International Journal of Recent Technology and Engineering (IJRTE)
ISSN: 2277-3878, Volume-8 Issue-4, November 2019

Heat Transfer in Hairpin Heat Exchanger using Magnetite/Water Nanofluid

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Abstract— The present work deals with heat transfer augmentation in a Hair-Pin heat exchanger using magnetite/water nanofluid at volume concentrations of 0.004%, 0.006% and 0.008% under turbulent flow, the effect of different concentration of magnetite nanoparticles are added in pure water as basefluid on heat transfer coefficient and pressure drop in a hair-pin heat exchanger for counteract flow arrangement are investigated. The magnetite/water nanofluid is flowing through the inner tube and Reynolds number considered is in the range of 16000 to 30000. The results showed that there is 25-33% enhancement in heat transfer coefficient at 0.008% to the water at Reynolds number range of 16000 to 30000.

Keywords: Hair-pin, counter flow, SDS, magnetite.

I. INTRODUCTION

An engineering device used for exchange of heat between two fluids at dissimilar temperatures is known as heat exchanger. The main principle is either add heat to a fluid or remove heat from the fluid and some applications of heat exchangers are air-conditioning and power plants, refrigeration, sewage treatment, condensers, space heating, recuperators etc., **Duangthongsuk et al.** found an increase 6% to 11% coefficient of heat transfer of 21nm size particles of 0.2% titanium oxide nano fluid intended for characteristics of heat transfer enhancement and pressure drop. **RizaAghayari et al.** under counter flow for aluminum oxide nanofluid of particle of 20nm resulted 19% to 24% enhancement of heat transfer coefficient and nusselt number in a double piped heat exchanger. **Chandrasekhar Reddy et al.** using TiO_2/water nanofluid for diverse volume concentrations for Re range up to 23000, establish that heat transfer coefficient is proportional to the volume concentration. **Senthil raja et al.** in a heat exchanger De-ionized water was selected as base fluid and CuO nanoparticles (size 27nm) at various volume concentrations (0.1% and 0.3%) gave result in nusselt number increases with increase in mass flow rate. **Pak et al.** concluded that two various metal oxides such as gamma-aluminium oxide and titanium oxide with the size of 13nm and 27nm were used as suspended nanoparticles. After suspending gamma Al_2O_3 and TiO_2 in base fluids, then viscosity measurements were conducted using viscometer and the viscosities at 10% volume fraction were 200 and 3 times larger compared to the water. **Dongsheng Wen et al.** in his experiments using aluminium oxide/water nanofluid under laminar flow conditions which is passing through the copper tube, found that increase in heat transfer coefficient was particularly significant in entrance region due to random motion of nanoparticles and ensuing fracas of the boundary layer. **Chandrasekhar et al.** the friction factor and heat transfer characteristics in a circular tube under laminar flow condition using aluminium oxide nanofluid of diameter 43nm and distilled water as base fluid enhanced Nu by 15.91% and 21.55% at same Re number with nanofluid. **Xuan et al.** determined suspending nanoparticles at same Reynolds number, there is a greater enhancement by 40% at 2% volume concentration at the condition that velocity is fixed at all concentrations.

II. EXPERIMENTAL DETAILS

A. Experimental Setup

Fig. 1 shows the experimental setup with a heat exchanger, concentric tubes, reservoirs with a 2 kW immersion heater. The concentric tubes made of MS material are arranged in series. The diameters of the inner tube is ϕ_{in} = 19mm and ϕ_{out} = 25mm respectively. Similarly, outer tube is ϕ_{in} = 50mm and ϕ_{out} = 56mm respectively.

Fig 1: Experimental Setup

Manuscript published on November 30, 2019.

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To measure the T_{in} and T_{out} of fluids, thermocouples are arranged at diverse locations.

B. Preparation of Magnetite/Water Nanofluid

Fig. 2 shows the magnetite (Fe_3O_4) nanoparticles of <50nm diameter. The colour of nanoparticles is black and its purity >99%. Fig. 3 shows the nanofluid preparation using mechanical stirrer. Due to lack of sonicators and particle sedimentation problem, low concentrations are selected with a two-step process. Nanofluids at various volume concentrations in the range 0.004% - 0.008% are prepared.

Fig 2: Magnetite (Fe_3O_4) nano particles of <50nm diameter

To prepare magnetite / water nano fluid of 0.004% density, 25 liters of water, 5.2 grams of magnetite nano particles have to be supplementary. To set up nano fluids of specific amounts of density, samples are initially primed by toting up SDS surfactant in varying congruity in water and the mixture is stirred in a reservoir for 10minutes. Magnetite nano particles are added and shaken incessantly for 24 hrs & nano fluids are observed for dispersal and immovability. SDS 1 / 10ths mass magnetite nano particles are added to the base fluid giving consistent dispersal without sedimentation.

C. Sedimentation Test

A conical flask with 250ml of distilled water is mounted on the magnetic stirrer equipment and Sodium Dodecyl Sulphate (SDS) is mixed into the distilled water. It is then continuously stirred for 10min. Later, magnetite nano particles are supplemented as per required attentiveness to the blend as per required concentration & stirred for 24 hrs. The time taken by the particles to be uniformly dispersed is observed.

D. Experimental Procedure

- At the constant flow rate (i.e., 8lpm) of the cold water and varying the nanofluid concentrations and hot water flow rates at 0.004%, 0.006%, 0.008% and 8 lpm, 10 lpm, 12 lpm, 14 lpm are considered to generate the turbulent flow.
- Fig. 3 shows Nanofluid Preparation using Mechanical Stirrer. Two reservoirs are one with cold water and nano fluid in the other.
- For heating up the nano fluid, Switch ON the immersion heater .
- After attaining the desired temperature to circulate nano fluid through the inner tube Switch ON the Centrifugal pump..
- Started to supply the cold water which flows through the annulus keeping flow rate as constant and nano fluid flows through the tube.
- The T_{in} & T_{out} of both cold fluid and nano fluid were taken until they achieved steady state.

Fig 3: Nanofluid Preparation using Mechanical Stirrer

III. OBSERVATIONS AND CALCULATIONS

The experimental observations are presented at different concentrations. Based on the experimental observations, the sample calculations are presented. The properties of nanofluid are calculated based on the literature. Calculations of Nanofluid properties in terms of volume concentrations are as follows:

Density of nanofluid (ρ_{nf})

According to Xuan and Roetzel correlation, the ρ_{nf} is calculated by

$$\rho_{nf} = (1 - \Phi)\rho_{bf} + \rho_{np}\Phi$$

$\rho_{bf} = 988.775\mathrm{kg/m^3}$, $\rho_{np} = 5100 kg/m^3$, $\phi = 0.008\%$

$\rho_{nf} = 989.21\ \mathrm{kg/m^3}$

Specific heat of Nanofluid (C_{pnf}):

According to the Pak B.C. and Cho Y.I. correlation, the specific heat of nano fluid is calculated by

$$C_{pnf} = \frac{(1 - \Phi)\rho_{bf}C_p + \Phi C_{pnp}\rho_{np}}{\rho_{nf}}$$

$C_{p,bf} = 4181.0625 J/kg - K$, $C_{p,np} = 670 J/kg - K$, $\phi = 0.008\%$

$$C_{pnf} = 4179.59\ \mathrm{KJ/kg - k}$$

Thermal conductivity of the nanofluid (k_{nf})

Under the assumption that indiscriminately isolated and homogeneously sized spherical nano particles by Hamilton Crosser correlation , the effective thermal conductivity is calculated by

$$k_{eff} = \frac{k_p + 2k_{bf} + 2(k_p - k_{bf})\Phi}{k_p + 2k_{bf} - (k_p - k_{bf})\Phi} k_{bf}$$

$k_p = 80.3\mathrm{W/m - K}$, $k_{bf} = 0.6422\mathrm{W/m - K}$, $\phi = 0.008\%$

$k_{eff} = 0.64365\mathrm{W/m\text{-}K}$

Viscosity of nanofluid (μ_{nf})

the viscosity correlation i.e.

extended to Einstein's equation based on dispersions with particle volume
concentration usually less than 4% as

$$\mu_{nf} = \frac{\mu_{bf}}{(1-\Phi)^{2.5}}$$

$$\mu_{bf} = 0.00054127, \phi = 0.008\%$$

$$\mu_{nf} = 0.00054237 \text{ N-s}/m^2$$

IV RESULTS AND DISCUSSIONS

Based on the literature reported, Gnielinski correlation is considered to determine the theoretical convective heat transfer coefficient for the Reynolds number range 16,000 to 30,000.

$$Nu = \frac{h_i d_i}{k} = \frac{\left(\frac{f}{8}\right) * (Re - 1000) * Pr}{1.07 + 12.7\left(\frac{f}{8}\right)^{0.5} (Pr^{0.67} - 1)}$$

$$f = (0.79 ln(Re) - 1.64)^{-2}; Re > 3000$$

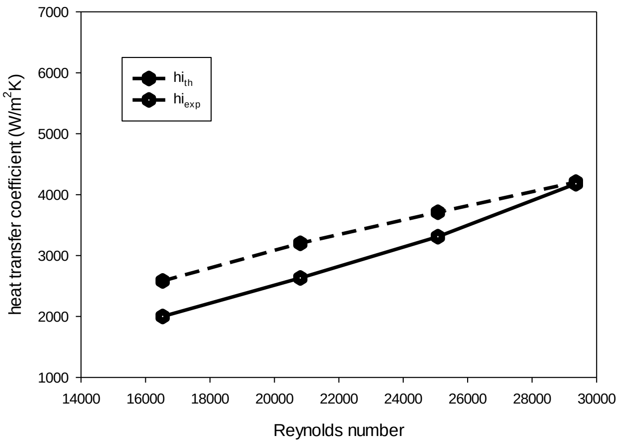

Fig 4: Convective heat transfer coefficient VS Re for plane tube

Fig. 4 shows the variation of convective heat transfer coefficient with Reynolds number for a hair-pin heat exchanger. As the mass flow rate of hot water increases the degree of turbulence increases which increases Nusselt number and convective heat transfer coefficient.

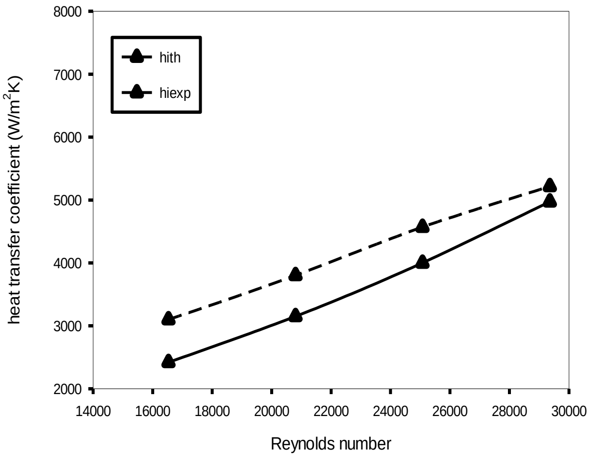

Fig 5: Convective coefficient of heat transfer VS Re for concentration φ=0.004%

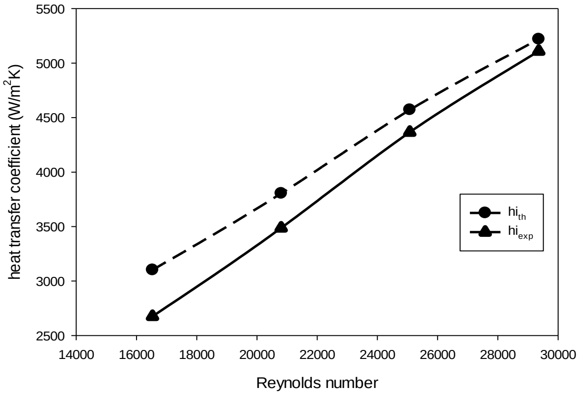

Fig 6: Convective heat transfer coefficient versus Reynolds number for concentration φ=0.006%

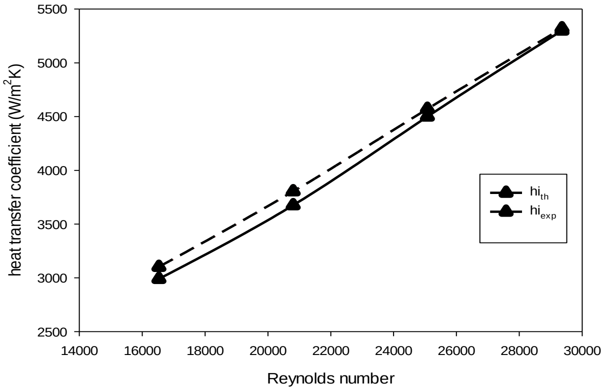

Fig 7: Convective heat transfer coefficient VS Re for concentration φ=0.008%

From the Fig. 5, Fig. 6 and Fig. 7, it has been observed that the convective heat transfer coefficient increases with increasing Reynolds number and volume concentration of Magnetite nanoparticles in both experimentally and analytically. Possible mechanisms for this enhancement are might be due to nanoparticles diffusion and increased turbulence. The variation between experimental and theoretical values is decreasing from 0.004% to 0.008% volume fraction. This might be due to the high mobility of nanoparticles at low volume concentrations.

V. CONCLUSION

Thus the following conclusion drawn from the above experimental investigation on heat transfer enhancements in hairpin heat exchanger using magnetite/water nanofluid: From the experimental data there is 25-33% enhancement in heat transfer coefficient at 0.008% volume concentration of magnetite nanofluid compare to the water at Reynolds number range of 16000 to 30000. It is observed that pressure drop is increased up to 20% at 0.008% volume concentration of magnetite nanofluid compare to the water at Reynolds number range of 16000 to 30000.

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