IMECE2014-36964

Enhancement of Heat Transfer Coefficient in an Automobile Radiator Using Multi Walled Carbon Nano Tubes (MWCNTS)

Ramgopal Varma Ramaraju [1*], Ph.D
Senior Lecturer,
Faculty of Engineering Technology,
University Malaysia Pahang
Gambang, Pahang, Malaysia
ramgopal@ump.edu.my

Manikantan Kota[1]
Research Engineer
Sun Tech Solutions, Hyderabad,
Andhra Pradesh, India.
manikantan_kota@hotmail.com

Hadi Bin Manap[1], Ph.D
Senior Lecturer,
Faculty of Engineering Technology,
University Malaysia Pahang
Gambang, Pahang, Malaysia
hadi@ump.edu.my

Vasudeva Rao Veeredhi[2], Ph.D
Professor
Department of Mechanical and
Industrial Engineering
CSET, University of South Africa,
Johannesburg, South Africa
v_vasudevarao@yahoo.com

ABSTRACT

Enhancement of heat transfer coefficient continues to be an important research area in various fields of engineering ranging from microelectronics to high powered automobiles. The initial effort in the present research study is to enhance the heat transfer coefficient in a vehicle radiator using nanofluids with high thermal conductivity. The world's most abundant element 'Carbon' astoundingly exists in various structures and one such form is tube commonly known as **Carbon Nanotubes** (CNTs). Heat transfer enhancement in water and coolant based systems with different concentrations of nano particles (carbon nanotubes) have been investigated from an engineering system perspective. One such system considered is a "SUZUKI (800CC) - CAR RADIATOR", cooling circuit using different nanofluids to replace the conventional engine coolant. In the present study, the effect of nano-fluid heat transfer to enhance in water and coolant based systems with multi walled carbon nanotubes has been investigated. The improvement of heat transfer when compared to water, coolant (water + ethylene glycol 60:40) and water with MWCNTS and coolant with MWCNTS has been studied.

It has been observed that there is an enhancement of heat transfer up to 30% when coolant and CNTS are used as a cooling medium.

KEYWORDS

HEAT TRANSFER, CARBON NANOTUBES, AUTOMOBILE RADIATOR, NANOFLUID.

INTRODUCTION

Conventional Coolants have been widely employed to dissipate heat in majority of the engineering applications. Typical coolants include three states of matter namely solid, liquid and gas based on the application and mode of heat transfer. However, with the latest technological advancements an emerging class of new coolants NANOCOOLANTS (Coolant with nano particles dispersed) find their applications in macro and microscopic scale. Nanofluids, find their application in a variety of engineering applications. A typical nanofluid is prepared by dispersing nano particles in the base fluid (water, ethylene glycol, coolant) with different volume concentrations.

[1] Faculty of Engineering Technology, University Malaysia Pahang, Gambang, Pahang, Malaysia
[2] Department of Mechanical and Industrial Engineering, CSET, University of South Africa, Johannesburg, South Africa

The specific advantages of the nano fluids include enhanced thermal properties when compared with the base fluid. Usage of additives in coolants has been employed from decades to enhance the heat transfer phenomenon and reduce the pressure head. However, enough care is to be exercised when additives are employed since they not only improve the heat transfer but also responsible to the loss of life cycle of the components by fouling and other factors like loss of pressure head, sedimentation and more. With the increased demands for higher power and exhaust gas regulations necessity for hybrid vehicles and vehicles with higher power are increasing enormously. On the other hand only 60 % of the heat developed during combustion is utilized for generating useful power and remaining heat is transferred to exhaust. Hence there is a necessity to regulate this heat and maintain the temperature of the engine so as to enhance the performance. The common additives in cooling system of an automobile include ethylene glycol which improves the properties of water like freezing point and boiling point. Majority of the automobile radiators uses a liquid cooling system where water with ethylene glycol is employed as cooling medium to transfer the excess heat from the engine. However, such conventional coolants provide inadequate heat transfer and therefore a necessity for high performing thermal system arises. This can be achieved by increasing the size of the thermal system/cooling system. Due to the stringent design conditions, increased frontal areas, drag coefficients, in an automobile, the necessity for improving the heat transfer phenomenon in the cooling medium is becoming essential. To present the state of the art a review has been carried highlighting the contributions of each article and summarized below.

In the review article by Gabriela Huminic and Angel Huminic[1], which summarizes the important published articles on the enhancement of the convective heat transfer in heat exchangers using nanofluids on two topics. One focuses on presenting the theoretical and other on experimental results for the effective thermal conductivity, viscosity and the Nusselt number on application of nanofluids in various types of heat exchangers like plate heat exchangers, shell and tube heat exchangers, compact heat exchangers and double pipe heat exchangers. A similar study on the nanofluids with correlations developed for heat transfer and friction factor for different kinds of nanofluids flowing in a plain tube under laminar to turbulent flow conditions have been compiled. It is reported about the correlations developed for the estimation of heat transfer coefficient and friction factor of nanofluid in a plain tube with inserts under laminar to turbulent flow conditions in [2]. Thermophysical properties and heat transfer characteristics in forced convective heat transfer in nanofluids are reviewed and the specific applications of nanofluids are presented

in [3]. Experimental investigation on the heat transfer characteristics of γ-Al_2O_3/water and TiO_2/water nanofluids were conducted in a shell and tube heat exchanger under turbulent flow condition by Farajollahi*et al* [4]. It has been concluded that nanoparticle with small mean diameter (TiO_2 nanoparticle) has a lower optimum volume concentration. TiO_2/water and γ-Al_2O_3/water nanofluids possess better heat transfer behavior at the lower and higher volume concentrations, respectively. The heat transfer coefficient and friction factor of the TiO_2–water nanofluid flowing in a horizontal double-tube counter flow heat exchanger under turbulent flow conditions are investigated by Duangthongsuk and Wongwises [5]. The results show that the convective heat transfer coefficient of nanofluid is slightly higher than that of the base liquid to an extent of 6–11%. The heat transfer coefficient of the nanofluid increases with an increase in the mass flow rate of the hot water and nanofluid, and increases with a decrease in the nanofluid temperature, and the temperature of the heating fluid has no significant effect on the heat transfer coefficient of the nanofluid. In the works of Zamzamian*et al* [6], nanofluids of aluminum oxide and copper oxide were prepared with ethylene glycol as base fluid and the convective heat transfer coefficient of the nanofluids using theoretical correlations is compared with the experimental data from a double pipe heat exchanger. It has been reported that the enhancement in convective heat transfer coefficient of the nanofluids as compared to the base fluid is ranging from 2% to 50%. Similar study on the enhancement of heat transfer coefficients can be seen in the works of Naphon, Assadamongkol and Borirak[7]. They studied enhancement of heat pipe thermal efficiency with nanofluids. Titanium nanoparticles of 21nm in size were chosen and effect of %charge of working fluid, heat pipe tilt angle and % nanoparticles volume concentrations on the thermal efficiency of heat pipe are considered. In the works of Noie*et al* [8], a two-phase closed thermo syphon (TPCT) was considered as a heat transfer device and Al_2O_3 nano fluid is considered as working fluid at concentrations of 1-3%. It has been reported that the efficiency of the TPCT increases up to 14.7% when Al_2O_3/water nanofluid was used in comparison to the base fluid water. Jung *et al* [9], conducted experiments on the enhancement of the convective heat transfer coefficient with nanofluids flowing in micro channels. It has been found that Nusselt number increases with increase in the Reynolds number in laminar flow regime. In the study, by Tam, Ghajar[10], the heat transfer behavior in the transition region for plain horizontal tubes under a uniform wall heat flux boundary condition are considered. The influence of inlet configuration and free convection super imposed on the forced convection (or mixed convection) at the start and end of the transition region and the magnitude of heat transfer are addressed.

The applicability of existing correlation in the transition region based on a comparison with an extensive set of experimental data was established. In the works of Sajadi, A.R. and Kazemi[12], a new correlation for the Nusselt number is presented using the results of the experiments with titanium dioxide nanoparticles dispersed in water. Titanium dioxide/water nanofluid was used as a working fluid in a circular pipe where the volume fraction of nanoparticles in the base fluid was less than 0.25%. Nguyen et al [13], investigated the behavior and heat transfer enhancement of Al_2O_3 nanofluid, flowing inside a closed system for cooling of microprocessors or other electronic components. The heat transfer coefficient has been found to increase as much as 40% compared to that of the base fluid at 6.8 % volume concentration. It has also been found that an increase of particle concentration has produced a clear decrease of the heated component temperature. Nanofluid with 36 nm particle diameter provides higher heat transfer coefficients than nanofluid with 47 nm particle size. Leong et al [14], studied the application of nanofluids as working fluids in shell and tube heat recovery exchangers in a biomass heating plant. The observed increase in heat transfer coefficient was 7.8% when 1% copper nanoparticles in ethylene glycol based fluids are used. Park and Jung[15], observed the enhancement of nucleate boiling heat transfer in refrigerants for building chillers by adding about 1% CNTS to refrigerants R123 and R134a. Tests concluded that CNTS enhanced the heat transfer coefficients for these refrigerants up to 36.6% at low heat fluxes. Kulkarni et al [16], conducted experiments to determine how nanofluid heat transfer characteristics get enhanced as volume concentration is increased. Experiments were performed on copper oxide, aluminum oxide and silicon dioxide nanofluids, each in an ethylene glycol and water mixture. The analysis concluded that by using nano fluids excess pumping power can be saved by reducing the volumetric and mass flow rates. In the works of, Qijun Yu et al [17], an engineering model has been formulated to study the effects of porosity and pore diameter on the thermal efficiency of the carbon foam finned heat exchanger. In this study enhancement of 15% in the thermal performance is observed to the conventional aluminum finned-tube radiators, without changing the frontal area, or the air flow rate and pressure drop. Harris et al [18], designed and developed a micro cross flow heat exchanger to maximize the heat transfer between working fluid and air. They also predicted the performance of the plastic, ceramic and aluminium heat exchangers to the current car radiators. In the study of Joardar and Jacobi [19], a delta wing type vortex generator is experimentally tested in a wind tunnel for a compact heat exchanger. The heat transfer and pressure drop are assessed successfully in dry and wet conditions and vortex generator method is proven to be improving the thermal-hydraulic performance. Yulong Ding et al [20], has observed significant enhancement of the convective heat transfer in a horizontal tube using CNT nanofluids. It has been reported that this enhancement is attributed to the flow conditions mainly due to Reynolds number, CNT concentration and the pH value. For a nanofluid containing 5% weight CNTs, the enhancement reaches over 350 % at Re 800.

In a typical cooling system of an automobile radiator, the cooling medium is pumped into the exchanger by a pump and heat transfer takes place from the hot fluid and in to the forced air which is drawn over the passage of the tubes where this cooling medium is being carried. A number of fins are arranged to convect away heat. A few papers on the application of the nano fluids in automobile radiators can be seen in [21-25]. However the necessity for improvement made the authors to investigate further with different concentrations of nano particles and different operating conditions. Earlier research articles were restricted to the laminar flow of the coolant which is rarely observed in automobiles. Hence in the present research the Reynolds number of the cooling medium is maintained at transition region. On the other hand, the value of pH in the fluid is more than 7, which makes the fluid to be acidic assisting in corrosion and fouling of the channels, reported in the earlier studies. With the considerations above and varying factors the present research has been carried out to investigate the performance of the automobile radiator using the test rig developed for the purpose.

NOMENCLATURE

A = Area, m^2

C = Specific Heat, $J/_{kg} K$

D = Inner diameter of the tube, m
d = Diameter of the helical coil, m
f = Friction factor

h = Heat transfer coefficient, $W/_{m^2} K$

k = Thermal conductivity, $W/_m K$
L = Length of the tube, m

m = Mass flow rate, $kg/_{sec}$

Nu = Nusselt number, $^{h D}/_k$

Pr = Prandtl number, $^{\mu C}/_k$

Re = Reynolds number, $^{4 m}/_{\pi D \mu}$

Q = Heat flow, Watts
T = Temperature, $°C$
v = Velocity, $m/_{sec}$

Greek Symbols:

δ Uncertainity
ΔT Temperature difference

Δp Pressure drop

φ Volume concentration of nanoparticles

μ Dynamic viscosity, $\frac{kg}{m^2}$ sec

ρ Density, $\frac{kg}{m^3}$

Subscripts:

bf   Base fluid

c   Cold fluid

Exp   Experimental

h   Hot fluid

i   inlet

nf   Nano fluid

o   outlet

PREPARATION OF NANO FLUID

The fluid utilized in the current research is prepared by using carbon nanotubes procured from [26] in volumetric concentration and 40:60 EG + water and coolant as base fluids individually. The volumetric concentration of the nano particles is calculated as using the following formula,

$$Volumetric\ Concentration\ \varphi \ \times 100 = \left[\frac{\frac{W_P}{\rho_P}}{\frac{W_P}{\rho_P}+\frac{W_F}{\rho_F}}\right] \qquad (1)$$

The CNTs are initially treated with HNO3: H2SO4 in 1:1 ratio to attach functional groups for improving the suspendability of CNTs in base fluid. The functionalized CNTs are added to 500ml of DI water and sonicated in bath type ultra sonicator. This initial Sonication is done to individualize the CNTs in the base fluid. A surfactant, CTAB is then added immediately and further sonicated for 30minitues. The hydrophobic ends of the surfactant surround the individual CNTs and construct a uniform dispersion of CNTs in base fluid. A mechanical stirrer is employed to stir the nanofluid continuously for about 6 hours accounting for uniform dispersion. However, a surfactant C-TAB (Cetyl Trimethyl Ammonium Bromide) equal to the weight of the nano particles was also added. The volumetric concentration of 0.02vol% of carbon nanotubes for water/EG and coolant in 5 liters each are prepared for the present experimentation. The properties of the nano fluid and the base fluid are given in Table 1.

Table 1 Properties of the nano fluid and base fluid at 30° C

Material	Density kg/m³	Viscosity m Pa sec	Specific heat k J/kg K	Thermal Conductivity W/m K
MWCNTS	180.0	--	6.693	14.25
EG	1100.0	0.0161	2.2	0.2530
Water	1000.0	0.0008	4.184	0.6130
Air	1.1839	0.000018	1.005	0.024
EG 50	1055.3	0.00226	3.502	0.4120
+50 Water				
0.02 % MWCNTS	977.2	0.00116	4.197	0.6761

NANOFLUID PROPERTIES

Nanofluid is prepared by dispersing CNTs in DI water and also in coolant. Properties of the nanofluid like thermal conductivity, viscosity, density and specific heat were estimated through the equations available in the literature. Solid-fluid homogeneous models for density and specific heat of nanofluid are given below:

$$\rho_{nf} = \left(1 - \frac{\varphi}{100}\right)\rho_{bf} + \frac{\varphi}{100}\rho_p \qquad (2)$$

$$C_{nf} = \left(1 - \frac{\varphi}{100}\right)C_{bf} + \frac{\varphi}{100}C_p \qquad (3)$$

Absolute viscosity of nanofluid is estimated from Einstein [27] model which is given below:

$$\mu_{nf} = \mu_{bf}\left(1 + \frac{5}{2}x + \frac{\varphi}{100}\right) \qquad (4)$$

Thermal conductivity of nanofluid is estimated from Maxwell model [28] and is given by the following equation.

$$k_{nf} = k_{bf}\left[\frac{k_p + 2\,k_{bf} + 2\frac{\varphi}{100(k_p - k_{bf})}}{k_p + 2\,k_{bf} - \frac{\varphi}{100(k_p - k_{bf})}}\right] \qquad (5)$$

EXPERIMENTAL ANALYSIS

The experimental test setup to simulate the heat exchange process has been built and developed using commercially available automobile parts. The developed test setup consists of a coolant storage tank, an industrial heater, a high temperature durable pump, a radiator, a fan, thermocouples, anemometer, and a temperature indicator to record the temperatures. The schematic view and the developed test set-up are given in Fig 1.a, Fig 1.b. The coolant in the tank is heated up to the desired temperature and the pump is switched on allowing the coolant to flow through the radiator. The fan is switched on for heat dissipation in the heat exchanger. The temperatures are recorded at the inlet and out let of the radiators collecting chamber. The nano fluid is assumed to be flowing through with a uniform Reynolds number assuming no mal distribution in the channels of the radiator. The coolant flows through the 3 rows of 104 tubes each of φ 5 mm and length of 0.3 m. The coolant is allowed to flow with three levels of flow rate 6L/min, 4L/min and 2L/min. The velocity of air has also been varied according to three levels 4m/s, 3m/s and 2m/s.

The necessity for varying the flow rates of coolant and air is to simulate the operating conditions of an automobile to the possible extent during varying engine loads. Temperature of air entering the radiator and leaving the radiator has been recorded. The heat generation is simulated by using an industrial heater where the range has been set up from 39°C to 95° C. Once the required temperature (95° C) is attained the high temperature durable coolant pump is switched on facilitating the circulation of the coolant across the heat exchanger through a nonreturn flow control valve. A set of 6 K type thermocouples have been used to record the temperatures of 1) the coolant tank 2) inlet chamber (collecting) of the radiator 3) exit chamber (collecting) of the radiator 4) one closely placed near the passage tubes of the radiator and 5) two thermocouples one in the front and another in the rear side of the radiator to record the temperature of the air. The temperature recorded by thermocouple placed near the passage tube at the center of the radiator is to assess the heat lost and to calculate the bulk temperature. All the thermocouples, the temperature recorder, and anemometer were calibrated prior to the experimentation.

Figure1a Schematic view of an automobile radiator and cooling circuit test rig.

Figure1b Photograph of an automobile radiator and cooling circuit test rig.

EXPERIMENTAL HEAT TRANSFER COEFFICIENT

Rate of heat flow from the hot fluid and transferred to the cold fluid are calculated based on the following equations which are given below.

$$Q_h = m_h \times C_h \times (T_{h,o} - T_{h,i}) \quad (6)$$

$$Q_c = m_c \times C_c \times (T_{c,o} - T_{c,i}) \quad (7)$$

$$Q_{average} = \frac{Q_h + Q_c}{2} \quad (8)$$

The amount of heat lost between hot and cold fluids was found as ±2.5%. Experimental heat transfer coefficient for nanofluid in a tube with and without inserts is calculated based on the Newton's law of cooling and the expression is given below

$$h_{Exp} = \frac{Q_{average}}{A\,(\Delta T)_{LMTD}} \quad (9)$$

$$(\Delta T)_{LMTD} = \frac{(T_{h,i} - T_{c,o}) - (T_{h,o} - T_{c,i})}{ln\left(\frac{T_{h,i} - T_{c,o}}{T_{h,o} - T_{c,i}}\right)} \quad (10)$$

$$Nu_{Exp} = \frac{h_{Exp} \times D}{k} \quad (11)$$

The following are some of the important correlations available in the literature and presented in the literature review.

Gnielinski [10] correlation for single phase fluid

$$Nu = \frac{\left(\frac{f}{2}\right)(Re - 1000)Pr}{1 + 12.7\left(\frac{f}{2}\right)^{0.5}\left(Pr^{\frac{2}{3}} - 1\right)}$$

$$f = (1.58\,ln(Re) - 3.82)^{-2}$$

$$2300 < Re < 5 \times 10^6$$

$$0.5 < Pr < 2000 \quad (12)$$

Tam and Ghajar [11] correlation for single phase fluid
$$Nu = 0.023\,Re^{0.8}Pr^{0.385}\left(\frac{L}{D}\right)^{-0.0054} * \left(\frac{\mu_b}{\mu_w}\right)^{0.14}$$

$$3 \leq \frac{L}{D} \leq 192$$

$$7000 \leq Re \leq 49000$$

$$4 \leq Pr \leq 34$$

$$1.1 \leq \frac{\mu_b}{\mu_w} \leq 1.7 \quad (13)$$

Duangthongsuk and Wongwises [5] correlation for nanofluid

$$Nu = 0.074 \, Re^{0.707} Pr^{0.385} \varphi^{0.074}$$

$$3000 < Re < 18000$$

$$0 < \varphi < 2.0\ \% \qquad (14)$$

Sajadi and Kazemi [12] correlation for nanofluid

$$Nu = 0.067 \, Re^{0.71} Pr^{0.35} + 0.0005 \, Re \quad (15)$$

$$5000 < Re < 30000$$

$$0 < \varphi < 2.5\ \%$$

A systematic error analysis is made to estimate the errors associated in the experimental analysis like Reynolds number, heat flux, heat transfer coefficient, Nusselt number and friction factor following the procedure detailed by Beckwith *et al*. [29] and the detailed analysis is shown below.

Reynolds number,

$$Re = \frac{4\,m}{\pi\,D\,\mu} \qquad (16)$$

$$\frac{\delta_{Re}}{Re} = \sqrt{\left(\frac{\delta_m}{m}\right)^2 + \left(\frac{\delta_\mu}{\mu}\right)^2} = \sqrt{(0.00001)^2 + (0.1)^2} = 0.1\ \%$$

$$q = \frac{P}{A} = \frac{V \times I}{\pi\,D\,L}$$

Heat flux,

$$q = \frac{\left(\frac{V^2}{R}\right)}{\pi\,D\,L}$$

$$\frac{\delta_q}{q} = \sqrt{\left(\frac{2\,\delta_v}{v}\right)^2 + \left(\frac{\delta_R}{R}\right)^2}$$

$$= \sqrt{(2 \times 0.04545)^2 + (0.1876)^2}$$

$$= 0.2\ \% \qquad (17)$$

Heat transfer coefficient,

$$h_{Exp} = \frac{Q_{average}}{A\,(\Delta T)_{LMTD}}$$

$$\frac{\delta_h}{h} = \sqrt{\left(\frac{\delta_q}{q}\right)^2 + \left(\frac{\delta_{(\Delta T)_{LMTD}}}{(\Delta T)_{LMTD}}\right)^2}$$

$$= \sqrt{(0.2)^2 + (-0.09)^2}$$

$$= 0.22\ \% \qquad (18)$$

Nusselt number,

$$Nu = \frac{h\,D}{k}$$

$$\frac{\delta_h}{h} = \sqrt{\left(\frac{\delta_h}{h}\right)^2 + \left(\frac{\delta_k}{k}\right)^2}$$

$$= \sqrt{(0.22)^2 + (0.1)^2} = 0.25\ \% \quad (19)$$

RESULTS AND DISCUSSION

The variation of non-dimensional heat transfer coefficient Nu is represented as a function of Re in Fig. 2a. The results of heat transfer coefficient are plotted for the base fluid (Water plus Ethylene Glycol) alone and base fluid plus desired quantity of CNT. As a general trend the Nusselt number increased with Reynolds number for both the cases. The Reynolds number is varied in the range from 2000 to 7500. While the variation of Nusselt number is comparable to one another, for the case of base fluid and base fluid plus CNT, it can be seen that consistently base fluid plus CNT mixture exhibited higher value of heat transfer coefficient at all data points.
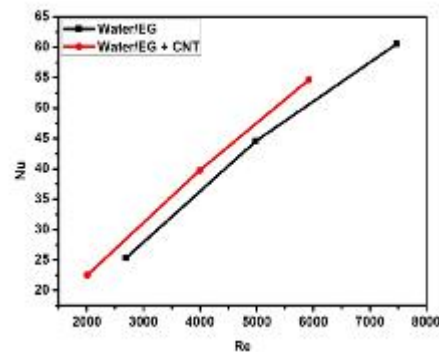

Fig.2a Variation of Nusselt number as a function of Reynolds number for base fluid with and without MWCNTS
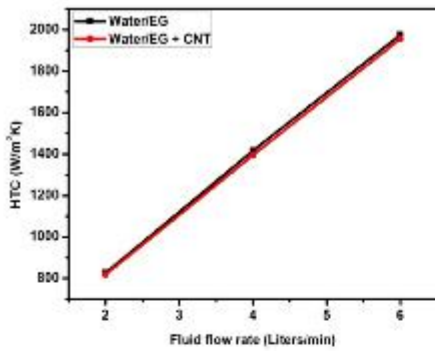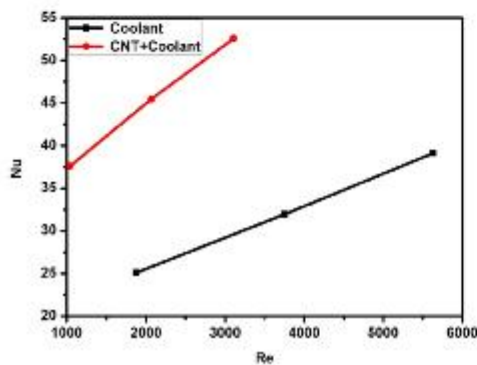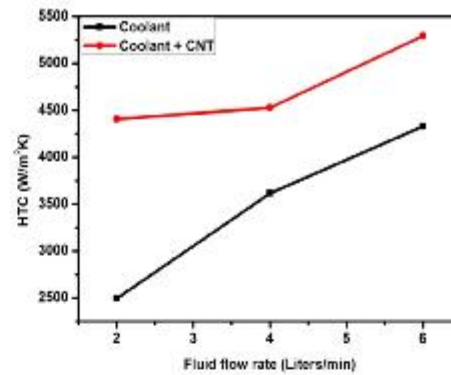
Fig.2bVariation of Heat Transfer Coefficient as a function of fluid flow rate for base fluid with and without MWCNTS

Fig.2b shows the variation of heat transfer coefficient as a function of fluid flow rate. It can be seen that both the graphs are more or less falling on the same line. This trend indicates that the addition of CNTs to base fluid (water+EG) did not improve HTC in this particular case.

Fig. 3a shows the variation of non-dimensional heat transfer coefficient Nu as a function of Reynolds number Re in the range of 1000 to 6000 for radiator coolant. The two graphs in Fig.3a represent one for radiator coolant and the other for coolant mixed with CNT. In this case when the CNTs are added to the radiator coolant, the enhancement in the Nusselt number is much higher when compared enhancement in water+ EG with CNTs around 30%.

Fig.3a Variation of Nusselt number as a function of Reynolds number for radiator coolant with and without MWCNTS

Fig.3bVariation of Heat Transfer Coefficient as a function of fluid flow rate for radiator coolant with and without MWCNTS

The variation of heat transfer coefficient as a function of fluid flow rate in the case of radiator coolant with and without addition of CNTs. It can be seen from both the figures 3a and 3b, the heat transfer coefficient increased considerably. While the results are promising and encouraging, more experimental data is required before taking steps to commercial the product.

CONCLUSIONS

From the experimental data and preliminary analysis of results of the investigation, it can be concluded that nano coolant is a potential candidate in cooling applications and can be effectively used as a coolant in automobile radiators. Addition of a very small percentage of MWCNTS by volume, used in the present investigation, improves the quality of coolant for quick dissipation of heat in an automobile radiator. Experiments are underway to quantify the friction losses and fouling of the radiator, if any, due to the addition of nano particles. However, in all the experiments conducted, in the present investigation there are no visible symptoms' of fouling. This observation of the authors may be attributed to the addition of surfactants to the cooling medium which prevents deposition or fouling. It is further concluded that the improvement in the performance of an automobile radiator has been very encouraging with an improvement of around 30%.

REFERENCES

1. Gabriela Huminic and Angel Huminic. Application of nanofluids in heat exchangers: A review, Renewable and Sustainable Energy Reviews, 16 (2012) pp: 5625–5638

2. L. SyamSundar and Manoj K Singh, Convective heat transfer and friction factor correlations of nanofluid in a tube and with inserts: A review, Renewable and Sustainable Energy Reviews 20 (2013), pp:23–35

3. M. Chandrasekar, S. Suresh, T. Senthilkumar, Mechanisms proposed through experimental investigations on thermophysical properties and forced convective heat transfer characteristics of various nanofluids – A review, Renewable and Sustainable Energy Reviews 16 (2012), pp: 3917– 3938

4. B. Farajollahi, S.Gh. Etemad, M. Hojjat, Heat transfer of nanofluids in a shell and tube heat exchanger, Int. J. Heat Mass Transfer 53 (2010) 12-17.

5. W. Duangthongsuk, S. Wongwises, Heat transfer enhancement and pressure drop characteristics of TiO2ewater nanofluid in a double-tube counter flow heat exchanger, Int. J. Heat Mass Transfer 52 (2009) 2059-2067.

6. Zamzamian, S.N. Oskouie, A. Doosthoseini, A. Joneidi, M. Pazouki, Experimental investigation of forced convective heat transfer coefficient in nanofluids of Al2O3/EG and CuO/EG in a double pipe and plate heat exchangers under turbulent flow, Exp. Therm. Fluid Sci. 35 (3) (2011) 495-502.

7. P. Naphon, P. Assadamongkol, T. Borirak, Experimental investigation of titanium nanofluids on the heat pipe thermal efficiency, Int. Commun. Heat Mass Transfer 35 (2008) 1316-1319.

8. S.H. Noie, S.Z. Heris, M. Kahani, S.M. Nowee, Heat transfer enhancement using Al2O3/water nanofluid in a two-phase closed thermosyphon, Int. J. Heat Fluid Flow 30 (2009) 700- 705.

9. J.Y. Jung, H.S. Oh, H.Y. Kwak. Forced convective heat transfer of nanofluids in microchannels, in: Proceeding of ASME International Mechanical EngineeringCongress and Exposition (IMECE 2006), 2006.

10. Gnielinski, V., New equations for heat and mass transfer in turbulent pipe and channel flow, International Chemical Engineering, vol. 16, pp. 359-368, 1976.

11. Tam, L.M., Ghajar, A.F., Transitional heat transfer in plain horizontal tubes, Heat Transfer Engineering, vol. 27, no. 5, pp. 23-38, 2006.

12. Sajadi, A.R., Kazemi, M.H., Investigation of turbulent convective heat transfer and pressure drop of TiO2/water nanofluid in circular tube. International Communications in Heat and Mass Transfer 2011;38:1474–1478.

13. C.T. Nguyen, G. Roy, C. Gauthier, N. Galanis, Heat transfer enhancement using Al2O3 water nanofluid for an electronic liquid cooling system, Appl. Therm. Eng. 27 (2007) 1501-1506.

14. K.Y. Leong, R. Saidur , T.M.I. Mahlia , Y.H. Yau , Modeling of shell and tube heat recovery exchanger operated with nanofluid based coolants International Journal of Heat and Mass Transfer 55 (2012),pp: 808–816

15. K.J. Park, D. Jung, Boiling heat transfer enhancement with carbon nanotubes for refrigerants used in building air-conditioning, Energy Build. 39 (2007) pp.1061-1064.

16. D.P. Kulkarni, D.K. Das, R.S. Vajjha, Application of nanofluids in heating buildings and reducing pollution, Appl. Energy 86 (2009) 2566-2573.

17. Q. Yu, A.Straatman, and B. Thompson, "Carbon-Foam Finned Tubes in Air-Water Heat Exchangers," *Applied Thermal Engineering*, 26 (2006) pp. 131-143.

18. C. Harris, M. Despa, and K. Kelly, "Design and Fabrication of a Cross Flow Micro Heat Exchanger,"*Journal of Microelectro mechanical Systems*, vol. 9, no. 4, pp. 502-508, December 2004.

19. A. Joardar and A.Jacobi, "Impact of Leading Edge Delta-Wing Vortex Generators on the Thermal Performance of a Flat Tube, Louvered-Fin Compact Heat Exchanger," *International Journal of Heat and Mass Transfer*, 48 (2005) pp. 1480-1493.

20. Ding, Y., H. Alias, D. Wen, and A. R. Williams (2006). Heat transfer of aqueous suspensions of carbon nanotubes (CNTnanofluids), *Int. J. Heat and Mass Transfer*, 49

21. K.Y. Leong et al , Performance investigation of an automotive car radiator operated with Nano fluid-based coolants (nanofluid as a coolant in a radiator), Applied Thermal Engineering 30 (2010) pp.2685-2692

22. 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 (2013) pp: 8-16

23. S.M. Peyghambarzadeh , S.H. Hashemabadi , M. Seifi Jamnani , S.M. Hoseini "Improving the cooling performance of automobile radiator with Al2O3/water Nanofluid, Applied Thermal Engineering 31 (2011) 1833-1838

24. S.C. Pang, M.A. Kalam , H.H. Masjuki, M.A. Hazrat A review on air flow and coolant flow circuit in vehicles' cooling system, International Journal of Heat and Mass Transfer 55 (2012) pp: 6295–6306

25. S.M. Peyghambarzadeh, S.H. Hashemabadi, S.M. Hoseini, M. Seifi Jamnani, Experimental study of heat transfer enhancement using water/ethylene glycol based nanofluids as a new coolant for car radiators, International communications in Heat and Mass Transfer 38 (2011) 1283–1290

26. www.sigma-aldrich.com.

27. A. Einstein, Investigations on the theory of the Brownian movement, Dover Publications, New York, 1956.

28. J.C. Maxwell, On electricity and magnetism, Oxford, Oxford University press, 1881.

29. Beckwith, T.G., Marangoni, R.D., Lienhard, L.H., Mechanical measurements, 5th Edition, Addison–Wesley publishing company, New York, pp. 45-112, 1990.