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A Review on Cooling of Internal Combustion Engine by Means of Nanofluids

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Abstract: *Transportation system plays a vital role in our society, so it is important to improve the engine efficiency of the automobiles in today's world. Cooling system is one of the important systems which enhances the performance of internal combustion engines (I.C.E). Researches in heat transfer have been carried out over the previous several decades, leading to the development of the currently used heat transfer enhancement techniques. The use of additives is a technique applied to enhance the heat transfer performance of base fluids. Nanofluids are potential heat transfer fluids with enhanced thermo physical properties and heat transfer performance can be applied in many devices such as heat exchangers for better performances. This review summarizes recent experimental and numerical studies by previous researchers on automotive cooling system using nanofluid as a coolant. This comprehensive study on cooling system importance and challenges of Nanofluids as a coolant have been compiled and reviewed for automobile radiator.*

Keywords: *I.C.E, cooling, heat exchanger, enhancement, nanofluid.*

INTRODUCTION

In an automobile, fuel and air produce power within the engine through combustion. Only a portion of the total generated power actually supplied to the automobile with power, the rest is wasted in the form of exhaust and heat. If this excess heat is not removed, the engine temperature becomes too high which results in overheating and viscosity breakdown of the lubricating oil, metal weakening of the overheated engine parts, and stress between engine parts resulting in quicker wear, among the related moving posts . A cooling system is used to remove this excessive heat. Most automotive cooling systems consist of the following components: radiator, water pump, electric cooling fan, radiator pressure cap, and thermostat. Of these components, the radiator is the most prominent part of the system because it transfers heat. As coolant travels through the engine's cylinder block, it accumulates heat. Once the coolant temperature increases above a certain threshold value, the vehicle's thermostat triggers a valve which forces the coolant to flow through the radiator. As the coolant flows through the tubes of the radiator, heat is transferred through the fins and tube walls to the air by conduction and convection. (Bhogare and Kothawale, 2014)
Almost all automobiles in the market today have a type of heat exchanger called a radiator. The radiator is part of the cooling system of the engine as shown in Figure 3 below. As you can see in the figure, the radiator is just one of the many components of the complex cooling system. (Fell *et al.,* 2007)

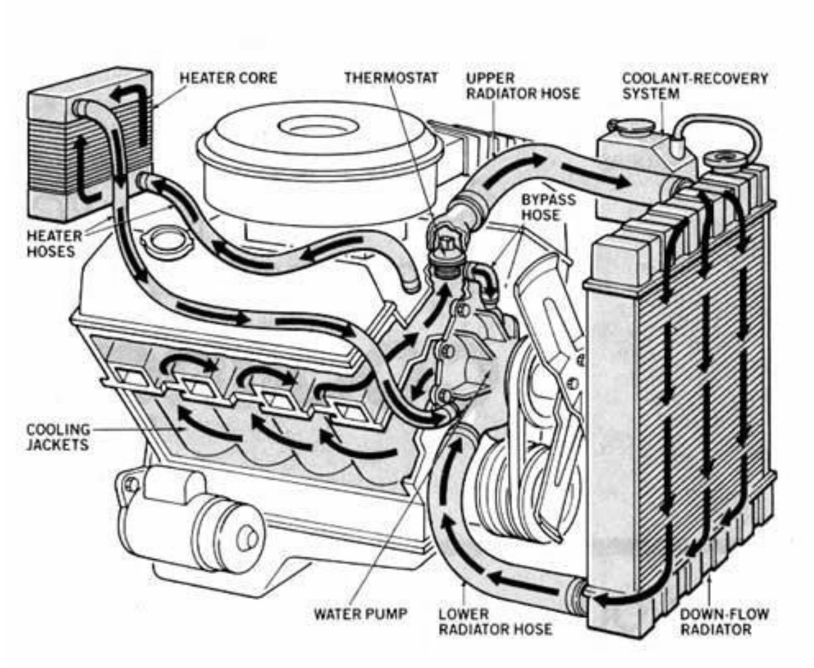

Figure 1. Coolant path and Components of an Automobile Engine Cooling System

The radiator is an important accessory of vehicle engine. Normally, it is used as a cooling system of the engine and generally water is the heat transfer medium .For this liquid-cooled system, the waste heat is removed via the circulating coolant surrounding the devices or entering the cooling channels in devices. The coolant is propelled by pumps and the heat is carried away mainly by heat exchangers. Continuous technological development in automotive industries has increased the demand for high efficiency engines. A high efficiency engine is not only based on its performance but also for better fuel economy and less emission. Reducing a vehicle weight by optimizing design and size of a radiator is a necessity for making the world green. Addition of fins is one of the approaches to increase the cooling rate of the radiator. It provides greater heat transfer area and enhances the air convective heat transfer coefficient. However, traditional approach of increasing the cooling rate by using fins and microchannel has already reached to their limit. (Kulkarni *et al.,* 2008) In addition, heat transfer fluids at air and fluid side such as water and ethylene glycol exhibit very low thermal conductivity. As a result there is a need for new and innovative heat transfer fluids for improving heat transfer rate in an automotive car radiator.

The use of nanofluids as coolants would allow for smaller size and better positioning of the radiators. Owing to the fact that there would be less fluid due to the higher efficiency, coolant pumps could be shrunk and engines could be operated at higher temperatures allowing for more horsepower while still meeting stringent emission standards. (Bhogare and Kothawale, 2013)

Nanofluids seem to be potential replacement of conventional coolants in engine cooling system. Recently there have been considerable research findings highlighting superior heat transfer performances of nanofluids. Nanofluids can be used for a wide variety of industries, ranging from transportation to energy production and in electronics systems like microprocessors, Micro- Electro-Mechanical Systems (MEMS) and in the field of biotechnology. Recently, the number of companies that observe the potential of nanofluids technology and their focus for specific industrial applications is increasing. In the transportation industry, nanocars, GM and Ford, among others are focusing on nanofluids research projects. Nanofluids 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 to improve its efficiency. The measurement of nanofluids critical heat flux (CHF) in a forced convection loop is useful for nuclear applications. If nanofluids improve chiller efficiency by 1%, a saving of 320 billion kWh of electricity or an equivalent 5.5 million barrels of oil per year would be realized in the US alone. Nanofluids find 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 nanodiamond particles. Application areas can be summarized as (Kosti, 2009): Heat-transfer, Tribological, Surfactant and coating, Chemical, Process/extraction Environmental (pollution cleaning), Bio- and pharmaceutical, and Medical (drug delivery and functional tissue–cell interaction).

Yu et al, (2007) first reviewed the potential of nanofluid for transportation. He reported that about 15-40% of heat transfer enhancement can be achieved by using various types of nanofluids. With these superior characteristics, the size and weight of an automotive car radiator can be reduced without affecting its heat transfer performance. This translates into a better aerodynamic feature for design of an automotive car frontal area. Coefficient of drag can be minimized and fuel consumption efficiency can be improved. Another review articles about the various current and future applications of nanofluids have been presented by Loeng et al (2011) and Wong et al (2010). However, detailed review/information regarding automotive cooling and lubrication using nanofluids is scare in open literature. Therefore, the present review summarizes recent developments trend in research on automotive cooling and lubrication system using nanofluids.

Nanofluid as Radiator Coolant

Theoretical Investigation

Recent advanced developments in computer and computational schemes have attracted the interest of many researchers in computational physics. Unlike conventional experimental approach, computational or numerical predictions allow more comprehensive research to be conducted at low cost. Numerical studies on nanofluids have become the alternative approach to demonstrate their superior performance to traditional heat transfer fluids. (Sidik, Yazid and Mamat, 2015)

Ollivier *et al.,* (2006) numerically investigated the possible application of nanofluids as a jacket water coolant in a gas spark ignition engine. Authors performed numerical simulations of unsteady heat transfer through the cylinder and inside the coolant flow. Authors reported that because of higher thermal diffusivity of nanofluids, the thermal signal variations for knock detection increased by 15% over that predicted using water alone.

Saripella *et al.,* (2007) modeled the cooling system of class 8 truck engine using flow master computer code. Authors done numerical simulation to replace the standard coolant, 50/50 mixture of ethylene-glycol and water, with nanofluid comprised of CuO nanoparticles suspended in a base fluid of 50/50 mixture of ethylene-glycol and water. The authors show that there is a 5% increase in engine horsepower rejected to the coolant using the nanofluid compared to the standard coolant as shown in Table 1. He also showed a reduction in pump power as much as 88% with nanofluid compared to base fluid alone (Table 2) and possible reduction of surface area of the air side of the radiator due to increased heat transfer coefficient of nanofluids compared to base fluid alone.

Table 1. Increased engine heat rejection with nanofluids

Coolant	Base Fluid (50/50 ethylene glycol/water mixture)	Nanofluid-1 (vρ = 2% CuO in base fluid)	Nanofluid-2 (vρ = 4% CuO in base fluid)
Engine Heat Rejection to Coolant Circuit	400 HP	410 HP	420 HP

Table 2. Reduced pump speed with nanofluids

Coolant	Base Fluid (50/50 ethylene glycol/water mixture)	Nanofluid-1 (vρ = 2% CuO in base fluid)	Nanofluid-2 (vρ = 4% CuO in base fluid)
Pump speed	1600 RPM	1150 RPM	800 RPM
Pump power	0.75 HP (0.56 kW)	0.266 HP (0.2 kW)	0.09 HP (0.0675 kW)

Table 3. Reduced radiator air side area with nanofluids

Coolant	Base Fluid (50/50 ethylene glycol/water mixture)	Nanofluid-1 (vρ = 2% CuO in base fluid)	Nanofluid-2 (vρ = 4% CuO in base fluid)
Engine Heat Rejection to Coolant Circuit	400 HP	410 HP	420 HP

Leong and Saidur (2010) investigated the heat transfer enhancement of an automotive car radiator operated with nanofluid-based coolants. In their investigation, they compared nanofluids (with ethylene glycol the base fluid) to ethylene glycol (i.e. base fluid) alone. They observed that, about 3.8% of heat transfer enhancement could be achieved with the addition of 2% copper particles in a base fluid at the Reynolds number of 6000 and 5000 for air and coolant respectively. They also show that almost 18.7% reduction of air frontal area is achieved by adding 2% copper nanoparticles at Reynolds number of 6000 and 5000 for air and coolant respectively. In addition to that they also found that additional 12.13% pumping power is needed for a radiator using nanofluid of 2% copper particles at 0.2 m3/s coolant volumetric flow rate compared to that of the same radiator using only pure ethylene glycol coolant.

Das and Strandberg (2010) compared the performance of hydronic finned-tube heating units with nanofluids with a conventional heat transfer fluid comprised of 60% ethylene glycol and 40% water, by mass (60% EG) using a mathematical model. The model predicts that finned-tube heating output with Al2O3/60% EG nanofluid is superior compared to that of the heating capacity with CuO/60% EG nanofluid, and of the base fluid. Finned-tube heating capacities with the CuO/60% EG and Al2O3/60% EG nanofluid are superior to that with the base fluid at all concentrations examined. For both nanofluids, heating capacity increases with nanoparticle volumetric concentration.

Vajjha & Das (2010) numerically studied a three-dimensional laminar flow and heat transfer with two different nanofluids, Al2O3 and CuO, in an ethylene glycol and water mixture circulating through the flat tubes of an automobile radiator and evaluate their superiority over the base fluid. They shows that Heat transfer for Al2O3 and CuO nanofluids with varying particle volumetric concentrations exhibit substantial increase in the average heat transfer coefficient with concentration. For example, at a Reynolds number of 2000, the percentage increase in the average heat transfer coefficient over the base fluid for a 10% Al2O3 nanofluid is 94% and that for a 6% CuO nanofluid is 89%. For the same amount of heat transfer, the pumping power requirement is 82% lower for a Al2O3 nanofluid of 10% concentration and 77% lower for a CuO nanofluid of 6% concentration when compared to the base fluid.

Zhou *et al.,* (2010) have done a numerical simulation method to study the use of nanofluids for cooling of an internal combustion engine. They reported that the application of nanofluids significantly enhanced the heat transfer, and the effect was larger with an increasing concentration of nanoparticles. The pumping power of the cooling system was increased by the use of nanofluids, but this can be accepted by considering the enhanced heat transfer.

In the same manner Peng and Liu (2011) have done the simulation of cooling effects of water, TiO2 nanofluid, Al2O3 nanofluid and CuO nanofluid and they show that compared to water by using TiO2, Al2O3 and CuO nanofluid, the average surface heat transfer coefficient is increased by 10.82%, 8.43% and 11.24%, and correspondingly the pump power is increased only by 1.06%, 1.30% and 1.98%, respectively. It is clear that the heat transfer coefficient increases significantly at a tiny loss of pump power with nanofluid as coolant, which is beneficial to the heat exchange of cooling system.

Experimental Investigation

Putra and Maulana (2008) have done the measurement of forced convective coefficient onnanofluid by using car radiator in cross flow arrangement for water based nanofluid containing Al2O3 Nanoparticles. They show that the enhancement in heat transfer convective coefficient compared to the base fluid 31-48% for 1% particle concentration and 52-79% for 4% particle concentration.

Zhong *et al.,* (2011) study heat transfer effect of the nanofluid in internal combustion engine cooling system. Authors reported that the heat transfer capability of nanofluid is 4.6% and 19.0% higher than those of water and antifreeze under 85°C inlet temperature, and 63.7% higher than that of antifreeze when the inlet temperature raise to 120°C. In the similar manner, Zhong *et al.,* (2011) experimentally study on heat exchange enhancement of nanofluids in vehicle oil cooler and they reported that the nanoparticle addition can efficiently enhance heat exchange capability of the base fluid, and the enhancement effect increases with particle volume fraction increasing. Under different inlet temperatures and temperature differences, both heat exchange capacity and heat exchange coefficient for the 5% nanofluids are higher than conventional coolants (water and antifreeze). Increasing volumetric fraction may also raise the viscosity and flow resistance of the nanofluids.

Peyghambarzadeh and Hashemabadi (2011) experimentally performed the forced convection heat transfer in a car radiator and they showed the heat transfer performances of pure water and pure EG comparison with their binary mixtures. Additionally different amounts of Al2O3 nanoparticle have been added into these base fluids and its effects on the heat transfer performance of the car radiator have been determined. They reported that by the addition of only 1 vol.% of Al2O3 nanoparticle into the water or EG, an increase in Nusselt number of about 40% in comparison with the pure water and pure EG as shown in Figure 2. They also found that an increase in the fluid inlet temperature slightly improves the heat transfer performance. Such as by increasing the inlet temperature of water based nanofluids from 35 °C to 50 °C can enhance Nusselt number up to 16%. For EG based nanofluids, the temperature elevation from 45 to 60 °C creates maximum enhancement of 7% as shown in Figure 3.

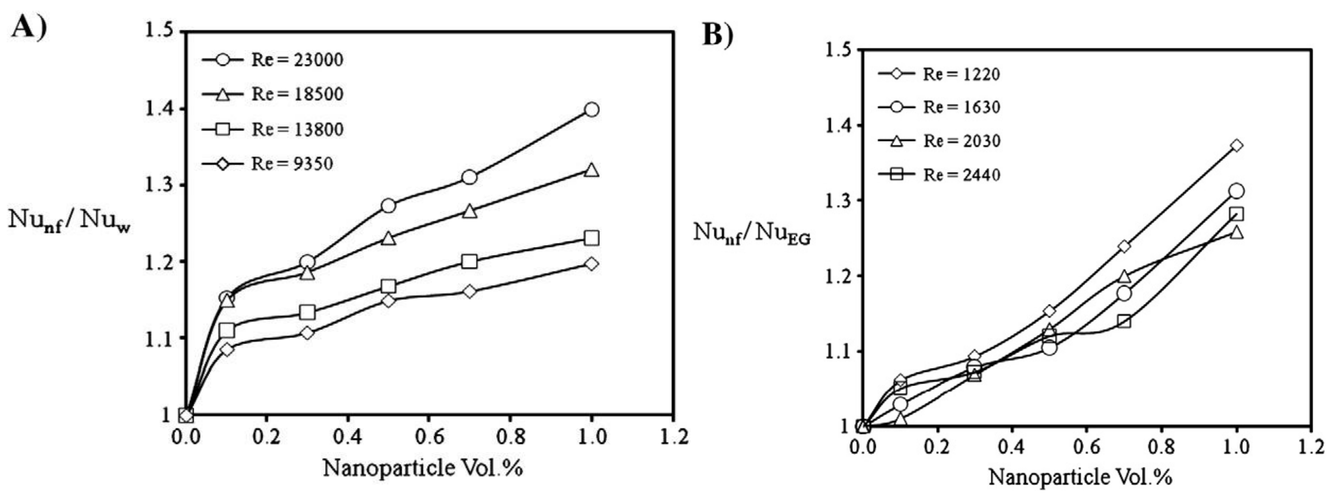

Figure 2. Variations of Nusselt number at different Reynolds number as a function of nanoparticle concentration. (A) Water based nanofluids. (B) EG based nanofluids.

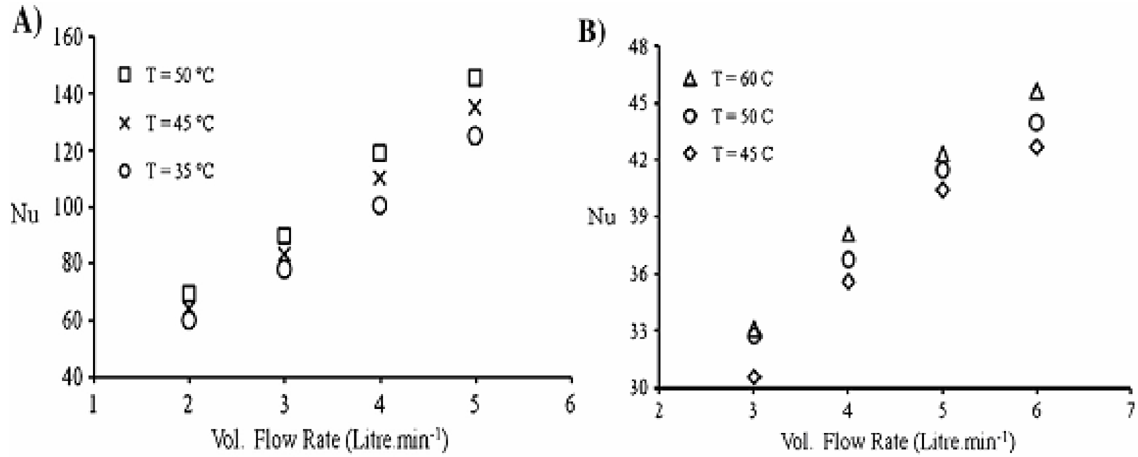

Figure 3. Effect of inlet temperature on Nusselt number: (A) Water based nanofluid at 1 vol. % concentration, (B) EG based nanofluid at 0.7 vol. % concentration

Sharma *et al.,* (2014) experimentally study the Heat Reduction FromIc Engine by Using Al2O3 Nanofluid In Engine Cooling System and they showed A savings of 12-18 % of surface area can be seen by use of Nanofluids. As the load on the engine and the speed of the engine increases the percentage savings of surface area also increases. The thermal conductivity of Nanofluid is temperature dependent. As the temperature increases at higher load and speeds the heat carrying capacity of Nanofluids increases. This is advantageous when engine is running at high speed and load.

Arjun.A *et al.,* (2016) implemented a model of automotive cooling system in which any kind of coolants can be used. They showed that nanofluids can be considered as a potential candidate for Automobile application. Automobile radiators can be made energy efficient and compact as heat transfer can be improved by nanofluids. Reduced or compact shape may result in reduced drag, increase the fuel economy, and reduces the weight of vehicle.

Nanofluid as Engine Lubricating Oil

Engine oil based nanofluid improves the heat transfer and may reduce friction and wear, although research on this field is limited. Wu and Kao (2011) studied application of TiO2 nanofluid as an additive for engine lubricating oil for reducing friction and wear. The result was shown that the TiO2 nanoparticle additive exhibited lower friction force as compared to original oil. Their experiment showed that a smaller particle size exhibits better friction reduction with particle size ranging from 59 to 220 nm.

Mohsen Mosleh, Ph.D. (2009) invent Nanolubricant and Nanofluid Formulations for Tribological and Thermal management. This portfolio of patents at Howard University introduces several technologies related to nanolubricant and nanofluids including:

- Nanolubricants containing special nanoparticles for reduction of wear
- Nanolubricants containing specially design and synthesized nanoparticles for conditioning and polishing surfaces for lower friction through in-situ nanopolishing
- Cutting nanofluids that improve tool life and surface finish of the workpiece in sheet metal working and machining operations
- Nanolubricants, nanofluids and coolants with enhanced thermal conducting for improved heat transfer in addition to their improved lubrication and tribological properties
- Below-room-temperature and at-room-temperature gelling of nanofluids for dispersion stability and prolonged shelf life without particle settlement.

This portfolio of technologies yields improvements to critical characteristics of lubricants and fluids used in tribological and thermal transfer applications. These improvements include lower wear and maintenance, lower friction, in-situ polishing of moving surfaces, and higher thermal conductivity. These technical improvements translate into more reliability, reduced energy consumption and lower cost of operation.

Conclusion

Applications of nanofluids as coolant and lubricant in IC engine are reviewed in this study. Based on literatures, it has been found that by using nanofluid as a coolant there is an enhancement of heat transfer and happen with the increase in its nanoparticle concentration which result reduced the size of the cooling system in the automotive application. A vast number of available references showed that nanofluids have a great application prospect in the development of modern engines. In addition, the presence of nanoparticles in engine oil will also improve the performance of lubricants and reduce friction. However, the optimum amount of nanoparticles in engine oil still remains unknown and it should be noted that many challenges need to be identified and overcome for different applications. Another method for cooling the engine system is by dispersing nanoparticles in a conventional coolant radiator. Heat transfer coefficient can be improved up to 50% compared to the original coolant; however, the problem of pressure drop limits the efficiency factor of the cooling system. For this case, most researchers agree that the optimum performance of cooling system can be achieved at low volume fraction of nanoparticles (<1%). Nanofluids stability and its production cost are major factors that hinder the commercialization of nanofluids. By solving these challenges, it is expected that nanofluids can make substantial impact as coolant in heat exchanging devices.

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