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# Experimental Study on Effect of Nano ZnO on the Cooling Performance of Motorcycle Radiator

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**ABSTRACT**

An internal combustion engine requires a proper cooling system to release heat from the engine. The working fluid or coolant in a water-cooled engine impacts the overall radiator cooling performance. Several studies show that nanopowder can increase the thermal performance of the base fluids, although the pressure drops increase significantly. This paper describes the experimental study of motorcycle radiator cooling performance using nanopowder ZnO with distilled water and commercial coolant as the base fluids. The study began by measuring the boiling point and the specific heat of the base fluid (distilled water and commercial coolant) and nanofluids. Then, the flow rate of the cooling fluid was measured as the function of the engine's rotation speed. The results show that the boiling point of all nanofluids increases with the highest boiling point achieved by 0.5% ZnO – coolant, i.e., 110.06°C. Thus, the nanopowder will keep the cooling fluid in the liquid phase and lower the fluid's specific heat. The fluid with the lowest specific heat is nanofluid 0.5% ZnO – coolant. Low specific heat relates to the higher temperature drops. Nanofluid 0.5% ZnO – coolant has the highest temperature drop. Unfortunately, nanopowder also increases pressure drop by approximately twice the base fluid. Nanofluid 0.5% ZnO – coolant gives the highest overall heat transfer coefficient than other nanofluids or the base fluid, i.e., 42.7 $W/m^2.°C$ when its flow rate is 44.2 ml/s.

## 1. Introduction

An internal combustion engine converts thermal energy from the fuel to mechanical energy. Then, it will drive some equipment, such as electrical generators, automobiles, lawnmowers, military, and emergency vehicles, railroad locomotives, construction equipment, boats, etcetera [1]. In the combustion process, there is an increase in the temperature of the combustion chamber, the walls, and its surroundings. Since the strength of the engine's material is limited, cooling is an essential process in equipment that uses an internal combustion engine as its driving force.

Generally, the cooling media used is either water or air. Air is easier to handle and less expensive compared to water for the cooling of an internal combustion engine. However, the heat transfer rate

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of water is much higher than that of air. That is why much working fluid is water for the cooling process in gasoline or diesel cars and some motorcycles—the heat produced during the combustion process is released from the outer surface of the cylinder to the air. Some fins are inserted since the convection heat transfer in the air is lower than in water. Fins are generally cast integrally with the cylinder. The fins extend the area of heat transfer and thus improve the cooling process.

Engine coolant is preferred over water, considering it has some disadvantages compared to engine coolant. Water has a higher freezing point, lower boiling point, and is more corrosive compared to the coolant. Thus, coolant is mostly used in the cooling system of an internal combustion engine.

Water or coolant will flow through the cylinder block and absorb some heat from the cylinder. Then, water or coolant will release the heat while it flows in a radiator. A fan is installed in front of the radiator to draw ambient air to cool off the liquids. The flow rate of the cooling liquid entering the engine is primarily controlled by a thermostat. The thermostat controls the flow so that the engine continues to operate at an optimum temperature [2].

If the operating temperature of the cylinder is too high, then it could be harmful to the cylinder, especially if the cylinder is made of aluminium, a head-cylinder gasket, and other equipment such as a pump. But if it is too low, more thermal energy will be transferred to the cooling media. Then it will lead to improper vaporization of the fuel and decrease the performance of the Internal Combustion Engine. So, the cooling liquid needs to be controlled to maintain the temperature of the engine within the optimum range [1-3].

For an old car, the radiator might have some deposit inside or outside the pipes and the fan’s performance might decrease. These conditions reduce heat transfer from the cooling liquid to the ambient air, especially when there is a traffic jam on a hot summer day. It is shown by an indicator that water temperature is higher than the recommended value.

Thanks to God for nanotechnology. It can be applied in any area of our lives, including in solar collectors and as coolants in automotive heat exchangers [4]. Nanopowder CuO in water or nanofluid has improved fluids’ thermal properties and increased the Nusselt number by increasing the Reynolds number and thus improving the convection heat transfer coefficient [5]. Nanofluid CuO could increase overall heat transfer compared to distilled water [6]. Titanium oxide was used as the nanoparticles in cooking oil as the fluid base. The heat transfer rate increased 36.25% for 0.09% of nanofluid volume concentration [7]. An experiment used Alumina nanoparticles which size was 22 nm diameter. Alumina-water-based nanofluid was produced with different concentrations of Alumina particles using an ultra-sonicator. The heat transfer rate increases as the particle size decreases [8]. The heat transfer improved by using nano aluminium oxide with 20 nm particle size and some volume fraction from 0.001 to 0.002. The overall heat transfer coefficient increases by 8%–10% [9]. The $Al_2O_3$ nanoparticles of about 30 nm diameter are used in water. The convective heat transfer coefficient of nanofluid is higher than that of the base liquid at the same mass flow rate and inlet temperature [10]. Nanofluid flows inside the inner tube and hot pure water flows in the outer tube. Results show that the overall heat transfer coefficient increases with nanoparticle volume concentrations in the heat exchangers [11]. The effect of various nanofluids such as $Al_2O_3$, $TiO_2$, $SiO_2$ on automotive engine (Aprilia SXV 450 engine) cooling was experimentally studied. For the 1% volume concentration of nanoparticles, they found that $TiO_2$, $SiO_2$, and $Al_2O_3$ nanofluids could give higher heat transfer than the base fluid, i.e., 31.9%, 27.7%, and 12.5%, respectively at flow rate = 3.5 GPM [12]. Another researcher investigated numerically the effect of three types of nanoparticles: copper oxide (CuO), aluminium oxide ($Al_2O_3$), and titanium dioxide ($TiO_2$) on the cooling capabilities of ethylene glycol (EG)-based fluid in a radiator. Mahat *et al.,* [14] developed a mathematical model for magnetohydrodynamics (MHD) viscoelastic nanofluid flow around a linear horizontal circular cylinder with constant heat flux. The skin friction increases but the heat transfer coefficient decreases for the increasing values of the magnetic field [14]. Rusdi *et al.,* [15] did research about the impact of nanoparticle penetrate over a shrinking sheet with thermal radiation and partial slip. The effects of silver (Ag) nanoparticles with water base and kerosene base are investigated. Using Matlab software, the founding was that the velocity profile increases when both nanoparticle volume fraction and suction parameter increase. While the increasing in suction parameter to the decreasing in the temperature profile. Besides that, skin friction coefficient and Nusselt number increase when the suction parameter increases [15]. Halim and Sidik [16] reviewed past research on nanofluid used in refrigerants and their performance in refrigeration system.

The effect of zinc oxide (ZnO) water-based nanofluids was also studied on Suzuki Mehran (VXR) 2016 radiator. They studied the heat transfer and also the pressure drop and friction factor. Three kinds of volumetric concentrations of ZnO nanoparticles were employed, i.e., 0 – 0.3% [17]. Another study on automotive car radiators was applying copper to the ethylene glycol or coolant. Thus, it turned to be ethylene glycol copper nanofluids. The heat transfer enhancement of the radiator with this nanofluid increased 3.8% when the copper added as much as 2% at Reynolds number of 6000 and 5000 for the air and coolant [18]. The presence of zinc oxide (ZnO) in aqueous-based nanofluid effectively increases the heat absorption capacity. The ZnO nanoparticles used were in the range of 19 to 30 nm [19]. The ZnO-water nanofluid is used in a concentric tube heat exchanger. The overall heat transfer coefficient for ZnO-water nanofluid is increased by 11% with a volume fraction of 0.5% compared with water [20]. ZnO nanoparticles in ethylene glycol (EG) improve the transport properties of ZnO–EG nanofluids. ZnO–EG–water nanofluid has the thermal conductivity enhancement of 17.26% and viscosity reduction of 17.34% at 27°C.

In recent years, nanoparticles have been extensively applied in many heat exchangers including radiators. Many researchers were using ZnO nanoparticles but the base fluid used nanoparticles was majority water. Some research used ethylene glycol as the base fluid but did not use ZnO for the. Suganthi *et al.,* [21] investigated ZnO-ethylene glycol nanofluid, but they discussed a lot about the transport properties and not on the heat transfer nor the pressure drop. This paper will discuss the result of an experiment conducted to find the effect of nanopowder Zinc Oxide (ZnO) added to the cooling liquid of the radiator of a motorcycle Vixion 2012. The specification sheet of the ZnO and 2012 Vixion motorcycle are attached in Figure 1 and Figure 2, respectively. Some parameters to be measured were the boiling point, specific heat, the temperature of the cooling liquid at the inlet and outlet of a radiator, and pressure drop of liquid.

**CERTIFICATE OF ANALYSIS**
**ZINC OXIDE PHARMACEUTICAL**
**DATE : MARCH 3, 2021**

| Test Item | Result | Specified Limit | | Method |
|---|---|---|---|---|
| ZnO | 99.9154 | 99.900 | % Min. | ILCS03-LAB-34 Reff ASTM D5280 -85 |
| Moisture Content | 0.0935 | 0.1500 | % Max. | ILCS03-LAB-35 Reff ASTM D 280 -01 |
| Ignition Loss | 0.0526 | 0.1000 | % Max. | ILCS03-LAB-38 ( GRAVIMETRIC TEST ) |
| HCl Insoluble | 0.0179 | 0.0500 | % Max. | ILCS03-LAB-40 ( GRAVIMETRIC TEST ) |
| Chloride | 0.0051 | 0.0200 | % Max. | ILCS03-LAB-24 ( TITRIMETRIC TEST ) |
| Iron | 0.0001 | 0.0001 | % Max. | ILCS03-LAB-26 Reff ASTM D 4075 -06 |
| Lead | 0.0004 | 0.0020 | % Max. | ILCS03-LAB-26 Reff ASTM D 4075 -06 |
| Manganese | trace | 0.0005 | % Max. | ILCS03-LAB-26 Reff ASTM D 4075 -06 |
| Copper | trace | 0.0005 | % Max. | ILCS03-LAB-26 Reff ASTM D 4075 -06 |
| Cadmium | trace | 0.0005 | % Max. | ILCS03-LAB-26 Reff ASTM D 4075 -06 |

Batch No: A D I I 811 VII 15
A C I II 811 VII 23

Quantity : 25 Bags ( 500 Kgs )

Depok, March 3, 2021
Lab. Department

| Prepared by | Checked by | Approved by |
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| Doni T | Mukti | Nugroho A.P. |

**Fig. 1.** The specification sheet of the ZnO

**Fig. 2.** Vixion Yamaha 2012 motorcycle and its radiator

## 2. Methodology

There were six fluids observed in this experiment, i.e., (1) distilled water, (2) distilled water + nanopowder ZnO 0.3%, (3) distilled water + nanopowder ZnO 0.4%, (4) distilled water + nanopowder ZnO 0.5%, (5) commercial coolant (ethylene glycol), (6) coolant (ethylene glycol) + nanopowder ZnO 0.5%.

The first thing conducted was doing the preliminary experiment to find the boiling point and specific heat of the six fluids, as shown in Figure 3 and Figure 4, respectively. The boiling point of nanofluid is higher than the base fluid. It is true for distilled water and coolant. More concentration of the nanopowder ZnO makes the boiling point increase. The highest boiling point is given by 0.5% ZnO – coolant, i.e.,1 110.06°C. The boiling point increases 1.81% for 0.5% ZnO – distilled water and 9.13% for 0.5% ZnO – coolant. Thus, the nanofluid will keep the cooling fluid stay in a liquid phase. The measured temperature has an uncertainty of ± 0.1°C or around 0.1%. Then, the boiling point of the six fluids is very accurate.

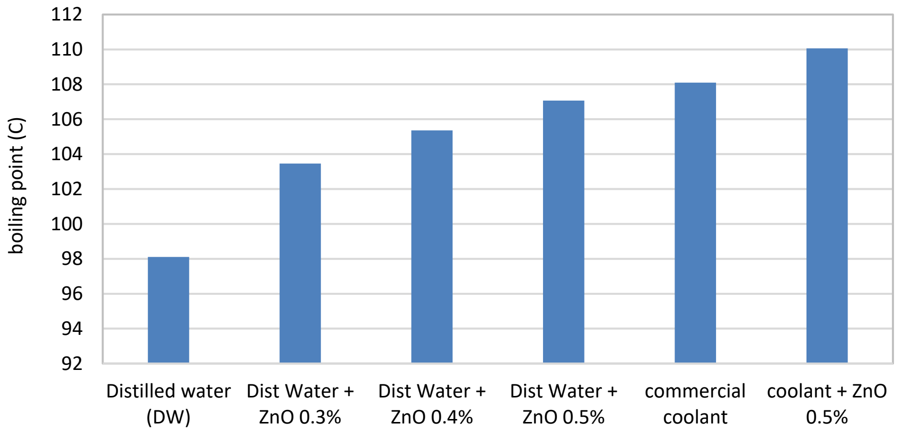



**Fig. 3.** The boiling point of the six fluids studied

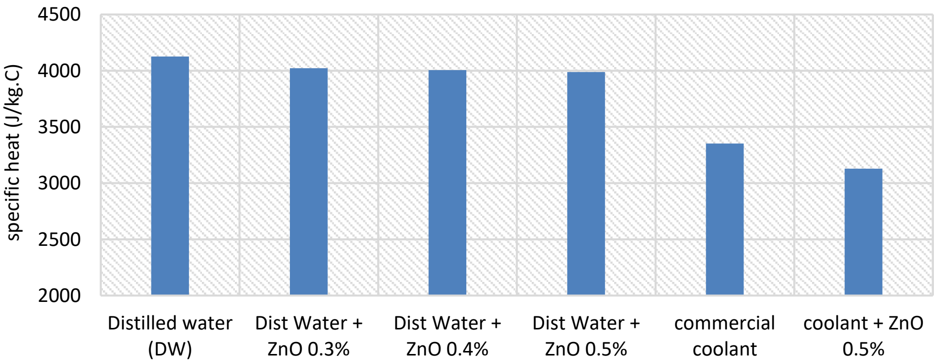



**Fig. 4.** The specific heat of six fluids in this study

Figure 4 shows that the higher concentration of ZnO, the lower the specific heat of the nanofluid. The result of the experiment with distilled water determined the concentration of ZnO used with coolant. Since the specific heat of distilled water with ZnO 0.5% is the least, the experiment will use coolant with ZnO 0.5% as the nanofluid. The nanofluid will absorb and release heat easier. The specific heat was measured using a calorimeter. The quantities to be measured were the weight and the temperature. The smallest weight measured was 31.9 grams. While the scale has an uncertainty of ± 0.1 gram or around 0.3%. The uncertainty of the specific heat depends on the uncertainty of the scale, i.e., 0.3%, and the thermometer used, i.e., 0.1%. The uncertainty of the specific heat was 0.4% or around $\pm$ 12 – 17 J/kg.C. The uncertainty was minimal, and the measurement was adequate.

The fluid velocity flowing inside the radiator pipe is needed to obtain the convection heat transfer coefficient. The flow rate of the cooling fluids in radiator Vixion 2012 was measured at different engine rotation speeds, as seen in Figure 5. The flow rate of the cooling fluid increases when the engine speed increases. The engine needs much cooling when speeding up because more combustion energy is released.

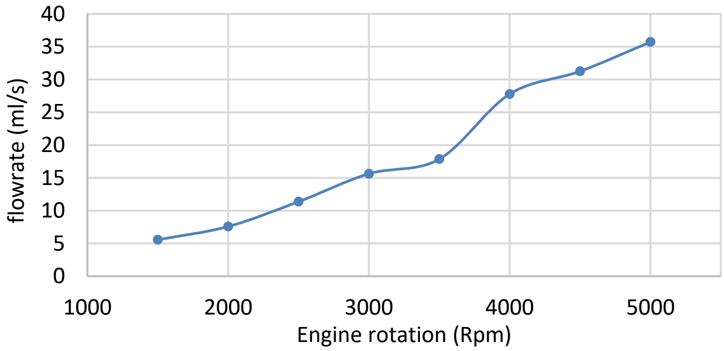



**Fig. 5.** The cooling fluid flow rate at a different engine rotation speed

The experiment cannot be conducted on the motorcycle because some instruments, such as thermocouples, airflow meter, U-tube to measure pressure drop, need to be installed. Then, a set of equipment was prepared, as seen in Figure 6. The water flowing into the radiator was heated in a hot water tank until it reached the optimum operating temperature of the radiator in a real motorcycle. A ball valve was installed to control the flow rate of the cooling fluid entering the radiator to have the same flow rate that was measured during the preliminary experiment. Cooling fluid released the heat to the air drawn by a fan in front of the radiator. Then, fluid flowed down to the reservoir tank and circulated back to the hot water tank by a pump.

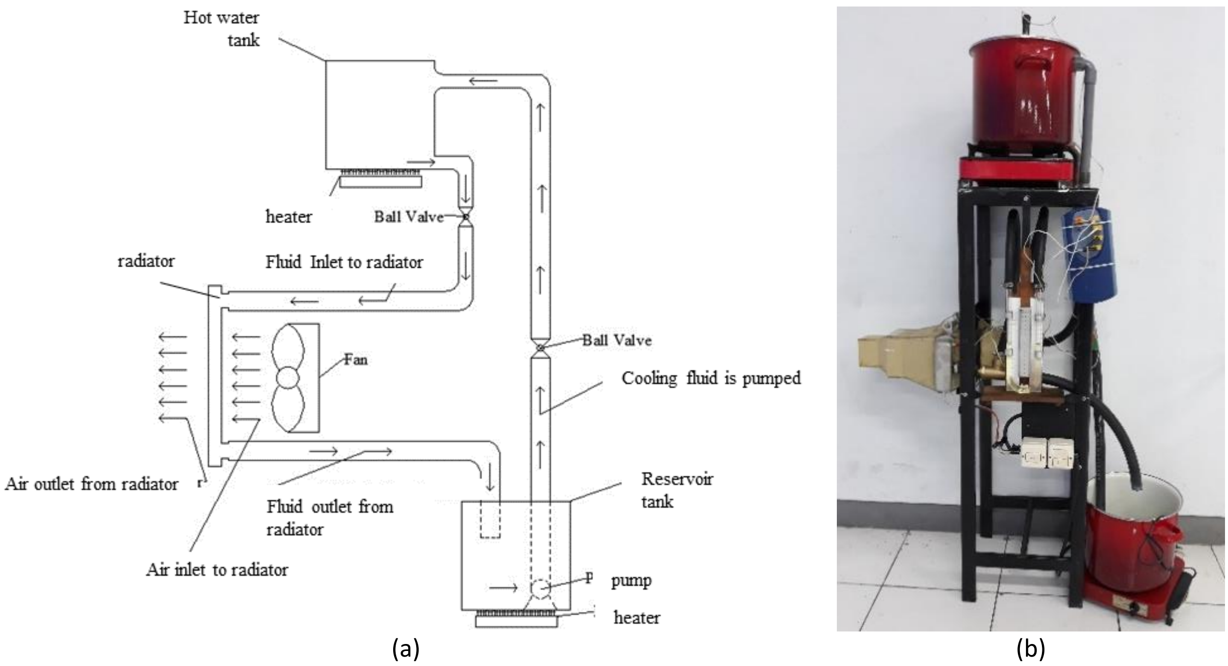
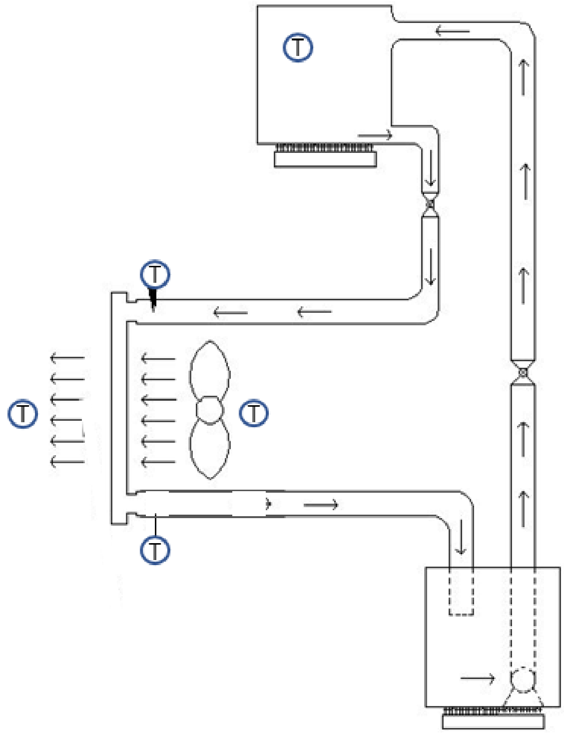
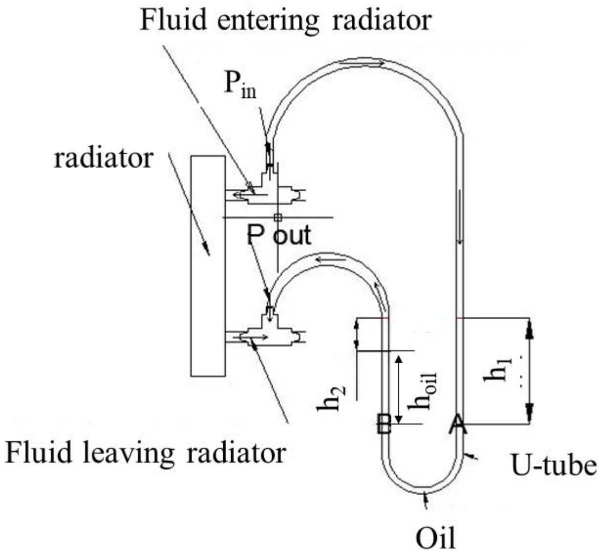



**Fig. 6.** The equipment used during experiments; (a) Schematic diagram, (b) Experimental setup

The K-type thermocouple was installed at the inlet and outlet of the cooling fluid, at the inlet and outlet of the air crossing radiator, and at the hot water tank to ensure that the temperature of the cooling fluid entering the radiator was at the optimum temperature. U-tube was installed to measure the pressure drop of cooling fluid passing through the radiator. Figure 7(a) and Figure 7(b) show the location of the instruments installed.




(a)




(b)

**Fig. 7.** The location of the instruments installed; (a) Location of K-type thermocouple, (b) Location of U-tube

## 3. Result and Discussion

The effect of nanofluid using ZnO as the cooling fluid in the radiator of motorcycle Vixion 2012 is discussed in this section. The ambient air temperature during the experiment was between 29.2 – 32.1°C. Nanofluid with more concentration of ZnO gives a higher temperature drop for the cooling fluid passing through the radiator. It is valid for both base fluids, distilled water, and coolant. Figure 8 shows that the highest temperature drop occurs for nanofluid 0.5% ZnO-coolant. A higher temperature drop means higher heat transferred from the cooling fluid to the air. The slightest temperature difference between both cooling fluid and air is when distilled water is used as the cooling fluid.

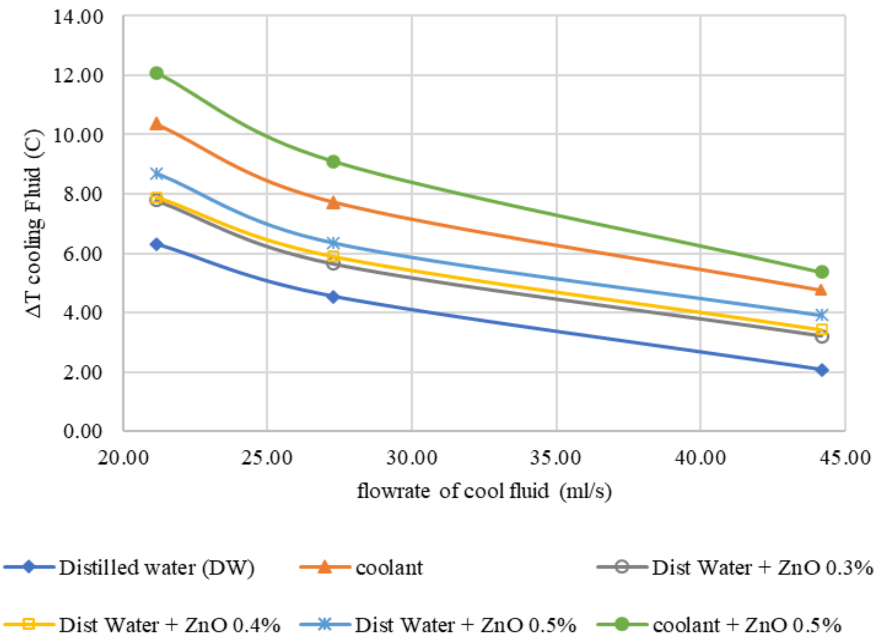



**Fig. 8.** Temperature drops of cooling fluid passing through the radiator

The most significant temperature drop among the cooling fluids is in nanofluid 0.5% ZnO – coolant. The specific heat of this nanofluid is the smallest in Figure 4. For the same flow rate and heat transfer, the smaller the specific heat, the higher the temperature difference.

### *3.1 Overall Heat Transfer Coefficient*

Heat transfer in the radiator involves convection in each fluid and conduction through the wall separating the air and cooling fluid. An overall heat transfer coefficient *U* is used to account for the contribution of all these effects on heat transfer. The rate of heat transfer from the cooling fluid is equal to the rate of heat transfer to the air, as shown in Eq. (1):

$$\dot{Q} = \dot{m}_{cooling\ fluid}\ c_p \Delta T_{cooling\ fluid} = UA\ \Delta T_{LM} \tag{1}$$

Where log-mean temperature difference, $\Delta T_{LM}$, is defined as in Eq. (2):

$$\Delta T_{LM} = \frac{\Delta T_2 - \Delta T_1}{ln\left(\frac{\Delta T_2}{\Delta T_1}\right)} \tag{2}$$

$$\Delta T_2 = T_{cooling\ fluid,in} - T_{air,out}$$

$$\Delta T_1 = T_{cooling\ fluid,out} - T_{air,in}$$

The overall heat transfer coefficient, *U*, in the radiator is shown in Figure 9. Nanofluid 0.5% ZnO – coolant gives the highest value compared to other nanofluids or the base fluid, i.e., 42.7 W/m$^2$.°C when the flow rate is 44.2 ml/s. The lowest value is 14.7 W/m$^2$.°C when the fluid is distilled water flowing at 21.1 ml/s.

When coolant is the base fluid, the 0.5% nanopowder ZnO increases the overall heat transfer coefficient by 10.8%, 8.7%, and 12.4% for a flowrate of 21.1 ml/s, 27.3 ml/s, and 44.2 ml/s, respectively. The finding with distilled water as the working fluid is that 0.3% nanopowder ZnO increases the overall heat transfer coefficient by 19.4%, 30.6%, and 60.8% for a flowrate of 21.1 ml/s, 27.3 ml/s, and 44.2 ml/s, respectively.

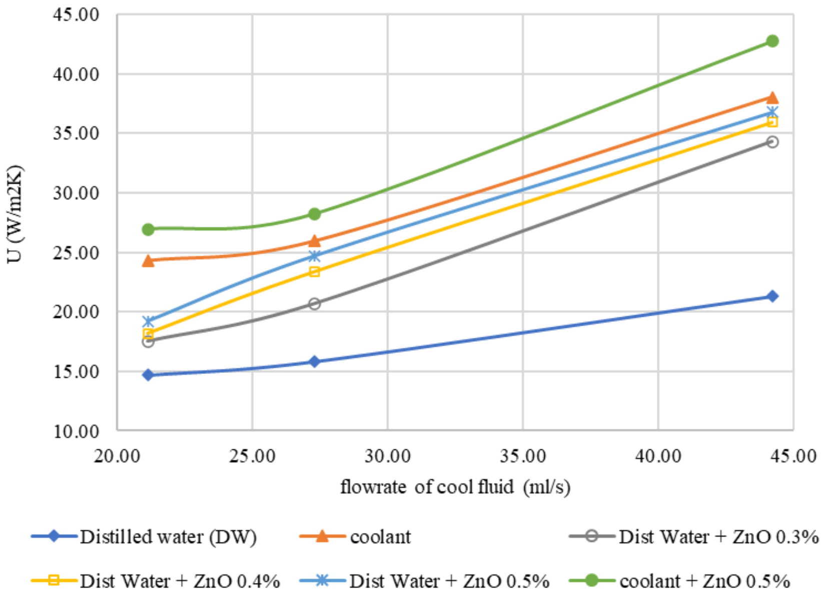



**Fig. 9.** The overall heat transfer coefficient in the radiator

The nanopowder ZnO can increase the overall heat transfer coefficient, U, for any base fluid. More concentration will produce a higher overall heat transfer coefficient, U, of the radiator. The overall heat transfer coefficient improvement occurs, mainly when the engine rotates at high speed. This finding can be helpful to overcome the degradation of the old radiator.

The overall heat transfer coefficient increases as more ZnO is used in the coolant-based or water-based nanofluid. This trend is the same as what Suganthi *et al.,* [21] found. They reported that the thermal conductivity increased 33.4% when ZnO-EG (Ethylene Glycol) nanofluids contained 4% and only 17.26% for 2%. The thermal conductivity of both nanofluids increased linearly with nanoparticle concentration.

### *3.2 Pressure Drop*

Any viscous fluid will experience a pressure drop when it flows inside a pipe or enclosure. The pressure drop is caused by (1) friction between the fluid and the surface of the straight pipe or enclosure and (2) various fittings such as valve, elbow, tee, inlet, exit, expansion, and contractions in addition to the straight pipe. Figure 10 shows the pressure drop of the six-cooling fluid studied. Since coolant is more viscous than distilled water, its pressure drop is higher than water. It is valid for both the base fluid and nanofluid. More concentration of nanopowder ZnO in the fluid increases its pressure drop. So, the increasing overall heat transfer coefficient also produces a higher pressure drop.

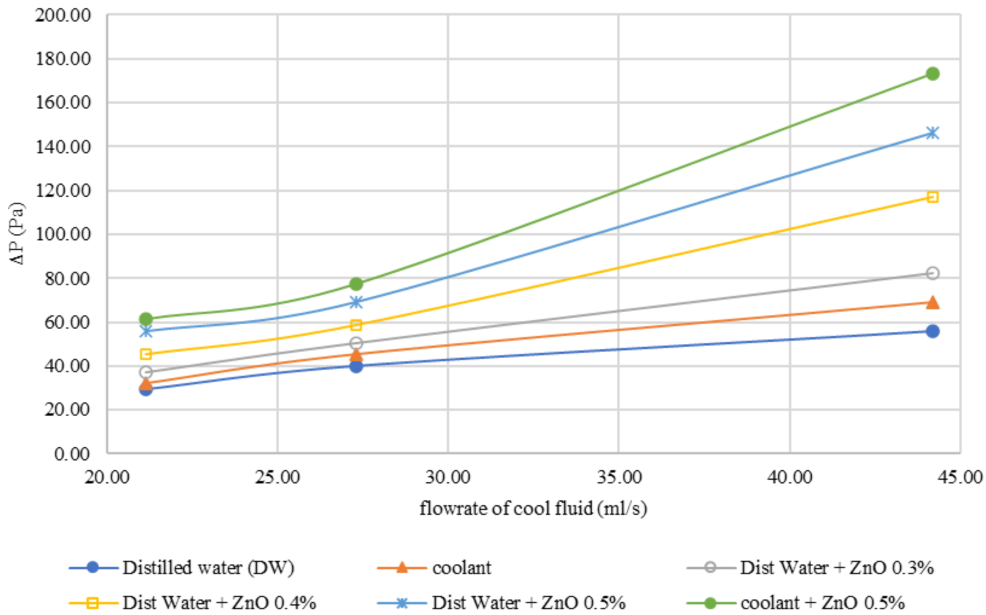



**Fig. 10.** Pressure drops of cooling fluid passing through the radiator

The highest-pressure drop was given by nanofluid 0.5% ZnO – coolant, i.e., 61.24 Pa, 77.22 Pa, and 173.07 Pa for the flow rate of 21.1 ml/s, 27.3 ml/s, and 44.2 ml/s, respectively. While pressure drop given by base fluid coolant was only 31.95 Pa, 45.27 Pa, and 69.23 Pa for flow rate of 21.1 ml/s, 27.3 ml/s, and 44.2 ml/s. Nanopowder ZnO with a concentration of 0.5% approximately doubled the pressure drop. Increasing pressure drop is undesirable since it means more pumping power to circulate the cooling fluid to the radiator.

The higher the nanopowder's concentration, the higher the pressure drop. The trend is corresponding to the other researchers' findings, such as Qasim *et al.,* [17] and Suganthi *et al.,* [21].

### *3.3 The Uncertainties of Measurement Apparatus*

The measurement apparatus used in the experiment are shown in Table 1. From the uncertainties of the measurement, the uncertainties of some variables calculated could be determined. The most significant uncertainty of some variables calculated is 5.31% for the density, 6.67% for the flow rate, 1.3% for the specific heat, 5.49% for the overall heat transfer coefficient, and 8.75% for the pressure drop. Thus, the results can be accepted.

**Table 1**
The uncertainties of measurement apparatus used

| Instruments used | Accuracy | Smallest data measured | Biggest uncertainties |
|---|---|---|---|
| k-type thermocouple | 0.1°C | $T_{ambient\text{-}air}$ = 29.2°C | 0.34% |
| Scale | 0.1 gr | $m_{copper}$ = 31.9 gram | 0.31% |
| Measuring cup | 10 ml | $V_{water}$ = 200 ml | 5% |
| Stopwatch | 0.1 s | $T_{water\text{-}flow}$ = 6.0 s | 1.67% |
| mm block in u-pipe | 1 mm | H = 48 mm | 2.08% |
| Meter | 1 mm | H = 70 mm | 1.43% |
| Anemometer | 0.1 m/s | 5.8 | 1.72% |

## 4. Conclusions

From the experiment conducted in a radiator Vixion 2012, nanopowder ZnO can increase boiling point, reduce the specific heat of the cooling fluid, increase temperature drop when it passes through the radiator, increase overall heat transfer coefficient, but also increase pressure drop.

The highest boiling point is given by 0.5% ZnO – coolant is 110.06°C. The boiling point increases 1.81% for 0.5% ZnO – distilled water and 9.13% for 0.5% ZnO – coolant. Thus, the nanopowder will keep the cooling fluid in a liquid phase. Nanopowder ZnO can lower the specific heat of the fluid. The fluid with the lowest specific heat is nanofluid 0.5% ZnO – coolant. Low specific heat relates to the higher temperature drops. Nanofluid 0.5% ZnO – coolant has the highest temperature drop.

Nanofluid 0.5% ZnO – coolant gives the highest overall heat transfer coefficient than other nanofluids or the base fluid, i.e., 42.7 $W/m^2.{}^{\circ}C$ when its flow rate is 44.2 ml/s. However, nanopowder also increases pressure drop. The pressure drops of nanofluid 0.5% ZnO – coolant is approximately twice that of the base coolant.

**Acknowledgement**
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## References

[1] Arcoumanis, Constantine, ed. *Internal combustion engines*. Academic Press, 1988.
[2] Virale, Avinash Gangadhar, and Pravin T. Nitnaware. "Experimental analysis of jacket cooling of SI engine and study of operating parameters and emissions." *International Journal of Advances in Engineering & Technology* 10, no. 1 (2017): 113.
[3] Hossain, Abul K., David I. Smith, and Philip A. Davies. "Effects of engine cooling water temperature on performance and emission characteristics of a compression ignition engine operated with biofuel blend." *Journal of Sustainable Development of Energy, Water and Environment Systems* 5, no. 1 (2017): 46-57. https://doi.org/10.13044/j.sdewes.d5.0132
[4] Gupta, Munish, Vinay Singh, Rajesh Kumar, and Z. Said. "A review on thermophysical properties of nanofluids and heat transfer applications." *Renewable and Sustainable Energy Reviews* 74 (2017): 638-670. https://doi.org/10.1016/j.rser.2017.02.073
[5] Senthilraja, S., and K. C. K. Vijayakumar. "Analysis of heat transfer coefficient of CuO/water nanofluid using double pipe heat exchanger." *International Journal of Engineering Research and Technology* 6, no. 5 (2013): 675-680.
[6] Choudhury, Promit, Priya Garg, and Srishti Jha. "Study of nano particles for enhanced heat transfer characteristics of base fluids for cool thermal energy system." *International Journal of Engineering Research and Applications* 4, no. 4 (2014): 97-101.
[7] Kottasamy, A., K. Kadirgama, Keeran Annamalai, K. Mohanesan, D. Ramasamy, M. M. Noor, M. M. Rahman, and M. Razali Hanipah. "Titanium oxide with nanocoolant for heat exchanger application." *Journal of Mechanical Engineering and Sciences* 11, no. 3 (2017): 2834-2844. https://doi.org/10.15282/jmes.11.3.2017.6.0257
[8] Rao, M. Siva Eswara, and Dowluru Sreeramulu. "Experimental Investigation of Heat transfer rate of Nano fluids using a Shell and Tube Heat exchanger." In *IOP Conference Series: Materials Science and Engineering*, vol. 149, no. 1, p. 012204. IOP Publishing, 2016. https://doi.org/10.1088/1757-899X/149/1/012204
[9] Aghayari, Reza, Heydar Madah, Bahram Keyvani, Abdolreza Moghadassi, and Fatemeh Ashori. "The Effect of Nanoparticles on Thermal Efficiency of Double Tube Heat Exchangers in Turbulent Flow." *ISRN Mechanical Engineering* (2014): 1-5. https://doi.org/10.1155/2014/274560
[10] Albadr, Jaafar, Satinder Tayal, and Mushtaq Alasadi. "Heat transfer through heat exchanger using $Al_2O_3$ nanofluid at different concentrations." *Case Studies in Thermal Engineering* 1, no. 1 (2013): 38-44. https://doi.org/10.1016/j.csite.2013.08.004
[11] Mahrooghi, Ali, and Mohammad Moghiman. "Effect of nano particles on heat transfer in heat exchangers." *Ciência e Natura* 37, no. 6-1 (2015): 199-206. https://doi.org/10.5902/2179460X20848
[12] Mathivanan, Elankathiravan, David Gasior, Liping Liu, Kingman Yee, and Yawen Li. *Experimental Investigation of the Impact of Nanofluids on Heat Transfer Performance of a Motorcycle Radiator*. No. 2017-01-1611. SAE Technical Paper, 2017. https://doi.org/10.4271/2017-01-1611

[13] Mutuku, Winifred Nduku. "Ethylene glycol (EG)-based nanofluids as a coolant for automotive radiator." *Asia Pacific Journal on Computational Engineering* 3, no. 1 (2016): 1-15. https://doi.org/10.1186/s40540-016-0017-3

[14] Mahat, Rahimah, Muhammad Saqib, Imran Ulah, Sharidan Shafie, and Sharena Mohamad Isa. "MHD Mixed Convection of Viscoelastic Nanofluid Flow due to Constant Heat Flux." *Journal of Advanced Research in Numerical Heat Transfer* 9, no. 1 (2022): 19-25.

[15] Rusdi, Nadia Diana Mohd, Siti Suzilliana Putri Mohamed Isa, Norihan Md Arifin, and Norfifah Bachok. "Thermal Radiation in Nanofluid Penetrable Flow Bounded with Partial Slip Condition." *CFD Letters* 13, no. 8 (2021): 32-44. https://doi.org/10.37934/cfdl.13.8.3244

[16] Halim, Nur Fazlin Che, and Nor Azwadi Che Sidik. "Nanorefrigerants: A Review on Thermophysical Properties and Their Heat Transfer Performance." *Journal of Advanced Research in Applied Sciences and Engineering Technology* 20, no. 1 (2020): 42-50. https://doi.org/10.37934/araset.20.1.4250

[17] Qasim, Muhammad, Muhammad Sajid Kamran, Muhammad Ammar, Muhammad Ali Jamal, and Muhammad Yasar Javaid. "Heat transfer enhancement of an automobile engine radiator using ZnO water base nanofluids." *Journal of Thermal Science* 29, no. 4 (2020): 1010-1024. https://doi.org/10.1007/s11630-020-1263-9

[18] Leong, K. Y., Rahman Saidur, S. N. Kazi, and A. H. Mamun. "Performance investigation of an automotive car radiator operated with nanofluid-based coolants (nanofluid as a coolant in a radiator)." *Applied Thermal Engineering* 30, no. 17-18 (2010): 2685-2692. https://doi.org/10.1016/j.applthermaleng.2010.07.019

[19] Bhagat, U. K., P. V. More, and P. K. Khanna. "Study of zinc oxide nanofluids for heat transfer application." *SAJ Nanotechnology and Nanoscience* 1, no. 1 (2015): 1-7.

[20] Krishna, V. Murali. "Heat Transfer Enhancement by using ZnO Water Nanofluid in a Concentric Tube Heat Exchanger under Forced Convection Conditions." *International Journal of Innovations in Engineering and Technology* 7, no. 4 (2016): 177-184.

[21] Suganthi, K. S., V. Leela Vinodhan, and K. S. Rajan. "Heat transfer performance and transport properties of ZnO-ethylene glycol and ZnO-ethylene glycol-water nanofluid coolants." *Applied Energy* 135 (2014): 548-559. https://doi.org/10.1016/j.apenergy.2014.09.023