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Effects of surfactant on stability and thermo-physical properties of metal oxide nanofluids

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ABSTRACT

Optimal thermo-physical properties of nanofluids provide an opportunity to overcome energy associated difficulties, in addition to providing new alternatives to catch, store and exchange of energy. A significant reduction in energy consumption is possible by improving the performance of a heat exchanger circuit, and may in part alleviate current energy related challenging issues such as global warming, climate change, and the fuel crisis. The objective of this work is to gain an insight into the overall stability of nanofluids with respect to pH, zeta potential, particle size distribution, and its effect on viscosity and thermal conductivity. For the purpose of this study two nanofluids were selected (water based alumina and copper oxide). Various nanoparticles concentrations as well as anionic surfactants (sodium dodecylbenzene sulfonate) were investigated for their stability, viscosity as well as thermal conductivity. The results clearly showed that nanofluid stability has a strong relation with viscosity and thermal conductivity. The stability of the nanofluid was found to be improved with a decrease in viscosity and an increase in thermal conductivity.

1. Introduction

Cooling is one of the most important scientific challenges in production related industries, such as, transportation, manufacturing and microelectronics. Technological advancements have led to increase in thermal load and thus, improvements to cooling systems have become a necessity. Maximising the surface area of heated surface and increasing the coolant flow rate are the conventional approaches for enhancing heat dissipation. However, these methods lead to an undesirable increase in the size and cost of thermal management systems. Thus, there is an urgency for an alternative coolants with an enhanced thermal performance. One such coolant is the innovative concept of 'nanofluids', which is a mixture of metallic/nonmetallic nanoparticles in a base fluid. The term nanofluid was originally introduced by Choi at Argonne National Laboratory [1]. A substantial difference in thermo-physical properties of the nanofluids in comparison to a basefluid, is the unique feature of the nanofluids. Apart from thermophysical properties, the relatively large overall surface area of the nanoparticles not only improves heat transfer capabilities, but also increases the stability of the suspension by alleviating particle settlement phenomenon. There are also several advantages in employing nanofluids, specifically: better long-standing stability compared to millimetre or even micrometre sized particle suspensions and lower erosion and pressure drop, especially in micro-channels.

Stability of the nanoparticles is a vital concern in nanofluid research, as achieving the long term well suspended nanofluid remains as a big challenge. Nanofluid generally is treated as a two component mixture (base fluid + nanoparticles) with no chemical reaction between these two components. In this case, the stability of the nanoparticles in a base fluid depends on various parameters for instance [2]: (a) nanofluids are multiphase dispersion systems with high surface energy of the nanoparticles results in an overall thermodynamically unstable colloid, (b) nanoparticles dispersed in the base fluid have a strong Brownian motions. The nanoparticles' movement can offset their sedimentation due to gravity, (c) the dispersed nanoparticles in the base fluid may settle out with time because of nanoparticle aggregation, which is initiated by van der Waals forces. Therefore it is clear that the aggregation and sedimentation are the two critical phenomena in relation to the stability of a nanofluid which can directly affect its thermo-physical properties [3]. It is well established from the

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literature that the thermal developing length of some of the nanofluids is higher when compared to the pure base fluid [4]. Therefore, the increment in heat transfer, when using nanofluids, can be related to the reduced thermal boundary layer thickness because of the non-uniform distribution of viscosity and thermal conductivity resulting from Brownian motion of the nanoparticles [5]. Nanoparticle clustering is considered as a notable reason for disagreement in experimental results [6]. Though there are no universally recognised and accepted quantitative values, it is well-known that the level of clustering has an effect on the viscosity and thermal conductivity of nanofluids [7,8]. The clustering level relies on several variables such as the addition of surfactants and tuning the value of the nanofluids' pH to allow for better dispersion, and prevent the extent of clustering [9].

Chen et al. [10] suggested that the aggregation of nanoparticles is one of the main reasons for the observed enhancement in viscosity of nanofluids when compared to the theory (i.e. the classical Einestien equation). To take into account the effect of aggregation, Chen et al. [10] proposed their model by adding an aggregation effect to the original Krieger and Dougherty [11] model. Good agreement was found between their experimental data and the proposed model. Wang et al. [9] studied the effect of aggregation and stability on heat transfer performance of water based nanofluids through changing the pH value as well as sodium dodecylbenzene sulfonate (SDBS) surfactant concentrations. They concluded that the nanofluids stability have a direct relation to the improvement in thermal conductivity, in other words the improved surfactant behaviour was the cause for the observed enhancemnet in thermal conductivity.

True evaluation of nanofluid feasibility should be performed while the thermal conductivity and viscosity of nanofluid taken into account at the same time. Prasher et al. [12] have shown that if the increase in viscosity ratio (the ratio of viscosity of nanofluid to viscosity of base fluid) becomes more than four times that of a comparable increase in thermal conductivity ratio (ratio of the nanofluid thermal conductivity to the base fluid thermal conductivity), then the use of nanofluid is not economically viable due to increased pumping power. They found that this ratio is equal to two for alumina/propylene gylcol (PG) nanofluids, as a result alumina–PG nanofluids may be more efficient than the base fluid for heat transfer applications. However, the cost associated with alumina/PG nanofluids and their losses need to be taken into consideration for practical applications. Venerus et al. [13] also ran a benchmark study on the viscosity behaviour of ten different nanofluids and concluded that all of the nanofluids used in their study clearly failed the qualifications of practical nanofluids proposed by Prasher et al. [12].

For implementing nanofluid in practical applications, true evaluation of thermo-physical properties of the nanofluid of interest such as pH and zeta potential, effective thermal conductivity, dynamic viscosity and particle size distribution should be analysed. A number of methods have been employed to determine the dispersion stability of nanofluids, such as a Malvern ZS Nano S analyzer (Dynamic Light Scattering) [14], UV–vis. Spectrophotometer [15], Small Angle X-ray Scattering (SAXS) [16] etc. These methods are able to determine the degree of dispersion between the initial state of the nanofluid preparation and afterwards.

A number of studies have investigated the outstanding thermo-physical properties (such as thermal conductivity, density, specific heat and viscosity etc.) of nanofluids [7,17,18]. However, the number of studies on the effect of zeta potential and particle size distribution on nanofluid viscosity as well as thermal conductivity is very limited in the current literature. Moreover, small attention has been given to understand the influence of anionic surfactants on pH, viscosity, thermal conductivity and stability mechanism (in terms of zeta potential and particles size distribution in base fluid) of nanofluids. As mentioned earlier, the overall effectiveness of nanofluids in heat transfer applications can be best evaluated if the enhancements in both thermal conductivity and viscosity are considered at the same time. When the real application of nanofluids is taken into consideration, two key issues emerge: settlement and erosion. Possible difficulties related to these issues need to be explored and solved prior to the commercialisation of nanofluids. It should also be noted that nanofluids may enhance the viscosity under certain conditions and this is a significant disadvantage due to the associated rise in pumping power. Keeping this in mind, the current work focuses on the investigation of nanofluids' stability and attempted to demonstrate correlations among stability features, thermal conductivity and the viscosity of nano-suspensions. In particular, surface potential is controlled by changing the weight concentrations of SDBS and nanoparticles. Afterward, the effects of SDBS and nanoparticle weight concentrations on the stability of nanofluids in terms of viscosity, thermal conductivity ratio, zeta potential and particle size distribution in base fluid is analysed. The alumina and copper oxide nanoparticles have been selected for the purpose of this study, broadly used material in a water based nanofluid applications [2]. The current work focuses on investigating the stability characteristics of Al_2O_3 and CuO nanofluids with different weight concentrations of SDBS and nanoparticle in a DI-water as a base fluid. The ultimate aim of this work is to evaluate the optimum weight fraction of SDBS as well as nanoparticles in base fluid to achieve the most stable and most efficient nanofluid which may lead to a decrease in the value of viscosity and enhancement in thermal conductivity, thus enhance the overall heat transfer performance.

2. Experimental procedure

2.1. Preparation of nanofluids

Nanoparticles used in this study were CuO and Al_2O_3 with sizes of 30–50 nm and 10 nm respectively, supplied by Nanostructured & Amorphous Materials, Inc., USA. The experiments were carried out with different nanoparticles weight fractions in the range of 0.05–0.15%. Deionised water was utilised as the base fluid. Different weight fractions, from 0.05% to 0.2%, of the dispersant sodium dodecylbenzene sulfonate (SDBS, Sigma–Aldrich Pty. Ltd.) were used to stabilise the nanoparticles. All the samples were prepared at ambient temperature by the two-step method [2]. The prepared nanofluids did not show any visual signs of nanoparticle sedimentation and were found to be very stable, with the visual stability lasting over a week in all cases. Table 1 presents the properties of Al_2O_3 and CuO nanoparticles utilised in this study.

2.2. Measurement of rheological behaviour

The dynamic viscosity of Al_2O_3/DI-water and CuO/DI-water nanofluids was measured using an AR-G2 rotational rheometer

Table 1
Properties of Al_2O_3 and CuO nanoparticles.

Product name	Molecular formula	Mean particle size	Surface area	Density
Aluminium oxide	Al_2O_3	10 nm	160 m^2/g SSA	3.7 g/cm^3 at 20 °C
Copper (II) oxide	CuO	30–50 nm	13 m^2/g SSA	6.3–6.49 g/cm^3 at 20 °C