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Intensification of heat transfer rate using alumina-silica nanocoolant

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ABSTRACT

Efficient energy utilization and management has been the major criteria in industrial and transportation sectors. Particularly, thermal energy management is the benchmark in various applications like automotive, energy storage, nuclear cooling, medical fields among others. Usage of microchannel devices to increase the thermal energy pose various disadvantages like high mechanical power requirement, frequent cleaning and sensitive to corrosion and fouling. Hence, nanofluids came into existence by dispersing high thermal conductive material in conventional base liquid to intensify the heat transfer rate. Hybrid nanofluids have higher thermal energy performance compared to mono nanofluids. In this research work, alumina-silica nanofluids were synthesized using 50% ethylene glycol by the two step method. The synthesized fluid was characterized using UV–Vis spectroscopy, SEM- EDS to confirm the size, shape and composition of nanoparticles. Zeta potential analysis was used to identify the particle size distribution and dispersion stability of the fluid. Experiments were carried out to find the overall coefficient of the nanofluids for various volume concentrations of 0.05%, 0.1% and 0.2% after determining its thermophysical properties. The percentage enhancement of overall heat transfer coefficient of nanofluid was 52.8% compared with the 50% ethylene glycol which implies that nanofluid can be used as a coolant to increase the thermal energy performance in various applications.

1. Introduction

The colloidal mixture of metal, metal oxide or ceramic nanoparticles with basefluids like water, ethylene glycol, oil or combination of these base fluids are termed as nanofluids. These suspensions intensifies heat transfer rate compared to original base fluid since the metal, metal oxide and ceramic particle have higher thermal conductivity. The millimeter or micron sized particles of metals and ceramics would tend to settle down quickly in basefluid due to gravitational effect. Hence, nanoparticles are suspended in base liquids to avoid rapid settling of particles and this concept was introduced by Choi in 1995 [1]. The advantages of nanofluids include (i) Increase in surface area and heat capacity of fluid, (ii) Effective thermal conductivity enhancement, (iii) Augmentation of collision among nanoparticles and the flow passage surface, and (iv) reduced activity of particle agglomeration [2].

Nanofluids can be used in various industrial applications, engineering, biomedical and heat transfer applications because of its excellent thermophysical properties. Heat transfer applications include industrial equipment cooling, IC engine cooling, electronics equipment cooling etc. Cooling is a major challenge for applications like car engines, power electronics, computers which are caused by higher power rating and smaller size. A significant increase in fuel consumption occurs when larger size radiators are used to achieve high engine power [3,4].

Minsta et al. established the relation of thermal conductivity on temperature for alumina and cupric oxide mono nanofluids [5]. Rise in thermal conductivity of nanofluid with increase in the particle volume fraction and decreasing particle size was achieved in addition to the higher significance on temperature. Sidik et al. [6] used nanofluids as a substitute for conventional coolants and the thermal performance of vehicle engine for nanofluids was studied. The heat transfer coefficient can be improved by 30% at a volume fraction of 1% when compared with the conventional coolant.

Gu et al. [7] studied the effect of shape on thermal conductivity values for carbon nanotubes, silver nanowires and copper nanowires. They concluded that the thermal conductivity values showed a significant change with the particle shape.

Peyghambarzadeh et al. [8] investigated the forced convective heat transfer for alumina nanofluids using water as base fluid in an automobile radiator for various volume concentration. The effect of inlet temperature of the fluid on the heat transfer coeffi-

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Table 1
Properties of ethylene glycol, alumina and silica nanoparticles at 30 °C.

Properties	50% Ethylene glycol [19]	Alumina nanoparticle [20]	Silica nanoparticle [20]
Thermal conductivity (W/m.K)	0.316	30	1.4
Density (Kg/m^3)	1089	3950	2650

cient was also studied and showed that increasing the circulating rate of fluid gradually increases the heat transfer performance. Heat transfer rate of the automobile radiator was enhanced by adding alumina nanoparticle. Heat transfer coefficient and thermal conductivity of nanofluids were increased because of Brownian motion of nanoparticles.

In early days, water has been used as a cooling medium for IC engines but found difficulties in continuous operations. At elevated temperature, water could not be able to remain in liquid state because of its low boiling point. To avoid the difficulties in using water as coolant despite of its good properties, it has been used in combination with ethylene glycol. The freezing point of 50% ethylene glycol is −36.8 °C and its boiling point is 107 °C [9–12]. Addition of ethylene glycol to water decrease the thermal conductivity and hence to overcome this, nanoparticles can be suspended in water-ethylene glycol mixture. Using nanofluids as coolant, smaller sized and better position of radiators could be achieved [13]. Engines with nanofluid coolant, will pave way for increased power output with less fuel consumption and emissions. Usage of hybrid nanofluids instead of mono nanofluids would further enhance the thermal conductivity which results in increased heat transfer rate and higher power output of IC engine.

Jana et al. [14] synthesized and studied the thermal conductivity characteristics of water based CNT-gold nanoparticles and CNT- copper nanoparticles. They observed that the CNT did not increase the thermal conductivity of both hybrid nanofluids. Lack of interaction between gold-CNT nanomaterials decrease the thermal conductivity and the addition of CNTs to copper nanoparticles reduces the dispersibility which results in low thermal conductivity and agglomeration of nanoparticles.

Suresh et al. [15] observed that the thermal conductivity is increased for Al_2O_3–Cu /water hybrid nanofluids from 0.1% to 2% volume fraction. The viscosity of hybrid nanofluids for various volume concentration showed that the effective viscosity increases with volume concentrations and the experimental results of viscosity were higher than the theoretical models.

Baghbanzedh et al. [16] measured the thermal conductivity of water based silica- MWNT hybrid nanofluids and the enhancement of thermal conductivity of hybrid nanofluids is falling in between the increase of MWNT nanofluids and Silica nanofluids. They have shown MWNT was the reason behind increase in thermal conductivity and addition of surfactant causes an adverse effect on thermal properties.

Abbasi et al. [17] mentioned that the thermal conductivity of water based hybrid nanofluids (Al_2O_3/MWCNT) depends on the synthesis method and the stability of hybrid nanofluids. Munkhbayar et al. [18] studied the dependence of temperature on the effective thermal conductivity of hybrid nanofluids containing silver/ MWNT and showed that higher thermal conductivity could be achieved with hybrid nanofluids compared to nanofluids containing MWNT.

In this article, alumina-silica nanoparticles are dispersed in water-ethylene glycol mixture to study the heat transfer characteristics. Alumina and silica nanoparticles are used in this study because of its reasonable thermal conductivity, low cost and good thermal stability and its thermal properties are provided in Table 1.

2. Materials and methodology

2.1. Materials

Aluminium nitrate powders, ethanol and ammonium hydroxide solution, Tetra Ethyl Ortho Silicate (TEOS) and ethylene glycol were purchased from M/S. Alfa Aesar. The chemicals and reagents purchased were analytical grade and used as received.

2.2. Preparation of individual nanoparticles

2.2.1. Alumina nanoparticles preparation

Alumina nanoparticles were prepared by adding 250 ml aluminium nitrate and 200 ml of ammonium hydroxide to water followed by stirring, centrifugation and calcination for 4 h [21].

2.2.2. Silica nanoparticles preparation

Silica nanoparticles were produced by sol-gel process. Ethanol in water was added to TEOS solution ensued by the addition of ammonium hydroxide. The mixture was sonicated for 60 min and dried in oven to produce silica nanoparticles [22]. Hydrolysis and condensation reaction occurs during the preparation of silica nanoparticles. Hydrolysis of TEOS in ethanol mixture and to promote the condensation reaction, ammonium hydroxide was used as a catalyst.

2.3. Preparation of nanofluids

2.3.1. Preparation of mono nanofluids

The chosen nanoparticles such as alumina and silica were dispersed by suspending the required amount of particles in 100 ml of 50% ethylene glycol mixture using a bath sonicator for the preparation of nanofluids. For obtaining the uniform concentration and dispersion of nanofluids, the sonication process was continued at a time interval of 4 h at 40 kHz. The amount of nanoparticles required for preparation of nanofluid can be found from the Eq. (1) based on volume percentage of nanofluids and volume of base fluid.

$$Volume\,\% = \frac{Weight\ of\ nanoparticle / Density\ of\ nanoparticle}{Weight\ of\ nanoparticle / Density\ of\ nanoparticle + Volume\ of\ base\ fluid} \quad (1)$$

2.3.2. Synthesis of alumina -silica hybrid nanofluids

To prepare hybrid nanofluids, mono nanofluids are required. After the preparation of mono nanofluids, hybrid nanofluids were synthesized at a volume ratio of 80:20 by dispersing specified quantity of alumina nanofluid (80 ml) in silica nanofluid (20 ml) in a bath sonicator for 2 h at 40 kHz to achieve uniform dispersion and stable suspension. pH adjustment has been done to achieve stability prior to sonication. The volume ratio to prepare hybrid nanocolloid would be based on the thermal conductivity of individual alumina and silica nanofluids.

2.4. Characterization studies

Various characterization studies have been carried out to understand the crystallite size, crystal structure and morphology