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Heat Transfer Enhancement in Fe3O4-water Nanofluid through a Finned Tube Counter Flow Heat Exchanger

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Abstract

In this paper, Nanofluid formed by the stable suspension of spherical Fe_3O_4 nanoparticles of average diameter of 75 nm in water was used for the experimental work on counterflow heat exchanger. The convective heat transfer coefficient of Fe_3O_4 water nanofluid for flow through the internally finned tube and plain tube is evaluated under the turbulent flow conditions for the volume concentrations of 0.02, 0.04, 0.06, 0.08 and 0.1 % of Fe_3O_4 nanoparticles. Nanofluid heat transfer is 50-80 % more in finned tube compared to plain tube for experimental volume concentrations.

Keywords: Nanofluid, finned tube, plain tube, heat transfer enhancement

INTRODUCTION

Heat transfer enhancement by modifying the fluid thermo physical properties by dispersing metallic particles to the base fluid has been the acceptable practice from past few years which was well discussed by Maxwell [1] and Liu et al. [2] .Dispersion of nano sized particles in a base fluid like water or Ethyl Glycol is well known as nanofluid. The experimental studies of Masuda et al.[3],Choi[4],Eastman et al.[5] have reported significant enhancement of effective thermal conductivity of nanofluid which is of great interest to make use nanofluids for heat transfer enhancement.

Several well established studies on nanofluid heat transfer are available in the literature.

Wen and Ding [paper 1, 6] investigated with Al_2O_3 water nanofluid flowing through copper tube and observed the heat transfer enhancement with increase in Reynolds number and volume concentration. Sundar and M.T.Naik et al. [7] conducted experiments with Fe_3O_4 magnetic nanofluid in circular tube and observed the enhancement of heat transfer coefficient. Xuan and Li [8] investigated the experimental results of Cu nanofluid in circular tube under turbulent flow conditions regression equation is presented. Convective heat transfer enhancements with Fe_3O_4 magnetic nanofluid in circular plain tube with wire coil inserts is explained by some researchers. Sundar et al. [9] has worked on twisted tape inserts in plain tube with Fe_3O_4 magnetic nanofluid. W.Yu,H.Xie et al.[10] observed the enhanced heat transfer in plain tube with Fe_3O_4 kerosene nanofluid.

Weerapun Duangthongsuk and Somachai Wong wises [11,12] investigated the heat transfer of the TiO_2 water nanofluid flowing in horizontal double tube counter flow heat exchanger under turbulent flow conditions. Their results showed that the heat transfer coefficient of nanofluid was higher than that of the base liquid and increased with increasing the Reynolds number and particle concentrations.

The present work is to study the forced convective heat transfer of Fe_3O_4 water nanofluid at different volume concentrations of Fe_3O_4 nanoparticles flowing through the internally finned tube under turbulent flow conditions.

NOMENCLATURE

C_p	Specific heat ,J/kg K
D	tube diameter
h	Convective heat transfer coefficient $W/m^{2}\,^{0}C$
k	Thermal conductivity $W/m^{0}C$
l	length of the tube,m
Nu	Nusselt number
Re	Reynolds number
Pr	Prandtl number
Q	heat transfer rate,W
q	heat flux, W/m^2

T	temperature ^{0}C
f	friction factor
Greek symbols	
ϕ	volume fraction
μ	dynamic viscosity, kg/ms
ρ	density, kg/m^3
Subscript	
np	nanoparticle
Eff	effective
nf	nanofluid
W	water
Wall	tubewall
Ave	average
f	Fluid
In	Inlet
Out	Outlet

EXPERIMENTAL APPARATUS

To study the convective heat transfer of Fe_3O_4 water nanofluid flowing in a horizontal longitudinal finned tube, an experimental set up was designed and fabricated (Fig.1).The test section consists of hot water tank, cooler tank, hot water pump, fluid pumps and data acquisition system. The test section of 1.55m long counter flow horizontal longitudinal finned tube in tube heat exchanger with Fe_3O_4 water nanofluid flowing inside the finned tube and hot water flows through the annular space.

The inner tube is made of stainless steel of 27 mm outer diameter and 21 mm inner diameter. Three longitudinal copper strips of 3 mm thick and 6 mm wide are attached to the inner wall and used as fins to enhance the heat transfer. The outer tube is made of stainless steel with 50 mm outer diameter and 42 mm inner diameter.

The outer tube is insulated by using asbestos rope to minimize the heat loss to the surroundings. J-Type thermocouples are mounted at inlet and outlet sections to measure the inlet and outlet temperatures of fluids. The hot water tank is of 70 litres capacity with 9 kW heating capacity by using electric heater with thermostat to maintain the constant temperature of water. The cooler tank with 5.25 kW cooling capacity with mechanical mixing unit is used with thermostat to maintain the constant temperature of nanofluid. The hot water flow rate is measured by rotameter and nanofluid flow rate is adjusted by bypass valve and measured by volumetric approach.

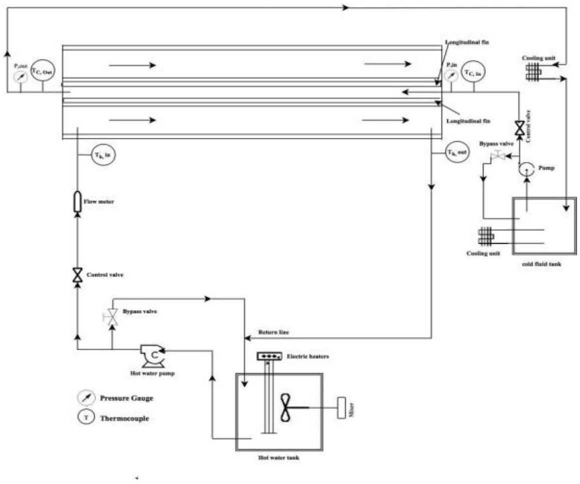

Figure 1: Schematic diagram of the experimental setup

NANOFLUID PREPARATION AND PROPERTIES

Fe_3O_4 nano particles of average size of 75 nm are procured from Sigma Aldrich ,USA.

Octadecenoic acid($C_{18}H_{34}O_2$) with very low concentration (about 0.08 %) is used as surfactant and mixed with distilled water to ensure better stability and proper dispersion of the nano particles without affecting the thermo physical properties of the nanofluid.

Fe_3O_4 particles were mixed in the water base fluid in specified amounts to obtain the required volumetric concentration of nanofluid. Nanofluid is sonicated by using ultrasonic vibrator to ensure complete dispersion of particles.

The physical properties such as the volumetric concentration, density, viscosity, specific heat and thermal conductivity of the nanofluid are calculated using the published correlations in the literature as given under.

Density of nanofluids can be calculated by mixing theory is calculated from Pak and Cho [13]

$$\rho_{eff} = \rho_b(1-\phi_{np}) + \rho_{np}\,\phi_{np} \qquad (1)$$

Where ρ_{eff} is the effective density of nano fluid, ρ_b is the density of the base fluid, ϕ_{np} is the volumetric concentration of nanoparticles and ρ_{np} is the density of nanoparticles.

Effective thermal conductivity of Nano fluids can be calculated from the following equation given by Maxwell model [14].

$$k_{eff} = \frac{k_b\left[k_{np} + 2k_b - 2\phi_{np}(k_b - k_{np})\right]}{k_{np} + 2k_b + \phi_{np}(k_b - k_{np})} \qquad (2)$$

Where k_{eff} is the Effective thermal conductivity, k_b is the thermal conductivity of base fluid, k_{np} is the thermal conductivity of nanoparticles and ϕ_{np} is the volumetric concentration of nanoparticles.

Specific Heat of Nano fluids can be calculated from the following equation given by

$$C_{peff} = \frac{(1-\phi_{np}) \times \rho_b C_{pb} + (\phi_{np} \times \rho_{np} C_{pnp})}{\rho_{eff}} \tag{3}$$

Where C_{peff} is the effective specific heat, C_{pb} is the specific heat of base fluid , C_{pnp} is the specific heat of nanoparticles and ϕ_{np} is the volumetric concentration of nanoparticles.

Dynamic Viscosity of nanofluids can be calculated from the following equation given by Einstein model

$$\mu_{eff} = (1 + 2.5\phi_{np})\mu_b \tag{4}$$

Where μ_{eff} is the effective dynamic viscosity, μ_b is the dynamic viscosity of base fluid and ϕ_{np} is the volumetric concentration of nanoparticles.

DATA ANALYSIS

The heat transfer rate from hot fluid (water) is given as

$$Q_w = m_w C_{pw} (T_{in} - T_{out})_w \tag{5}$$

Where Q_w is the heat transfer rate of hot fluid (water) and m_w *and* C_{pw} are the mass flow rate and specific heat of the hot fluid respectively.

$$Q_{nf} = m_{nf} (C_p)_{nf} (T_{out} - T_{in})_{nf} \tag{6}$$

Where Q_{nf} is the heat transfer rate of cold fluid (Fe_3O_4 – water nanofluid) and m_{nf} *and* $C_{p\,nf}$ are the mass flow rate and specific heat of the cold fluid respectively.

The average heat transfer is given as

$$Q_{ave} = \frac{Q_w + Q_{nf}}{2} \tag{7}$$

In the experimental study, energy transfer difference between hot fluid and cold fluid is around 3-5 % under the different mass flow rate conditions.

The experimental heat transfer coefficient of nanofluid is calculated from the following equation:

$$q_{ave} = h_{nf} (T_{wall} - T_{nf}) \tag{8}$$

Where q_{ave} is average heat flux between the hot fluid and cold fluid, T_{wall} is the average wall temperature and T_{nf} is the bulk temperature of the nanofluid. h_{nf} is the inside convection heat transfer coefficient.

Experimental Nusselt number for nanofluid can be estimated from

$$Nu_{nf} = \frac{h_{nf} D}{k_{nf}} \tag{9}$$

RESULTS AND DISCUSSION

Experimental heat transfer coefficient of nanofluid in plain tube

The accuracy of experimental setup is validated by using water as the working fluid for plain tube .Experimental results for water are compared with those predictions of Gnielinski equation [16] and Dittus-Boelter equation [17] for the turbulent flow.

The Gnielinski correlation is defined as:

$$Nu_D = \frac{(f/2)(\mathrm{Re} - 1000)\,\mathrm{Pr}}{1 + 12.7 (f/2)^{0.5} (\mathrm{Pr}^{2/3} - 1)} \tag{10}$$

Where Nu is the nusselt number, Re is the Reynolds number ,Pr is the Prandtl number.

f is the friction factor which can be obtained from

$f = (1.58 \ln \mathrm{Re} - 3.82)^{-2}$, $2300 < \mathrm{Re} < 5\times10^6$, $0.5 < \mathrm{Pr} < 2000$ (11)

The Dittus-Boelter correlation [17] for turbulent flow :

$Nu = 0.023\,\mathrm{Re}^{0.8}\,\mathrm{Pr}^{0.4}$, $0.6 < \mathrm{Pr} < 200$ (12)

Experiments are performed at different mass flow rates with water as cold fluid to estimate the inside convection heat transfer coefficient (h) from Eq. (8) and shown in Fig. 2. and compared with the values evaluated with the equations of Gnielinski [16] and Dittus-Boelter . There is good agreement between the experimental data and values obtained by the correlations which indicates that the experimental setup is reliable.

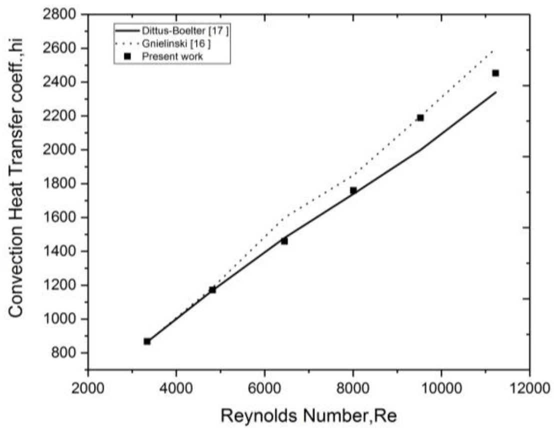

Figure 2: Comparision between experimental convection heat transfer coefficient and calculated data fromGnielinski equation[16] and Dittus-Boelter correlation[17].

In the present work the experimental work is carried with Fe_3O_4 water nanofluid at different volumetric concentrations (i.e. 0.02, 0.04, 0.06, 0.08 and 0.1 %) in plain tube and finned tube.

The average inside convection heat transfer coefficient of nanofluid as a function of Reynolds number for different nanoparticle concentrations for plain tube heat exchanger is given in the Fig.3.

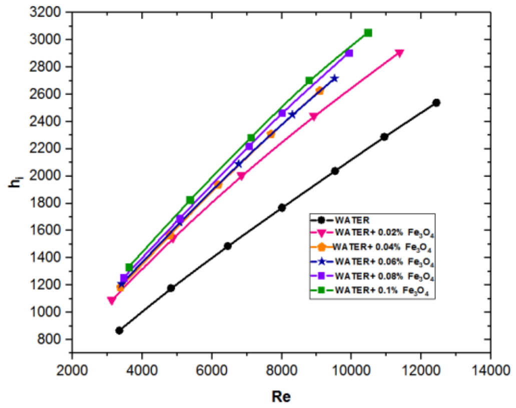

Figure 3: Experimental convection heat transfer coefficient at different Reynolds numbers for plain tube.

The results show that inside convection heat transfer coefficient increases with the increase of Reynolds number.

It is observed that heat transfer coefficient for nanofluids is higher compared to the base fluid (water) and increases with the increase of nanoparticle concentration.

The experimental Nusselt number is higher for nanofluids compared to the base fluid and increases with the increase in particle volumetric concentration and Reynolds number in the plain tube. The similar result was observed by Pak and cho [13] with Al_2O_3 and TiO_2 nanofluid, Xuan and Li [8] with cu nanofluid and L.Syam sundar[9] with Fe_3O_4 water nanofluid.

Experimental heat transfer coefficient of nanofluid in finned tube

The main objective the present work is to estimate the heat transfer coefficient of Fe_3O_4 water nanofluid flowing inside a finned tube and to compare it with the plain tube for different Reynolds number.

Fig.4. shows the variation of experimental heat transfer coefficient as a function of Reynolds number. It clearly shows that the heat transfer coefficient for the case of finned tube is very much higher compared to the Plain tube for a given Reynolds number.

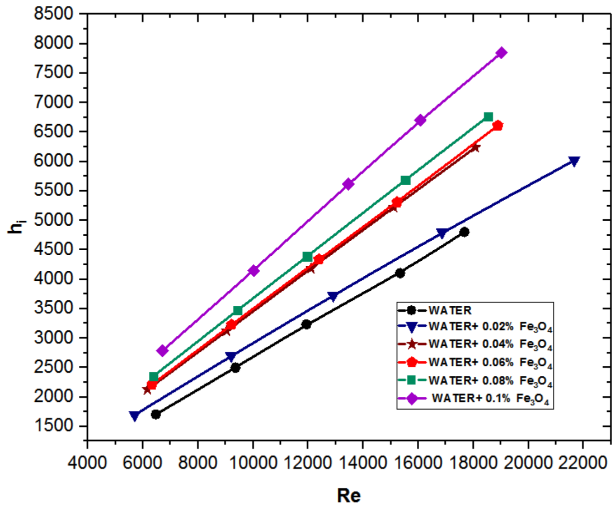

Figure 4: Experimental convection heat transfer coefficient at different Reynolds numbers for finned tube.

The comparison of convection heat transfer coefficient for 0.1 % Fe_3O_4 water nanofluid for plain tube and finned tube is shown in Fig.5.

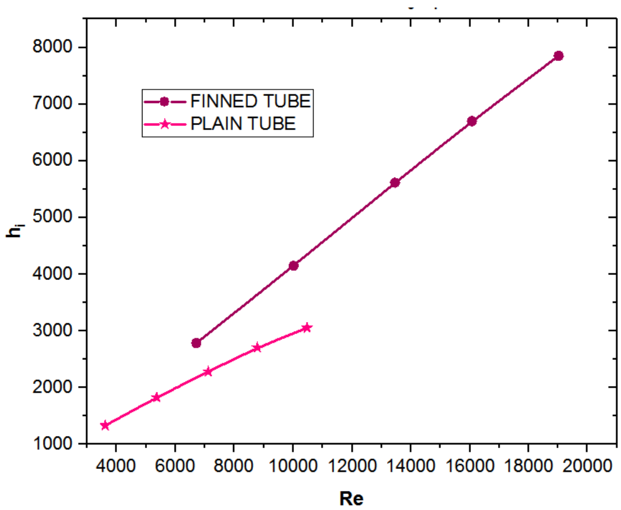

Figure 5: Comparison of plain tube and finned tube heat transfer coefficients as a function of Reynolds number at volumetric concentration of 0.1% Fe_3O_4 water nanofluid

Fig.6. shows the heat transfer rate of plain tube and finned tube as a function of Reynolds number at 0.1% volume concentration of Fe_3O_4 water nanofluid. It can be clearly seen that heat transfer rate is very much higher for finned tube at a particular Reynolds number.

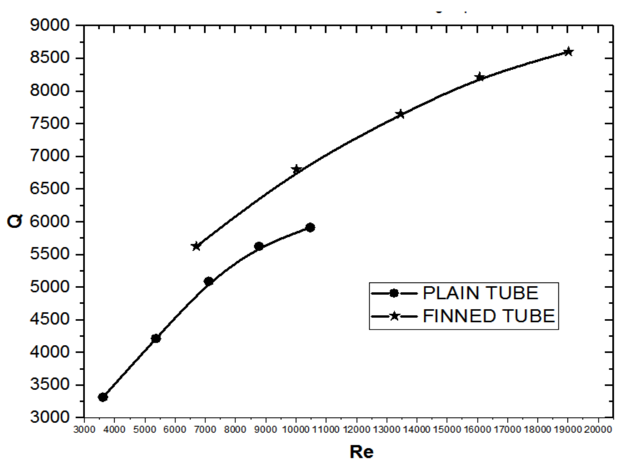

Figure 6: Variation of heat transfer rate with Reynolds number for plain tube and finned tube heat exchanger for 0.1 % Fe_3o_4 –water nanofluid

CONCLUSIONS

The convective heat transfer performance of Fe_3O_4 –Water nanofluid flowing in horizontal double tube counter flow heat exchanger of both plain tube and finned tube were experimentally investigated. The effect of Reynolds number and volumetric concentration of nanoparticles on the heat transfer coefficient and heat transfer rate were investigated. The following conclusions have been drawn.

- Experimental convection heat transfer coefficient and heat transfer rate increases with the Reynolds number for both plain tube and finned tube heat exchangers by using Fe_3O_4 –Water nanofluid compared to the base fluid.
- Heat transfer rate is more for 0.1 % Fe_3O_4 –Water nano fluid for both plain tube and finned tube heat exchangers compared with the 0%, 0.02 %, 0.04%, 0.06%, and 0.08% water nanofluids.
- Heat transfer rate in finned tube heat exchanger is 50% - 80 % more compared to the plain tube heat exchanger for the cases of 0%, 0.02 %,0.04%,0.06%, 0.08% –Water nanofluids

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