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Comparison of Heat transfer Performance with Cu/water and CuO/water Nanofluids in Truck Radiator

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ABSTRACT

The thermal performance of tractor radiator is improved with Cu/water when compared with CuO/water nanofluids as workings fluid. The nanomaterial plays a vital role for past two decades in the research areas like thermal management and material science. Miniaturization and increased operating speeds of heat exchangers warranted the need for new and innovative cooling concepts for better performance. The nano materials and its suspension in fluids as particles have been the subject of intensive study worldwide recently since pioneering researchers recently discovered the anomalous thermal behavior of these fluids. For heavy vehicles the engine cooling is an important factor for their performance in the intended application. Here the tractor engine radiator cooling is enhanced by nanofluid mechanism of heat transfer for its improved performance in agricultural work. If the tractor engine cooling is enhanced then using this farm equipment more agricultural field can be ploughed which can be utilized for cultivation within a short period of time. Heat transfer in automobile is achieved through radiators. In this research work an experimental and numerical investigation for the improved heat transfer characteristics of a radiator using Cu/water and CuO/water nanofluid for 0.025, 0.05 and 0.075% volume fraction is done with inlet temp of 50 - 60°C under the turbulent flow regime ($8000 \leq Re \leq 25000$). The overall heat transfer coefficient decreases with increase in nanofluid inlet temperature of 50 - 60°C. The experimental results of the heat transfer using the Cu metal particles of nanofluid is compared with Oxide and the numerical values which shows an increase in heat transfer coefficient. The results in this work suggest that the best heat transfer enhancement can be obtained compared with the base fluid and oxide form by using a system with Cu/water nanofluid-cooled radiators. The nanofluids showed better heat transfer characteristics as a new alternative coolant for the radiator.

1. Introduction

Nomenclature

A	Cross section area (m^2)
D_h	Hydraulic diameter (m)
h	Convective heat transfer coefficient(kW/m^2 K)
k	Thermal conductivity (W /mK)
m	Mass flow rate (kg/s)
Nu	Nusselt number
Pr	Prandtl number
Q	Heat transfer (W)
R_e	Reynolds number
T	Temperature (K)
$(C_{p)nf}$	Nanofluid specific heat capacity (J/kgK)
ρ_{bf}	Density of base fluid (kg/m^3)
ρ_p	Density of particle (kg/m^3)
$(C_p)_p$	Particle heat capacity (J/kgK)
K_p	Thermal conductivity of particle (W /mK)
K_{bf}	Thermal conductivity of base fluid (W /mK)
μ_{nf}	Viscocity of nanofluid (kg/m^2 s)
C*	C_p min / C_p Max
L	Tube length in (m)
U	Overall heat transfer coefficient (W /m^2K)

Greek symbols	
μ	Dynamic viscosity (kg/m^2 s)
ρ	Density(kg/m^3)
φ	Volume fraction of nanoparticles (%)
δ	Tube thickness (m)
ε	Effectiveness
Subscripts	
b_f	Base fluid
n_f	Nanofluid
p	Particle
w	Water
a	Air
b	Bare
i	Inlet , tube side
o	Outlet, air side
Abbreviation	
Cu	Copper
CuO	Copper oxide
NTU	Number of transfer unit

The energy consumption reduction can be improved by improving the performance of heat exchange systems and introducing various heat transfer enhancement techniques.

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In the middle of 1950's some efforts have been done on the variation in the geometry of heat exchanger apparatus using different fin types or various tube inserts or rough surface [1-7]. Some researchers have focused on electric or magnetic field application or vibration techniques [8-11]. Even though an improvement in energy efficiency is possible from the topological and configuration points of view, much more is needed from the perspective of the heat transfer fluid. More improvement in heat transfer is always in demand, as the efficiency of these devices depends on the cooling rate. New technology and advanced fluids with greater potential to improve the flow and thermal characteristics are two options to enhance the heat transfer rate and the present article deals with the latter options.

Although there is an alternate in conventional fluid such as refrigerants, water, engine oil, ethylene glycol, etc, shows some improvement in heat transfer performance and therefore high compactness and effectiveness of heat transfer systems are necessary to achieve the required heat transfer. Emerging improvements in nanotechnology have allowed development of a new category of fluids termed nanofluids. Such fluids are liquid suspensions containing particles that are significantly smaller than 100 nm, and have a bulk solids thermal conductivity higher than the base liquids [12].

Nanofluids are formed by suspending metallic or non-metallic oxide nanoparticles in traditional heat transfer fluids. These so called nanofluids display good thermal properties compared with fluids conventionally used for heat transfer and fluids containing particles on the micro meter scale [13]. Nanofluids are the new window which was opened recently and it was confirmed by several authors that these working fluid can enhance heat transfer performance.

The researchers Pak and Cho [14] done an experimental investigation for the convective turbulent heat transfer characteristics of water nanofluid with 1-3 vol. %. The Nusselt number for the nanofluids increases with the increase of nanofluid volume concentration and Reynolds number. The researchers Wen and Ding [12] experimented the convective heat transfer of nanofluids in the entrance region under laminar flow conditions. Aqueous based nanofluids containing Al_2O_3 nanoparticles (27-56 nm; 0.6-1.6vol. %) with sodium dodecyl benzene sulfonate (SDBS) as the dispersant, were tested under a constant heat flux boundary condition. For nanofluids containing 1.6 vol. %, the local heat transfer coefficient in the entrance region was found to be 41%higher than that of the base fluid at the same flow rate. The researchers Heris et al. [15] examined and proved the enhancement of in-tube laminar flow heat transfer of nanofluids (water/Al_2O_3) in a constant wall temperature boundary condition. In other work, Heris et al. [16] presented an investigation of the laminar flow convective heat transfer of Al_2O_3/water under constant wall temperature with 0.22 vol. % of nanoparticle for Reynolds number varying between700 and 2050. The Nusselt number for the nanofluid was found to be greater than that of the base fluid and the heat transfer coefficient increased with an increase in particle concentration. The ratio of the measured heat transfer coefficients increases with the Peclet number as well as nanoparticle concentrations.

Lai et al. [17] experimented the flow behaviour of nanofluids (Al_2O_3-water; 20 nm) in a stainless steel test tube, subjected to constant wall heat flux and a low Reynolds number (Re< 270). The Nusselt number enhances with the nanofluid by 8% at the concentration of 1 vol. % was recorded. Jung et al. [18] conducted convective heat transfer experiments for a nanofluid (Al_2O_3/water) in a rectangular micro channel under laminar flow conditions. The convective heat transfer coefficient increased by more than 32% for 1.8 vol. % nanoparticle in the base fluids. The Nusselt number increased with an increasing Reynolds number in the laminar flow regime (5< Re< 300) and a new convective heat transfer correlation for nanofluids in micro channels was also proposed. Sharma et al. [19] implemented a 12.5 vol.% Al_2O_3 in water in a horizontal tube geometry and concluded that at Peclet number of 3500 and 6000 up to 41% promotion in heat transfer coefficient compared to pure water may occurr. Ho et al. [20] conducted an experiment for cooling in horizontal tube in laminar flow of Al_2O_3-water at 1 and 2 vol. % concentrations and concluded an interesting enhancement of 51% in heat transfer coefficient. Nguyenet al. [21] performed their experiments in the radiator type heat exchanger and with a 6. 8 vol. % Al_2O_3 in water obtained a 40% increase in heat transfer coefficient.

There is limited data available on the thermal conductivity enhancement of copper in ethylene glycol nanofluids. Eastman *et al*.[22] first reported an almost 40% improvement in thermal conductivity through the dispersion of 0.3 vol % Cu nanoparticles in ethylene glycol. They used direct condensation of metallic vapor into nanoparticles by contact with a flowing low vapor pressure liquid. Zhu *et* al[23] produced cop per in ethylene glycol nanofluid by reducing a mixture of copper sulfate pentahydrate in ethylene glycol with sodium hypophosphite monohydrate. They used polyvinylpyrrolidone as a surfactant and reported an almost 9% increase in thermal conductivity with 0.1 vol % loading of copper nanoparticles in ethylene glycol. The thermal conductivity enhancement was reported for only 1 vol % loading and the effect of polyvinylpyrrolidone on the thermal conductivity of ethylene glycol was not reported. Liu *et al*.[24] synthesized copper nanoparticles in water using the chemical reduction method. Samples of volume fractions ranging from 0.05% to 0.2% of copper nanoparticles in water were prepared. They reported a maximum increase in thermal conductivity of water of about 23.8% with a volume fraction of 0.1 vol % copper nanoparticles in water. However, the reported thermal conductivity increase was found to be a strong function of time after sonication and decayed to nearly zero after about 10 min of sonication. It was not clear if the measured enhancement was due to the instability of the nanofluid. The instability of the nanofluid also affects the accuracy of the measurement and it was not clear what the accuracy of the thermal conductivity measurement was.

Naraki et al.[25] in 2013 has experimentally conducted the heat transfer performance of car radiator using CuO nanofluid under laminar flow regime with inlet temperature of 50 to 80 °C and concentration for 0 to 0.4% which shows improved heat transfer performance than the base fluid water, with maximum increase in 8% of heat transfer rate.

In this paper, forced convection heat transfer coefficients are reported for pure water and water with Cu and CuO nanopowder mixtures under fully turbulent conditions. The test section is composed of a typical farm equipment tractor radiator, and the effects of the operating conditions on its heat transfer performance are analyzed.

2. Nanofluid Preparation and Stabilization

Nano fluids preparation is the preliminary step in experiential studies.

The essential requirements for the nanofluids are, it should be even, stable suspension, adequate durability, negligible agglomeration of particulates, no chemicals change of the particulates or fluid, etc., Nano fluids can be prepared by dispersing nanometer scale solid particles into base fluids such as water, ethylene glycol, oil etc., In the synthesis of nano fluids, agglomeration is major problem. The single step and two step methods are used to produce nano fluids.

Two step method

Here we use two step method which is extensively used in the synthesis of nanofluids considering the availability of nanopowders supplied by various companies. In this method nano particles were produced first and then dispersed in base fluids. The dispersion of particles is produced by ultrasonic equipment and it reduces the agglomeration of particles also.

The process of preparation of the nanofluid and stabilization is an important activity since extracting the benefits of nanoparticle in thermal cycle is required. Poorly prepared nanofluids results in biphasic heat transfer (i.e. solid–liquid). Particle instability results in particle fouling in reservoir, pipes, pumps and other equipment of the thermal cycle, as well as reduced pressure.

The nanoparticles used in this study were Copper and Copper oxide nanoparticles of approximately 40nm in diameter and 95%, 99% purity. The Cu/Water and CuO/water nanofluid are shown in Table 1, samples of 0.025, 0.05 and 0.075%, fluid were prepared without surfactants and subsequent ultrasonic irradiation for 2 h as shown in figure 1. These samples proved highly appropriate in terms of homogenous dispersion and long term stability the stability of the nanofluid remains for 3-4 hrs. Figure 2 shows the SEM image of the Cu nanofluid. The particles are homogenously dispersed throughout the basefluid in an acceptable fashion.

Fig 1. Ultrasonic vibration bath and nanofluids samples.

Table 1. Characteristics of copper nanoparticle and base fluid.

Properties	Nanoparticle (Cu)	Nanoparticle (CuO)	Basefluid (water)
Appearance	Black powder	Black powder	-
Purity	99 %	95%	-
Grain size	40nm	40nm	-
Specific surface area	80 m^2/g	80 m^2/g	-
Density (ρ) Kg/m^3	8933	6500	998.2
Specific heat Cp (J/kg K)	385	535.6	4182
Thermal Conductivity K (W/m k)	401	76.5	0.613
Viscosity(μ) N/m^2	--	-	0.001003

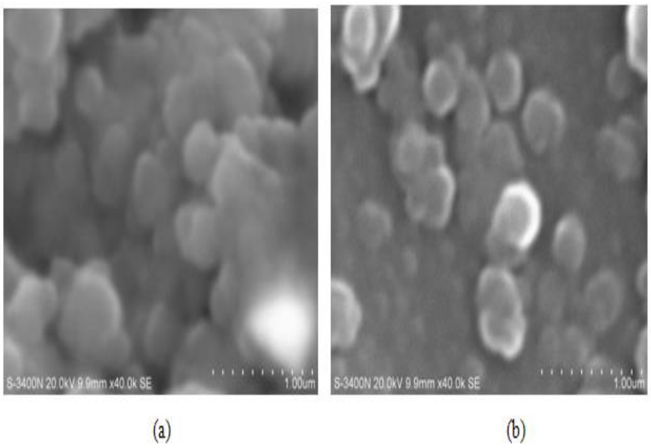


Fig 2. SEM image of (a) CuO/water and (b) Cu/water

2.1. Characterisation of Nanofluid

Characterization analysis was carried out using a Scanning Electron Microscope (SEM) as shown in Fig 2. (a) and (b).

3. Experimental Setup

The test rig shown in Fig. 4 was used to measure the heat transfer coefficient in the tractor radiator. This experimental setup included a steel reservoir tank, an electric heater, a centrifugal pump, a flow meter, tubes, valves, a fan, a DC power supply, ten J-type thermocouples for temperature measurement, and a heat exchanger (tractor radiator). An electric heater (1500W) inside a steel storage tank was used to represent the engine and to heat the fluid. A voltage regulator (0–220 V) provided the power to regulate the temperature in the radiator (30–120 °C). A flowmeter (1–15 LPM) and two valves were used to measure and control the flow rate. The fluid flow was measured through plastic tubes (0.5 in.) by a centrifugal pump (0.5 hp and 3 m head) from the tank to the radiator at the flow rate range of 1–15 LPM. The total volume of the circulating fluid (3 l) was constant in all experimental steps.

Two J-type thermocouples (copper–constantan) were connected to the flow line to record inlet and outlet temperatures of the fluid. The tractor radiator has louvered fins and 40 flat vertical Aluminium tubes with a flat cross-sectional area. The distance between the tube rows was filled with thin perpendicular Aluminium fins. For the air side, an axial force fan (1500 rpm) was installed close to the axis line of the radiator.

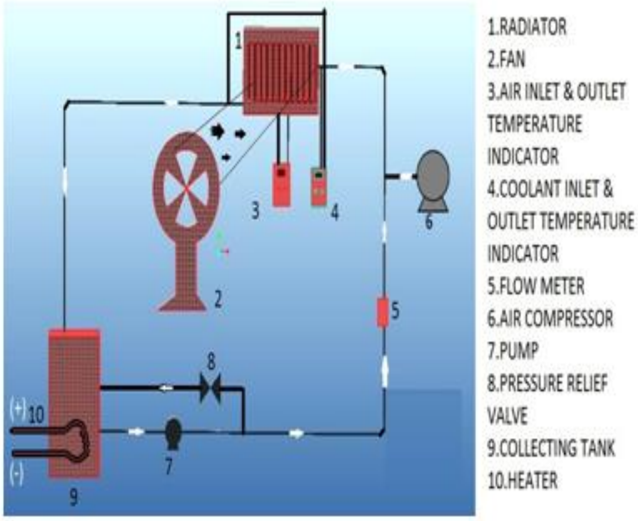


Fig 3. Designed experimental setup.

Fig 4.Photographic view of experimental setup.

Tabel 2. Geometrical characteristics of tractor radiator.

Description	
Fin type	Ruffled
Fin thickness (cm)	0.01
Hydraulic diameter Dh (cm)	0.3911
Frontal air sized dimension(m)	0.45x0.40
Number of tubes	80
External total area (m2)	4.3
Internal tube area (m2)	0.5049

4. Nanofluid Thermophysical Property

Since we use nanofluids for the heat removal their thermo physical properties such as density of nanofluid, specific heat of nanofluid, thermal conductivity of nanofluid and kinematic viscocity, the governing equation involved are calculated using the following equations [26, 27-29]

$$\rho_{nf} = \emptyset.\rho_p + (1-\emptyset).\rho_w \qquad (1)$$

$$(\rho C_p)_{nf} = \emptyset(\rho C_p)_p + (1-\emptyset)(\rho C_p)_w \qquad (2)$$

$$\mu_{nf} = \mu_w(123\emptyset^2 + 7.3\emptyset + 1) \qquad (3)$$

$$k_{nf} = \frac{k_p+(n-1)k_w-\emptyset(n-1)(k_w-k_p)}{k_p+(n-1)k_w+\emptyset(k_w-k_p)} \qquad (4)$$

5. Data Reduction

Calculation of heat transfer coefficient

In these experiments, the nanofluid flowing inside the tube transfers heat to the outside air flowing in the air flow channel. The air-side and the tube-side heat transfer rates can be calculated as:

$$Q_a = m_a C_{p,a}(T_{a,o} - T_{a,i}) \qquad (5)$$

$$Q_{nf} = m_{nf} C_{p,nf}(T_{nf,i} - T_{nf,o}) \qquad (6)$$

where Qa and Qnf are the heat transfer rates at the air and nanofluid flows, respectively. The arithmetic average of the heat transfer rate is:

$$Q_{ave} = 0.5(Q_a + Q_{nf}) \qquad (7)$$

The performance of the heat exchangers is analyzed by the conventional ε-NTU technique and the effectiveness, ε, is defined as:

$$\epsilon = \frac{Q_{ave}}{(mC_p)_{min}(T_{nf,i} - T_{a,i})} \qquad (8)$$

The relationship of the effectiveness, the number of transfer unit (NTU), and the minimum heat capacity flow rate $(mC_p)_{min}$, at the air side could be [30]:

$$\epsilon = \frac{1}{C^*}\left[1 - e^{-\left(1-e^{-NTU}\right)}\right] \qquad (9)$$

$$NTU = \frac{UA}{(mC_p)_{min}} \qquad (10)$$

$$C^* = \frac{(mC_p)_{min}}{(mC_p)_{max}} \qquad (11)$$

Using Eqs. (9) and (10) the experimental overall heat transfer coefficient, UA, could be evaluated.

The overall heat transfer coefficient can also be estimated from the following overall resistances [31] for the comparison with the experimental data:

$$\frac{1}{UA} = \frac{1}{\eta_o h_o A_o} + \frac{\delta}{k_t A_t} + \frac{1}{h_i A_i} \qquad (12)$$

where h is heat transfer coefficient, A is surface area, k_t is thermal conductivity of the tube wall, δ is wall thickness, η_o is surface efficiency and the subscripts o, i, t denote the air-side, the tube-side and the tube wall, respectively. The tube-side heat transfer coefficient can be calculated by Dittus Boelter [32] correlation for the turbulent flow

$$Nu = 0.0236 Re^{0.8} Pr^{0.3} \qquad (13)$$

where Re is the tube-side Reynolds number based on tube hydraulic diameter, and Pr is Prandtl number.

The air-side heat transfer coefficient can be calculated from Vithayasai et al. [30] correlation suggested for the radiator as:

$$Nu_a = [10.145 \times Ln(Re_a - 46.081)] \times Pr_a^{0.33} \qquad (14)$$

6. Result and Discussion

6.1 Impact of nanofluid on the overall heat transfer rate

Figure.5 presents the overall heat transfer rate of the Cu/ water nanofluid as a function of nanofluid flow rate at various fan speeds . As can be seen, the overall heat transfer rate of the nanofluid increases significantly with an increase in temperature. The overall heat transfer rate at a constant nanofluid flow rate increases with nanoparticle concentration compared with the base fluid.

These increases in the overall heat transfer rate with the nanofluid can be explained by the increase of heat transfer efficiency due to the enhancement of thermal conductivity, the activation of convective heat transfer or the thinning of the thermal boundary layer. In addition, there will be one important mechanism for this enhancement on thermal conductivity of nanofluid in the piping flow. That is the non-uniform particle concentration in the cross-section of the tube. Ding and Wen [33] investigated the particle migration by shear rate gradient, viscosity gradient, and Brownian motion which causes non-uniformity in particle concentration. The results state that the overall heat transfer rate of the nanofluid is higher than the base fluid water and increases with the input temperature.

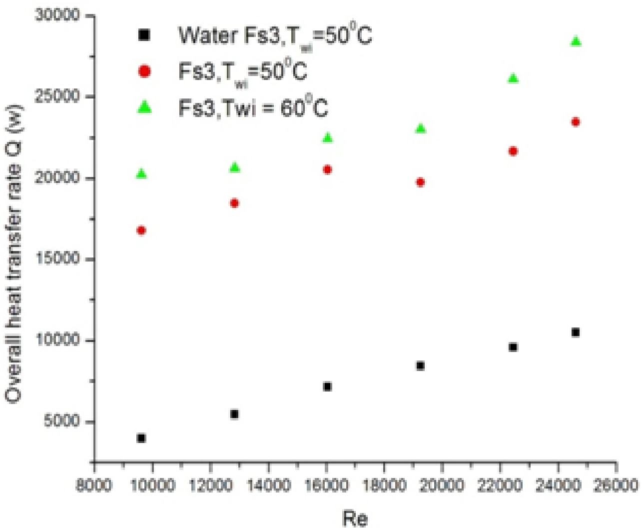


Fig 5. Overall heat transfer rate Vs Reynolds number for 0.025 % vol fraction.

6.2 Comparison of heat transfer coefficient of Cu and CuO/water nanofluids for different air flow rate

In Fig 6 the overall heat transfer coefficient increases for different fan speed(Fs1, Fs2, Fs3). The temperature is maintained constant at 50°C and 60°C for three different fan speed. The experimental results reveal that as the fan speed increases the overall heat transfer coefficient increases for a fixed volume concentration of 0.025%. The overall heat transfer coefficient of Cu/water nanofluid shows improved heat transfer coefficient than CuO/water nanofluid. The heat transfer coefficient increases by 2 to 5% from CuO/water to Cu/water nanofluid with also as the fan speed increases. The results also show that as the Reynolds increases the overall heat transfer rate and the heat transfer coefficient also increases.

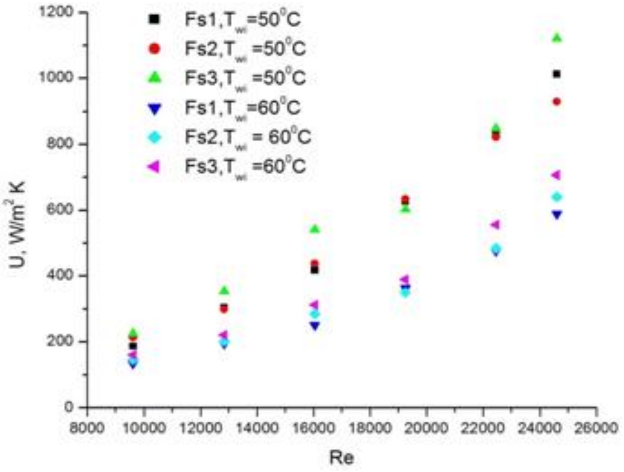
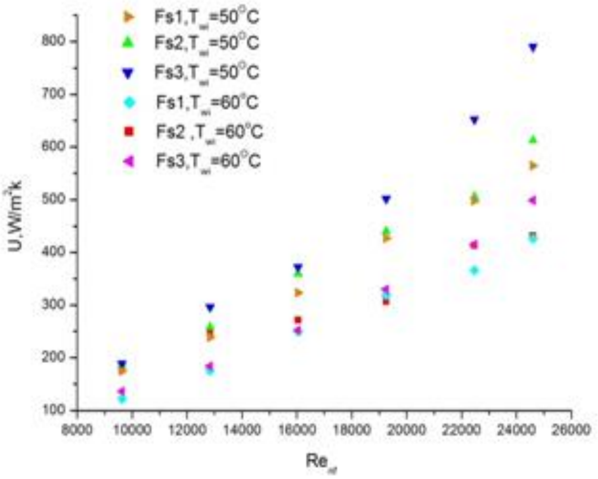


Fig 6a. The Overall heat transfer coefficient Cu/water at the concentration of 0.025 vol%.



(a) CuO/water

Fig 6b. The Overall heat transfer coefficient CuO/water at the concentration of 0.025 vol%.

Figure. 7 shows the experimental data and the theoretical heat transfer coefficient. The comparison was made between the experiment and data and the well known empirical relation correlation suggested by Dittus – Boelter respectively. In Fig.7 reasonably good agreement can be seen between the Dittus Boelter equation and the measurement over the Reynolds number range used in this study. The results prove that as the air flow rate increases the heat transfer coefficient increases for a fixed temperature and increasing Reynolds number It seems that the Nusselt number increases with an increasing Reynolds number, volume concentration and air flow rate as shown in Fig.8.

The maximum values of the Nusselt number are 620 for the Cu/water nanofluid respectively. It appears that the Cu/water nanofluid is better than base fluid for heat transfer enhancement when compared with pure water.

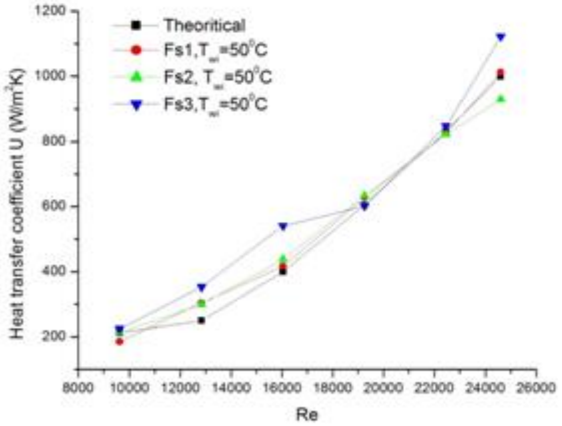


Fig 7. Theoretical and experimental heat transfer coefficient for different Reynolds number.

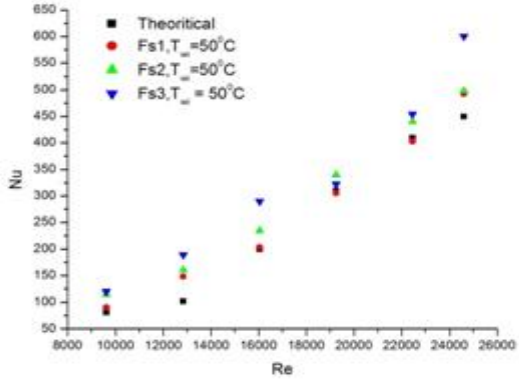


Fig 8. Nusselt number Vs Reynolds number.

6.3 Effect of nanofluid concentration on overall heat transfer coefficient

In Fig. 9 the heat transfer coefficient for two different concentrations 0.025 %, 0.05% and 0.075% is compared along with the water the base fluid in the tractor radiator. The results reveal that as the nanoparticle concentration increases the heat transfer coefficient with 60% in 0.025 concentarion and 71% in 0.05% concentration and 88% in 0.075% concentration compared with base fluid at constant input temperature. The Cu/water nanofluid has better heat transfer performance than the base fluid water in the tractor radiator as seen from the graph.

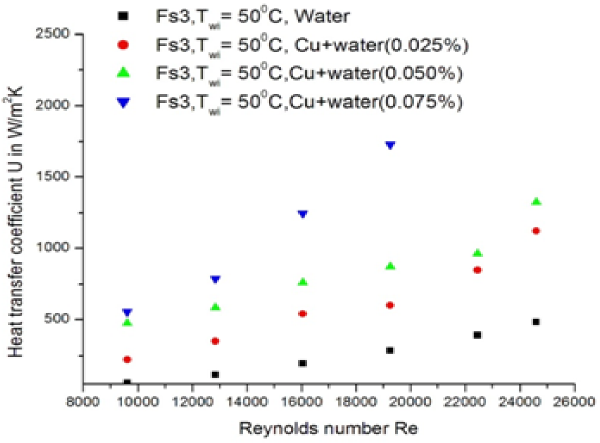


Fig 9. Heat transfer coefficient Vs concentration of nanofluid.

7. Conclusion

In this article, the experimental overall heat transfer coefficient in a tractor radiator has been measured using a Cu/water and CuO/water nanofluid at different air and liquid volumetric flow rates, various nanofluid concentrations and several inlet liquid temperatures of the liquid. The major conclusions are as follows:

1- The overall heat transfer coefficient increases with the decreasing inlet temperature of the nanofluid and Cu/water nanofluid shows enhanced heat transfer performance than CuO/water nanofluid.

2- The overall heat transfer coefficient is enhanced with the addition of nanoparticles to the base fluid. The heat transfer coefficient of Cu/water increases by 16% from 0.025% to 0.05% concentration and from 0.05% to 0.075% concentraion by 19% enhancement. The heat transfer coefficient increases by 31% from minimum concentration of 0.025% to maximum concentration of 0.075%.

3- The heat transfer coefficient increases by 58% from base water to cuO/water nanofluid and 60% from base water to Cu/water. While comparing the metal form of nanofluid Cu/water to metal oxide form of nanofluid CuO/water there is 5% increases in overall heat transfer coefficient for volume concentration of 0.025% and inlet temperature of 50°C. The overall heat transfer coefficient enhanced significantly in the nanofluid compared with the pure water.

4- The overall heat transfer coefficient increases with the enhanced volumetric flow rate of the nanofluid and increasing the air flow rate.

5 - Increasing the flow rate of the air (equal Re) enhances the overall heat transefer coefficient

6- The best operating conditions include minimum temperature, maximum concentration of nanofluid, maximum flow rate of nanofluid and maximum flow rate of air.

7- The thermal performance of nanoparticles increase through its thermophysical property, The superior of nanofluids thermophysical properties in consequence of the nanoparticles dispersion have been demonstrated to the world. Nowadays, the stage of research is changing from investigating the thermophysical properties based on the nanoparticles types and nanoparticles volume fraction to the development of nanofluids in diverse industries to make it useful as a new energy-efficient heat transfer fluid in real world application.

8- By introducing nanofluids with superior thermophysical properties, the radiator size can be reduced but at the same time, it is offering identical heat transfer rate. The frontal area of the vehicle could be redesigned to reduce aerodynamic drag so that less fuel consumption is required.

9- The research work also draws the attention of the many researchers to concentration on farm equipment development for the improved performance in their field. The thermal management of heavy vehicles like tractor and earth moving equipment through nano mechanism are essential areas for future researchers.

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