Application of Nanofluids as Automobile Radiator Coolants - A Review

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***Abstract*— Nanofluids have been demonstrated to enhance the thermal properties of base fluids. Through the last two decades, researchers have shown that adding nanoparticles to existing coolant fluids can enhance their heat transfer performance. Conventionally water and ethylene glycol are used as engine radiator coolants. The addition of ethylene glycol is needed to increase the boiling point of the coolant and decrease the freezing point. This is a requirement for vehicles that are being used under harsh weather conditions. The downside of this is a loss in thermal conductivity and hence loss in efficiency of the vehicle.**

Nanofluids have found great many applications in the past decade. As many researchers have shown, they can be used to enhance radiator performance as well. In this review paper, studies of heat transfer performance of various Nanofluids as engine coolants conducted by researchers are studied. Finally, a conclusion is presented.

***Index Terms*— Enhancement, heat-transfer, nanofluids, nanoparticles, radiator.**

1. INTRODUCTION

With ever-increasing global competition, companies are always on the edge to produce the most efficient product. In many industries, an efficient heat exchange system is very important to its proper functioning. Heat transfer is important in many sectors, including the automotive industry, chemical industry, food processing industry and many other industries. Also, heat transfer systems are paramount in consumer products like vehicles, electronics and heating and cooling equipment's. Thermal conductivity of heat transfer fluids is an influential factor in the development of heat transfer systems, like engine radiators. Nanofluids, a suspension of Nano-sized particles in a base fluid, are a new class of hotly researched fluids because of their enhanced thermal and physical properties. Adding metallic particles in a fluid can increase properties like thermal conductivity by as much as 3 to 4 times. Although research on this has been going on from the time of Maxwell in 1881, recent advances in this field have been achieved by the advent of nanomaterials and nanoparticles. One such work, published by Masuda et. al., 1993[2]reports that they have been able to alter the thermal conductivity and viscosity of fluids by adding ultra-fine particles in the fluid.Nanofluid is a term coined by Choi and Eastman [3]in their research paper published in 1995, where they report that adding nanoparticles in a base fluid can largely enhance thermal conductivity. They also concluded that Nanofluids could result in lowering the pumping power of cooling systems to achieve higher heat transfer by a big margin. Following this, many researchers[4-8, 10, 38]have shown that Nanofluids show enhanced thermal conductivity as compared to base fluids. There are many review papers published on this [11-13, 17]. Because of their advantages, Nanofluids have found many applications quickly, as heat transfer fluids in a large number of industries, due to increased thermal conductivity, as lubricants in machinery, due to the increased viscosity, as storage systems in electronics, as drug delivery agents, in aiding surgery, and also as energy storage systems[13, 14, 20, 21, 24, 28, 37].

The purpose of this review paper is to highlight the importance of Nanofluids and to give an overview of the latest state of research conducted in using Nanofluids as coolants in vehicle radiators.

II. PREPARATION OF NANOFLUIDS AND FACTORS AFFECTING THEIR PROPERTIES

The different ways of preparation of Nanofluids are well documented in literature. The two well-reported methods are the one-step-method and the two-step-method.

In one of the first ever papers on Nanofluids, Choi et. al. [3]discuss three existing methods to produce nanophase materials which have the potential to cause the particles to agglomerate while in Nanofluid form. They discuss a fourth method, by Akoh et. al.[1] in which the nanoparticles are already present in a base fluid. According to the authors, this is a promising technique to produce Nanofluids.

The two-step method is the more widely used method[18]. In the two-step method, the required nanomaterial is produced in the first step by chemical or physical methods. In the second step these nanomaterials are mixed with the base fluid[18, 39]. Nanoparticles are mainly mixed by sonication, magnetic agitation, homogenizing or high-shear mixing. This method is more widely chosen as it is more economical since the desired nanoparticles are easily available in the market.Sidik et. al.[25] discuss the challenges of Nanofluids, which mainly are long-time stability, higher viscosity of the fluid, pressure drop developed during the flow, cost of Nanofluids and the inconsistency in the results of researchers and also among their own experiments. While applying surfactants is one solution for agglomeration, it can cause reduction in thermal conductivity[18].

The one-step method was developed by Akoh et. al. in 1978[1], which involves condensing nanophase powders from the vapour phase directly into a flowing low vapour pressure fluid. This method was also tested and reported to be better than the two-step method by Eastman et. al in 2001[6]. They also report that this method has better dispersion characteristics than two-step method. But this method is not widespread as it can be applied only on low-vapour pressure fluids and also it is not proper for mass production [41].A detailed method of production by the one-step method is given by Wei & Xu[18].

Factors affecting the properties of Nanofluids are widely covered in literature. Choi et. al.[9] published a paper where they concluded that the volume fraction, temperature and nanoparticle size are the most major factors that affect Nanofluid thermal conductivity. Chen et. al.[19] report from their experiments that cluster formation and percolation are the key factors of thermal conductivity enhancement in Nanofluids. Mishra et. al.[23] reviewed theoretical models of viscosity in Nanofluids, concluding that it varies with many factors including particle volume fraction, shape, size, fluid temperature, surfactants and dispersion techniques. However, no proper mathematical model exists which taking into effect all the parameters. Aybar et. al. [26]have reported that the different factors affecting thermal conductivity of Nanofluids are molecular-level layering of the liquid at the liquid/particle interface, Brownian motionof the nanoparticles, clustering, nanoparticle size, pH, temperature and the nature of heat transport in the nanoparticle. Afrand et. al. [33]reported that increasing solid volume fractions increase the dynamic viscosity while increasing temperature decrease it. Ali et. al. published a paper stating that among non-circular shaped Nanofluids, platelet shaped nanoparticles have the most thermal conductivity. They also concluded that higher viscosity of Nanofluids result in lower freezing points[45].

III. ENGINE RADIATOR SYSTEM

The radiator in a vehicle is responsible to keep the temperature of the engine in the desired range. The performance of the radiator affects the performance and efficiency of the vehicle[50]. In a typical vehicle radiator system, an engine coolant is circulated through the engine block, where it collects the heat from the engine and then is made to pass through the radiator, where it loses the heat to the atmosphere. The coolant is passed through a pump to maintain pressure.

The coolant is generally a water-based liquid with additives to improve its performance. Earlier, coolants used to be mixed with anti-freeze to keep the coolant from freezing in cold weathers. Later, the need to prevent it from boiling under hot weather conditions led to the use of glycol-water coolants. These coolants are generally able to sustain different climatic conditions without much modification. There is a widespread use of ethylene-glycol coolants. While water is a good heat dissipater, ethylene glycol is not that much good. As a result, the mixture of ethylene glycol and water results in a coolant not as effective as water.

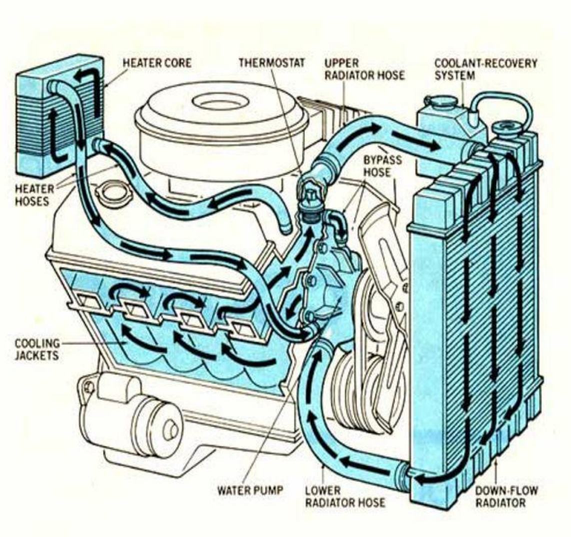

Figure 1: Typical engine radiator system

Currently there is a rising need to produce more efficient vehicle engines. Companies are in a race to produce the most efficient machine. Among many of the parameters, an effective cooling system is very important to increase engine efficiency. Mounika et. al. [35]have reported the changes that could increase the cooling performance of radiators using ethylene-glycol based coolants. While there are many factors including the number of fins and geometry of fins that affect cooling performance, these have reached their limits of improvement. With current generation coolants improving radiator performance requires increased power consumption and size. Therefore, as pointed out in the paper published by Choi et. al. [3], Nanofluids can help improving radiator performance without additional work input. Such coolants which are basically Nanofluids are known as Nano coolants.

IV. LITERATURE REVIEW

One of the first experimental papers published on thermal conductivity enhancement with addition of nanoparticles in fluids was by Masuda et. al.in 1993. They experimented with addition of Al_2O_3, SiO_2 and TiO_2 nanoparticles in water as base fluid. Electrostatic repulsion technique was used to create the required suspension. They used the unsteady wire heating method to measure thermal conductivity of the Nanofluids. They concluded that the thermal conductivity of SiO_2-water Nanofluid was not greater than that of water alone, but for the other two Nanofluids, thermal conductivity increased greatly. Also, their thermal conductivity got enhanced with an increase in particle concentration. They had also experimented with viscosity of Nanofluids[2].

The paper by Choi et. al.was the first to use the term Nanofluids. They experimented the change in thermal conductivity of water on the addition of copper nanoparticles and have shown that for a Nanofluid having thermal conductivity three times that of conventional fluids, heat transfer can be increased by a factor of two. Experimentally they have shown that this can cause in reduced pumping power to increase heat transfer. The reduction in pumping power compared to conventional fluids can be as great as 10 times for double the heat transfer rate. Also, they have shown that shape of nanoparticles is an important factor that affect conductivity. The lesser the sphericity of the particle, the greater will be the thermal conductivity[3].

In the work published by Wang et. al., they compared the thermal performances of base fluids with those of base fluids with nanoparticles dispersed in them. They chose water, vacuum pump fluid, engine oil and ethylene glycol as their base fluids and Al_2O_3 and CuO nanoparticles. In all the cases they observed, they reported that adding nanoparticles to the base fluids always increased thermal conductivity, although the increase is different for different base fluids. For Al_2O_3 particles in ethylene glycol and engine oil, the increase is high, but it is not so much for water and pump fluid. They also showed that thermal conductivity increased with decrease in the particle size. Also, the dispersion technique used has an effect on the thermal performance of the Nanofluids. Their experiments also show that increasing particle concentration increased the viscosity of the Nanofluids. They report that below 10% volume fraction, the Nanofluids remain stable and above that, the fluid becomes flocculate[4].

Xuan and Lipublished their work in 1999 where they described the two-step method of Nanofluid production and measured their thermal conductivity. They also discussed the effect of different factors of nanoparticles on the properties of the Nanofluids. They used the hot-wire method to measure the thermal conductivity and found that for Cu-water Nanofluid system, the thermal conductivity increases by 24% to 78% when the particle concentration varies from 2.5 vol% to 7.5 vol%, which shows that conductivity increases with particle concentration.

They showed that the trend is similar for alumina-water Nanofluid and transformer oil-copper Nanofluid. They reported that the lower the sphericity of the particles, the better is the heat transfer[5].

In their work published in 1999, Eastman et. al.had conducted experiments with Al_2O_3, and CuO nanoparticles in ethylene glycol and water and shown that thermal conductivity increases with the addition of nanoparticles. In 2001, they published another work where they reported that copper particles in ethylene glycol can increase its conductivity tremendously, by about 40% for particle loadings below 1 volume per cent. They also showed that thioglycolic acid mixed with the Nanofluids had a great effect at increasing the thermal conductivity as wellwhile helping the Nanofluid in stabilizing it. The acid did not have any effect on the thermal conductivity of the pure base fluid whatsoever. Another result they found is that fresh nanoparticles showed greater conductivity than particles that were few months old[6].

In a widely cited paper, Saidur et. al.reported their findings of using a Nanofluid as the radiator coolant. In their experiments, they used copper nanoparticles and ethylene glycol as the base fluid. They found as the volume fraction of copper particles increased in the solution, the coolant mass flow rate increased while the coolant volumetric flow rate decreased. This happened due to increase in the dynamic viscosity of the fluid on adding of the nanoparticles. Another finding is that with increase in volume fraction of nanoparticles, the Prandtl number and Nusselt number both had decreased. Also, they showed that heat transferincreased with increasing volume percent upto 2%, beyond which heat transfer did not increase. At 2% volume fraction heat transfer increased by about 3.8%. Also, increasing nanoparticle volume fraction increased the pressure drop linearly causing a linear increase in the pumping power of the radiator[15].

Hashemabadi et. al.conducted experiments by adding Al_2O_3 nanoparticles in ethylene glycol and water. The used these Nanofluids as radiator coolant and compared their performance to that of the base fluids alone. The volume fraction of Al_2O_3 added to the base fluid was up to 1%. They showed a significant increase in the heat transfer on adding nanoparticles, of up to 40%. The highest enhancement of Nusselt number were observed to be up to 40%. They conclude that the increase in the heat transfer was highly dependent on the particle concentration – with increase in concentration, heat transfer increased. But it was weakly dependent on the temperature. According to them, temperature did not have much effect in the heat transfer rates of Nanofluids[16].

Ali et. al.conducted experiments on forced convection heat transfer on vehicle radiators with $Al_2O_3$and water based Nanofluid as the coolant at different concentrations – 0.1%, 0.5%, 1%, 1.5% and 2% by volume. The cooling system used in this case was that of a 2007 Toyota Yaris. They showed that heat transfer by the coolant increases upon increasing the volume fraction up to 1%, beyond which it deteriorates. The coolant air heat transfer coefficient reached their maximum at volume fraction of 1%. The maximum increase in the coolant heat transfer rate, coolant heat transfer coefficient and Nusselt number was 14.79%, 14.72% and 9.51% respectively. The maximum value of air side heat transfer coefficient and Nusselt number also occurred at same concentration and increased by 14.45% and 13.94% respectively. Their experiments also show a steady increase in pumping power required with increasing concentration[22].

Kannan and Sivakumar conducted experiments on car radiator with SiO_2 and CuO nanoparticles mixed with water as base fluid. They showed that on increasing volume fraction of SiO_2 and CuO nanoparticles in water, heat transfer increased linearly. Their experimental setup included a car radiator with aluminium tubes. They conducted the experiments at different air velocities and temperatures and concluded that heat transfer increased in all cases on adding nanoparticles[27].

Parashurama et. al.conducted experiments on an army tanker diesel engine radiator with CuO-water Nanofluid as the coolant. They fixed the amount of CuO particle volume fraction at 10% and varied the air velocity from 3 m/s to 11.4 m/s while also varying mass flow rate. They showed that at the high concentration of nanoparticles, heat transfer increased of the Nanofluids at all mass flow rates but only at low air velocities. On increasing air velocities, the Nanofluidsdid not show much improvement in heat transfer compared to pure water as coolant. They also concluded that adding nanoparticles increases the pumping power of the radiator to maintain flow rate[29].

Vivek et. al. conducted experimental study on heat transfer enhancement in radiators using Al_2O_3 nanoparticles on a commercial automobile radiator. They compared the heat conductance of pure water as coolant, water-ethylene glycol (EG) mixture as coolant and water-EG with Al_2O_3 nanoparticles as Nano coolant. The water-EG proportion in the Nanofluid was 80:20. The particle concentration of Al_2O_3 particles was about 0.1%. They reported that water-EG mixture resulted in very low thermal conductivity as compared to water alone. But on addition of Al_2O_3 nanoparticles, the thermal conductance increased by about 37%. They also showed that in the temperature range of 44℃ to 70℃, heat conductance did not show much variance with temperature. They also reported that on adding the nanoparticles, the Prandtl number of water and water-EG based Nanofluids increased by 61% and 106% respectively[32].

Chen and Jiaconducted an experimental study of TiO_2Nanofluid coolant for automobile cooling applications. They evaluated the thermal conductivity enhancement on use of TiO_2Nanofluids comparing with the base fluid alone. The Nanofluid was synthesized using sol-gel and hydrothermal techniques.They added the nanoparticles to a 85 wt. % ethylene glycol mixture. The resulting Nanofluid had 1 wt.% TiO_2 nanoparticle concentration. They also added corrosion inhibitors in the mixture. The nanoparticles used were of ca. 18nm in size with a very narrow size distribution. They reason that this could be because of good dispersion characteristics of the Nanofluid. From their experiments, they found that the heat transfer performance of the engine coolant significantly improved on addition of the nanoparticles – thermal conductivity increased by 3% and convective heat transfer increased by 10%. They also reported that upon increasing the flow rate, the convective heat transfer increased for the base fluid till a maximum was reached whereas for the Nano coolant it kept on increasing. They also observed that increasing mass fraction increased relative viscosity along with relative thermal conductivity. After conducting corrosion tests on an aluminium pump, they found no such metal loss, corrosion or erosion occurred in the pump. As they point out, this suggests that TiO_2 based Nanofluidscan be used as vehicle coolants[34].

In the paper published by Mutuku the cooling capabilities of ethylene glycol based Nanofluids containing CuO, Al_2O_3 and TiO_2 nanoparticles are investigated. He also measured the effect of an external magnetic field on the Nanofluids thermal performance. He observed that the fluid velocity decreases with increase in nanoparticle concentration and magnetic field strength. Increase in field strength, Eckert number, Biot number and nanoparticle concentration lead to an increase in Nanofluid temperature. The skin friction and rate of heat transfer at the plate surface increase with increase in nanoparticle concentration. Also, an increase in the magnetic field led to an increase in the skin friction and a decrease in the rate of heat transfer. He reports that CuO-EG Nanofluids lead to a rapid decrease of temperature at the boundary layer. He concluded that by employing TiO_2 – EG Nanofluid as coolant under the influence of a magnetic field, the cooling effect is maximised on reducing the fluid flow velocity, enhancing the rate of heat transfer at the plate surface as well as minimising the skin friction at the plate surface[36].

Hamzah and Al-Amir published a paper on their experimental work where they measured the effect on the thermal conductivity of water after adding MgO nanoparticles. They had considered six different concentrations of Nanofluids with particle concentration varying as 0.125%, 0.25%, 0.5%, 1%, 1.5% and 2%. Keeping coolant flow rate at 5 L/min and air velocity at 7 m/s and varying nanoparticle concentration, they observed that there is a need to increase pumping power. Varying volume fraction from 0.125% to 2%, pumping power had to be increased from about 6% to about 30%. They also showed that at any mass flow rate, the rate of heat transfer increases with increase in nanoparticle concentration from about 40% at 8 L/min to about 66% at 2 L/min. They also showed a linear increase in the overall heat transfer coefficient with increase in the nanoparticle concentration. Just like heat transfer, the overall heat transfer coefficient also increases with concentration at any mass flow rate. Also, they reported that the Nusselt number increases with increasing liquid flow rate and increasing Reynolds number[40].

Salamon et. al. have conducted experimental investigation of heat transfer characteristics of automobile radiator using water/propylene glycol based TiO_2Nanofluid coolant. The water/propylene glycol mixture was at 70:30 ratio. The concentrations of TiO_2 used were 0.1 vol% and 0.3 vol%. They found that the Nusselt number of the Nanofluid was dependent on the volume flow rate and increased with temperature and flow rate. The 0.3 vol% TiO_2 solution showed a Nusselt number enhancement of 8.3%. similar to the Nusselt number, heat transfer rate increased with increasing volume flow rate and with increasing temperature. They achieved an 8.5% enhancement in heat transfer for the 0.3 vol% TiO_2Nanofluid at 80℃. They concluded that TiO_2 nanoparticles enhance the heat transfer rate at higher flow rate and higher temperatures, making them suitable for heavy-duty applications[42].

Ahmed et. al. conducted experimental investigation of radiator performance on a Fiat Doblo 1.3MJTD ENG engine system. In their experiments, they compared the cooling performance of TiO_2-water Nanofluid with that of pure water as coolant. They varied the particle concentration as 0.1%, 0.2% and 0.3% by volume. The Nanofluids were prepared in a two-step process with 0.1 to 0.5% surfactant. They found that for all concentrations of Nanofluids, viscosity decreased with the increase in temperature. With an increase in volume concentration, the thermal conductivity of the Nanofluid increases, which they compared and found to be in agreement with existing data. They also measured the average heat transfer coefficient as a function of Reynolds number and found that it increases almost linearly with a greater slope for Nanofluids with greater particle concentration. In both the cases, the Nanofluid with concentration 0.2% showed significant improvement in performance. They concluded that TiO_2-water Nanofluid with 0.2% particle concentration is best for use in a vehicle radiator system[43].

Subhedar et. al.have conducted experimental investigation of heat transfer of Al_2O_3 / Water-Mono Ethylene Glycol based Nanofluids as car radiator coolant. The base fluid was a 50:50 mixture of water and mono ethylene glycol. They measured the effect of nanoparticle volume fraction, coolant flow rate, inlet temperature on the heat transfer performance of the radiator. They have found that heat transfer rate by Nano coolant is significant with the increase in concentration of nanoparticles. For a volume flow rate of 4.06 L/min, as the particle concentration increased from 0.2 vol% to 0.8 vol%, the Nusselt number enhanced from 3.89% to 28.47%. The enhancement of heat transfer varies insignificantly with inlet temperature of coolant. The major factors affecting the heat transfer are flow rate and particle concentration. They also showed that with increase in volume fraction of particles, the frontal area of the radiator could be reduced dramatically up to 75%, which could help reduce drag by a large amount and hence save fuel in the long run[47].

Khan et. al.conducted experimental investigation of heat transfer of a car radiator using ZnO nanoparticles in H_2O-ethylene glycol mixture. The mixture had water and EG in 50:50 ratio. They varied the nanoparticle volume fraction as 0.01%, 0.02%, 0.03% and 0.04% and flow rate from 4 L/min to 12 L/min. They found that increasing Reynolds number increased the heat transfer for all concentrations of Nanofluids used. Also, increasing particle concentration increased the overall heat transfer coefficient, which is in accordance with earlier experimental results. Also, a direct proportionality in the increase in pumping power was seen with increase in particle concentration. They noted an increase of 1% in pumping power for a particle concentration of 0.04%. With an increase in inlet temperature from 60℃ to 68℃, heat transfer had been observed to increase about 7% for EG based Nanofluids while Nusselt number increased 36% for water based Nanofluids. They conclude that Nanofluid based coolants could be more effective than the present ones, allowing for a lower radiator opening which would decrease drag and increase efficiency of the engine. Also, they point out the main hindrances to using Nanofluids as coolants are mainly their long-term stability and cost of production[48].

V. CONCLUSION

Nanofluids have proved to be more effective heat transfer fluids than conventional coolants. As has been shown by a vast number of researchers, they have the potential to be used as next generation coolant in engine radiator systems. Adding nanoparticles in almost every type of coolant increases its thermal performance by about 40%.

Nanoparticles can also be added to conventional EG based coolants to increase their thermal performance while retaining their anti-freezing properties and a higher boiling point. They can be helpful in reducing pumping power and radiator opening to increase efficiency of vehicles.

However, Nanofluids still face some challenges before being used commercially. They are costly to produce and are not very stable over long periods of time. Adding stabilizing agents to the mixturehas an adverse effect to the Nanofluid and can render their addition useless. Also, there is no nanoparticle or nanoparticle-base fluid combination that is clearly better than all other options. The concentration of nanoparticles is still a debatable factor, although there is good evidence that a low concentration ~1 vol% is favourable. Overall, it is clear that Nanofluids can be used in place of contemporary coolants in vehicle radiators. The state of research is still in its infancy and more experiments need to be carried out to come to clear conclusions of the above-mentioned problems. Also, better methods of production and stabilization of Nanofluids are needed.

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