An experimental investigation into heat transfer characteristics of aqua based Cu nanofluid for automobile radiator

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Abstract: In this experimental research work, heat transfer characteristics of water based copper (Cu) nanofluids has been investigated and compared with conventional fluids for an automobile radiator under the laminar flow regime. In this study, 37 verticals with cross section of stadium shaped tubes and having multi louvered fins inaugurated on their outer body act as a radiator. Forced air with constant velocity flowing through bunches of fins becomes potential factor for heat transfer. The variation in liquid flow rate through radiator has been kept in the range of 2-5LPM. Three different volumetric concentrations (0.3%, 0.6% and 1.0%) of water based copper nanofluids have been prepared for use. Also, the inlet temperature has been varied in the range of 45-55°C to investigate the effect of inlet temperature of the coolant fluids over Nusselt number. The maximum enhancement of 39.53% in Nusselt number has been observed as compared to that for distilled water and accordingly, its effectiveness got raised by 10.73% at 1.0% volumetric concentration of the nanoparticles. The salient feature of this experimental study is that water based copper nanofluids come out as suitable and better coolant for the radiator.

Keywords: Nanofluids, Heat transfer characteristics, Multi louvered fins, Radiator

1. Introduction

In this era of technological advancement in industrialization to improve quality of human life ecological concern has become a rider to make efficient and economical use of energy. Such use of energy can only be ensured by thermal processes wherein heat transfer plays a pivotal role. The heat exchangers are one of the vital components for many industries such as nuclear power plants, automobile industries, chemical industries and aerospace industries and they are used as a means of heat recovery or rejection from a system [1].

The overall efficiency of a system depends upon various factors such as geometry of its component and spatial as well as kinetic aspects related to heat transfer [2]. Lower convective heat transfer and poor properties of standard fluids like water, oil, and glycol utilized in heat transfer has drawn attention of researchers endeavored for improvement in their energy potential in nature. Sensing this need Choi and Eastman carried out experiments by dispersing nano size high conductive particles into liquid and gave birth to a new term “Nanofluid”. A wide range of study has been done to investigate
and analyze the behavior of metal as well as metallic oxide based nanofluids by using temperature dependent characteristics in terms of particle size and volume fraction of nanoparticles. Choi and Eastman dispersed the nanoparticles into the fluids in their experiments and determined their thermal conductivity [3]. The experimental study carried out by researchers in the field has shown enhancement in thermo-physical properties, better stability or convective heat transfer (CHT) as compared to base fluids but that also showed a slight increase in pressure drop giving room for requirement of additional pumping power [4-6].

2. Literature review

A large number of investigation conducted to study thermo-physical properties of nanofluids paved way for various classical physical models for predicting behaviors of nanofluids but most of the estimated values showed wider deviation from real values. However, models suggested by Maxwell [7], Hamilton and Crosser [8], Xiang and Arun [9] are utilized to predict their behavior and these predicted values are more closer to real values. Le and Xuan [10] investigated heat transfer phenomena and fluid flow behavior of water based Cu nanofluids through a brass tube with turbulent and laminar flow regime and found increase by 60% as compared to H₂O at same Reynolds number. 

Xuan and Li [11] analyzed one phase flow and heat transfer utility of nanofluids under turbulent flow in tubes. The result found that the heat transfer coefficient as well as Nusselt number got raised with Reynolds number and concentration of nanoparticles in the fluids.

Wen and Ding [12] observed that aluminum oxide based nanoparticles when dissolved in base fluid, causes its thermal conductivity to rise. Consequently, it has been observed that CHT increases with Reynolds number and particle concentration under laminar regime. In another research, the researchers investigated heat transfer behavior of multiwall carbon nanotubes under laminar flow regime through a horizontal tube. The investigation concluded that the maximum heat transfer was about 350% with 0.5% weight concentration at Reynolds number of 800.

Peyghambarzadeh et. al. [13] tried to gauge heat transfer characteristics of heat exchanger by conning overall heat transfer and by making use of NTU methodology. CuO and Fe₃O₄ nanoparticles were accessorial to water at 3 volumetric concentrations 0.15%, 0.4% and 0.65%. Three different inlet temperature levels were used for carrying out experiment. Radiator functioning with nanofluids showed improved performance as compared to the radiator using conventional fluids.

Ali et. al. [14] analyzed the convective heat transfer and its dependence on fluid temperature and ZnO nanofluid concentration in an automotive radiator. The findings revealed that at 0.2% and 0.3% (volume) concentration enhancement in CHT by 46.5% and 34% occurs. As the temperature increases from 45 to 55 degree Celsius, Nusselt number enhances by 4%.

Vermahmoudi et. al. [15] experimentally examined heat transfer behavior of a car radiator functioning on aqua based Fe₃O₄ (40 nm) nanofluid under laminar flow regime and found that enhancement in inlet temperature of nanofluids improved heat transfer rate by 116% at maximum flow rate. Also, for 0.65% volume concentration of particles, increase in overall heat transfer coefficient occurs up to 13%.

Sahoo and Sarkar [16] conducted an experiment on louvered fin heat exchanger radiator using 5 different nanoparticles (metal + non-metals) suspended with ethylene glycol based Al₂O₃ with 1.0% volume concentration. Results demonstrate that Ag hybrids fluid has high heat carrying capacity and thermal conductivity. Also, effectiveness and heat transfer rate showed an increase by 5% and 87% respectively with 1.0% volume fraction for Al₂O₃ followed by Cu. Pressure drop is maximum for Ag followed by the Cu, CuO, TiO₂ and SiC.

From the literature survey [17-18], it is observed that more work has been carried out in the field of oxide based nanofluids for a car radiator. The thermal resistance of the metallic fluids is always lower than that of oxide based fluids [19]. In the present paper, heat transfer behavior and friction factor with respect to Nusselt number of water based copper (Cu) nanofluids have been investigated and the effect of various input parameters on effectiveness of the radiator has been analyzed.
3.0 Experimental setup

Figure 1 shows the experimental test rig which consists of a storage tank, a heater, a duct with forced draft fan, centrifugal pumps, flow meter and U-tube manometer. The test section used for current research is a cross flow compact heat exchanger - the cooling unit of an automobile. Two centrifugal pumps are placed in storage tank. One is for circulating hot fluid through the test rig which gives a constant flow rate of 7 LPM, while the second one is used to circulate the fluid within the storage tank to avoid localized heating and for uniform mixing of the base fluids as well as nanofluids. The total capacity of the storage tank is 19 liters. To manipulate and control flow rate of the fluids for experiments, a rotameter (EUREKA industrial equipment MG-6Z types) with accuracy of 0.1L/min was used.

![Figure 1. Layout of experimental setup.](image)

10 RTD (pt100Ω) thermocouples are pasted at different locations in radiator for measuring inlet and outlet temperatures of the fluids. A manometer (U-type glass tube) is also attached near to the entrance and outlet limbs of the radiator. This U-tube manometer measures pressure drop in radiator tubes.

The liquid used in this research is nanofluids which consist of distilled water and copper (Cu) nanoparticles. From Transmission Electron Microscope (TEM) images, the mean diameter of nanoparticles is calculated as 15nm.

4.0 Synthesis of nanoparticles [20]

4.1 Preparation of Copper (Metallic) nanoparticles.

Commonly, the synthesis of Copper nanoparticles is done in neck covered flask by mixing up the two equal certain volume of water based CTAB solutions. One containing hydrazine solution whiles the other is constituted of cupric chloride. Later on, pH value of the solution was constrained at 10 by using ammonia solutions. The reduction reaction for the formation of copper nanoparticles may be indicated as:

\[
2\text{Cu} (\text{NH}_3)_2\text{Cu}^+ + \text{N}_2\text{H}_4 + 4\text{(OH)}^- \rightarrow 2\text{Cu}^+ \text{N}_2 + 4\text{(NH}_4)^+ \text{OH} \tag{1}
\]

A typical transmission electron micrograph for Cu nanoparticles obtained at a desired concentration is shown in Figure 2. The typical XRD graph of Cu nanoparticles is shown in Figure 3. Formation of pure copper particles is indicated by the two peaks occurring at \(2\theta = 43.3^\circ\) and \(50.4^\circ\). Hence, this vindicates that FCC (Cu) particles thus prepared are pure in nature.
Figure 2. TEM image of Copper particles.

Figure 3. XRD images of Cu nanoparticles.

5.0 Nanofluids physical properties

To achieve a uniform suspension of nanoparticles in the fluids, two hours of ultra sonication has been carried out. To measured the thermo physical properties of the suspension following classical formulae are used. [13]

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

\[
\mu_{nf} = \mu_b (123\phi^2 + 7.3\phi + 1) \tag{3}
\]

\[
K_{nf} = \frac{K_{np} + (\beta-1)K_b - \phi(\beta-1)(K_b - K_{np})}{K_{np} + (\beta-1)K_b + \phi(K_b - K_{np})} K_b \tag{4}
\]

\[
(\rho C_p)_{nf} = \phi (\rho C_p)_{np} + (1-\phi) (\rho C_p)_b \tag{5}
\]

In the given correlations, subscripts “np” indicates the particles. “b” and “nf” refers to water and nanofluids respectively. “β” is shape factor. It is considered equal to three. Shape factor is given by \(3/\psi\), and “ψ” refers to particle sphericity which is described as the “ratio of surface area of the sphere with volume equals to that of particles to the surface area of particle”. “φ” is the volumetric concentration of the particles into the base fluid.

6.0 Calculations of heat transfer coefficient

The effectiveness of the radiator is analyzed under the various input parameters such as inlet temperature of the fluids (45°C, 50°C and 55°C), flow rate of the liquid (2, 3, 4 and 5 LPM) and concentrations of the particles in the fluids (0.3, 0.6 and 1.0% by volume). The velocity of air for cooling the heated fluids is kept 5.38 m/s for all the experiments. To determine heat transfer coefficient, the followings methods have been adopted. As per enunciation made by Newton for cooling phenomenon:

\[
Q = hA\Delta T = hA (T_{bulk} - T_{wall}) \tag{6}
\]

Heat transfer rate, \(Q\), may also be found as:

\[
Q = mC_p (T_{in} - T_{out}) \tag{7}
\]

Equating the above equations (6) and (7)

\[
h = \frac{mC_p (T_{in} - T_{out})}{A (T_{bulk} - T_{wall})} \tag{8}
\]

The corresponding Nusselt number may be calculated as:

\[
Nu = \frac{hD_h}{K} \tag{9}
\]

In the above equations, “Nu” is Nusselt number, and bulk mean temperatures are specified by “\(T_{bulk}\)” – the average value of entrance and exit temperatures of moving fluids. “\(T_{wall}\)” is wall temperature of flow channel and calculated by taking mean value of two thermocouples placed at the wall of the tube radiator. “\(h\)” is convective heat transfer coefficient. “\(m\)” is mass flow rate inside the tubes. The hydraulic diameters of the tubes are denoted by “\(D_h\)”. “\(K\)” refers to the thermal conductivity. Specific heat is denoted by “\(C_p\)”. It is to be noticed that all the liquid properties utilized for calculations are taken at bulk mean temperature.
7.0 Results and discussion

7.1 Thermo physical properties of nanofluids:
The graph between thermal conductivity of the fluids and temperature demonstrate that conductivity increases with rise in temperature. Consequently, this plot reveals that the thermal conductance of water based Cu nanofluids is strong ramification of temperature. The reason behind such enhancement in the conductivity is the random motion exhibited by nanoparticles within the fluids.

![Figure 4](image1.png)  
**Figure 4.** Impact of temperatures on thermal conductivity.

![Figure 5](image2.png)  
**Figure 5.** Impact of temperatures on density of fluids.

As solid particles are added to the base fluid, density and viscosity of the resultant solution increases. Consequently, additional forces are required to overcome the inertia forces. Moreover, decrement of viscosity with increase in temperature has been observed.

![Figure 6](image3.png)  
**Figure 6.** Impact of temperature on viscosity of fluids.

![Figure 7](image4.png)  
**Figure 7.** Effect of Reynolds number on Nusselt numbe at various concentrations.

**Hot fluid side analysis**
Expermentation work has been carried out by altering factors like flow rate, fluid temperature and concentration of particles in the base fluid. The outcome of the experiment was obtained in the form of Nusselt number, heat transfer co-efficient and Friction factor.

7.2 Reynolds number and particles concentration and their impact on Nusselt number:
Nusselt number is an outcome of Prandtl number as well as Reynolds number. So, it is a function of flow and fluidic properties. Figure 7 represents variation of Nusselt number exhibited by distilled water and nanofluids at different concentrations. Obviously from the graph, it appears that the Nusselt number shows increase with the rise in Reynolds number for the flow and particles concentration in the base fluid. As concentration of nanoparticles increases, the probability of their collisions rises and thermal conductance of the fluid enhances which results into improved rate of heat transfer. However,
this increase in concentration leads to increase in viscosity of the fluids. Moreover, there is an added advantage of thermal conductance being dominant over rise in viscosity, which requires more power. Altogether, this rise of thermal conductance is beneficial in serving the very purpose of radiator.

7.3 Friction factor and its dependence on flow rate and concentration:
Friction factor is calculated for pressure drop along radiator tubes. It is necessary to be analyzed as it indicates the pump power requirement for circulation of hot fluid through heat exchanger. From the experiment it has been observed that any increase in Reynolds number gives rise to decrease in friction factor. Although, addition of particles leads to enhancement in the thermal conductivity and further increase in heat transfer, it requires a little more pumping power.

7.4 Influence of inlet fluid temperature over Nusselt number:
As the inlet temperature of hot fluid rises, enhancement in the Reynolds number is observed due to the influence of temperature over viscosity of fluids. On the other hand, Prandtl number drops because of dominant rise in thermal conductivity and drop in viscosity. Figure 9 shows variation of Nusselt number with change in inlet temperature of fluids. Similar relation has been observed for different concentrations of Cu/water nanofluids.

7.5 Influence of temperature of fluid on friction factor:
As Reynolds number of the nanofluids increases the friction factor decreases. Also, when the inlet temperature of the fluids is increased, viscosity drops slightly and friction factor gets decreased.
8.0 Conclusion
The Experimental work has been carried out using conventional fluids and nanofluids by selecting and varying three different parameters namely temperature of inlet fluids, concentration of particles and liquid flow rate and maintaining velocity of cooling medium (air passing through the bundles of fins of the radiator) constant. Based on the experimental work, the followings conclusions have been drawn:

- Thermal conductivity of fluid depends upon temperature and concentration of particles. Enhancement of 57.51% in thermal conductivity has been found at 40°C but the rate of increase decreases with increase in temperature for distilled water. Similarly, for enhancement in temperature from 35°C to 60°C density and viscosity of nanofluids show decrease by 0.867% and 35.447% respectively.
- Nusselt number of heated fluid gets increased with increase in Reynolds number and volumetric conc. of nanoparticles. For 45°C temperature of fluid, mean value of Nusselt number are elevated than that of conventional fluids by 30.72%, 24.20% and 30.77% for 0.3%, 0.6% and 1.0% concentration respectively. Also, at 0.6% particle volume concentration, enhancement of 2.173% and 4.004% has been found in Nusselt number as compared to conventional fluids with increase in temperature from 45°C to 50°C and 55°C respectively.
- With the aid of nanofluids, heat transfer coefficients are enhanced by 19.187%, 23.425% and 26.465% for 0.3%, 0.6% and 1.0% volumetric concentration respectively than those for conventional fluids. By the addition of particles into the distilled water, enhancement in the friction factor has been observed. At a constant flow rate and 45°C, friction factor was increased by 20.93%, 34.83% and 39.53% for 0.3% and 0.6% and 1.0% volumetric concentrations respectively than those for conventional fluids. As the inlet temperature of fluid is increased, drop in friction factor has been observed. For 0.6% concentration of nanoparticles, friction factor was decreased by 5.146% and 11.342% when temperature was increased from 45°C to 50°C and 55°C respectively.
- Effectiveness of the radiator is also intensified significantly by the application of aqua based copper nanofluids. The effectiveness for conventional fluids is recorded as 68.76% and it attains a rise to 73.52%, 75.36% and 79.49% for 0.3%, 0.6% and 1.0% particle volume concentration respectively.

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