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# Erosion-corrosion effect of nanocoolant on actual car water pump

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**Abstract.** In automobile cooling system, water and ethylene glycol are usually used as coolant. For many years, nanofluid has been reported to enhance thermal properties of conventional heat transfer fluid due to dispersion of solid particles which exhibit superior thermal conductivity. Many past researchers found improvement of heat transfer rate in automobile cooling system by using nanofluid as coolant. However, there are very few reported on drawback such as tribological impact on components in automobile cooling system. Hence, this paper focused to determine erosion-corrosion effect of nanofluid on aluminium impeller in Perodua Kancil D37 water pump. Working parameters such as inlet pressure, coolant temperature and rpm of pump were in line with ASTM D2809-09 standard. Testing coolants were made up of corrosive water, ethylene glycol and graphene nanoplatelets. Each pump surface profile was inspected using 3D imaging microscope after undergoing 100 hours of testing continuously. Also, precise weight measurement was carried out before and after testing to determine total material loss. It was observed that corrosion effect was about the same for both base coolant and nanocoolant. Erosion-corrosion effect increased material loss when nanocoolant was used instead of base coolant. Based on ASTM 2809-09 standard, erosion-corrosion damage on impeller was found to be minimal and scored high rating in evaluation. Thus, both coolants can be considered to be incorporated in future cooling system.

## 1. Introduction

Nanotechnology has been widely developed in various applications such as vehicle engine cooling, electronics cooling, solar collectors, biomedical, refrigeration, thermal energy storage system and machining. One of the most striking nanoscience today is known as nanofluid. Nanofluid is a two phase system which consists of base fluid and solid nanoparticles. Common nanoparticles used in past studies are made up of metallic or non-metallic material (oxides, carbides, carbon allotropes and etc.) while base fluid is usually composed of water, ethylene glycol, water/ethylene glycol or oil. Nanofluid was first proposed by Choi [1] and this mixture was believed capable to increase thermal conductivity of conventional heat transfer fluid due to solid particles which characterized by superior heat conductivity with respect to pure liquid. This idea was then proven by many researchers that the addition of nanoparticles provides higher heat transfer performance and thermal conductivity than respective base fluid in various applications .



## 2. Coolant in automobile cooling system

Few decades back, water was first used as coolant in vehicle cooling system. In certain countries with very cold weather, water in vehicles tends to freeze and eventually damaging flowing tubes and engine block due to its volume expansion. Then, ethylene glycol (antifreeze agent) was introduced as additive to improve unsatisfying freezing point and low boiling point of water. Higher boiling point of coolant allows more heat absorption and higher operating temperature, thus more heat can be rejected in a cycle which mean higher power engine can be implemented [2]. For a long time, water-ethylene glycol mixture is widely used as conventional automobile coolant because water and ethylene glycol alone are poor heat transfer fluid.

In 2017, there was a report on the impact of ethylene glycol (EG) ratio in coolant mixture. Chiam et al [3] showed that higher portion of EG in water/EG mixture led to increment of thermal conductivity and decrement of viscosity. The authors revealed that 1.0 vol%  $\text{Al}_2\text{O}_3$  provides 6.6%, 8.9% and 12.8% of thermal conductivity enhancement at 60:40, 50:50 and 40:60 ratio of water/EG. On the other side, the same concentration nanofluid showed 49.6%, 46.8% and 42.7% of viscosity decrement as EG concentration was varied from 40% to 60%. From this study, it clearly shows that the reason which mixture of water/EG is widely used as vehicle coolant nowadays.

### 2.1. Heat transfer behavior and performance of nanofluid in automobile cooling system

The use of nanofluid in vehicle cooling system was initiated by Choi et al [4] in 2001. They found that thermal conductivity of metal oxide nanofluids were much higher than expected values and they proposed that nanofluid could enhance vehicle thermal performance. Since then, many researchers started to explore the behavior and performance of nanofluid in automobile cooling system using actual radiator and conventional coolant in their test rig. Elias et al [5] in 2014 found that maximum thermal conductivity enhancement (8.3%) of water/EG mixture was found at addition of 1 vol%  $\text{Al}_2\text{O}_3$  nanoparticles. Dispersion of 4 vol%  $\text{Al}_2\text{O}_3$  nanoparticles into water increased thermal conductivity from 9.4% to 24.3% when temperature was increased from 21 to 51 °C [6]. Selvam and his team [7] reported thermal conductivity of 0.45 vol.% graphene-water/EG nanofluid increased thermal conductivity by 18% but decreased specific heat capacity by 8% when compared to base fluid.

In 2014, Ali et al [8] investigated forced convection heat transfer of  $\text{Al}_2\text{O}_3$  nanofluid using radiator in Toyota Yaris 2007. Different volume concentration of nanofluids were prepared: 0.1%, 0.5%, 1.0%, 1.5% and 2%. The optimum heat transfer coefficient was found at 1% volume concentration and heat transfer deterioration occurred when the concentration was further increased. 14.72% and 9.51% of maximum increment were obtained for Nusselt number and heat transfer coefficient of the coolant respectively.

Using a shell-and-tube heat exchanger, Barzegarian et al [9] found that 0.3 vol% of  $\gamma$ -  $\text{Al}_2\text{O}_3$ -water nanofluid has 29.8% and 19.1% higher value than water in term of Nusselt number and overall heat transfer coefficient. There are also published results on cross-flow type heat exchanger which is widely used in most of the vehicles nowadays. Both 0.65 vol%  $\text{Fe}_2\text{O}_3$  and  $\text{Al}_2\text{O}_3$  water based nanofluid were reported to enhance heat transfer of water by 9% and 7% respectively [10]. Another author [11] reported that dispersion of 0.3 vol% aluminium nanoparticles into water enhanced overall heat transfer coefficient of the heat exchanger by 11.57% and heat transfer coefficient by 18.39%. In addition, higher coolant flow rate was reported able to improve heat exchange capacity and system efficiency factor in an air-cooled type heat exchanger [12].

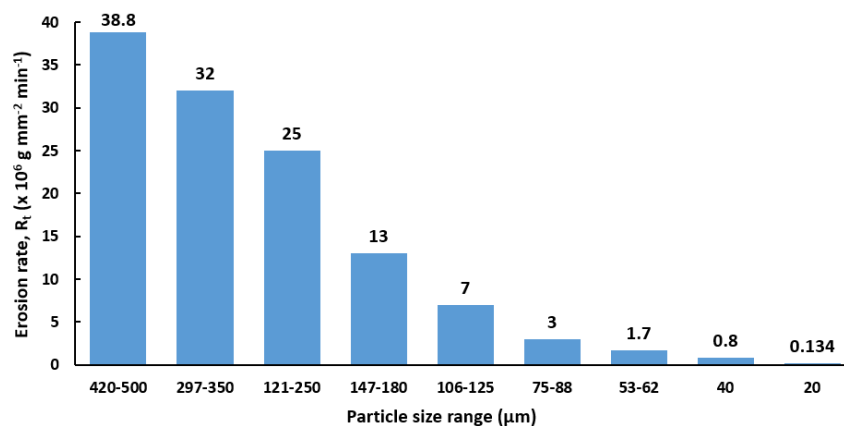
Selvam et al [13] investigated thermal performance of graphene nanoplatelets (GnP)-water/ethylene glycol nanofluid in a louvered fin flat tube. From their results, about 104% and 81% of enhancement were found at inlet temperature of 35 °C and 45 °C respectively, with nanoparticle concentration (0.5 vol.%), nanofluid flow rate (62.5 g/s) and ambient air velocity (5 m/s). Then, the same authors [14] affirmed the statement from their previous work in which mass flow rate of nanocoolant was the dominant factor for pressure drop increment. For convective heat transfer coefficient, 51% and 20% of enhancement were found at 45 °C and 35 °C respectively, with nanoparticle concentration of 0.5% and mass flow rate of 100 g/s.

### 3. Erosion-corrosion mechanism

From literature, nanofluid is proven to be a better heat transfer fluid with the demerit of increased pressure drop. But there are some reports on possible drawback of using it, such as tribological impact on typical material surfaces. One of the most destructing defect is erosion-corrosion effect on metal surfaces. Erosion itself is the removal of material from a surface results from continuous impact of small particles and it is known to cause wear, abrasion and scouring. On the other side, corrosion forms a layer of rust on metal surface due to chemical or electrochemical reactions. The combined effect of these two phenomenon accelerates the rate of material loss which eventually deteriorates the durability of a material body and could lead to system failure.

#### 3.1. Effect of particles size on material loss

One of the earliest approach in determining the effect of solid particles size on erosion rate was mixing micrometer sized material into slurry [15]. A slurry is a heterogeneous mixture of fluid or sometimes with the addition of solid particles (micron to millimeter size) [16]. In the study, 1.2 wt% of silicon carbide (SiC) powders with irregular shapes and different sizes were dispersed into commercial diesel fuel oil. Cylindrical shaped specimens were used, in which copper rod (diameter of 5.17 mm) and API P110 steel (diameter of 4.76 mm) were used for short-duration test and long-duration test respectively. An erosion pot tester was operated at rotational speed of 18.7 m/s and 40 °C, meanwhile the specimens were placed at outer part of the rotating cup to ensure cylindrical flow pattern at specimens. Their result is illustrated as in Figure 1, it is clearly seen that smaller particle size can reduce erosion rate and authors explained that this is due to the combined effect of lower collision frequency and impact velocity of smaller particles.



**Figure 1.** Erosion rate of steel corresponding to size of SiC particles.

#### 3.2. Effect of impinging jet configuration

An experimental study on heat transfer performance and erosion effect of using nanofluids in liquid evacuated impinging jet system was carried out in 2008 [17]. The authors altered Reynolds number from 1700 to 20000 and different nozzle-to-surface distance (2, 5 and 10 mm). They found that 5 vol%  $\text{Al}_2\text{O}_3$ -water nanofluid enhanced surface heat transfer coefficient of distilled water by 72%. Besides that, impinging nanofluid jet with 19 m/s velocity on an aluminium disk (100 mm diameter and 100 mm length) for 180 hours led to total mass loss of 14 mg. This suggested that the use of nanofluid could produce significant erosion effect in similar applications.

In 2014, 2 vol%  $\text{Al}_2\text{O}_3$ -water/EG nanofluid was used to impinge on aluminium 3003-T3 alloy and copper-alloy-100 plates (3 inch x 2 inch x 0.05 inch) [18]. The test duration was ranged from 3 to 112 hours

and all the plates were polished using sand paper with different grit. They observed from variation of roughness value and suggested that surface cleaning and loose material removal occurred during first 3 hours of testing, polishing scratch lines removal within first 14 hours and followed by erosion after 28 hours. From 28<sup>th</sup> hour to 112<sup>th</sup> hour interval, there were no significant difference found between roughness value of aluminium plate after impingement using base fluid and nanofluid. But their optical microscopy imaging showed another mechanism, in which base fluid removed all polishing scratches and expanded original pitting size during 112 hours testing while nanofluid removed portion of polishing scratches and led to widespread small pitting which clustered along scratching lines. They proposed that insignificant chemical erosion is due to the chemical inertness of aluminium. On the other side, both base fluid and nanofluid did not cause significant change on roughness value of copper plate under same testing condition as aluminium plate. For microscopy imaging, both fluid treatment did not remove initial polishing scratches. After 112 hours, impingement using base fluid led to widespread small pitting whereas enlargement of pitting and clustering of pitting along scratch lines were observed for nanofluid.

George et al [19] tested erosion effect of impinging TiO<sub>2</sub>-water nanofluid on aluminium and cast iron at different angle. Their test lasted for 10 hours and jet speed were varied to 5 m/s and 10 m/s. Maximum erosion rate was observed at 20° and 90° angle of impingement for aluminium and cast iron respectively. From their SEM and AFM scanning, corrosion-assisted erosion is the main factor for material removal in cast iron whereas aluminium smoothening is due to mild abrasive erosion.

### 3.3. Erosion-corrosion damage on different metal plates

Celata et al [20] tested erosion-corrosion effect on three different flat metal plates which include stainless steel AISI 316, copper and aluminium. In their experiment, they used water and different water-based nanofluids: 9 wt% TiO<sub>2</sub>, 9 wt% Al<sub>2</sub>O<sub>3</sub>, 9 wt% ZrO<sub>2</sub>, 3 wt% SiC and 3 wt% Al<sub>2</sub>O<sub>3</sub>. For their comparison purpose, they covered portion of the metal plate with erosion-resistant material so a reference point was created for showing the difference of plate thickness before and after erosion test using profilometer. The erosion effect due to different nanofluids is summarized in Table 1 below. In addition, they observed that TiO<sub>2</sub> caused least pump gears damage meanwhile 9 wt% Al<sub>2</sub>O<sub>3</sub> caused the most severe damage. From their SEM image, they concluded that material removal by mechanical erosion is due to the use of nanofluids while water caused intergranular corrosion on the metals.

**Table 1.** Erosion effect of various nanofluids on different metals

Nanofluid	Erosion effect on metals
TiO <sub>2</sub>	No effect on copper and stainless steel. Some effect on aluminium, but water caused more material loss.
Al <sub>2</sub> O <sub>3</sub>	No effect on stainless steel. Small effect on copper. Extreme large effect on aluminium, about 300 times more than effect of water.
ZrO <sub>2</sub>	No effect on stainless steel. Large effect on copper. Very large effect on aluminium.
SiC	Small effect on all tested metals.

Rashidi et al [21] investigated the synergistic effect of sea water and gamma-alumina nanoparticles on cylindrical carbon steel specimens using a hydrodynamically smooth rotating cylinder electrode. Sea water is produced using distilled water and sodium chloride with pH around 8.3. Diameter of nanoparticles are averagely sized 20 nm. From their results, nanoparticles were found to be a corrosion inhibitor but still had

higher impact on erosion rate of low carbon steel when compared to sea water. Besides that, erosion-corrosion was found to contribute the most in material loss compared to pure corrosion and erosion, in both nanofluid and base fluid testing.

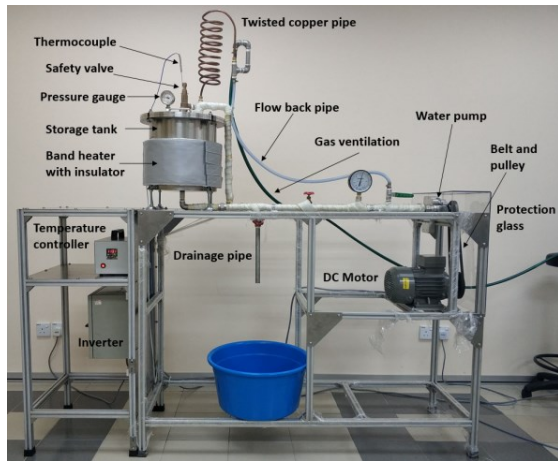
There was a study about behaviour of MWCNT-nanofluid on heat transfer performance and corrosion effect [22]. The study was separated into two parts: polarization test for corrosion and radiator test for thermal performance. For polarization test, their results were in-line with other researchers who used different methods, in which aluminium specimen showed the highest corrosion rate compared to copper and stainless steel. Among three metals, copper showed the lowest corrosion rate. Also, it was observed that MWCNT-nanofluid caused the least corrosion damage compared to EG and water due to the addition of GA which slowed down corrosion process. On the other side, highest temperature difference between inlet and outlet of radiator was observed for MWCNT-nanofluid, followed by EG and water for all rpm. This proved that nanofluid has better cooling capability (heat transfer) and corrosion resistance (with corrosion inhibitor added) than conventional base fluid.

As shown in literature, the use of nanofluid could cause thinning of material by erosion. One of the most common problem existing in current automobile cooling system is coolant leaking due to severely eroded pipes or impellers. Impeller in car water pump is usually placed in static or dynamic aqueous environment which made up of water or water-coolant mixture. For cooling process in vehicles, cooled-coolant is pumped into engine block system from radiator. In this moment, impeller in water pump rotates and delivers incoming coolant away. When nanofluid is used as coolant, it is believed that collision of solid particles will lead to erosion on impeller. However, there is still no published results on erosion effect of nanofluid on actual car water pump. Hence, this study aimed to determine the corrosion-erosion effect of different coolants on actual car water pump (Perodua D37 water pump). Material loss due to erosion-corrosion effect was compared between conventional coolant and nanofluid. Surface profile inspection was carried out for each pump to determine the thickness change of impeller. Graphene nanoparticles are used in this study due to its rising role in recent nanofluid researches.

## 4. Methodology

### 4.1. Experimental setup

Figure 2 presents the experiment setup used in this research. Stainless steel 304 pipes are used to prevent corrosion and erosion attack due to long duration testing. Total length and internal diameter of pipes are about 2.6 m and 1.5 cm respectively. Glass wool was wrapped around the pipes as insulator to minimize heat loss to surrounding. The 25 L tank is made up of stainless steel 304 with thickness of 11 mm and several openings were made on the tank cover to install pressure gauge, thermocouple, safety valve, flow back pipe and coolant feeder. Pressure gauges were placed above tank and before pump inlet to obtain system pressure and pump inlet pressure. Three-phase DC motor with 2 horsepower, 380 V and 2715 rpm was used. An inverter (Schneider ATV312) was installed between motor and power source so the speed of motor can be varied. Shimaden SRS10A temperature controller (250 V, AC) with accuracy of 0.1 °C was used. Constant heat flux was supplied to the tank by employing a band heater (Sakaguchi E.H VOC. Corp.) with rated power of 1400 W, 240 V and maximum heating temperature of 300 °C. Glass wool of 25 mm thickness was applied on band heater for reducing heat loss and safety purpose. Twisted copper pipe was placed above safety valve to allow condensation of steam back into liquid droplet and flow back into flowing pipe. Besides that, another opening was made to ventilate excess and smelly gas from the tank.



**Figure 2.** Experimental setup for erosion testing.

#### 4.2. Preparation of coolants

In this study, corrosive water was prepared as stated in ASTM D2809-09 standard. Sodium sulfate, sodium chloride and sodium bicarbonate were first mixed into distilled water with quantity of 148 ppm, 165 ppm and 138 ppm respectively. The corrosive water was made and then kept at room temperature. For base coolant, 2 L of pure ethylene glycol was poured into corrosive water in volume ratio of 1:5. For nanocoolant (nanofluid), ethylene glycol containing graphene nanoplatelets (20 ppm) was provided by Scomi Group Bhd. The details of graphene nanoplatelets (GnP) are shown in Table 2. The nanocoolant was diluted with corrosive water in 1:5 volume ratio also. The mixture was then stirred at 500 rpm for 30 minutes.

**Table 2.** Properties of graphene nanoplatelets.

Thickness	0.5 – 3 nm
Average diameter	0.25 $\mu\text{m}$ (0.15 to 1 $\mu\text{m}$ )
Carbon purity	> 99.5%
Graphene purity	> 90%
Catalyst impurities	No catalyst

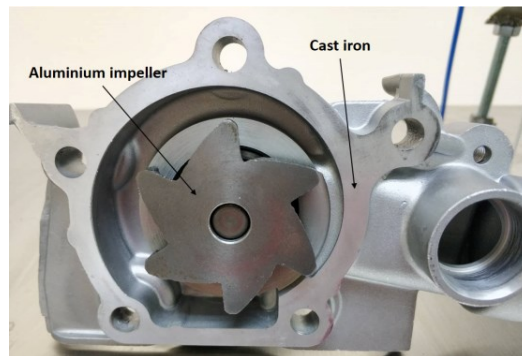
#### 4.3. Experimental procedure

Cleaning process was performed before each test was carried out. Firstly, a flushing pump was installed to circulate tap water in the system. The pump speed was adjusted to around 2675 rpm and run for 5 min, for three times. Digital tachometer TM-4100 with resolution of 0.1 rpm was used and three readings were taken to ensure rotational speed accuracy. The system was drained and filled with another cleaning solution. The cleaning solution which made up of water, oxalic acid and citric acid was then heated and controlled at about 80°C with the pump operating at 2675 rpm for 60 min. The system was drained and cleaned with tap water for 5 minutes (for three times). Cool tap water was then mixed with sodium carbonate and circulated in the system no more than 10 min to avoid the formation of carbonates on copper components. The system was drained and cleaned with tap water. A portion of last flushed water was mixed with 5 wt% calcium chloride and if precipitation or turbidity was observed, system cleaning with tap water was repeated until clear mixture was obtained.

Every impeller was weighted before installing the whole pump for each test. The system was first filled with 12 L of corrosive coolant prepared earlier, followed by these three conditions:

1. Pump speed with 4600 rpm
2. 35 to 38°C coolant temperature
3. Pump inlet pressure with gage reading of 6.8 kPa vacuum by adjusting throttling valve.

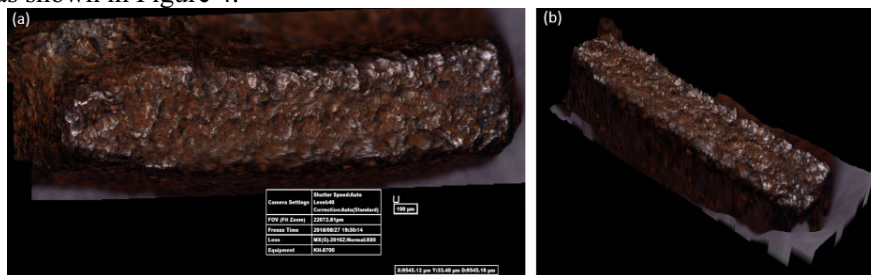
After achieving conditions above, coolant temperature was further increased to 113°C and the position of throttling valve was remained untouched till the end of experiment. The temperature controller was calibrated two times at 113°C to maintain temperature of coolant all the time. The whole system was operated continuously for 100 hours. When the experiment was completed, pump cover and impeller were cleaned with distilled water and dried for microscopic inspection and weight measurement as shown in Figure 3.



**Figure 3.** Unused Perodua Kancil D37 water pump.

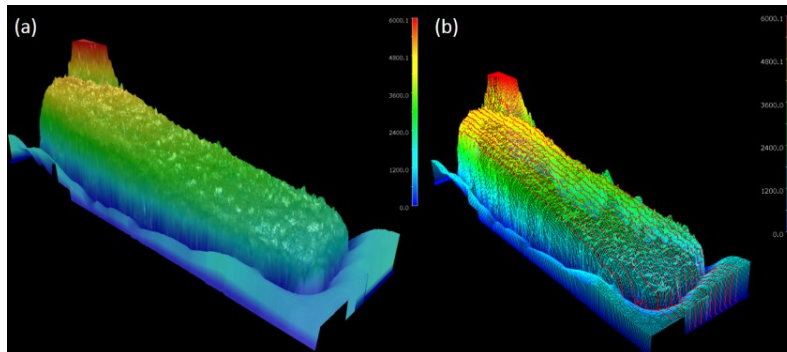
## 5. Results and Discussion

Every impeller was inspected using Hirox KH-8700 3D digital microscope. Low range high resolution MXG-2016Z lens with 20-160x magnification was used. In accordance to ASTM D2809-09, maximum depth of eroded part represents rating of a blade. For each impeller, two blades with the most corroded or eroded surface were chosen for study. Surface profiles of all blades were obtained by scanning top surface of the blades, as shown in Figure 4.

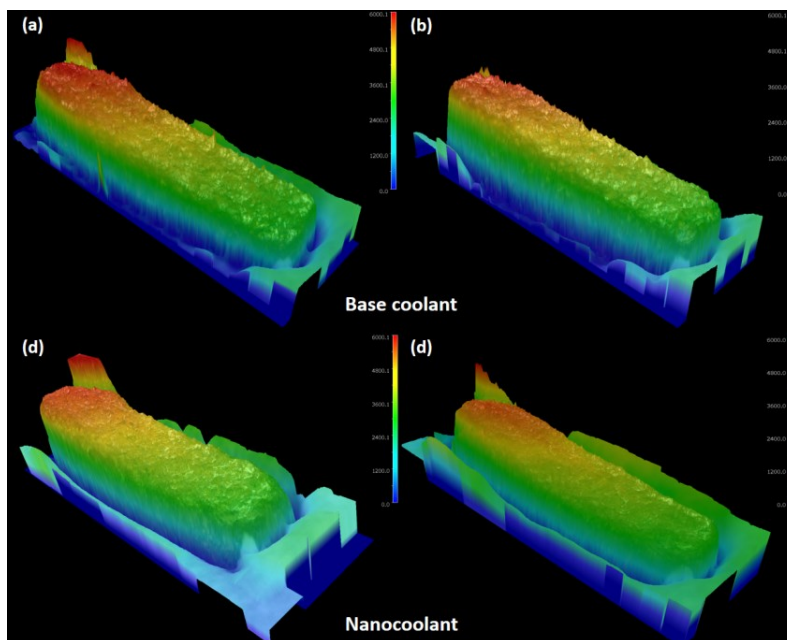


**Figure 4.** (a) 2D (b) 3D representation of blade.

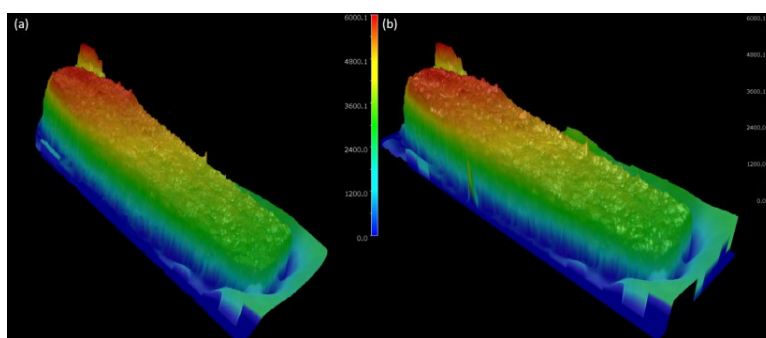
Before determining the deepest eroded part of each blade, width of blade (before testing) was divided into several sections from respective contour profile as shown in Figure 5. After 100 hours testing, sections (before testing) that close to the deepest pitting in contour profile (after testing) were chosen for study. On the other side, Figure 6 presents surface profile for two different blades for each coolant after testing. Then, one of the two blades with the most obvious contour change between before and after testing in base coolant and nanocoolant are illustrated in Figures 7 and 8 respectively.



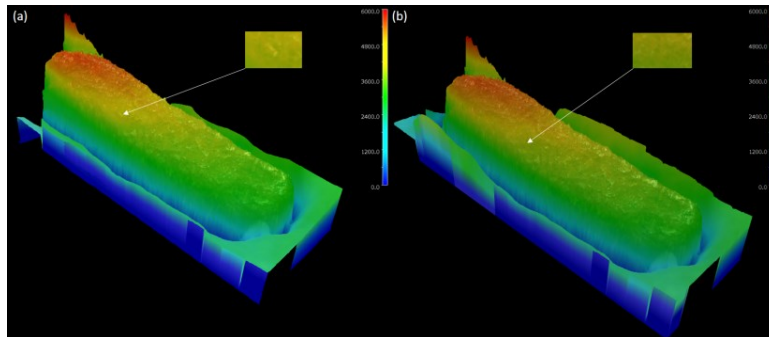
**Figure 5.** Contour of a sample blade before testing (a) Original (b) After divisions.



**Figure 6.** Different blades of impeller after using base coolant (a),(b) and nanocoolant (c),(d).



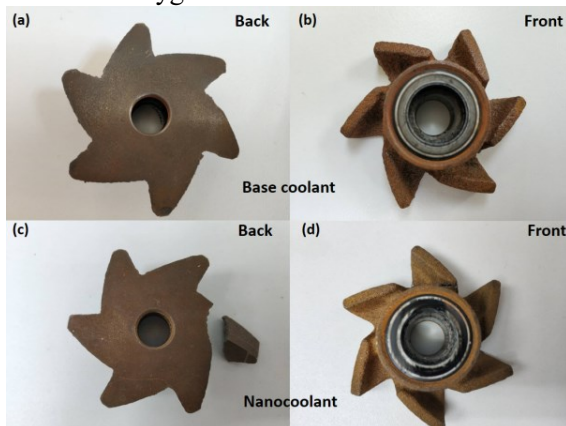
**Figure 7.** Contour profile of base coolant case (a) Before (b) After.



**Figure 8.** Contour profile of nanocoolant case (a) Before (b) After.

From Figure 7, it was observed that base coolant did not cause any significant damage on the blade surface. In this case, authors decided to choose few points and made comparison between nearby divided sections. Generally, there was only minor dimensional change found and studied area showed no more than  $100\text{ }\mu\text{m}$  of dimensional change averagely. Next, Figure 8 illustrates the profile for nanocoolant case. There were a bit more ‘yellowish region’ on blade surface before using nanocoolant which means the addition of graphene nanoparticles slightly depleted portion of the blade surface. The pointed area showed maximum dimensional change of about  $330\text{ }\mu\text{m}$ , which is higher than all chosen area in base coolant case. This is due to the synergistic effect of erosion-corrosion which will be discussed below.

Both coolants caused general corrosion on impeller as shown in Figure 9. By visual inspection, nanocoolant caused more corrosion damage on back side of the impeller whereas both nanocoolant had similar severity of corrosion damage on front side. Corrosion reaction takes place when there are oxygen atoms pass through diffusion layer and reach the sample surface. The presence of nanoparticles was reported to act as corrosion inhibitor and cause less material loss than base fluid in past study [21]. It was explained that nanoparticles may attach to metal surface and hence reducing exposed surface area against oxygen atoms which would induce corrosion reactions. In this study, the difference between both cases was not distinct. This may due to very low concentration of GnP was not able to act as a strong barrier against the diffusion of oxygen atoms onto aluminium surface.



**Figure 9.** Different views of impeller for base coolant (a), (b) and nanocoolant (c),(d).

This study included dynamic corrosive environment only, thus weight loss due to pure erosion and pure corrosion is not available. Weight losses due to erosion-corrosion effect were  $0.8141\text{ g}$  and  $3.9886\text{ g}$  for base coolant and nanocoolant respectively. This result is in line with past study which used sea water containing alumina nanoparticles, where nanofluid showed more material loss in erosion-corrosion [21]. The increment of weight loss may due to accelerated corrosion rate in dynamic environment. Oxygen

containing fluid in this turbulent environment was continuously in contact with the impeller surface and as result corrosion rate was increased. The presence of nanoparticles increased kinematic viscosity and surface shear stress of flowing fluid which would peel down the oxide layers. In fact, erosion occurs when surface shear stress is higher than critical value. In addition, collision of solid particles would further exacerbate material loss due to high collision energy from this turbulent environment.

Combining all information above, the final rating of erosion-corrosion effect on Perodua Kancil D37 water pump based on ASTM D2809-09 standard is concluded in Table 3.

**Table 3.** Rating of erosion-corrosion damage on aluminium impeller.

Sample	Rating based on ASTM D2809-09 standard	Maximum eroded depth
Base coolant	9/10	Less than 100 $\mu\text{m}$ , with minimal erosion and general corrosion.
Coolant with GnP	8/10	Less than 400 $\mu\text{m}$ , with light erosion and general corrosion.

## 6. Conclusion

The objective of this paper is accomplished. In short, it is concluded that:

- I. the corrosion effect is almost similar for both coolants.  
This is due to low concentration of GnP could not act as a strong barrier against the oxygen atoms diffusing onto impeller surface. On the other side,
- II. material loss due to erosion-corrosion effect in nanocoolant is more than that of base coolant.  
The highly turbulent environment contributed to high collision energy of GnP which exacerbates material loss compared to base coolant.

In future work, authors proposed to conduct few more testing using different concentration and type of nanoparticles to differentiate their impact on actual car water pump. It is important to determine various aspects such as cost, drawbacks, stability, advantage, optimum ratio in order to commercialize nanofluid in daily applications.

## Acknowledgements

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