Experimental investigation of enhanced cooling performance with the use of hybrid nanofluid for automotive application

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Abstract: The hybrid nanofluids exhibit remarkable thermal performance as coolant in automobile radiators. Hybrid nanofluid predominantly improves the heat transfer performance as compared to conventional coolants. Therefore, the present research work is focused on the hybrid nanofluids as coolant for automobile radiator. Due to improved heat transfer rate of hybrid nanofluid, the overall size of automobile radiator can be reduced. The heat transfer characteristics of Multi Walled Carbon Nanotubes (MWCNT)-Copper Oxide (CuO) /deionized water and Graphene/deionized water nanofluids were analyzed experimentally compared with deionized water. The experimental work aimed to find thermo physical properties such as thermal conductivity, specific heat capacity, and density of hybrid nanofluids. The concentrations of MWCNT-CuO and Graphene nanofluid were varied from 0.05 to 0.15wt%. Significant improvement in the stability was observed by magnetic stirring and ultra-sonication process with the Sodium dodecyl sulphate (SDS) surfactant. The effect of SDS surfactant on stability of MWCNT/CuO and Graphene nanofluid experimentally investigated. Effect of coolant flow rate on heat transfer rate is studied experimentally by varying coolant flow rate (3-7 lit/min) for different temperature (50°C to 80°C) conditions.

Based on the experimental observations it was noticed that the Nusselt number of the hybrid nanofluid is linear relationship with the nanocoolant flow rate and a highest Nusselt number of 37.7 was observed at 0.1 %wt and 7 lit/min nanocoolant flow rate at 80°C inlet temperature. It was observed that aqueous based MWCNT-CuO hybrid nanofluid enhanced the convective heat transfer coefficient by 295% as compared to conventional base fluid at 80°C and 7 lit/min nanocoolant flow rate. It was also observed that the convective heat transfer coefficient for MWCNT-CuO/Deionized water hybrid nanofluid is 30% more than graphene based nanofluid at higher operating temperature (80°C) and higher coolant flow rate (7 lit/min). Further experiments were conducted at higher mass flow rates and temperature to investigate the maximum heat transfer ability of Graphene-CuO and MWCNT-CuO hybrid nanofluids as a feasible nanocoolant for automotive application.

Keywords: Hybrid nanofluid, Nusselt number, Car radiator, heat transfer rate, thermal conductivity

1. INTRODUCTION

In automotive sector heat transfer plays a major role in cooling and heating applications by use of appropriate coolants. However, the conventional cooling fluids experiences poor thermal conductivity and hence poor heat transfer rates associated with them. Therefore, it is important to find new and alternative heat transfer fluids which can enhance heat transfer rate or facilitate higher thermal performance compared to other conventional fluids. In order to overcome the drawbacks of conventional coolants it is required to find a new class of fluid namely Nanofluid. From the literature it is found that nanofluids will provide better thermal performance compared to conventional fluids [1,
5. 7]. Hence, the present work is an attempt to evaluate use of such nanofluids as prospective coolants which will facilitate maximum heat transfer rates.

| Nomenclatures                      |
|------------------------------------|
| \( Q \) Heat transfer rate (W)    |
| \( T \) Temperature (°C)          |
| \( Nu \) Nusselt number           |
| \( Cp \) Specific heat capacity(kJ/kg K) |
| \( H \) Convective heat transfer coefficient (W/m²K) |
| \( K \) Thermal conductivity(W/m K) |
| \( L \) Length (m)                |
| \( M \) Mass flow rate (kg/s)     |
| \( Dh \) hydraulic diameter (m)   |

| Greek Symbols                      |
|------------------------------------|
| \( \phi \) Weight fraction of nanoparticles or Weight concentration (%wt) |

| Subscript                        |
|----------------------------------|
| \( Bf \) Base fluid             |
| \( Nf \) Nanofluid              |
| \( Hnf \) Hybrid nanofluid      |

Radiators in automobiles are used to remove excess heat from the vehicle engine. Conventionally, car radiator pumps water as the heat transfer medium through the chambers within the engine block to absorb the heat [2]. Peyghambarzadeh et al [3] investigated heat transfer of coolant flow through the automobile radiators which play a major role in the optimization of fuel consumption. The heat transfer performance of the automobile radiator was evaluated experimentally by calculating the overall heat transfer coefficient (U) according to the conventional 3-NTU technique.[3] Copper oxide (CuO) and Iron oxide (Fe₂O₃) nanoparticles were added to the water at three concentrations of 0.15, 0.4, and 0.65 vol. % considering the best pH for longer stability. Results demonstrated that both nanofluids showed greater overall heat transfer coefficient in comparison with water up to 9%. Furthermore, increasing the nanoparticle concentration in the coolant air velocity and nanofluid velocity enhanced the overall heat transfer coefficient.

Saidur et al [4] found that the dynamic viscosity and mass velocity of nanofluid is increased with the increase in volume concentration of copper nanoparticles. The researchers observed that the coolant side pressure drop increased with increase in volume fraction of copper nanoparticles. Due to this extra pressure drop, a higher coolant pumping power is needed for nanofluid as compared with conventional coolants. The pumping power also depends on density of the nanofluid. As the density of nanofluid increases the pumping power required to pump the nanofluid also increases.

Hussien et al [11] experimentally studied the heat transfer enhancement using hybrid nanofluid. They were used MWCNTs and GPNs hybrid nano particle for the preparation of hybrid nanofluid for their study. The experiments were conducted for finding the thermo physical properties, pressure drop and convective heat transfer coefficient. They assumed that flow is fully laminar flow, Reynolds number is in the range of 200-500. From their study, maximum heat transfer enhancement (43.4%) for hybrid nanofluid (0.25 MWCNTs + 0.035 GPNPs) at Reynolds number 200 is observed. The Brownian motion of the hybrid nano particles play a major role in enhancing the thermo physical properties. It is also observed that the pressure drop is increased by 11% when the nanofluid is used. Selvam et al. [9] did the experimental investigations on automobile radiator with graphene nanofluid for improving the heat transfer characteristics. The experiments were conducted by varying graphene nanofluid volume concentration from 0.1% to 0.5%. Thermal conductivity, specific heat, density, viscosity and pressure drop of graphene nanofluid were experimentally measured. Stability of graphene nano fluid is
analysed by UV-vis absorption spectroscopy analysis and zeta potential analysis. Convective heat transfer coefficient, Nusselt number and friction factor of nanofluids is experimentally investigated in laminar region. From above experiments they noticed that maximum enhancement (29%) of thermal conductivity and convective heat transfer coefficient at 0.5 vol%.. From the exhaustive literature survey conducted on the feasibility studies of coolants it is found the applications of nano- coolants require in-depth analysis so that the new and hybrid nano coolants developed could address the shortcomings of the conventional fluids. The present work looks into these finer aspects of development of newer hybrid nanofluids for future radiator applications.

2. PREPARATION OF NANOFLUID

The preparation of nanofluid plays a major role to achieve proper dispersion of nanoparticles in the base fluid. During the preparation of nanofluid there will be a higher chance of formation of precipitation or sedimentation in the solution. This will lead decrease in thermal conductivity of nanofluid, as a result heat transfer rate will decrease. To overcome this problem, proper surfactants (dispersants) were used in the present work to achieve good stability. Hybrid nanofluids were prepared to enhance the heat transfer rate of the working medium. Initially nanoparticles of MWCNT, CuO and Graphene in the range from 50-100nm were procured from Sigma Aldrich Corporation chemicals company. In this study equivalent weight (50:50) of each nanoparticles (MWCNT & CuO) were taken to prepare hybrid nanofluid and weighed systematically and were added gradually to the deionized water. Then 500ml of deionized water (base fluid) is taken in a beaker and subjected to magnetic stirring process. The duration of stirring action is around 30 minutes. During the stirring action the surfactant is added to the mixture in order to stabilize the solution. Surfactant used in the preparation of hybrid nanofluid is Sodium Dodecyl Sulphate (SDS) Figure. 1 shows Nanofluids used in the study. Figure. 2 shows the MWCNT-CuO/ deionized water-based nanoparticles undergoing drying in ultrasonic cleaner along with surfactants

Later, the mixture of nanoparticles with deionized water undergoes sonication process in bath sonicator by using ultrasonic cleaners. Sonication process is carried out for 120 minutes to achieve uniform distribution of nanoparticle in the base fluid. By doing sonication process, the agglomerated nano particles disperse and a homogeneous nanofluid with smaller sized nanoparticles is obtained [12]. After the completion of the ultra-sonication process the nanoparticles were allowed to get dry completely and it is converted into amorphous form. The amorphous nanoparticles are then weighed with respect to the required quantity in order to mix with the base fluid.

Same procedure is repeated to prepare graphene based nanofluid. Table (1-3) shows the geometrical properties of MWCNT, CuO and Graphene nanoparticles.

![Figure 1](image1.png)

**Figure.** 1 The image of the Nanofluid samples with different weight concentration

A,B,C and D - Ethylene glycol based Graphene nanofluid samples
E,F,G and H – Ethylene glycol based MWCNT – CuO based hybrid nanofluid samples
Figure 2: MWCNT-CuO ethanol-based nanoparticles undergoing drying in ultrasonic cleaner along with surfactants.

Table 1. Geometrical properties of Multiwalled carbon nanotubes (MWCNT)

| Parameter          | Remark       |
|--------------------|--------------|
| Purity             | >99%         |
| Appearance         | Black        |
| Particle size      | 50-100nm     |
| Length             | 20μm         |
| Thermal conductivity | 1500-3000 W/mK |
| True density       | 3.250 g/cm³  |
| Specific surface area | 90-350 m²/g |

Table 2. Geometrical properties of Copper oxide (CuO)

| Parameter          | Remark       |
|--------------------|--------------|
| Purity             | >99%         |
| Appearance         | Black        |
| Particle size      | 50-100nm     |
| Thermal conductivity | 33 W/mK        |
| True density       | 6320 kg/m³   |
| Specific heat      | 550.5 J/kgK  |

Table 3. Geometrical properties of graphene

| Parameter          | Remark       |
|--------------------|--------------|
| Purity             | >99%         |
| Particle size      | 50-100nm     |
| Thermal conductivity | 2500 W/mK    |
| True density       | 2250 kg/m³   |
| Specific heat      | 2100 J/kgK   |

2.1 Stability evaluation of nanofluid

The addition of dispersants or surfactants is generally preferred to stabilize the nanofluid. Addition of dispersive agent lowers the surface tension of host fluid and increases the immersion capability of the nanofluid. In this work, initial focus was on the effect of weight concentration of SDS as surfactant for stable dispersion of MWCNT-CuO in deionized water. Hybrid nanofluid sample of MWCNT-CuO/Deionized water at 0.1 %wt and different weight concentration (0.05 %wt – 0.15 %wt) of SDS were prepared. Table 4 shows optimization of the surfactant used.
Table 4. Optimization of the surfactant

| % weight concentration (Surfactant) | Surfactant (SDS)gms | Nanoparticles (MWCNT+CuO) grams | Remarks |
|-----------------------------------|---------------------|---------------------------------|---------|
| 0.05                              | 0.125               | 0.25                            | Settlement of nanoparticles observed |
| 0.075                             | 0.1875              | 0.25                            | Partial settlement of nanoparticles observed |
| 0.1                               | 0.2500              | 0.25                            | No agglomeration, no settlement of nanoparticles observed (Stable fluid) |
| 0.15                              | 0.3750              | 0.25                            | No agglomeration, no settlement of nanoparticles observed (Stable fluid) |

In the present study stability evaluation is carried out by using zeta potential test. Zeta potential of nanofluid was measured using Zetasizer from Malvern company. From the experimental results, the Zeta potential of MWCNT/CuO hybrid nanofluid at 0.1% wt is -36 mV, this indicates that prepared hybrid nanofluid is stable.

The Figure 3 shows the graph of zeta potential analysis for MWCNT-CuO/Deionized water hybrid nanofluid

2.2 Thermo-physical properties

2.2.1 Density of nanofluids

Heat transfer through nanocoolant depends on its density. Density of nanofluid and hybrid nanofluid were mathematically found by the below equations, [4, 6]

\[
\rho_{hfnf} = \phi_{np1}\rho_{np1} + \phi_{np2}\rho_{np2} + (1-\phi_{np1} - \phi_{np2})\rho_{bf} \tag{1}
\]

\[
\rho_{nf} = \phi_{np}\rho_{np} + (1-\phi_{np})\rho_{bf} \tag{2}
\]

Where \(\phi\) is the percentage of weight fraction, np1 and np2 are two different nanoparticles used in the study (CuO and MWCNT nanoparticles), \(\rho\) is the density of nanoparticle (kg/m\(^3\)). The suffixes p is for particle, bf is for the base fluid, hnf is for the hybrid nanofluid and nf for the nanofluid.

Figure. 3 Graph of zeta potential analysis for MWCNT-CuO/Deionized water hybrid nanofluid
2.2.2 Specific heat of nanofluids [4, 6]

Prepared water-based hybrid nanofluids containing MWCNT/CuO were used to estimate experimentally the specific heat and it is observed that experimental values were in good agreement with those given by specific heat mixture formula. The specific heat mixture formula for hybrid nanofluids is given as follows:

\[
\rho_{\text{nf}}C_{p,\text{nf}} = \phi_{\text{np1}}\rho_{\text{np1}}C_{p,\text{np1}} + \phi_{\text{np2}}\rho_{\text{np2}}C_{p,\text{np2}} + (1 - \phi_{\text{np1}} - \phi_{\text{np2}})\rho_{\text{bf}}C_{p,\text{bf}} \quad (3)
\]

\[
\rho_{\text{nf}}C_{p,\text{nf}} = \phi_{\text{np}}\rho_{\text{np}}C_{p,\text{np}} + (1 - \phi_{\text{np}})\rho_{\text{bf}}C_{p,\text{bf}} \quad (4)
\]

\(\text{np1 and np2 are two different nanoparticles used in the study (CuO and MWCNT nanoparticles), } \rho \text{ is the density of nanoparticle (kg/m}^3\text{), } C_p \text{ is the specific heat (J/kg K). The suffixes np, hnf and bf are related to nano particle, hybrid nanofluids and base fluid, respectively.}\)

Eq. (3) is used to find the specific heat of MWCNT/CuO nanoparticles theoretically. The Eq. (4) is used to find the specific heat of the Graphene nanofluid. Table 5 shows the physical properties of MWCNT-CuO/Deionized water at 80°C, weight concentration of MWCNT-CuO/Deionized water is varied from 0.050-0.150%wt. Table 6 shows the physical properties of Graphene/Deionized water at 80°C

| Sl.No. | Weight Concentration % | Density (kg/m\(^3\)) | Specific heat (J/kg.K) | Thermal conductivity(W/mK) |
|-------|------------------------|-----------------------|------------------------|---------------------------|
| 1     | 0.050                  | 1166.550              | 4302                   | 0.700                     |
| 2     | 0.075                  | 1262.800              | 4334                   | 0.710                     |
| 3     | 0.100                  | 1359                  | 4361                   | 0.710                     |
| 4     | 0.150                  | 1551                  | 4405                   | 0.710                     |

| Sl.No. | Weight Concentration % | Density (kg/m\(^3\)) | Specific heat (J/kg.K) | Thermal conductivity(W/mK) |
|-------|------------------------|-----------------------|------------------------|---------------------------|
| 1     | 0.050                  | 937.300               | 3680                   | 0.510                     |
| 2     | 0.075                  | 918.950               | 3688                   | 0.510                     |
| 3     | 0.100                  | 900.600               | 3990                   | 0.510                     |
| 4     | 0.150                  | 864                   | 3995                   | 0.510                     |

3. EXPERIMENTAL SET-UP

This section explains the experimental test rig used and the specification of the radiator used. Figures 4 and 5 show the schematic diagram and image of experimental set-up used.
Tables 7 and 8 shows the equipment and radiator Specifications

| Sl. No. | Parameter           | Specification                      |
|---------|---------------------|------------------------------------|
| 1       | Pump                | 0.5 Hp                             |
| 2       | Fan                 | 2300rpm, 50cm and 48W              |
| 3       | Tank                | 20 liters (R=15cm and H=25cm)      |
| 4       | Heater              | 1.5 kW                             |
| 5       | Rotameter           | 360(lph)                           |
| 6       | Temperature indicator| Sensor (Thermocouples)                  |
The specification of the radiator used in the experimental setup is shown in the table 8.

| Slno | Parameter                      | Nomenclature | Measured Value |
|------|--------------------------------|--------------|----------------|
| 1    | Length of the automotive radiator | \( L_R \)   | 0.35 m         |
| 2    | Automotive Radiator height      | \( H_R \)   | 0.30 m         |
| 3    | Automotive Radiator width       | \( W_R \)   | 0.018m         |
| 4    | Height of the fin               | \( H_{fin} \) | 0.00047m       |
| 5    | Thickness of the fin            | \( t_{fin} \) | 0.0001m        |
| 6    | Width of the tube               | \( W_t \)   | 0.0018m        |
| 7    | Number of tubes                 | \( N_t \)   | 40             |
| 8    | Thickness of the tube           | \( \Delta t \) | 0.00008m       |
| 9    | Length of the tube              | \( L_t \)   | 0.30 m         |
| 10   | Width of the fin                | \( W_{fin} \) | 0.0018m        |
| 11   | Tube height                     | \( H_t \)   | 0.018m         |
| 12   | Fin length                      | \( L_{fin} \) | 0.01m          |

4. EXPERIMENTAL CALCULATION \[8,10,13\]

The convective heat transfer coefficient \((h)\) and Nusselt number \((N_u)\) for the automotive heat transfer application is given by

According to Newton’s law of cooling,

\[
Q = hA(T_b - T_w),
\]

where \(A\) is the surface area, \(T_b\) is the average bulk temperature, and \(T_w\) is the average wall temperature.

\[
T_w = \frac{T_1 + T_2 + \cdots + T_{12}}{12},
\]

here \(T_1\) to \(T_{12}\) are the temperatures of radiator tubes at different locations measured by using 12 thermocouples situated on the radiator.

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

Here \(T_{in}\) and \(T_{out}\) are radiator inlet and outlet temperatures respectively.

Now, the heat transfer rate can be also calculated as

\[
Q = mC_p (T_{in} - T_{out}).
\]

With the use of Eqs. (5) and (8), we can calculate the convective heat transfer coefficient of the nanofluid.

\[
h_{expr} = \frac{mC_p (T_{in} - T_{out})}{A(T_b - T_w)}.
\]

Now, the average Nusselt number \(Nu\) can be evaluated by using following equation:

\[
Nu_{expr} = \frac{h_{expr} \times D_{hy}}{k},
\]
Where $C_p$ is the specific heat capacity of the nanofluid, $k$ is the thermal conductivity of the fluid, $\text{Nu}_{\text{expt}}$ is the actual Nusselt number from the experimental calculation and $D_h$ is the hydraulic diameter of the tube.

5. RESULTS AND DISCUSSION

In the present work, the convective heat transfer coefficient, Nusselt number and heat transfer rate of an automobile radiator using graphene/deionized water and MWCNT-CuO/deionized water as coolant for various weight concentrations ($\varphi = 0.05$-$0.15$ %wt) were investigated experimentally. The experiments were conducted for various nanofluid volume flow rate and inlet temperature. The heat transfer rate, convective heat transfer coefficient and Nusselt number for graphene/deionized water (Nanocoolant) at 0.1% wt for various volume flow rate (3 to 7 L/min) at 80°C is tabulated in Table 9.

| Sl. No | Nano-coolant Temperature | Volume flow rate (L/min) | Nu  | $h$ (W/m²K) | $Q$ (W) |
|-------|--------------------------|--------------------------|-----|-------------|---------|
| 1     |                          | 3                        | 5.80| 740         | 4440    |
| 2     |                          | 4                        | 8.70| 1110        | 5106    |
| 3     | 80°C                     | 5                        | 14.10| 1809        | 6512    |
| 4     |                          | 6                        | 20.50| 2619        | 7334    |
| 5     |                          | 7                        | 29  | 3708        | 8158.50 |

The heat transfer rate, convective heat transfer coefficient and Nusselt number for deionized water for various mass flow rate (3 to 7 L/min) at 80°C is tabulated in Table 10.

| Sl. No | Deionized water Temperature | Volume flow rate (L/min) | Nu | $h$ (W/m²K) | $Q$ (W) |
|--------|-----------------------------|--------------------------|----|-------------|---------|
| 1      |                            | 3                        | 2.33| 350         | 2940    |
| 2      |                            | 4                        | 3  | 464         | 3528    |
| 3      | 80°C                       | 5                        | 4.4 | 658         | 3750    |
| 4      |                            | 6                        | 6.2 | 930         | 4091    |
| 5      |                            | 7                        | 9.55| 1432        | 4295    |

The heat transfer rate, convective heat transfer coefficient and Nusselt number for MWCNT-CuO/deionized water (Hybrid Nanocoolant) at 0.1% wt for various mass flow rate (3 to 7 L/min) at 80°C is tabulated in Table 11.

| Sl. No | Hybrid Nanocooolant Temperature | Volume flow rate (L/min) | Nu | $h$ (W/m²K) | $Q$ (W) |
|--------|---------------------------------|--------------------------|----|-------------|---------|
| 1      |                                 | 3                        | 7  | 1221        | 7324.8  |
| 2      |                                 | 4                        | 11.28| 1975        | 9085    |
| 3      | 80°C                            | 5                        | 17.24| 3017.5      | 10862.9 |
| 4      |                                 | 6                        | 26.20| 4655.54     | 13035.5 |
| 5      |                                 | 7                        | 37.70| 6598.56     | 14516.84|
The maximum value of Nusselt number was observed in MWCNT+CuO/ Deionized water hybrid nanofluid (0.1% wt concentration) at 80°C as compared with the deionized water, Graphene/deionized water nanofluid (0.1% wt concentration). The maximum enhancement in the Nusselt number was observed to be 295% for MWCNT-CuO/Deionized water hybrid nanofluid (0.1% wt concentration) as compared with the deionized water at 80°C. 7 L/min volume flow rate. Nusselt number for nanocoolant increases with increase in coolant volume flow rate is observed. The maximum Nusselt number (Figure 6) enhancement was found to be 30% for MWCNT-CuO/Deionized water hybrid nanofluid (0.1%wt concentration) compared with Graphene/deionized water based nano coolant at 80°C.

![Figure 6](image)

**Figure 6** Variation of Nusselt number with the nanocoolant volume flow rate

Figure 7 shows the variation of Heat transfer coefficient with mass flow rate of the nanofluids used. The maximum value of convective heat transfer coefficient was observed in MWCNT+CuO/ Deionized water (0.1% wt) hybrid nano coolant at 80°C as compared with the deionized water, Graphene based nanofluid. The enhancement in the convective heat transfer coefficient of MWCNT-CuO/ Deionized water was observed in the range of 65% to 87% at different coolant volume flow rate (3 L/min to 7L/min) as compared with the Graphene/ deionized water based nanofluid.

![Figure 7](image)

**Figure 7** Variation of Heat transfer coefficient with the nanocoolant volume flow rate

Figure 8 shows the variation of Heat transfer with mass flow rate of the nanofluids used. Significant
increase in the heat transfer rate was observed with increase in hybrid nanocoolant flow rate. The maximum enhancement in the heat transfer rate for aqueous based MWCNT-CuO hybrid nanofluid was observed at coolant flow rate of 7 L/min and temperature of 80°C.

![Figure 8](image)

**Figure 8** Heat transfer variation with the nanocoolant volume flow rate

Present study also focused on thermal conductivity enhancement of MWCNT-CuO hybrid nanofluid and graphene nanofluid. Thermal conductivity of nanofluids at different temperature and at different weight concentration were experimentally measured. Thermal property analyser (KD2 Pro, Decagon device) is used to measure thermal conductivity of nanofluid and hybrid nanofluid. Transient hot wire technique (THW) is employed in the KD2 Pro, Decagon device.

Table 12 gives the information about thermal conductivity variation with Deionized water, Graphene and MWCNT-CuO hybrid nanofluid at different temperature at 0.1 %wt. Thermal conductivity variation with Deionized water, Graphene and MWCNT-CuO hybrid nanofluid at different weight concentrations for 80°C is shown in table 13.

**Table 12.** Thermal conductivity variation with Deionized water, Graphene and MWCNT-CuO hybrid nanofluid at different temperature at 0.1 %wt

| Sl.No. | Weight Concentration % | Temperature (°C) | Thermal conductivity (W/mK) Deionized water | Thermal conductivity (W/mK) Graphene nanofluid | Thermal conductivity (W/mK) MWCNT-CuO hybrid nanofluid |
|--------|-------------------------|------------------|---------------------------------------------|-----------------------------------------------|-----------------------------------------------------|
| 1      | 0.1                     | 70               | 0.60                                        | 0.62                                          | 0.75                                                |
|        |                         | 80               | 0.61                                        | 0.64                                          | 0.78                                                |
|        |                         | 90               | 0.62                                        | 0.65                                          | 0.81                                                |

**Table 13.** Thermal conductivity variation with Deionized water, Graphene and MWCNT-CuO hybrid nanofluid at different weight concentrations for 80°C

| Sl.No. | Weight Concentration % | Thermal conductivity (W/mK) Graphene nanofluid | Thermal conductivity (W/mK) MWCNT-CuO hybrid nanofluid |
|--------|-------------------------|-----------------------------------------------|-----------------------------------------------------|
| 1      | 0.050                   | 0.61                                          | 0.75                                                |
| 2      | 0.075                   | 0.62                                          | 0.76                                                |
| 3      | 0.100                   | 0.64                                          | 0.78                                                |
| 4      | 0.150                   | 0.65                                          | 0.79                                                |

From the experimental observation it is evident that thermal conductivity of graphene nanofluid and
MWCNT-CuO hybrid nanofluid is a function temperature and weight concentration of nanoparticle. Thermal conductivity of nanofluid is in linear relationship with the nanoparticle concentration and temperature of nanofluids.

Thermal conductivity of nanofluids increases with increase in nanoparticle weight concentration which is shown in Figure 10 it is due to mean free path between the particles decreases as the nanoparticle concentration increased [15].

From the Figure 9 it is evident that thermal conductivity of nanofluids increases with increase in temperature of nanofluid, it is because of Brownian motion of the nanoparticle [15].

Maximum of 30% enhancement in thermal conductivity was obtained for 0.1 %wt MWCNT-CuO hybrid nanofluid at 80°C.

![Figure 9](image-url)  
**Figure 9** Thermal conductivity variation of Deionized water, Graphene and MWCNT-CuO hybrid nanofluid with different temperature at 0.1 %wt concentration

![Figure 10](image-url)  
**Figure 10** Thermal conductivity of Graphene and MWCNT-CuO hybrid nanofluid at different wt concentration
6. CONCLUSIONS

In the present study the performance of aqueous based hybrid nanofluid MWCNT-CuO and graphene as automobile radiator coolant has been experimentally investigated at different inlet temperatures. The weight fraction of nanoparticle is varied from 0.05-1.15 %wt. The experiment was conducted with the variation of nanocoolant flow rates from 3 L/min to 7 L/min and at the temperature range of 50°C to 80°C with regular increments of 10°C.

From this study following conclusions can be drawn:

- Significant increase in the heat transfer rate was observed with increase in hybrid nanocoolant flow rate.
- Increase in the hybrid nanocoolant flow rate enhances the Nusselt number and convective heat transfer coefficient.
- The enhancement in the convective heat transfer coefficient of MWCNT-CuO/Deionized water was observed in the range of 65% to 87% at different coolant flow rate (3 L/min to 7L/min) as compared with the Graphene/deionized water based nano coolant.
- The maximum enhancement in the Nusselt number was observed in MWCNT-CuO/Deionized water (0.1% wt) nano coolant at 80°C as compared with the deionized water, graphene.
- The maximum Nusselt number enhancement was found to be 295% for MWCNT-CuO/Deionized water hybrid nanofluid at 0.1% wt concentration as compared with the deionized water at 80°C, 7 L/min flow rate.
- The maximum enhancement in the Nusselt number was found to be 30% for MWCNT-CuO/Deionized water (0.1% wt) compared with Graphene/deionized water based nano coolant at 80°C.
- With the increase in the nano-coolant flow rates, the heat transfer rate, Nusselt number and the convective heat transfer coefficient enhances for all values of nano particle weight concentration.
- Thermal conductivity of graphene nanofluid and MWCNT-CuO hybrid nanofluid is a function of temperature and weight concentration of nanoparticle. Thermal conductivity of nanofluid is in linear relationship with the nanoparticle concentration and temperature of nanofluids.
- Maximum of 30% enhancement in thermal conductivity was obtained for 0.1%wt MwCNT-CuO hybrid nanofluid at 80°C.

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