Review on Performance of Automotive Radiator operated with Nanofluid based coolants (nanofluid as a coolant in a radiator)

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Abstract: **- Mixture of water and ethylene glycol as conventional coolants has been widely used in an Automobile radiator for many years. These heat transfer fluids offer low thermal conductivity. With the advancement of nanotechnology, the new generation of heat transfer fluids called, "nanofluids" have been developed and researchers found that these fluids offer higher thermal conductivity compared to that of conventional coolants. Consistent 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 micro channel has already reached to their limit. 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. Water and ethylene glycol as conventional coolants have been widely used in an automotive car radiator for many years. These heat transfer fluids offer low thermal conductivity. With the advancement of nanotechnology, the new generation of heat transfer fluids called, "nanofluids" have been developed and researchers found that these fluids offer higher thermal conductivity compared to that of conventional coolants which results in higher heat transfer coefficient, smaller and lighter radiator size. Which in turn benefit almost every aspect of car and truck performance and lead to increased fuel economy. This review comprises of the performance of automotive radiator with nanofluid based coolant.**

Keywords- Automotive Radiator, Hybrid Nanofluid, CuO, Fe_2O_3, Heat transfer enhancement

I. INTRODUCTION

The demand for more powerful engines in smaller hood spaces has created a problem of insufficient rates of heat dissipation in automotive radiators. Upwards of 33% of the energy generated by the engine through combustion is lost in heat. Insufficient heat dissipation can result in the overheating of the engine, which leads to the breakdown of lubricating oil, metal weakening of engine parts, and significant wear between engine parts. To minimize the stress on the engine as a result of heat generation, automotive radiators must be redesigned to be more compact while still maintaining high levels of heat transfer performance. 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.

Conventional fluids, such as water, engine oil, ethylene glycol, etc. have poor heat transfer performance and therefore high compactness and effectiveness of heat transfer systems are necessary to achieve the required heat transfer. Heat transfer enhancement is a major concern in the field of thermal engineering. Therefore, efforts need to be put to improve the heat transfer performance of thermal devices used in many engineering applications. Heat transfer improvement can be made by increasing (i) heat transfer area, (ii) temperature, and (iii) heat transfer co-efficient [1]. However, technologies have already reached their limit for the cases (i) and (ii). Among the efforts for enhancement of heat transfer the application of additives to liquids is more noticeable. Base fluids (water, ethylene glycol and glycerol) have been used as conventional coolants in cross flow heat exchanger (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.

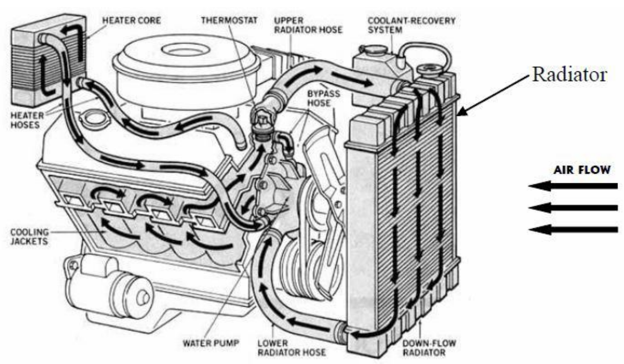

Fig.1:-Components of automotive cooling system.[1]

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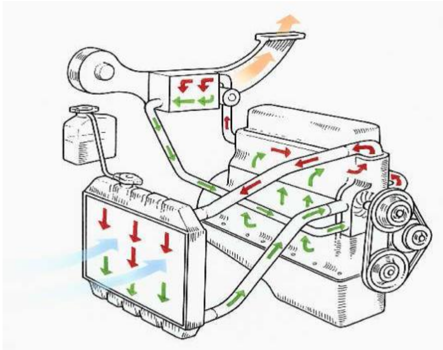
Fig.2:-Liquid cycle in automotive cooling system. [2]

This resulted in nanofluids being used instead of these base fluids. Recently many researchers found that dispersing nanosized particles into the liquids result in higher heat transfer co-efficient of these newly developed fluids called nanofluids compared to the traditional liquids [2]. For this reason, nanometer size particles with the diameter of 1–100 nm are suspended in a liquid called nanofluid which was invented by Choi and the author found considerable enhancement of the thermal conductivity of the suspension.

Among the efforts for enhancement of heat transfer the application of additives to liquids is more noticeable. Recent advances in nanotechnology have allowed development of a new category of fluids termed nanofluids. Such fluids are liquid suspensions containing particles that are significantly smaller than 100 nm, and have a bulk solids thermal conductivity higher than the base liquids . Nanofluids are formed by suspending metallic or non-metallic oxide nanoparticles in traditional heat transfer fluids. Nanofluids as introduced earlier are characterized by an enrichment of a base fluid like Water, toluene, Ethylene glycol or oil with nanoparticles in variety of types like Metals, Oxides, Carbides, Carbon. Mostly commonly recalled Nanofluids could be typified as TiO_2 in water, CuO in water, Al_2O_3 in water, ZnO in Ethylene Glycol. These so called nanofluids display good thermal properties compared with fluids conventionally used for heat transfer and fluids containing particles on the micrometer scale. Nanofluids are the new window which was opened recently and it was confirmed by several authors that these working fluid can enhance heat transfer performance one such application is implementation of nanofluids instead of the conventional fluids in car radiators which is recently under studied. The radiator is an important accessory of vehicle engine. Normally, it is used as a cooling system of the engine and generally water is heat transfer medium. The current research studies show that application of nanofluids instead of water enhances thermal performance of the automobile cooling system.

II. THERMAL PERFORMANCE OF RADIATOR WITH NANOFLUID

The developments are being carried out continuously in the field of Nanofluids, Advanced Radiator designs, Effective cooling methods, etc. Numbers of studies have been carried out on thermal performance of automotive radiator and found more increase in the cooling efficiency in comparison to conventional methods of cooling and fluid used for heat transfer. These studies include thermal performance of radiator using different nanofluids, different designs of radiators, etc.

Ding et al. [2] it summarises some of our recent work on the heat transfer of nanofluids. It covers heat conduction, convective heat transfer under both natural and forced flow conditions, and boiling heat transfer in the nucleate regime. The results show that, despite considerable data scattering, the presence of nanoparticles enhances thermal conduction under macroscopically static conditions mainly due to nanoparticles structuring / networking. The natural convective heat transfer coefficient is observed to decrease systematically with increasing nanoparticle concentration, and the deterioration is partially attributed to the high viscosity of nano-fluids. The results also show that the boiling heat transfer is enhanced in the nucleate regime for both aluminium and titanium nanofluids, and the enhancement is more sensitive to the concentration change for TiO_2 nanofluids. It is concluded that there is still some way to go before we can tailor-make nanofluids for any targeted applications.

Y. Xuan et al.[3] studied Investigation on convective heat transfer and flow features of nanofluids. Heat transfer rate is considered as critical aspect for the design of rapid heating and cooling environment. The convective heat transfer can be enhanced passively by changing the flow geometry, boundary conditions, or by enhancing the thermal conductivity of the fluid. Researchers tried to increase the heat transfer rate by increasing the thermal conductivity of the fluid. The thermal conductivity of the fluid can be boosted by the use of nanopowder in the base fluid (uniformly suspended). Nanofluids are termed as the next generation heat transfer elements. Nanofluids cause drastic change in the properties of the base fluid. The mass concentration of nanoparticles is proportional to the rate of heat transfer within critical limit.

Yu et al.[4] Nanofluids, the fluid suspensions of nano materials, have shown many interesting properties, and the distinctive features offer unprecedented potential for many applications. This review summarizes the recent progress on the study of nanofluids, such as the preparation methods, the evaluation methods for the stability of nanofluids, the ways to enhance the stability for nanofluids, the stability mechanisms of nanofluids, and presents the broad range of current and future applications in various fields including energy, mechanical and biomedical fields.

Prasad et al. [5] the thermal conductivity of heating or cooling fluids is a very important property in the development of energy efficient heat transfer systems, which is one of the important needs of many industries. However, low thermal conductivity is a primary limitation in developing energy-efficient heat transfer fluids that are required for cooling purposes. Nanofluids are nanotechnology-based heat transfer fluids that are engineered by stably dispersing nanometre-sized solid particles. In conventional heat transfer fluids at relatively low particle volume concentrations. These suspended nanoparticles can change the transport and thermal properties of the base fluid. It focuses on some of the automotive applications such as coolant for automobiles, showcases a few of them that are believed to have the highest probability of success in this highly competitive industry and to raise the awareness on the promise of nanotechnology, its potential impact on the future of the automotive industry.

Naraki et al. [6] Performed research, the overall heat transfer coefficient of CuO/water nanofluid investigated experimentally under laminar flow regime (100 Re 1000) in a car radiator. The experimental system is quite similar to cars cooling system. The nanofluids in all the experiments have been stabilized with variation of pH and use of suitable surfactant. The results show that the overall heat transfer coefficient with nanofluid is more than the base fluid. The overall heat transfer coefficient increases with the Enhancement in the nanofluid concentration from 0 to 0.4 vol. %. Conversely, the overall heat transfer coefficient decreases with increasing the nanofluid inlet temperature from 50 to 80 ºC. The implementation of nanofluid increases the overall heat transfer coefficient up to 8% at nanofluid concentration of 0.4 vol. % in comparison with the base fluid.

Leong et al. [7] Water and ethylene glycol conventional coolant shave been widely used in an automotive car radiator for many years. These heat transfer fluids offer low thermal conductivity. With the advancement of nanotechnology, the new generation of heat transfer fluids called, “nanofluids” have been developed and researchers found that these fluids offer higher thermal conductivity compared to that of conventional coolants. Relevant input data, nanofluid properties and empirical correlations were obtained from literatures tom investigate the heat transfer enhancement of an automotive car radiator operated with nanofluid-based coolants. It was observed that, overall heat transfer coefficient and heat transfer rate in engine cooling system increased with the usage of nanofluids compared to ethylene glycol alone. It is 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.

Peyghambarzadeh et al. [8] The forced convective heat transfer in a water based nanofluid has experimentally been compared to that of pure water in an automobile radiator. Five different concentrations of nanofluids in the range of 0.1 volume % have been prepared by the addition of Al_2O_3 nanoparticles into the water. The Test liquid flows through the radiator consisted of 34 vertical tubes with elliptical cross-section and air makes across flow inside the tube bank. Results demonstrate that increasing the fluid circulating rate can improve the heat transfer performance while the fluid inlet temperature to the radiator has trivial effects. Meanwhile application nanofluid with low concentration can enhance heat transfer efficiency up to 45% in comparison with pure water.

Peyghambarzadeh et al [9] Heat transfer of coolant flow through the automobile radiators is of great importance for the optimization of fuel consumption. The heat transfer performance of the automobile radiator is evaluated experimentally by calculating the overall heat transfer coefficient (U) according to the conventional.NTU technique. Copper oxide (CuO) and Iron oxide (Fe_2O_3) nanoparticles are added to the Water at three concentrations 0.15, 0.4, and 0.65 volume% with considering the best pH for longer stability. The ambient air for cooling of the hot liquid is used at constant temperature. Results demonstrate that both nanofluids show greater overall heat transfer coefficient in comparison with water. Increasing the nanoparticle concentration, air velocity, and nanofluid velocity enhances the overall heat transfer coefficient.

Peyghambarzadeh et al. [9] The efficiency of the vehicle cooling system strongly depends on the air flow through the Radiator core. A clear understanding of the flow pattern inside the radiator cover is essential for optimizing the radiator cover shape to increase the flow through the radiator core, thereby increasing the thermal efficiency of the radiator. The airflow distribution inside the radiator cover and the flow through the radiator core was monitored to provide a quantitative basis for the optimization process. The enabled optimization led to radiator cover configuration that eliminated these recirculation regions and increased the flow through the radiator core by 34%. It is anticipated that this increase in radiator core flow would significantly increase the radiator thermal efficiency.

S. Suresh et al [21] Preparation of nanofluids is the first key step in experimental studies. In the present work, Al_2O_3–Cu/water hybrid nanofluid of volume fraction 0.1% was prepared

Ref No.	Author	Title	Year	Type Of Nanofluid & Size	Base Fluid
08	S.M. Peyghambarzadeh and et al	Improving the cooling performance of automobile radiator with Al_2O_3/Water nanofluid	Mar2011	Al_2O_3(20 nm)	Water & sodium dodecyl benezene sulfonate (SDBS) as dispersant
09.	S.M. Peyghambarzadeh and et al	Experimental study of overall heat transfer co-efficient in the application of dilute nanofluids in the car radiator	Nov. 2012	CuO (60 nm) & Fe_2O_3(4o nm)	Water
22.	Adnan M. Hussein and et al	Study of forced convection nanofluid heat transfer in automotive cooling system	Dec. 2013	SiO_2(30 nm)	Water
24.	Hwa-Ming Nieh and et al	Enhanced heat dissipation of a radiator using oxide nano-coolant	Dec. 2013	Al_2O_3(10-20nm) & TiO_2(20-30nm)	Water + ethylene glycol chitsan as dispersant
23.	Adnan M. Hussein and et al	Heat transfer enhancement using nanofluids in an automotive cooling system	Feb. 2014	TiO_2 & SiO_2	Water
25.	M.M. Elias and etal	Experimental investigation on the thermo-physical properties of Al_2O_3 nanoparticles suspended in car radiator coolant	Mar2014	Al_2O_3(13 nm)	Water and Ethylene glycol based coolant

using two step methods. Specified amount of Al_2O_3–Cu nanoparticles were dispersed in deionized water with sodium lauryl sulfate (SLS) as dispersant by using an ultrasonic vibrator (Lark, India) generating ultrasonic pulses in the power of 180W at 40 kHz. To get a uniform dispersion and stable suspension, which determine the final properties of nanofluids, the nanofluids were kept under ultrasonic vibration continuously for 6 h . Stability of the prepared nanofluid was studied by measuring the pH values. The pH was measured using a pH meter (Deep Vision: Model 111/101) and the values were found to be around 5.5 which is far from the iso-electric points (IEP) of alumina and copper nanoparticles. This ensured that the nanoparticles were well dispersed and the nanofluid was stable because of very large repulsive forces among the nanoparticles when pH is far from isoelectric point..

III. EFFECT ON OVERALL HEAT TRANSFER COEFFICIENT AND HEAT TRANSFER USING CUO/WATER AND FE_2O_3/WATER NANOFLUIDS UNDER LAMINAR FLOW.

Peyghambarzadeh et al. presented the paper titled “Experimental study on overall heat transfer coefficient in the application of dilute nanofluids in the car radiator” In this study, the heat transfer performance of the automobile radiator is evaluated experimentally by calculating the overall heat transfer coefficient (U) according to the conventional 3-NTU technique. Copper oxide (CuO) and Iron oxide (Fe_2O_3) nanoparticles are added to the water at three concentrations 0.15, 0.4, and 0.65 vol.% with considering the best pH for longer stability.

In these experiments, the liquid side Reynolds number is varied in the range of 50-1000 and the inlet liquid to the radiator has a constant temperature which is changed at 50, 65 and 80^0C. The ambient air for cooling of the hot liquid is used at constant temperature and the air Reynolds number is varied between 500 and 700. However, the effects of these variables on the overall heat transfer coefficient are deeply investigated. Results demonstrate that both nanofluids show greater overall heat transfer coefficient in comparison with water up to 9%. Furthermore, increasing the nanoparticle concentration, air velocity, and nanofluid velocity enhances the overall heat transfer coefficient. In contrast, increasing the nanofluid inlet temperature, lower overall heat transfer coefficient was recorded.

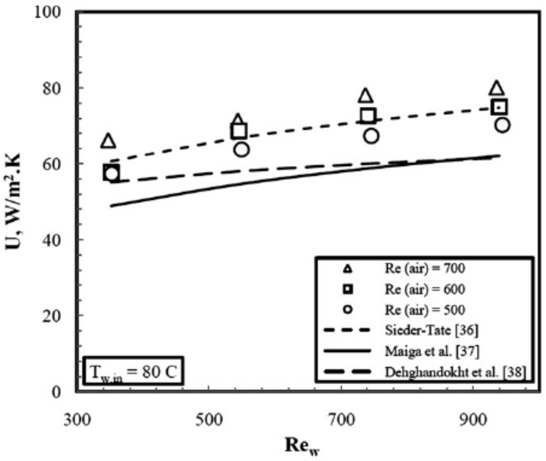

Fig.3. Effect of water side and air side Reynolds numbers on the experimental overall heat transfer coefficient and the predictions with three different correlations for internal heat transfer coefficient. [9]

In conjunction with the three aforementioned correlations in this paper for the calculation of water side heat transfer coefficient hi are compared with the experimental overall heat transfer coefficients of pure water in Fig. 3. As can be seen, reasonably good agreement exists between the experimental data and the prediction of Equations mentioned in paper.

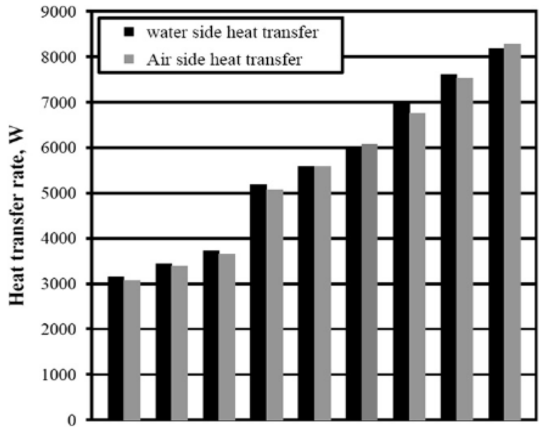

Fig. 4. The equality of water side and air side heat transfer rate in the Fe_2O_3/water nanofluids experiments at the liquid flow rate of 0.14 l/s. [9]

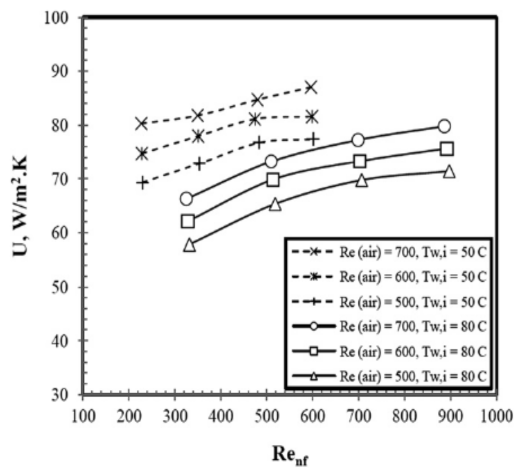

Fig. 5. The overall heat transfer coefficient of CuO/water nanofluids at the concentration of 0.15 vol. %.[9]

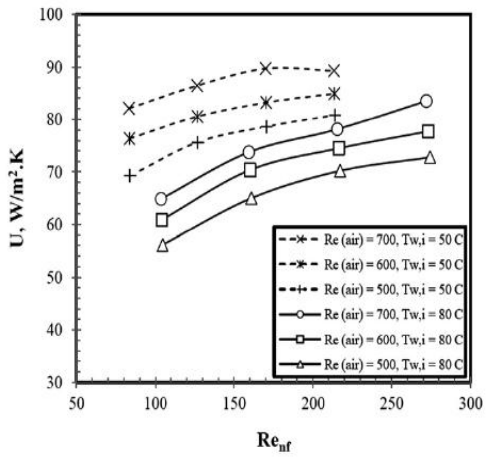

Fig. 6. The overall heat transfer coefficient of Fe_2O_3/water nanofluids at the concentration of 0.15 vol. %.[9]

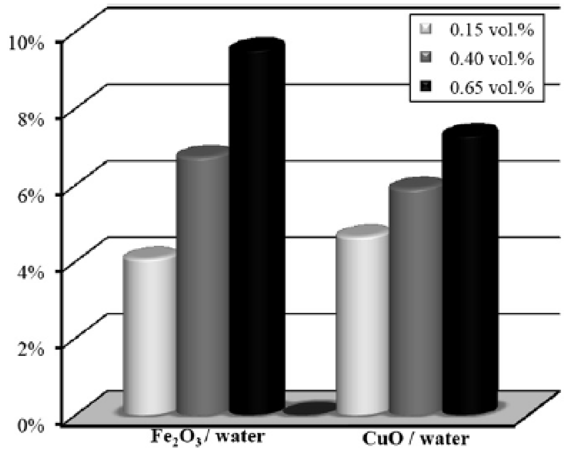

Fig.7. The percentage of heat transfer enhancement using different nanofluids at different concentrations in comparison with distilled water. [9]

Considering the consistency of the nanofluids experimental results by the observation of heat transfer rates in liquid side and air side of the heat exchanger. According to the energy conservation law and also acceptable insulation of the apparatus, the heat transfer rates on both sides of the radiator must be equal in each experiment. Fig. 4 shows this equality for 9 experiments performed with Fe_2O_3/water nanofluids. As can be seen, reasonably good agreements existed between liquid side and air side heat transfer rates in each experiment which indicates the accuracy of the results.

Minor differences in some of the experiment can be related to small heat loss from the apparatus, or from the variation in the ambient temperature along the days the experiments performed. Fig. 5. Depicts the overall heat transfer coefficients of CuO/water nanofluids at the concentration of 0.15 vol.% as a function of water side and air side Reynolds number. Also, the influences of liquid inlet temperature are shown in this figure. As it is shown the overall heat transfer coefficient of CuO/water nanofluid enhances with increasing of Reynolds number. Meanwhile, the effect of temperature is somewhat complicated.

It was previously shown that increasing the liquid inlet temperature enhances the liquid convection coefficient [7,8].Fig. 5.implies that the overall heat transfer coefficient reduces as the inlet temperature rises. The effects of operating temperature on the overall heat transfer coefficient were also investigated in other types of heat exchanger and similar results were obtained [16]. Fig.6 shows the similar results for Fe_2O_3/water nanofluids at the concentration of 0.15 vol.%. The effects of operating parameters are similar to those obtained for CuO/water nanofluids. It can be seen from Figs.5 and 6 that Reynolds number for Fe_2O_3/water nanofluids is greater than that of CuO/water nanofluids. It is mainly due to the lower viscosity of Fe_2O_3/water nanofluids in comparison with CuO/water nanofluids.

The effect of nanofluids concentration is shown in Fig. 7 by plotting the heat transfer enhancement obtained in each concentration of nanofluids. The results clearly state that increasing the nanoparticle concentration enhances the heat transfer rate. This effect magnifies itself for the case of Fe_2O_3/water nanofluids. Ultimately, at the concentration of 0.65 vol.%, the heat transfer enhancement of about 9% is obtained for Fe_2O_3/water nanofluids in comparison with pure water. Furthermore, the experimental data prove that the addition of low concentrations of CuO and Fe_2O_3 nanoparticles into the water give almost similar heat transfer enhancement for the application in the car radiator. It should also be mentioned that application of nanofluids causes the liquid exits the radiator at lower temperature and also the air gets warmer comparing with the application of pure water.

IV. COMPARISON AND EFFECT OF COOLANT PRESSURE DROP ON PUMPING POWER

Leong et al performed the experimentation on the Performance investigation of an automotive car radiator operated with nanofluid-based coolants (nanofluid as a coolant in a radiator) In this section analyses of the coolant pressure drop and pumping power of a radiator at a fixed coolant flow rate (0.2 m^3/s) and an air Reynolds number of (4000) with varying copper nanoparticles volume fraction is incorporated.

It was observed that the coolant pressure drop increased with the addition of copper nanoparticles. The result reveals that a pressure drop of 110.97 kPa was obtained by adding 2% copper particles compared to a pressure drop of 98.93 kPa for a base fluid. Due to this extra pressure drop, a higher coolant pumping power is needed. The pumping power is calculated by using appropriate correrelations calculated results indicate that about 12.13% increase in pumping power is observed at 2% addition of copper nanofluids compared to a base fluid. These trends are shown in Figs.8 and 9. Increase in density increases pressure drop of flowing liquids. Adding particles in a base liquid increases density of the fluid and augments pressure drop at a low percentage as observed in the present study. Similarly results were reported by Ko et al. [18] and Duangthongsuk and Wongwises [19].

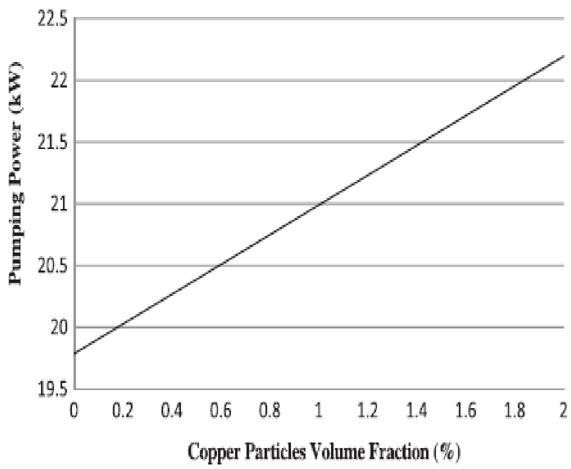

Fig. 9. Influence of copper volume fraction to pumping power at fixed coolant volumetric flow rate.[12]

V. FUTURE SCOPE FOR RESEARCH

- Extensive work has been carried out to check the feasibility of nanofluid as coolant in cross flow heat exchanger particularly in automotive cooling system. The researchers have used the different nanopowders in conventional base fluids with variation in the volume concentration, mass flow rate of coolant, coolant inlet temperature under laminar and turbulent flow conditions. But nobody has prepared the nanofluid by using the conventional base fluid recommended by the heat exchanger manufacture which ultimately describes the close feasibility of nanofluid in actual practical applications. This work directly prepares the hybrid nanofluid which uses the base fluid (coolant) prescribed by the manufacturer with engine compatible additives in addition to mixture of two different nanopowder materials.
- Comparison of the existing research in connection with Performance of Automotive Radiator with Nanofluid based coolant shows that relative increase enhancement occurs with copper nanopowder based nanofluid. As the practical situation approaches towards the turbulent flow, it is necessary to investigate the behaviour of copper based nanofluid under turbulent flow in automotive radiator.
- Exact mechanism of enhanced heat transfer for nanofluids is still unclear as reported by many researchers and parameters related to the nanofluid need to be optimized. However, it should be noted that many challenges need to be identified and overcome for different applications.
- 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.
- A traditional effective medium theory failed to explain the results. More research on the oxide nanofluids may not be needed but there may be some controlling parameter which increases the thermal conductivity we did not recognize. Future research needs to focus on finding out the main parameters affecting the thermal conductivity of nanofluids. The thermal conductivity of nanofluids can be a function of parameters such as particle shape, particle agglomeration, particle poly disparity, etc. In order to clarify these variables, a number of experiments will be necessary as varying only one parameter among the selected parameters.
- The thermal conductivity of oxide nanofluids

may also be affected by the particle shapes. The challenging point is to obtain the desirable nanoparticle product. Currently, the available nanoparticles are limited and their specifications are not accurate.

- The development of the nanoparticle production technique will be very helpful for the nanofluid research. Finally, a theoretical model needs to be developed which explains the empirical data.

VI. CONCLUSION

Presented review deals with the heat transfer augmentation of automotive radiator using nanofluids, following are some of the concluding remarks, Numerous researchers have added nanomaterial's to the working fluid to form a stable suspension and called this stable suspension as "nanofluids", the purpose of which is to obtain excellent thermal conductivity and heat transfer performance in cross flow heat exchanger (radiator) of automotive cooling system. The details of same and their findings are summarized below.

- Heat transfer of coolant flow through the cross flow heat exchanger is of great importance for the optimization of fuel consumption.
- Application of nanofluids instead of water enhances thermal performance of the cross flow heat exchanger.
- Al_2O_3 / Water Nanofluid with low concentrations (0.1 vol.%) can enhance heat transfer efficiency up to 45% in comparison with pure water
- Copper oxide (CuO) and Iron oxide (Fe_2O_3)/Water nanofluid with concentrations 0.15, 0.4, and 0.65 vol.% increases the overall heat transfer coefficient in comparison with water up to 9%.
- Increasing the nanoparticles concentration, air velocity, and nanofluid velocity enhances the overall heat transfer coefficient.
- This new working fluid with higher heat transfer performance would promote the car engine performance and would reduce fuel consumption.
- Therefore, it can be followed by other investigators to optimize the parameters related to nanofluid (nanoparticles material, size, volume concentration, base fluid etc) and eliminate the probable deficiencies for industrialization in the car industries.
- There are various combinations of base fluid and nanopowder have been used as nanofluid coolant and extensive research related to same also found in the literature which enhances the heat dissipation in cross flow heat exchanger with nanofluid.
- Dispersion of the nanoparticles into the base liquid as coolant increases the thermal conductivity and viscosity of the nanofluids, and this augmentation increases with increasing particle concentrations. The significant increase in convective heat transfer coefficient is mainly contributed by increased thermal conductivity of nanofluid and increased convection by molecular collisions. Other parameters like particle size, particle shape, agglomerations and nanolayer also augments heat transfer by convection.
- Nanofluids seem to be potential replacement of conventional coolants in engine cooling system.
- As heat transfer can be improved by nanofluids, in Automobile radiators can be made energy efficient and compact. Reduced or compact shape may results in reduced drag, increase the fuel economy, and reduces the weight of vehicle.
- This new working fluid with higher heat transfer performance would promote the car engine performance and would reduce fuel consumption. Therefore, it can be followed by other investigators to eliminate the probable deficiencies for industrialization in the car industries.
- The overall heat transfer coefficient enhances with the addition of nanoparticles to the base fluid in case of automotive radiator. The optimisation of the nanofluid volume concentration should be addressed

considering the heat transfer enhancement with different materials of nanopowder, nano particle size, base fluid, pressure drop and pumping power.

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