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Experimental Study of Convective Heat Transfer in a Horizontal Tube Using Nanofluids

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Abstract—*Experimental analysis of heat transfer characteristics of Al_2O_3/water and CuO/water nanofluids flowing inside a horizontal circular tube heated with uniform heat flux is conducted at Reynolds number range of 2800 to 5000. Al_2O_3 and CuO nanoparticles of 45 nm average size dispersed in distilled water to form stable nanofluids. The volume concentration range of both nanofluids was 0.1% to 0.7%. The result indicates that heat transfer coefficient of both nanofluids increase as compared to base fluid, water. The heat transfer coefficient of CuO/water nanofluid is higher than that of Al_2O_3 nanofluid for the same concentration and same Reynolds number. In case of CuO/water nanofluid the percentage increase in heat transfer coefficient at Reynolds number 4800 was 40% as compared to water (at 0.1 vol. %) while in case of Al_2O_3/water nanofluid it was 22.2%. Further, the pressure drop by using nanofluids was not noticeable.*

Keywords— Enhancement, Heat transfer, heat exchanger, nanofluid, thermal conductivity.

Nomenclature

A Outer surface area of the experimental tube (m^2)
Cp specific heat of fluid (J/kg K)
d_{hyd} hydraulic diameter of experimental tube (m)
h heat transfer coefficient (W/m^2K)
k thermal conductivity (W/m K)
m mass flow rate of the fluid (kg/s)
Nu average Nusselt number = $(h_{exp}\, d_{hyd}) / k$
P tube periphery (m)
Pr Prandtl number = μ Cp/k
Q heat transfer rate (W)
Re Reynolds number = $\rho\, u\, d_{hyd} / \mu$
S cross- sectional area of the experimental tube
T temperature (K)
U fluid velocity (m/s)

Greek letters

ρ Density (kg/m^3)
μ Viscosity (kg/m s)
Ø Volume fraction

Subscripts

b bulk
exp. experimental
in inlet
nf nanofluid
out outlet
p particle
w wall

I. INTRODUCTION

In the last few decades we have seen unprecedented growth in electronics, communication and computing technologies and will continue to grow at the faster rate. Thermal management of high power systems like hybrid electric vehicles (HEV), aerospace applications, microprocessors heat fluxes etc. are challenging issues. Electronic devices, lasers, high-power x-rays, and optical fibers are integral parts of today's computation, scientific measurement, medicine, material synthesis, and communication devices all these require high performance compact cooling techniques. Enhancement of heat transfer and reduction of energy losses is most important to deal with the energy wastage problems. Extended surfaces technologies such as fins, micro channels are reaching to their limits. Therefore, new technologies which have potential to improve the thermal properties of cooling fluids are of great interest to the researchers. Conventional fluids such as water, ethylene glycol and mineral oils possess poor thermal conductivity. A possible effective way of improving heat transfer performance on conventional fluids is to suspend small solid particles, such as metallic (e.g. Cu, Ag) and non-metallic (e.g. CuO, Fe_2O_3, Al_2O_3, TiO2) particles in conventional fluids. Recent developments in nanotechnology and related manufacturing techniques have made possible to manufacture the nanosized particles. Fluids with nanoparticles (diameter less than 100 nm) suspended in conventional fluids are called nanofluids, as coined by Stephen U.S.Choi and J.A.Eastman [1] early in 1995, Argonne National Laboratory, U.S.A., to increase the heat transfer characteristics. Nanofluid due to its molecular chain behavior, nanoparticles properly dispersed in the base fluid achieved major benefits such as higher heat conduction, microchannel cooling without clogging, reduced chances of erosion and pumping power with enhancement in thermal conductivity and stability of mixture. Heat transfer takes place at the surface of particles and therefore it is desirable to use particle size with a large surface area. Nanoparticles have extremely large surface areas and therefore much higher heat transfer. Particles having size less than 20 nm carry 20% of their atoms on their surface [13] making them available instantaneously for thermal interaction. In general the above features of nanofluids provide us the new area of research in nanofluid technology, plays an important role to improve heat transfer and energy efficiency in several areas including vehicular cooling in transportation, power generation, defense, nuclear, space, microelectronics and biomedical devices.

C.J.Ho et al.[2] experimentally investigated the forced convective cooling performance of a copper microchannelheat sinkwith Al_2O_3/water nanofluid as the coolant, Reynolds number ranging 226 to 1676. Results showed that the nanofluid-cooled heat sink have significantly higher average heat transfer coefficient and therby lower thermal resistance, friction factor was found slightly increased. Zeinali Heris et al. [3] experimentally investigated convective heat transfer of Al_2O_3 nanofluid in laminar flow through circular tube with constant wall temperature. The results indicate that heat transfer coefficient of nanofluids increases with Peclet number as well as nanoparticles concentration. Thermal conductivity may not be the only reason for heat transfer enhancement in nanofluids. Dispersion and chaotic movement of nanoparticles Brownian motion and particle migration may also cause the enhancement. S. M. Peyghambarzadeh et al. [4] convective heat transfer in Al2O3/water nanofluid has been experimentally compared with that of pure water in automobile radiator. Concentration range used was 0.1 to 1.0 vol.%, liquid flow rate 2 – 5 liters/min., turbulent flow range $9x\ 10^3 < Re < 2.3\ x10^4$. In addition the effect of inlet temperature of 37 – 49^0C to the radiator on heat transfer analysed. Results demonstrate that flow rate increase improve the heat transfer performance while flow inlet temperature to the radiator has trival effects. S.M.Fotkian et al.[5] experimentally investigated turbulent heat transfer and pressure drop of Al_2O_3/water nanofluid in a circular tube. The volume fractions of nanoparticles in base fluid were 0.03%, 0.054%, 0.067% and 0.135%. Results indicated the enhancement of heat transfer, but increasing the volume fraction of nanoparticles in the range used in their work did not show much effect on enhancement of heat transfer. Pressure drop observed was much grater than base fluid. Experimental results were compared with the existing correlations. .Mangrulkar C.K., Vilayatrai M.Kriplani [6] reviewed the work of the researchers. K.B.Anoop et al. [7] an experimental investigation on convective heat transfer characteristics in the developing region of tube flow with constant heat flux was carried out with alumina-water nanofluids to evaluate the effect particle size on convective heat transfer in laminar developing region. Average particle size of 45 nm and 150 nm were used. Nanofluid with 45 nm particles showed higher heat transfer coefficient than that with 150 nm particles in laminar developing region than developed region. M.H.Kayhani et al. [8] Experimental analysis of turbulent convective heat transfer of Al2O3/water nanofluid flowing inside uniformly heated horizontal tube with Al2O3 nanoparticles 40 nm size, volume concentration 0.1, 0.5, 1.5 and 2.0% was conducted. Results show that convective heat transfer enhancement for 2.0% volume concentration Nusselt number increased by 22% ar Re no. 13500.Comparaison between experimental results with existing correlations was also done. Ahmed Elsayed et al. [10] their work presents a numerical study to investigate the combined effect of using helical coils and nanofluids on heat transfer characteristics and pressure losses in turbulent flow regime. Combine effect of Al2O3nanofluid and tube coiling could enhance the heat transfer coefficient by up to 60% compared with that of pure water in straight tube at the same Reynolds number. Pressure drop in helical coils using Al2O3/water for volume fraction of 3% was six times that of water in straight tube (80% of pressure drop increase due to nanoparticles addition). M.Naraki et al.[11] experimentally investigated the overall heat transfer coefficient of CuO/water nanofluid under laminar flow ($100 \leq Re \leq 1000$) in a car radiator. Results indicate the increase in overall heat transfer coefficient with increase in nanofluid concentration (0 to 0.4 vol.%). However, it decreases with increase in nanofluid temperature from 50 to 80^0C.In the developing region, the heat transfer coefficients show higher enhancement than in developed region. At concentration of 0.15 and 0.4 vol.% of CuO nanoparticles, he overall heat transfer coefficient enhancements compared with the pure water are 6% and 8%.

The main objective of work was experimental investigation of heat transfer enhancement in horizontal tube using naofluids. The nanoparticles, Al_2O_3 and CuO, were selected, as metallic oxides are cheaper than metallic one,

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though metals have much higher thermal conductivity than metallic oxides and therefore, higher heat transfer enhancement. Base fluid chosen was distilled water.

II. NANOFLUID PREPARATION

The first step in experimental studies is the preparation of nanofluids. Preparation of a stabilized nanofluid is of great importance in heat transfer applications of nanofluids. Poorly prepared nanofluids will render biphasic heat transfer (i.e. solid-liquid). Dispersant or surfactant was not added as they may change the properties of the nanofluid. Nanofluids were prepared with nanoparticles Al_2O_3 and CuO (average size 45 nm) with deionized water as base fluid. The nanoparticles were purchased from Sigma Aldrich, Germany.

Specific quantities of nanoparticles were mixed with distilled water as the base fluid for both and stirred with magnetic stirrer for about eight hours. The stirred nanofluid was kept for about 24 hrs. And no sedimentation was observed. Immediately the experiment was started.

Table.I: Properties of Al_2O_3 and CuO nanopowders

Properties	Al_2O_3	CuO
Diameter (nm)	45	45
Density (kg/m3)	3700	800
Sp.Heat (J/kg-K)	880	660
Thermal Conductivity (W/m-K)	46	62

III. NANOFLUID PROPERTIES

Thermophysical properties of the nanofluid must be known before using for experimental test. The nanoparticles are assumed to be well dispersed in the base fluid and concentration of nanoparticles is assumed to be uniform in the tube. The thermo-physical properties of prepared nanofluids are calculated from water and nanoparticles characteristics at mean inlet and outlet bulk temperatures. The following correlations for thermal conductivity, density, specific heat, viscosity are used.

The density of nanofluids can be predicted by the mixing theory as:

$$\rho_{nf} = (1-\emptyset)\,\rho_{bf} + \emptyset\,\rho_{np} \qquad (1)$$

$$k_{nf} = [\{k_{np} + (n-1)\,k_{bf} - \emptyset(n-1)(k_{bf} - k_{np})\} / \{k_{np} + (n-1)\,k_{bf} + \emptyset(k_{bf} - k_{np})\}]\,k_{bf} \qquad (2)$$

The following relationship is used for calculation of specific heat which is same approach as the mixing theory of ideal gases:

$$Cp_{nf} = \emptyset\,Cp_{np} + (1-\emptyset)\,Cp_{bf} \qquad (3)$$

$$\mu_{nf} = \mu_{bf}\,(123\,\emptyset^2 + 7.3\,\emptyset + 1) \qquad (4)$$

In the above equations, the subscripts “nf”, “np” and “bf” refer to the nanofluid, nanoparticle and base fluid respectively. $\emptyset$ is the volume fraction of the nanoparticles added to base fluid. ‘n’ is the imperial shape factor given by $n = 3/\psi$, and ψ is the particle sphericity, defined as the ratio of the surface area of a sphere with volume equal to that of the particle, to the surface area of the particle, and in this paper n considered to be 3.

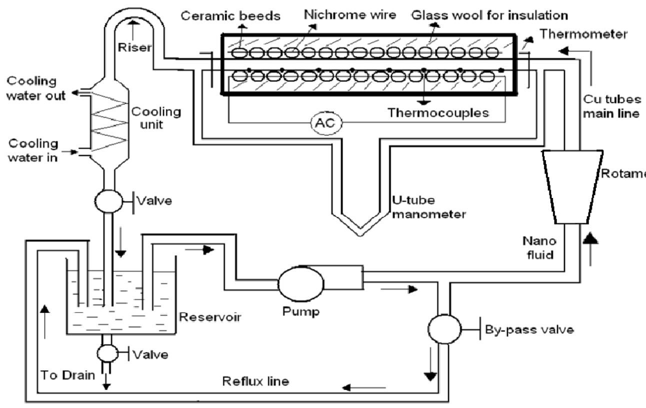

Fig.1: Experimental set up

IV. EXPERIMENTAL APPARATUS

An experimental apparatus is designed and constructed to investigate the convective heat transfer of nanofluids in a horizontal circular tube heated with uniform heat flux (Fig.1). The test section is a smooth horizontal copper tube, inner diameter (ID) 9.5 mm, 1 mm thick and length 1.0 meter. Electrically insulated nickrome heating wire was uniformly wound along the length of the tube. The terminals of the nickrome wire were connected to the variac transformer. Thermocouples were tapped along the tube wall for monitoring the local temperatures of the surface tube wall. The heating tube and thermocouples were covered with insulation to minimized heat loss to surrounding. The pump gives constant flow rate. The flow rate in the test section is regulated by adjusting the bypass valve located in the reflux line Thermometers will measure the inlet and outlet temperatures of working fluid, rotameter to measure required flow rates of the fluid. Cooling unit at the exit of test section will cool the test fluid to the inlet temperature. To measure the pressure drop along the test section a manometer was used. Readings were taken after the system reached the steady state condition.

V. DATA ANALYSIS

Observations were taken at steady state conditions. Initially experiment was performed with distilled water at various mass flow rates and then for Al_2O_3/water and CuO/water nanofluids with volume concentrations 0.1- 0.7%. Flow rates were same for all three fluids. Constant heat flux was maintained in all the cases. According to the Newton's law of cooling,

$Q=h_{exp}A(Tw–Tb)$ (5)

Where mean bulk temperature is given by

Tb = (Tin+Tout)/2

Where Tin = inlet temperature of fluid

Tout = outlet temperature of fluid

Heat transfer rate,

$Q=mCp_{nf}(Tout–Tin)$ (6)

Equating (5) & (6)

h_{exp} A (Tw – Tb) = m Cp_{nf} (Tout–Tin)

$h_{exp}=[mCp_{nf}(Tout–Tin)]/[A(Tw-Tb)]$ (7)

Nu = (h_{exp} D_{hyd}) / k

D_{hyd} = 4S/P

All the physical properties are evaluated at bulk mean temperature Tb, of the fluid.

VI. RESULT AND DISCUSSION

Experimental results are compared with Dittus-Boelter (eq.8) and Gnielinsky (eq. 9) correlations

$Nu=0.023Re^{0.8}Pr^{0.4}$ (8)

$Nu= [(f/8) (Re – 1000) Pr]/ [1+12.7 (f/8)^{0.5} (Pr^{2/3} – 1)]$ (9)

$3000 \le Re \le 5 \times 10^6$ and $0.5 \le Pr \le 2000$

Where from Petukhov, 1970, friction factor f, was calculated using equation (10)

$f = (0.79 \ln Re – 1.69)^{-2}$ (10)

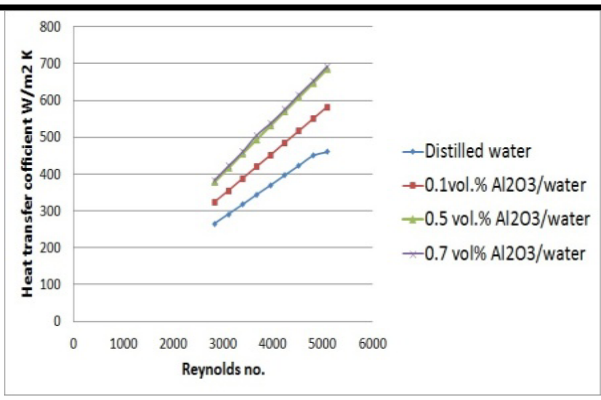

Fig. 2 Heat transfer coefficient Vs Reynolds number

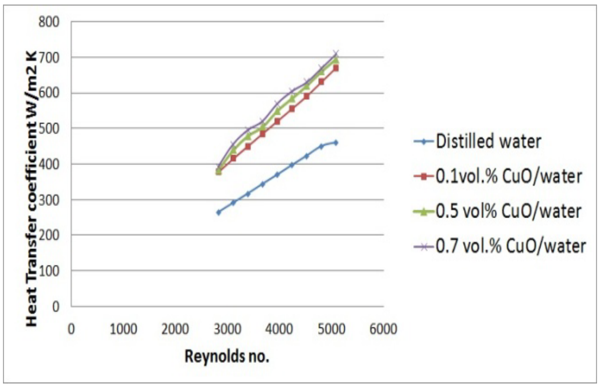

Fig. 3: Heat transfer coefficient Vs Reynolds number

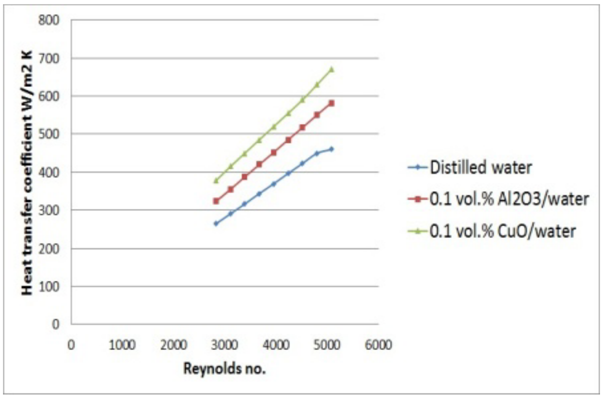

Fig. 4: Heat transfer coefficient Vs Reynolds number

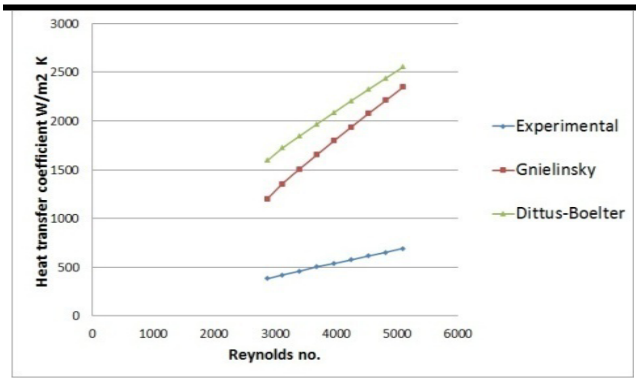

Fig. 5: Heat transfer coefficient Vs Reynolds number, 0.7 vol.% Al_2O_3/water

To validate the heat transfer coefficient enhancement of nanofluids experiment was performed on distilled water. Experimental results of heat transfer coefficient of nanofluids with varying volume concentrations were compared with that of base fluid, distilled water. Also experimental results were compared with that of predictions of Dittus-Boelter and Gnielinski correlations [5].

Heat transfer coefficient increases with Reynolds number and with increase in volume concentration of nanoparticles. In case of Al_2O_3/water nanofluid (Fig.2), increase in heat transfer coefficient at volume concentration of 0.7% and at Reynolds no. 4800, is 44.8% as compared with distilled water. Similarly in case of CuO/water nanofluid (Fig.3), at volume concentration 0.7% and Reynolds no. 4800, it is 48.8%. Fig.4 shows the increase in heat transfer coefficient for Al_2O_3/water and CuO/water nanofluids as compared with distilled water. At Reynolds no. 4800 and 0.1vol. %, increase is 22.2% and 40% for Al_2O_3/water and CuO/water nanofluid respectively. Experimental values of heat transfer coefficient (Fig.5) are compared with that of predicted by Dittus-Boelter and Gnielinsky correlations (8, 9). At Reynolds no. 4800 and 0.7vol. %, heat transfer coefficient increase predicted is 2.39 times and 2.74 times with Gnielinski and Dittus-Boelter correlations respectively. Enhancement of heat transfer in nanofluid is due to much higher thermal conductivity of nanoparticles dispersed in base fluids. Nanofluid concentration results increase in effective thermal conductivity. Heat transfer enhancement is associated with particle motion in the form of Brownian motion [13] by which particles move through liquid and possible collide, enabling direct solid to solid transporting of heat from one to another, and expecting increase in thermal conductivity. Other possible concept in nano-convection of fluid around particles due to their motion, particle transport some of the amount of heat transferred through agitation in the liquid. Yet another concept is liquid layering around the particle may give path for rapid thermal conduction. A liquid shell around the particles behave like solids, is assumed [13].

Concluding remarks

Nanofluid with enhanced thermal conductivity brings about enhanced heat transfer. However, in addition, with other suitable conditions such as nanoparticles material and size, appropriate particle concentration range, additives to maintain the stability may achieve higher heat transfer coefficients. However, thermal conductivity is not the sole reason for heat transfer enhancement. Suspended nanoparticles increase the surface area and the thermal conductivity of suspensions increases with the ratio of the surface area to volume of the particle, hence increase in heat transfer rate. As volume concentration of nanoparticles increases the heat transfer enhancement increases.

Metals (Al, Cu, and Ag) have higher thermal conductivity and therefore experiments with metallic nanofluids be performed. Lesser the particle size greater will be heat transfer enhancement. This is because of increase of heat transfer area. Size of nanoparticles should be small, as large particles tend to quickly settle out of suspension and thereby causing severe clogging while passing through microchannels and increase pressure drops considerably. Further large size particles may damage the equipment, such as pump, piping etc.

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