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Experimental Study on the Effect of CuO/DI Water Nanofluids on Heat Transfer and Pressure Drop in a Circular Tube with Inserts

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ABSTRACT

In this experimental study, convective heat transfer and friction factor characteristics of CuO / DI water nanofluids flowing through a plain tube with spiraled rod inserts (SRI) is studied. The experiment is conducted under laminar flow and constant heat flux conditions. CuO nanoparticles are dispersed in Deionized (DI) water to prepare CuO / DI water nanofluids with 0.1% volume concentration of nanoparticles. From the experimental results, it is found that the inclusion of nanoparticles in DI water enriches the Nusselt number. The enhancement in Nusselt number is 19% at Re 2240 for a plain tube with nanofluids of 0.1% volume concentration compared to DI water. Two copper SRIs with pitches 50 mm and 30 mm are used which increased the Nusselt number by 35.9% and 37.2% respectively with nanofluids of 0.1% volume concentration compared to DI water. The estimated friction factor with the use of nanofluids is 4.2% more than the DI water, which is an insignificant one, so there is no penalty in pumping power.

KEYWORDS: *CuO/DI Waternanofluids, Laminarflow, Heat transfer enhancement, frictionfactor*

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1. INTRODUCTION

Solid particles having diameter less than 100 nm are added in the base fluids such as water, oil, etc. to form nanofluids. It has been investigated and applied for the augmentation of heat transfer. Nanofluids have proven to be of having massive potential in revolutionizing many industrial processes such as transportation, power generation, chemical processes, heating, and cooling processes, and other micro-sized applications. In the year 1995 Choi [1] used the nanoparticles to enhance heat transfer. Since then, many numbers of researches have followed keeping his work as the base. Researchers have also used various inserts to enhance heat transfer rate such as twisted tape inserts, spiraled rod inserts, wire coil inserts, and many other inserts.

Kyo Sik Hwang et al.[2] investigated the convective heat transfer characteristics of Al_2O_3/water nanofluids. According to their experimental results, there was an 8% rise in heat transfer coefficient at a concentration of 0.3 vol% compared to pure water. S. Zeinalia et al. [3] conducted the convective heat transfer study in a circular plain tube. They used Al_2O_3/water nanofluids as working fluids for the heat transfer investigation and found that the heat transfer coefficient increased with the increase of concentration of nanoparticles. They also obtained that the enhancement in heat transfer was much raised in than the base fluids.

M. Saeedinia et al.[4] studied the thermal and rheological characteristics of CuO-Base oil nanofluids flow inside a circular tube. They found that there was an increase in heat transfer coefficient of nanofluids to that of pure oil flow and they found maximum enhancement of 12.7% in heat transfer coefficient for 2wt% nanofluids. In horizontal tube using SiO_2/water nanofluids, hydraulic and heat transfer studies were conducted with imposed wall temperature conditions by Sebastein Ferrouillat et al.[5]. Their results showed a 10% to 60% rise in heat transfer coefficient compared with pure water. W. Duangthongsuk et al. [6] estimated that the enhancement of heat transfer and pressure drop behavior of TiO_2/Water nanofluids in a double-tube counter flow heat exchanger. Their result showed a 6-11% rise in heat transfer rate than the base fluid.

Wei Yu et al. [7] examined the heat transfer properties of Al_2O_3 nanofluids. They used ethylene glycol -water mixture as base fluid and found a 57% and 106% rise of heat transfer coefficient for 1.0 vol% and 2.0 vol% of nanofluids respectively. M. Chandrasekar et al.[8] studied the heat transfer and friction factor characteristics of

Al_2O_3/Water nanofluids in a circular pipe. The experiment was conducted under laminar flow. Two-wire coil inserts made of stainless steel with pitch ratios 2 and 3 were used in their study. According to their experimental results, 12.24% of the rise in Nusselt number was found for 0.1% volume concentration of nanoparticles. When wire coil inserts were used, the Nusselt number was found to increase by 15.91% and 21.53% respectively with nanofluids compared to water. Heat transfer characteristics of nanofluids in a uniformly heated circular tube fitted with helical inserts in laminar flow was studied by Govardhan Parthipakka et al.[9]. They used helical coil inserts with twist ratios 2.93, 3.91, and 4.89 with Al_2O_3 nanoparticles in the water of 0.1, 1.0, and 1.5% concentrations respectively. It was found that the heat transfer augmentation was directly proportional to nanoparticles volume concentration and Reynolds number, and inversely proportional to the twist ratio. In their research work, the maximum heat transfer rate of 31.29% was obtained for 1.5% concentration of nanoparticles with helical inserts having a twist ratio of 2.93. L. Syam. Sundar et al. [10] studied the combined effect ofFe_3O_4nanofluids and full-length twisted tape inserts on heat transfer and friction factor.According to their results, they obtained the maximum enhancement of 51.88% in heat transfer when compared to plain water.

M. Saeedinia et al.[11] experimented on heat transfer and pressure drop of nanofluids in horizontal coiled wire inserts. The experiment was carried out under constant heat flux conditions. They concluded that nanofluids gave better heat transfer in tubes using wire coil insert than the plain tube. They obtained a maximum heat transfer enhancement of up to 40.2%.

S. Suresh et al.[12] conducted a comparative study on the thermal performance of helical screw tape inserts in laminar flow. For the comparative study, they used $Al_2O_3$and CuO – water based nanofluids. They found that CuO – water nanofluidswith helical screw inserts gave higher thermal performance than Al_2O_3 – water nanofluids. C. J. Ho et al.[13] examined the laminar convective cooling performance of hybrid water-based suspensions of Al_2O_3 nanoparticles and MEPCM particles in a circular tube. Their results presented that the hybrid-based suspension showed a significant increase in heat transfer rate when compared to pure PCM suspension, nanofluids, or water. However, they found that this enhanced heat transfer technique could not be manipulated due to the high-pressure drop caused by the hybrid suspension compared to the nanofluids or water cause of the drastic increase in viscosity. S. Suresh et al.[14] experimented on the effect of Al_2O_3-Cu/water hybrid nanofluids in heat transfer. They found a maximum enhancement of 13.56% in Nusselt number at a Reynolds number of 1730 when compared to Nusselt number of water. They also found that 0.1% Al_2O_3-Cu/water hybrid nanofluids had a raised friction factor when compared to 0.1% Al_2O_3/water nanofluids. A comparison of thermal behavior of Al_2O_3/water and CuO/water nanofluids through a circular duct fitted with helical screw tape inserts was carried out by S. Suresh et al.[15] and their experimental results presented 156.24,122.16 and 89.22% average enhancement in Nusselt number corresponding to twist ratios of 1.78, 2.44, and 3 respectively. The experimental investigation also presented that CuO/water nanofluids gave a higher performance than Al_2O_3/water nanofluids with helical screw tape inserts.

H. R. Rayatzadeh et al. [16] experimented with the effect of constant sonication on laminar convective heat transfer inside the tube. They used TiO_2/water nanofluids for 0.1, 0.15, and 0.25% volume concentration of nanofluids. They found that with the rise in nanoparticles volume concentration heat transfer rate also raised except for 0.25% volume concentration.

In the present experimental work heat transfer and friction factor characteristics of CuO/DI water nanofluids in a smooth circular tube underlaminar flow is studied with spiraled rod inserts.

2. Experimental methods

2.1. Preparation of CuO/DI water nanofluids

The required amount of CuO nano particles is dispersed in DI water to prepare the nanofluids.

The volume concentration used in this study is 0.1%. Then the nanofluid is stirred in a REMI magnetic stirrer to obtain a homogeneous mixture. Then, the nanofluid is sonicatedusing a LARK ultrosonicator for 6 hrs duration to confirm stable suspension.

2.2. Experimental set-up

The schematic diagram of the experimental setup is showed in Fig. 1. The key components of the experimental setup are (i) calming section, (ii) test section, (iii) riser section, (iv) air-cooled heat exchanger, (v) fluid storage tank, (vi) centrifugal pump, and (vii) arrangements to measure pressure drop and temperature. The fluid is pumped from the reservoir by using a centrifugal pump and the flow rate is maintained by the use of flow control valve and bypass valve. The flow rate of the fluid is measured by a rotameter. Initially, the fluid enters the calming section whose length is just enough to remove the entrance effects, so that the fully developed flow is obtained when it enters the test section.

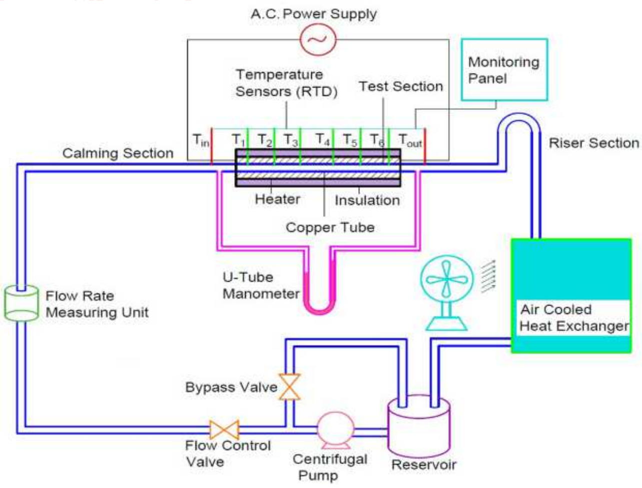

Fig.1.The schematic diagram of experimental setup

The fluid then flows through the riser section and enters the heat exchanger and is finally collected in the fluid reservoir. A straight copper smooth tube of length1000 mm, inner diameter (ID) 14 mm, and outer diameter (OD) 16 mm is used as the test section.

The test section is uniformly heated by using Nichrome wire of resistance 120 Ω. To vary the heat flux an autotransformer is used. Resistance Temperature Detectors (RTD PT 100) are used at six different locations to measure the inlet, outlet, and wall temperatures. A U–tube manometer is used to estimate the pressure drop across the test section. Insulation encompassing of glass wool, ceramic fiber, and asbestos rope are provided over the heating coil to avoid radial heat losses.

2.3. Technical details of Spiraled rod inserts

Fig.2 shows the spiraled rod inserts made-up of using 3.5mm copper rod to which pin-like projections of length 10mm and 2.5mm diameter were attached at an angle of 22˚ to the copper rod at a distance of 50mm and 30mm perpendicular to each other for the full length of copper rod for insert 1 and 2 respectively.

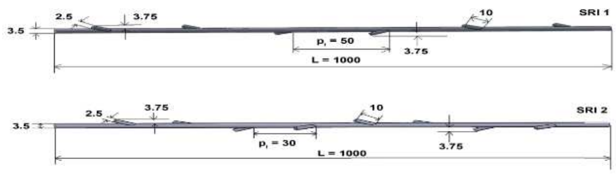

Fig.2. Geometrical configuration of spiraled rod inserts

3. Data Reduction

3.1. Thermo-physical properties of nanofluids

The density of Al_2O_3 nanofluids was found by Pak and Cho's equation [17]

$$\rho_{nf} = \emptyset\rho_s + (1-\emptyset)\,\rho \qquad (1)$$

The specific heat of the nanofluids was found using Xuan and Roetzel's equation [18]

$$(\rho C_p)_{nf} = (1-\emptyset)(\rho C_p) + \emptyset(\rho C_p)_s \qquad (2)$$

Brookfield cone and plate viscometer (LVDV-I PRIME C/P) from Brookfield engineering laboratories, USA was used to find out the viscosity of nanofluids. The viscosity of the nanofluids could be calculated using the viscosity correlation proposed by Einstein [19]

$$\mu_{nf} = (1 + 2.5\emptyset) \qquad (3)$$

KD2 Pro thermal property analyser (Decagon Devices, Inc., USA) was used to measure the thermal conductivities of nanofluids, the effective thermal conductivity of the nanofluidsk_{nf} is found using Maxwell equation [20]

$$\frac{k_{nf}}{k} = k_s + 2k + \frac{2\emptyset(k_s-k)}{k_s} + 2k - \emptyset(k_s - k) \qquad (4)$$

3.2. Heat transfer calculations

Total heat transfer,

$$Q_t = VI \qquad (5)$$

The loss of heat through the insulation (Q_{loss}) wasassessed to be 3.5% of the total heat supplied from the measurements of wall temperature and ambient temperature.Therefore, the total heat supplied by the heater,

$$Q_1 = Q_t - Q_{loss} \qquad (6)$$

The heat absorbed by the fluid was calculated by the following equation,

$$Q_2 = mc_p(T_{f,out} - T_{f,in}) \qquad (7)$$

The average heat transfer rate of the heat delivered by electrical winding and heat gained by the fluid was taken for the calculation of convective heat transfer coefficient. Therefore,

$$Q = \frac{(Q_1+Q_2)}{2} \qquad (8)$$

Heat flux was calculated as,

$$q'' = \frac{Q}{(\pi DL)} \qquad (9)$$

From the equation given below the local heat transfer coefficient was estimated using local wall temperature, local fluid temperature and heat flux

$$h_x = \frac{q''}{(T_{wx}-T_{fx})} \qquad (10)$$

The local fluid temperature was estimated from the energy balance equation given below,

$$T_{fx} = T_{in} + \frac{(q''P_x)}{(\rho c_p v A)} \qquad (11)$$

The local Nusselt number $Nu_x$was calculated as,

$$Nu_x = \frac{(h_x D)}{k} \qquad (12)$$

The average heat transfer coefficient is calculated using average wall temperature, mean fluid temperature and heat flux from the equation given below,

$$h = \frac{q''}{(T_w - T_f)} \qquad (13)$$

The average Nusselt number was calculated as,

$$Nu = \frac{(hD)}{k} \qquad (14)$$

Thermal resistance was calculated as,

$$R = \frac{(T_w - T_f)}{q''} \qquad (15)$$

3.3. Pressure drop calculations

The pressure drop (Δp) measured across the test section using U-tube manometer under isothermal condition was used to find the friction factor (f) using the equation below:

$$f = \frac{\Delta p}{\frac{1}{2}\rho v^2\left(\frac{L}{D}\right)} \qquad (16)$$

4. Results and discussions

4.1. Heat transfer study

Fig. 3 represents the Nusselt number variation with Reynolds number.In the present study. Nanofluids and inserts are used to enhance the heat transfer rate. It can be evidently seen that the Nusselt number increases with Reynolds number. A CuO/DI water nanofluid of 0.1% volume concentrations is used in this experimental work. The addition of nanoparticles has an encouraging effect on the Nusselt number. The augmentation in Nusselt number for 0.1% volume concentrations of nanofluids is 19% compared to DI water.

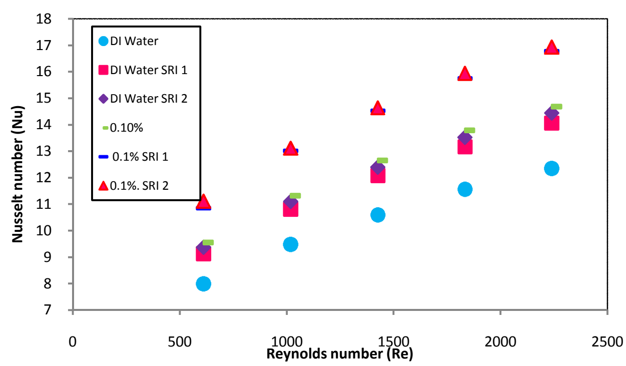

Fig.3. Variation of Nusselt Number with Reynolds number for plain tube

The enhancement in Nusselt number due to the addition of nanoparticles is primarily attributed to the reduction of boundary layer thickness and delayed growth of boundary layer, Brownian motion, increased thermal conductivity, relocation and rearrangement of particles, and large energy exchange due to chaotic motion of particles. The use of spiraled rod inserts in plain tube further enhances the Nusselt number compared with DI water in plain tube. Two inserts having pitches of 50 mm (SRI 1) and 30 mm (SRI 2) are used in this study. The Nusselt number is found to increase in both cases compared to DI water in plain tube. The Nusselt number also increases with a decrease in pitch of SRI. The enhancement in Nusselt number is 14 and 17% for SRI 1 and SRI 2 respectively. It can be professed from Fig. 3 that the use of spiraled rod inserts with nanofluids enhances the Nusselt number further compared to the plain tube. The enhancement in Nusselt number obtained is 35.9 for 0.1% volume concentrations with SRI 1 and 37.2% for SRI 2 compared to DI water in plain tube.

The heat transfer augmentation due to the SRIs is primarily because of the following reasons: (1) The pins attached on the SRI act as turbulent promoters; (2) Growth of secondary flows; (3) Decrease in hydraulic diameter; (4) Enhanced energy exchange in the fluids due to uneven and random movement of the particles; (5) Outstanding fluid mixing and an efficient redevelopment of the thermal and hydrodynamic boundary layers due higher turbulence intensity close to the tube wall.

4.2. Friction factorstudy

Friction factor variations with the Reynolds number are revealed in Fig. 4 for the plain tube. The friction factor decreases with increasing Reynolds number. The friction factor to some extent increases with the addition of nanoparticles due to the increased shear force between the wall and the nanoparticles and also due to increased viscosity. But the increase in friction factor is not noteworthy compared with DI water and hence the pressure drop penalty is negligible. The increase in friction factor for 0.1% volume concentration is 4.2% compared with DI water.

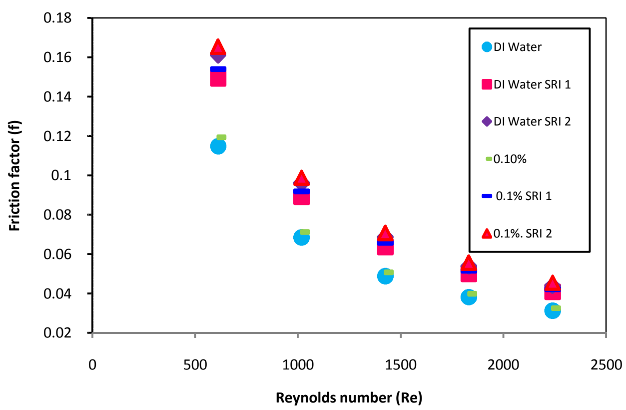

Fig.4. Variation of friction factor with Reynolds number for plain tube

The friction factor further increases in the plain tube fitted with SRIs. The rise in friction factor in the case of plain tubes with DI water, 0.1% volume concentrations of nanofluids are 30.65, 34.99% for SRI 1 and 40.8, 45.4% for SRI 2 compared to DI water without inserts. The use of inserts increases the friction factor for both DI water and nanofluid. The pitch of SRIs plays an important role in the friction factor, increasing pitch reduces the friction factor. This is due to the geometry and more contact surface. Also, the inserts reduce the free flow area and induce turbulence in the flow. This leads to increased friction between the surface of the core rod and the internal wall of the tube.

5. Conclusions

Heat transfer and friction factor studies are carried out using CuO/DI water nanofluids in plain tube with SRIs.

The experimental results are as follows:

A. Nanofluids gives better heat transfer than the base fluid.
B. Enhancement in Nusselt number using insert is higher than the addition of nano particles to the base fluids.
C. The maximum enhancement in Nusselt number in plain tube with SRI 2 is 37.2% is obtained for 0.1% volume concentration of CuO/DI water nanofluids.
D. The Pressure drop penalty by using nanofluids in plain tube is insignificant; hence it can be used for heat transfer applications.

Nomenclature

A	cross sectional area (m^2)
c_p	specific heat(J/kgK)
D	test section diameter (m)
f	friction factor
h	heat transfer coefficient(W/m^2K)
I	current (A)
L	length of the test section (mm)
m	mass flow rate(kg/s)
Nu	Nusselt number (hD/k)
p_i	pitch of the spiraled rod inserts (mm)
P	perimeter (m)
Pr	Prandtlnumber($c_p\mu/k$)
Q	electrical heat input (W)
R	thermal resistance ($^\circ Cm^2/W$)
q″	heat flux(w/m^2)
Re	Reynolds number ($\rho vD/\mu$)
T	Temperature (K)
v	fluid velocity(m/s)
V	voltage (V)
x	axial distance from tube entrance(mm)

Greek symbol

ρ	density(kg/m^3)
μ	dynamic viscosity(kg/m^2s)
Ø	Volume concentration (%)
Δp	pressure drop(N/m^2)

Subscripts

f	fluid
in	inlet
nf	nanofluid
out	outlet
s	solid phase
t	total
w	wall

Abbreviations

SRI	Spiraled rod insert
DI	Deionized

References

[1] S. U. S Choi, Enhancing thermal conductivity of fluid with nanoparticles in: D. A. Siginer, H. P. Wang (Eds.), Developments and Applications of Non-Newtonian Flows, FED-V.231/MD-V.66, ASME, New York, 1995, pp.99-105

[2] KyoSik Hwang, SoekPil Jang, Stephen U.S. Choi, Flow and convective heat transfer characteristics of water-based nanofluids in fully developed laminar flow regime. Int. j. Heat and Mass Transfer 52(2009) 193-199.

[3] S. ZeinaliaHeris, M. Nasr Esfahany, S.Gh. Etemad, Experimental investigation of convective heat transfer of Al_2O_3/Water nanofluid in circular tube. Int. j. Heat and Fluid Flow 28(2007) 203-210.

[4] M. Saeedinia, M. A. Akhavan-Behabadi, P. Razi, Thermal and rheological characteristics of CuO-Base oil nanofluid flow inside a circular tube, Int. Communications in Heat and Mass Transfer 39(2012)152-159.

[5] SebasteinFerrouillat, Andre Bontemps, Joao-Paulo Ribeiro, Jean- Antoine Gruss, Olivier Soriano. Hydraulic and heat transfer study of SiO_2/Water nanofluid in horizontal tubes with imposed wall temperature boundary conditions, Int. j. Heat and Fluid Flow 32(2011) 424-439.

[6] WeerapunDuangthongsuk, SomachiWongwises, Heat transfer enhancement and pressure drop characteristics of TiO_2/water nanofluid in a double-tube counter flow heat exchanger,. Int. j. Heat and Mass Transfer 52(2009) 2059-2067.

[7] Wei Yu, HuaqingXie, Yang Li, Lifei Chen, Qiang Wang, Experimental investigation on the heat transfer properties of Al_2O_3 nanofluid using the mixture of ethylene glycol and water as base fluid. Powder Technology 230(2012) 14-19

[8] M. Chandrasekar, S. Suresh, A.Chandra Bose, Experimental studies on heat transfer and friction factor characteristics of Al_2O_3/Water nanofluid in a circular pipe under laminar flow with wire coil inserts, Experimental Thermal and Fluid Science 34(2012) 122-130.

[9] GovarthanPathipakka, P. Sivashanmugham, Heat transfer behavior of nanofluids in a uniformly heated circular tube fitted with helical inserts in laminar flow, Super lattices and Microstructures 47(2012)349-360.

[10] L. Syam Sundar, N. T. Ravi Kumar, M. T. Naik, K. V. Sharma, Effect of full-length twisted tape inserts on heat transfer and friction factor enhancement with Fe_3O_4 magnetic nanofluid inside a plain tube: An experimental study, Int. j. Heat and Mass Transfer 53(2012) 2761-2768.

[11] M. Saeedinia, M. A. Akhavan-Behabadi, M. Nasr, Experimental study on heat transfer and pressure drop of nanofluid flow in a horizontal coiled wire inserted tube under constant heat flux, Experimental Thermal and Fluid Science 36(2012) 158-168.

[12] S. Suresh, K. P Venkitaraj, P. Selvakumar, Comparative study on thermal performance of helical screw tape inserts in laminar flow using Al_2O_3/Water and CuO/Water nanofluids, Super lattices and Microstructures 49(2011) 608-622.

[13] C. J. HO, J. B. Huang, P. S. Tsai, Y. M. Yang, On laminar convective cooling performance of hybrid water-based suspensions of Al_2O_3 nanoparticles And MEPCM particles in a circular tube. Int. j. Heat and Mass Transfer 54(2011) 2397-2407.

[14] S. Suresh, K. P Venkitaraj, P. Selvakumar, M. Chandrasekar, Effects of Al_2O_3-Cu/Water hybrid nanofluid in heat transfer, Experimental Thermal and Fluid Science 38(2012) 54-60.

[15] S. Suresh, K. P. Venkitaraj, P. Selvakumar, M. Chandrasekar, A comparison of thermal characteristics of Al_2O_3/Water and CuO/Water nanofluids in transition flow through a straight circular duct fitted with helical screw tape inserts, Experimental Thermal and Fluid Science 39(2012)37-44.

[16] Hamid Reza Rayatzadeh, MajidSaffar-Avval, Mohsen Mansourkiaei, Abbas Abbassi, Effects of continuous sonication on laminar convective heat transfer inside a tube using water- TiO_2 nanofluid, Experimental Thermal and Fluid Science 48(2013) 8-14.

[17] B.C. Pak, Y. Cho, Hydrodynamic and heat transfer study of dispersed fluids with submicron metallic oxide particle, Exp. Heat Transfer. 11 (1998)151-170.

[18] Y. Xuan, W. Roetzel, Conceptions of heat transfer correlation of nanofluids, Int. j. Heat Mass Transfer. 43(2000) 3701-3707.

[19] A. Einstein, Investigation on the theory of Brownian motion, Dover, Newyork, 1956.

[20] J. C. Maxwell, Treaties on Electricity and Magnetism, Dover, Newyork, 1954.