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A REVIEW ON PREPARATION OF AL_20_3 –DISTILLED WATER BASED NANOFLUID FOR COUNTER FLOW HEAT EXCHANGER

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Abstract: ultrahigh performance cooling is today's important needs of many industries. But, less thermal conductivity is a primary limitation in developing efficient heat transfer fluids that are required for cooling purposes. Nanofluids are bring about by suspending nanoparticles with average sizes below 20 to 50 nm in heat transfer fluids such as water, oil, diesel, ethylene glycol, etc. Advanced heat transfer fluids are produced by mixing metallic or nonmetallic nanometer-sized solid particles. Experimentations have shown that nanofluids have significant higher thermal conductivities compared to the base fluids. These suspended nanoparticles can change the transport and thermal properties of the base fluid. This is seen from the works, wide investigation has been carried out in alumina-water and CuO-water systems as well few reports in Cu-water-, TiO_2, zirconia-, diamond, SiC-, Fe_3O_4, Ag-, Au-, and water-based systems. The purpose of this review is to study recent developments in research on the constancy of nanofluids, improvement of thermal conductivities, viscosity, and heat transfer characteristics of alumina (Al_2O_3) - water based nanofluids

Keywords: Aluminum Oxide, nanoparticles, heat exchanger, Nanofluid.

I. INTRODUCTION

Todays used fluids, likely water, engine oil, and ethylene glycol are normally used as heat transfer fluids. Even though various methods are applied to improve the heat transfer, less heat transfer performance of these conservative fluids obstructs the performance improvement and compactness of heat exchangers. The usage of solid particles as an additive put off into the base fluid is method for the heat transfer improvement. Enlightening the thermal conductivity is the key idea to improve the heat transfer features of conventional fluids. Subsequently a solid metal has a larger thermal conductivity than a conventional fluid, dispersing metallic solid fine particles into the base fluid is likely to improve the thermal conductivity of that fluid. The improvement of thermal conductivity of conventional fluids by the postponement of solid particles, like millimeter- or micrometer-sized particles, has been well-known for many years [4]. Though, they have not been of attention for practical applications due to problems such as clogging leading to increased pressure drop in the flow channel. The current advance in material technology has made it probable to produce advanced heat transfer fluids by mixing nanometer-sized particles in base fluids which can change the transportation and heating properties of the base fluid. Nanofluids are solid-liquid complex materials consisting of solid nanoparticles or nanofibers with sizes typically of 20 to 50 nm suspended in distilled water. The nanofluid is not a simple liquid-solid mixture, the most vital criterion of nanofluid is agglomerate-stable suspension for long durations without causing any chemical changes in the base fluid. This can be attained by decreasing the density between solids and liquids or by increasing the viscosity of the liquid; by using micrometer-sized particles and by stopping particles from cluster, the settle down of particles can be avoided. Nanofluids have attracted great interest recently because of reports of improved thermal properties [4]-[6]. Widespread investigation has been carried out on alumina-water and CuO-water based systems as well few reports in Cu-water, C- nanotubes water systems. This article goals overview of the concept of AL_2O_3-distilled water based Nanofluids surveyed by an account on the complete research events carried out around the world. The review will focus mainly on engineering application parameters, likely the thermal conductivity and viscosity etc., without giving much important on the theoretical aspects

II. PREPARATION OF NANOFLUIDS

There are two fundamental methods to obtain nanofluids:

- Single-step direct vaporization method: In this method, the direct evaporation and condensation of the nanoparticle materials in the distilled water are obtained to prepare unchanging nanofluids.
- Two-step method: In two step method, first the nanoparticles are obtained by different methods and then are spread into the base liquid.

III. FACTORS AFFECTING ON THERMAL CONDUCTIVITY

A. Thermal conductivity measurement techniques

Thermal conductivity is most important criteria in improving the heat transfer characteristics of a base fluid. As the thermal conductivity of solid metals is greater than that of fluids, the mixed particles are expected to increase the thermal conductivity and heat transfer Characteristics. Too Many investigators have stated experimental studies on the thermal conductivity of nanofluids. The steady-state parallel plate method, and transient hot-wire method [4] have been employed to measure the thermal conductivity of nanofluids. But, the transient hot-wire method has been extensively used by many investigators A full review on different methods for measurement of thermal conductivity of nanofluids is available in the literature [5].

B. Experimental results on thermal conductivity of stilled water based nanofluids

Al_2O_3 is the most common nanoparticle used by many researchers in their experimental works. Many efforts have been made to study the thermal conductivity of nanofluids. The summary of experimental studies on the thermal conductivity of Al_2O_3-based nanofluids are given Usually, thermal conductivity of the nanofluids increases with increasing volume fraction of nanoparticles; with decreasing particle size, the shape of particles can also effect the thermal conductivity of nanofluids, temperature, Brownian motion of the particle, interfacial layer, and with the additives.

C. Effect of volume fraction of nanoparticles on thermal conductivity of Al2O3-based nanofluids

The effect of volumetric concentration on Al_2O_3-water based nanofluids is shown in Figure 1. The investigators used different sizes of Al_2O_3 nanoparticles at different temperatures in water and ethylene glycol with particle volume concentration typically less than 5% with few exclusions. The maximum improvement in thermal conductivity observed for 4% vol. load in the case of water-based nanofluid was 32% [15] and in the case of ethylene glycol-based nanofluid was 30% [13], respectively. Hwang et al. [14] observed a 4% improvement in thermal conductivity at 1 vol% concentration; the observed improvement was more compared to other researchers at same the volume fraction of solids. Lee et al. [16] observed a 2 % improvement at a lower volume percent for 35- nm-sized Al_2O_3 particles. In the case of Li and the thermal conductivity improvement was decreased as concentration increased from 6% to 10%, but in the case of Timofeeva et al. [11], the thermal conductivity was increased as concentration increased from 2% to 10% even though the particle size was almost the same in both the cases.

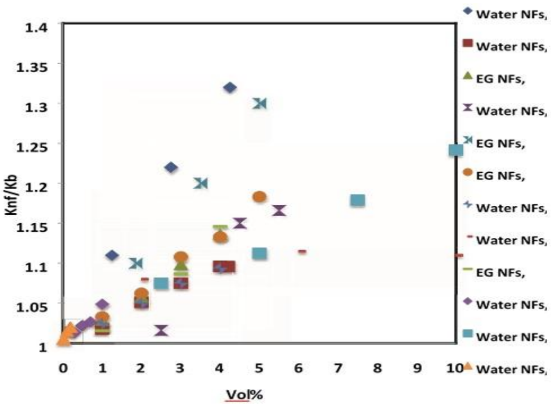

Figure 1. Effect of volume fraction of nanoparticles on ratio thermal conductivity of Al2O3-based nanofluids

D. Effect of particle size on thermal conductivity of Al2O3 based nanofluids

Figure 2 reveals the effect of particle size on thermal conductivity of Al_2O_3-water based nanofluids, the particles used were in the range of 13 to 50 nm. Alumina, 38.4 nm, in water resulted in thermal conductivity improvement in the range of 2% to 10% in two studies but up to 21% in some study. The thermal conductivity improvement for the nanofluids with 40 nm [7] particles was lying in between that of 38.4 and 60.4 nm, which cannot be explained. Murshed et al. [4] observed higher improvement with 80- and 150-nm-sized particles at 1 vol. % compared to the nanofluids with 2.5 vol. % of 28-nm particles in ethylene glycol-based Al_2O_3 nanofluids. The authors have demonstrated that 80- nm particles showed higher thermal conductivity improvement at 1 vol% compared to similar data reported earlier. Xie et al. [13] used 15- and 60.4nm sized particles, observed higher thermal conductivity improvement for larger nanoparticles in ethylene glycol-based nanofluids. The results cited here do not correlate the size effect of nanoparticles in thermal conductivity improvement. More research is required to understand this size effect.

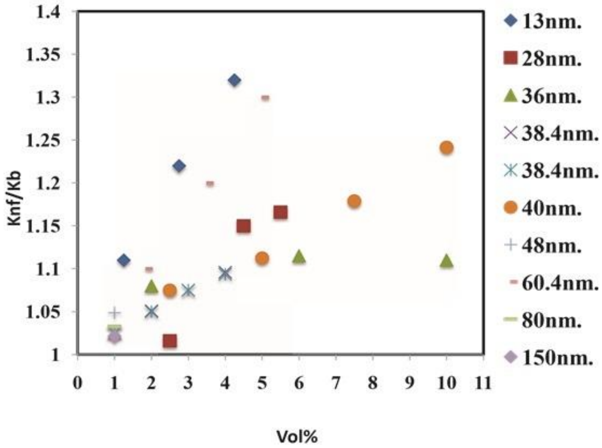

Figure 2. Effect of particle size on thermal conductivity of nanofluid.

E. Effect of base fluids on thermal conductivity of Al2O3based nanofluids

The effect of base fluid on thermal conductivity is shown in Figure 3. The result in Figure 3 shows that the thermal conductivity improvement is least for the water-based nanofluids compared with other nanofluids. This result is encouraging because heat transfer improvement is often most needed when poorer heat transfer fluids are involved. The improvement in the case of PO is 38% at 5 vol. % compared to that of 20 % at 4 vol. % TO in contrast to 10.8% improvement with the same volume fraction of nanoparticles in water. Figure 3 thus categorically indicated that the thermal conductivity improvement for the poorer heat transfer fluids is good compared to the fluids with better thermal conductivity such as water.

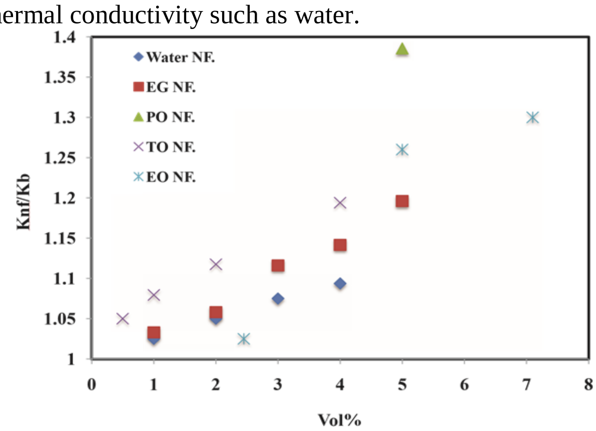

Figure 3. Effect of base fluid on thermal conductivity of nanofluid.

F. Effect of preparation method on thermal conductivity of Al2O3-based nanofluids

Thermal conductivities of the nanoparticle fluid mixture were first reported by Masuda et al. The average diameter of the particles used in their experiments was 20 nm, and the particles dispersed in water by using a high speed shearing dispenser ≈ 20,000 rpm. The writers reported a 32.4% increase in thermal conductivity for the volume fraction of 4.3 vol. % against 20% for 3 vol. % nano alumina. Though, the experiment was carried out at a higher room temperature of nearly 32°C, which is higher than most other investigators' reported data at room temperature ranging from 21°C to 28°C. Additional, the authors used a high-speed dispenser with adding of HCl and NaOH to the fluids so that electrostatic repulsive forces among the particles kept the powder well dispersed. Lee et al. [16] dispersed 40-nm-sized Al_2O_3 nanoparticles in water and ethylene glycol by using polyethylene container and shaken carefully to ensure a homogeneous mixture for producing stable mixture. The authors observed an increase of only 10% at the 4.3 vol% and 8% for the 3% load. The same enhancement was observed by Das et al. [6] for the particle size of 38.4 nm and for the particle load between 1% and 4%. Wang et al. [7] dispersed 28-nm-sized Al_2O_3 nanoparticles in different base fluids and prepared nanofluids by mechanical blending, coating particles with polymers and filtration method. The thermal conductivity enhancement was 16% for 5.5 vol. % and 12% for 3% volume faction. In the case of Xie et al. [13], the researchers used 60.4-nm-sized Al_2O_3 dispersed in water and prepared stable solution by adjusting pH. Nanoparticles are de-agglomerated by using an ultrasonic disrupter after mixing with a base fluid and were homogenized by using magnetic force agitation. The enhancement observed was 21% for 5% volume fraction and 14% at 3.2% volume raction.

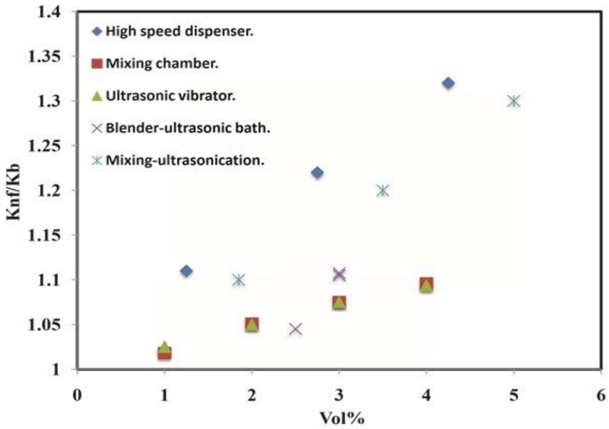

Figure 4. Effect of preparation method on thermal conductivity of nanofluid.

Figure 4 shows that the enhancement in the case of Xie et al. [13] is more compared to others even though they used lesser particles and in the case of Wang et al. [7] shows lesser enhancement at 2.5 vol. % compared to Das et al. [6] and Lee et al. [16]. The same method of synthesis in the latter two cases validated similar enhancement ratios. These results validate that a stable dispersion can be achieved by many different methods, but the thermal conductivity enhancement is dependent on the preparation methods. These results need further studies since the stability of such fluids in the long run has not been studied and the data reported here is immediately after obtaining the nanofluid.

G. Effect of temperature on thermal conductivity of Al2O3based nanofluids

The thermal conductivity of nanofluids is temperature sensitive compared to that of base fluids. The effect of temperature on water-based Al2O3 nanofluids is shown in Figure 6. Different groups measured thermal conductivity at different temperatures. Das et al. [6] varied temperatures in the range of 21°C to 51°C demonstrating an enhancement of 2% to 10.8% for the particle load of In Figure 7, the same trend is observed for ethylene glycol-based nanofluids. Both Murshed et al. [4] and Beck et al. [19] observed higher conductivity enhancement for the suspensions containing surfactants, though particle size of solids were different in both cases. Recently, Beck et al. [19] measured thermal conductivity of the ethylene glycol-based nanofluids in the range of 296 to 400 K and showed that thermal conductivity behavior of nanofluids is related the behavior of the base fluid, and they suggested that temperature dependence of nanofluids is due mostly to the base fluids. These results of temperature dependence of thermal conductivity enhancement in nanofluids based on alumina during the last 15 years since 1993 is confusing and hence needs thorough analysis. The data must be interpreted in conjunction with the base fluid behavior, particle size, and surfactant effect.

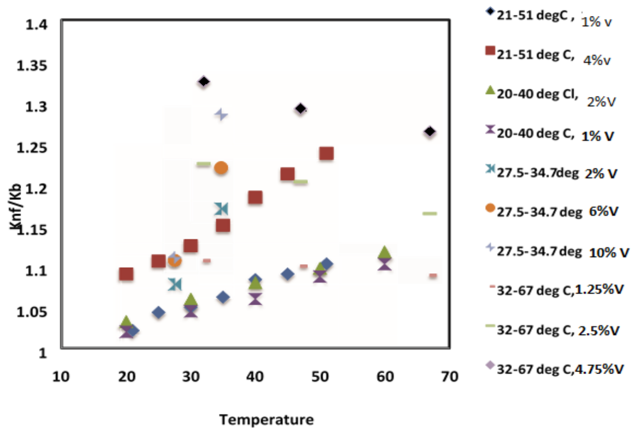

Figure 5. Effect of temperature on thermal conductivity nanofluid.

H. Thermal conductivity of Al2O3 nanofluids measured by different techniques

Figure 6 shows the thermal conductivity measurement of Al_2O_3 water-based nanofluid measured by different techniques. A trend shows that thermal conductivity increased with the increase in volume fraction. The thermal conductivity data in the case of Oh et al. [20] were in well agreement with that reported by Wang et al. [7] which, however, was higher than the results of Lee et al. [16] and Das et al. [6] for similar nanofluids but measured by different techniques. The reason for this discrepancy during the measurement may be due to the sedimentation and aggregation of nanoparticles, particle diameter, and nanofluid preparation. In comparing the thermal conductivity measurement techniques, the steady state parallel plate method seems to be least affected by the particle sedimentation since the thickness of the loaded sample fluid is less than 1 mm. The transient hot-wire method can be affected by the sedimentation of the nanofluids. Non-homogeneous nanoparticle concentration in the direction of gravity can give rise to temperature gradient within the vertical hot wire, which may be a source of measurement errors. This is also true for the temperature oscillation technique [23]. It is not clear how these techniques will behave for a stable nanofluid which does not at all sediment during the measurement. Therefore, it is essential to produce nanofluids which can be stable for long periods of time without any noticeable sedimentation.

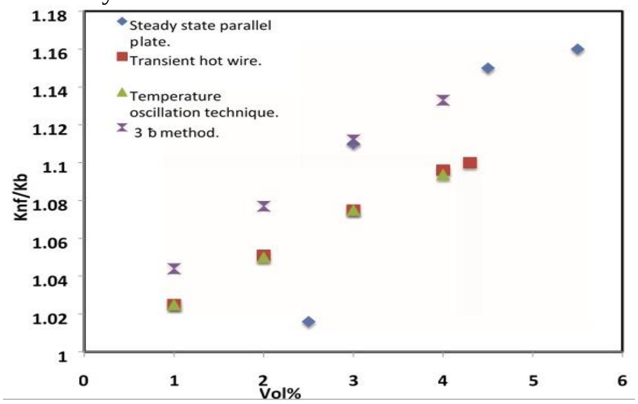

Figure 5. Effect of temperature on thermal conductivity nanofluid.

I. Effect pH on thermal conductivity of Al2O3 water-based nanofluids

Xie et al. [13] prepared various suspensions containing Al_2O_3 nanoparticles with specific surface areas in a range of 5 to 124 m^2/g, and their thermal conductivities were measured using a transient hot-wire method at a pH range of 2 to 11.5. It was noted that the nanoparticle suspensions, containing a small amount of Al_2O_3, have substantially higher thermal conductivity than the base fluid, with the enhancement increasing with the volume fraction of Al_2O_3. The enhanced thermal conductivity increases with an increase in the difference between the pH value of aqueous suspension and the isoelectric point of the Al_2O_3 particle. The enhancement observed for 60.4-nm-sized particle between 1.8 and 5 vol. % is 7 % to 21%. The effect of pH on thermal conductivity of water-based Al_2O_3 nanofluids is shown in Figure 7.

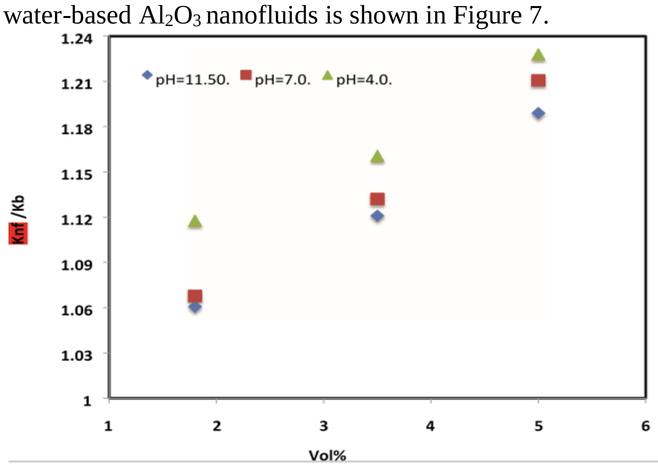

Figure 7. Effect of pH on thermal conductivity of nanofluid.

J. Effect of surface active agents on thermal conductivity of water-based Al2O3 nanofluids

Figure 10 compares the thermal conductivity enhancement of Al_2O_3 nanofluids with and without a surfactant. Wen et al. [21] used 42-nm-sized Al_2O_3 nanoparticles and dispersed them in water using sodium dodecyl benzene sulfonate (SDBS) as surfactant; the enhancement observed was 10% for 1.59 vol.% which is comparable with the data reported earlier [1,7,18]. Recently, Kole et al. [22] dispersed < 50-nm-sized Al_2O_3 using oleic acid as surfactant in a car engine coolant and observed 10.41% enhancement for 3.5 vol. %. The authors have demonstrated the stability of such fluids for more than 80 days with thermal conductivity enhancement of 13% and 12% for ethylene glycol-based Al_2O_3 nanofluids at 5 vol. % solid loading. As shown in Figure 10, the additives will enhance the thermal conductivity of the nanofluids and give good stability, but the question which is unresolved is the contribution of thermal conductivity enhancement from the surfactant effect to the overall enhancement of the nanofluids.

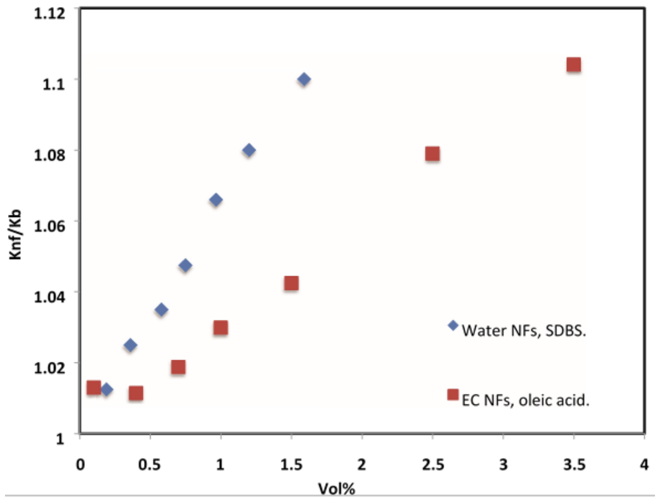

Figure 8. Effect of additives on thermal conductivity of nanofluid.

K. Experimental results on viscosity of Al2O3-based nanofluids

Compared with the experimental studies on thermal conductivity of nanofluids, there are limited rheological studies reported in the literature. In one study [8], the Al_2O_3-water mixture showed a viscosity increase between 20% and 30% for 3 vol. % Al_2O_3 solution compared to that of water alone. The results by Das et al. [6] on the viscosity of alumina-water nanofluids against shear rate demonstrated an increase of viscosity with increased particle concentrations indicating strong possibility that nanofluid may be non-Newtonian. Further investigations are, however, required to define the viscosity models of nanofluids.

In another study, a two-step method was used to produce Al_2O_3-water nanofluids with low concentrations of Al_2O_3 nanoparticles from 0.01 to 0.3 vol. % without any surfactant [19] and measured viscosity at the temperature range from 21°C to 39°C. Experimental results showed that the effective viscosities of the dilute Al_2O_3- water nanofluids significantly decreases with increasing temperature and slightly increases with increasing volume fraction. The measured viscosity of the Al_2O_3-water nanofluids is nonlinear with the Al_2O_3 nanoparticle volume concentration. The nonlinear viscosity behavior occurs at very low particle concentrations far below 2 vol. %. Nonlinear behavior implies that there is particle-particle interactions which invalidate the Einstein equation developed for dilute suspensions. The result is similar in another experiment, wherein, the viscosity increased by 83.4% at a volume fraction of 0.05 (5 vol. %). The viscosity study on Al_2O_3water nanofluids with 36- and 47- nm, and CuO-water nanofluid with 29-nm average particle size was reported by Nguyen for particle volume fraction ranging from 1% to 9.4% and for temperatures varying from room temperature to approximately 75°C. The hysteresis behavior for 36-nm particle size and four particle volume concentrations indicated drastic changes with heating of samples beyond a critical temperature. On cooling after being heated beyond a critical temperature, a hysteresis phenomenon can occur. It is very interesting to note that hysteresis is predominant only in fluids with higher nanoparticle concentration.

The measured viscosities of Al_2O_3 (80 nm) and deionized water (DIW)-based nanofluids were also found to increase by nearly 82% for the maximum volumetric loading of 5% nanoparticles [20]. A similar increment (86%) of the effective viscosity of Al_2O_3 (28 nm)/distilled water-based nanofluids was also observed by Wang et al. [7] for the same volume fraction of 0.05. The reasons for the differences could be due to the difference in the size of the particle clusters, differences in the dispersion techniques, and the use of a surfactant similar to that reported earlier for thermal conductivity data. At lower concentrations, the change in relative viscosity over temperature was minimal. Xie et al. [13] also demonstrated that the viscosity of the nanoparticle suspension is much larger than the corresponding value predicted by the theoretical formula. The enhancements ratio of the viscosity of ethylene glycol (EG)-based suspensions are smaller than those of water-based suspensions, indicating the significant influence of the base fluid on the viscosity of the fluid-nanoparticle mixtures. The recent report by Kole et al. [22] of alumina in engine oil demonstrated that there is a transition from Newtonian characteristics for the base fluid to non-Newtonian behavior with increasing content of Al_2O_3 in the engine coolant. The data also show that the viscosity increases with an increase in concentration and decreases with an increase in temperature.

The analysis of limited data indicated that an optimization is required for the solid loading in nanofluids so that the viscosity rise is not high for the application and at the same time there is significant enhancement in the thermal conductivity of nanofluids. More studies are required in this direction.

IV. HEAT TRANSFER CHARACTERISTICS OF AL2O3-BASED NANOFLUIDS

While heat transfer aspects of suspensions are important in applications in general, the aspect of natural convection in multiphase emulsions becomes more critical during storage and special phenomena such as melting of clathrate, which is used for storing coldness by releasing latent heat, separates out as organic liquid and an emulsion of hydrofluorocarbon dispersed in water [4].

Pak and Cho studied the heat transfer enhancement in a circular tube, using g-Al_2O_3 and TiO_2 nanoparticle fluid mixtures as the flowing medium. They observed an increase in the Nusselt number with the increasing volume fraction and Reynolds number. Putra et al. [24] studied the natural convection of nanofluids inside horizontal cylinder heated from one end and cooled from the other. An apparently paradoxical behavior of heat transfer deterioration was observed in the experimental study. The nature of this deterioration and its dependence on parameters such as particle concentration, material of the particles, and geometry of the containing cavity was investigated. The fluid characters are distinct from that of common slurries.

Heris et al. [25] dispersed CuO and Al_2O_3 oxide nanoparticles in water as base fluid in different concentrations, and the laminar flow convective heat transfer through circular tube with constant wall temperature boundary condition were examined. The experimental results obtained for CuO-water and Al_2O_3-water nanofluids indicate that heat transfer coefficient ratios for nanofluid to homogeneous model in low concentrations are close to each other, but by increasing the volume fraction, higher heat transfer enhancement for Al_2O_3/ water was observed. The same authors worked on laminar flow forced convection heat transfer of Al_2O_3/water nanofluid inside a circular tube with constant wall temperature [33] and measured the Nusselt numbers for different nanoparticle concentrations as well as various Peclet and Reynolds numbers. Experimental results emphasized the enhancement of heat transfer due to the presence of nanoparticles in the fluid. Heat transfer coefficient increased by increasing the concentration of nanoparticles in nanofluid.

The turbulent convective heat transfer behavior of alumina (Al_2O_3) and zirconia (ZrO_2) nanoparticle dispersions in water is investigated experimentally in a flow loop with a horizontal tube test section at various flow rates ($9{,}000 < Re < 63{,}000$), The experimental data were compared to predictions made using the traditional single-phase convective heat transfer and viscous pressure loss correlations for fully developed turbulent flow, Dittus-Boelter, and Blasius/MacAdams, respectively. It was shown that if the measured temperature- and loading-dependent thermal conductivities and viscosities of the nanofluids are used in calculating the Reynolds, Prandtl, and Nusselt numbers, the existing correlations accurately reproduce the convective heat transfer and viscous pressure loss behavior in tubes. Therefore, no abnormal heat transfer enhancement was observed in this study.

Xuan and Li [8] conducted an experiment to investigate convective heat transfer and flow features of the nanofluid in a tube. Both the convective heat transfer coefficient and friction factor of the sample nanofluids for the turbulent flow were measured, respectively. The effects of such factors as the volume fraction of suspended nanoparticles and the Reynolds number on the heat transfer and flow features are discussed in detail. Wen and Ding [21] reported an experimental work on the convective heat transfer of nanofluids, made of gAl_2O_3 nanoparticles and DIW, flowing through a copper tube in the laminar flow regime. The results showed considerable enhancement of convective heat transfer using the nanofluids; the enhancement was particularly significant in the entrance region, and was much higher than that solely due to the enhancement on thermal conduction. The possible reasons for the enhancement are migration of nanoparticles and the resulting disturbance of the boundary layer.

You et al. measured the critical heat flux (CHF) in the pool boiling of Al_2O_3-water nanofluids. They discovered an unprecedented phenomenon: a threefold increase in CHF over that of pure water. The average size of departing bubbles increased, and the bubble frequency decreased significantly in nanofluids when compared with those in pure water. Bang studied boiling heat transfer characteristics of Al_2O_3-based nanofluids. Pool boiling heat transfer coefficients and phenomena of nanofluids are compared with those of pure water, which are acquired on a smooth horizontal flat surface (roughness of a few tens of nanometers). The experimental results showed that these nanofluids have poor heat transfer performance compared to pure water in natural convection and nucleate boiling. On the other hand, CHF has been enhanced in not only horizontal but also vertical pool boiling. This is related to a change of surface characteristics by the deposition of nanoparticles.

Experimental study conducted by Das et al. [6] on pool boiling in water-Al_2O_3 nanofluids on horizontal tubes of small diameter revealed that the deterioration in performance in boiling is less in narrow tubes compared to that in large industrial tubes which makes it less susceptible observed that the nanoparticle settlement mainly took place at the evaporator. The change of surface condition at the evaporator due to nanoparticle settlement was found to be the major reason for the enhanced thermal performance of the alumina nanofluid-charged oscillating heat pipe.

Recently, conducted an experiment on natural convection of heat transfer of a nanofluid in vertical square enclosures of different sizes, in the solid loading range of 0.1 to 4 vol. % noted the Rayleigh's number varying in the range of 6.21×10^3 to 2.56×10^8. The experimental result for the average heat transfer rate across the three enclosures appeared generally consistent with the assessment based on the changes in thermophysical properties of the nanofluid formulated, showing systematic heat transfer degradation for the nanofluid containing nanoparticles volume fraction ≥2 vol. % over the entire range of the Rayleigh's number considered. The nanofluid containing 0.1 vol. %, a heat transfer enhancement of 18% compared with that of water, was found to arise in the largest enclosure at sufficiently high Rayleigh's number. The authors suggested that such enhancement is not only due to the relative changes in thermophysical properties of the nanofluid containing low particle fraction, other factors may come into play.

Although addition of local losses (prefacing) may suppress instabilities, however, it is accompanied by a significant flow reduction which is detrimental to the natural circulation heat removal capability. Nayak et al. [42] demonstrated experimentally, with Al_2O_3 nanofluids, not only the flow instabilities are suppressed but also the natural circulation flow rate is enhanced. The increase in steady natural circulation flow rate due to addition of nanoparticles is found to be a function of its concentration in water. The flow instabilities are found to occur with water alone only during a sudden power addition from cold condition, step increase in power, and step decrease in power (step back conditions). With a small concentration of Al_2O_3 nanofluids, these instabilities are found to be suppressed significantly.

The heat transfer studies on alumina-based nanofluids can give rise to the possibility of their use in actual applications. However, cost of such fluids is a major concern vis-à-vis the stability duration of such fluids in ideal condition. Further, the effect of acids and bases or surfactants used for stabilization of nanoparticles in actual applications needs to be studied in detail.

V. APPLICATIONS OF ALUMINA-BASED NANOFLUIDS

A nanofluid can be used to cool automobile engines and welding equipment and to cool high heat flux devices such as high-power microwave tubes and high-power laser diode arrays. A nanofluid coolant could flow through tiny passages in MEMS too to improve its efficiency. The measurement of nanofluid CHF in a forced convection loop is useful for nuclear applications. If nanofluids improve chiller efficiency by 1%, a savings of 320 billion kWh of electricity or an equivalent 5.5 million barrels of oil per year would be realized in the USA alone. Nanofluids find a potential for use in deep drilling application. A nanofluid can also be used for increasing the dielectric strength and life of the transformer oil by dispersing nano diamond particles.

The experimentally investigated the behavior and heat transfer enhancement of an Al_2O_3 nanoparticle-water mixture, flowing inside a closed system that is destined for the cooling of microprocessors or other electronic components. Experimental data, obtained for turbulent flow regime, have clearly shown that the inclusion of nanoparticles into distilled water has produced a considerable enhancement of the cooling block convective heat transfer coefficient. For a particular nanofluid with 6.8% particle volume concentration, heat transfer coefficient has been found to increase as much as 40% compared to that of the base fluid. It has also been found that an increase of particle concentration has produced a clear decrease of the heated component temperature. Experimental data also showed that a nanofluid with a 36-nm particle provides higher heat transfer coefficients than a 47-nm particle size. In another experiment, You et al. [36] measured the enhancement of the CHF in pool boiling from a flat square heater immersed in alumina-based water nanofluid in a concentration range of 0 to 0.05 g/l. The test results showed that the enhancement of CHF was drastic when nanofluid was used as a cooling liquid instead of pure water. It was concluded that the increase in CHF levels present the possibility of raising chip power in electronic components or simplifying cooling requirements for space applications. Tzeng dispersed CuO and Al_2O_3 nanoparticles and antifoam, respectively into cooling engine oil for the cooling of automotive transmission. The experimental platform was a four-wheel drive transmission vehicle. It adopts advanced rotary blade coupling (RBC), where a high local temperature occurs easily at high rotating speeds. Therefore, it is imperative to improve the heat transfer efficiency. The experiment measures the temperature distribution of the RBC exterior at four different rotating speeds (400, 800, 1,200, and 1,600 rpm), simulating the conditions of a real car at different rotating speeds and investigating the optimum possible compositions of a nanofluid for higher heat transfer performance. Used Al_2O_3 nanofluid as a coolant in a diesel electric generator. Specific heat measurements of aluminum oxide nanofluid with various particle concentrations were studied and showed that applying nanofluids resulted in a reduction of cogeneration efficiency. This is due to the decrease in specific heat, which influences the waste heat recovery from the engine. However, it was found that the efficiency of waste heat recovery heat exchanger increased for nanofluid due to its superior convective heat transfer coefficient.

Recently, observed the potential of Al_2O_3-H_2O nanofluids as a new phase change material for the thermal energy storage of cooling systems. The thermal response test shows the addition of Al_2O_3 nanoparticles remarkably decreases the super cooling degree of water, advances the beginning freezing time, and reduces the total freezing time. The infrared imaging photographs suggest that the freezing rate of nanofluids is enhanced and by only adding 0.2 wt. % Al_2O_3 nanoparticles, the total freezing time of Al_2O_3-H_2O nanofluids can be reduced by 20.5%. Transformer cooling is important to the Navy as well as the power generation industry with the objective of reducing transformer size and weight. The ever growing demand for greater electricity production can lead to the necessity of replacing and/or upgrading transformers on a large scale and at a high cost. A potential alternative in many cases is the replacement of conventional transformer oil with a nanofluid. Such retrofits can represent considerable cost savings. It has been demonstrated that the heat transfer properties of transformer oils can be significantly improved by using nanoparticle additives the above experimental results demonstrated that alumina-based nanofluids have a significant potential in applications. However, large volumes of nanofluid experiments are lacking in literature. Further, most of the applications are limited to closed loop configuration. A need thus arises to test such fluids with suitable modifications in open loop applications.

VI. CONCLUSION

Alumina-based nanofluids are important because they can be used in numerous applications involving heat transfer and other applications. Most of the Al_2O_3- based nanofluids are prepared by using an ultrasonic vibrator which is not stable for a longer time. Researchers therefore had concentrated on preparing stable nanofluids by using different surfactants, optimizing pH, temperature for different nanofluids, and by surface modification of the particles. The thermal conductivity enhancement observed for Al_2O_3 nanofluid by different researchers is not consistent; the reason for this enhancement is not clear in the available literature. Very few literatures are available on the enhancement of thermal conductivity due to surface area, acidic or basic media, and due to the shape factor. The nanofluids prepared with acidic and basic media may not be useful for the heat transfer application, since it may cause adverse effects on the heat transfer properties. The effect of temperature observed by different authors demonstrates different degrees of enhancement for the same volume fraction. The technique for the measurement of thermal conductivity may also alter the values. The effect of temperature on thermal conductivity at lower volume fractions, which has been measured up to 400 K, has been reported. No work has yet been reported with experiments dealing with the measurement of thermal conductivity at low (sub-zero)-range temperatures. The behavior of the thermal conductivity at low temperatures are yet to be found out and can point a new direction in this field of research.

Very few reports described the effect of temperature on the viscosity at a higher volume fraction and at a higher temperature observing hysteresis phenomenon. The heating phase beyond the critical temperature may become more viscous which indicates a rather drastic alteration of the nanofluid rheological properties leading to hysteresis. Viscosity has raised a serious concern regarding the use of nanofluids for enhancing heat transfer mobility. Researchers can concentrate on the effect of temperature and the hysteresis behavior for Al_2O_3 nanofluids and can try to increase the temperature withstanding capacity of the Al_2O_3 nanofluids. From the observed results, it is clearly seen that nanofluids have a greater potential for heat transfer enhancement and are suitable for application in practical heat transfer processes.

The review has summarized the basics of nanofluid, its preparation methods, and the factors affecting the thermal conductivity enhancement in the Al_2O_3-based nanofluid. It has also identified the areas which require more research for better understanding. The enhancement of thermal conductivity of base fluid will be a definite requirement in the future to improve the thermal efficiency of different systems.

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