PERFORMANCE INVESTIGATION OF HEAT EXCHANGER USING NANOFLUID AS A COOLANT

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Abstract: Heat exchangers are important part of industrial applications in thermal field from long time. In that shell and tube heat exchangers are widely used in different applications like refrigeration, process industry, chemical industries etc. Due to some limitations shell and tube heat exchangers have low heat transfer rate. Various heat transfer enhancement techniques are available such as extended surfaces, fluid vibration, swirl flow device etc. Nano technology provides us a new way to use fluid with suspended nanoparticles which is known as nanofluid. In this paper, 0.1%, 0.2%, 0.3% volume concentrations of Al_2O_3-water and CuO-water nanofluid is used for investigation and their effect on different thermal parameters such as convective heat transfer coefficient, overall heat transfer coefficient, heat transfer rate of shell and tube heat exchanger are evaluated experimentally. Nanofluids are used as cold working fluid or cold fluid and sent in tubes of shell and tube heat exchanger. A notable increment in overall heat transfer coefficient and convective heat transfer coefficient is found in this experimental analysis. Pressure drop is more in nanofluid as compared to base fluid but not much more difference because of laminar region.

***Index Terms* – Shell and tube heat exchanger, Al_2O_3-water nanofluid, CuO-water nanofluid, volume concentration, heat transfer rate, overall heat transfer coefficient, Pressure drop**

I. INTRODUCTION

Energy conservation is one of the biggest needs of this century. Energy resources are reducing day by day. Twenty first century's fast and advanced lifestyle creating more energy consumption as before and also energy crisis. Energy saving and conservation are therefore required and one way of doing it is efficient use of energy and equipments. Shell and tube heat exchangers are widely used in industries because of their robust construction, easy maintenance and upgrades. For a long time, steps have been taken to increase heat transfer of heat exchangers by addition of extended surfaces such as fins, coiled tubes, swirl flow devices etc. But this geometrical modification adds weight and volume making heat exchanger bulky. So this ways also reached at their limitations. Other than geometrical modifications, improvisation in thermal properties of working fluid is also a way to improve heat transfer and efficiency. Nanotechnology provides us this new way to use fluid with suspended nanoparticles which is known as nanofluid. The concept of nanofluid was given first time by Choi in 1995[1]. Nanofluids are fluids in which nanosized solid particles are suspended. [2] Mehdi Bahiraei and Reza Rahmani critically reviewed recent investigations in which nanofluids are used in heat exchangers. In this research they have included different heat exchangers and concluded that using nanofluids with heat exchangers are beneficial in many ways and nanofluid can provide a great advancement in developing heat exchanger. [3] Sayantan mukherjee presented different methods of preparation and stability of nanofluid. They come to know that Two-step preparation method is simple and economical and so it is widely used by researchers. [4]S.Senthilraja presented in the study on thermal conductivity of Al_2O_3-water, CuO-water and Al_2O_3-CuO/water nanofluid that thermal conductivity of nanofluids are the function of volume concentration and temperature. [5] Ramtin Barzegarian have carried out an experimental analysis using Al_2O_3-water nanofluid in horizontal shell and tube heat exchanger under forced circulation and reported augmentation of 6.55 and 18.95 in thermal performance factor compared to base fluid for volume concentrations 0.03 and 0.3% respectively. [6] I.M.Shahrul worked on three different fluids Al_2O_3-water, SiO_2-water and ZnO-water in shell and tube heat exchanger for 2-8lpm and found overall performance improvement of shell and tube heat exchanger by 35% with ZnO-W nanofluid.[7] Nishant Kumar have performed experimental study of Al_2O_3-water nanofluid for volume concentrations 0.01-0.08% , concluded that with increment in volume concentration heat transfer coefficient improved and at high turbulence high enhancement is achieved.[8] B. Farajollahi used Al_2O_3-water and TiO_2-water results show that maximum enhancement of convective heat transfer coefficient were obtained for Al_2O_3-water is at 0.5 vol% Al_2O_3-water and 0.3 vol% TiO_2-water exceeds 50%. [9] Bayram Sahin investigated experimentally Heat transfer and Pressure drop of CuO-water nanofluid for volume fractions 0.5%, 1%, 2% and 4%. The author concluded that volume concentration greater than 1% was not suitable for heat transfer performance and highest heat transfer was achieved at Re= 16.000 and 0.5 vol%. [10] S.M.Fotukian have carried out experimental study of CuO-water nanofluid inside circular tube for very dilute less than 0.24 vol% and results show 25% increase in heat transfer coefficient with 20% pressure drop. [11] K.B. Anoop studied effect of particle size on convective heat transfer in nanofluid with two particle size 45nm and 150nm and results showed that 45nm particles gave higher heat transfer coefficient than 150nm particles.

II. EXPERIMENTAL SETUP

The experimental system used for this study is shown in figure 1. The system contains two loops nanofluid loop and water loop. It also includes shell and tube heat exchanger, a water tank, a nanofluid reservoir tank, two pumps in order to provide required flow rates, digital thermometers and rota meter. The test section is shell and tube heat exchanger with geometrical specifications as 48 tubes, 5mm tubes inside diameter, 0.5 mm tubes thickness, 6mm tubes outside diameter and 202mm length, shell with 71.4mm inside diameter and 74.8mm outside diameter [5].

Figure 1 Experimental setup

III. NANOFLUID PREPARATION

This study was carried out with Al_2O_3 and CuO nanoparticles procured from Jyotirmay overseas private Ltd. and volume concentration of nanofluid was 0.1%, 0.2% and 0.3%. The amount of nanoparticles required for preparation of nanofluid is calculated using the law of mixture formula. The amount of nanoparticles required for preparation of nanofluid for a particular volume concentration is calculated by using Eq. 1

$$\% \text{ volume concentration} = \frac{m_n/\varrho_n}{m_n/\varrho_n + m_f/\varrho_f} \quad (1)$$

After calculation amount nanoparticles required, particles were weighed and mixed with water. For proper mixing Magnetic stirrer was used. Polyvinylpyrolidone K-30 was used as surfactant. Addition of surfactant increases stability of nanofluid. By this way 2.4 litres of Al_2O_3 -W and CuO-W nanofluid of 0.1, 0.2, 0.3 vol% concentration was prepared. The prepared CuO-W and Al_2O_3 -W nanofluid is shown in **Figure 2** and **Figure 3** respectively.

Figure 2 Prepared CuO-W nanofluid

Figure 3 Prepared Al_2O_3 –W nanofluid

IV. DATA REDUCTION

4.1 Nanofluid properties

The most important properties needed for estimation of convective heat transfer coefficient of nanofluids are its density; thermal conductivity; viscosity and specific heat. Physical properties of Al_2O_3 and CuO nanoparticles are given in **Table 1.**

Table 1: Physical properties of nanoparticles

Nanoparticles	Density(kg/m3)	Specific heat (J/kg K)	Thermal conductivity (W/m.K)
Al_2O_3	3690	880	18
CuO	6300	535	20

The following equations are used to determine properties of nanofluids.

For calculation of viscosity of nanofluid, Einstein equation [12] is used which is as follows:

$$\mu_{nf} = \mu_{bf}\,(1+2.5ø) \quad (2)$$

where μ_{bf} is base fluid viscosity

To determine density of nanofluid Pak and Cho [13] equation is used which is as follows:

$\rho_{nf} = ø\rho_p + (1- ø)\, \rho_{bf}$ (3)

where ρ_{bf} is base fluid density and ρ_p is nanoparticle density.

To evaluate specific heat capacity of nanofluid, Xuan and Roetzel [14] equation is used:

$$Cp_{nf} = \frac{ø(\rho Cp)p+(1-ø)(\rho Cp)bf}{\rho nf} \quad (4)$$

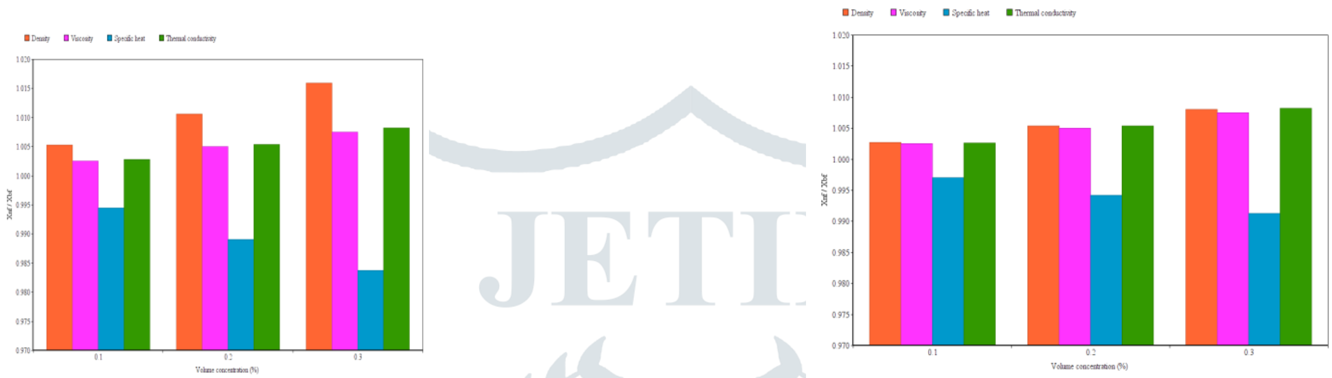
where Cp_p is nanoparticles specific heat capacity and Cp_{bf} is base fluid specific heat capacity

For calculation of thermal conductivity of nanofluid Maxwell model [15] is used:

$$\frac{knf}{kbf} = \frac{knp + 2kbf + 2ø(knp - kbf)}{knp + 2kbf - ø(knp - kbf)} \quad (5)$$

where k_{bf} is base fluid thermal conductivity, k_{np} is nanoparticle thermal conductivity and ø denotes nanoparticle volume concentration.

Figure 3 (a) and (b) shows enhancement and variation in properties of nanofluids for different volume concentration



(a) (b)

Figure 3 (a) Enhancement of properties for CuO-W nanofluid (b) Enhancement of properties for Al_2O_3-W nanofluid

4.2 Calculation method

Experiment was done and experimental data such as temperature, pressure, flow rate at inlet and outlet of shell and tube heat exchanger were collected. All correlations are collected from the ref. [7].

Heat transfer rate on tube side is calculated by Eq. (6);

$Q_c = m_c\, C_{pc}\, (T_{co} - T_{ci})$ (6)

Heat transfer rate on shell side is calculated by Eq. (7);

$Q_h = m_h\, C_{ph}\, (T_{ho} - T_{hi})$ (7)

Logarithmic mean temperature difference (ΔT_m) is evaluated from Eq.(8);

$$\Delta T_m = \frac{(Thi-Tco)-(Tho-Tci)}{\ln\frac{(Thi-Tco)}{(Tho-Tci)}} \quad (8)$$

Overall heat transfer coefficient is found from Eq. (9)

$Q_{avg} = UA\, \Delta T_m$ (9)

where U is overall heat transfer coefficient and A is heat transfer area

Convective heat transfer coefficient is calculated using Eq. (10)

$Q = h\, A\, \Delta T_m$ (10)

where h is convective heat transfer coefficient and Q is heat transfer rate.
The temperature of wall and water are assumed to be equal.

The Nusselt number of the nanofluid is calculated by Eq. (11):

$$Nu = \frac{hD}{k} \quad (11)$$

where D is internal diameter of tube and K is thermal conductivity.

The Reynolds and Prandtl number estimated by Eq. (12) & Eq. (13) respectively,

$$Re = \frac{\varrho v D}{\mu} \quad (12)$$

$$Pr = \frac{\mu Cp}{k} \quad (13)$$

where μ is viscosity, v is velocity of fluid, ρ is density and C_p is specific heat of fluid.

V. RESULT AND DISCUSSION

Fig. 4 shows Nusselt number vs Reynolds number for nanofluids at different volume concentrations. From the graph it is seen that Nusselt number of cold working fluid increases with increment in Reynolds number and at a specific Reynolds number, Nusselt number increases as nanofluid volume concentration increases.

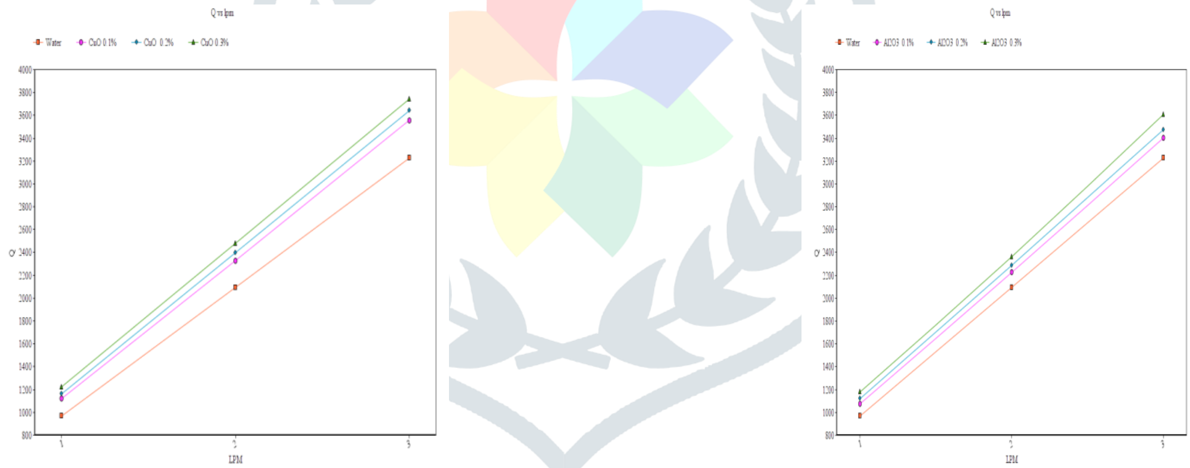
Fig. 5 shows effect of volume flow rate on heat transfer. It shows that with increase in volume flow rate heat transfer rate was increased. Fig. 6 shows effect of volume flow rate on convective heat transfer coefficient. It shows that with increment in volume flow rate convective heat transfer coefficient also increases and this enhancement as compared with base fluid convective heat transfer is more at high volume flow rate.

Fig. 7 shows ratio of pressure drop with nanofluid as working fluid to base fluid vs volume flow rate. From the graph it is seen that with nanofluid as working fluid pressure drop is more as compared with base fluid which is water and with increment in volume flow rate this pressure drop increases.

Fig. 8 shows overall heat transfer coefficient for various nanofluid concentration at different volume flow rate. With increase in volume concentration and volume flow rate overall heat transfer coefficient increases and for same volume flow rate overall heat transfer coefficient of both nanofluids is higher than base fluid.

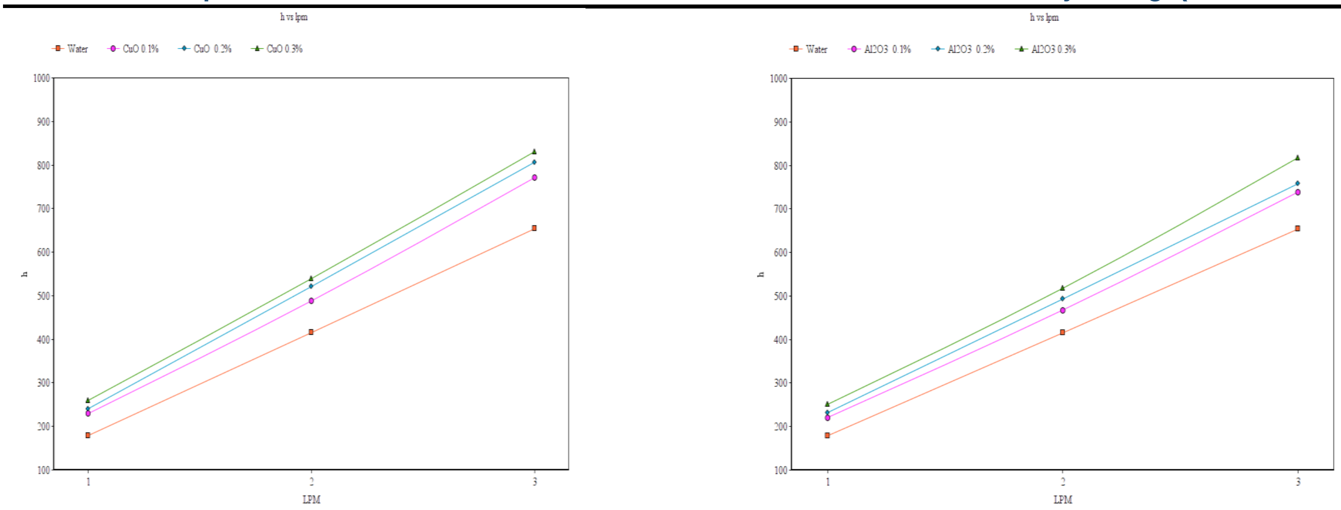
(a) (b)

Figure 4: Comparison between the Nusselt number of cold working fluid at different volume concentrations for (a) CuO-w nanofluid (b) Al_2O_3-w nanofluid.



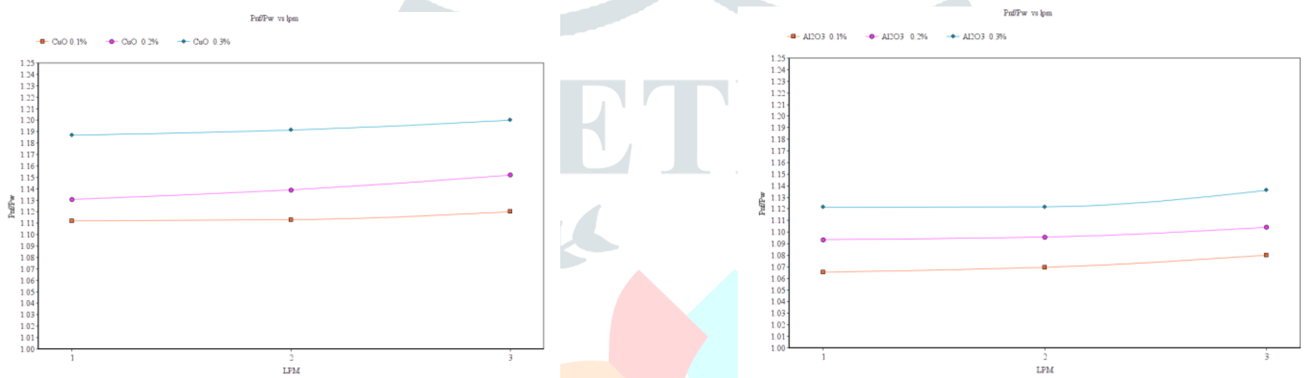
(a) (b)

Figure 5: Actual heat transfer at various volume flow rates for (a) CuO-w nanofluid (b) Al_2O_3-w nanofluid.



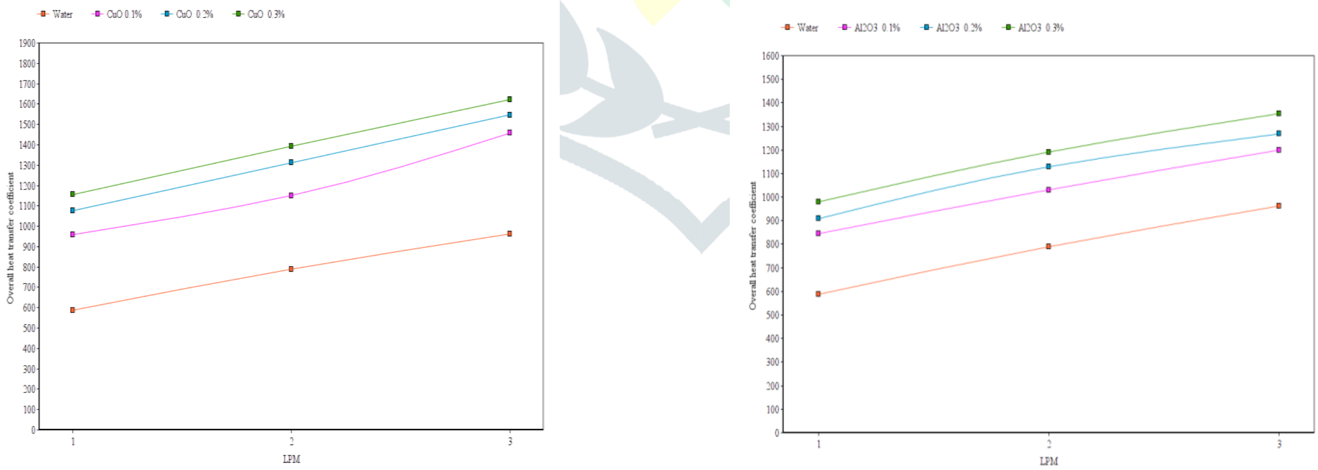
(a) (b)

Figure 6: Convective heat transfer coefficient at different volume flow rate for (a) CuO-w (b) Al_2O_3-w nanofluid.



(a) (b)

Figure 7: Ratio of pressure drop against volume flow rate ($\Delta P_{nf} / \Delta P_w$ vs lpm) for (a) CuO-w (b) Al_2O_3-w nanofluid.



(a) (b)

Figure 8: Overall heat transfer coefficient at different volume flow rate for (a) CuO-w (b) Al_2O_3-w nanofluid.

VI. CONCLUSION

In this paper, performance of shell and tube heat exchanger is investigated experimentally with Al_2O_3-w and CuO-w nanofluids at different concentrations and at different volume flow rates. Following conclusions were obtained:

- The study shows that with increment in Reynolds number heat transfer parameters also increases. The overall heat transfer coefficient and Nusselt number enhance with Reynolds number. Also for a particular Reynolds number with increment in volume concentration of nanofluid, both Nusselt number and overall heat transfer coefficient increases.
- The overall heat transfer also enhanced by 26% and 21% for CuO-w and Al_2O_3-w nanofluid respectively at 0.3% volume concentration as compared with base fluid water.
- Pressure drop is more while using nanofluid as working medium. It was observed that around 20% and 13% more pressure drop occurred for CuO-w and Al_2O_3-w nanofluid respectively as working fluid as compared with base fluid water.
- Thermal conductivity of both nanofluids was investigated for different volume concentrations. With increment in volume concentration, thermal conductivity increases because nanoparticles which were suspended in nanofluid increases turbulence which enhance energy exchange process.

VII. ACKNOWLEDGEMENT

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REFERENCES

[1] S.U.S. Choi, Enhancing thermal conductivity of fluids with nanoparticles, Proc. ASME Int. Mech. Eng. Congress Expos. 66(1995) 99-105.
[2] Mehdi Bahiraei, Reza Rahmani (2018) "Recent research contributions concerning use of nanofluids in heat exchangers: A critical review", Applied thermal engineering 133 pp 137-159, Elsevier.
[3] Sayantan Mukherjee, Somjit Paria(2013), "Preparation and Stability of nanofluids – A review", IOSR journal of mechanical and civil engineering volume 9, issue 2, PP 63-69
[4] S.Senthilraja, K.Vijaykumar (2015),"A comparative study on thermal conductivity of Al_2O_3/water, CuO/water and Al_2O_3-CuO/water nanofluids" Digest journal of Nanomaterials and Biostructures vol. 10, pp 1449-1458.
[5] Ramtin Barzegarian (2017), "Thermal performance augmentation using water based Al_2O_3-gamma nanofluid in a horizontal shell and tube heat exchanger under forced circulation", International communications in heat and mass transfer 86, pp 52-59.
[6] I.M. Shahrul (2016), "Experimental investigation on Al_2O_3-w, SiO_2-w and ZnO-w nanofluids and their application in shell and tube heat exchanger" International journal of heat and mass transfer 97, pp 547-558.
[7] Nishant Kumar (2018), "Experimental study of thermal conductivity, heat transfer and friction factor of Al_2O_3 based nanofluid", International communications in heat and mass transfer 90, pp 1-10
[8] B.Farajollahi (2010), "Heat transfer of nanofluids in a shell and tube heat exchanger", International journal of heat and mass transfer 53, pp 12-17.
[9] Bayram Sahin (2015), "An Experimental study on heat transfer and pressure drop of CuO-water nanofluid", Journal of Nanimaterials, Hindawi Publication Corporation.
[10] S.M. Fotukian (2010), "Experimental study of turbulent convective heat transfer and pressure drop of dilute CuO/water nanofluid inside a circular tube", International communications in heat and mass transfer 37, pp 214-219
[11] K.B. Anoop (2009), "Effect of particle size on the convective heat transfer in nanofluid in the developing region", International journal of heat and mass transfer 52, pp 2189-2195.
[12] A. Einstein, Investigation on the theory of Brownian motion, Dover, New York, 1956.
[13] B.C. Pak, Y.I. Cho, Hydrodynamic and heat transfer study of dispersed fluids with submicron metallic oxides, Exp. Heat Transf. 11(1998) 151.
[14] Y. Xuan, W. Roetzel, Conceptions for heat transfer correlation of nanofluids, Int. J. Heat Mass Transf. 43(2000) 3701-3707.
[15} J.C. Maxwell, A Treatise on electricity and Magnetism, Second ed. Clarendon Press, Oxford University, UK, 1881.