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Original article

A study on corrosion effects of a water based nanofluid for enhanced thermal energy applications

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ABSTRACT

Nanofluid is defined as the colloidal dispersion of nanoparticles into base fluid. Introducing the nanoscale solid particles into base fluid has shown to improve its thermal conductivity. Nanofluids possess improved efficiency in cost and size of production, energy consumption, and emission reduction. There are various applications of nanofluids in the heat transfer field, such as in automotive, heating, ventilation and air conditioning, as well as in power generation. An experiment is conducted to investigate the effects of aluminum oxide/water nanofluid on aluminum, copper, and stainless steel. These metals are submerged in the beakers of sulphuric acid and hydrochloric acid solutions of pH = 3.7 for a period of 8 months. Scanning Electron Microscope and Energy Dispersive Spectroscopy are used to capture images, map notes, and analysis of all sample surfaces. A comparative study of the corrosion effect on materials in contact with a nanofluid is essential to be considered when designing heat-transfer systems as well as determining the performance and applicability of nanofluids. Results show that the corrosivity of the nanofluid in aluminum and copper is found significant; whereas, it is negligible in stainless steel. Achieving higher fluid thermal conductivity is important in many industrial processes for efficient heat transfer. The present experimental data involving thermal conductivity of nanofluids is lacking consistency, therefore, further experimental studies are needed. An experimental investigation of the effect of different temperatures and nanofluid concentrations on the thermal conductivity of an Al_2O_3/water nanofluid is presented. Different temperatures and fluid concentrations are considered. An increase of about 17% in the thermal conductivity of the nanofluid was found compared to the base fluid. This enhancement shows that nanofluids can be considered as potential energy efficient heat transfer fluids.

Introduction

Nanotechnology is gaining a huge attraction nowadays due to its widespread use ranging from agriculture, Biomedical, water treatment to energy storage. The recent advancement in nanotechnology made it possible to disperse nanosize particles into a base liquid to enhance its thermodynamic properties. The resultant fluid is called a Nanofluid. The nanoparticles used in nanofluids can be metals, oxides, carbon nanotubes, etc. The first study on a two component mixture fluid was done by Maxwell [1]. He analytically studied conduction through suspended micro size particles. The Maxwell equation represented thermal conductivity for low particles volume concentration mixtures.

A later development in nano technology attracted the attention to investigate nanosize particles dispersed in a base fluid. Experimental effects of nanofluid flow on different type of materials is studied by Celata et al. [2] highlighting the importance of studying the effect of the nanofluid on the material surface before adopting it as a heat transfer fluid. Experimental study was performed by Bubbico et al. [3] where metallic targets were exposed in a flow of nanofluid. Their results show that the damage on the metals was due to the effect of corrosion more than erosion and that the *pH* level of the suspension is very important. Carbon nanotubes effect on corrosion of different metals (Al, SS, and Cu) using different types of fluids was studied by Rashmi [4]. They reported the highest corrosion occurred for Aluminum regardless of the fluid used. They also extended their investigation to compare a standard radiator with a conventional fluid to a smaller radiator with a CNT-nanofluid. Their finding was the last showed enhanced heat transfer over the conventional.

Applications of nanofluids include but not limited to HVAC, electronics, automotive, and biomedical. In heat transfer applications, studies on the use of nanofluids to enhance the heat exchange process have been done. Substitution of cooling and heating water with nanofluids in industrial cooling systems was

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examined by Routbort et al. [5]. The study found around 300 million kWh in energy saving every year in the electric power industry field in the unified conditions of the United States using nanofluids, this is equal to the energy required by 50,000–150,000 families.

Furthermore, the stability of several nanofluids was examined by Hwang et al. [6] with UV–vis spectrophotometer. Many types of nanoparticles have been used to prepare nanofluids to investigate the thermal properties of such fluids. Their findings were the stability of nanofluids was affected by the characteristics of the suspended particles and base fluids, the stability of the fluid can be improved by adding a surfactant, and the thermal conductivity depends on the volume fraction of nanofluids. In addition, Li et al. [7] studied the dispersion behavior of water based copper nanofluid to have a superior comprehension of its stability Results based on the sediment photographs and particle size distribution show better dispersion conduct in the suspension when adding dispersant. Additionally, a significant impact of pH on the stability of the copper suspension was found.

Das et al. [8] examined the increase of thermal conductivity of nanofluids with temperature having water as the base fluid and two types of particles, Al_2O_3 & CuO. Their main results yielded an increase of thermal conductivity enhancement with temperature. Buongiorno et al. [9] measured the thermal conductivity of identical samples of nanofluids using various experimental approaches over 30 organizations worldwide. Different base fluids and nanoparticles were used at a variety of concentrations. Results showed that the nanofluids thermal conductivity increases as the particle concentrations increase. Li et al. [10] experimentally measured the thermal conductivity and viscosity of aqueous magnetic fluids. Their study included the presence and absence of an external magnetic field. Their conclusion was that the thermal conductivity of the magnetic fluid is higher than that of a pure fluid. The effect of the magnetic field on thermal conductivity was found to be increasing when it is parallel to the temperature gradient and no effect was found when it is perpendicular. Water based aluminum oxide nanofluid was used to study its effect on enhancing the heat transfer performance of heat exchangers by Issa [11]. With two types of exchangers used, results showed an enhancement of effectiveness of about 49%. Furthermore, adding low concentration caused a noticeable improvement in the thermal performance of the system.

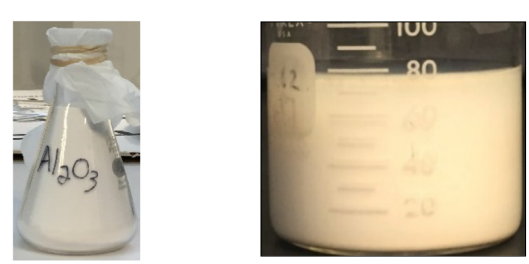
Additional investigation on the safe handling of nanoparticles or nanofluids is important since the particles used in nanofluids are very small and are within a range of (1–100 nm). The presence of nanoparticles in the base fluid has a positive effect on the energy exchange process, however, the occupational exposure limit proposed by the National Institute for Occupational Safety and Health or equivalent organizations should be taken into account. Studies on health effect of the exposure to various nanofluids are still behind the continuous growth of nanotechnology. Up to date, no records of harmful effects of working with nanofluids on health is found, however, a high level of precaution is to be followed when dealing with nanofluids due to the incomplete information on their safety and further studies are to be considered in order to identify a proper safety procedure. The research organizations in US and Europe as well as the National Science Foundation (NSF) and the National Toxicology Program have been investigating the toxicology of nanoparticles. They proposed the use of safety measures introduced by Massachusetts Institute of Technology (MIT) [12] for handling nanoparticles on nanofluids. From the open literature, there is no noticeable hazardous issue observed using nanofluids but due to the safety precautions of using nanoparticles, high safety measures, standards, and precautions should be followed in handling nanofluids. Nowadays, nanofluids, especially water-based nanofluids, are being used safely and successfully in industrial, biomedical engineering, and bioscience applications Wong [13].

This paper presents the pH impact of aluminum oxide/water (Al_2O_3/W) nanofluid on aluminum (Al), copper (Cu), and stainless steel (SS) which are used in common applications. Experiments on the most common materials will be performed to show the highest and lowest corrosive metals to be used. Two different solutions of same pH level of (3.7) of the Al_2O_3/W nanofluid are prepared with H_2SO_4 + NaOH and HCl + NaOH. The effect of the solutions on the materials in a long term is examined with Scanning Electron Microscope/Energy Dispersive Spectroscopy (SEM/EDS) and WiTec system with an accelerating voltage of 5.0 kV. The effect of adding nanoparticles to a base fluid on the thermal conductivity of the fluid is also presented at various temperatures (20, 30, and 40 °C). After measuring the thermal conductivity, it is presented as a function of temperature and fluid concentration. In thermal systems for example, nanofluids are used to enhance the heat transfer. Results from this study will provide insight on the interaction of these nanofluids with the contact materials. Understanding the interaction of these fluids with the contact material used to serve as an important parameter when designing a thermal system with a nanofluid as the working fluid.

Experimental procedure

The corrosive effect of a nanofluid on three different materials is investigated. An experiment is conducted using aluminum oxide/water (Al_2O_3/W) as the nanofluid and aluminum (Al), copper (Cu), and stainless steel (SS) as the targeted materials. The mentioned materials are chosen as the test cases due to their wide use in thermal systems such as automotive, HVAC, and power plants. The nanoparticles are known with their agglomeration and sedimentation in the base fluid, therefore, special methods are used to prepare nanofluids.

The presented nanofluid for this study Al_2O_3 is prepared using a 2-step method where nanoparticles are purchased and then are dispersed into the base liquid. The nanoparticles size used is 50 nm of aluminum oxide (Al_2O_3), (AL-0405, 99.5%), dispersed into the base fluid which is DI-water. The preparation procedure included adding surfactant and using rod sonication technique to improve the uniformity and stability of the nanofluid. This method led to a change in the pH value of the nanofluid to about 3.7. The material samples used in this study are immersed in beakers containing solutions of sulphuric acid (H_2SO_4) and hydrochloric acid (HCl) of pH = 3.7. These solutions are prepared by adding sodium hydroxide (NaOH) to the acids. The samples are left for a period of 8 months to see the long-term effect as shown in Fig. 1. Deionized water (DI) is used to wash the samples, after that, they are gold coated using the sputter coater machine. A thin layer of gold helps to have clear images while using Scanning Electron Microscope and Energy Dispersive Spectroscopy (SEM/EDS) machine. Map notes, images, and analysis of all the surfaces of the samples captured are put together for final interpretation.



(a) (b)

Fig. 1. Samples of (a) Al_2O_3 nanoparticles (50 nm) and (b) Al_2O_3/W nanofluid (volumetric concentration = 5%).