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HEAT TRANSFER ENHANCEMENT BY USING CUO-WATER NANOFLUID IN A CONCENTRIC TUBE HEAT EXCHANGER- AN EXPERIMENTAL STUDY

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ABSTRACT

In industries such as power generation, chemical production, air conditioning, transportation, and microelectronics the cconventional heat transfer fluids such as water, mineral oil, and ethylene glycol are used to transfer heat from one fluid to another. The low thermal conductivity of conventional fluids increase the size of the heat transfer device for the given heat transfer. So there is a need to develop energy-efficient heat transfer fluids that are required in a plethora of heat transfer applications. Modern materials technology provided the opportunity to produce nanometer-sized particles which are quite different from the parent material in mechanical, thermal, electrical, and optical properties. The heat transfer properties of these conventional fluids can be significantly enhanced by dispersing nanometer-sized solid particles such as Al_2O_3, Cu, CuO and Fe_2O_3. The suspended nano-sized metallic and metal oxide particles change the transport properties and heat transfer characteristics of the base fluid. Thus the preparation of nanofluids using metal and metal oxide nanoparticleswill play an important role in developing the next generation of cooling technology. The CuO nanoparticles are prepared by adopting sol-gel techniquein the present work. The CuO nanoparticles are prepared from copper nitrate by passed it through different stages such as dissolving, preparation of solution, formation of gel, filtration and drying to get the nano-sized CuO particles. The nanoparticles are sintered for 3 hours at a temperature of 200^0C in the furnace to remove the liquid traces completely from nanoparticles. TheCuO-water nanofluids are prepared at different volumetric concentration of CuO nanoparticle in the base fluid. To find the heat transfer rates of CuO -water nanofluid for different Reynolds numbers and for different volume fractions of nano-particles in the base fluidthe experiments are conducted in a double pipe counter flow heat exchanger. The experimental overall heat transfer coefficients calculated are compared with the base fluid water. Also the theoretical overall heat transfer coefficients of CuO-water nanofluid are determined by evaluating the physical and thermal properties of nanofluid with the correlations available in the literature.

KEYWORDS: CuO-Water Nanofluid, Double Pipe Heat Exchanger, Enhancement of Heat Transfer, Sol-Gel Method

INTRODUCTION

The last few decades of the twentieth century have seen unprecedented growth in electronics, communication, and computing technologies, and it is likely to continue unabated into the present century. The exponential growth of these technologies and their devices through miniaturization and an enhanced rate of operation and storage of datahave brought about serious problems in the thermal management of these devices. The increasing power of these devices with decreasing size also calls for innovative cooling technology.Modern materials technology provided the opportunity to produce nanometer-sized particles which are quite different from the parent material in mechanical, thermal, electrical, and optical properties. The suspended nano-sized metallic and metal oxide particles change the transport properties and heat transfer characteristics of the base fluid. Thus the preparation of nanofluids using metal and metal oxide nanoparticles will play an important role in developing the next generation of cooling technology. Pak and Cho [1] used the Al_2O_3 and TiO_2 nano-sized particles under turbulent flow conditions and observed that the Nusselt number increased with increasing Reynolds number and particle volume fractions.Lee et al. [2] observed the enhancement of thermal conductivity of nanofluids while using CuO and Al_2O_3 nanoparticles with water and ethylene glycol compared to base fluids. Roy et al. [3] conducted a numerical study of heat transfer for Al_2O_3 /water nanofluids in a radial cooling system. They found that addition of nanoparticles in the base fluids increased the heat transfer rates considerably. Xuan and Li [4] conducted the experiments using 100nm copper particle under turbulent flow conditions and found that the convective heat transfer coefficient increased with an increasing Reynolds number and particle volume fractions. Xuan and Roetzel [5] concluded that the heat transfer enhancement is due to increase in thermal conductivity caused by random motion of the particles. Choi et al. [6] found that the nanofluids with metallic nanoparticles have a higher thermal conductivity than nanofluids is non-metallic nanoparticles. Xie et al. [7] measured the thermal conductivity of aqueous Al_2O_3 with varying particle sizes and showed for the first time that the thermal conductivity of nanofluids depends strongly on particle size. Das et al. [8] used temperature oscillation technique to find the variation of thermal conductivity of nanofluids with temperature and observed an increase in thermal conductivity with temperature. Xue [9] developed a numerical model of nanofluid by considering the particles to be ellipsoids interacting with spherical fluid particles. The classical Maxwell model was introduced by Yu and Choi [10]. Wen and Ding [11] conducted experiments at the tube entrance region under laminar flow conditions and found the local heat transfer varied with volume loading and the Reynolds number. Hwang et al. [12] conducted experiments and studied convective heat transfer characteristics of Al_2O_3/water nanofluid with particles varying in the range of 0.01–0.3%. Yang et al. [13]conductedexperiments in a horizontal tube heat exchangerunder laminar flow conditions and found the convective heat transfer coefficients of several nanoparticle-in-liquid dispersions.

Assael et al. [14] used the transient hot-wire method to determine the thermal conductivity of nanofluids andobserved a significant increase in thermal conductivity of nanofluid with addition of nano-sized particles. Koo andPantzali et al. [15] studied the effect of use of a nanofluid (CuO-water, 4% v/v) in a miniature plate heat exchanger (PHE) with modulated surface. They concluded that, for a given heat duty, the nanofluid volumetric flow rate required was lower than that of water causing lower pressure drop. Noie et al. [16] conducted experiments with a two-phase closed thermo-syphon (TPCT) to study the heat transmission using Al_2O_3 -water nanofluid. Experimental results showed that for different input powers, the efficiency of the TPCT increases up to 14.7% when Al_2O_3 -water nanofluid was used instead of pure water. Heris et al. [17] conducted experiments with CuO/water and Al_2O_3/water nanofluids and found enhancement of Nusselt numberwith increase in volume fraction and Reynolds number. Zhang et al. [18] used transient short-hot-wire technique to measure the thermal conductivity and thermal diffusivity of Au-toluene, Al_2O_3-water, TiO_2-water, CuO-water and carbon nanotubes-water nanofluids. They observed no enhancement in the thermal conductivity as well as thermal diffusivity of nanofluids, above that of predictions of the Hamilton-Crosser model [19]. In the present work chemical sol-gel technique is used for preparation of CuO nanoparticles. The nanoparticles prepared are mixed with base fluid water in different concentrations. The CuO-water nanofluid is used as a coolant in a typical horizontal double pipe heat exchanger changer. The experiments are conducted to determine the enhancement in heat transfer with CuO-water nanofluid. The experiments are conducted in the heat exchanger for different concentrations of CuO nanoparticles in CuO-water nanofluid and Reynolds numbers.

CUO NANO-PARICLES PREPARATION

Sol-gel technique is adopted for preparation of CuO nanoparticles. The raw material copper nitrate is dissolved in water for about 20 minutes to get copper sulfate solution. The CetylTrimethylAmmonium Bromide (CTAB) is dissolved in water and stirs the contents thoroughly for about 15 minutes. If CTAB is not dissolved add few drops of hydrogen chloride. Then polyvinyl pyrolidene (PVP) is dissolved in isopropyl alcohol and stir the contents thoroughly for about 15 minutes to get a clear solution. Add drop-wise the solution of CTAB to copper sulfate solution. To the mixture so obtained add drop-wise the solution of PVP. Stir moderately while the addition of PVP to the mixture. Then sodium hydroxide is added drop-wise to the mixture obtained while stirring the contents moderately. A homogeneous bluish precipitate will form. Filter the precipitate using a whatman filter paper and wash the precipitate with distilled water at least 5 to 6 times. Dried the precipitate obtained. Transfer the dried precipitate on to a petri dish and dry the precipitate in hot air oven at 70^0C for 8 hours. Then sinter the dried precipitate at 200^0C temperature for 3hours in air ambient. Divide the sintered material into 2 parts one for the characterization (1g) and remaining for the testing for heat exchange experiments.

Figure 1: CuO Nanoparticles (a) Before Sintering (b) After Sintering

PREPARATION OF CUO-WATER NANOFLUID

The CuO-water nanofluid is prepared according to the procedure given by Choi et.al [6]. They concluded that nanoparticles are very small in their size, so the nanoparticles can be kept in dispersions for much longer time compared with the suspension of larger particles. Also the erosion and clogging reduces with nanoparticles as they may act like macromolecules in solution. The heat transfer rate increases due to larger surface area of nanoparticles. To prepare nanofluid mix required quantity of nanoparticles in the base fluid water and take the mixer proportions into a small beaker. Then 10% of Cetyltrimethyl ammonium bromide surfactant is added to the mixer to stabilize the nanofluid. Fix the beaker under the probe properly. To avoid breakage of the glass beaker and to produce vibrations maintain some gap between the probe and the glass beaker. The timer is set to 30seconds on time and 5seconds off time. Set the sonicator probe to 15 times per cycle and switch on the probe sonicator. Due to vibration of probe the nanoparticles mixes with the base fluid. Then keep the beaker in an ice bath so that it gets cooled or it transfers the heat produced in the beaker due to vibrations. The above process can be repeated at least for four cycles to disperse the nanoparticles completely in the base fluid water. The experiments are to be conducted using CuO-water nanofluid before the nanoparticles settle down.

EXPERIMENTAL SETUP

Description of Experimental Facility

The system comprises of a concentric tube heat exchanger. The heat transfer is through the wall of the inner pipe. So the material used for inner pipe is copper and for the outer pipe is stainless steel. The experimental setup also consists of heating unit to heat the water, and also comprises temperature measurement system. Temperature is measured at different locations using thermocouples. The hot water passes through the inner copper pipe and the nano fluid/other fluid flows through the annular space between the inner and outer pipes. To maintain the required flow rate each flow loop is equipped with a pump with a flow meter, a reservoir and a bypass valve. All the instruments i.e. thermocouples and flow meters are calibrated before installing to the experimental facility. The nanofluid is stored in a separate tank with temperature control set up to main the nanofluid at required temperature. To measure the temperature of hot fluid and nanofluids thermocouples are installed in nanofluid storage tank and hot water tank. Insulation is provided on the outer steel pipe to prevent heat transfer to surroundings and ensure the heat transfer is only between the nanofluid and hot water. The photographic view of the experimental setup is shown in Figure 2.

Figure 2: Photographic View of Experimental Setup

Experimental Procedure

The main switch is turned on and followed by turning on the console and the heater. The cold water at constant flow rate from the reservoir is pumped to the heat exchanger through the heater. The heater heats the water to the required temperature. The hot fluid is maintained at desired temperature using the thermostat. The nanofluid is allowed to flow through the annulus at the desired flow rate and temperature. The inlet and outlet temperatures of both the nanofluid (cold fluid) and water (hot fluid) are noted down after reaching steady state conditions. Similarly the flow rates of nanofluid and hot water are noted down. The flow rates of nanofluid and hot water can be adjusted with the help of a cold fluid flow meter and hot water flow meter respectively. The experiments can be conducted for different flow rates of nanofluid with different volumetric compositions of nanoparticle and hot water using the same procedure.

Overall Heat Transfer Coefficient

In heat exchangers heat is transferred form hot fluid to cold nanofluid by both conduction and convection. So the overall heat-transfer coefficient is to be determined to evaluate the performance of heat exchanger. The fouling resistance is neglected in the present work as the heat exchanger is relatively new. The outer radius based overall heat transfer coefficient based for the concentric tube heat exchanger, U_0, can be expressed as

$$\frac{1}{U_0} = \frac{1}{h_0} + \frac{r_0}{k}\ln\frac{r_0}{r_i} + \frac{1}{h_i}\frac{r_0}{r_i} \quad (1)$$

Where h_0 is the annulus fluid heat transfer coefficient, h_i is the hot fluid heat transfer coefficient, k is the thermal conductivity of copper, r_o is outer radius of inner copper pipe and r_i is inner radius of copper pipe

Experimental Overall Heat Transfer Coefficient

Experiments are conducted at different Reynolds numbers of hot and cold fluid, and different concentrations of nanoparticles in the base fluid water. The experimental overall heat transfer coefficient ($U_{0,\,E}$) can be calculated by the procedure given below. The logarithmic mean temperature difference (LMTD) is the appropriate average temperature difference used to find heat transfer in a heat exchanger. The LMTD can be calculated by

$$\mathrm{LMTD} = \frac{\Delta T_1 - \Delta T_2}{\ln\left(\frac{\Delta T_1}{\Delta T_2}\right)} \quad (2)$$

Where $\Delta T_1 = T_{h_i} - T_{c_i}$ and $\Delta T_2 = T_{h_0} - T_{c_o}$; T_{ci} is the inlet temperature of cold fluid, T_{co} is the outlet temperature of cold fluid, T_{hi} is the inlet temperatureof hot fluid and T_{ho} is the outlet temperature of hot fluid

The heat transfer rate (Q) can be calculated by

$$Q = \dot{m}_h \dot{C}_{p_h}(T_{h_1} - T_{h_o}) \quad (3)$$

Where m_h is hot fluid mass flow rate and $C_{p,h}$ is hot fluid specific heat

The experimental overall heat transfer coefficient ($U_{0,\,E}$) can be found by

$$Q = U_{o,E}\dot{A}_o(\mathrm{LMTD}) \quad (4)$$

Where A_o is the copper pipe outer surface area

Theoretical Overall Heat Transfer Coefficient

The experimental set up is calibrated by finding the theoretical and experimental heat transfer coefficient for water flow through the setup at different temperatures and flow rates. Also the theoretical overall heat transfer coefficient of heat exchanger with nanofluid is calculated by finding the properties of nanofluid using the correlations available in the literature. The theoretical overall heat transfer coefficient ($U_{0,\,T}$) can becalculated by the proceduregiven below. The physical properties of cold fluid are calculated at bulk mean temperature of $T_f = \frac{Tci+Tco}{2}$.

The cold fluid velocitycan be determined by

$$Q = AV \quad (5)$$

Where Q= cold fluid flow rate, A= area of cross section of annulus = $\frac{\pi}{4}\,(D_i^2 - d_o^2)$ and V= velocity of cold fluid

The Reynolds number can be determined by

$$R_e = \frac{V(D_i - d_o)}{\vartheta} \quad (6)$$

Where D_i inner diameter of steel pipe and d_0 is outer diameter of copper pipe

From the Dittus-Boelter equationthe Nusselt number can be calculated by

$$N_u = 0.023 \times R_e^{0.8} \times P_r^{n} \qquad \text{(n=0.4 for heating)} \quad (7)$$

The cold fluid heat transfer coefficient (h_o) is calculated by

$$N_u = \frac{h_o(D_i - d_o)}{k_{water}} \quad (8)$$

The bulk mean temperature of hot fluid is given by

$$T_f = \frac{Thi + Tho}{2} \quad (9)$$

The hot fluid Reynolds number can be calculated by

$$R_e = \frac{VD}{\vartheta} \quad (10)$$

From the Dittus-Boelter equation, Nusselt number of hot fluid is given by

$$N_u = 0.023 \times R_e^{0.8} \times P_r^{n} \qquad \text{(n=0.3 for cooling)} \quad (11)$$

The hot fluid heat transfer coefficient fluid can be determined by

$$N_u = \frac{h_i d_i}{k_{water}} \quad (12)$$

The theoretical overall heat transfer ($U_{0,T}$) can be calculated by

$$\frac{1}{U_{o,T}} = \frac{1}{h_i}\frac{r_o}{r_i} + \frac{r_o}{k_{cu}} \ln\frac{r_o}{r_i} + \frac{1}{h_o} \quad (13)$$

Calibration of Experimental Set Up

The accuracy of the data collected depends on reliability of the experimental set up. The reliability of the concentric tube heat exchanger in the present work is ensured by calibrating the experimental system by using water as working fluid. Before the calibration of experimental facility the instruments used to measure the temperature and flow rate are calibrated. Then hot and cold water allow to flow through the pipe and annulus respectively. The thermocouple and flow meter readings are noted for different mass flow rates of hot and cold fluids. The experimental and theoretical overall heat transfer coefficients are calculated by the procedure given above. Figure 3 shows the variation of overall heat transfer coefficient with Reynolds number. From the Figure 3, it can be found that the good agreement between the experimental and theoretical overall heat transfer coefficients for water. This indicates that the precision of the experimental setup is good.

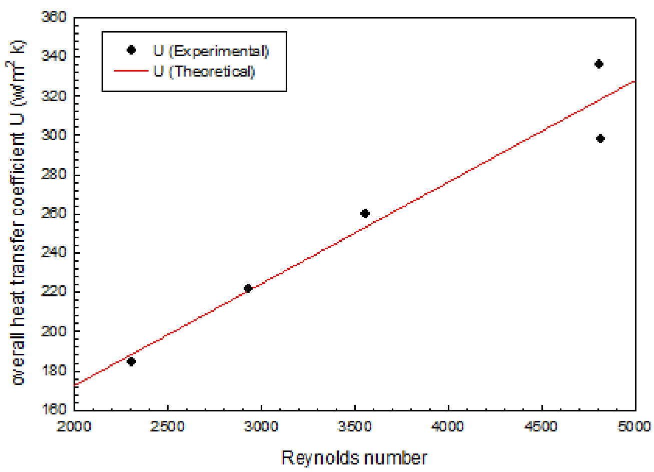

Figure 3: Experimental Setup Calibration

RESULTS AND DISCUSSIONS

Sol gel process is adopted for preparation of CuO nano particles. CuO is extracted from copper nitrate. Here CuO is used as precursor and copper nitrate is the raw material..In order to dissolve the raw material isopropyl alcohol is used as a solvent. Polyvinylpyrolideneis employed to connect the metal centers with M-O-M bridges, so that no polymers are generated in solution. Thus the formation of a gel like biphasic system containing both a liquid phase and a solid phase takes place. Surfactantcetyltrimethyl ammonium bromide is used to decrease the surface tension of the solution. It also maintains the stability of nanoparticles. Three dimensional network structure gels are formed due to the aging of sols. The catalyst used is ammonium hydroxide. It helps in precipitation of nanoparticles. Nanoparticles are obtained by passing the precipitate through drying and sintering processes. A probe sonicator is used for preparation of CuO-water nanofluid with different volumetric concentrations ranging from 0.1 to 0.5% by volume of nanoparticles. Surfactant is added to nanofluid to ensure the stability of nanoparticles. Then the experiments are conducted for different mass flow rates of nanofluids and different volume fractions of nanoparticlesbefore the nanoparticles are settled down in the nanofluid.

The experiments are conducted for different mass flow rates and volumetric concentrations of nanoparticles in nanofluids in a concentric tube heat exchanger. The inlet and outlet temperatures of cold nanofluid and hot water and mass flow rates of hot and cold fluids are recorded for the given mass flow rate and volumetric fraction of nanoparticles in nanofluid. The procedure laid down in the experimental setup section was used for calculation of experimental overall heat transfer coefficient. The variation of Reynolds number or mass flow rate of nano fluid flowing through the annulus on experimental overall heat transfer coefficient for different volumetric concentrations of nanoparticles in water is depicted in the figure 4. The effect of Reynolds number of pure water on experimental heat transfer coefficient for different mass flow rates is also shown in the figure 4. It was observed from the Figure 4 that the overall heat transfer coefficient is enhanced by 22% with volume fraction of 0.5 percent of CuO nanoparticles in CuO-water nanofluid compared with pure water at a Reynolds number of 5000. This is due to increase in thermal conductivity of CuO-water nanofluid with the addition of CuO nanoparticles. Also the random motion of CuO nanoparticles suspended in water and availability of larger surface area with nano sized particles increases heat transfer to the cold fluid from the hot fluid. With the increase in volume fraction of nanoparticles in the base fluid water the experimental heat transfer coefficient of CuO-water nanofluid increases due more number of CuO particles present in the base fluid with increase in volume fraction. The same trend can be observed in the figure 4. Also it can be observed from Figure 4 that the experimental heat transfer coefficient of the CuO-water nanofluid increases with the increase in flow rate of nanofluid.

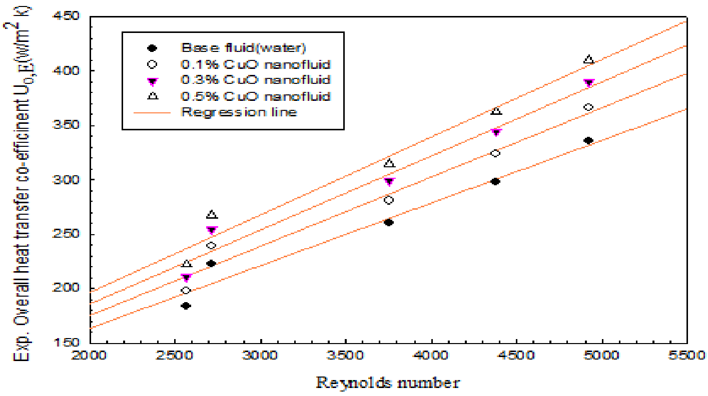

Figure 4: Effect of Reynolds Number on Experimental Overall Heat Transfer Coefficient

The physical and thermal properties density, viscosity and specific heat of the CuO-water nanofluid are calculated using the correlations available in literature. The thermal conductivity of nanofluid is calculated by using the procedure given by Hamilton and Crosser [19]. They found that the thermal conductivity of nanofluid depends on thermal conductivity of both base fluid and nanoparticles material, volume fraction of nanoparticles, surface area of nanoparticles and shape of nanoparticles in the liquid. The properties of nanofluid are calculated at bulk mean temperature of CuO-water nanofluid to determine the theoretical overall heat transfer coefficient. The hot water properties are calculated at bulk mean temperature of hot fluid. The procedure laid down in the experimental setup section was used for calculation of theoretical overall heat transfer coefficient. As expected theoretical overall heat transfer coefficientincreases with increase in mass flow rate of the nano-fluid and volume fraction of CuO particles in the CuO-water nanofluid. The effect of Reynolds number of CuO-water nanofluid flowing through the annulus on theoretical overall heat transfer coefficient for different CuO nanoparticle concentrations in base fluid is shown in figure 5. The effect of Reynolds numberon theoretical overall heat transfer coefficient for pure water is also shown in figure 5.

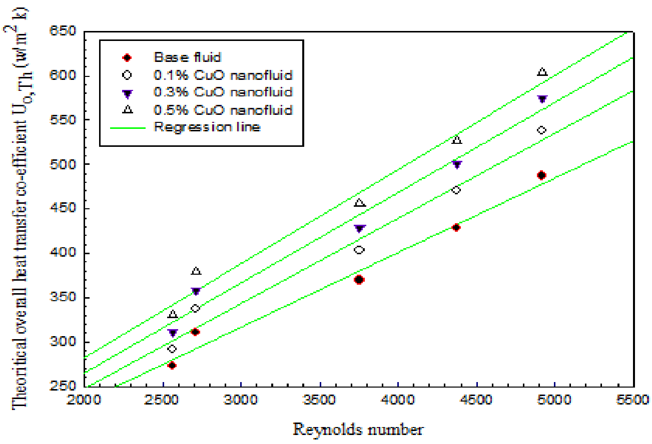

Figure 5: Effect of Reynolds of CuO –Water Nanofluid on Theoretical Overall Heat Transfer Coefficient

CONCLUSIONS

Sol gel technique is used for preparation of CuO nano particles. The raw material copper nitrate is dissolved in water, Cetyltrimethyl ammonium bromide and polyvinyl pyrolidene for preparation of solution. A gel is then formed by filtration. The gel is dried in hot air oven at 70^0C for 8 hoursto get the nano sized particles. The nanoparticles are sintered for 3 hours at a temperature of 200^0Cin the furnaceto remove the liquid traces completely from nanoparticles. The method given by choi et al.[6] is adopted for preparation of CuO-water nanofluid at different volume fractions of CuO nanoparticles. Experiments are carried out in a concentric tube heat exchanger. The heat exchanger is calibrated before conducting the experiments. The CuO-water nanofluid is passed through annulus and hot water is sent through copper tube and temperature and flow rate readings are noted down. The experimental overall heat transfer coefficients of CuO-water nanofluid are compared with pure water. It is found that the overall heat transfer coefficient for CuO-water nanofluid is increased by 22% with CuO nanoparticles volume fraction 0.5% in nanofluid compared with pure water. The increase in heat transfer is due to increase in thermal conductivity of CuO-water nanofluid with the addition of CuO nanoparticles. Also the random motion of CuO nanoparticles suspended in water and availability of larger surface area with nano sized particles increases heat transfer to the cold fluid from the hot fluid. With the increase in volume fraction of nanoparticles in the base fluid water the experimental heat transfer coefficient of CuO-water nanofluid increases due more number of CuO particles present in the base fluid with increase in volume fraction.

REFERENCES

1. Pak B., Cho Y., Hydrodynamic and heat transfer study of dispersed fluids with sub-micron metallic oxide particles, Experimental Heat Transfer, 11 (1998) 151-170.
2. Lee S, Choi S.U.S, Li S, Eastman J.A., Measuring thermal conductivity of fluids containing oxide nanoparticles. ASME J Heat Transfer, 121 (1999) 280–289.
3. Roy G, Nguyen CT, Lajoie PR (2004) Numerical investigation of laminar flow and heat transfer in a radial flow cooling system with the use of nanofluids. Superlatt.Microstruct, 35: 497-511.
4. Xuan Y, Li Q, Heat transfer enhancement of nanofluids, Int J Heat Fluid Flow 21 (2000) 58–64.
5. Xuan Y, Roetzel W, Conceptions for heat transfer correlation of nanofluids, Int. J. Heatand Mass Transfer, 43 (2000) 3701-3707.
6. Choi S.U.S, Zhang Z.G, Yu W, Lockwood F.E, Grulke E.A., Anomalous thermal conductivity enhancement in nanotube suspension, ApplPhysLett 79 (2001) 2252–2254.
7. Xie H, Wang J, Xi T, Liu Y, Ai F, Wu Q., Thermal conductivity enhancement of suspensions containing nanosized alumina particles, J ApplPhys 91(2002) 4568–4572.
8. Das S.K, Putra N, Thiesen P, Roetzel W., Temperature dependence of thermal conductivity enhancement for nanofluids, ASME J Heat Transfer 125 (2003) 567–574.
9. Xue Q.Z., Model for effective thermal conductivity of nanofluids, Phys. Lett. A., 307 (2003) 313-317.
10. Yu W, Choi S.U.S., The role of interfacial layer in the enhanced thermal conductivity of nanofluids- A renovated Maxwell model, Journal of Nanoparticles Research, 5 (2003) 167-171.
11. Wen, D. and Ding, Y. Effective thermal conductivity of aqueous suspensions of carbon nanotubes (carbon nanotube nanofluids). Journal of Thermophysics and Heat Transfer, 18, no. 4, 481–485 (2004a).
12. Hwang, Y. J., Ahn, Y. C., Shin, H. S., Lee, C. G., Kim, G. T., Park, H. S., and Lee, J. K. Investigation on characteristics of thermal conductivity enhancement of nanofluids. Current Applied Physics, 6, no. 6, 1068–1071 (2005).
13. Yang Y, Zhang Z.G., Grukle A.K., Anderson W.B., Wu G., Heat transfer properties of nanoparticle-in-fluid dispersions (nanofluids) in laminar flow, Int. J. Heat and Mass Transfer, 48 (2005) 1107-1116
14. Assael M., Metaxa I., Arvanitidis J., Christofilos D., Lioutas C., Thermal conductivity enhancement in aqueous suspensions of carbon multi-walled and double-walled nanotubes in the presence of two different dispersants, Int J Thermophysics, 26 (2005) 647-664.
15. Pantzali, M.N.; Kanaris, A.G.; Antoniadis, K.D.; Mouza, A.A. &Paras, S.V., Effect of nanofluids on the performance of a miniature plate heat exchanger with modulated surface. Int. J. Heat Fluid Flow, 30 (2009), 691-699.

16. Noie. S. H., S. ZeinaliHeris, M. Kahani, S.M. Nowee., Heat transfer enhancement using Al2O3/water nanofluid in a two-phase closed thermo-syphon, International Journal of Heat and Fluid Flow 30 (2009) 700–705
17. Heris, S., Esfahany, M., and Etemad, S. G. Experimental investigation of convective heat transfer of Al_2O_3/water nanofluid in circular tube. International Journal of Heat and Fluid Flow, 28, no. 2, 203–210 (2007).
18. Zhang X, Gu H, Fujii M, Effective thermal conductivity and thermal diffusivity of nanofluids containing spherical and cylindrical nanoparticles, Expt. Thermal Fluid Sciences, 31 (2007) 593-599.
19. Hamilton R.L., Crosser O.K., Thermal conductivity of heterogeneous two-component systems**,** I&EC Fundam**.,** 1 **(**1962**)** 182–191.