Experimental investigation of heat transfer coefficient of CuO/Water nanofluid in double pipe heat exchanger with or without electric field

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Abstract—**This article reports an experimental study of heat transfer coefficient of CuO/Water nanofluid flowing in a horizontal double pipe counter flow heat exchanger in the presence and absence of electric field. The CuO nanoparticles of about 27nm diameter were used in this study. The heat exchange takes place between a CuO/water nanofluid circulating inner tube and a hot air stream flowing through the outer tube. The electric field was supplied on the air side of the heat exchanger and its voltage was varied from 0kV to 6kV. The experimental results indicated that the convective heat transfer coefficient of the nanofluid increased up to the volume fraction of 0.15% and also the heat transfer rate was enhanced while applying the high voltage supply to the electrode. The convective heat transfer coefficient of the nanofluid was increased with increasing the electric field intensity and nanofluid volume concentration.**

Keyword-Heat transfer, Electric field, Double pipe heat exchanger, Nanofluid.

I. INTRODUCTION

Heat exchanger is a device which is used to transfer the heat from one fluid to another fluid. It is widely used in several industries such as power plants, air conditioning equipments, Automobile, chemical processing plants etc. [1,2]. The conventional heat transfer fluids such as water, Ethylene Glycol, Propylene Glycol, mineral oil etc are widely used as a heat transfer medium in all the heat exchangers. Because of poor heat transfer characteristics of conventional heat transfer fluids, the researchers showed their interest to develop a new kind of heat transfer fluids to enhance the efficiency of the heat exchanger. These special kinds of heat transfer fluids are named as “Nano fluids”. Nano fluids are relatively new class of fluid containing suspension of nanometer sized particles in the base fluids. In the year of 1993 the scientist S.U.S. Choi had developed a special kind of fluid by dispersing particle with a diameter of 1~100nm in the base fluids for his “Advanced fluid program” project at Argonne National Laboratory (ANL). The term Nanofluid was coined by S.U.S Choi in 1995 [3]. The Nanofluids possess the following advantages over the conventional heat transfer fluid which contains millimeter or micrometer sized particles. (1) High dispersion stability. (2) Surface to volume ratio is high therefore more heat transfer surface between particles and fluid. (3) Particle clogging is reduced as compared to conventional heat transfer fluids. (4)Less pumping power is required as compared to conventional heat transfer fluids. (5)The properties can adjust easily by varying particle concentrations to suit different applications.

Over the past 10 years, many researchers have studied the thermal characteristics of various nanofluids. From their research results, nanofluids have been found to possess enhanced thermal conductivity compared to the base fluids. Choi et al [4], [5] have suspended various metal and metal oxide nanoparticles in different base fluids. They found that the thermal conductivity of metal or metal oxide nanoparticle dispersed fluid increased remarkably compared to the base fluids. Zhang et al [6] have studied the thermal conductivity enhancement of Poly (α-Olefin) oil with Multi-wall carbon nanotube (MWCNT) at 1 vol. %. They found that the thermal conductivity of the nanofluid is increased upto 150% compared to base fluids. Over the past few decades, Pak and Cho [7] have investigated the heat transfer performance of Al_2O_3 and TiO_2 nanoparticles dispersed in water flowing in a horizontal circular tube. Their experimental results showed that the convective heat transfer coefficient of the nanofluids with 3 vol. % nanoparticles was 12% lower than that of pure water at a given Reynolds number.many researchers [8] – [17] were investigated the thermophysical properties of different nanofluids with different volume fractions. Their investigation results clearly showed that the nanofluids possess higher thermophysical properties over the base fluids. Li and Xuan [18], [19] have studied the heat transfer and flow characteristics of Cu/Water nanofluid flowing through a tube under laminar and turbulent flow conditions.

The experimental results showed that the heat transfer characteristics of Copper nanoparticle suspended fluid remarkably increased over the conventional base fluids. Heris et al. [20], [21] have investigated the convective heat transfer coefficient of Al_2O_3–water and CuO–water nanofluids for laminar flow in an annular tube under a constant wall temperature boundary condition. From this research the authors found that the Al_2O_3/water nanofluids showed greater enhancement compared with CuO/water nanofluids. Many research works reported that the performance of double pipe heat exchanger in the presence of external electric field. Wangnipparnto et al. [22], [23] have investigated the heat transfer rate of the thermosyphon heat exchanger with external electrical field. The authors were noticed that heat transfer rate is increased with the use of electric field. Cooper [24] investigated the nucleate boiling heat transfer of R114 in a lo-fin tube with copper wire mesh cylinder electrode. The research results demonstrated that, as with all EHD phenomena observed in this study, A.C. electric fields and D.C. fields of either polarity were equally effective. Cheung et al. [25] have conducted an experimental study on EHD enhancement of boiling heat transfer of R-134a in a tube bundle utilizing three electrode configurations. In configuration A, all electrodes were energized with a positive field polarity. In configuration B, the upper portion electrodes of the bundle were charged negatively and the lower portion electrodes were charged positively. Configuration C simply represented the reverse case of configuration B. Kui [26] have analyzed the performance of air to air heat pipe under the electric field and developed the heat transfer model for the equipment. Allen and Karayiannis [27] have presented the effect of electric field on single phase and two phase heat transfer. They showed that the heat transfer rate increased significantly due to the electric field. Vithayasai et al [28] have studied the effect of electric field on heat transfer performance of automobile radiator at low frontal air velocity. From the experiment, the authors were found that the unit with electric field pronounced better heat transfer rate, especially at low frontal velocity of air. The correlations for predicting the air-side heat transfer coefficient of the automobile radiator, with and without electric field, at low frontal air velocity were also developed and the predicted results agreed very well with the experimental data.The effect of the electrode polarity on EHD enhancement of boiling heat transfer for R-123 in a vertical tube was investigated by Yongqi Liu et al [29]. The cylindrical brass electrode was applied either positive or negative high voltage, with the stainless steel tube grounded. It was demonstrated that the positive high voltage gave much greater enhancements and require lower average electric field strength to obtain a maximum enhancement factor than the negative high voltage.

II. EXPERIMENTAL APPARATUS

The schematic diagram of the experimental setup used in this research as illustrated in Fig.1. The experimental setup consists of test section, nanofluid reservoir, pump, Heat exchanger, fan, brass electrode. The test section is a 1000mm long horizontal double pipe heat exchanger with nanofluid flowing inside the tube while the hot air flows in the annular. The inner tube is made from copper material with an outer diameter of 9.53mm and an inner diameter of 8.13mm while the outer tube is made from PP (poly propylene) material with an outer diameter of 33.9mm and an inner diameter of 27.8mm. The outer tube is wound with insulation material for minimizing the heat loss to atmosphere. The Iron constantan (K-type) thermocouple was mounted at both ends of the test sections to measure the temperature of the nanofluid. To measure the inner tube wall temperature four K-type thermocouples were placed at equal intervals of 200mm in the axial direction of the test section.

Hot air from a 7.5kW blower flowed through the outer tube of the test section. The volumetric flow rate of the hot air measured and adjusted by the rotameter and globe valve situated before the inlet port. The electrical heater was used to heat the inlet air and the energy input to the heater was adjusted by variable output voltage transformer. Both inlet and outlet temperature of the hot air were measured by K-type thermocouple. Four straight brass cylindrical rod electrodes of 10mm in diameter were mounted in between the inner tube and the outer tube. The gap between the electrode and the outer surface of the inner tube was 4.5mm. The positive terminal of the high voltage generator was connected to the electrodes and the copper tube was grounded. The data acquisition system with personal computer was used to record the real time temperatures.

III. PREPARATION OF NANOFLUIDS

We adopted two step method to prepare the nanofluids. CuO nanoparticle of 27nm average diameter was purchased from Sigma Aldrich chemicals Ltd, USA [30]. The physical properties of the CuO nanoparticles are listed in Table 1. Because of its small size the nanoparticle has a high surface to volume ratio. The distilled water was used as a base fluid for this study. The nanofluids of different volume concentrations were prepared by dispersing different volume of CuO nanoparticles in distilled water. To obtain uniform dispersion solution, the prepared CuO/water was ultrasonicated for about 3-4h. Following this the sonicatednanofluid was stirred continuously for 1h. The photographic representation of the CuO/water nanofluid is shown in Fig.2 .Fig.3 depicts the dispersion of CuO nanoparticles in water before and after sonication. As can be seen, the particles are homogenously dispersed throughout the base fluid in an acceptable fashion.

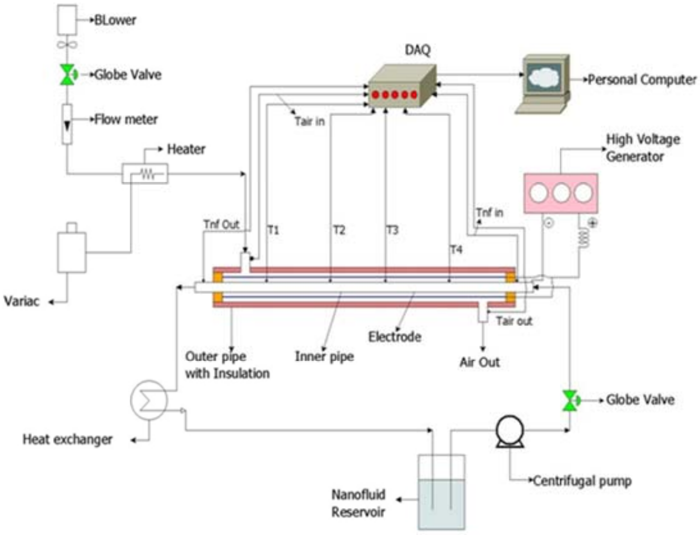

Fig.1.Schematic diagram of experimental setup

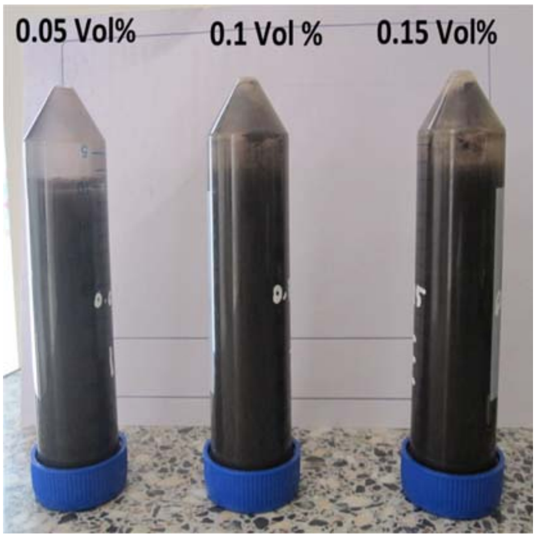

Fig.2. Photo of CuO/water nanofluid at different volume concentration.

TABLE 1 Physical property of CuO nanoparticle and water.

S.No	Nanoparticle /fluid	Mean Diameter (nm)	Specific surface (m^2/g)	Density (Kg/m^3)	Thermal conductivity (W/mK)	Specific Heat (J/kg K)
1.	CuO	27	29	6310	32.9	550.5
2.	Water	-	-	997.5	0.628	4178

The amount of CuO nanoparticles required to prepare the nanofluid was calculated from the equation given below.

$$\%\ \text{Volumeconcentration}(\emptyset v) = \frac{\text{VolumeofCuO}}{\text{VolumeofCuO} + \text{Volumeofwater}} X100 \qquad (1)$$

$$\%\ \text{Volumeconcentration}(\emptyset v) = \frac{\frac{W_{Cuo}}{\rho_{Cuo}}}{\frac{W_{Cuo}}{\rho_{Cuo}} + \frac{W_{water}}{\rho_{water}}} X100 \qquad (2)$$

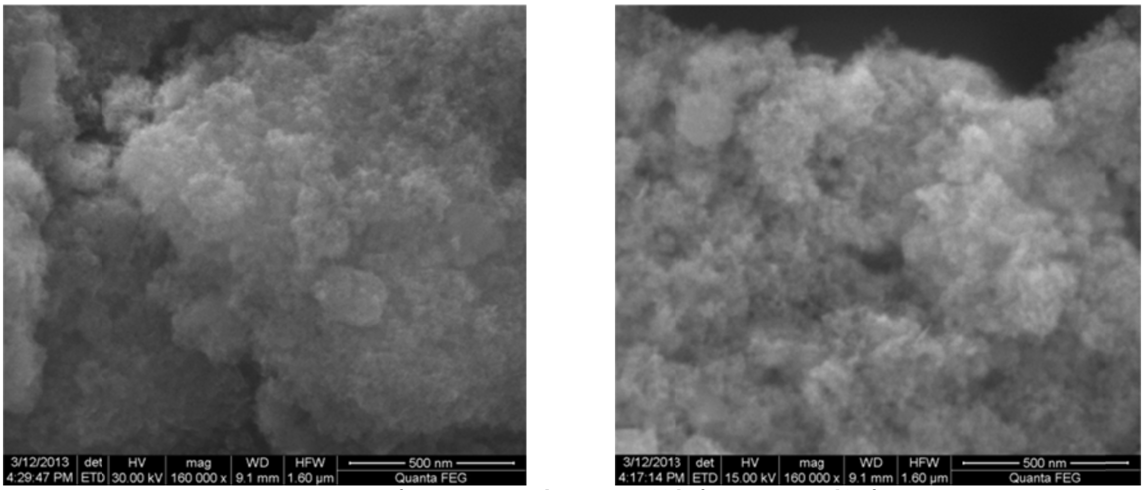

Fig.3 SEM images of CuO nanoparticles in water (a) before sonication (b) after sonication.

IV. DATA REDUCTION

The heat is transferred from the hot air in outer tube can be expressed as

$$Q_{air} = \dot{m}_{air}(Cp)_{air}(T_{in} - T_{out})_{air} \quad (3)$$

Where Q_{air} is the heat transfer rate of the hot air, $\dot{m}_{air}$ is the mass flow rate of hot air.
Q_{nf} is the heat transferred to the nanofluid in the inner tube is calculated as

$$Q_{nf} = \dot{m}_{nf}(Cp)_{nf}(T_{in} - T_{out})_{nf} \quad (4)$$

Where $\dot{m}_{nf}$ is the flow rate of nanofluid.The average heat transfer rate (Q_{avg}) can be calculated as

$$Q_{avg} = \frac{Q_{air} + Q_{nf}}{2} \quad (5)$$

The equation of Newton's law of cooling Eq. (6) is used to calculate the convective heat transfer coefficient

$$h_{exp} = \frac{Q_{avg}}{A(T_W - T_m)} \quad (6)$$

Where

$$A = \pi DL \qquad T_w = \frac{T_1+T_2+T_3+T_4}{4} \qquad T_m = \frac{(T_{in} + T_{out})_{nf}}{2}$$

The average Nusselt number can be expressed as follows

$$Nu_{exp} = \frac{h_{exp}\ D}{k_{nf}} \quad (7)$$

The thermophysical properties of nanofluid such as density, specific heat and thermal conductivity were calculated using the equations available in the literatures.

From Xuan and Roetzel's equation [31], the specific heat of the nanofluid is given as

$$(Cp)_{nf} = \frac{\varphi\rho_s\ (Cp)_s + (1-\varphi)\rho_f\ (Cp)_f}{\rho_{nf}} \quad (8)$$

The density of nanofluid (ρ_{nf}) is calculated from Pak and Cho [7] using the general formula given below.

$$\rho_{nf} = (1-\varphi)\rho_f + \varphi\rho_s \quad (9)$$

Maxwell model [32] is used to calculate the thermal conductivity of the nanofluid is given below.

$$k_{nf} = \frac{k_f + k_s - 2\varphi\ (k_s - k_p)}{k_f + k_s + \varphi\ (k_s - k_p)} k_f \quad (10)$$

V. RESULT AND DISCUSSION

The experimental Nusselt number was verified with the Naphon et al. [33] study. They have studied the heat transfer coefficient characteristics in a double pipe heat exchanger for a plain and helical corrugated tube. They achieved the correlation for Nusslelt number as a function of Reynolds number. The following equation was used to predict the Nusselt number by Naphon et al.

$$Nu = 1.84\ (Re - 1500)^{0.32} Pr^{0.07} \quad (11)$$

The comparison of Nusselt number between the experimental data and the equation available in the Naphon et al. study is presented in Fig.4. It can be observed that Nusselt number increases with increase of Reynolds number. The maximum difference between the experimental results and predicted values from Naphon et al. study is less than 5%.

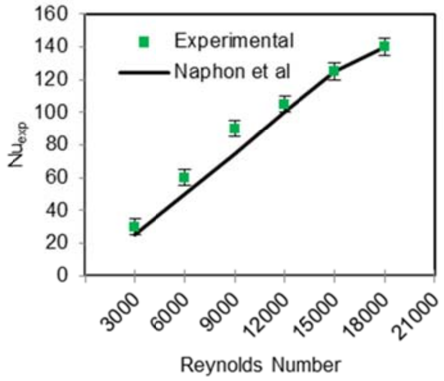

Fig.4.The experimental Nusselt number and the prediction of Naphon et al. correlation for water versus Reynolds number.

In this experimental work CuO/water nanofluid with different volume fractions of 0.05%, 0.1% and 0.15% were used to investigate the effect of Reynolds number and temperature changes in a test section. The experimental conditions that are used in this study are as follows.

1. The Reynolds of the fluid varies in the range of 3000 to 20,000.
2. The mass flow rates of the hot air are 3LPM.
3. The voltages applied to the electrodes are 0kV, 2kV, 4kV and 6kV.

The results are reported and discussed in the following sections.

VI. 1. CONVECTIVE HEAT TRANSFER COEFFICIENT (WITHOUT ELECTRIC FIELD)

Fig.5 shows the convective heat transfer coefficient of the double pipe heat exchanger without electric field. It can be clearly seen that the convective heat transfer coefficient of the nanofluid is higher than that of the conventional heat transfer fluids at a given Reynolds number and also found that the heat transfer coefficient increases with an increasing Reynolds number. The heat transfer rate was increased because of the following reasons: (1) increased heat transfer surface between the suspended particle and the fluid. (2) Uncontrolled movement of nanoparticle in the fluid. (3) The nanoparticle suspended fluid increases the thermal conductivity of the mixture.

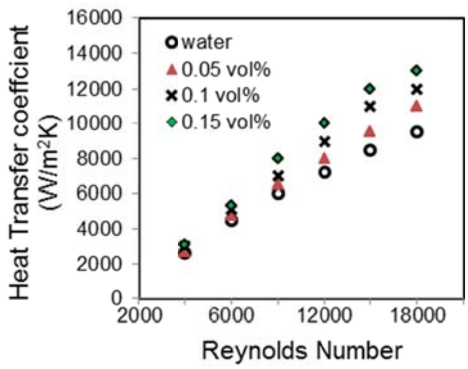

Fig.5. Heat transfer coefficient of water and different volume concentration of CuO/water nanofluid without electric field (0kV)

VI. 2 EFFECT OF CONVECTIVE HEAT TRANSFER COEFFICIENT (WITH ELECTRODE VOLTAGE 2KV)

Fig.6. shows the convective heat transfer coefficient of water and different volume concentrations of CuO/water nanofluid in the presence electric field (Supplied voltage = 2kV). The experimental result clearly shows that the presence of electric field heat transfer increases by addition of CuO nanoparticles in base fluid (water). Increasing volume fraction of nanoparticle after 0.15% deteriorates the heat transfer due to intensified viscosity and deposition of nanoparticles in the pipe surfaces. It can be seen that the heat transfer coefficient of the nanofluid is enhanced by applying a high voltage supply to the electrode.

VI. 3 EFFECT OF CONVECTIVE HEAT TRANSFER COEFFICIENT (WITH ELECTRODE VOLTAGE 4KV)

The variation of convective heat transfer coefficient of water and various concentrations of CuO/water nanofluid in the presence of electric field (supplied voltage=4kV) is depicted in Fig.7. It can be seen that the presence of electric field convective heat transfer coefficient increases with increasing Reynolds number. The heat transfer coefficient was enhanced because of the corona wind generated around the electrode when high voltage is supplied to the electrode. Therefore small turbulence of air stream occurs in the outer tube. The heat transfer rate of CuO/water nanofluid increases with increasing the volume concentration of nanofluid and supplied voltage to the electrode.

VI. 4 Effect of Convective heat transfer coefficient (with electrode voltage 6kV)

Another observation, from Fig.8.is that the convective heat transfer coefficient of the double pipe heat exchanger with the supplied voltage of 6kV, is increased with increasing Reynolds number. Similar behavior was observed for different volume concentrations of CuO/water nanofluid and water as shown in Fig.6 and Fig.7. The heat transfer rate is increased due to the disturbances induced in the flow filed by the external electric field.

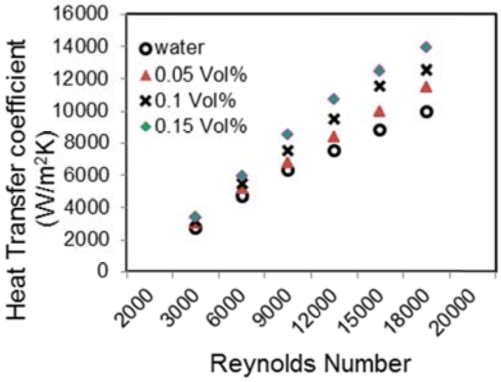

Fig.6. Heat transfer coefficient of water and different volume concentration of CuO/water nanofluid with electric field (2kV)

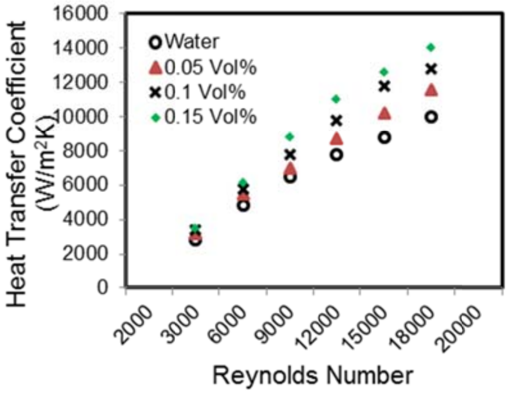

Fig.7. Heat transfer coefficient of water and different volume concentration of CuO/water nanofluid with electric field (4kV)

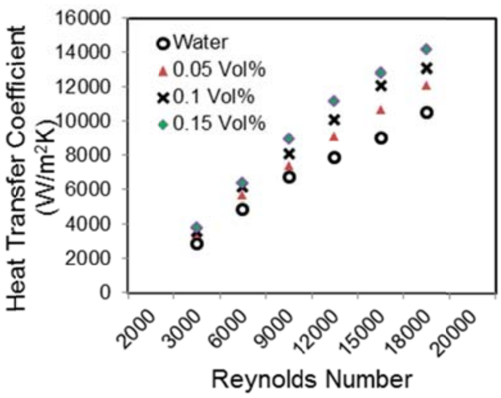

Fig.8. Heat transfer coefficient of water and different volume concentration of CuO/water nanofluid with electric field (6kV)

VII. Conclusion

In the present study the convective heat transfer coefficient of CuO/Water nanofluid in a double pipe counter flow heat exchanger with the presence and absence of electric field was investigated experimentally. The major conclusions of this study are as follows.

1. The use of CuO/water nanofluid gives higher heat transfer coefficient than the base fluid (water).
2. The convective heat transfer coefficient increases with an increasing Reynolds number.

3. The convective heat transfer efficient of the nanofluid was increased upto the volume fraction of 0.15%. After increasing the nanoparticle in the base fluid the heat transfer rate was decreased because of the deposition of the nanoparticles in the pipe surfaces.
4. Increasing the supplied voltage results in higher heat transfer rate in double pipe heat exchanger.

VIII. REFERENCES

[1]. RM Manglik and AE Bergles, “Heat transfer and pressure drop correlations for twisted-tape inserts in isothermal tubes, Part I. Laminar flows”, ASME Journal Heat Transfer, J.Heat Transfer 115(4), 881-889 (1993).
[2]. WJ Marner and AE Bergles, “Augmentation of highly viscous laminar heat transfer inside tubes in constant wall temperature”, Experimental Thermal Fluid Science, 2(3), 252-267 (1989).
[3]. SK Das, SUS Choi, Wenhua Yu, and T Pradeep, “Nanofluids: Science and Technology”, 1st edition. Hoboken, NJ: John Wiley & Sons, Inc.; 2007.
[4]. SUS Choi, “Nanofluid technology: current status and future research”, Korea-U.S. Technical Conf. on Strategic Technologies, Vienna, V.A. Oct.1998, pp. 22-24,
[5]. S Lee, SUS Choi, S Li, and JA Eastman, “Measuring thermal conductivity of fluid containing oxide nanoparticles”, ASME Journal of Heat Transfer, 121(2), 280–289 1999.
[6]. ZG Zhang, SUS Choi, W Yu, FE Lockwood, and EA Grulke, “Anomalous thermal conductivity enhancement in nanotube suspensions”, Appl. Phys. letter. 79(14), 2252-2254 (2001).
[7]. BC Pak, and YI Cho, "Hyrdrodynamic and Heat Transfer Study of Dispersed Fluids with Submicron Metallic Oxide Particles." Experimental Heat Transfer, 11(2), 151-170 (1998).
[8]. JA Eastman, SUS Choi, S Li, LJ Thompson, and S Lee “Enhanced thermal conductivity through the development of nanofluids." Proceedings of the Materials Research Society (MRS), Boston, USA, Volume 457 (1996).
[9]. X Wang, X Xu, and SUS Choi, "Thermal Conductivity of Nanoparticle - Fluid Mixture", J. Thermophys. Heat Transfer, 13(4), 474-480 (1999).
[10]. HE Patel, SK Das, T Sundararajan, Sreekumaran Nair, B George, and T Pradeep, "Thermal conductivities of naked and monolayer protected metal nanoparticles based nanofluids: manifestation of anomalous enhancement and chemical effects" Appl. Phys. letter. 83(14), 2931-2933 (2003).
[11]. H Xie, J Wang, T Xi, Y Liu, Fei Ai, and Q Wu, "Thermal conductivity enhancement of suspensions containing nano sized alumina particles", J. Appl. Phys., 91(7), 4568-4572 (2002).
[12]. R Prasher, P Bhattacharya, and PE Phelan, "Thermal Conductivity of Nano scale Colloidal Solutions (Nanofluids)", Phys. Rev. Lett., 94(2), 025901 (2005).
[13]. S Krishnamurthy, P Bhattacharya, PE Phelan, and RS Prasher, "Enhanced Mass Transport in Nanofluids" Nano Lett., 6(3), 419-423 (2006).
[14]. MS Liu, MCC Lin, IT Huang, and CC Wang, "Enhancement of thermal conductivity with CuO for nanofluids" Chemical engineering and technology”, 29(1), 72- 77 (2006).
[15]. SMS Murshed, KC Leong, and C Yang, "Enhanced thermal conductivity of TiO2-water based nanofluids" Int. J. of Thermal Sciences, 44(4), 367- 373 (2005).
[16]. CJ Ho, LC Wei, ZW Li, "An experimental investigation of forced convective cooling performance of a micro channel heat sink with Al2O3/water nanofluid ", Applied Thermal Engineering, 30 (2-3), 96–103 (2010).
[17]. RS Vajjha, DK Das, and PK Namburu, “Numerical study of fluid dynamic and heat transfer performance of Al2O3 and CuOnanofluids in the flat tubes of a radiator” Int. J. of Heat and Fluid Flow, 31(4), 613–621 (2010).
[18]. Li Qiang and XuanYimin, “Convective heat transfer and flow characteristics of Cu–water nanofluid”, Sci. China (Series E), 45 (4), 408-416 (2002).
[19]. Y Xuan and Q Li, “Investigation on convective heat transfer and flow features of nanofluids”, ASME J. Heat Transfer, 125(1), 151-155 (2003).
[20]. SZ Heris, SG Etemad and MN Esfahany, “Experimental investigation of oxide nanofluids laminar flow convective heat transfer”, Int. Commun. Heat Mass Transfer, 33(4), 529-535 (2006).
[21]. SZ Heris, MN Esfahany and SG Etemad, “Experimental investigation of convective heat transfer of Al2O3/water nanofluid in circular tube”, Int. J. Heat Fluids Flow, 28 (2), 203-210 (2007).
[22]. S Wangnipparnto, J Tiansuwan, S Jiracheewanun, T Kiatsiriroat and CC Wang, “Air side performance of thermosyphon heat exchanger in low Reynolds number region: with and without electric field”, Energy Convers. Manage. 43(14), 1791–1800 (2002).
[23]. S Wangnipparnto, J Tiansuwan, T Kiatsiriroat and CC Wang, “Performance analysis of thermosyphon heat exchanger under electric field”, Energy Convers. Manage. 44(7), 1163–1175 (2002).
[24]. P Cooper, “EHD enhancement of nucleate boiling”, ASME, J. Heat Transfer, 112 (2), 458–464 (1990).
[25]. KH Cheung, MM Ohaddi and S Dessiatoun, “Compound enhancement of boiling heat transfer of R-134a in a tube bundle”, ASHRAE Trans. 101 (1), 1009-1019, (1995).
[26]. L Kui, “The enhancing heat transfer of heat pipe by electric field”, in: Proceedings of the 7th International Heat Pipe Conference, Begell House, 563–567 (1993).
[27]. PHG Allen, and TG Karayiannis, “Electro hydrodynamic enhancement of heat transfer and fluid flow”, Heat Recov. Systems and CHP, 15 (5), 389– 423 (1995).
[28]. S Vithayasai, T Kiatsiriroat, and A Nuntaphan, “Effect of electric field on heat transfer performance of automobile radiator at low frontal air velocity”, Applied Thermal Engineering 26(17-18), 2073–2078 (2006).
[29]. Y Liu, R Li, F Wang, and H Yu, “The effect of electrode polarity on EHD enhancement of boiling heat transfer in a vertical tube”, Exp. Thermal and Fluid Science 29(5), 601–608 (2005).
[30]. http://www.sigmaaldrich.com
[31]. Y Xuan, W Roetzel, “Conceptions for heat transfer correlation of nanofluids”, Int. J. Heat Mass Transfer, 43(19), 3701-3707 (2000).
[32]. JC Maxwell, “A Treatise on Electricity and Magnetism”, Second ed. Clarendon Press, Oxford, UK, 1881.
[33]. P Naphon, M Nuchjapo, J Kurujareon, “Tube side heat transfer coefficient and friction factor characteristics of horizontal tubes with helical rib”, Energy Conversion and Management, 47(18-19), 3031–3044 (2006).