Corrosion effects of CNT-nanofluids on different metals

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Abstract

This study aims to determine the corrosion rates of three different metals (copper, stainless steel, and aluminium alloy) using CNT-nanofluids. Nanofluids have been extensively studied in enhancing heat transfer rates of conventional base fluids due to its efficiency and high thermal conductivity. Carbon nanotube (CNT) based nanofluids have demonstrated significantly higher thermal conductivity compared to nanofluids based on other nanoparticles. Though transport properties of CNT-nanofluids including their thermal conductivity, density, and viscosity have been investigated by large scientific community, there are only few studies carried out on its physical properties especially their reaction towards corrosion of different metals. Therefore, this study is carried out to compare the corrosion rates of three different metals using four different engine coolants with the variation of temperature from 27°C to 90°C. The coolants deployed in this work include ethylene glycol, water, and CNT-nanofluids with two different concentrations of 0.1 wt % and 0.02 wt % CNT. The CNT-nanofluids are stabilized using the Gum Arabic (GA) as the dispersant. The results reveal that for each metal, the corrosion rates in water are the highest followed by ethylene glycol and CNT-nanofluids with 0.02 wt % and 0.1 wt %. Among the three metals, the highest rate of corrosion occurs to aluminium, followed by stainless steel and copper, for all coolants used in this experimental study. Finally, the rate of corrosion increases with the increase of temperature for all cases.

Keywords: corrosion, nanofluids, CNT, metals.

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1 Introduction

The term "Nanofluid" was first introduced by Choi [1] in 1995. Nanofluid is the dispersion of nanoparticles homogeneously in a base solution. One of the main challenges is to produce stable and high-quality nanofluids. Since solids have higher thermal conductivity than fluids, the idea of combining solid and fluid is to increase their performance in heat transfer.

The applications of nanofluids are expanding over time. Nanoparticles have very good mechanical, chemical, thermal, and electrical properties. As a result, nanoparticles are being used to produce nanocomposites and nanofluids. Generally, the most interesting application for nanofluids is in cooling system as a heat transfer fluid replacing the conventional one. Some of them are in the engine cooling system, electronics devices, and even nuclear reactor system. Some other applications of nanofluids in energy efficiency enhancement and biomedical systems are also discussed and explored [1].

In the automotive design, engineers are exploring the idea of using nanofluids as coolants to reduce the size, weight, and cost of the radiator. This will result in better fuel consumption and lower car prices. It has been shown that the thermal conductivity can be increased by more than 200% using nanofluids.

Numerous studies have also been conducted to compare and to determine the thermal conductivity of different types of nanofluids [2]. These works contribute in deciding the nanofluid that best suited to be the coolant in the cooling system. Nevertheless, not many researches are being done to check the compatibility of nanofluids to be used as a coolant in the engine radiator. A good quality coolant must possess high thermal capacity, low viscosity, nontoxic, chemically inert, low cost, low electrical conductivity and it should resist oxidation. Water is a basic coolant that is commonly used as a heat transfer fluid, due to its high thermal conductivity, cheap, and readily available. However, water freezing point at 0°C limits its capability to act as a pure coolant without any addition of ethylene glycol.

In addition, most of coolants are added with inhibitor to prevent corrosion in the engine radiator. In the case of highly corroded cooling system, the performance of the car will be severely affected. The damage occurs because of the heat that cannot be transferred directly from the engine to the coolant thus increasing the engine temperature. Furthermore, corrosion may cause the cavitation in the radiator that later on will restrict the flows of the coolant in the cooling system.

There are also many studies that have been done to investigate the effect of a coolant especially ethylene glycol towards different materials used in the cooling system. Some of the common metals used to manufacture the cooling system are aluminium, steel, cast iron, and copper. Some researchers investigated the corrosion effects of ethylene glycol on steel and copper [3, 4] whereas others studied the corrosion effects on aluminium [5, 6]. All of the tests were mostly restricted to ethylene glycol with different concentrations and inhibitors.

Thus, not many systematic studies of the corrosion effects had been done with the new advance thermal fluids such as nanofluids. The previous studies done used rotating disc electrode (RDE) [4–7]. This work involved rotating the solution instead of the working electrode. Therefore, this paper presents the results of the corrosion effects of different types of coolants on three different metals with varying temperatures.

2 Preparation of CNT nanofluids

Stable CNT-nanofluids using Gum Arabic (GA) are prepared using the method described in our earlier work [8]. For its transport property, the thermal conductivity of the CNT-nanofluid solution containing CNT and GA is increasing with the increase of CNT concentration [9]. It has been shown that the highest thermal conductivity obtained by the nanofluid has a maximum concentration of CNT of 0.1 wt %, so 0.1 wt % of CNT is used in this present study. In addition, a CNT-nanofluid with 0.02 wt % CNT concentration is also used to make comparison with other solutions and the effect of the CNT concentration can be studied.

The optimum GA concentration and sonication time have been found to be very important parameters in preparing ultra-stable CNT-nanofluids which were stable for more than two years. The optimum GA concentration for 0.1 wt % CNT-nanofluid was found to be 2.5 wt % [8]. Meanwhile, the GA concentration for 0.02 wt % CNT-nanofluid is 1.0 wt %. If too much amount of GA is added, it will make the CNT-nanofluid unstable because of the self-aggregation of the GA molecules. Sedimentation or instability of the CNT-nanofluid will only increase with the increase of the GA concentration and sonication time beyond the optimum level. This is due to the fact that higher GA concentrations cause self-aggregation and prolonged sonication time will change the morphology and damage the CNT structure.

The solution is then mixed homogeneously with a homogeniser (Fluko, Germany) at 28,000 rpm for 10 min. Later, the solution is sonicated for 4 h using the bath sonicator. It has been demonstrated that the sonication process is important to help CNT disperse in the base solution and decompose the dispersant into new structure thus decreasing the sedimentation rate of the CNT-nanofluids [8].

3 Corrosion test

3.1 Preparation of sample

All of the metal specimens are prepared before they are being used as the working electrode. Some cutting, grinding, polishing, washing, and drying processes are done. The specimen of copper, stainless steel, and aluminium alloy plates are cut with dimension of 1 cm × 1 cm with metal scissor. The metals are then grounded with different grades of emery paper from 100 degree of fineness and increasing up to 800 degree of fineness. Since the samples are small in size, they are first mounted together before grinding.

The metal pieces are mounted with cooper wire connected to the metal. The copper wire is used as a wire connection of the working electrode to the circuit. The mounted metal mould makes the grounding process easier. Then, they are polished with aluminium oxide on the horizontal polishing machine manually. This is done to remove all the scratch marks on the metals surfaces. These mounted metals are polished until they looked like mirror image. The shinier the metal surfaces, the more easy reading can be taken. Next, the metals are washed with distilled water twice to remove the metals residue. Finally, they are being dried with hair dryer.

3.2 Polarization test

Before the polarization test is done, all of the equipment and samples are prepared in advance and setup is done as shown in Figure 1. A 50 ml solution of water is prepared in 100 ml beaker as the electrolyte for the test. While making sure the working electrode is fully immersed in the electrolyte, the other two electrodes that are counter electrode and reference electrode are also connected to the circuit. The reference electrode that is used here is saturated calomel electrode (SCE) and the counter electrode is the platinum plate.

The test is done with the variation of temperature of the coolant. The coolant is heated on the hot plate. After it reaches the desired temperature, the polarisation test is done on the metal and solution. The experiment is only done with the variation of temperature after the solution has attained a steady state condition. The temperature is varied in increasing range from 27°C to 90°C by 10°C increment. Readings are tabulated and the polarization graphs are plotted for every measurement.

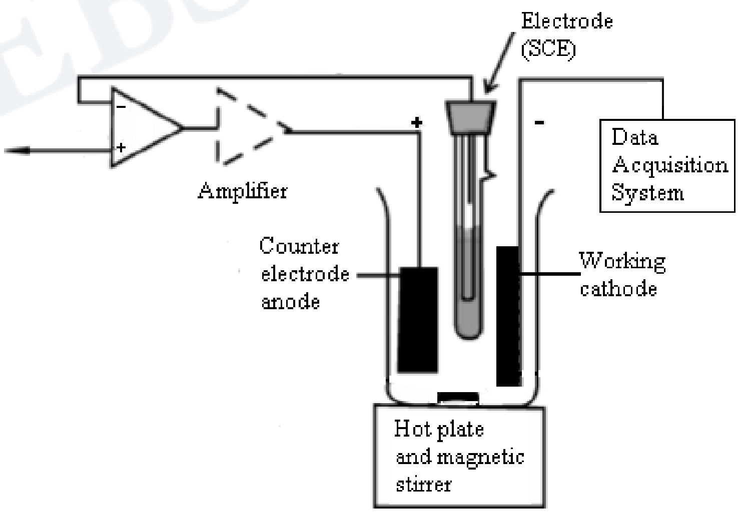

Figure 1: Polarization test setup.

4 Results

The corrosion rates of aluminium alloy, stainless steel, and copper, using 0.1 wt % CNT-nanofluid for different temperatures are presented in Figure 2. Tables 1, 2, and 3 tabulate the corrosion rates using the four different coolants at different temperatures for aluminium alloy, stainless steel, and copper, respectively.

As revealed in Figure 2, copper shows the lowest corrosion rate value compared with the other two metals. The highest corrosion rate at a fixed temperature is obtained by aluminium alloy in all of the coolants as depicted by the results in Tables 1, 2, and 3. This can be explained by the galvanic series for metal and alloy where aluminium alloy position is the nearest to active side of metals. For all coolants, the stainless steel corrosion rates are between copper and aluminium alloy. The results also demonstrate that the rate of corrosion increases with the increase of temperature for all cases.

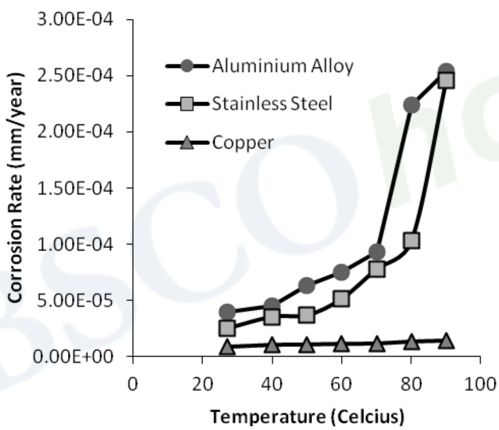

Figure 2: Corrosion rates of metals using 0.1% CNT-nanofluid.

Table 1: Corrosion Rate of Aluminium Alloy (mm/yr).

Temperature (°C)	Water	Ethylene Glycol	Nanofluid 0.1 wt %	Nanofluid 0.02 wt %
27	3.01E-02	1.85E-02	3.95E-05	9.23E-05
40	3.64E-02	2.01E-02	4.49E-05	1.36E-04
50	3.94E-02	2.39E-02	6.29E-05	1.64E-03
60	4.15E-02	3.02E-02	7.47E-05	1.74E-03
70	6.99E-02	3.72E-02	9.29E-05	4.82E-03
80	7.88E-02	3.84E-02	2.24E-04	6.09E-03
90	9.75E-02	4.15E-02	2.54E-04	6.66E-03

Table 2: Corrosion Rate of Stainless Steel (mm/yr).

Temperature (°C)	Water	Ethylene Glycol	Nanofluid 0.1 wt %	Nanofluid 0.02 wt %
27	1.59E-02	1.42E-02	2.48E-05	3.32E-05
40	2.01E-02	1.76E-02	3.53E-05	3.59E-05
50	2.03E-02	1.94E-02	3.66E-05	4.85E-05
60	3.68E-02	2.47E-02	5.14E-05	7.11E-05
70	3.94E-02	2.91E-02	7.81E-05	7.66E-05
80	8.31E-02	3.90E-02	1.03E-04	9.73E-05
90	8.60E-02	4.03E-02	2.46E-04	1.41E-04

Table 3: Corrosion Rate of Copper (mm/yr).

Temperature (°C)	Water	Ethylene Glycol	Nanofluid 0.1 wt %	Nanofluid 0.02 wt %
27	1.06E-02	1.46E-03	8.54E-06	4.56E-05
40	1.30E-02	1.57E-03	1.03E-05	5.64E-05
50	1.57E-02	1.59E-03	1.07E-05	5.94E-05
60	2.17E-02	4.18E-03	1.13E-05	7.10E-05
70	2.89E-02	2.01E-02	1.16E-05	7.10E-05
80	3.72E-02	3.17E-02	1.35E-05	9.16E-05
90	7.97E-02	3.81E-02	1.43E-05	1.01E-04

For water, Table 1 indicates that the corrosion rate for aluminium alloy varies from 3.01×10^{-2} mm/yr at 27°C to 9.75×10^{-2} mm/yr at 90°C. Meanwhile, the corrosion rates for stainless steel (Table 2) and copper (Table 3) vary from 1.59×10^{-2} mm/yr to 8.60×10^{-2} mm/yr and 1.06×10^{-2} mm/yr to 7.97×10^{-2} mm/yr, respectively. Table 1 also shows that aluminium alloy has the highest corrosion rate compared to stainless steel and copper in both CNT-nanofluids with the value of 3.95×10^{-5} mm/yr (at 27°C) to 2.54×10^{-4} mm/yr (at 90°C) for 0.1 wt % CNT-nanofluid and 9.23×10^{-5} mm/yr (at 27°C) to 6.66×10^{-3} mm/yr (at 90°C) for 0.02 wt % CNT-nanofluid.

On the other hand, lower corrosion rates are produced when ethylene glycol and CNT-nanofluids are being used as the solution. The reason for this is the existent of inhibitor in ethylene glycol that prevents corrosion from happening. Interestingly, the corrosion rates of metals using the CNT-nanofluid are the lowest compared to the corrosion rates using water and ethylene glycol. Some researchers have observed that nanofluids show lower and more stable friction coefficients and they also have self-healing lubricating effects [10]. This could be the main reason for low corrosion rate of metals in nanofluids. It has been reported that the stably dispersed nanoparticles in mineral oils are effective in reducing wear and increasing load carrying capacity. Furthermore, the friction can be reduced between the moving mechanical parts. The corrosion rates produced by the 0.1 wt % CNT-nanofluid and 0.02 wt % CNT-nanofluid are very similar.

Another reason for the low corrosion rates of both CNT-nanofluids is the presence of GA in the solution. In chemical industry, it has been widely known that GA is commonly used as an inhibitor and its function is to prevent or slow down the corrosion process. As these CNT-nanofluids use GA as their dispersant, indirectly the inhibitor characteristics of the nanofluids are enhanced. As a result, lower corrosion rates of metals are recorded in the experiment using the CNT-nanofluids.

5 Conclusion

Since the corrosion rates of the three metals are the lowest using the CNT-nanofluids prepared in this laboratory, it can be concluded that the nanofluids can be used as a better coolant for various cooling systems. With much higher thermal conductivity, the size and the weight of the heat transfer system can be drastically reduced. In the automotive industry, the improved system will provide better engine performance as well as lower fuel consumption. The results of this study should promote further investigations on the optimal operating process conditions using the CNT-nanofluids.

Acknowledgments

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