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APPLICATION OF NANOTECHNOLOGY TO IMPROVE THE PERFORMANCE OF TRACTOR RADIATOR USING CU-WATER NANOFLUID

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ABSTRACT

This paper gives the performance improvement of tractor radiator by Cu/water nanofluid through the mechanism of nanotechnology. It was found that the use of the nanofluid in heat transfer field can play a crucial role in increasing the efficiency of equipment. 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. Tractor 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. The experimental and numerical investigation for the improved heat transfer characteristics of a radiator using Cu/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 when compared with numerical shows enhanced heat transfer coefficient. The results also proved that nanofluid is better heat transfer fluid than the base fluid water. Experimental results emphasize the enhancement of heat transfer due to the nanoparticles presence in the fluid. Heat transfer coefficient increases by increasing the concentration of nanoparticles in nanofluid. The nanofluids are projected as alternative cooling fluid in heat exchangers through its nano mechanism. Further researches are required to study the effect of nanotechnology to enhance the heat exchanger performance over the next several coming years.

Keywords: *Heat Transfer Enhancement, Nanofluid Cu/Water, Tractor Radiator*

INTRODUCTION

A decade ago, with the faster development in modern nanotechnology, particles of nanometre-size (normally less than 100 nm) are used instead of micrometre-size for dispersing in base liquids, and they are called nanofluids. This term was first suggested by Choi [1] in 1995, and it has become popular in many research fields. Many researchers have done investigation in heat transfer characteristics of heat exchangers through nanofluids with different nanoparticles and base fluid materials. The following survey provides the details of experimental results of nanofluids subjected to heat transfer application with their outcome in supporting nanofluids as one of the alternate fluid in heat exchanging and giving way for the miniaturization in the equipment development. Abu-Nada, et al. [2] used an efficient finite-volume method to study the heat transfer characteristics of natural convection for CuO/EG/water nanofluid in a differentially heated enclosure. His results show that the dynamic viscosity and friction factor increased due to dispersing the alumina nanoparticles in water. Chein and Chuang [3] reported experimentally on microchannel heat sink (MCHS) performance using CuO-water nanofluids as coolants for their improved heat transfer performance. The presence of nanoparticles creates greater energy absorption than pure water at a low flow rate and that there is no contribution from heat absorption when the flow rate is high which depicts the Brownian motion of nanoparticles the one of mechanism of nanotechnology.

The thermal and physical properties of nanofluids were calculated using the following equations: the Brinkman equation [4] for viscosity, the Xuan and Roetzel equation [5] for specific heat, and the Hamilton and Crosser model [6] for thermal conductivity. The effect of thermophysical properties models on prediction of the heat transfer coefficient and the heat transfer performance and friction characteristics of nanofluid, were reported by

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Duangthongsuk and Wongwises [7, 8]. The results showed that the various thermophysical models have no significant effect on the predicted values of Nusselt number of the nanofluid. The results also indicated that the heat transfer coefficient of nanofluid is slightly greater than that of water by approximately (6–11) %. Hwang, et al. [9] through experimental investigation of flow and convective heat transfer characteristics of Al2O3/water nanofluid, with convective heat transfer characteristics of Al2O3/water nanofluid with particles varying in the range of 0.01- 0.3% in a circular tube of 1.812 mm inner diameter with the constant heat flux in fully developed laminar regime reported improvement in convective heat transfer coefficient in the thermally fully developed regime.

Li and Xuan [10] and Xuan and Li [11] studied experimentally the convective heat transfer and flow features for Cu-water nanofluids flowing through a straight tubeunder laminar and turbulent flow regimes with a constant heat flux. The experimental results showed that addition of nanoparticles into the base liquid remarkably enhanced the heat transfer performance of the base liquid. An automotive cooling system usually consists of radiator, water pump, thermostat, radiator pressure cap, and electric cooling fan Maple [12]. The radiator is the main component as it was designed to remove heat from an engine block by using specified coolants. Generally, the coolant of the radiator is either water or water and ethylene glycol (anti-freezing fluid), which flows inside the tubes. In fact, the coolants have poor heat transfer properties in nature. Another type of coolant is outside air which flows through the fins to cool down the temperature of water. Now a days, the researchers and engineers from automotive industries have been applying green technology concept and desiring for a compact engine system with low fuel consumption. Consequently, the study of nanofluids as an application in the automotive industries has developed throughly. 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 a car could be redesigned to reduce aerodynamic drag so that less fuel consumption is required Leong et al.[13] and Wong et al.,[14].

Argonne researchers proved that despite nanofluids thermal conductivity depends on temperature and particle volume fraction, it still showing high thermal conductivity than conventional radiator coolants Choi, [15]. The heat transfer rate and thermal performance of Cu/EG coolant in an automotive radiator can be enhanced by increasing the particle volume fraction from 0 % to 2 % Leong et al., [13] The enhancement of heat transfer depends on air and coolant Reynolds number (Re) which is increasing with nanoparticle concentration. Mare et al. [16] experimentally proved that the convective heat transfer coefficient of CNTs nanofluid increased about 50 % in comparison to water for the same Reynolds number. Basically, there are five factors that can enhance the heat transfer; Brownian motion, layering at the solid/liquid interface, Ballistic phonon transport through the particles, nanoparticles clustering, and friction between the nanoparticles and fluid (Wang and Mujumdar, [17] Meanwhile, Xuan and Li [18] agreed dispersed phase of nanoparticles caused pressure drop slightly but the nanoparticles dispersion is stable either with surfactant or conventional fluid only. Razi et al. [19] investigated the heat transfer and pressure drop of CuO-base oil nanofluid flow inside horizontal flattened tubes under constant heat flux of 2600 W/m2 and proved that the pressure drop of nanofluids increased with nanoparticle concentration. There is also a withdrawn investigation of nanofluids natural convective heat transfer since the suspension of nanoparticles caused higher viscosity and pressure drop as compared to conventional fluid (Calvin and Peterson,[20]

Roubert et al.[21] started a project in 2008 that employed nanofluids for industrial cooling that could results in energy savings & resulting emission reductions. [22] Singh et al. have investigated that the use of high thermal conductivity nanofluids in radiators can lead to reduction in the frontal area of the radiator by up to 10%. The fuel efficiency and also vehicle performance will increase by reducing the size of the components [23]. Vasu et al. have used aqueous alumina as a coolant on automobile flat tube plain fin compact heat exchanger. This project concluded that the heat transfer rate will decrease by increasing the air inlet temperature [24]. Tzeng et al. investigated the temperature distribution of rotary blade coupling transmission used in four wheel drive vehicles. They concluded that use of nanofluids in the transmission has a clear advantage from the thermal performance view point . Ravikanth et al. used the nanofluids in radiator to study the heat transfer performance. They used the CuO and Al2O3 for their study [25].

In this paper, forced convection heat transfer coefficients are reported for pure water and water/Cu nano powder 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.

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

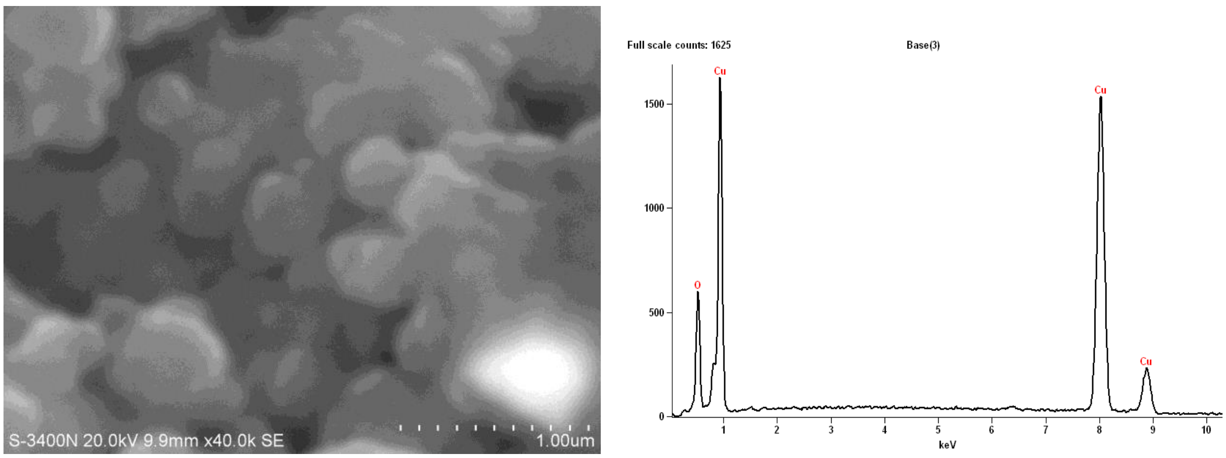
Two-step method is the most widely used method for preparing nanofluids. Nanoparticles, nanofibers, nanotubes, or other nanomaterials used in this method are first produced as dry powders by chemical or physical methods. Then, the nanosized powder will be dispersed into a fluid in the second processing step with the help of intensive magnetic force agitation, ultrasonic agitation, high-shear mixing, homogenizing, and ball milling. Two-step method is the most economic method to produce nanofluids in large scale, because nanopowder synthesis techniques have already been scaled up to industrial production levels. Due to the high surface area and surface activity, nanoparticles have the tendency to aggregate. The important technique to enhance the stability of nanoparticles in fluids is the use of surfactants. However, the functionality of the surfactants under high temperature is also a big concern, especially for high-temperature applications.

The nanoparticles used in this study were Copper nanoparticles of approximately 40nm in diameter and 95% purity. The Cu/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.

Figure 1. Ultrasonic vibration bath [34]

Table 1. Characteristics of copper nanoparticle and base fluid

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



(a) (b)

Figure 2. SEM image of Cu/water

Characterisation of Nanofluid

Characterization analysis was carried out using a Scanning Electron Microscope (SEM) as shown in Figure 2. (a) and (b) and an energy dispersive Atomic X Ray(EDAX).

Experimental Setup

The test rig shown in Figure 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.

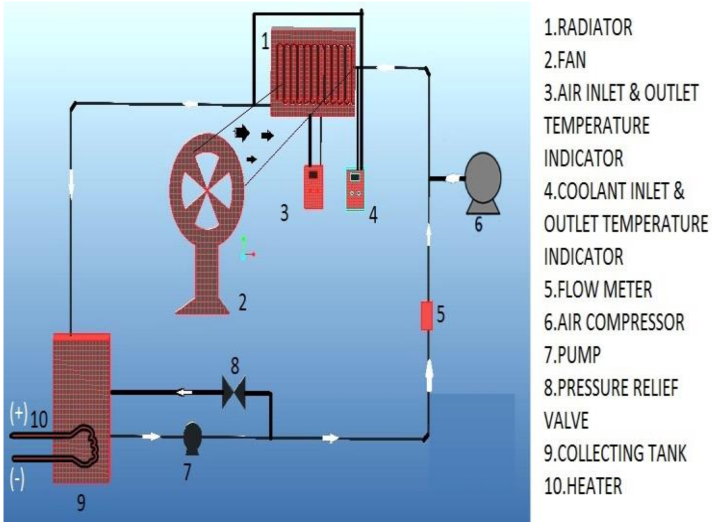


Figure 3. Designed experimental setup (from Ravisankar et.al [34])

Figure 4. Photographic view of experimental setup (from Ravisankar et.al [34])

Table 2. Geometrical characteristics of tractor radiator (from Ravisankar et.al [34])

Description	
Fin type	Ruffled
Fin thickness (cm)	0.01
Hydraulic diameter D_h (cm)	0.3911
Frontal air sized dimension(m)	0.45x0.40
Number of tubes	40
External total area (m^2)	4.3
Internal tube area (m^2)	0.5049

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], (from Ravisankar et.al [34])

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

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

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

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

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:

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

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

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:

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

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

$$\in = \frac{\boldsymbol{Q_{ave}}}{(\boldsymbol{m}C_{\boldsymbol{p}})_{\boldsymbol{min}}(\boldsymbol{T_{nf,i}} - \boldsymbol{T_{a,i}})} \tag{8}$$

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]:

$$\in = \frac{1}{C^*}[1 - e^{-(NTU)}] \tag{9}$$

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

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

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:

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

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 surface efficiency is related to fin efficiency and it is calculated as 0.53 for the present experimental setup. The tube-side heat transfer coefficient can be calculated by Dittus Boelter [32] correlation for the turbulent flow

$$Nu = 0.0236 Re^{0.8} Pr^{0.3} \tag{13}$$

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:

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

RESULT AND DISCUSSION

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.

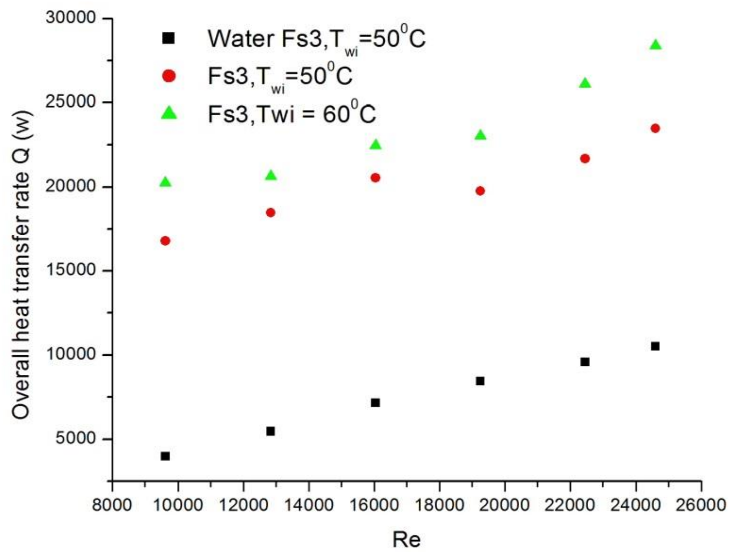


Figure 5. Overall heat transfer rate Vs Reynolds number for 0.025 % vol fraction

Increasing heat transfer coefficient for different air flow rate

In Figure 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 results also show that as the Reynolds increases the overall heat transfer rate and the heat transfer coefficient also increases.

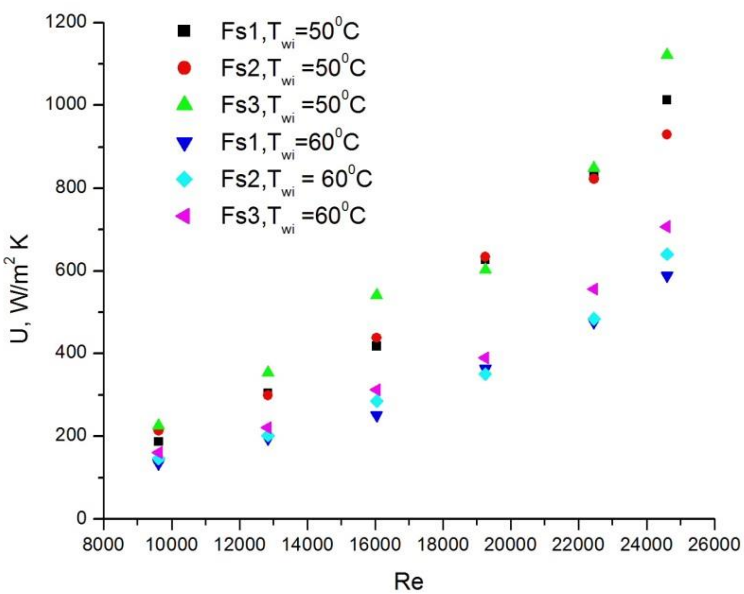


Figure 6. Overall heat transfer coefficient Vs Reynolds number at the concentration of 0.025 vol%

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 Figure 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

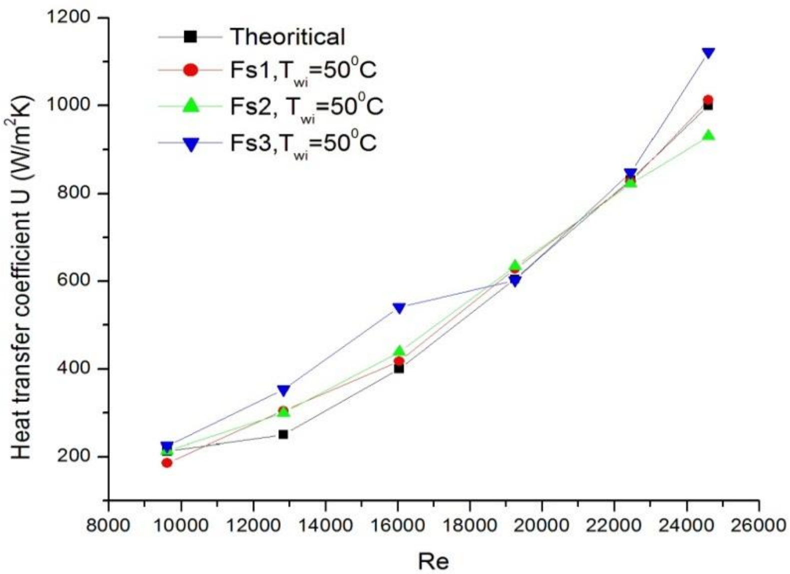


Figure 7. Theoretical and experimental heat transfer coefficient for different Reynolds number

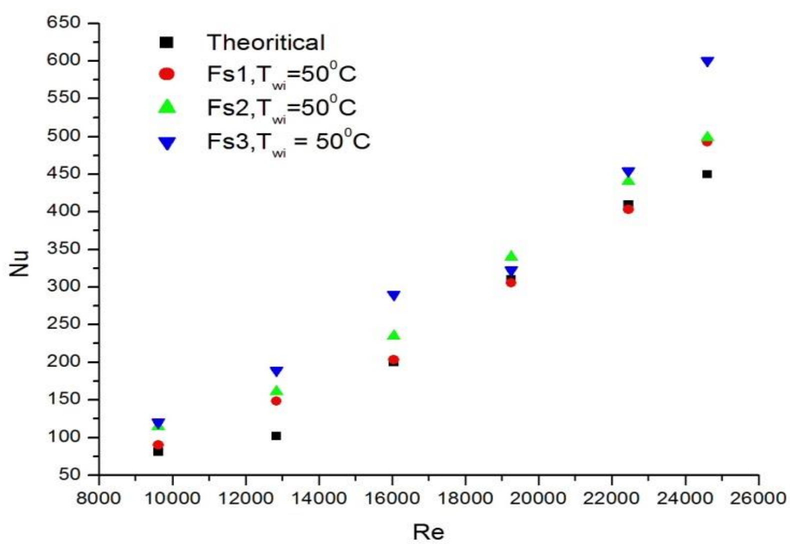


Figure 8. Nusselt number Vs Reynolds number

It seems that the Nusselt number increases with an increasing Reynolds number, volume concentration and air flow rate as shown in Figure 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.

Effect of nanofluid concentration on overall heat transfer coefficient

In Figure 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.

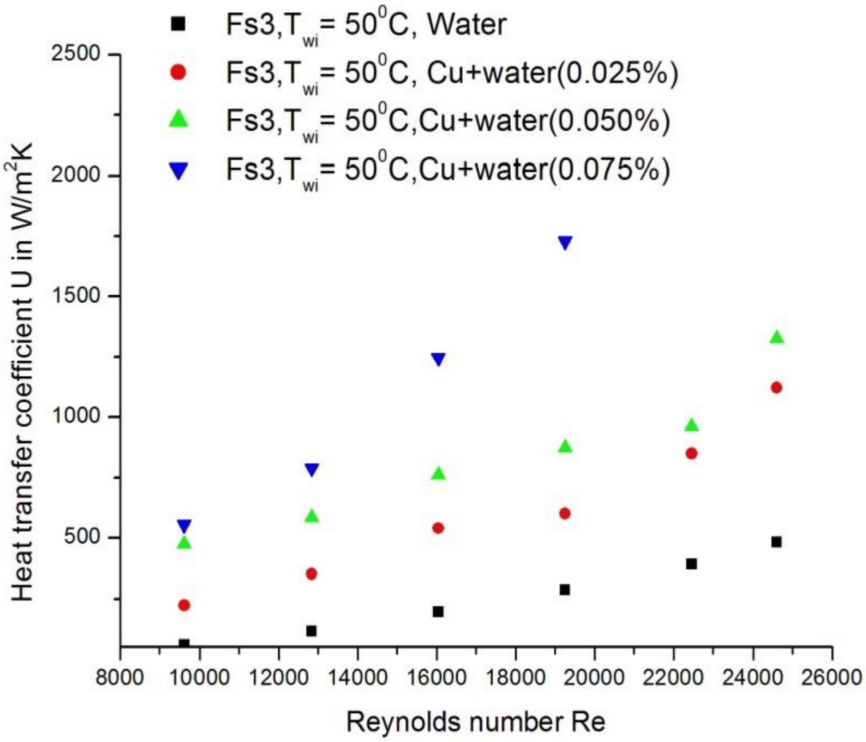


Figure 9. Heat transfer coefficient vs concentration of nanofluid.

Concluding Remarks

The convective heat transfer performance and flow characteristics of copper nanofluid flowing in a radiator heat exchanger has been experimentally investigated. Experiments have been carried out under turbulent conditions. The effect of particle concentration and the Reynolds number on the heat transfer performance and flow behaviour of the nanofluid has been determined. Important conclusions have been obtained and are summarized as following:

Overall heat transfer coefficient

- Increases with the decreasing inlet temperature of the nanofluid and enhanced with the addition of nanoparticles with base fluid. The heat transfer coefficient 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%. The overall heat transfer coefficient enhanced significantly in the nanofluid compared with the pure water.

- The overall heat transfer coefficient increases with the enhanced volumetric flow rate of the nanofluid and increasing the air flow rate. As similar trend followed (from Ravisankar et.al.[34]).

The best operating conditions include minimum temperature, maximum concentration of nanofluid, maximum flow rate of nanofluid and maximum flow rate of air. By introducing nanofluids as alternate coolant, 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 obtained.

Suspected nanofluid mechanism

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. The Brownian motion of nanoparticles is suspected in favoring for the enhanced heat transfer in radiator as the geometry is cross flow type, which makes the nanoparticle to often contact the walls of tubes in removing the heat. 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.

Recommendation for future work

The research work also draws the attention of the many researchers to concentration on farm equipment development for the improved productivity in crop cultivation. 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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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 s)
C*	C_p min / C_p Max
L	Tube length in (m)
U	Overall heat transfer coefficient (W /m^2K)
μ	Dynamic viscosity (kg/m s)
ρ	Density(kg/m^3)
φ	Volume fraction of nanoparticles (%)
δ	Tube thickness (m)
ε	Effectiveness
b_f	Base fluid
n_f	Nanofluid
p	Particle
w	Water
a	Air
b	Bare
i	Inlet , tube side
o	Outlet, air side
Cu	Copper
NTU	Number of transfer unit

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