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AN EXPERIMENTAL STUDY ON THERMAL PERFORMANCE OF NANO FLUIDS IN MICROCHANNEL HEAT EXCHANGER

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ABSTRACT

The enhancement of heat transfer performance in heat exchanger is achieved by reducing the size of the hydraulic diameter or by using a working fluid that has a better thermal conductivity compared to conventional working fluids. The application of a small hydraulic diameter can be found in the microchannel heat exchanger (MCHE). The design and the testing of the MCHE were done in this research. The MCHE was tested with several working fluids, such as the distilled water, the Al_2O_3-water nanofluids at 1%, 3% and 5% volume concentration, and the SnO_2-water nanofluids at 1% volume concentration. The temperature of inlet and outlet were set at 50°C and 25°C, respectively. The variations of flow rate at the inlet were applied from 100 ml/min up to 300 ml/min. The addition of nanoparticle in the base fluid was proven to improve the heat transfer of the MCHE, the 5% Al_2O_3-water and 1% SnO_2-water nanofluids are able to absorb the heat 9% and 12% higher than the base fluid. The overall heat transfer coefficient of MCHE with 5% Al_2O_3-water and 1% SnO_2-water nanofluids were 13% and 14% higher than the base fluid.

Keywords: Heat transfer; Microchannel heat exchanger; Nano fluids; Pressure drop

1. INTRODUCTION

Nowadays, computer becomes one of the most important things in human daily activities. Almost all of the activities, such as creating reports, performing calculations, reading articles, studying, or just playing games can be done with the computer. Throughout its development, the computer workload progressively heavier. It should be able to complete a number of complicated tasks. Certainly, the results will be determined by the microprocessor or is commonly referred to as CPU (central processing unit). The microprocessor is a chip on the computer functioned to process data, generally determined by the characteristics of microprocessor clock speed. Clock speed is the speed of the microprocessor to process data with Hertz. The development of microprocessor processing speed is increasing that directly proportional to the heat generated by the microprocessor.

In recent years, a significant increase in power dissipation of microprocessors due to the increasing calculation and processing speed of the processor, has also led to the increase of the heat flux which is predicted at more than 100 W/cm^2 (Putra et al., 2011). The trend from the past decades shows that the heat dissipated by microprocessors is rising up to 100 W/cm^2 in 2010 and likely to exceed that number in the near future (Marcinichen et al., 2012) Therefore, thermal management becomes challenging and critical for the performance of the cooling system.

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Conventional cooling systems using air was no longer able to deal with the heat flux which has been stated by Putra et al. (2011) and Huang et al. (2010). Therefore, the utilization of liquid cooling system has been developed to solve the problem of high heat flux by Zhang et al. (2005). The ability of the liquid-cooled system is still considered less than optimal to absorb heat. The ideas to improve the heat transfer liquid-cooled system have been conducted by many researchers. There were two ideas proposed by Jang and Choi (2007), i.e.; reducing the characteristic length, Δh, and increasing the value of heat transfer coefficient, in order to determine the optimum geometry of the equipment and to improve cooling performance. This idea was commonly called the microchannel. Research in the field of liquid-cooled system with a microchannel cooling shows that the system can deal with higher heat fluxes up to hundreds W/cm^2.

The need for small channel dimensions for heat transfer applications was proposed by Kandlikar et al. (2006), due to three main reasons: the increase in the value of heat transfer, the increase of dissipation of heat flux on microelectronic devices, and the emergence of micro-scale devices that require cooling system.

Kee et al. (2011) designed, fabricated, and evaluated the microchannel heat exhcanger (MCHE) made of alumina ceramics that are able to operate at extremely high temperatures. The manufacturing process PLIS (Pressure Laminated Integrated Structure) is used to make this MCHE. In this MCHE, there are 10 microchannels with 500 mm height and 2.8 mm width. The results indicated that the heat exchanger effectiveness was 70%. In addition, the pressure drop showed that in the low Reynolds number, the heat transfer occurred more dominant than the pumping losses due to pressure drop. Koyuncuoğlu et al. (2012) developed a novel microchannel heat sink fabrication technique for the liquid cooling of integrated circuits. The design allows the monolithic implementation of the heat sink with a CMOS compatible fabrication process requiring no change in the layout of the electronic circuit. The monolithic design minimizes the thermal resistance introduced by the heat sink. Dang et al. (2010) have done both simulation and experimental works to investigate the characteristics of fluid flow and heat transfer in MCHE with rectangular channels. Dix et al. (2010) performed a study of the fluid flow rate and heat transfer in MCHE by combining the results of simulation and experiment. From the experimental results, it was found that using the concept of microchannel design in heat exchanger will increase not only the heat transfer but also the pressure drop significantly.

Beside reducing the characteristic length, the using of additive to the base fluid could be one of the ways to improve the heat transfer. The addition of nano-size metal based particle have been investigated and proven to increase the thermal conductivity of the working fluid (Choi, 1995; Xuan & Li, 2000). Nano-fluid is a suspension of the base fluid with solid particles having a diameter in units of nanometers. The effect of nanofluids was tested in MCHE by some researchers (Mohammed et al., 2011; Hung et al., 2012). Their experiments tested the heat transfer performance in MCHE using water/water as working fluids, and using water and nanofluid with variation of volume concentrations. Ho et al. (2009) investigated forced convection cooling performance in microchannel heat sinks made from copper using nano-fluid Al_2O_3- water as the cooling fluid. MCHE consists of 25 square channels with channel lengths of 50 mm, width 283 μm, and 800 μm. The Al_2O_3-water 1%, 2% and distilled water were used for this experiment. The results showed that the heat transfer coefficient of Al_2O_3-water 1% was much better than the base fluid.

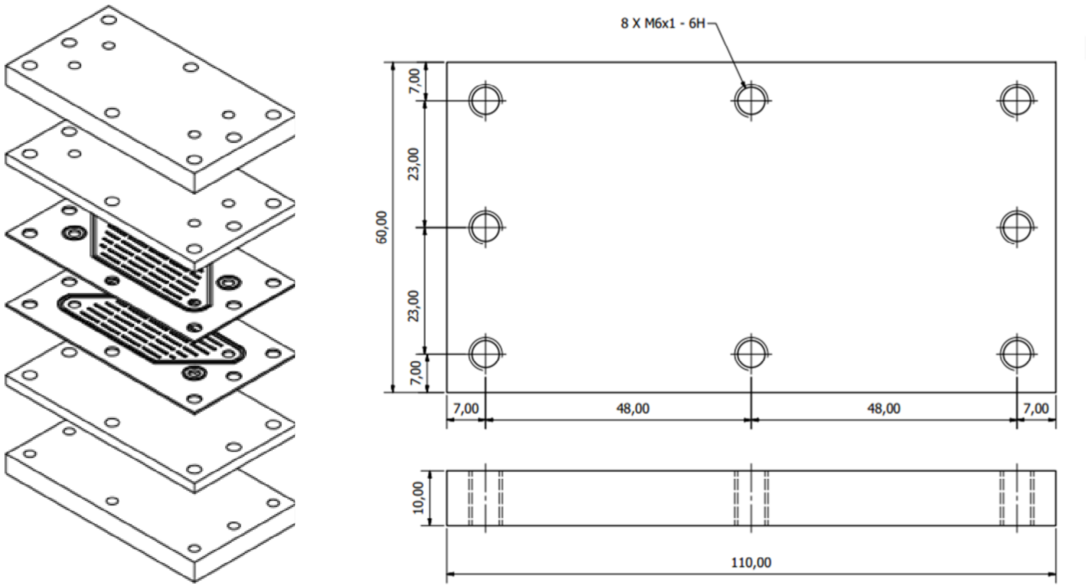
Pantzali et al. (2009) conducted experimental and numerical analysis on the use of nano-fluid on a miniature plate heat exchanger (PHE). The 2%, 4% and 8% CuO-water nanofluids were used in this research. The results generally showed that the use of nanofluids could reduce the flow rate of up to 4 times lower than using pure water and also reduce pressure drop to 6 times lower. Therefore, using nano-fluid not only absorbs as much energy as using a lower flow rate, but also reduces the pumping power.

Based on the previous researches conducted, in this research, the thermal performance of the MCHE with nanofluids will be examined.

2. EXPERIMENTAL

2.1. Design

In this study, the construction of microchannel heat exchanger was made by combining the concept of microchannel and plate heat exchanger. Figure 1 shows the microchannel heat exchanger that has been used during the research. The channel was made of copper plate with 1.5 mm thickness. Figure 2 shows the plates which have channels for the fluid flow with 0.5 mm height. In this section, there were eight pieces of sub-channel with 3 mm width. Sub channel served to make the fluid flow evenly and to make the flow becomes more turbulent. The hydraulic diameter of the MCHE is 852 μm.



(a) (b)

Figure 1 Design of the: (a) Microchannel heat exchanger (MCE); (b) Geometry illustration of MCE

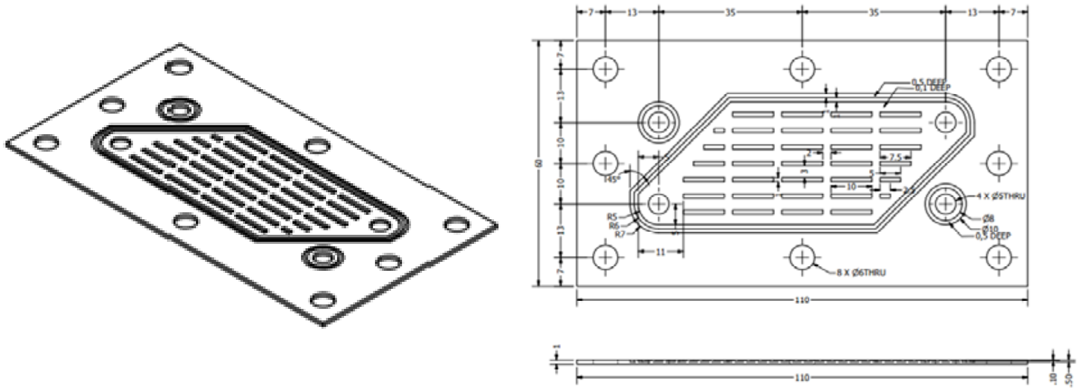


Figure 2 The layer of microchannel

2.2. Experimental Set-up

Figure 3 shows the experimental setup of this research. To measure the temperature of the fluid at the inlet and the outlet of the MCHE, thermocouples should be placed on fluid flow in the hose as close as possible to the hole hose fittings. Four thermocouples type K were placed at the inlet and the outlet of both hot and cold side. All thermocouples were then connected to the data acquisition system NI-9211 with the NI cDAQ-9172 chassis. Peristaltic pump OMEGAFLEX FPU500 and circulating thermostatic bath (CTB) was combined to control the flow rate and the fluid temperature respectively. The hose mounted on MCHE must follow the rules as seen in Figure 3 that the configuration was a counter-flow. Differential pressure transmitter by Omega connected to the NI-9203 and were used to measure the pressure drop.

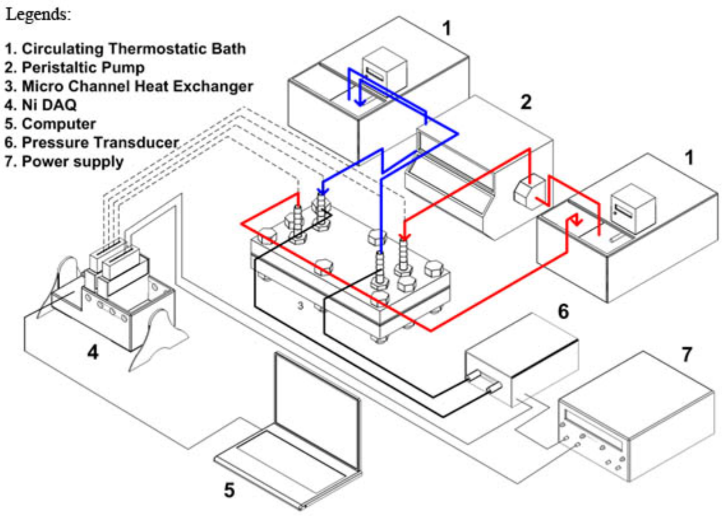


Figure 3 Experimental set-up of microchannel heat exchanger

In order to determine the thermal performance of MCHE, the experiment was conducted under the variation of flow rate (100, 150, 200, 250, 300 ml/minutes) and variation of working fluids which were water, Al_2O_3-water 1%, 3%, and 5% and SnO_2-water 1%. The inlet temperature of the hot side was maintained at 50°C, while the cold side inlet temperature was set at 25°C. Table 1 shows the properties of the working fluid such as thermal conductivity and dynamic viscosity. The thermal conductivity of the fluids was measured with the KD2 method, the same method was also used by Wen and Ding (2004), Mintsa et al. (2009), and Putra et al. (2012). The Brookfield LVDV-E rotational viscometer was used to measure the dynamic viscosity of the fluids. All the properties were measured at 25°C.

Table 1 Thermal conductivity and dynamic viscosity of working fluid at 25°C

Working Fluid Cold Side	Thermal Conductivity k (W/m.K)	Dynamic Viscosity μ (N/m^2s)
Water	0.52	0.001
Al_2O_3-water 1%	0.54	0.001141
Al_2O_3-water 3%	0.56	0.001171
Al_2O_3-water 5%	0.57	0.001197
SnO_2-water 1%	0.60	0.001279

3. RESULTS AND DISCUSSION

3.1. Data of Outlet Temperature in Hot Side and Cold Side

Figure 4 shows the outlet temperature of working fluid for hot side and cold side under the variation of flow rate. The graph shows that the addition of nano-particles aluminum oxide for the cooling fluid reduces the hot side temperature. Temperature drop occurs at some variations of flow rate. With the increase of the flow rate, the temperature difference between inlet and outlet becomes smaller compared to the base fluid. Thus, the heat transfer coefficient will increase.

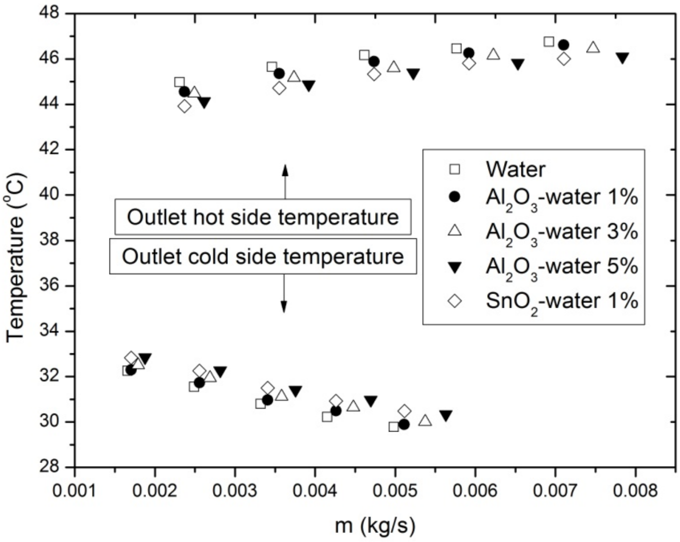


Figure 4 The distribution of outlet temperature for hot and cold side of MCHE

3.2. Overall Heat Transfer Coefficient on MCHE

The absorbed heat on the cold side was calculated with Equation 1,

$$Q_c = \dot{m}_c Cp_c (T_{c,o} - T_{c,i}) \tag{1}$$

where Qc is the heat absorbed by the cooling fluid, the mc is the cooling fluid flow rate, the Cp_c is the heat capacity of the cooling fluid, $T_{c,i}$ and $T_{c,o}$ are temperature of cooling fluid at the inlet and outlet respectively.

Overall heat transfer coefficient (U) is an important parameter in the analysis of heat exchanger. The overall heat transfer coefficient of MCHE can be calculated from overall heat transfer coefficient obtained from Equation 2

$$Q = U.A.\Delta T_m \tag{2}$$

and

$$\Delta T_m = \frac{(T_{h,i} - T_{c,o}) - (T_{h,o} - T_{c,i})}{\ln \frac{(T_{h,i} - T_{c,o})}{T_{h,o} - T_{c,i}}} \tag{3}$$

where ΔT_m is the logarithmic mean temperature difference (LMTD),

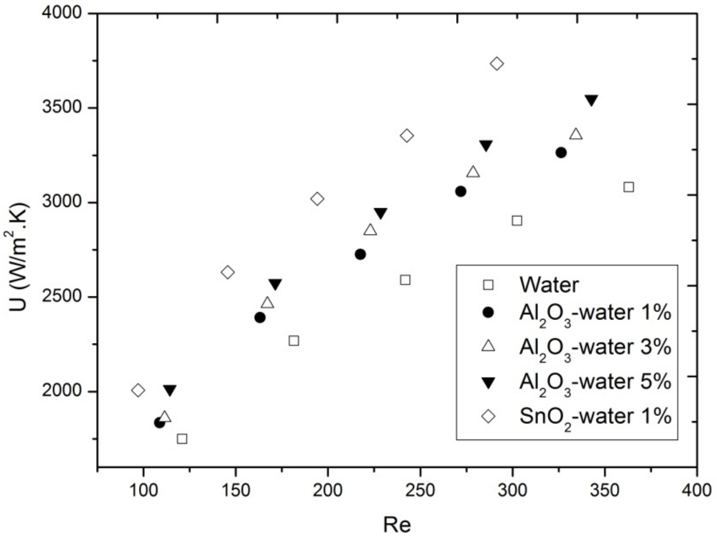


Figure 5 Overall heat transfer coefficients for every working fluid.

Figure 5 shows the value of the overall heat transfer coefficient of the working fluid under the variation of Reynolds numbers. From Figure 5, it can be seen that the heat transfer coefficients significantly increase with the increase of the Reynolds number. It showed that the overall heat transfer coefficient of MCHE with nanofluids as working fluid was higher than base fluid. The volume concentration of nanofluids also affected the value of the overall heat transfer coefficient. Increasing value of heat transfer coefficient occurred in nanofluid Al_2O_3-water 1%, 3%, 5% and SnO_2-water 1% were 5%, 8%, 13%, and 14%, respectively. In this result, the SnO_2-water 1% has the highest overall heat transfer coefficient for every Reynolds number. It might be affected by the high thermal conductivity of the SnO_2-water 1%, shown in Table 1.

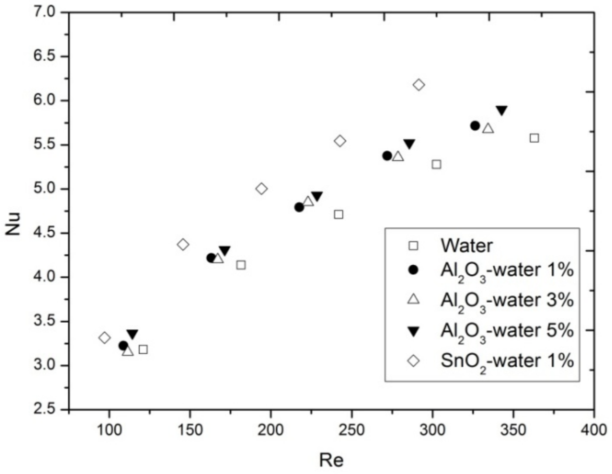


Figure 6 Nusselt number of the working fluid at different variation Reynolds numbers

Figure 6 shows the influence of the concentration of nanoparticles on the working fluid to the Nusselt number. Compared to base fluid, nano fluid Al_2O_3-water at all concentrations have a higher Nusselt numbers, although the Reynolds number was lower than the base fluid due to the higher viscosity and density of the nanofluid. SnO_2-water 1% had the highest Nusselt number in every variation of Reynolds number.

3.3. Effectiveness Value and NTU on MCHE

Effectiveness (ε) is a measure of the performance of a heat exchanger. Effectiveness is defined as the ratio of heat transfer that occurs actually from hot fluid to cold fluid with heat transfer that may occur (Qmax). The general equation to calculate the effectiveness was shown in Equation 4.

$$\varepsilon = \frac{Q}{Q_{max}} \tag{4}$$

In the calculation, the equations were used to obtain the value of the MCHE effectiveness shown in Equation 5. Cmin is the specific heat capacity of the lowest between the hot and cold fluid. In this experiment, the value of Cmin is the hot fluid. ΔT_{max} is the difference in temperature that may occur in the heat exchanger. For all cases, the value is the difference between the temperature ΔT_{max} at the inlet of the hot side ($T_{h,i}$) and at the inlet of the cold side temperature ($T_{c,i}$).

$$\varepsilon = \frac{UA}{C_{min}} \frac{\Delta T_m}{\Delta T_{max}} \tag{5}$$

NTU (number of transfer units) is a non-dimensional number that shows the size or thermal or heat transfer of a heat exchanger. Equation 6 shows the relationship between NTU with UA and C_{min}.

$$NTU = \frac{UA}{C_{min}} \tag{6}$$

Figure 7 shows that the addition of nano-particles in water-based fluids can increase the effectiveness of MCHE from 36% to 43% in the SnO_2-water concentration of 1% at the highest flow rate testing.

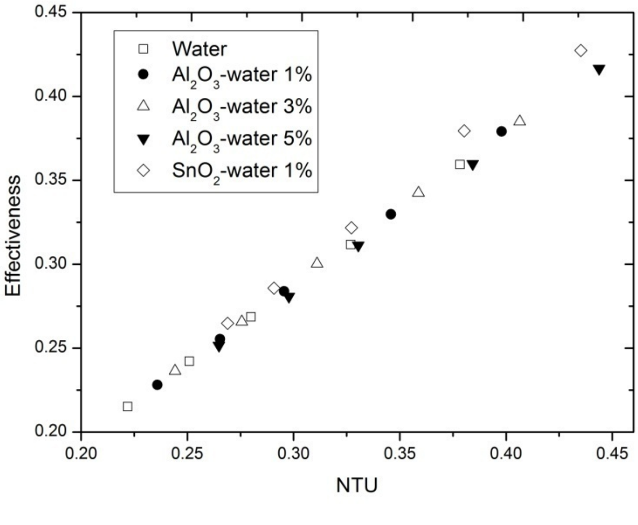


Figure 7 Effectiveness - NTU of MCHE

3.4. Pressure Drop in MCHE

Figure 8 shows the pressure drop in MCHE. The pressure drop was measured to examine the pressure drop characteristics of the MCHE under the variations of flow rate and working fluid.

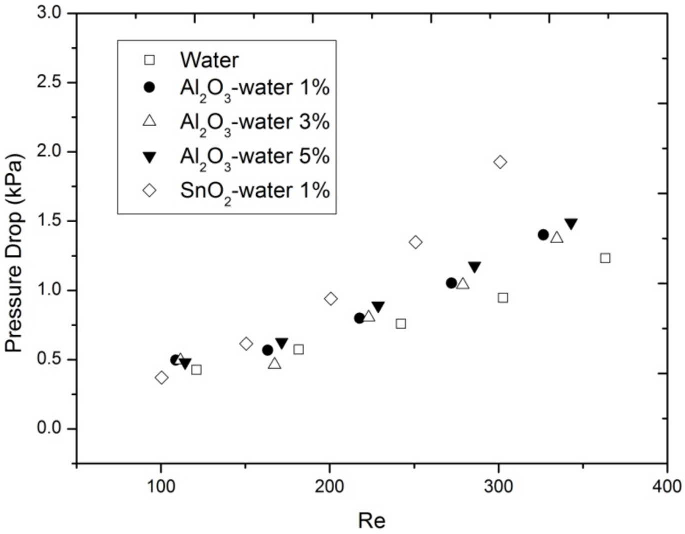
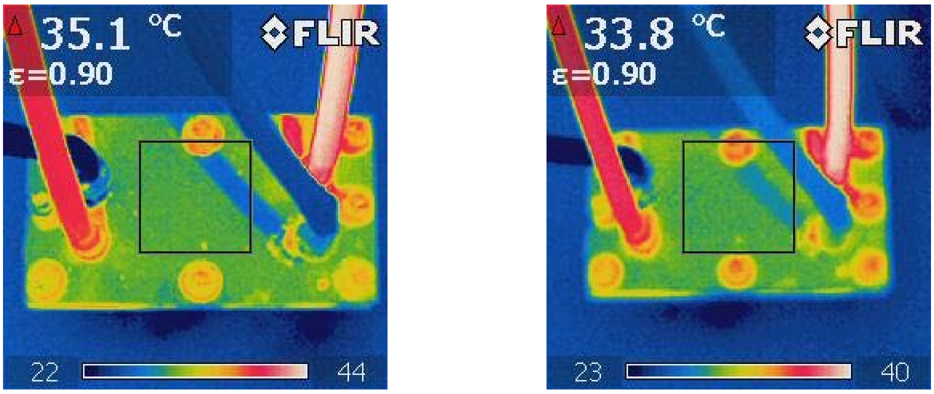


Figure 8 Pressure drop under the variation of working fluid.

Figure 8 shows the distributions of pressure drop per unit length for different working fluids. It can be seen from the figure that the pressure drop continues to increase with Reynolds number. It can also be seen that the overall pressure drop generated by the nanofluids was higher than base fluid. In addition, the concentration of nano particles also has significant affect to the pressure drop. The addition of nano particles on the the base fluid increase the dynamic viscosity of base fluid, so that the pressure drop will be higher. Naphon and Khonseur (2009) stated that the factor of the shape and the size of roughness irregularities of the micro-channel surface could also have significant effect on the pressure drop variations, but these factors were not investigated in this research

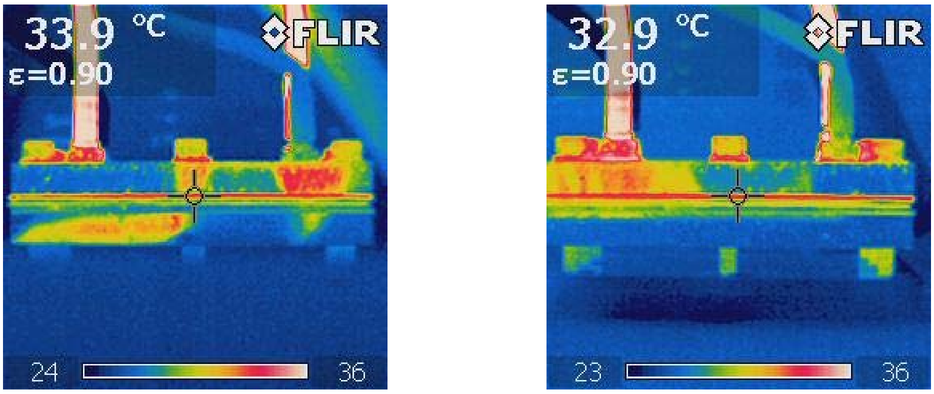
3.5. Comparison of MCHE Surface Temperature

Besides measuring the temperature in both of the fluid flow at the inlet and outlet of MCHE, temperature distribution on the surface of MCHE was also measured using the FLIR thermal imaging camera. In this test, only two types of working fluids were used, the water (a) and nano-fluid Al_2O_3-water 5% (b). Flow rates for both types of working fluid was 300 ml/min. Figure 9 shows the thermal image from the top side of the MCHE and Figure 10 shows thermal image channel side of the MCHE. From the pictures, it can be seen that the outer surface temperature of MCHE with nano fluid was lower than the base fluid. These thermal images indicated that the nano fluid could absorb more heat than the base fluid.



(a) (b)

Figure 9 Thermal imaging on upper surface MCHE



(a) (b)

Figure 10 Thermal imaging on copper plate the working fluid flow area.

4. CONCLUSION

Design and testing of the microchannel heat exchanger using water, Al_2O_3 nanofluids under volume concentration of 1%, 3%, and 5% and SnO_2-water 1% have been conducted. Nanofluids had a better thermal performance than the base fluid in MCHE. From the experimental results, Al_2O_3-water 5% and SnO_2-water 1% volume concentration have better thermal properties compared to water. In terms of heat absorption, Al_2O_3 nanofluids and 5% SnO_2 nanofluids absorbed heat 9% and 12%, respectively better than water. Then, the overall transfer coefficient MCHE when using Al_2O_3-water 5% and SnO_2-water 5% can be increased up to 13% and 14%. This results show that nanofluids is a potential working fluid for microchannel in the future.

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