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Metal and oxide form of nanoparticles heat transfer in radiator: A review

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Abstract
The increasing demand of nanofluids in cooling applications has led to increased attention from many researchers. This increased thermo physical properties of nano particle can be applied for better performance in energy, heat transfer and other performance. In this paper a survey of heat transfer enhancement through oxide form of nanoparticle and metal form of nanoparticle is done and the results are interesting that nanofluids enhances the heat transfer rate in all heat exchangers. Radiators are compact heat exchangers optimized and evaluated by considering different working conditions. The cooling system of a car plays an important role in vehicle's performance, consists of two main parts, known as radiator and fan. Improving thermal efficiency of engine leads to increase the engine's performance, decline the fuel consumption and decrease the pollution emissions. Effects of fluid inlet temperature, the flow rate and nano particle volume fraction on heat transfer are considered. Results show that there is increased thermal conductivity with increases in volume fraction of nanoparticle. The results also says that there is increased heat transfer rate in metal form of nanoparticle compared with the oxide form is noted. Comparing with conventional fluids the nanofluids either metal or oxide form has enhanced heat transfer rate. Through this survey the importance of nano sized in heat transfer is understood and the reason behind the enhanced heat transfer the mechanism given by various researchers is also compiled even though there is no clear definition towards the nano particle heat transfer. The results of heat transfer in radiator by various nanofluid also suggest that there is improved heat transfer rate. The enhanced heat transfer principle of nano sized particle also favours for the miniaturization of the heat exchangers especially like radiators.

Keywords: nanofluids, oxide nanoparticle, metal nanoparticle, thermal conductivity, heat transfer rate

Introduction
The main reason solid particles less than 100 nm are added to a liquid is to improve its thermal properties; this new fluid is then defined as a nanofluid. Solid metallic or nonmetallic materials dispersed in base fluids such as water, ethylene glycol and glycerol have become a topic of interest in recent years [1, 7]. The particle may be either metal or metal oxide which increases conduction and convection of heat transfer coefficient, when compared with coolant [8].
There are various applications of thermo fluid systems, including automotive cooling systems [8, 9]. Base fluids (water, ethylene glycol and glycerol) have been used as conventional coolants in an automobile radiator for many years; however, these offered low thermal conductivity, which has prompted researchers to find fluids that offer higher thermal conductivity compared to that of conventional coolants. This resulted in nanofluids being used instead of these base fluids [10, 11]. Forced convection heat transfer to cool circulating water from an automobile radiator was carried out by Peyghambarzadeh *et al.* [12]. The effects of different amounts of Al2O3 nanoparticles on the heat transfer performance of the automobile radiator were determined experimentally. The range of flow rate changed from 2 to 6 LPM with the changing inlet temperature of the fluid for all the experiments. The results showed a 40% increase in heat transfer by nanofluids compared to water. A numerical study of laminar heat transfer (CuO and Al2O3) with ethylene glycol and water inside the flat tube of a car radiator was carried out by Vajjha *et al.* [13].
Serrano *et al.* [15], provided excellent examples of nanometer in comparison with millimeter and micrometer to understand clearly as can be seen in Fig. 1 Nanofluids are defined as suspension of nanoparticles in a base fluid. Some typical nanofluids are ethylene glycol based copper nanofluids and water based copper oxide nanofluids, Nanofluids are dilute suspensions of functionalized nanoparticles composite materials developed about a decade ago with the specific aim of increasing the thermal conductivity of heat transfer fluids, which have now evolved into a promising nanotechnological area. Such thermal nanofluids for heat transfer applications represent a class of its own difference from conventional colloids for other applications. Compared to conventional solid–liquid suspensions for heat transfer intensifications, nanofluids possess the following advantages [14].

- Increased surface area therefore more heat transfer surface between particles and fluids
- High dispersion stability with predominant Brownian motion of particles.
- The pumping power is reduced as compared to pure liquid due to heat transfer intensification
- There is no particle clogging compared to conventional slurries which results in system miniaturization
- Adjustable properties, including thermal conductivity and surface wettability, by varying particle concentrations to suit different applications.

Nanotechnology is being used or considered for use in many applications targeted to provide cleaner, more efficient energy supplies Examples of how nanotechnology may be integrated into each of these technological areas are highlighted in the following specific applications [14, 16, 17] and uses. Engine cooling, Engine transmission oil, In diesel electric generator as jacket water coolant, Boiler exhaust flue gas recovery, Heating and cooling of buildings, Cooling of electronics, Cooling of welding, Nanofluids in transformer cooling oil, Nuclear systems cooling, Solar water heating, Nanofluids in drilling, Refrigeration (domestic refrigerator, chillers), Defense, Space, High-power lasers, microwave tubes, Biomedical applications, Drilling, Lubrications, Thermal storage, Drag reductions.

Recent researches have indicated that substitution of conventional coolants by nanofluids appears promising in Automobile radiator. Nanofluids have great potential to improve automotive and heavy–duty engine cooling rates by increasing the efficiency, lowering the weight and reducing the complexity of thermal management. Alternatively, it is beneficial to design more compact cooling system with smaller and lighter automobile radiators

There are many researches on the enhanced heat transfer characteristics of nanofluids especially on thermal conductivity and convective heat transfer. Eastman *et al.* [18]. Liu *et al.* [19]. Hwang *et al.* [20]. Yu *et al.* [21] and Mintsa *et al.* [22], observed great enhancement of nanofluids' thermal conductivity compared to conventional coolants. Enhancement of convective heat transfer was reported by Zeinali Heris *et al.* [23], Kim *et al.* [24], Jung *et al.* [25] and Sharma *et al.* [26]. Applications of nanofluids in industries such as heat exchanging devices appear promising with these characteristics. However, the development and applications of nanofluids may be hindered by several factors such as long term stability,

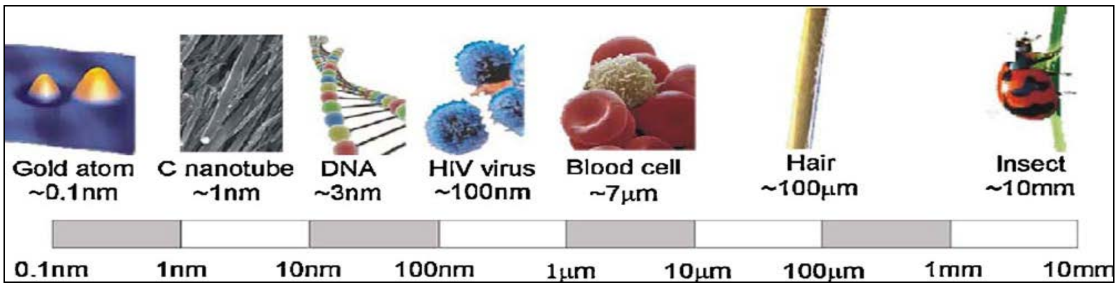

Fig 1: Length scale and some examples related [15].

Increase pumping power and pressure drop, nanofluids' thermal performance in turbulent flow and fully developed region, lower specific heat of nanofluids and higher production cost of nanofluids.

In the review on thermal and rheological properties, different modes of heat transfer including boiling one have been reported by many researchers. However, to the best of authors' knowledge, there is no comparative survey on the oxide and metal form of nano particle has been done surely this will help many researchers in selecting the nanoparticle while heat transfer projects. And also we suggest to improve the performance of the nanoparticle in future.

Nano fluids Heat Conductivity

It represents the ability of material to conduct or transmit heat. Considerable researches have been carried out on this topic. Eastman *et al.* [27], found that thermal conductivity of 0.3% copper nanoparticles of ethylene glycol nanofluids is increased up to 40% compared to basefluid. Liu *et al.* [28], investigated the thermal conductivity of copper–water nanofluids produced by chemical reduction method. Results showed 23.8% improvement at 0.1% volume fraction of copper particles. It is also noted that thermal conductivity increases with particles volume fraction but decreases with elapsed time. Hwang *et al.* [29], suggested that thermal conductivity enhancement of nanofluids is greatly influenced by thermal conductivity of nanoparticles and basefluid. For instance, thermal conductivity of water based nanofluids with multiwalled carbon nanotube have noticeably higher thermal conductivity compared to SiO2 nanoparticles in the same basefluid. However, Yoo *et al.* [30], argued that surface to volume ratio of nanoparticles is a dominant factor that influences the nanofluids thermal conductivity rather than nanoparticles thermal conductivity. Surface to volume ratio is increased with smaller sizes of nanoparticles.

The researchers says that thermal conductivity increases compared to basefluids. Its value increases with particles concentration. Temperature, particles size, dispersion and stability do play important role in determining thermal conductivity of nanofluids [31] Figs. 2 and 3 show the thermal conductivity of nanofluids at different temperatures.

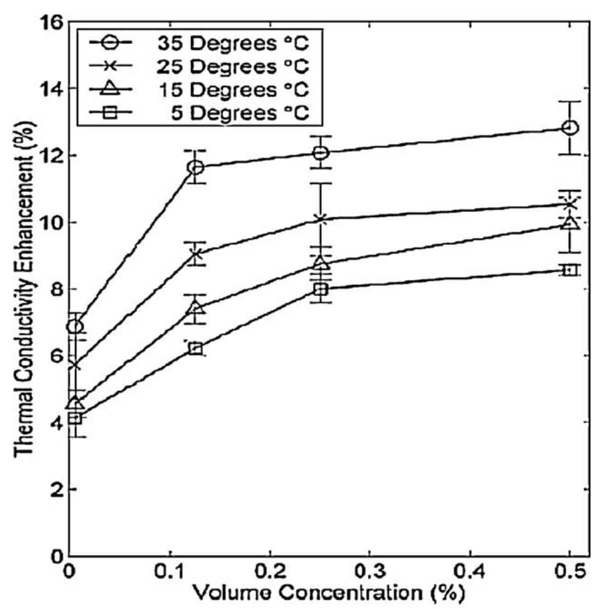

Fig 2: Thermal conductivity enhancement of 2 nm gold nanoparticle in water as a function of volume concentration [44].

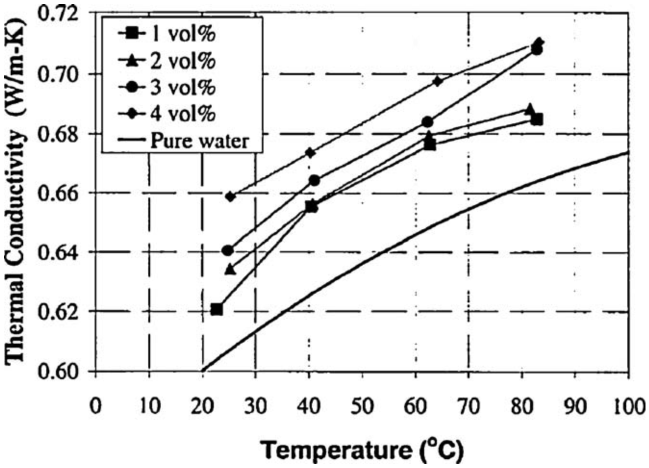

Fig 3: Thermal conductivity with temperature [43]

The tribological properties also been improved by the nanoparticle additives (MoS2, CuO, TiO2, diamond, etc.).The nanoparticle shows improved wear resistance, load carrying capacity [32, 33]. This properties made nanofluids very attractive in lubricating application in many industries including manufacturing, transportation, energy, and electronics, etc.

Heat transfer improvement by Oxide form of nanoparticle

This was the first type of nanoparticle investigated for improved performance. First conductivity in fluids which contained Al_2O_3 and CuO nanoparticle in water and ethylene glycol was the major publication [34]. Conductivity was measured by the traditional transient hot-wire (THW) method. The results indicated the thermal conductivity enhancemet of the Al2O3 and CuO nanofluids were high. They used volume fractions of only 1– 5%. The enhancement was higher when ethylene glycol was the base fluid.

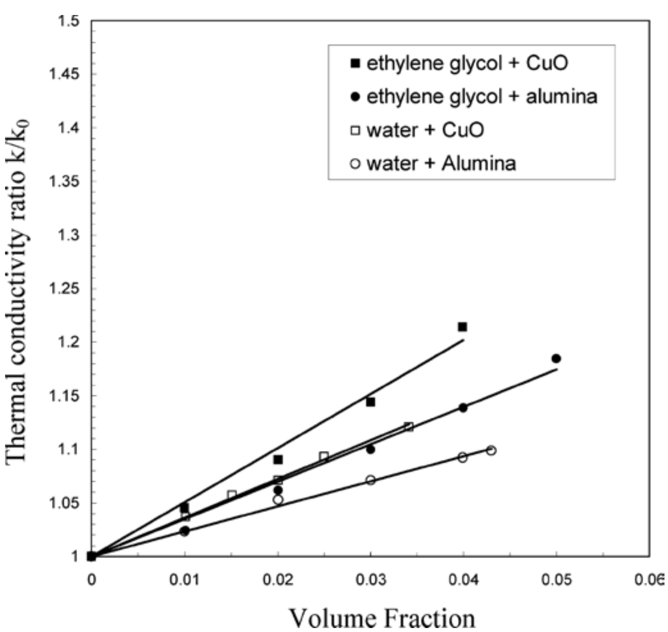

Fig 4: Enhanced thermal conductivity of oxide nanofluids systems as measured by Lee *et al.* [31]. *k/ko* denotes the ratio of thermal conductivity of nanofluid to that of the base fluid.

An enhancement of 20% was observed at 4% volume fraction of CuO. The enhancement when water was the base fluid was lower but still substantial, with 12% enhancement at 3.5% CuO, and 10% enhancement with 4% Al2O3. The results of improved thermal conductivity is shown in Fig 4. Maxwell [35] showed a still improved thermal conductivity which was again improved in 1962 [36]. These increase in heat transfer is due to the effect of particle shape. These models predict the effective thermal conductivity as essentially a weighted average of solid and liquid conductivity derived from a point source method.

Thus, it has been generally found that oxide ceramic particles, which themselves do not exhibit very high thermal conductivity, can enhance the thermal conductivity of fluids in nano suspensions. The main reason for the many studies on oxide particle-based nanofluids is the availability of oxide nanoparticles. Murshed *et al.* [37], who measured the thermal conductivity of aqueous solutions of spherical and cylindrically shaped TiO2 nanoparticles, found that 15 nm-sized spherical particles show slightly less enhancement than 10 × 40 nm rods, which showed an enhancement of 33% for a volume fraction of 5%. However, the enhancement was far more than that predicted by the Hamilton-Crosser model. Another feature brought out in this work was the nonlinear dependence of enhancement in thermal conductivity on particle concentration at lower volume fractions.

Metallic nanoparticle in heat transfer enhancement

The copper metallic nanoparticle was first used by Xuan and Li [19] in the transformer oil. This was the big step forward. They used a copper particle-based nanofluids of transformer oil of (∼100 nm) the enhancement reported was 55% with 5% volume fraction.

Then ANL group reported a 40% enhancement of conductivity with only 0.3% concentration of 10 nm-sized copper particles suspended in ethylene glycol [35]. This report clearly showed the particle size effect and the potential of nanofluids with smaller particles. The nanofluids were stabilized with thioglycolic acid. Figure 5 shows the measured values of thermal conductivity for Cu–ethylene glycol nanofluids. In another study, Patel *et al.* [40] used gold and silver for the first time to prepare nanofluids. They also used a transient hot wire method for measuring thermal conductivity. The most important observation in their study was a perceptible enhancement in thermal conductivity for vanishingly small concentrations. It was reported that at room temperature, the conductivity of toluene-gold nanofluid was enhanced by 3–7% for a volume fraction of only 0.005–0.011%, whereas the enhancement for water–gold nanofluid was 3.2–5% for a vanishingly small concentration of 0.0013–0.0026% volume fraction. The main reason for such an enhancement was the small size (∼10–20 nm) of the particles. The enhancement was greater with water-based nanofluids because bare particles were used, and was lower for toluene-based nanofluids where the nanoparticles were protected by a layer of thiolate coating, which was used to prevent agglomeration. Another important observation of their study was the relatively lower conductivity of water–silver nanofluids. It clearly showed that even though silver is higher in conductivity, it provided less enhancement because its size was relatively larger (~60–80 nm). This finding indicates that particle size can override the particle conductivity or concentration effects.

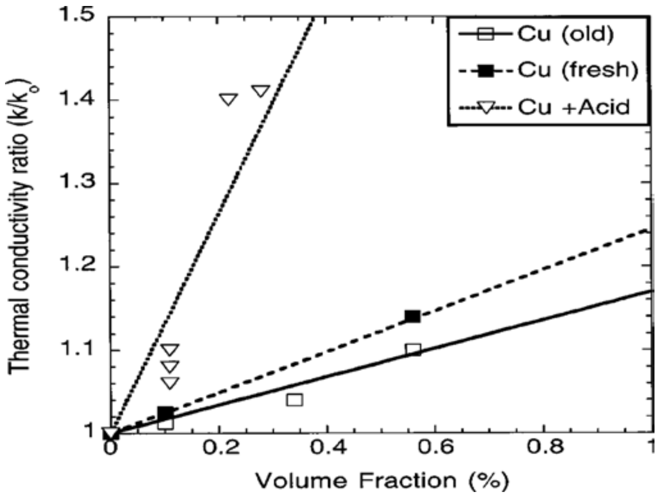

Fig 5: Thermal conductivity enhancement for various nanofluids [35].

Xie *et al.* [41] studied the dependency of thermal conductivity of nanoparticle–fluid mixtures on the base fluid. These investigators studied nano-sized α-Al2O3 dispersed in deionized water, glycerol, ethylene glycol, pump oil, ethylene glycol-water mixture, and glycerol-water mixture. It was found that thermal conductivity ratios decrease with the increased thermal conductivity of the base fluid.

Hong *et al.* [42] achieved an enormous increase in the thermal conductivity of nanofluids of 10 nm-sized Fe nanoparticles suspended in ethylene glycol. They obtained an enhancement of 18% with just 0.55% volume fraction. They also showed that the sonication of the nanofluid has an important effect on the thermal conductivity of nanofluid, indirectly proving the effect of particle size on the thermal conductivity of nanofluid.

Ollivier *et al.* [43] found that the use of the nanofluids leads to increased thermal signal variations by around 15% over that predicted using water alone. Authors employed a CFD numerical simulation method to analyze the application value of nanofluids in engine cooling. The simulation results indicated that nanofluids could enhance engine heat dissipating capacity and Cu–water nanofluids had better heat-transfer capability. It was also found that the more concentrations of the nanoparticles, the more enhancement of the engine heat dissipating capacity. When the concentration reached 5%, the heat dissipating capacity increased by 44.1%. With a remarkable enhancement on heat-transfer capability, the workload of the pump of engine cooling system only increased by 6%, which could be acceptable.

Experimental studies in the convective heat transfer of nanofluids are needed. Many issues, such as thermal conductivity, the Brownian motion of particles, particle migration, and thermo physical property change with temperature, must be carefully considered with convective heat transfer in nanofluids. Though, all the convective studies have been performed with oxide particles in high concentrations (for example Pak and Cho [44] used 10 vol. % of Al2O3 which increased the viscosity and pumping power of the fluid, it is interesting to know the energy transport in low concentration (<1 vol.%) nanofluids with metallic particles since the thermal conductivity of pure metallic nanoparticles is more than 100 times higher than that of the oxide nanoparticles.

Effect of nanoparticle material

Many reports show that the k enhancement of nanofluid is higher when the suspended nanoparticles have higher k [67, 69, 95, 143, 170] whereas some reports show that the k of nanoparticles is not a principal factor related to k of nanofluids [17, 19, 31, 72, 95, 97]. Thermal conductivity studies done on water, EG and transformer oil based Cu, CuO, Al and Al2O3 nanofluids show high k enhancements for metallic nanofluids compared to oxide nanofluids [69]. In a recent report the effect of nanoparticle species on k was studied by using alumina, copper oxide, and a 1:1 mixture of alumina and copper oxide nanoparticles dispersed in ethylene glycol. The results show a high k for CuO nanofluids compared to alumina nanofluid, which has a lower k. In addition, the k of 1:1 mixture of alumina and copper

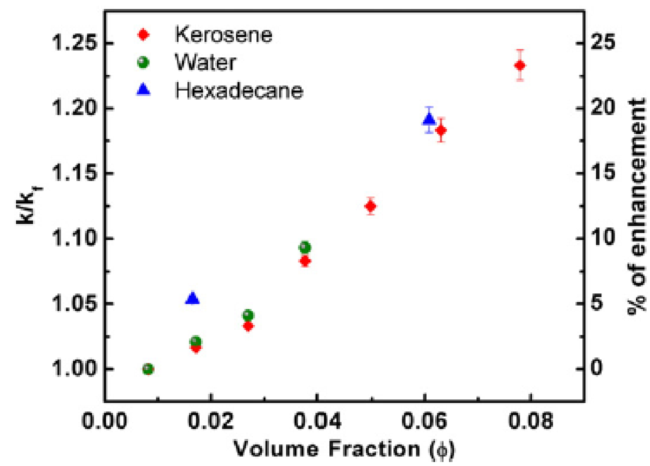

Fig 6: The variation of k/kf as a function of ϕ for Fe3O4 nanofluids with particle size 6 nm in different base fluids of kerosene, hexadecane and water [45].

Oxide in EG lies in between those two nanofluids at higher concentrations [67]. For 1.0 vol. % Cu (20 nm) nanofluids, the k enhancement was in the range 48–70%, while it was around 21–33% for 1.0 vol.% of Fe (10 nm) nanofluids [35]. Studies on Al2O3 and Cu nanofluids show a high k enhancement for water based Cu nanofluids compared to water based Al2O3 nanofluids, which was attributed to the higher k of copper nanoparticles [170]. For a particle loading of 0.3 vol.%, Fe nanofluid showed 16.5% k enhancement whereas WO3 nanofluid showed only 13.8% k enhancement [95]. Among water based CuO, SiO2 and MCNT nanofluids, MWCNT nanofluid showed the highest k and SiO2 nanofluid showed the lowest k. These results show that the k enhancement of nanofluid was higher when the suspended nanoparticles have higher k [143].

Conclusions

- The nanoparticle in base fluid has contributed for the heat transfer improvement through various nanomechanism identified. And these nanomechanism are still under research for proving matahematically. The experimental results shows that the nanofluids has important role in the cooling and related technologies.

- While comparing the conventional fluids there is significant increase in the heat transfer performance of the nanofluids either in metal or its oxide form.
- The metal form of nanoparticle in base fluid shows enhanced heat transfer compared with oxide form of nanoparticle from review results. It also reveals that as the nanoparticle size increases there is decrease in heat transfer performance.
- Though there is different nanofluid heat transfer mechanism the concept of nano-convection of fluid around the particles due to their motion. In this concept, the particles move randomly and hit the walls of heat exchangers for contribute to the total heat transfer through agitation in the liquid this is known as Brownian motion. From a physical point of view, this phenomenon seems to be a potential explanation for the behavior of nanofluids.
- The thermal conductivity of nanofluid is higher when the particle thermo physical properties is high whether it may be oxide or metal form.
- The enhanced thermal performance of nanofluids in especially in radiator heat exchanger contributes for the miniaturizing the power plant of the automotive system.
- The nanoparticle taken for research is limited with few of the materials for both the oxide and metal form and new material has to be taken for nanofluid with subject to heat transfer application.

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