VOL. 11, NO. 16, AUGUST 2016 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

EXPERIMENTAL HEAT TRANSFER ANALYSIS OF MAGNETIC MICRO FLUID IN THE PRESENCE OF MAGNETIC FIELD

Nagarjunavarma Ganna[1] and Govind Nandipati[2]
[1]Department of Mechanical Engineering, Anurag Engineering College, Kodad, India
[2]Department of Mechanical Engineering, RVR & JC College of Engineering, Guntur, India
Email: ganna609@gmail.com

ABSTRACT

An experimental forced convective heat transfer analysis is done on magnetic micro fluid flowing through a copper tube in the presence of magnetic field for different mass fractions of magnetic particles, different Reynolds numbers and different Hartmann numbers. The flow is passing through the tube under a laminar condition. The experimentation has done under uniform heat flux and constant wall temperature cases. An increase in flow rate (Reynolds number) or Magnetic Field (Hartmann Number) or mass fractions of magnetic particles resulted in increase in the rate of convective heat transfer (Nusselt Number) for both the cases.

Keywords: convective heat transfer, magnetic micro fluid, magnetic field.

INTRODUCTION

Always there is a demand for efficient cooling system (heat exchangers) for many industries. An efficient cooling system means which has less surface area per unit heat transfer rate i.e. having high overall heat transfer coefficient (U). This overall heat transfer coefficient mainly depends on convective heat transfer between the fluid and the pipe [1].

The convective heat transfer coefficient depends on geometry of the system flow velocity and the type of the fluid [2]. With fixed flow velocity and type of the fluid, designing compact heat exchanger is a challenging task and can be achieved by using nanofluids instead of conventional fluids as working fluids. A nanofluid is a fluid containing nanometer sized particles, called nanoparticles. These fluids are engineered colloidal suspensions of nanoparticles in a base fluid. Nanofluidswere traced back to 1998 [3].

Elena V. Timofeeva analyzed the cooling efficiency criteria for single-phase fluids the properties of nanofluids that are important for heat transfer were identified and concluded that nanoparticle concentration, base fluid, and particle size appear to be the most influential parameters for improving the heat transfer efficiency of nanofluid. From the experimental studies it is found that it is possible to tune the thermal conductivity of polymeric nanofluids and their solid counterparts by dispersing them with appropriate nanoparticle in desired concentrations [4]. Gupta H.K had concluded that nanofluids are important because they can be considered as a potential candidate for numerous applications involving heat transfer and their use will continue to grow [5]. YiminXuan has developed a preparation method of nanofluid. With this method, several sampled nanofluid have been prepared by directly mixing nanophase powders and base fuids, which reveals the possibility of practical application of the nanofluid. The nanofluid shows great potential in enhancing the heat transfer process. One reason is that the suspended ultra-fine particles remarkably increase the thermal conductivity of the nanofluid. The volume fraction, shape, dimensions and properties of the nanoparticle affect the thermal conductivity of nanofluids. Results illustrate that the thermal conductivity of nanofluid remarkably increases with the volume fraction of ultra-fine particles [6]. Sidi El Be has considered two particular nanofluids, namely Ethylene Glycol–Al_2O_3 and water–Al_2O_3. Results have clearly revealed that the addition of nanoparticle has produced a remarkable increase of the heat transfer with respect to that of the base liquids. Ethylene Glycol mixture yields, so far, a better heat transfer enhancement than water [7]. Wen and Ding conducted an experiment on forced convection heat transfer with γ-Al_2O_3/water nanofluid and achieved maximum improvement in heat transfer, and also, some other researchers conducted similar investigations with different nanofluid under laminar flow conditions and observed heat transfer enhancement [8]. Selvakumar and Suresh studied the convective performance of CuO/water nanofluid in an electronic heat sink and observed a 29% heat transfer enhancement against 15% pumping power increase compared to DI-water [9]. Nakatsuka *et al.* Investigated heat transfer characteristics of a heat pipe containing water-based magnetic fluid and reported 13% increase of heat transfer efficiency caused by non-uniform magnetic field [3]. Jafarietal. Ghofrani *et al.* investigated the effect of constant and alternating magnetic fields on the forced convection heat transfer in a short tube. They showed that increasing the alternating magnetic field frequency increases the heat transfer up to of 27.6 % in low Reynolds numbers [10].

Innocent Nkurikiyimfura had observed that magnetic nano fluids under the influence of magnetic field can transfer the heat through convection more efficiently when compared with the transfer of heat without magnetic field [11]. Li and Xuan conducted experiments about forced convection of magnetic nanofluids under turbulent flow conditions with different volume concentrations and concluded that magnetic particles caused 31% enhancement in heat transfer [12]. Sundar *et al.* studied turbulent forced convection heat transfer and friction factor of Fe_3O_4 magnetic nanofluid in a tube in the absence of magnetic field and developed correlations for the

ARPN Journal of Engineering and Applied Sciences

estimation of Nusselt number and friction factor. Their results show that the heat transfer coefficient is enhanced by 30.96 % and friction factor by 10.01 % at 0.6 % volume fraction compared to the base fluid [13].

It is also understood that to prepare nanofluids by suspending nanoparticle into base fluids, some special requirements are necessary such as even suspension, durable and stable suspension, low agglomeration of particles and no chemical change of fluid. There are three general methods used for preparation of stable nanofluid: (1) Addition of acid or base to Change the pH value of suspension (2) Adding surface active agents and/or dispersants to disperse particles into fluid (3) Using ultrasonic vibration. Nanofluids are prepared by either one step or two step methods. Both methods require advanced and sophisticated equipments. This leads to higher production cost of nanofluids. Therefore high cost of nanofluids is drawback of nanofluid applications[5]So, in the present work we used the magnetic micro fluid, which is simple to prepare and much cheaper compared to nano fluids. In the present work we have used vegetable oil as carrier fluid, oleic acid as surfactant andtoner powder as solid suspension. Preparation of magnetic micro fluid by these constants is very cheaper when compared to preparation of other Magnetic Nano fluids.

However, the micro fluid heat transfer has not been satisfactorily studied so far. An experimental research may be helpful to studying this phenomenon. An admirable experimental study was conducted in last few years [2006-2012] regarding thermal conductivity measurement of ferrofluids. [14-17]results show under the absence of magnetic field and[18, 19]results shows under the presence of magnetic field. Results of the [14-17] indicate thermal conductivity increases with particle volume fraction and temperature. However, in the presence of magnetic field, thermal conductivity has been enhanced. Among them, Philip *et al.* [18] and Gavali *et al.* [19] who observed 300 % and 200 % thermal conductivity enhancement for Fe_3O_4 ferrofluid respectively.

In the present work convective heat transfer characteristic of the above combination has been studied experimentally when the fluid is flowing through the circular pipe under the magnetic field.

EXPERIMENTAL SETUP

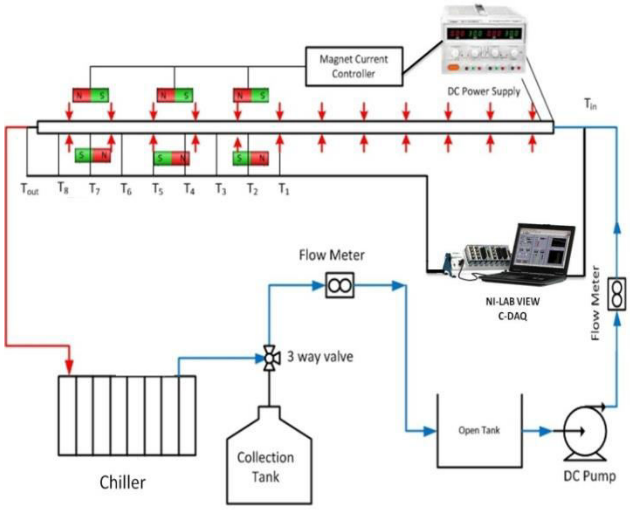

Figure-1. Experimental setup.

This experimental setup as shown in Figure-1 consists of tape heater, copper tube, thermocouples, flow meter, pressure transducer, ½ HP centrifugal pump with VFD, magnetic setup, dimmer start, volt meter, ammeter, micro fluid, gauss meter, NI-Compact DAQ, AC/DC convertor, optical pyrometer and chiller. A straight copper tube with 1500mm length, 12mm inner diameter, and 13 mm outer diameter was used as a test section. Eight thermocouples are connected at different places of the heat transfer test section to measure the wall temperature. ½ HP centrifugal pump is used to circulate ferrofluid the chiller with 1.6 KW cooling capacity is used to keep a constant temperature of the ferrofluid at an inlet of the test section. To apply a constant-heat flux, the test section was heated electrically with tape heater wounded around copper tube by a maximum 150volt and 3Amps power supplier. In order to minimize the heat loss from the test section, the whole test section was thermally isolated with asbestos rope. Also, data acquisition system registers thermocouples, pressure transducer and flow meter readings.

A magnetic field with the magnitude of up to 1500 Gausshas been developed and controlled by an AC/DC controller and an iron rod wounded by copper wire with 450 turns along a test section.

CALCULATIONS

Calculations of properties

In this work, vegetable oil is taken as the base liquid in which toner powder was added to. The properties of the base liquid and toner powder is shown in Table-1 [20].

ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

Table-1. Thermo physical properties.

Properties	Base liquid (Vegetable oil)	Toner powder	Oleic acid
C_p(J/kg k)	2.076×10^3	200×10^3	2.235×10^3
ρ (kg/m^3)	908	4620	889.2
K(W/mk)	0.168	80	0.224
μ (kg/ms)	0.04914	0.005	0.03038

Thermo physical properties of the magnetic micro fluid can be calculated using following equations [21].

Density of nanofluid

$$\rho_m = (1-\o)\rho_f + \o\,\rho_p$$

Dynamic viscosity of nanofluid

$\mu_m = \mu_f(1-\o)^{-2.5}$[when nanoparticle volume concentration is <5%]

$\mu_m = \mu_f(1 + 7.3\emptyset + 123\emptyset^2)$[When nanoparticle volume concentration is greater or equal to 5%]

Coefficient of thermal expansion of nanofluid

$$\beta_m = (1-\o)\beta_f + \o\beta_p$$

Specific heat coefficient of nanofluid:

$$cp_m = \frac{1}{\rho_m}\left[(1-\emptyset)\rho_f cp_f + \emptyset\rho_p cp_p\right]$$

Heat conductivity of nanofluid

$$k_m = k_f\left[\frac{2 + k_{pf} + 2\emptyset(k_{pf}-1)}{2 + k_{pf} - \emptyset(k_{pf}-1)}\right]$$

Where$k_{pf} = \frac{k_p}{k_f}$

ø = volume concentration of Nano fluid, m - Index is related to Nano fluid properties, f - Index is related to carrier fluid properties, p - Index is related to Nano particle properties.

Formulas for calculating convective heat transfer coefficient(h) are given below [23].

Local convective heat transfer coefficient,

$$h(x) = \frac{q''}{(T_w(x) - T_{ff}(x))}$$

Average convective heat transfer coefficient,

$$h = \frac{1}{L}\int_0^L h(x).\,dx$$

q"is the constant-heat flux,

$$q'' = \frac{Q}{A_h} = \frac{IV}{\pi DL}$$

Where I is the measured current, V the supplied voltage, D the tube diameter and L the heating length. Tw(x) is the local outer wall temperatures, which were measured by thermocouples placed on the tube wall and T_{ff} is determined by an energy balance

$$T_{ff}(x) = T_{ff1} + \frac{Q}{\rho_{ff}\,c_{ff}V}\frac{x}{L}$$

Where$T_{ff}(x)$, ρ_{ff}, $c_{ff}$and V are thetemperature of ferrofluid at a distance of “x” from starting of test section, ferrofluid density, the ferrofluid heat capacity, and the ferrofluid volumetric flowrate, respectively. The x variable represents axial distance from the entrance of the test section. Note that all ferro fluid thermal properties in above equation are calculated at the average temperature of the fluid [23]

RESULTS AND DISCUSSIONS

Experimental setup validation

For constant heat flux case

Before conducting systematic experiments with Ferrofluid in the presence of magnetic field, the reliability and accuracy of the experimental equipment were validated using distilled water as the working fluid. The results are shown in Figure-2, together with prediction of the following well-known Shah equation[24] for laminar flow under the constant-heat flux boundary condition. Reasonably good agreement has been observed between the Shah equation and experimental results.

$$Nu_X = \begin{cases} 1.953\left(RePr\frac{D}{X}\right)^{\frac{1}{3}};\left(RePr\frac{D}{X}\right) \geq 33.3 \\ 4.364 + 0.0722\,RePr\frac{D}{X};\ \left(RePr\frac{D}{X}\right) < 33.3 \end{cases}$$

VOL. 11, NO. 16, AUGUST 2016 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

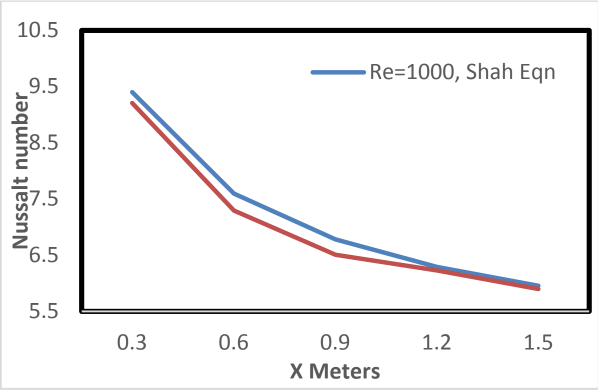

Figure-2. Prediction for laminar flow under the constant-heat flux boundary condition.

For constant-wall temperature case

The results are shown in Figure-3, together with prediction of the following well-known Hausen equation[25] for laminar flow under the constant-wall temperature case are in well agreement with experimental results.

$$Nu_X = 3.657 + \frac{0.19\left(RePr\frac{D}{X}\right)^{0.8}}{1 + 0.117\left(RePr\frac{D}{X}\right)^{0.467}}$$

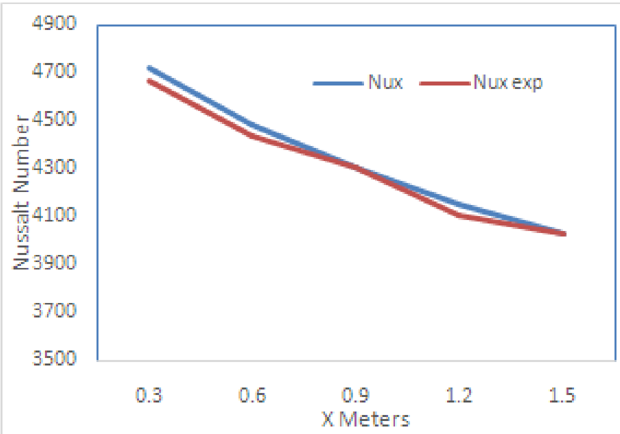

Figure-3. Prediction for laminar flow under the constant-wall temperature case.

RESULTS

Variation of average heat transfer coefficient with magnetic field for different mass Fraction at the flow rate of 7.5cc/sec:

Figure-4 shows that, increase in the mass fraction of toner powder result in increase in convective heat transfer coefficient (h) because this may increase mixture thermal conductivity.

It is also observed from the figure that increase in the magnetic field result in increase in convective heat transfer coefficient because as we keep on increasing magnetic field the solid suspensions in fluid come closer to the walls of pipe thereby they can carry more heat comparative to the earlier.

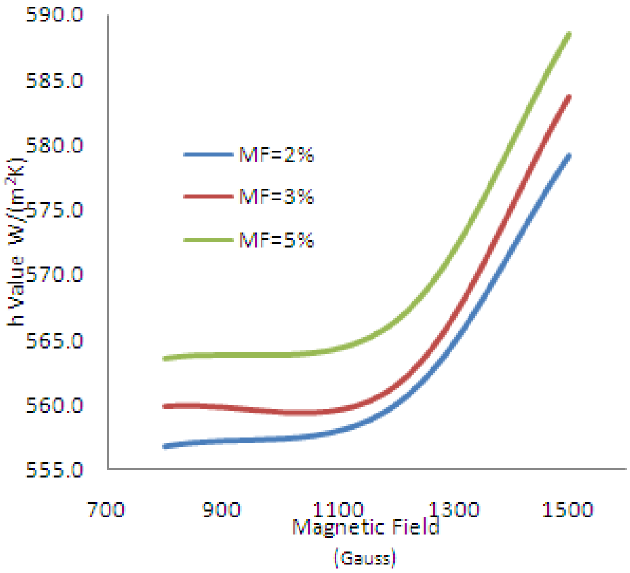

Figure-4. Increase in the mass fraction of toner powder result in increase in convective heat transfer coefficient (h).

Variation of average heat transfer coefficient with flow rate for different magnetic field at the mass fraction of 3%:

Figure-5 shows that, increase in the flow rate of fluid result in increase in convective heat transfer coefficient because this increases the Reynolds number, there by Nussult number and convective heat transfer coefficient.

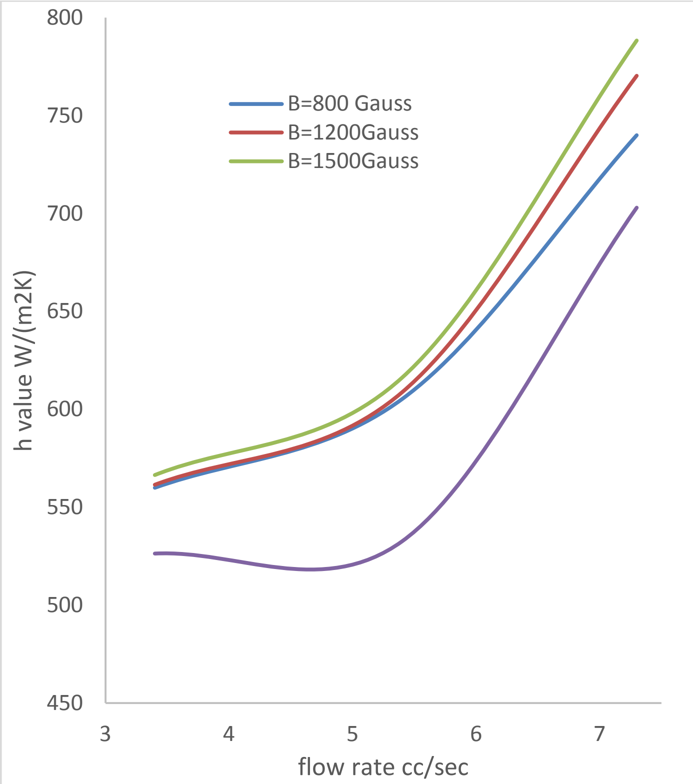

Figure-5. Increase in the flow rate of fluid result.

CONCLUSIONS

The convective heat transfer performance of oil based Ferro fluid in a heated copper tube was experimentally investigated for laminar flow under the influence of external magnetic field. The following conclusions were obtained:

- The enhancement of heat transfer coefficient h is particularly significant under the influence of an applied magnetic field and magnetic nano particle volume fraction. By changing flow rate, a considerable increase in heat transfer coefficient could be observed.
- Without continuous starring, micro particles in collecting tank will settle down, for continuous starring purpose a stirrer can be used.

REFERENCES

[1] E. A. D. Saunders, "Heat exchangers: selection, design and construction," Harlow, Essex, England: Longman Scientific and Technical; New York, NY: J. Wiley, 1989.

[2] F. P. I. Theodore L. Bergman, "Introduction to Heat Transfer," John Wiley & Sons, 2011.

[3] B. J. K. Nakatsuka, S.Neveu, H. Koganezawa, "Themagnetic fluid for heat transferapplications," J. Magn. Magn. Mater, 2002.

[4] W. Y. Elena V. Timofeeva, David M. France, Dileep Singh, Jules L. Routbort, "Nanofluids for Heat Transfer: An Engineering Approach," Nanoscale Research Letters, 2011.

[5] A. G. D. Gupta H.K, Mathur J, "An overview of Nanofluids: A new media towards green environment," International journal of environmental sciences vol. 3, 2012.

[6] Q. L. Yimin Xuan "Heat transfer enhancement of nanofuids," International Journal of Heat and Fluid Flow, pp. 58-64, 2000.

[7] S. E. B. C. Maı¨ga, "Heat transfer enhancement by using nanofluids in forced convection flows," International Journal of Heat and Fluid Flow 2005.

[8] D. A. Y. D. Wen, "Experimental investigation into convective heat transfer of nano fluids at the entrance region under laminar flow conditions," International Journal of Heat and Mass Transfer, 2004.

[9] S. S. Selvakumar P, "Convective performance of CuO/ water nanofluid in an electronic heat sinks," Exp Thermo Fluid Sci 2012.

[10] D. M. Ghofrani A, Hakim Sima A, Shafii MB "Experimental investigation on laminar forced

convection heat transfer of ferrofluids," Experimental Thermal and Fluid Science., vol. 49, 2013.

[11] I.Nkurikiyimfura,"Heat transfer enhancement by magnetic nanofluids - A review," Renewable and Sustainable Energy Reviews, pp. 548–561, 2013.

[12] Q. A. Y. X. Li, "Experimental investigation on heat transfer characteristics of magnetic fluid flow around a fine wire under the influence of an external magnetic field," Experimental Thermal and Fluid Science., 2009.

[13] N. M. Sundar LS, Sharma KV, Singh MK, Reddy "Experimental investigation of forced convection heat transfer and friction factor in a tube with Fe3O4 magnetic nanofluid," Exp Therm Fluid Sci 2012.

[14] K. L. Tsai TH, Chen PH, Yang CT "Thermal conductivity of nanofluid with magnetic nanoparticles," Piers Online, 2009.

[15] G. E. Abareshi M, Zebarjad SM, Fadafan HK, Youssefi A "Fabrication, characterization and measurement of thermal conductivity of Fe3O4 nano fluids," Journal of Magnetism and Magnetic Materials, vol. 322, pp. 3895-3901, 2010.

[16] L. J. Lugo L, Piñeiro MM "Enhancement of thermal conductivity and volumetric behavior of Foxy nano fluids," Journal of Applied Physics, 2011.

[17] S. P. Philip J, Raj B "Enhancement of thermal conductivity in magnetite based nanofluid due to chainlike structures," Applied Physics Letters, 2007.

[18] T. D. Wright B, Hong H, Groven L, Puszynski J, Duke E, Ye X, Jin S, "Magnetic field enhanced thermal conductivity in heat transfer nano fluids, containing Ni coated single wall carbon nano tubes.," Applied Physics Letters, vol. 91, 2007.

[19] Z. F. Gavili A, Isfahani TD, Sabbaghzadeh J "The thermal conductivity of water base ferrofluids under magnet," Experimental Thermal and Fluid Science., vol. 41, 2012.

[20] E. A. D. Saunders, "Heat exchangers: selection, design and construction," Harlow, Essex, England: Longman Scientific and Technical, 1989.

[21] M. B. S. Mohammad Hosseindibaeebonab, Mohammad Hasan and Nobakhti, "Numerical Simulation of Internal Convection Heat Transfer Of Ferrofluidsunder Alternating Magnetic Field," Indian Journal of Scientific Research, pp. 733-743, 2014.

[22] C. L. B. Jean-Frédéric Gerbeau, and Tony Lelièvre, "Mathematical Methods for the Magnetohydrodynamics of Liquid Metals," Oxford, 2006.

[23] R. E. Rosensweig, "Ferrohydrodynamics," Dover Publications, 1997.

[24] R. K. Shah, "Thermal entry length solutions for the circular tube and parallel plates," Heat Mass Transfer Conference, Indian Inst. Technol 1975.

[25] Hausen, "Gleichungen für die Wرmeübertragung bei freier und erzwungener Strmung," Wرmetechnik 1959.