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ABSTRACT: In order to eliminate the use of toxic acids in common carbon nanomaterial functionalization methods, a facile and eco-friendly procedure is introduced in this study to synthesize highly dispersed, covalently functionalized multiwalled carbon nanotubes (MWCNTs) for use in heat transfer fluids. The MWCNTs are treated covalently with clove buds in one pot using a free radical grafting reaction. The clove-treated MWCNTs (C-MWCNTs) are then dispersed in distilled water (DI water) at three different concentrations of C-MWCNTs (0.075, 0.125, and 0.175 wt %), resulting in C-MWCNT-DI water nanofluids. The effectiveness of the functionalization process is then verified using Fourier transform infrared (FTIR) spectroscopy, thermogravimetric analysis (TGA), and transmission electron microscopy (TEM). UV–vis spectroscopy is also used to examine the stability of the C-MWCNTs in the base fluid. The thermal conductivity, density, and dynamic viscosity of the C-MWCNT-DI water nanofluids are studied experimentally, and the results show that there is significant thermal conductivity enhancement for the C-MWCNT-DI water nanofluids, whereas there is only a slight increase in the viscosity and density of these nanofluids. Lastly, convective heat transfer experiments are carried out for the C-MWCNT-DI water nanofluids flowing through an annular heat exchanger at constant heat flux and fully developed turbulent flow conditions. The results show that there is a significant enhancement in the convective heat transfer coefficient and Nusselt number for the C-MWCNT-DI water nanofluids, whereas the increase in friction factor is almost negligible for these nanofluids. On the basis of the results, it can be concluded that the eco-friendly C-MWCNT-DI water nanofluids have strong potential for use as effective working fluids in various heat transfer applications.

1. INTRODUCTION

Heating or cooling fluids such as air, water, Freon, ethylene glycol, and mineral oil play a vital role in various industrial sectors such as chemical production, power generation, microelectronics, transportation, and air-conditioning. However, conventional heating or cooling fluids do not have superior capability to transfer or dissipate heat from industrial thermal equipment with high heat flux.1 One of the promising solutions to address this issue is to disperse nanoparticles with high thermal conductivity (e.g., metal, carbon, or metal oxide nanoparticles) into the base fluid in order to enhance the thermal performance of heat transfer systems.2–6 In this regard, Choi et al.7 found that the thermal conductivity of the CNT-water nanofluids is higher compared to that of water. They measured the effective thermal conductivity of a nanofluid containing 1.0 vol % of multiwalled carbon nanotubes (MWCNTs) dispersed in synthetic poly (ethylene oxide) oil and reported a thermal conductivity enhancement of 160%.8 Sadri et al. studied the sonication time effect on the dynamic viscosity, thermal conductivity, and dispersion of MWCNT aqueous suspensions. The results represented that the viscosity decreases, whereas the thermal conductivity of the nanofluids increases with an increase in temperature and sonication time. The maximum thermal conductivity enhancement was found to be 22.31% (ratio of 1.22) at a temperature and sonication time of 45 °C and 40 min, respectively.9 Philip et al.10 investigated the thermal conductivity enhancement of kerosene-based Fe3O4 nanofluids under the influence of a magnetic field and the results showed that the enhancement of thermal conductivity is 300% (Δκfluid/κbase = 4.0) at a concentration of 6.3 vol % and particle size of 67 nm. Pak and Cho11 investigated the heat transfer performance of γ-Al2O3 and TiO2 nanoparticles dispersed in water flowing through a horizontal circular tube under turbulent flow and constant heat flux conditions. The results represented that the Nusselt number of the nanoparticles aqueous suspensions increases by increasing the Reynolds number and nanoparticle concentration. Moreover, they discovered that the convective heat transfer coefficient of the nanofluids is lower than that for water by 12% for a given condition when the particle loading is 3 vol %. They proposed a new heat transfer correlation to predict the convective heat transfer coefficient of nanofluids in a turbulent flow regime. Annular heat exchangers are commonly used in industrial applications, particularly in heat transfer equipment. These heat exchangers have gained much attention from scientists and researchers, and they have been used in various applications.

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