Comparative Study of Cooling Performance of Automobile Radiator Using Cuo-EG And Multi Walled Carbon Nanotube-EG Nanofluid

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Abstract- *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. The present study dealt with the forced convective heat transfer performance of two different nanofluids, namely, CuO-EG and MWCNT-EG. The study was experimentally carried out in an automobile radiator. Two different concentrations of nanofluid of 0.20–0.30 vol. % were prepared by the additions nanoparticles into the base fluid. The coolant flow rate was varied in the range of 0.04 kg/s – 0.2 kg/s. Nanocoolants made significant change in the heat transfer performance of the radiator compared with the conventional coolant. The heat transfer performance of MWCNT-EG nanofluid was found to be better than CuO-EG nanocoolant. Furthermore, the Nusselt number is found to increase with the increase in the nanoparticle concentration and nanofluid flow rate.*

Keywords- Nanofluids; MWCNT; CuO; Heat transfer performance ; Nusselt number

I. INTRODUCTION

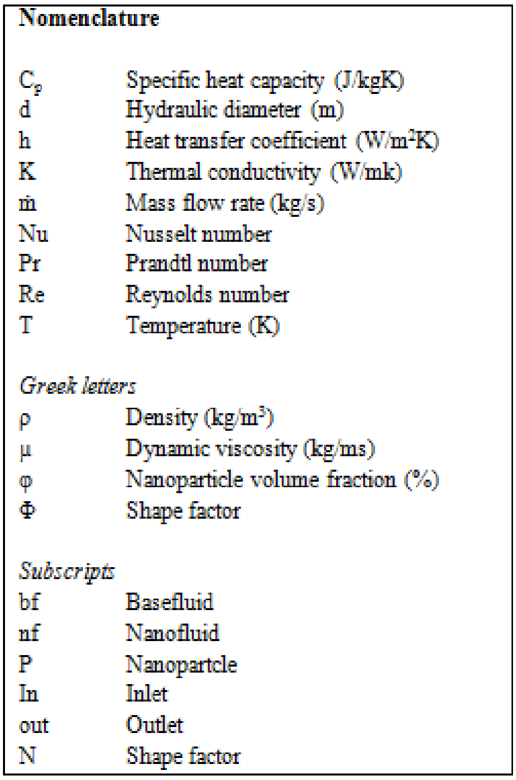
Energy needs are increasing exponentially day by day. The search for every possible way of diminishing the energy consumption or in other words energy saving methodologies was constantly being explored, revisited and revised from time to time. Energy is of two form (i) energy in storage (ii) energy in transit. Energy in transit plays an important part in the modern world and earns itself a formidable position in different fields viz. industries, refineries, space applications, domestic purposes etc. Since the middle of the 20thcentury, efforts have been periodically made to improve the energy transfer. Energy as a common has two major parts, work energy and heat energy. Energy transfer in the form of heat happens by the virtue of temperature difference between the systems within which the heat transfer takes place. The transfer of heat energy could occur in any of the following three modes such as (i) conduction (ii) convection and (iii) radiation or in a combination with the above three modes. Every mode of heat transfer has their own limitations. The first step in carrying out any heat transfer calculations is the determination of the modes of heat transfer. The modes of heat transfer largely depend on the medium of heat transfer. The heat transfer by conduction mode involves a solid medium (closely packed molecules) and it is not possible in all cases. In such deviating cases, transfer of heat with the help of fluids can be economical. Heat transfer with the aid of fluids in bulk motion is termed as convection. Convection heat transfer largely depends on three factors viz. heat transfer coefficient (h), area of the surface in contact with the fluid (A) and temperature difference (ΔT). However, for a given surface area of contact and a given maximum temperature difference convective heat transfer depends on the heat transfer coefficient of the flowing fluids. Conventional fluids used are of many varieties each used depending on the areas of application. Of the liquids used, liquid metals possess the higher value of heat transfer coefficient. Liquid metals most widely used are Liquid Sodium (Na), Liquid Mercury (Hg). These liquid metals are hence used for high heat transfer applications as in nuclear applications. Heat exchanger apparatus is an inevitable part of any modern-day industry. Any modification or changes that are brought to the geometry of the heat exchanger will have a direct impact on the heat transfer values. Experiments were conducted to improve the performance of the heat exchanger devices. One method is to maximize the heat transfer surface area by the attaching with them some additional surfaces such as fins , creating rough surface or tube inserts.(1-7). Even some of the studies suggested using magnetic techniques and vibrational techniques to create some turbulence in the flow regime (8-11). Newer direction of research looked into the possibility of enhancing the characteristics of the heat transfer fluids. This is possible in either of the two ways (i) bring forth new technologies (ii) advanced fluids. This study concentrates on the latter part of option.

Conventional heat transfer fluids such as refrigerants, water, coolants, engine oil etc perform low in heat transfer process. This necessitates large heat exchangers with suitably high effectiveness for better heat transfer. Of the methods to enhance the heat transfer the application of additives to the conventional fluids is promising. Recent development in the field of nanotechnology unveils a new category of fluids termed as nanofluids. Nanofluids are the relatively new class of fluids consisting of a base fluid with metallic or non-metallic nano-sized particles ranging from 1 nm to 100 nm suspended in them. Some of the metallic nanoparticles widely in use are Copper (Cu), Iron (Fe), Gold (Au), Silver (Ag) and some of the non-metallic nanoparticles widely in use are Alumina oxide (Al_2O_3), Copper Oxide (CuO), Silicon Carbide (SiC), Titanium dioxide (TiO_2), Multiwalled Carbon nanotubes (MWCNT).Nanofluids in comparison with our conventional fluids meant for heat transfer possesses the following advantages [1]:

- High specific surface area and in turn more heat transfer surface between particles and fluids.
- Higher dispersion stability with the predominant Brownian motion of particles.
- Reduced pumping power as compared to pure liquid for the equivalent heat transfer rate.
- Adjustable properties by varying particle concentration to suit our demands.

Peyghambarzadeh et al.[1] presented an experimental investigation of forced convective heat transfer behavior of Al_2O_3-water nanofluids with 0.1-1 vol.%. The heat transfer rate increases with increasing flow rate. 45% increase in heat transfer rate at a concentration of 1 vol.% was recorded. Saidur et al. [1] discussed on the applications and challenges of nanofluids. To produce a better mixture of nanofluids, dispersants like thioglycolic acid, laurate salt could be used. Also, surfactant sodium dodecylbenzene sulfonate yields a better dispersion stability. Leong et al. [5] compared the performance of an automotive car radiator using Cu nanofluids. He observed 3.8% enhancement in heat transfer with the addition of 2% Cu particles. Also, 18.7% reduction of air frontal area is achieved at 5000 and 6000 Reynolds number by the addition of 2% Cu particles.

Peyghambarzadeh et al.[2] revealed that addition of Al_2O_3 to the base fluids increased the heat transfer rate of up to 40% in comparison with base fluids inside the flat aluminum tubes of a car radiator. Moreover, he concluded that the heat transfer behaviors of nanofluids were highly dependent on particle concentration and weakly dependent on the temperature. Selvam et al [7].reported nearly 170% increase in heat transfer coefficient with the addition of graphene nanoplatelets in ethylene glycol base fluid and also the pressure drop increases when the flow changes from laminar to turbulent. Peyghambarzadeh et al [4] evaluated experimentally and concluded that by the addition of CuO, Fe_2O_3 nanoparticles the overall heat transfer coefficient value enhances by 9%. In contrast, increasing the nanofluid temperature decreases the overall heat transfer coefficient value.



Nomenclature	
C_p	Specific heat capacity (J/kgK)
d	Hydraulic diameter (m)
h	Heat transfer coefficient (W/m^{2}K)
K	Thermal conductivity (W/mk)
$\dot{m}$	Mass flow rate (kg/s)
Nu	Nusselt number
Pr	Prandtl number
Re	Reynolds number
T	Temperature (K)
Greek letters	
ρ	Density (kg/m^3)
μ	Dynamic viscosity (kg/ms)
φ	Nanoparticle volume fraction (%)
Φ	Shape factor
Subscripts	
bf	Basefluid
nf	Nanofluid
P	Nanopartcle
In	Inlet
out	Outlet
N	Shape factor

II. MATERIALS AND EXPERIMENTATION

2.1 Preparation of nanofluids

Conventional automobile coolant (water + ethylene glycol), multi-walled carbon nanotubes, silicon dioxide were utilized to produce the nanofluids for this experimental study. Carbon nanotubes were purchased from Nanoshel and Copper Oxide particles were purchased from Nanoplatonic. It is a well-known fact that MWCNT are hydrophobic in nature which makes them susceptible to agglomerate and precipitate in water. Hence research was conducted in the past to find a suitable surfactant/dispersants that could well stabilize the MWCNT's. The nanoparticles dispersion in a base fluid could be carried out either by a two-step method or by a single step method. In either case, a well-mixed and uniformly dispersed nanofluid is necessary for excellent properties and hence better interpretation of experimental data. The two-step method involves two stages, in the first stage the nanoparticles were processed following a standard physical or chemical method and in the second stage dispersion of the measured volumetric concentration of nanoparticles uniformly in the base, fluid is carried out. In order to produce uniform, stable nanoparticle suspensions techniques such as high shear and ultrasound vibration are used. The weighted quantities of nanoparticles were mixed and dispersed in the base fluid. Ultrasonication dispersion technique is employed to disperse nanoparticles in the base fluids. Ultrasonication is performed in the Ultrasonicator. The Ultrasonicator incorporates intensive ultrasonication effects to prepare the nanofluids with minimal agglomeration of nanoparticles. This two-step method of preparation yields highly stabilized nanofluids. It has been stated that the ultrasonication time plays a significant role in the properties of nanofluids. MWCNT and Silicon dioxide nanoparticles are added to the base fluids and are subjected to intensive ultrasonification for a period of 2 hours. The volumetric concentration of nanoparticles added is 0.1% , 0.3% and 0.5% respectively for both the nanoparticles.

2.2 Measurement of Thermo-physical properties

The assumption made in this study is that the nanoparticles are well dispersed and the mixture is homogenous throughout the system. The thermophysical properties of the nanofluids are obtained from the classical formulas formulated especially for the two-phase method. The formulas used for the prediction of nanofluids properties are given below. The properties such as nanofluid density, specific heat, thermal conductivity, dynamic viscosity relatively at different temperatures and concentrations could be found out using the following formulations [3].

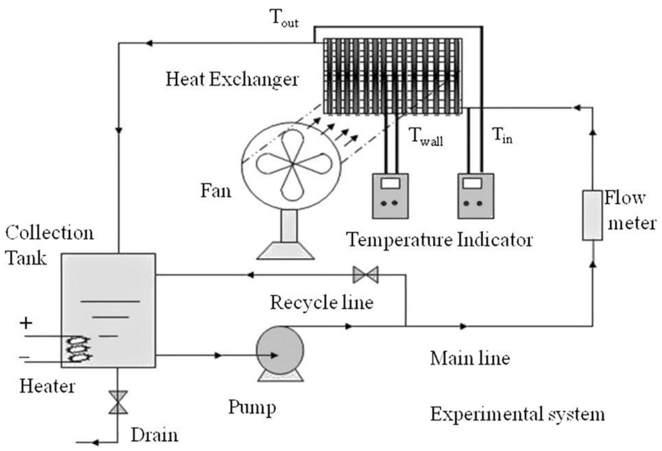


Fig.1 Schematic of the experimental setup.

Density of nanofluid (ρ_{nf})

$$\rho_{nf} = \varphi\rho_p + (1-\varphi)\,\rho_{bf}$$

Thermal conductivity (K_{nf})

$$K_{nf} = \frac{K_p+(n-1)K_{bf}-\varphi(n-1)(K_{bf}-K_p)}{K_p+(n-1)K_{bf}+\varphi(K_{bf}-K_p)}\,K_{bf}$$

Specific heat ($c_{p,nf}$)

$$C_{p,nf} = \frac{(1-\varphi)\rho_{bf}C_{p,bf}+\varphi\rho_p C_{p,p}}{\rho_{nf}}$$

Dynamic viscosity (μ_{nf})

$$\mu_{nf} = \mu_{bf}(123\,\varphi^2 + 7.3\,\varphi + 1)$$

Volume fraction(φ)

$$\phi = \frac{\left(\frac{w_p}{\rho_p}\right)}{\left(\frac{w_p}{\rho_p}\right)+\left(\frac{w_{bf}}{\rho_{bf}}\right)} * 100$$

In the above equations the subscripts “p”, “bf” and “nf “ refers to the particles, the base fluids, and the nanofluids respectively. φ is the volumetric concentration of nanoparticle-dispersed into the base fluid.

Table1.

Properties of the base fluids and nano fluids.

Properties	Units	Water	Water + EG	Air	CuO		MWCNT	
					0.20%	0.30%	0.20%	0.30%
Viscosity	Pa.S	0.00065	0.003036	0.000017894	0.003082	0.003106	0.003082	0.003106
Thermal Conductivity	W/mK	0.633	0.261	0.0242	0.262553	0.263332	0.261336	0.261505
Specific heat capacity	J/kg K	4174	2664	1006.43	2638.875	2626.496	2654.367	2649.572
Density	kg/m^3	992	1076	1.225	1086.648	1091.972	1079.168	1080.752

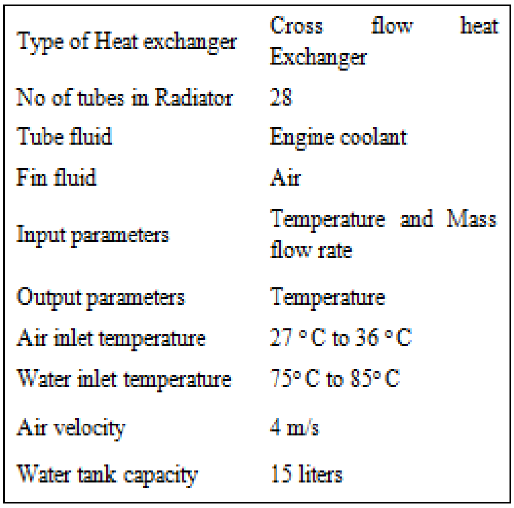
2.3 Experimental setup and Procedure

The schematic layout of the experimental setup with a cross-flow heat exchanger is shown in Fig.1. The test rig consists of a closed loop. The closed-loop routes the nanofluid from the storage tank cum heater segment to pump to flow meter to cross-flow heat exchanger and finally to the storage tank again. The temperature measurement is provided at the inlet of the cross-flow heat exchanger, the outlet of the cross-flow heat exchanger and inside the heater segment as well. As shown in Fig.1 the experimental test rig consists of flow lines, a reservoir tank, an electric heater, a centrifugal pump, a rotameter (flow measurement device), thermocouples for temperature measurement and a cross-flow heat exchanger (automobile radiator).

The nanofluids pass through 28 vertical tubes with the stadium-shaped cross-section. The materials of the fins and tubes are of aluminum. The overall dimensions of the radiator are given in. The hydraulic diameter of the tubes is 0.00256m.

The cooling of the hot coolant flowing through the radiator is done with the help of a forced draft fan. It is a variable speed fan, installed close to the face of the cross-flow heat exchanger unit. The inlet air temperature is measured to be27 ^{t}he centrifugal pump supplies the circuit with the nanofluids at a constant flow rate of 0.04 kg/s. The flow of nanofluids into the test section is regulated by opening and closing of the gate valve provided at the downstream section of the centrifugal pump. The reservoir tank is filled with 10 liters of testing fluid, which amounts to 66.67% of the liquid container. The capacity of the container is 15liters.The whole of the system is assumed to work as an open system ie. the liquid flow rate at any section at any time remains constant.

Specifications of Test rig



Type of Heat exchanger	Cross flow heat Exchanger
No of tubes in Radiator	28
Tube fluid	Engine coolant
Fin fluid	Air
Input parameters	Temperature and Mass flow rate
Output parameters	Temperature
Air inlet temperature	27 °C to 36 °C
Water inlet temperature	75° C to 85° C
Air velocity	4 m/s
Water tank capacity	15 liters

2.4 Data Reduction

In this study, the nanofluid passing through the tubes of the heat exchanger transfers heat to the surrounding flowing air predominantly by conduction and convection mechanisms. The air side and tube side heat transfer rates and other parameters are calculated using the following procedure.

Heat transfer in air (Qa)

$Q_a = \dot{m}\, C_p\, (T_{out} - T_{in})$

Heat transfer in nanofluid (Qnf)

$Q_{nf} = \dot{m}\, C_p (T_{in} - T_{out})$

Heat transfer rate (Q)

$Q = h\, A\, (\Delta T)_{lmtd}$

$Q = h\, A\, (\Delta T)_{lmtd} = \dot{m}\, C_p\, (T_{in} - T_{out})$

$$h = \frac{\dot{m}\, C_p\, (T_{in} - T_{out})}{A_i \Delta T_{lmtd}}$$

Log Mean Temperature Difference ($\Delta T)_{lmtd}$

$$(\Delta T)_{lmtd} = \frac{(T_{hi} - T_{co}) - (T_{ho} - T_{ci})}{\ln(\frac{T_{hi} - T_{co}}{T_{ho} - T_{ci}})}$$

Nusselt number (Nu)

$Nu = h\, d_{hy} / k$

III. RESULTS AND DISCUSSIONS

3.1 Effect of Volumetric concentration on the thermal performance

Effect of nanoparticle volumetric concentration on the heat transfer rate is shown in Figure 2. The figure shows the change in the heat transfer rate with the variation in the nanoparticle concentration in the coolant. It is well established that the heat transfer rate increases with the increase in the nanoparticle concentration. With the addition of more nanoparticles, the effective thermal conductivity of the nanofluid increases as can be seen from the Table 1. In addition to that, the enhancement in heat transfer coefficient is attributed to the associated collision among nanoparticles, between the nanoparticles and also between the tube wall of the automobile radiator. The increase in the Brownian motion of the fluids and the energy exchange rate of nanoparticles resulted in increased thermal performance. The addition of nanoparticle to the base fluids enriches the effective thermal conductivity, accelerates the Brownian motion of nanoparticles, speeds up particle migration at a faster rate. The combined effect of these phenomenon enhances the heat transfer coefficient and hence the thermal performance of the cross-flow heat exchanger.

The enhancement in heat transfer for the water, EG-MWCNT nanofluid, and EG-CuO is graphically represented in the Fig 2. The heat transfer enhancement for two concentrations (0.2% and 0.3%) of nanoparticles in comparison with base fluid is given in the table 2. The enhancement in heat transfer can be evaluated by,

$$\text{Percentage Enhancement} = \frac{Q_{nf} - Q_{bf}}{Q_{bf}} \times 100$$

The enhancement in heat transfer for MWCNT-water nanofluid over base fluid at 0.20%

nanoparticle volume concentration was found to be 22.42%, 36.025%, 30.924%, 26.957% and 21.186% for 0.04 kg/s , 0.08 kg/s, 0.12 kg/s , 0.16 kg/s and 0.2 kg/s respectively. While, the enhancement in heat transfer of MWCNT-EG nanofluid over base fluid at 0.3% nanoparticle volume concentration was found to be 27.115%, 38.67%, 31.45,34.82% and 25.01% for 0.04 kg/s,0.08 kg/s,0.12 kg/s,0.16 kg/s and 0.2 kg/s respectively. The maximum enhancement inNusselt number of 43.53% was found by using MCNT-water nanofluid of 0.3 % volume concentration with 0.16 kg/s coolant flow rate compared with the pure water results.

The enhancement in heat transfer for CuO-EG nanofluid over base fluid at 0.20% nanoparticle volume concentration was found to be 13.20%,13.20%,11.13%,10.06% and 8.06% for 0.04 kg/s, 0.08 kg/s,0.12 kg/s,0.16 kg/s and 0.02 kg/s respectively. While, the enhancement in heat transfer of CuO -EG nanofluid over base fluid at 0.3% nanoparticle volume concentration was found to be 16.30%, 19.9%, 23.20%,20.5% and 16.5% for 0.04 kg/s, 0.08 kg/s,0.12 kg/s,0.16 kg/s and 0.02 kg/s respectively. The maximum enhancement in Nusselt number of 15.48% was found by using CuO-EG nanofluid of 0.3% volume concentration with 0.20 kg/s coolant flow rate compared with the pure water results.

It may be inferred that by adding nanoparticles to the basefluid, heat could be effectively removed from the automobile radiator. This increase in heat transfer well reduces the size of radiators and hence the load in an automobile engine leading to decreased fuel consumption and improved fuel economy.

3.2 Effect of Mass flow rate on heat transfer coefficient

Fig. 3 plots the variation of overall heat transfer coefficient with nanofluids as a function of nanofluid flow rate by maintaining constant value of air flow rate and nanoparticle concentration. The curve is plotted for heat transfer coefficient and varying mass flow rates. It is clear from the graph that there is a significant improvement in the overall heat transfer coefficient with increasing flow rate of coolant.

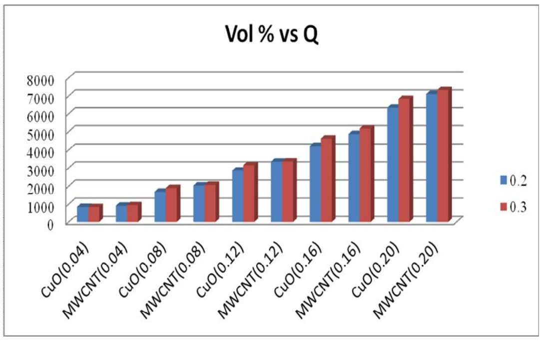


Fig.2 The effect of volumetric concentration on the thermal performance.

Also it can be understood, as the volumetric concentration of particle increases for a given flow rate the heat transfer coefficient value increases. For example, at the flow rate of 0.16 kg/s, the nanofluid concentration of 0.3 vol.%, and nanofluid inlet temperature of 80° C, an increase in overall heat transfer coefficient of 43.81% was registered with MWCNT-EG nanofluids and an increase of 16.52% was recorded with CuO-EG nanofluid at 0.3% volumetric concentration and at 0.2 kg/s.

$$\text{Percentage Enhancement} = \frac{h_{nf} - h_{bf}}{h_{bf}} \times 100$$

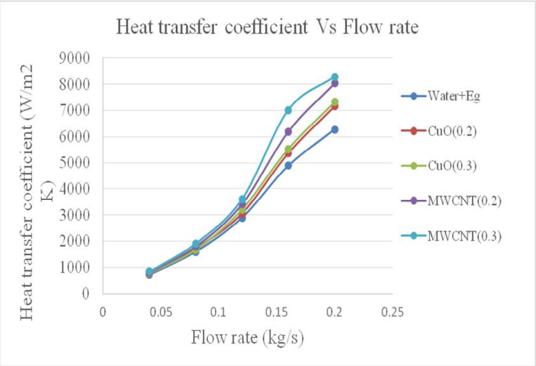


Fig.3 The variation of heat transfer coefficient with the varying conditions of flow rate.

Table.3 gives the detailed insight on variation of the values of heat transfer coefficient against varying flow rates of coolant liquid at two different concentration of nanoparticle.

3.3 Effect of mass flow rates on heat transfer

The nanofluids are implemented by the addition of CuO and MWCNT nanoparticles into the radiator base fluid at two different nanoparticle concentrations, i.e. 0.2, 0.3 vol.% .The mass flow rates of 0.04, 0.08, 0.12, 0.16 and 0.20 kg/s per each flat tube were used. To analyze the dependence of the thermal performance of the radiator on the volumetric concentration, the flow rate is varied at a fixed volumetric concentration. The two volumetric concentration were 0.2% and 0.3% for both EG-based nanofluids. The plot is made with mass flow rates as the abscissa and heat transfer rate as ordinate.

The earlier studies suggested that as mass flow rate increases, the liquid convection heat transfer follows the same path as is evident from the Table 4.The heat transfer amount enhances as the percentage volume of nanoparticle rises. Table 2 explains the effect of variation of volumetric concentration and the mass flow rates on the heat transfer. The nanofluids also show the same trend as do the base fluids with the increase in the flow rate. This increase in heat transfer rate for the nanofluids was found higher in comparison with the base fluids. Fig 4 gives the comparison results for base fluids and nanofluids at the concentration of 0.2 vol.% and 0.3 vol% at varying flow rates.

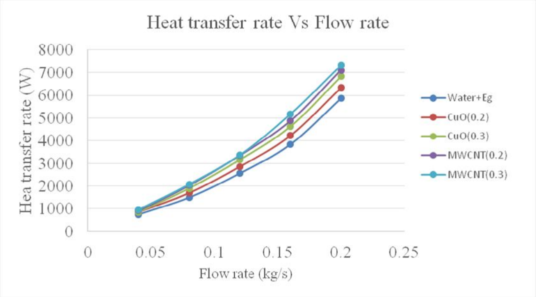


Fig.4 The Heat transfer rate depicting an increasing trend for differing nanofluid flow rates.

3.4 Effect on Nusselt number

Fig. 5 depicts the effect of the addition of different volumes of nanoparticles on the Nusselt number of nanofluids at the ambient temperature. It is dependent on parameters h, D_h and K. On increasing the volume concentration of particles, the Nusselt number increases at a significant rate for both the CuO-EG and MWCNT-EG nanofluids. In comparison with base fluids at an ambient temperature of 300 K, adding nanoparticles of 0.2% volume increases the Nusselt number value by 13.39%, 27.79% for CuO-EG and MWCNT-EG nanofluids respectively. The Nusselt number being proportional to heat transfer from conventional heat transfer equations . the increase in Nusselt number subsequently increases the convective heat transfer coefficient (h).

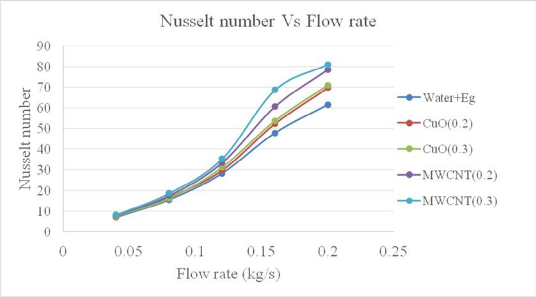


Fig.5 Nusselt number vs Flow rate

Fig.6 shows a comparison plot of the Nusselt number for CuO, and MWCNT nanofluidsat 0.2% and 0.3% particle concentration at differing mass nanofluid flow rates. The two nanofluids offer a higher value of Nusselt number than the base fluid. It is well established that the Nusselt number values for all variant of fluids shows an increasing trend with an increase in coolant mass flow rates.

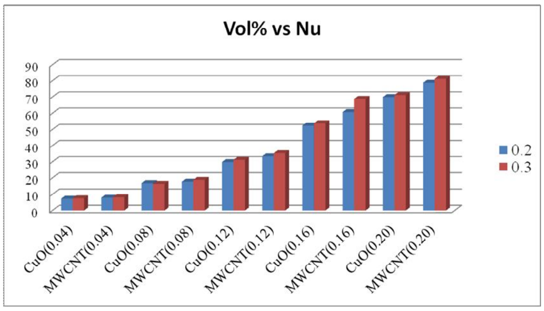


Fig.6 Impact of Volumetric concentration on the Nusselt number.

3.5 Effect of volumetric concentration on heat transfer coefficient

The plot for nanofluids volumetric concentration vs heat transfer coefficient is shown in Fig.7. The graph is plotted by taking heat transfer coefficient(h) on vertical axis and volumetric concentration on the horizontal axis. The results clearly indicates the enhancement of heat transfer coefficient value with the increase in nanoparticle concentration. Furthermore, the experimental results proved that, with the seeding of CuO and MWCNT nanoparticles into the base fluid, the heat transfer coefficient value enhances in the car radiator. It should also be mentioned that application of nanofluids causes the coolant liquid to exit at a relatively lower temperature than does the exit temperature of coolant liquid without nanoparticles. Also to be inferred from the Fig.7 is the comparative analysis of enhancement of heat transfer coefficient values for both the nanofluids at various flow rates. It is clear from the graph that basefluid incorporated with MWCNT nanoparticles provides a slightly better performance over the CuO nanoparticle mixed baseflud.

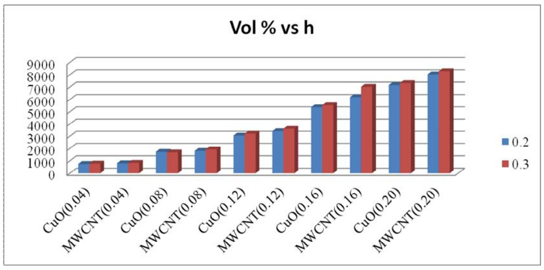


Fig.7 The heat transfer coefficient values of CuO,MWCNT nanofluids for different volumetric concentrations.

IV. CONCLUSIONS

In this article, the experimental heat transfer performance of an automobile radiator has been measured using CuO-EG nanofluid and MWCNT-EG at different liquid volumetric flow rates and two nanofluid concentrations.Following conclusions can be drawn from this study :

a) Heat transfer rate increases with the increase in volumetric concentration of the nanofluid and increasing mass flow rate of nanofluid.

b) Enhancement in heat transfer rate of 36.025% with the MWCNT-EG nanofluid over base fluid at 0.20% nanoparticle volume concentration and at 0.12 kg/s flow rate was observed.

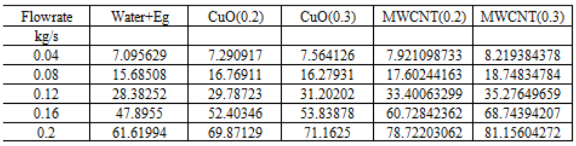
c) Enhancement in heat transfer rate of 38.67% with the MWCNT-EG nanofluid over base fluid at 0.30% nanoparticle volume concentration and at 0.12 kg/s flow rate was observed.

d) Heat transfer coefficient value increases with increase in the nanofluid flow rate. Also for a given flow rate, the addition of more and more nanoparticles improves the heat transfer coefficient value.

e) An increase of 13.39% and 27.79% was observed in the Nusselt number values for CuO-EG nanofluid and MWCNT-EG nanofluid over the conventional base fluid.

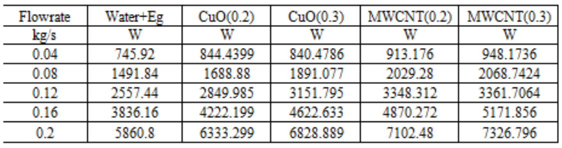
f) MWCNT based nanofluids produce superior heat transfer characteristics than CuO based nanofluids.

Table 2. Variation of Heat transfer for differing a flow rates and different volumetric concentration.



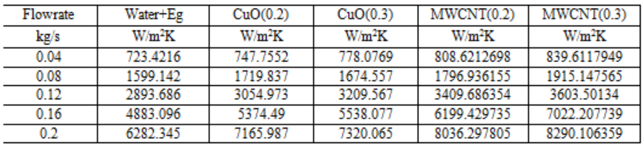
Flowrate	Water+Eg	CuO(0.2)	CuO(0.3)	MWCNT(0.2)	MWCNT(0.3)
kg/s					
0.04	7.095629	7.290917	7.564126	7.921098733	8.219384378
0.08	15.68508	16.76911	16.27931	17.60244163	18.74834784
0.12	28.38252	29.78723	31.20202	33.40063299	35.27649659
0.16	47.8955	52.40346	53.83878	60.72842362	68.74394207
0.2	61.61994	69.87129	71.1625	78.72203062	81.15604272

Table 3. Heat transfer coefficient for different flow rates of nanofluids and differing volumetric concentration of nano particles.



Flowrate	Water+Eg	CuO(0.2)	CuO(0.3)	MWCNT(0.2)	MWCNT(0.3)
kg/s	W	W	W	W	W
0.04	745.92	844.4399	840.4786	913.176	948.1736
0.08	1491.84	1688.88	1891.077	2029.28	2068.7424
0.12	2557.44	2849.985	3151.795	3348.312	3361.7064
0.16	3836.16	4222.199	4622.633	4870.272	5171.856
0.2	5860.8	6333.299	6828.889	7102.48	7326.796

Table 4. Effect of flow rates and volumetric concentration on Nusselt number.



Flowrate	Water+Eg	CuO(0.2)	CuO(0.3)	MWCNT(0.2)	MWCNT(0.3)
kg/s	W/m^2K	W/m^2K	W/m^2K	W/m^2K	W/m^2K
0.04	723.4216	747.7552	778.0769	808.6212698	839.6117949
0.08	1599.142	1719.837	1674.557	1796.936155	1915.147565
0.12	2893.686	3054.973	3209.567	3409.686354	3603.50134
0.16	4883.096	5374.49	5538.077	6199.429735	7022.207739
0.2	6282.345	7165.987	7320.065	8036.297805	8290.106359

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