Investigation on Al$_2$O$_3$ Nanoparticles for Nanofluid Applications- A Review

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Abstract. A nanofluid is a fluid containing nanometer-sized particles, called nanoparticles. The nanoparticles used in nanofluids are typically made of metals, oxides, carbides, or carbon nanotubes. Nanoparticles are distributed uniformly in a nanofluid, that improve the thermal performance of nanofluids. In this review, authors focused on the effects of Al$_2$O$_3$ metal oxide nanoparticle-water as nanofluids coolant for modern engine. It is observed that enhancement of thermal conductive mostly depends on size of metal oxide nanoparticles-water nanofluids. The major factors which control the thermal conductivity are (a) particle distribution of nanoparticles; (b) concentration of nanoparticles, (c) type of solvents, and (d) temperature and mixture of nanoparticles.

1. Introduction
Ultrahigh-performance cooling is one of the most vital needs of many industrial technologies. However, inherently low thermal conductivity is a primary limitation in developing energy-efficient heat transfer fluids that are required for ultra high-performance cooling. Modern nanotechnology can produce metallic or nonmetallic particles of nanometer dimensions. Nanomaterials have unique mechanical, optical, electrical, magnetic, and thermal properties. Nanofluids are engineered by suspending nanoparticles with average sizes below 100 nm in traditional heat transfer fluids such as water, oil, and ethylene glycol. A very small amount of guest nanoparticles, when dispersed uniformly and suspended stably in host fluids, can provide considerable improvements in the thermal properties of host fluids. Choi et al. [1] describe new class of nanotechnology-based heat transfer fluids that exhibit thermal properties superior to those of their host fluids or conventional particle fluid suspensions which is nanofluids. Nanofluid technology, a new interdisciplinary field of great importance where nanoscience, nanotechnology, and thermal engineering meet, has developed largely over the past decade. The goal of nanofluids is to achieve the highest possible thermal properties at the smallest possible concentrations (preferably<1% by volume) by uniform dispersion and stable suspension of nanoparticles (preferably<10 nm) in host fluids. To achieve this goal, it is vital to understand how nanoparticles enhance energy transport in liquids. In this review article we have described the Al$_2$O$_3$ nanoparticles as major nanofluid materials.

2. Production Techniques
The Al$_2$O$_3$ nanoparticles were synthesised by either top down or bottom up approaches. The top-down approach often uses the traditional workshop or microfabrication methods where externally controlled tools are used to cut, mill, and shape materials into the desired shape and order. Micropatterning
techniques, such as photolithography and inkjet printing belong to this category. Vapour treatment can be regarded as new top-down secondary approaches to engineer nanostructures. Bottom-up approaches, in contrast, use the chemical properties of single molecules to cause single-molecule components to (a) self-organize or self-assemble into some useful conformation, or (b) rely on positional assembly. These approaches utilize the concepts of molecular self-assembly and/or molecular recognition. The Al$_2$O$_3$ nanopowders were suspended at different concentration in water taken from reversed osmosis (Hydrolab Polska). The stabilizers used in the experiments were triammonium citrate, diammonium hydrogen citrate, sodium hexametaphosphate (SHMP), sodium dodecyl benzene sulfonate (SDBS), acetic acid and formic acid. Nanopowders were mixed with water and stabilizers and then sonicated by ultrasonic mixer Sonix VCX 130 (20 kHz, 130 W) with amplitude of 123 μm a set period of time. For selected samples extended preparation procedure was performed for 3 days and three consecutive sonications nanofluid was mixed for a day. For the best samples PSD (Malvern Zetasizer Nano S90) and zeta potential (Malvern Zetasizer Nano Z) analyses were performed.

3. Key Findings

The thermal conductivity of Al$_2$O$_3$ nanoparticles–water nanofluids were characterized by various research groups. Das et al.[2] investigated temperature dependent Al$_2$O$_3$–water nanofluids. Choi et al.[1] investigated particles size dependent of thermal conductivity of Al$_2$O$_3$ nanoparticles water nanofluid. As the size of Al$_2$O$_3$ nanoparticles-water nanofluids decreases, there will be considerable improvement in thermal conductivity. This may be due to enhancement of heat exchange among the nanoparticles in the nanofluids [3]. J.P Jang et al.[4] investigated Brownian motion of nanoparticles at the molecular and nanoscale level is a key mechanism governing the thermal behavior of nanofluids. The concentration and temperature-dependent conductivity, but also predicts strongly size-dependent conductivity in Al$_2$O$_3$ nanoparticles-water nanofluids. Furthermore, we have discovered a fundamental difference between solid/solid composites and solid/liquid suspensions in size-dependent conductivity Akshay Kumar Surana et al.[5] investigated on Numerical Investigation of Shell and Tube Heat Exchanger Using Al$_2$O$_3$ Nanofluid, they found the effect of number of tubes, unequal baffle spacing and tube diameter on heat transfer and pressure drop characteristics of a typical shell and tube type heat exchanger.

![Figure 1: Temperature dependent Al$_2$O$_3$–water nanofluids](image)

Behrouz Raei et al.[6] investigated on experimental study on the heat transfer and flow properties of ψ-Al$_2$O$_3$/water nanofluid in a double-tube heat exchanger, they found that for high-temperature, high-pressure applications double-tube heat exchanger is used due to their relatively small diameters. Its an experimental study performed to investigate the effects of ψ-Al$_2$O$_3$/water nanofluid on the hydrodynamics and convective heat transfer of a counter flow double-tube heat exchanger.
Fu et al. [7] investigated on evaporation of Al₂O₃-water nanofluids in an external micro-grooved evaporator, they found the importance of the duration of ultrasonication on the stability of nanofluids. This experiment concludes that longer duration of ultrasonication does not necessarily represent a better stability of nanofluids instead excessive duration of ultrasonication may cause adverse effect on producing a homogenous nanofluid. Azmi et al. [8] investigated on forced convection heat transfer of Al₂O₃ Nanofluids for different based ratio of water: ethylene glycol mixture, they found that nanofluids are used to improve the efficiency of the cooling system by minimizing the energy waste. This paper aims to investigate the forced convection heat transfer for Al₂O₃ nanofluids in different based ratio of water (W) and ethylene glycol (EG) mixture. Esfe et al. [9] investigated on the numerical study of laminar-forced convection of Al₂O₃-water nanofluids between two parallel plates, they found that laminar-forced convection of Al₂O₃-water nanofluid between two parallel plates was studied numerically. The channel walls were assumed to be isothermal. The effective viscosity and thermal conductivity of nanofluid were considered as variables, and the effects of applying a variable properties model were investigated by using two relatively new models. Choudhary et al. [10] investigated on stability analysis of Al₂O₃/water nanofluids, they found that the stability is investigated with the help of zeta potential and visual inspection methods. Detailed study has been done on the effects of pH and sonication time for the stability of nanofluids. For calculating the stability period of nanofluids visual inspection method is used. Karimzadehkhouei et al. [11] investigated on the effect of γ- Al₂O₃ (gamma-alumina) nanoparticles with an average solid diameter of 20 nm was considered. Nanoparticles were added to distilled water (base fluid) at five mass fractions (low mass fractions 0.05 wt.% and 0.2 wt.%; high mass fractions 0.5 wt.%, 1 wt.% and 1.5 wt.%). The results of dynamic light scattering (DLS) measurements for a dilute sample with mass fraction of 0.05 wt.% revealed that the hydrodynamic diameter of dispersed nanoparticles in the nanofluid remained approximately the same for the samples before and after the experiments.

![Figure 2: Temperature dependent thermal conductivity of Al₂O₃-water nanofluid of various particle sizes [3].](image)

Manetti et al. [12] investigated on the heat transfer coefficient during pool boiling of DI water and Al₂O₃-water based nanofluid at saturation conditions. Different volume concentrations (0.0007 vol.% and 0.007 vol.%, corresponding to low and high nanofluid concentration, respectively for the Al₂O₃ base nanofluid. The nanoparticle average size was 10 nm and the applied heat flux ranged from 100 to 800 kW/m², they found that increase in the heat transfer coefficient up to 75 %, and 15% for the smooth and rough surfaces, respectively, in comparison to that of DI water. The use of nanofluids is effective on pool boiling heat transfer, for moderate heat flux and low volumetric
concentration. Mehryan et al. [13] investigated on the free convective heat transfer of the 33 Al₂O₃-Cu water hybrid nanofluid in a cavity filled with a porous medium. Two types of important porous 34 media, glass ball and aluminum metal foam are considered for poros matrix, they found that enhancement in the thermal conductivity and dynamic viscosity of the synthesized 36 hybrid nanofluids. the average Nusselt number Nul is decreasing function of the volume fraction of nanoparticles and also reduction of heat transfer using nanoparticles in porous media. Moghadam et al. [14] investigated on an inclined three-dimensional nanofluid based tube-on-sheet flat plate solar collector (FPSC) in numerically modelled manner. They concluded that the working fluid was alumina/water (Al₂O₃/water) and it showed that the Nusselt number, the ratio of convection to conduction heat transfer, increases with an increase in the Reynolds number while it decreases as the Richardson number and volume fraction increases. Additionally, with enhancement of Al₂O₃, volume concentration weakens the effect of natural convection heat transfer and suppresses the only thermal plume existing inside the riser directed from upper side to the lower side of the riser and 58%-45% increase in the heat transfer coefficient is achieved when alumina/water nanofluid is utilized in comparison with pure water.

![Temperature-dependent thermal conductivity of nanofluids](image)

Figure 3: Temperature – dependent thermal conductivity of nanofluids of Al₂O₃ nanoparticles and Cu nanoparticles [4].

Chougule et al. [15] investigated on the laminar forced convection of Al₂O₃/water and multiwall carbon nanotubes (MWCNT)/water nanofluids through uniformly heated horizontal circular pipe with helical twisted tape inserts. Founders concluded that the use of helical screw tape inserts (HI) in plain tube causes intensification in heat transfer with a significant increase in pressure drop. The friction factor with helical inserts was found to be higher compared to the values obtained for the plain tube and increases with the decrease in twist ratio (TR). The Nusselt number is found to be higher compared to the plain tube for a given Peclet number. The enhancement in Nusselt number decreases with the increase in Peclet number and increases in the TR. The enhancement in heat transfer of MWCNT/water nanofluids is found to be higher compared to Al₂O₃/water nanofluids. The Nusselt number increases with the increase in Reynolds number and nanoparticle concentration. The HI give better thermal performance when used with the MWCNT/water nanofluid than with Al₂O₃/water nanofluid and the thermal performance factor using the MWCNT/water nanofluid is higher than the corresponding value using Al₂O₃/water for all twist ratios involved in this study. Zhao et al. [16] investigated on the thermal conductivity and viscosity of alumina (Al₂O₃)-water nanofluids, using an artificial neural network (ANN) approach. They concluded that both nanoparticle’s volume fraction
and temperature could enhance the thermal conductivity of Al₂O₃-water nanofluids. However, the viscosity only depended strongly on Al₂O₃ nanoparticle volume fraction and was increased slightly by changing temperature. In addition, the comparative analysis revealed that the RBF neural network had an excellent ability to predict the thermal conductivity and viscosity of Al₂O₃-water nanofluids with the mean absolute percent errors of 0.5177% and 0.5618%, respectively. Xie et al. [17] investigated on the intensification effect of Al₂O₃/water nanofluid used as the spray fluid on the thermal performance of counter flow closed wet cooling towers (CWCTs). Researchers found out that the thermal conductivity, density, and viscosity of Al₂O₃ nanofluids increased with the increase of mass fraction. The maximum mass transfer coefficient was found to be 0.16 kg·m⁻²·s⁻¹ for 0.5 wt % nanofluids and spray mass flow rate of 0.278 kg·s⁻¹. Moreover, the heat transfer capacity of the CWCT spraying 0.5 wt % Al₂O₃ nanofluid could reach 1.22 times that of the water case, while the water consumption reduced about 15% under the same heat transfer capacity. The Al₂O₃ nanoparticles enhanced the heat transfer and mass transfer in CWCTs; especially the heat transfer coefficient, mass transfer coefficient, and cooling efficiency were the highest at 0.5 wt %, which are 20, 17, and 19% higher than those of the water case, respectively. Khairul et al. [18] investigated on Al₂O₃/DI-water and CuO/DI-water nanofluids with three different nanoparticles weight concentrations under three different turbulent flow regimes. They observed that both Al₂O₃/DI-water and CuO/DI-water nanofluids showed a noticeable rise in heat transfer coefficient in comparison to the DI-water for all flow regimes (laminar, transitional and turbulent). The friction factor was decreased as either the Reynolds number as well as weight fraction of nanoparticles in the nanofluids increased. Pumping power was also increased with the increment in nanoparticle weight concentrations due to higher viscosity. Goudarzi et al. [19] investigated on heat transfer, friction factor and thermal performance factor characteristics of car radiator with coil wire inserts and Al₂O₃ nanofluid. It was observed that Nusselt number at Reynolds number in the range of 18500<Re<22700 with coil inserts was higher compared to EG without tube inserts. Nusselt number at Reynolds number of 18500 with the coil wire inserts (TIT1, TIT2 and TIT3) and the volume concentrations of 0.08%, 0.5% and 1% for the different fan speed in the range of 750<N<1220 increased with increasing speed of cooling fan. Friction factor at Reynolds number in the range of 18500<Re<22700 with the coil wire inserts (TIT1, TIT2 and TIT3) and the volume concentrations of 0.08%, 0.5% and 1% is higher compared to EG as base fluid. Prasanth Anand Kumar Lam et al. [20] investigated on effect of magnetic field on natural convection of Al₂O₃/water nanofluid in an enclosure containing twin protruding heat sources placed on top and bottom walls arranged in-line and staggered manner. Researchers concluded that for both in-line and staggered arrangement, average Nusselt number along global total entropy generation and average Nusselt number along top and bottom heat sources was obtained with increasing Ha and increasing Ra. Furthermore, for both in-line and staggered arrangement, variation in global total entropy generation and average Nusselt number along top and bottom heat sources with increasing nanoparticle volume fraction, depend on both Ha and Ra. Rahman et al. [21] investigated on the elucidate thermal behavior of hybrid nanofluids consisting of Al₂O₃ and Cu nanoparticles at ratio of 90:10 was conducted. It is found that the dominant nanoparticle in the hybrid nanofluids strongly influences the thermal behaviour of the hybrid nanofluids, and the heat transfer coefficient increases as the volume concentration of the hybrid nanoparticle increases in base fluids and the Reynolds number. Tang et al. [22] evaluate the overall heat transfer coefficient through an experimental analysis on the convective heat transfer and flow characteristics of a nanofluid. In this experiment, the nanofluid consists of water and one percentage volume concentration of Al₂O₃-water nanofluid flowing through parallel and counter flow in shell and tube heat exchangers. About 50 nm diameter of Al₂O₃ nanoparticles was used in this analysis and found that the overall heat transfer coefficient and convective heat transfer coefficient of nanofluid were slightly higher than those of the base liquid at same mass flow rate and inlet temperature, they found that the enhancement of overall heat transfer coefficient is likely to be feasible by means of increasing the mass flow rate of base fluid. The thermal conductivity and viscosity of the nanofluid increased through the scattering of Al₂O₃ nanoparticles whereas entropy generation and average Nusselt number along top and bottom heat sources was obtained with
nanoparticles presented in the water. Pourfattah et al. [23] investigated on the flow and heat transfer characteristics of the turbulent flow in the tube and the effect of attack angle of ribs and Al₂O₃ nanoparticle on the heat transfer enhancement, they found that the existence of ribs with the creation of eddy on the direction of flow causes better mixture of flow and consequently, heat transfer increases and adding nanoparticles to the base flow causes more augment of heat transfer. Using rib with angle of attack 90° inside the tube is suggested to improve the heat transfer without considering the applied pressure drop. The ratio of heat transfer enhancement to the applied pressure drop in the rib with attack angle of 60° is maximum. Mehrali et al.[24] investigated on heat transfer and entropy generation analysis of hybrid graphene/Fe₃O₄ ferro-nanofluid under the influence of a magnetic field, they found that the heat transfer characteristics and entropy generation Al₂O₃ rate of hybrid graphene-magnetite nanofluids under forced laminar flow were investigated. For this purpose, a nanoscale reduced graphene oxide-Fe₃O₄ hybrid was synthesized by using graphene oxide, iron salts and tannic acid as the reductant and stabilizer. Sekhar YR, et al. [25] researched on the viscosity and specific heat capacity characteristics of water-based Al₂O₃ nanofluids at low particle concentrations in which surfactant is used and magnetic stirring is done for 5 hours. Concentration of Al₂O₃-water used is 0.01-1% vol. Pranit Satish Joshi et al. [26] investigated on enhancement of natural convection heat transfer in a square cavity using MWCNT/Water nanofluid. They found out that MWCNT/Water nanofluid when compared with Al₂O₃/Water nanofluid yielded higher values of the Nusselt number for a given volume fraction. Factors such as percolation network in MWCNT/Water nanofluid which increases the heat transfer pathway between two walls and the role of slip mechanisms were the reasons for the enhancement.

4. Conclusion
In this review, Al₂O₃ metal oxide nanoparticle-water is described as nanofluids coolant for modern engine. The enhancement of thermal conductive mostly depends on size of metal oxide nanoparticles-water nanofluids. The major factors which control the thermal conductivity are (a) particles distribution of nanoparticles; (b) concentration of nanoparticles, (c) type of solvents, and (d) temperature and mixture of nanoparticles. This review suggest smaller Al₂O₃ nanoparticles with higher concentration of 4% is very useful for nanofluid applications.

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