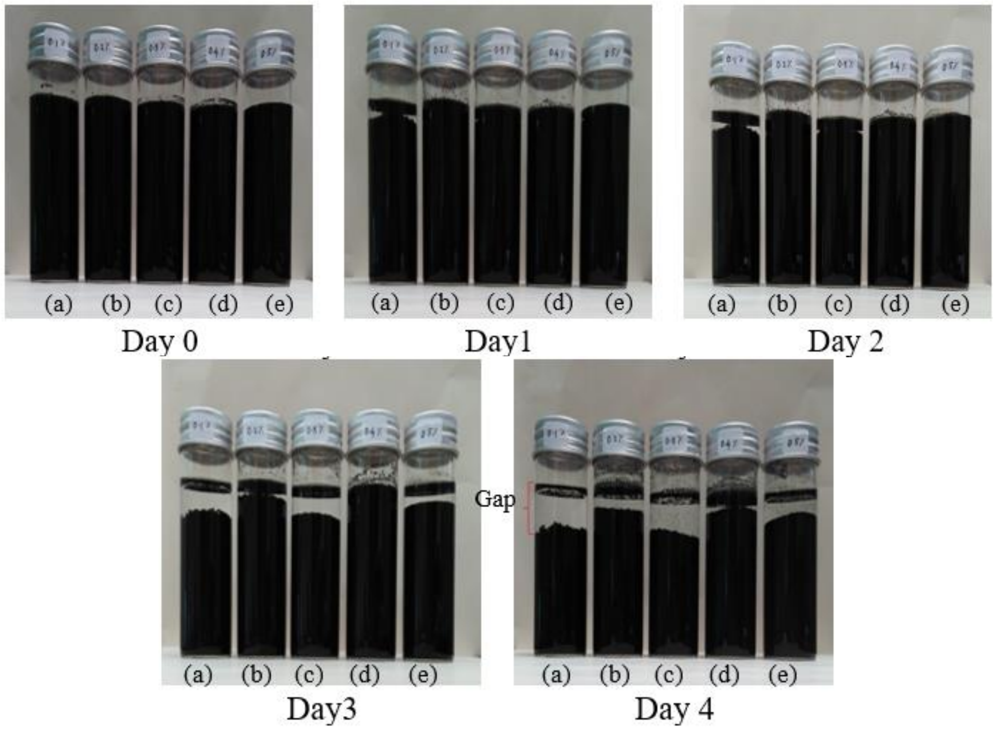


Figure 4. The dispersion behaviour of different concentrations MWCNT nanofluids; (a) 0.1, (b) 0.2, (c) 0.3, (d) 0.4 and (e) 0.5vol%

The effect of nanoparticle concentrations of mono nanofluids on the local heat transfer coefficient at fully laminar flow (Re = 112) is shown in Figure 5-6.

Figures 5-6 show the temperature of outer tube surface wall in channels 1 and 4 recorded by thermocouple along the test section using 0.1-0.5 vol% MWCNT nanofluid as coolant for 300 s, respectively. Data is tabulated for every 50 s. Channel 1 is the first location where the temperature drop in wall temperature was measured. Since in this channel, the temperature of fluid is about the same with inlet temperature of 23 ℃, it was observed that the temperature of wall has dropped significantly from 50 ℃ to an average of 39 ℃. This is equivalent to temperature drop of 22%.

For Channel 4, the temperature difference between nanofluids and distilled water is obvious where nanofluids show more reduction in temperature compared to distilled water. Figure 5 shows the heat transfer coefficient of distilled water and nanofluids. The figure shows the heat transfer coefficient of fluids in 4 channels (shown as Z/D_{in} at x-axis). It is found that the heat transfer coefficient decreased when the channel is far from the inlet. The results demonstrated that the heat transfer coefficient increased from 11.5% to 30.2% for 0.1 vol% MWCNT and 0.5 vol% MWCNT, respectively. The heat transfer coefficient decreases along the tube for all samples due to increase of thermal boundary layer thickness in the developing region. Furthermore, the reason for higher heat transfer coefficient at the entrance compared to other locations is due to the increment of flow disturbance at the inlet which is caused by sudden flow contraction. Similar result was also reported by Chabi et al. [10].

This result is corresponded with the temperature drop as shown in Figures 5 and 6. The trends shown in Figure 5 are in accordance with the previous work on MWCNT/GNP nanofluids by Hussien et al. [11]. They reported that the particle concentration has more effect on the heat transfer coefficient than the Reynolds numbers.

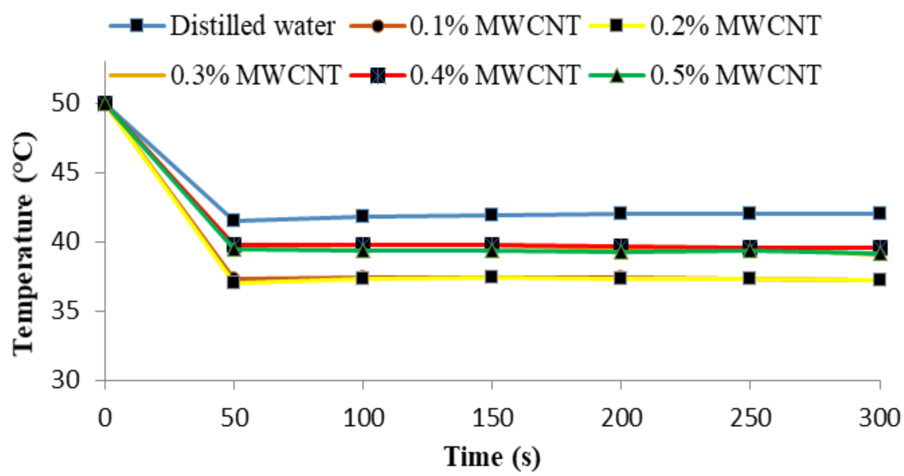


Figure 5. The temperature against time of different samples for Channel 1

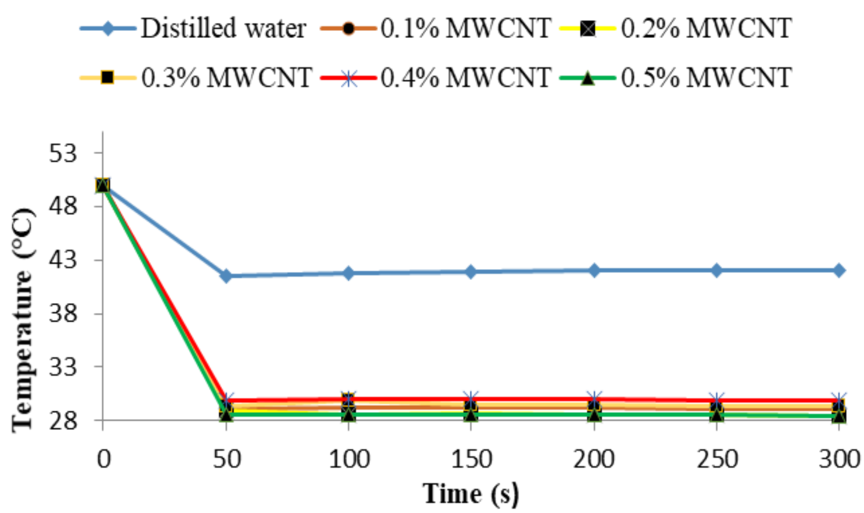


Figure 6. The temperature against time of different samples for Channel 4

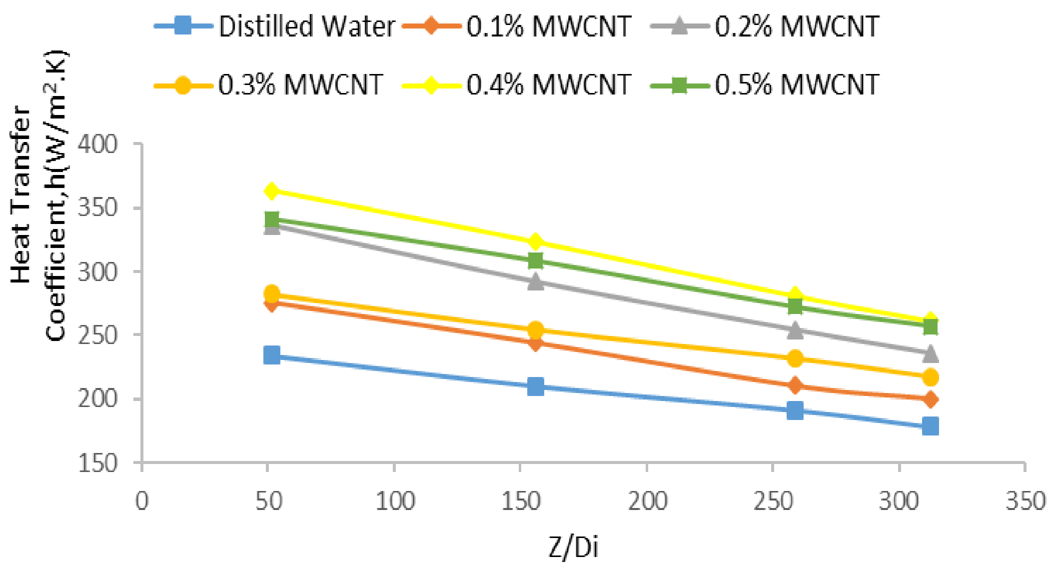


Figure 7. Heat Transfer Coefficient against Z/D_{in}

Table 3 shows that the average of heat transfer enhancement percentage based on simulated data for 0.3 vol% MWCNT to 0.55 vol% MWCNT. Data measured showed that the lowest heat transfer enhancement is shown by 0.3 vol% MWCNT nanofluids. The heat transfer enhancement percentage increased with increasing concentration of nanoparticles in the nanofluids. The best concentration from simulated data based on heat transfer enhancement percentage is 0.5 vol% MWCNT nanofluids. However, the heat transfer coefficient dropped for concentration of 0.55 vol% MWCNT nanofluids. Reduction in heat transfer coefficient for high concentration of nanoparticle are due the high liquid viscosity which influenced the flow rate of the nanofluids. According to Hussein et al. [12], the friction factor increased with increasing the volume concentration and fluid viscosity, this subsequently reduced the fluid velocity. The fluid velocity plays an important role on the heat transfer where low fluid velocity give low heat transfer coefficient [13].

It was found that 35% enhancement in thermal conductivity as shown in the simulation work is comparable with previous works on nanofluids using water as a working fluids. Vafaei and Wen [19] reported nanofluids with 40% thermal conductivity enhancement with addition of 1-7 vol% of Al_2O_3 with an average size of 25 nm. However in another study on Al_2O_3 by Buonomo et al. [20], they reported only 14% of thermal conductivity enhancement obtained with addition of 4 vol% of Al_2O_3 with average size of 40 nm. Nanofluids produced by addition of 1 vol% diamond resulted in 10% of thermal conductivity enhancement in the study reported by Jang and Choi [21].

Table 3. Heat transfer enhancement % based on simulated data

Nanofluid (vol %)	**Heat Transfer Enhancement (%)**				**Average Heat Transfer Enhancement (%)**
	Channel 1	**Channel 2**	**Channel 3**	**Channel 4**	
0.3% MWCNT	21.7	27.3	18.8	14.3	20.5
0.35% MWCNT	30.8	33.3	27.8	20.0	25.7
0.4% MWCNT	30.8	33.3	27.8	29.4	30.3
0.45% MWCNT	30.8	33.3	31.6	33.3	32.3
0.5% MWCNT	30.8	33.3	38.1	40.0	35.6
0.55% MWCNT	30.8	33.3	35.0	36.8	34.0

Conclusions

1. Data from experimental work showed that the heat transfer coefficient increased with increasing the MWCNT concentrations.
2. Data from simulation concluded that nanofluids with 0.5 vol% MWCNT provides the highest heat transfer enhancement by the value of 35.6%.
3. This is contrary to the experimental result where highest heat transfer coefficient enhancement percentage is 35% produced by nanofluids with 0.4vol% MWCNT. Reduction in heat transfer coefficient for 0.5 vol% MWCNT nanofluid in the experimental work is due the high viscosity which influenced the flow rate of the nanofluids.

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Author Contributions

All authors contributed toward data analysis, drafting and critically revising the paper and agree to be accountable for all aspects of the work.

Disclosure of Conflict of Interest

The authors have no disclosures to declare.

Compliance with Ethical Standards

The work is compliant with ethical standards.

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