Experimental Investigation of Heat Transfer Characteristics of Automobile Radiator using TiO$_2$-Nanofluid Coolant

V. Salamon$^1$, D. Senthil kumar$^{2*}$, S. Thirumalini$^3$

$^1$Graduate student, $^2$Assistant Professor, $^3$Professor
Department of Mechanical Engineering,
Amrita School of Engineering, Coimbatore
Amrita Vishwa Vidyapeetham, Amrita University, India

Abstract: The use of nanoparticle dispersed coolants in automobile radiators improves the heat transfer rate and facilitates overall reduction in size of the radiators. In this study, the heat transfer characteristics of water/propylene glycol based TiO$_2$ nanofluid was analyzed experimentally and compared with pure water and water/propylene glycol mixture. Two different concentrations of nanofluids were prepared by adding 0.1 vol. % and 0.3 vol. % of TiO$_2$ nanoparticles into water/propylene glycol mixture (70:30). The experiments were conducted by varying the coolant flow rate between 3 to 6 lit/min for various coolant temperatures (50°C, 60°C, 70°C, and 80°C) to understand the effect of coolant flow rate on heat transfer. The results showed that the Nusselt number of the nanofluid coolant increases with increase in flow rate. At low inlet coolant temperature the water/propylene glycol mixture showed higher heat transfer rate when compared with nanofluid coolant. However at higher operating temperature and higher coolant flow rate, 0.3 vol. % of TiO$_2$ nanofluid enhances the heat transfer rate by 8.5% when compared to base fluids.

Keywords: Heat transfer enhancement, Propylene Glycol, Radiator, TiO$_2$ Nanofluid coolant.

1. INTRODUCTION

The conventional heat transfer fluids for radiators such as water and ethylene glycol have poor heat transfer performance due to their low thermal conductivity. Numerous studies have been conducted to improve the heat transfer rate of the coolants. One among them was the suspension of solid metal or metal oxide nanoparticles which can improve the thermal conductivity of the coolant fluid [1]. The nanofluids have high thermo-physical properties and can be a potential replacement for the radiator coolants. Some of the research work done so far has been summarized below.

Peyghambarzadeh et al. [2] performed a heat transfer experiment with water based nanofluid in an automobile radiator and compared the results with pure water. The nanofluid was prepared by addition of Al$_2$O$_3$ nanoparticles in the range of 0.1-1 vol. % into the water. Liquid flow rate to radiator has been varied between 2 to 5 lit/min and the temperature was kept in the range of 37 to 49°C. They observed an increase in heat transfer rate with the presence of Al$_2$O$_3$ nanoparticles in the water and the degree of heat transfer enhancement depends on the amount...
of nanoparticles. At 1% volume concentration 45% enhancement was recorded.

An extensive review on water/ethylene glycol based nanofluids and their applications have been done by Azmi et al. [3]. The authors concluded that many investigations on nanofluids with different types of nanomaterials and based fluids have shown that nanofluids possess better thermal performance. They also found that heat transfer characteristics of nanofluids were influenced by the type of base fluids, ratio of water and ethylene glycol mixture, nanoparticle material, volume concentration, nanoparticle size and flow characteristics.

Peyghambarzadeh et al. [4] measured the overall heat transfer coefficient of copper oxide (CuO) and iron oxide (Fe$_2$O$_3$) nanoparticles suspended in water. They prepared the nanofluids at different pH level of water to get a stable suspension of the particles. The experiment was conducted by varying the liquid side and air side Reynolds number. It is found that overall heat transfer increased by 9% with the addition of nanoparticles. Leong et al. [5] investigated the performance of automotive car radiator operated with nanofluid based coolants. Ethylene glycol based copper nanofluid is used for the study of heat transfer characteristics. The authors concluded that heat transfer rate increases with increase in nanoparticle concentration; about 3.8% of heat transfer enhancement was achieved with addition of 2% copper nanoparticles. It is also estimated that 18% of frontal area can be reduced with addition of 2% of copper nanoparticle into the coolant.

Mekala Chandra Sekhara Reddy et al. [6] performed a forced convective heat transfer study in an automobile radiator with ethylene glycol and water based TiO$_2$ nanofluid. The nanofluid was prepared by taking 40:60 (EG:W) mixture as base fluid and dispersing TiO$_2$ nanoparticles at 0.1%, 0.3% and 0.5% by volume concentration. They observed 37% enhancement in heat transfer rate at 0.5% TiO$_2$ when compared to base fluid. Ibrahim Palabiyik et al. [7] conducted experiments to analyze dispersion stability and thermal conductivity of propylene glycol based nanofluids. Aluminum oxide (Al$_2$O$_3$) and Titanium oxide (TiO$_2$) nanoparticles were dispersed into propylene glycol using two-step method. The authors reported that the thermal conductivity increases non-linearly with particle concentration and the nanoparticles in base fluid was stable without any sedimentation.

Vivek et al. [8], [9] studied the heat transfer characteristics of Al$_2$O$_3$/water-ethylene glycol nanofluid coolant in automobile radiator. Heat transfer enhancement of about 37% was obtained with 0.1% of Al$_2$O$_3$ nanoparticles. They also conducted experiments with water/propylene glycol mixture as base fluid. An enhancement of 9% in the overall heat conductance was obtained with addition of 0.2% alumina nanoparticles into propylene glycol based coolant fluid.

It is seen that most of the research work done so far well based on water and water/ethylene glycol base nanofluids. Propylene glycol a non-toxic antifreeze agent is taken for the study as an alternative for ethylene glycol due to its ecofriendly characteristics. In this paper, the heat transfer characteristics of the radiator using water/propylene glycol based TiO$_2$ nanofluid coolant was analyzed experimentally. The heat transfer rate and the Nusselt number behavior of the nanofluid was compare with pure water and base coolant fluid mixture.
2. EXPERIMENTAL METHODOLOGY

2.1 Experimental Setup

The heat transfer rate of the nanofluid coolant was measured using an experimental setup as shown in Fig. 1. It consists of a car radiator, an electric heater, a reservoir tank, a centrifugal pump, an air blower, flow control valves and K-type thermocouples to measure inlet and outlet fluid temperature.

An electrical heater of 2 kW was used to heat the coolant in the reservoir tank. The coolant was circulated using a 0.5 HP centrifugal pump. A globe valve was used to vary the flow rate of the coolant fluid entering the radiator in between 3-6 lit/min. Two K-type thermocouples were placed at the inlet and the outlet of the radiator to measure the coolant temperatures. Thermocouples were also fixed on both the sides of the radiator wall surface to measure air temperatures.

2.2 Experimental Procedure

The forced convective heat transfer experiment was conducted in the radiator experimental setup using pure water, water/propylene glycol mixture (70:30), and water/propylene glycol/TiO$_2$ nanofluid (0.1% and 0.3% by volume). The coolant in the reservoir tank was heated up to the desired temperature and circulated through the radiator using the pump. The inlet temperature of the coolant to the radiator is kept constant at the nominal operating temperature range between 50°C to 80°C. The coolant flow rate was varied between 3 to 6 lit/min. The air flow rate to the radiator was kept constant at an average of 4 m/s. The outlet temperature of the coolant was recorded using K-type thermocouple. Furthermore K-type thermocouples were fixed on the radiator wall on both the sides to record the air temperature.

![Fig. 1 Schematic view of experimental setup](image)

3. NANOFLUID PREPARATION

Titanium dioxide (TiO$_2$) nanofluid was prepared in two different concentrations 0.1% and 0.3% by volume of the base fluid using two-step method to understand the effects of particle concentration on heat transfer rate. The base fluid was the mixture of water and propylene glycol in the ratio 70:30. The dry nanoparticles were added directly in the base fluid at required concentrations. The dispersion process was carried out using probe ultrasonicator ENUP 250.
The nanofluid was subjected to ultrasonication in the frequency of 20Hz for the duration of 6 hours.

The density, specific heat and thermal conductivity of nanofluid were calculated using two phase flow equations [10], [11].

\[ \rho_{nf} = \rho_p + (1 - \phi) \rho_b f \]  

(1)

\[ C_{p,nf} = (1 - \phi) \frac{C_{p,bf}}{\rho_b f} + \phi \frac{C_{p,p}}{\rho_b f} \]  

(2)

\[ k_{nf} = \frac{k_{p} + \phi(1 - \phi)k_{b} - \phi(1 - \phi)k_{b}}{k_{p} + \phi(1 - \phi)k_{b}} k_{bf} \]  

(3)

\[ \phi \] is the volume concentration and \[ \rho \] is the density.

\[ k \] is the thermal conductivity and \[ \phi \] is the shape factor of the nanoparticles.

4. HEAT TRANSFER CALCULATIONS

The heat transfer rate and the Nusselt number of the coolant were calculated by the following procedure. According to Newton’s law of cooling

\[ Q = hA \Delta T = hA_s(T_b - T_s) \]  

(4)

Where \( h \) is the overall heat transfer coefficient and \( A_s \) is the surface area of the tube, \( T_b \) is the bulk temperature

\[ T_b = \frac{T_i + T_o}{2} \]  

(5)

\( T_s \) is the tube wall temperature, obtained by the average of both the side thermocouples

\[ T_s = \frac{T_{in} + T_{out}}{2} \]  

(6)

Heat transfer rate is given by

\[ Q = mC_p \Delta T = mC_p(T_i - T_o) \]  

(7)

Where \( m \) is the mass flow rate of the coolant and \( C_p \) is the specific heat

The overall heat transfer coefficient can be obtained from the equation (4) & (7)

\[ h_{exp} = \frac{mC_p(T_i - T_o)}{A_s(T_b - T_s)} \]  

(8)

Nusselt number can be calculated by

\[ Nu = \frac{h_{exp} \times \Delta T}{k} \]  

(9)

\( D_h \) is the hydraulic diameter of the flat tube and \( k \) is the thermal conductivity of coolant fluid

5. RESULT AND DISCUSSION

5.1 Effect of flow rate on Nusselt number

The comparison of Nusselt number among TiO_2 nanofluid and base fluid at different temperatures and mass flow rate was shown in Fig. 2. It was observed that the Nusselt number
increases with increase in mass flow rate for both base fluid and nanofluid concentrations. Initially at 50°C of coolant inlet conditions the water/propylene glycol mixture has highest Nusselt number. The nanoparticles did not have much influence on the Nusselt number at lower inlet temperatures. The Nusslet number of nanofluids increases gradually with inlet temperature and at 80°C the nanofluid with 0.3% TiO$_2$ has highest Nusselt number as shown in Fig. 2 (d). This shows that the TiO$_2$-nanofluids have good conduction to convective ratio at higher temperature and flow rate. The particle concentration in nanofluid shows that, at 0.1% the Nusselt number does not show improvement when compared to water/propylene glycol mixture. When concentration increases to 0.3% the Nusselt number also increases above that of the base fluid.

Fig. 2 Effect of flow rate on Nusselt number (a) at 50°C (b) at 60°C (c) at 70°C (d) at 80°C
5.2 Effect of flow rate on Heat Transfer rate

The heat transfer rate of TiO$_2$ nanofluid coolant was compared with pure water and water/propylene glycol mixture. Fig. 3 illustrates that heat transfer rate of TiO$_2$ nanofluid increases with increase in volume flow rate. Initially at lower inlet temperature at 50°C the water and propylene glycol mixture shows higher heat transfer rate than nanofluids this was due to the high specific heat capacity and low density of water and base fluid mixture. When inlet temperature increases the heat transfer rate of nanofluid gradually increases due to the Brownian motion of nanoparticles. The density of coolant fluid decreases at higher temperature so that the random motion of nanoparticles increases and the particle comes in contact with surface of the fins which leads to increase heat transfer rate. Fig. 3 (d) shows that at 80°C of inlet conditions the nanofluid with 0.3% TiO$_2$ has highest heat transfer rate. Therefore heat transfer enhancement in TiO$_2$ nanofluid occurs at higher temperature and flow rate.

Fig. 3 Effect of flow rate on heat transfer rate (a) at 50°C (b) at 60°C (c) at 70°C (d) at 80°C
6 CONCLUSION

The forced convective heat transfer experiment have been performed in an automobile radiator using pure water, water/propylene glycol mixture and water/propylene glycol/TiO$_2$ nanofluid at two different concentrations and the following conclusions were obtained.

1. The experimental results shows that the Nusselt number behavior of the nanofluid was highly depend on the volume flow rate and a highest Nusslet number of 14.4 have been observed at 6 lit/min flow rate at 80°C inlet temperature.
2. The Nusslet number enhancement of 8.3% was obtained by addition of 0.3% of TiO$_2$ nanoparticles in the base coolant mixture.
3. Heat transfer rate increases with increase in nanoparticles concentration at higher operating temperatures and coolant flow rate.
4. The heat transfer enhancement of about 8.5% was achieved with addition 0.3% of TiO$_2$ nanoparticles at 80°C coolant inlet temperature.
5. The results shows that the nanofluid coolants have tendency to remove heat from the engines at higher operating temperatures and flow rate effectively which makes it suitable for heavy duty engines.

ACKNOWLEDGMENT

The authors gratefully acknowledge International Advanced Research Center for Powder Metallurgy and new materials (ARCI), Hyderabad, for providing nanoparticles for the research work.

REFERENCES

[1] S. Senthilraja, M. Karthikeyan and R. Gangadevi, “Nanofluid applications in future automobiles: comprehensive review of existing data”, Nano-Micro Letter, Volume 2, 306-310, 2010.
[2] S.M. Peyghambarzadeh, S.H. Hashemabadi, M. SeifiJamnani, S.M. Hoseini, “Improving the cooling performance of automobile radiator with Al$_2$O$_3$ /water nanofluid", Applied Thermal Engineering 31, 1833–1838, 2011.
[3] W.H. Azmi, K. Abdul Hamid, N.A. Usri, RizalmanMamat, and K.V. Sharma . “Heat transfer augmentation of ethylene glycol: water nanofluids and applications - a review”, International Communications in Heat and Mass Transfer 75, 13–23, 2016.
[4] S.M. Peyghambarzadeh, S.H. Hashemabadi, M. Naraki, Y. Vermahmoudi, “Experimental study of overall heat transfer coefficient in the application of dilute nanofluids in the car radiator”, Applied Thermal Engineering 52, 8-16, 2013.
[5] K.Y. Leong, R. Saidur, S.N. Kazi, and A.H. Mamunc, “Performance investigation of an automotive car radiator operated with nanofluid based coolants”, Applied Thermal Engineering 30, 2685-2692, 2010.
[6] DevireddySandhya, Mekala Chandra Sekhara Reddy, and VeeredhiVasudevaRao, “Improving the cooling performance of automobile radiator with ethylene glycol water based TiO$_2$nanofluids”, International Communications in Heat and Mass Transfer 78,121–126, 2016.
[7] Ibrahim Palabiyik, ZenfiraMusina, SanjeevaWitharana, and Yulong Ding, “Dispersion stability and thermal conductivity of propylene glycol based nanofluids”, J Nanopart Res 13, 5049–5055, 2011.

[8] KotiJeevith, M. Vivek, S. Thirumalini, “Study of heat transfer characteristics of Al₂O₃/water-Propylene glycol nanofluid as a coolant in an automobile radiator”, International Journal of Applied Engineering Research, Volume 10, pp 36204-36208, 2015.

[9] K.P. VasudevanNambeesan, M. Vivek, S. Thirumaliniet. al., “Experimental study of heat transfer enhancement in automobile radiator using Al₂O₃/water-ethylene glycol nanofluid coolant”, International Journal of Automotive and Mechanical Engineering, Volume 12, pp. 2857-2865, 2015.

[10] W. Duangthongsuk, S. Wongwises, “Effect of thermo-physical properties models on the predicting of the convective heat transfer coefficient for low concentration nanofluid”, Internal Communication of Heat Mass Transfer 35, 1320-1326, 2008.

[11] X. Wang, X. Xu, S.U.S. Choi, “Thermal conductivity of nanoparticles fluid mixture”, Journal of Thermo physical Heat Transfer, 13 (4), 474-480, 1999.

V. Salamon, pursuing Master of Technology in Automotive Engineering in Amrita School of Engineering, Coimbatore, India. He completed his B.E. in Mechanical Engineering from SVS college of Engineering, Coimbatore, Tamilnadu. He has presented a paper in national conference.

Mr. D. Senthil Kumar, working as Assistant professor, Department of Mechanical Engineering, Amrita school of Engineering, Coimbatore, India. Now he is pursuing his PhD in Amrita VishwaVidyapeetham University, Coimbatore. He received his Master degree in Thermal Engineering from Annamalai University. Earlier he completed his B.E degree from Bharathidasan University, Trichy. He has teaching experience of 12 years and his research interest are Engine testing, IC engines, and Alternate fuels. He has published around 12 papers in the international conferences and journals. He is a member of ISTE and SAE. (Email: d_senthilkumar@cb.amrita.edu)
Dr. S. Thirumalini, working as Professor and Chairperson, Department of Mechanical Engineering, Amrita School of Engineering, Coimbatore, India. She has completed her doctoral degree from Coimbatore Institute of Technology, Bharathiyar University during 2008. She obtained her master degree and undergraduate degree both from Coimbatore Institute of Technology, Bharathiyar University. She has nearly 21 years of teaching experience. Her research interest are, Engine testing, IC Engines, CFD. She has nearly 25 publications in reputed journals and international conferences. She got Best Engineer Award by “The Institution of Engineers (India) on September 2008. She got Ralph R Teetor Educational Award and Guru Award from SAE international during 2010 and 2014 respectively. She is a member of Board of studies in undergraduate and postgraduate level programmes.