EXPERIMENTAL INVESTIGATION OF CONVECTIVE HEAT TRANSFER ENHANCEMENT USING ALUMINA/WATER AND COPPER OXIDE/WATER NANOFLUIDS

by

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The nanofluids are widely used for heat transfer applications in the various engineering applications. The nanoparticles dispersed uniformly in the base fluid on proper mixing. In the present study, Al_2O_3 and CuO nanoparticles were selected and the changes in the heat transfer coefficient were investigated in the complete laminar and discrete points of transition fluid flow through a copper tube with constant heat flux. The heat transfer coefficient was investigated at different loading of Al_2O_3 and CuO nanopowders ranging from 0.1% to 0.5% of volume concentration in each case for the laminar and transition fluid flow zones, which is then compared with the distilled water as a plain base fluid. It is found that the optimum enhancement in heat transfer is observed at relatively lower volume fraction of nanoparticles ranging between 0.2 to 0.3%.

Key words: *heat transfer coefficient, nanofluids, heat transfer*

Background and introduction

The ongoing energy crisis motivated the researchers to develop more efficient heat transfer devices with higher effectiveness. Advancement in the development of smaller and compact equipments, which works at a much faster rate, requires large amount of heat to be handled. The higher performance devices generate large amounts of heat due to its smaller size, hence heat flux increases drastically. So cooling remains as a significant challenge in the modern engineering applications such as manufacturing, transportation, and microelectronics. Due to this downsizing of the equipment and increase in the heat flux, the traditional cooling involving natural convection or fan based cooling reaches to its critical point. Hence the rapid heat removal technique needs to be implemented so as to have better performance of the system, under normal operating condition. A number of ways which include – extended surface, mini channels, baffles are provided so as to withdraw the heat, but still more enhancements in the heating and cooling process are in great demand due to compacting of the process heat exchanger. This leads to the development of the innovative cooling process apart from the conventional ways. The conventional heat removal process is accelerated by enhancing the

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surface area, creating rough surface, or by changing system boundary conditions [1]. The active technique involves increasing the thermal conductivity of the base fluid itself is by addition of milli-sized metallic particles in the base fluid for heat augmentation. However addition of these particles suffers from high sedimentation time and more flow resistance, thereby requires higher pumping power. Further, these particles cause severe clogging and deposition at the corners and in pump valves creating malfunctioning of the system. The latest manufacturing process produces the ultra fine nanoparticles in metallic form, which has greatly influenced heat transfer methods. This forced to add further much finer grade particles, *i. e.* nano-sized particle to the base fluid in pure as well as an oxide form for the heat transfer enhancement. Such a fluid is often termed as nanofluids. This was first noted by Choi [2] in the year 1996 at the National Argonne Laboratory in U. S. A. The nanoparticles are produced by physical and chemical synthesis processes. The physical process involves mechanical grinding, mechanical milling, and inert gas condensation methods. Whereas chemical technique is associated with the chemical precipitation, chemical vapor deposition, spray pyrolysis band thermal spraying [2]. The single step and the two step technique facilitate the simultaneous production of nanopowders in crystalline, amorphous and disperse powders in the base fluid form. The nanofluids are the colloidal dilute dispersion of nanoparticles (a billionth of a meter) in small quantity of metals, oxides, carbides, or carbon nanotubes in the conventional base fluids such as water, ethylene glycol, or oil. The nanoparticle possesses superior thermal conductivity, lower specific heat, large surface area which makes nanofluids superior in an energy transport carrier.

Since last few years, the research activities related to the nanofluids have increased drastically. The majority of the studies since last decade focused on the convective heat transfer enhancement in the laminar and the turbulent region of the fluid flow [3, 4]. Suresh *et al* [3] experimentally studied the heat transfer and friction factor characteristics of CuO/water nanofluid under turbulent flow in a helical dimpled tube with constant heat flux conditions. The effect of CuO nanopowders on the heat transfer enhancement and friction factor was evaluated for the Reynolds number range from 2500 to 6000 and compared it with the plain tube. The height of the dimple was 0.6 mm, while the CuO concentrations were 0.1%, 0.2%, and 0.3% were selected. The experimental results indicate that the Nusselt number enhancement was found to be 19%, 27%, and 39% of the volume concentration of 0.1%, 0.2%, and 0.3%, respectively, while the friction factor was increased by 2-10% than plain tube. Further the ratio of the CuO/water nanofluid to that base fluid thermal conductivity was found to be 1.06 to 1.15 from 0.1% to 0.3% volume concentration. Although the friction factor is increased, but there is no penalty in the pumping power of the system. Albadr *et al* [4] investigated the performance of the Al_2O_3 nanofluid in the heat exchanger at different concentration and indicate that the heat transfer rate increases with the increase in the mass flow rate of the system and volume concentration of the system. The present study primarily focused on the laminar region for which the Reynolds number is up to 1800, however the heat transfer characteristics at slightly upper critical Reynolds number is also considered. Hence the Reynolds number up to 3000 is selected. The aim of the paper is to study the use of nanopowders blended with distilled water and estimate the changes in the heat transfer coefficient over distilled water itself with constant heat flux conditions in the laminar and transition region at the various concentration of the nanopowders in the base fluid. A number of researchers investigated the thermal performance by the use of Al_2O_3 and CuO nanoparticles [5-9]. Liu and Yu [5], investigated the enhanced heat transfer in both laminar and turbulent zones, but surprisingly reported that the transition region performance of nanofluid was far below than that of the distilled water itself. Hence the upper critical Reynolds number (up to Re = 3000) is selected in this present work. The majority of the research in the nanofluid indicates the remarkable increase in the thermal performance over the conventional fluid under identical conditions.

Need of nanofluid

The nanofluid contains nanoparticles uniformly suspended in the base fluid. The nanofluids are a relatively new class of fluids with the improved thermal properties for heat transfer augmentation. The typical range of scale for the nanoparticles is normally from 1 to 100 nm [1, 2]. The nanofluids are more promising heat transfer elements because of their higher surface area as compared to its volume. Due to nanosized particles in the base fluid, there is hardly any sedimentation in the system and almost no problem related to the clogging. The fluid is recognized as an integral fluid rather than solid-liquid system. The most effective parameter is its very high thermal conductivity, which enhance the heat transfer of the entire system. Owing to the nanosized element which is added in small volume, there is very less probability of getting chocked in the pump valve and at the corners of the system. Further variation in the thermo-physical properties of the nanofluids can be achieved by adding nanoparticles in the relative terms to the base fluid [1]. This is the vital parameter for the researchers to explore the field of nanofluid even further. The variable property of the nanofluids motivates the researchers to use the same nanofluid for different engineering application involving different thermo-physical properties. Hence nanofluids are considered as the next generation heat transfer elements. As the nanoparticles in the homogeneous mixtures are in suspended form the collision and interaction among the particles intensified, the net thermal transport rate increases [3].

Some of the most commonly available nanopowders are Cu, Al, Ti, Ag, Fe in pure form, and CuO, Al_2O_3, TiO_2, Fe_2O_3 in the oxide form. Many researchers [6-9] studied nanoparticles in the oxide form, as pure nanoparticles are highly unstable because of a very large surface area which ultimately leads to the rapid oxidation of the particles. Although use of pure nanoparticles is possible under the controlled environment. The use of the oxide form of nanoparticles is reported to be simpler and very stable at the room temperature. The characteristics of nanofluids are governed by a number of parameters such as properties of the base fluid, dispersed phase, particle concentration, particle size and shape along with surfactant [4]. The very fine grade nanoparticles will have greater surface area to volume ratio indicating more area available for the heat transport. The exact size of the nanoparticles can be estimated by transmission electron microscope (TEM). The fine grade nanoparticle possesses a higher surface area for heat transfer. Further finer grade particles have longer sedimentation time as compared with the coarse grade particles. Similarly the thermal performance too depends on the shape of the nanoparticles as spherical, elongated, *etc*. The addition of the surfactants improves the stability of the nanofluids by increasing the sedimentation time for the nanoparticles to settle down in the dispersed solution. The surfactant acts as a catalyst by causing a repulsive force between the suspended particles preventing the early sedimentation. However, in the present study no surfactant is used.

Properties of nanofluids

The mass of both the nanopowders is measured and selected as per the total volume of the base fluid. The measured nanopowders is then added to the base fluid to form the colloidal homogenous solution. The fluid is then treated as the working fluid so as to estimate the heat carrying capacity. In order to estimate the heat transfer enhancement by the working fluid, the various thermo-physical properties such as specific heat, density, viscosity of the fluid must be calculated. The various co-relations are available provided by the different researchers for estimating the physical properties of the nanofluid at the different concentration of nanopowders in the base fluid. The co-relations are in terms of the physical properties of the solid nanoparticles and the pure base fluid. So the properties of the nanopowders and the base fluids must be available independently, so as to evaluate the net effective properties of the working fluid itself. The table 1 shows the fundamental properties of commonly used nanopowders [10-12].

Table 1. Physical property of Al_2O_3, TiO_2, Fe_3O_4 and CuO nanopowders

Particle	Mean diameter [nm]	Density [kgm^{-3}]	Thermal conductivity [Wm^{-1}K^{-1}]	Sp. heat [Jgm^{-1}K^{-1}]
Al_2O_3	20	3700	46	880
TiO_2	10	4157	11.7	710
Fe_3O_4	36	5180	80.4	670
CuO	30	6350	69	550

Preparation of nanofluid and property evaluation

The commercially available nanopowders of Al_2O_3 and CuO are used for the experiments. The mean diameter of the nanopowders was 40 nm. The nanofluid is prepared on the basis of the percentage volume fraction of the base fluid. The electronic, chemical balance is used to measure the mass of the nanoparticles in terms of the percentage volume concentrations of the base fluid. The chemical balance with the accuracy of 0.1 mg is used for the experiment. The nanopowders were added to the base fluid in terms of the volume fraction of the base fluid. Initially 0.1% volume fraction is selected for both the nanopowders and then incremented by 0.1% until the total volume concentration reaches to 0.5%. As it has been observed from the literature survey that higher volume concentration is not much beneficial for heat transfer augmentation, hence in our experimentation we restrict the nanoparticles volume concentration to 0.5% only. The measured amount of nanopowders in terms of volume concentration is mixed with the pure to prepare homogenous dispersion of nanopowders in the base fluid. In the present study, no surfactant is used which prolong the sedimentation time of the nanoparticles and no sonicator (ultra sound mixing) is used, hence it is necessary to mix continuously for prolong duration. So the mixing in the magnetic stirrer continues for 7 to 8 hours before the actual experimentation. After the entire mixing process, it has been observed that the mixing of the nanoparticles is homogeneous in the base fluid and no sedimentation was observed in first 30 minutes. However, gradual sedimentation takes place after one hour, and complete sedimentation was observed in six hours. The present experimentation starts with the laminar fluid flow region and ends in the transition phase. As the fluid is continuously circulating the sedimentation of particles was not the major issue. The turbulent and transition fluid flow is much more beneficial as the higher shear force will even break the possible particle agglomerated and prevent them from sedimentation [9]. Further the flow fluctuations and disturbances are more in transition and turbulent region as compared to laminar region, which may lead to the improvement in the sedimentation time for the nanoparticles in the base fluid. For mixing, the magnetic stirrer was set at 300 rpm.

The nanofluid is basically the conventional fluid with nanosized foreign particles uniformly suspended. The nanoparticles in the fluid have higher thermal conductivity and surface area, resulting in energy transfer at the molecular level often termed as nano scale. However millions of particles and associated molecules raised the heat transfer process from nano to macro level, eventually affecting the net heat transfer rate of the system. This is similar to bubble rupturing process for nanofiber fabrication as explained by Rou-Xi Chen [13] and Fu-Juan Liu [14]. Further the addition of the nanoparticles to the base fluid is in number of intervals, so the properties will keep on varying and hence become very necessary to evaluate the effective properties at each interval. Due to homogeneity of mixing the identification of the powder in the liquid phase is very difficult. Hence the properties of the nanofluids are no longer same as that of the convectional fluid. The physical properties are calculated with the use of the various correlations available from the literature provided by the different researchers, applicable for the different environmental condition. Also the threshold value of the surface tension of the nanofluid may also get affected due to uniform suspension of nanopowders, which may be one of the factor for the delay in the sedimentation time of the particles [15, 16].

The density of the nanofluids cab be estimated by using Pak and Cho's equation [16]

$$\rho_{\mathrm{nf}} = \varphi \cdot \rho_S + (1-\varphi)\rho_S \tag{1}$$

The effective viscosity of the nanofluids is defined [17]:

$$\mu_{nf} = \mu_{\mathrm{w}} \cdot (1 + 2.5\varphi) \tag{2}$$

The specific heat of the fluid is evaluated by Xuan and Roetzel relation, [18]:

$$C_{p\mathrm{nf}} = \frac{\varphi(C_{p\mathrm{S}} \cdot \rho_{\mathrm{S}}) + (1-\varphi)\rho_{\mathrm{w}} \cdot C_{p\mathrm{w}}}{\rho_{\mathrm{nf}}} \tag{3}$$

It is observed from the above relation, that as the volume concentration of the nanoparticles increases in the base fluid, the net effective specific heat for the nanofluid will be relatively less than that of the pure base fluid only.

Thermal conductivity of nanofluid is proposed by the number of researcher as per the different nanoparticles used with the different base fluid. Also the thermal conductivity is quite an important amongst all the properties causing the sudden change in the base fluid characteristics. The different models suggested are as follows [19]:

$$k_{\mathrm{nf,Maxwell}} = \frac{2k_2 + k_1 + \varphi(k_2 - k_1)}{2k_2 + k_1 - 2\varphi(k_2 - k_1)} k_1 \tag{4}$$

$$k_{\mathrm{nf,Hamilton\text{-}Crosser}} = k_1 \left[\frac{k_2 + (n-1)k_1 - (n-1)\varphi(k_1 - k_2)}{k_2 + (n-1)k_1 + \varphi(k_1 - k_2)} \right] \tag{5}$$

where n is the shape factor defined as $n = 3/\psi$, where ψ is sphericity defined as the ratio of surface area of a sphere with the volume equal to that of the particle, and k_1 and k_2 are the thermal conductivity of the base fluid and solid nanoparticles;

$$k_{\mathrm{nf,Yu\text{-}Choi}} = \frac{k_2 + 2k_1 + 2\varphi(k_2 - k_1)(1+\beta)^3}{k_2 + 2k_1 - \varphi(k_2 - k_1)(1+\beta)^3} \cdot k_1 \tag{6}$$

where β is the ratio of nanolayer thickness and the original particle radius.

It has been noticed by Nsofor and Gadge [15], and Tiffman and Hillman [16] that the nano-layer thickness is in the range of 19% to 22% of the nanoparticle radius. Considering this aspect, in this study nano-layer thickness is found to be around 4 nm, which is very small, and hence $r + h \sim r$.

Most of the researcher preferred Yu-Choi relation for calculation of the effective thermal conductivity of the nanofluids, as it is much suitable with most of the nanofluids used with water as a base fluid. Figure 1 indicates the nano-layer thickness β used in Yu-Choi co-relation for the effective thermal conductivity of the nanofluid. Hence, in our study also the same co-relation is used for the calculation. It has been observed that there has been a considerable increase in the thermo-physical properties of the nanofluids which will enhance the heat transfer rate. Further, these properties vary with respect to the volume concentration of the nanoparticles in the base fluid.

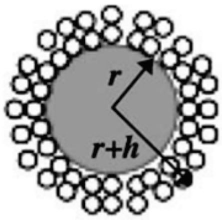

Figure 1. Nano-layer thickness

Experimental set-up

In order to estimate the heat transfer enhancement with nanofluids over the conventional fluid an experimental set-up is fabricated. Figure 2 shows the actual experimental set-up to fabricated for the experimentation. The experimental set-up consists of the close loop consisting of heating section, cooling section, and feedback unit along with the measuring unit. The flow circuit consists of reservoir, pump, rotameter, heater, and thermocouples. The test section consists of 0.8 m length of copper tube with 9.52 mm inner diameter. The Nichrome-60 wire (NiCr60 Type Alloy 675 Nickel Chrome Alloy) is wound on the periphery of the copper tube in the test section. The heating element has a rated power of 700 W, with average gauge size of 20. The power input is controlled with the help of dimmer stat with 0-2 A range. The rotameter is connected before the test section to measure the flow rate of the nanofluid flowing in the test section. The Acrylic Rotameter of CVG make with accuracy of ±2% full scale deflection (FSD), and repeatability of 0.25% FSD is used. The rotameter has the range from 5 to 50 liter per hour (LPH). Tullu TOP AC-15 pump with 0.028 kW drive and a capacity of 60 W is used to circulate nanofluid in the test section. The pump has a capacity of 180 LPH with 1800 rpm with total head of 4.5 m. The by-pass line with valve is connected so as to by-pass the excess of the nanofluid back to the reservoir. The reservoir with the capacity of 2 liters is connected at the bottom. A by-pass valve is fitted so as to direct the flow of the test fluid to the reservoir again and also to control the mass flow rate by controlling the valve opening. The thermocouples are connected at the various locations in and out of the test section so as to measure the temperature at the discrete points. The thermocouples of PT-100 type with probe of 316 steel are used for temperature measurement with copper constant. The thermocouple has a wide range from –50 °C to 250 °C. The thermocouple has an accuracy of 0.01 °C while the resolution of 0.001 °C. The test section is covered with the outer aluminum shell with densely packed glass wool insulation between the heating coil and the outer shell. The inner surface of the outer shell is covered with the silver paper so as to prevent the heat loss to the surroundings by the conduction and radiation mode. The calming section is provided just at the exit of the test section so as to ensure the complete fluid flow through the test tube. The


Figure 2. Actual experimental set-up

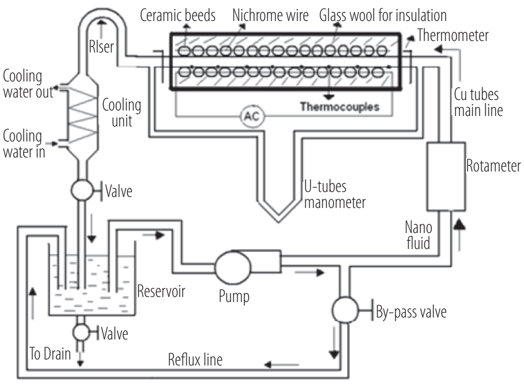

Figure 3. Schematic layout of set-up

complete fluid flow is necessary through the test section for measuring the local temperature of the test fluid within the test section. In order to remove the heat gained by the nanofluid in the test section, helical coils shell and tube type heat exchanger is fitted in line with the main copper tube. Proper care is taken so as to avoid water leakage in the heat exchanger. The heat exchanger was of counter flow type, which provides more effective area in the heat exchange process. The U-tube manometer is connected at both the ends of the test section, so as to evaluate the pressure loss in the test section. Mercury is used as the manometric fluid. A thermocouple is fixed in the collecting reservoir so as to check the temperature drop in the cooling unit, and adjust the mass flow rate of the inlet cooling water so that the temperature of the nanofluids in the reservoir will be maintained at constant temperature. The detailed schematic of the experimental set is shown. It consists of shell and tube type cooling unit. The hot fluid from the exit of the test section is allowed to cool with the help of cooling water at room temperature in the counter flow direction. Figure 3 indicates the schematic layout of experimental set-up. The cooling water flow rate is controlled in such a way that the exit temperature of the test fluid is almost equal to the entry temperature of the fluid to the test section.

Observations

The observations are taken after the steady state temperature has been achieved. Initial observations are noted for the pure distilled water at various mass flow rates. Similar observations are noted for Al_2O_3/water nanofluid for 0.1% volume concentration to 0.5% in the terms of 0.1% from 10 LPH to 50 LPH. The same procedure is then further repeated for the CuO/water nanofluid under the same boundary conditions. The heat input in terms of constant heat flux is maintained same for all the readings.

Heat input to the test section is given:

$$Q = VI \tag{7}$$

Heat gained by the water is given:

$$Q = (\rho UA)C_p(T_{b2} - T_{b1}) \tag{8}$$

Further convective heat transfer rate is:

$$Q = (\pi dL)h_{\mathrm{w(exp)}}\left(T_{\mathrm{w}} - \frac{T_{b2} - T_{b1}}{2}\right) \tag{9}$$

Hence, the experimental heat transfer coefficient is:

$$h_{\mathrm{w(exp)}} = \frac{(\rho_{\mathrm{nf}}UA)C_{p\mathrm{nf}}(T_{b2} - T_{b1})}{(\pi dL)\left(T_{\mathrm{w}} - \dfrac{T_{b2} - T_{b1}}{2}\right)} \tag{10}$$

In order to establish the reliability and accuracy in the calculated values of the heat transfer coefficient, the Saider-Tate equation is used to verify the same. The Zeinali *et al* [20] also calculated theoretical values with Saider-Tate equation and confirmed that the experimental values are in good agreement with theoretical values for laminar fluid flow with constant wall temperature condition. As the present study is majority deals with the laminar fluid flow with a slightly higher Reynolds number of 3000, the same Saider-Tate co-relation is used.

$$\mathrm{Nu}_{\mathrm{theo.}} = 1.86\left(\mathrm{Re}_{\mathrm{nf}}\,\mathrm{Pr}_{\mathrm{nf}}\,\frac{d}{L}\right)^{0.33}\frac{\mu_{\mathrm{nf}}}{\mu_{\mathrm{wnf}}} \tag{11}$$

The theoretical values of heat transfer coefficient obtained from the Saider-Tate equation are in good agreement with that of the experimental values of heat transfer coefficient as indicated in the graph at the lower concentration of nanoparticles and at lower Reynolds number. The variation in the values are observed as the Reynolds number for the flow rate increases.

Reynolds number and Prandtlt number calculated:

$$\mathrm{Re}_{\mathrm{nf}} = \frac{\rho_{\mathrm{nf}} U d}{\mu_{\mathrm{nf}}} \quad \text{and} \quad \mathrm{Pr}_{\mathrm{nf}} = \frac{\mu_{\mathrm{nf}} C_{p\mathrm{nf}}}{k_{\mathrm{nf}}} \tag{12}$$

Further, Nusselt number is defined:

$$\mathrm{Nu}_{\mathrm{theo.}} = \frac{h_{\mathrm{theo.}} d}{k_{nf}} \tag{13}$$

Similarly, heat transfer coefficient is evaluated experimentally and theoretically for all possible observations for both the nanofluids. The percentage increase in heat transfer coefficient is also calculated for both the nanofluids as compared to the conventional pure distilled water.

Much deeper theoretical aspect is further understood by considering the analogy of heat gained by burning heap of charcoal and by combustion of pulverized charcoal. This is due to the remarkable high surface to volume ratio generates higher thermal energy in case of pulverized charcoal, where as some portion in large heap is remains unburned or partially burned [14, 21]. Similar is the case of nanoparticles as each particle at the molecular level contribute to the energy transfer process by exchanging heat to the surrounding fluid molecules due to high surface area.

Results and discussion

The effective properties of the nanofluids at the different loading concentration of both the nanopowders is evaluated [22, 23]. The properties of the nanofluids show the significant rise as compared to the base fluids. Hence it can be concluded that the implementation of the nanopowders in the base fluid increases the heat transfer rate. It is also suggested that further research still has to be done in the synthesis and applications of nanofluids so that they may be applied as more efficient and compact heat transfer systems, maintaining a cleaner and healthier environment and unique applications. It is mainly concluded that the heat transfer enhancement mainly depends on the particle size and thermal conductivity of the particles physical properties such as liquid density and viscosity, surface tension and specific heat, *etc*. have a significant effect on nanofluid two-phase flow and thermal physics such as nucleate pool boiling, convective flow boiling and critical heat flux (CHF) in both pool and flow boiling processes.

Figure 4 shows the plot of heat transfer coefficient and Reynolds number for pure water and different volume concentration of Al_2O_3 nanoparticles in water. In fig. 4 the enhancement at increasing volume concentration is much higher above the critical Reynolds number, whereas in fig. 9 shows the plot of heat transfer coefficient and Reynolds number for pure water and different volume concentration of CuO nanoparticles in water, indicating the enhancement is higher at the critical Reynolds number with moderate loading of nanoparticles. Figure 5 to 8 shows the plot of the heat transfer coefficient and Reynolds number for the same volume fraction of each of the nanopowder of Al_2O_3 and CuO from 0.1%, 0.2%, 0.3%, and 0.5%. From the various graph plotted, it is found that the heat transfer coefficient is higher in case of CuO

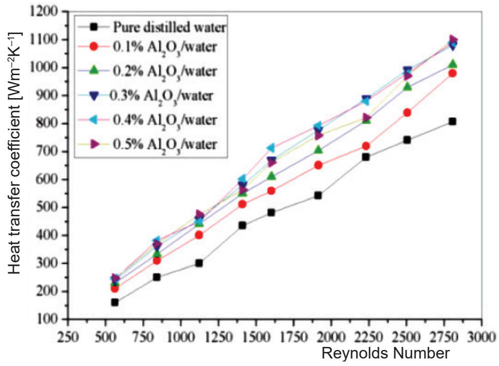

Figure 4. Heat transfer coefficient *vs.* Reynolds number of pure water and various loading of Al_2O_3 nanopowder in water

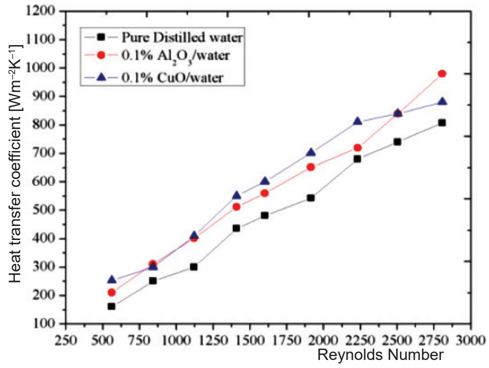

Figure 5. Heat transfer coefficient *vs.* Reynolds number for distilled water and 0.1% loading of CuO and Al_2O_3 nanopowder in water

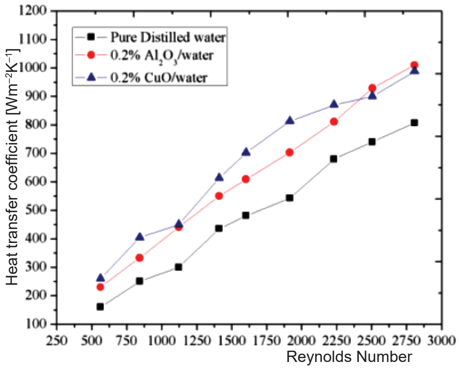

Figure 6. Heat transfer coefficient *vs.* Reynolds number for distilled water and 0.2% loading of Al_2O_3 and CuO nanopowder in water

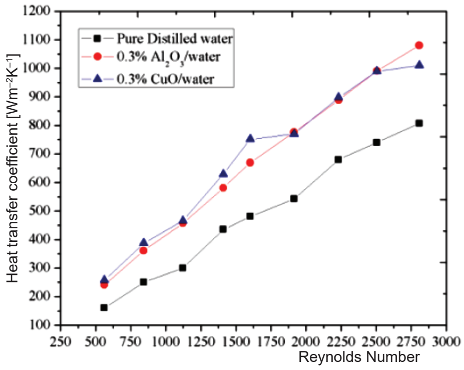

Figure 7. Heat transfer coefficient *vs.* Reynolds number for distilled water and 0.3% loading of Al_2O_3 and CuO nanopowder in water

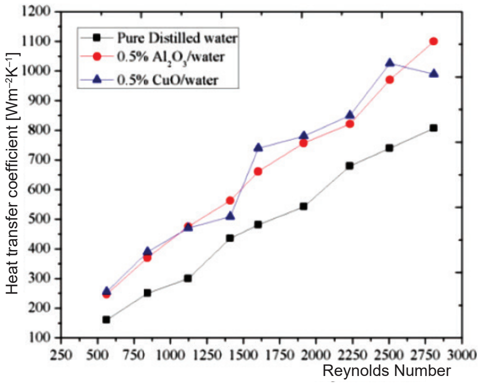

Figure 8. Heat transfer coefficient *vs.* Reynolds number of distilled water and 0.5% loading of Al_2O_3 and CuO nanopowders in water

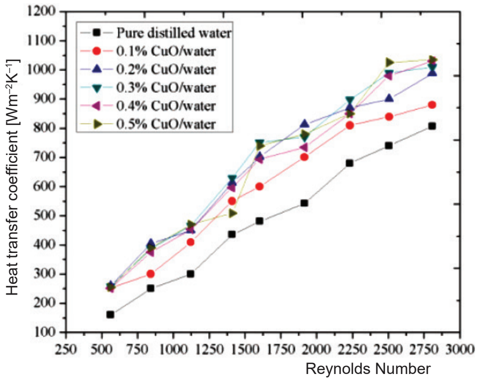

Figure 9. Heat transfer coefficient *vs.* Reynolds number for distilled water and different vol. concentration of CuO nanopowders in water

nanoparticles, if the volume concentration is low and fluid is in laminar region, whereas the Al_2O_3 is well suited if the percentage volume fraction is increased and also the fluid flow is in the transition zone. At all the volume concentration, the maximum enhancement is found around critical Reynolds number, *i. e*. 1500 < Re < 2200. Figure 10 and 11 shows the plot of heat transfer coefficient and Reynolds number for experimental and theoretical values at 0.1%, and 0.5% loading of Al_2O_3 nanoparticles. Similarly fig. 12 shows the experimental and theoretical values at 0.1% loading of CuO nanoparticles in the base fluid.

It can be concluded from the fig. 10, 11, and 12 that the theoretical values are significantly close to experimental values at the lower flow rate of the working fluid. In case of transition and turbulent region, the theoretical values are significantly lower than that of the experimental calculated values of heat transfer coefficient. It is found that the theoretical Saider-Tate co-relation used is suitable only at lower mass flow rate of the fluid.

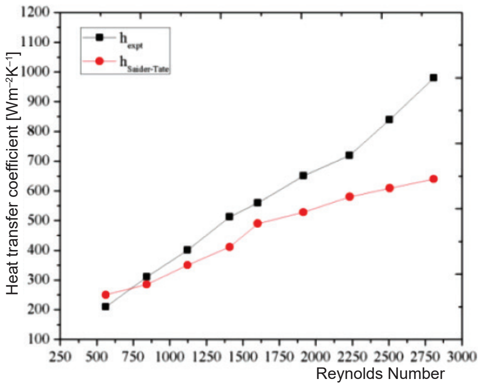

Figure 10. Heat transfer coefficient *vs*. Reynolds number for 0.1% loading of Al_2O_3 in water for experimental and theoretical values

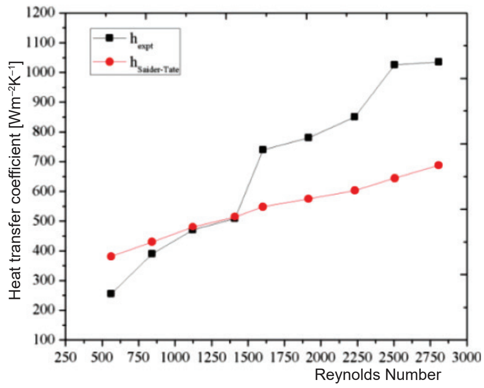

Figure 11. Heat transfer coefficient *vs*. Reynolds number for 0.5% loading of Al_2O_3 in water for experimental and theoretical values

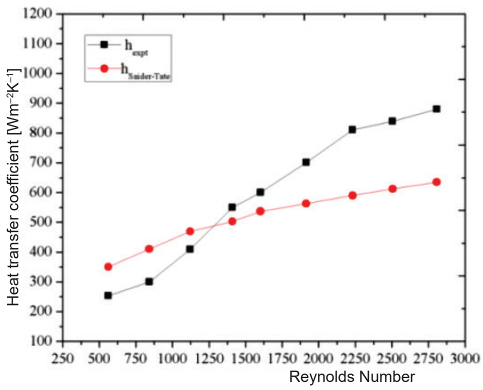

Figure 12. Heat transfer coefficient *vs*. Reynolds number for 0.1% loading of CuO in water for experimental and theoretical values

Conclusion

In this paper, the thermal characteristics of laminar and transition phase forced convective flow with Al_2O_3/water and CuO/water is experimentally evaluated for a wide range of Reynolds number between 500 < Re < 3000. The particle concentration and Reynolds number have a notable impact on the heat transfer enhancement of the system. The remarkable augmentation in the heat transfer was noticed in the laminar and transition phase with both the nanopowders. The heat transfer coefficient of the test fluid (nanofluid) increases as the Reynolds number for the flow increase. Further the heat transfer coefficient increases as the volume concentration of the nanofluid increases. The heat transfer enhancement at was found to be relatively less at the higher volume concentration rather at lower concentration. This may be due to the fact that at higher volume fraction, the viscosity of the fluid is much superior than that of the thermal conductivity. Also, higher volume fraction and lower the specific heat capacity of the fluid, which reduces the heat transfer rate. Some literature reports the decrease in the heat transfer by the use of the nanofluids [5]. For such cases the exact mechanism of energy transport at the atomic level must be analyzed. The stability of the nanofluids must be maintained for the enhanced performance of the nanofluid, as storage for longer duration may affect its PH value which affects the performance [13]. The maximum enhancement with alumina/water nanofluid was found to be around 52%, where with CuO/water was nearly 60%. This could be due to higher thermal conductivity and lower specific heat of the CuO nanopowders as indicated in table 1.

Future work

The nanofluids has great potential in a two phase heat transfer process specially in refrigeration and air conditioning devices. Further research is essential in estimating the optimum size and shape of the nanoparticles for the maximum thermal performance with the corresponding base fluid. This work has not been done yet. The particle motion experiences several forces such as Brownian motion, Staffman lift force, Soret and Dufour effect. Many of these phenomena are not yet completely understood, leading to the uncertainty in the use and result of the nanofluid [24-26]. The better understanding is required in the exact mechanism involve in surfactant impact on the nanofluid and the PH stability of the nanofluid at the elevated temperatures with reference to the heat transfer rate of the system. No work related to the optimum amount of surfactant for the heat transfer enhancement is studied for different base fluid. The separation process of nanoparticles from the base fluid is a vital process, so as to decompose the fluid and reuse the nanoparticles for the new base fluid. No work related to the separation process of nanopowder from the base fluid is being carried out which is environmental friendly and cost effective process.

Nomenclature

A – cross-section of the test section, [m^2]
$C_{p\mathrm{nf}}$ – specific heat of nanofluid, [Jgm^{-1}K^{-1}]
C_{ps} – specific heat of solid nanoparticles, [Jgm^{-1}K^{-1}]
$C_{p\mathrm{w}}$ – specific heat of distilled water (base fluid), [Jgm^{-1}K^{-1}]
D – diameter of the tube, [m]
h_{theo} – theoretical heat transfer coefficient, [Wm^{-2}K^{-1}]
$h_{\mathrm{w\,(exp)}}$ – heat transfer coefficient experi mental, [Wm^{-2}K^{-1}]
I – input current, [A]
k_{s} – thermal conductivity of solid nanoparticles, [Wm^{-1}K^{-1}]
k_{w} – thermal conductivity of water, [Wm^{-1}K^{-1}]
L – total length of the test section, [m]
$\mathrm{Nu_{theo}}$ – Nusselt number theoretical, [–]
$\mathrm{Pr_{nf}}$ – Prandtlt number of nanofluid, [–]
Q – heat input, [W]
$\mathrm{Re_{nf}}$ – Reynolds number of nanofluid, [–]
T_{b1} – temperature at the entry of the test section, [°C]
T_{b2} – temperature at the exit of the test section, [°C]
T_{w} – mean wall temperature of the test section, [°C]
U – mean velocity of the fluid, [ms^{-1}]
V – input voltage, [V]

Greek symbols

β – constant for water, 0.1, [–]
μ_{nf} – viscosity of nanofluid, [kgm^{-1}s^{-1}]
μ_{w} – viscosity of water, [kgm^{-1}s^{-1}]
ρ_{nf} – density of nanofluid, [kgm^{-3}]
ρ_s – density of solid nanoparticles, [kgm^{-3}]
ρ_s – density of solid particles, [kgm^{-3}]
ρ_{w} – density of distilled water (base fluid), [kgm^{-3}]
φ – percent volume concentration of nanoparticles, [%]

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