International Journal of Applied Engineering Research ISSN 0973-4562 Volume 10, Number 20 (2015) pp 41371-41376

A Review on Performance Characteristics of Heat Exchangers using Nanofluids

Subhasisa Rath

*PG Scholar Department of Mechanical Engineering Institute of Technical Education & Research (ITER)
Siksha 'O' Anusandhan University Bhubaneswar-751030, Odisha, India E-mail: subhasisa.rath@gmail.com*

Sikata Samantaray

*Assistant Professor Department of Mechanical Engineering Institute of Technical Education & Research (ITER)
Siksha 'O' Anusandhan University Bhubaneswar-751030, Odisha, India E-mail: sikatasamantaray@soauniversity.ac.in*

Abstract

Nowadays the heat exchanger with higher heat transfer in less area density is the vital requirement of the modern world. A Nanofluid is a fluid which contains nanometer-sized particles, called nanoparticles. Nanofluids are prepared by colloidal suspensions of nanoparticles as additives in a base fluid. The nanoparticles that are used in nanofluids are typically made of metals, oxides or carbides. Nanofluids have attractive thermal properties that make them potentially useful in many heat exchangers because of its superior thermal properties. The development of high performance thermal systems for heat exchanger enhancement has become popular nowadays. Nanofluids are primarily used as coolant in heat exchangers for the enhancement of its performance such as overall heat transfer coefficient. The performance of heat exchangers using different nanoparticles and its applications have been reviewed and presented in this paper. Study of optimization of the heat exchanger with nanofluid to maximize heat transfer and minimize economic cost is very limited.

Keywords: Heat Transfer; Heat Exchangers; Heat Transfer Co-efficient; Thermal Conductivity; Nanofluids; Entropy generation; Exergy loss; pumping power

Introduction

The fluids are generally used as a coolant for many industrial applications due to its superior thermal properties and hence the enhancement of the heat transfer behavior of these nanofluids is a key importance in many applications. In 1995 **Choi (1995)** developed a new class of fluids called nanofluids by dispersing nanometer-sized materials (nanoparticles) in the base fluids. The commonly used nanoparticles are CuO, Al_2O_3, TiO_2, ZnO, Fe_3O_4, SiO_2, Ag etc.

Heat exchanger's performance can be improved by increasing the thermal conductivity of the working fluid. Improving heat exchanger's performance by increasing the overall heat transfer coefficient as well as minimizing pressure drop is one of the most important fields of research to focus on. Nanofluids with higher thermal conductivity and better thermo-physical properties can be applied in heat exchangers to increase the heat transfer rate, So as to increase the performance of the heat exchangers.

The main aim behind the development of nanofluids is to use them as working fluids for different heat transfer application, where the enhancement of heat transfer coefficient and thus the size of heat transfer equipment can be reduced. It has been found that the nanofluids possess enhanced thermo physical properties such as thermal conductivity, thermal diffusivity, viscosity, and convective heat transfer coefficients as compared to those of base fluids such as oil, water or any other liquids

Preparation of Nanofluids

The preparation of nanofluids needs careful attention, as the properties of nanofluids largely depends on the suspension of nanoparticles. Nanofluids are classified according to the type material used as metallic and nonmetallic nanoparticles. Nanofluids are not only a simple mixture of liquid-solid, some key requirements are essential, such as, even and stable suspension, durable suspension, negligible agglomeration of particles, no chemical change of the fluid, etc. The base fluids such as water, ethylene glycol, oils, etc are used for the preparation of nanofluids. Agglomeration is a major problem for the synthesis of nanofluids. Different techniques used for the preparation of nanofluids are: the single-step method and the two-step method.

The single-step direct evaporation approach was developed by **Akoh et al. (1978)** and it is called as the VEROS (Vacuum Evaporation onto a Running Oil Substrate) technique. But it was very difficult to separate the nanoparticles from the base fluids to produce dry nanoparticles.

A modified VEROS process was developed by **Wagener et al. (1997).** They employed a high pressure magnetron sputtering for the preparation of nanofluids with metal nanoparticles such as Ag and Fe. Modified VEROS technique was developed by **Eastman et al. (1997).** In which Cu vapor is directly condensed into nanoparticles in contact with a flowing low-vapor-pressure liquid.

A new one-step chemical method for preparing Cu nanofluids by taking ethylene glycol as the base fluid was developed by **Zhu et al. (2004)** under microwave irradiation. Vacuum-submerged arc nanoparticle synthesis system (SANSS) method had been developed by **Lo et al. (2005)** for the preparation of Cu-based nanofluids. In which different dielectric liquids such as de-ionized water, with 30%, 50%, 70% volume solutions of ethylene glycol and pure ethylene glycol are used as the base fluid. CuO, Cu_2 O, and Cu based nanofluids can also be prepared by this technique. The advantage of the one step technique is that nanoparticle agglomeration is minimized, and the disadvantage is that only low vapor pressure fluids are compatible in this process.

In the two-step method nanoparticles are first produced and then dispersed in the base fluids. Generally, ultrasonic equipment is used for disperse the nanoparticles and to reduce the agglomeration of particles. **Eastman et al. (1997), Lee et al. (1999), and Wang et al. (1999)** used this method for the preparation of Al_2O_3 nanofluids.

Murshed et al. (2005) prepared TiO_2 suspension in water using the two-step method. Cu/water nanofluids having nanoparticle sizes of 1-100 nm is prepared using the two-step method by **Li et al. (2007)**

As compared to the single-step method, the two-step technique is more efficient for oxide nanoparticles, while it is less efficient for metallic particles.

Performance Analysis

Gabriela Huminic (2011)-A numerical study had been carried out under a laminar flow condition on the heat transfer behavior of nanofluids through a counter-flow double tube helical heat exchanger. In this work CuO/water and TiO_2/water nanofluids were used to investigate the heat transfer characteristics. And it was found that with the use of CuO/water and TiO_2/water nano-fluids the convective heat transfer in the laminar flow regime enhanced, and this enhancement increases with particle concentration level. Also, with increasing particle concentration level from the inner tube the outlet water temperature increases.

M.A. Khairul (2013)-The effects of water and CuO/water nanofluids (as coolants) on heat transfer coefficient, heat transfer rate, frictional loss, pressure drop, pumping power and exergy destruction in the corrugated plate heat exchanger was studied and examined. And it was found that the heat transfer coefficient of CuO/water nanofluids enhanced about 18.50 to 27.20% with the increase of volume concentration of nanoparticles from 0.50 to 1.50% as compared to water. But the exergy loss was reduced by 24% for the use of nanofluids in heat exchangers as compared to water.

The most important thermo physical property of nanofluids is thermal conductivity. The thermal conductivity of nanofluids depends on several factors such as volume fraction, temperature, material type, size and shape. **(W. Yu-2008 & E.V. Timofeeva-2011)-**It had been found that the thermal conductivity of nanofluid increases linearly with respect to the volume fraction of nanoparticles (**X. Wang-1999 & H. Xie-2002).**

M.A. Khairul (2013)-Heat transfer and the thermodynamic second law analysis of a helical coil heat exchanger using three different types of nanofluids (e.g. CuO/water, Al2O3/water and ZnO/water) were presented in this paper. Here the heat transfer coefficient and the entropy generation rate of helical coil heat exchanger were analytically investigated by considering the nanofluid volume Concentration and volume flow rates in the range of 1–4% and 3–6 L/min, respectively. And it was obtained that among the three nanofluids, CuO/water nanofluid had increased heat transfer rate and reduced entropy generation rate. The shape of the nanoparticle has also significant role to enhance rate of heat transfer.

M.M. Elias (2013)-The effect of different nanoparticle shapes (cylindrical, bricks, blades, and platelets) on the overall heat transfer coefficient, heat transfer rate and entropy generation of shell and tube heat exchanger with different baffle angles and segmental baffle were studied in this paper. And it was found that among all the shapes, nanofluid having cylindrical shape showed better overall heat transfer coefficient and for 20^0 baffle angles maximum overall heat transfer coefficient was found. The entropy generation rate was found very low for the cylindrical shape as compared to any other shapes at 20^0 baffle angle.

Kanjirakat Anoop (2013)-The thermal performances of nanofluids in heat exchangers was investigated in this study. Three mass particle concentrations of 2%, 4%, and 6% of silicon dioxide–water (SiO_2 –water) nanofluids were prepared by dispersing 20 nm diameter nanoparticles in distilled water. And from the experiment it was found that depending on flow rate both augmentation and deterioration of heat transfer coefficient for nanofluids was observed, the order of heat transfer enhancement was similar to that of thermal conductivity enhancements, increased in pressure drop with increase in viscosity, and there was an increase in heat transfer rate and the requirement of pumping power for these systems was also more.

N. Kannadasan (2012)-A comparison of heat transfer and pressure drop in a helically coiled heat exchanger held in horizontal and vertical positions by using CuO/water nanofluids was represented in this paper. And from the experimental results, it was found that as compared to water there was not much difference between horizontal and vertical arrangements in the enhancement of convective heat transfer coefficient and friction factors of nanofluids. But for higher concentration nanofluids, the friction factors obtained were high at low flow rates.

Arun Kumar Tiwari (2013)-The heat transfer performances of the plate heat exchanger using different nanofluids (CeO_2, Al_2O_3, TiO_2 and SiO_2) for various volume flow rates and wide range of concentrations was compared experimentally. And it was found that CeO_2 /water had maximum performance index enhancement of 16% with lower optimum concentration of (0.75 vol. %). At low volume concentrations, TiO_2 and CeO_2 nanoparticles had better heat transfer characteristics and at high volume concentrations $Al_2O_3$and SiO_2 nanoparticles were more effective.

Zan Wu, Lei Wang (2013)-For both laminar flow and turbulent flow inside a double-pipe helically coiled heat exchanger, the pressure drop and convective heat transfer coefficient of water and five alumina/water nanofluids of weight concentrations 0.78% wt., 2.18% wt., 3.89% wt., 5.68% wt. and 7.04% wt. were experimentally investigated in this paper. Here the effect of nanoparticles on critical Reynolds number was negligible. And it was found that at any average temperature, the pressure drop and heat transfer performances for water and the five nanofluids were identical.

Shive Dayal Pandey (2012)-The effects of nanofluid (Al_2O_3 in water 2, 3 and 4 vol.%) and water as coolants on heat transfer, frictional losses and exergy loss in a counter flow corrugated plate heat exchanger were experimentally investigated in this paper. And it was found that the heat transfer characteristics improved with increase in Reynolds number and Peclet number and with decrease in nanofluid concentration and with increase in nanofluid concentration for a given heat load, the required pumping power increased. Both power consumption and heat transfer rates were lower for water as compare to the nanofluids.

Pradyumna Ghosh (2013)-The heat transfer characteristics and pressure drop in a chevron-type corrugated plate heat exchanger using CeO_2/water nanofluid were experimentally investigated in this paper. It was found that the nanofluid in plate heat exchanger has maximum of 39% higher heat transfer coefficient compared to water at maximum concentration of 0.75 vol. %. The heat transfer coefficient of the nanofluid increases with an increased in the volume flow rate of the hot water and nanofluid, and negligible rise in pressure drop at optimum concentration.

F.S. Javadi (2013)-The effects of nanofluid on thermo-physical properties and heat transfer characteristics of a plate heat exchanger was experimentally investigated in this paper. In this study SiO_2, TiO_2 and Al_2O_3 are applied in a plate heat exchanger and the effects are compared with the base fluid. And it was found that TiO_2 and Al_2O_3 had the higher thermo-physical properties as compared to SiO_2 but the overall heat transfer coefficient was highest for Al_2O_3 nanofluid, which was 308.69 W/m2.K in 0.2 vol.% nanoparticle concentration. By using SiO_2 nanofluid, the heat transfer rate was improved around 30% and the pressure drop was reduced around 50% as compared to TiO_2 and Al_2O_3. The pressure drop increases because of high density of nanoparticles as compared to the base fluid and with increasing nanoparticle concentration.

Dustin R. Ray, Debendra K. Das (2013)-performance in a compact minichannel plate heat exchanger was studied theoretically by taking three nanofluids, aluminum oxide, copper oxide and silicon dioxide nanoparticles in ethylene glycol and water mixture. It had been found that all nanofluids have better performance compared to the base fluid.

T. Srinivas (2013)-The performance of a helical coil heat exchanger was evaluated in terms of the energy consumed to heat another fluid by using Al_2O_3 /water nanofluid. It had been found that, energy savings were more in laminar and turbulent regions than transition regime, and with increase in nanoparticle concentration, the percentage energy savings increased.

Ahmad Ghozatloo (2013)-The Convective heat transfer enhancement in a shell and tube heat exchanger under laminar flow was experimentally investigated by using graphene nanofluids. And it had been found that by adding 0.075% of graphene to the base fluid, the thermal conductivity improved up to 31.83%.

Wang et al. (1999)-By a steady-state parallel-plate technique the thermal conductivity of nanofluids were measured. Where the base fluids (water, ethylene glycol, and engine oil) contained 28 and 23 nm average diameters of Al_2O_3 and CuO suspended nanoparticles, respectively. And it had been found that the thermal conductivity of all the nanofluids were more than their base fluids. And also, the thermal conductivity of nanofluids increases with decreasing the size of nanoparticles.

Xuan and Li (2000)-By using Cu nanoparticles of comparatively large size (100 nm) to the same extent as that of using CuO particles of smaller size (36 nm), the thermal conductivity of water increases. And the stability of suspension can be improved by proper selection of dispersants. They used oleic acid for transformer oil-Cu nanofluids and laurite salt for water-Cu suspension in their study and it had been found that Cu particles in transformer oil had superior characteristics to that of suspension of Cu particles in water.

Eastman et al. (2001)-By using pure Cu nanoparticles of less than 10 nm size, it had been found that the thermal conductivity increases by 40% for only 0.3% volume fraction of the Cu nanoparticles dispersed in ethylene glycol. Also, they found by additive acid the suspension can stabilize and thus can increase the thermal conductivity.

Hong and Yang (2005)-Fe-nanofluid was prepared by taking ethylene glycol as base fluid. By a chemical vapor condensation process, Fe nanoparticles with mean size of 10 nm were prepared. And it was found that Fe nanofluids exhibited higher thermal conductivity than Cu nanofluids.

Das et al. (2003)-The effect of temperature on thermal conductivity for nanofluids containing Al_2 O_3 (38.4 nm) or CuO (28.6 nm) by using the temperature oscillation method. It was found that a (2 to 4) % increase in thermal conductivity over the temperature range of 21^0 C to 52^0 C. and smaller nanoparticles has greater increase of thermal conductivity with temperature as compared to larger nanoparticles.

Li and Peterson (2006)-An experimental investigation was conducted to examine the effects of the temperature variations and volume fraction on the thermal conductivity of water suspensions CuO (29 nm) and Al_2O_3 (36 nm). It was found that material of the nanoparticle, diameter of the nanoparticle, volume fraction and bulk temperature has significant effects on the thermal conductivity of the nanofluids.

Patel et al. (2003)-Nanofluids were prepared as gold (Au) and silver (Ag) nanoparticles with thoriate and citrate as coatings in water to check the enhancement of thermal conductivity with respect to the concentrations. And it was found that there was 5%-21% enhancement of the thermal conductivity of nanofluids for water with citrate in the temperature range 30^0C– 60^0C at a very low concentration of 0.00026 volume% of Ag particles and a concentrations of 0.011% of Au particles, the thermal conductivity was improved around 7%-14%.

Zhang et al. (2007)-The effective thermal conductivity and thermal diffusivity of Au/totuene, Al_2O_3/water, TiO_2 /water, CuO/water nanofluids were measured using the transient short-hot-wire (SHW) technique, which is based on the numerical solution of two-dimensional transient heat conduction for a short wire. The diameters of Au, Al_2O_3, TiO_2 and CuO spherical particles were 1.65, 20, 40 and 33 nm, respectively. It had been found that the effective thermal conductivities of the nanofluids show no such enhancement but the thermal diffusivity enhanced by a small amount.

Hwang et al. (2005)-The thermal conductivity of four kinds of nanofluids such as MWCNTs in water, CuO in water, SiO2 in water, and CuO in ethylene glycol were compared. And it was found that the thermal conductivity of MWCNT nanofluid increased up to 11.3% at 1 volume%, which is relatively higher than that of the other nanofluids.

Liu et al. (2005)-The thermal conductivities of nanofluids containing CNTs dispersed in ethylene glycol and synthetic engine oil were measured. The increase of thermal conductivity is up to 12.4% for CNT-ethylene glycol suspensions at 1.0 vol% and 30% for CNT-synthetic engine oil suspensions at 2 vol%.

Li et al. (2002)-The viscosity of water with CuO nanoparticle suspensions using a capillary viscometer was measured. And it was showed that with increasing temperature the viscosity of nanofluids decreased.

Wang et al. (1999)-The relative viscosity of Al_2O_3-water and Al_2O_3-ethylene glycol nanofluids were measured. And it was showed an increase of relative viscosity with increasing in solid volume fraction of the nanofluids.

Heris et al. (2006)-Laminar flow of CuO/water and Al_2O_3/water nanofluids were investigated through a 1 m annular copper tube with 6 mm inner diameter and with 0.5 mm thickness and 32 mm diameter outer stainless steel tube, where to create a constant wall temperature boundary condition saturated steam was circulated. And it was found that the heat transfer coefficient increased with increasing volume fraction of nanoparticles, as well as Peclet number, while Al_2O_3/water showed more enhancements as compared to CuO/water.

Chien et al. (2003)-Gold (17nm)/water nanofluids flowing in a disk-shaped miniature heat pipe with diameter of 9 mm and height of 2 mm was investigated. And it was found that with increased nanoparticle concentration the thermal resistance of the heat pipe fell appreciably.

Ding et al. (2005)-The heat transfer performance of Cu nano tube (CNT), nanofluids in a tube with 4.5 mm inner diameter was investigated. And it was found that the enhancement of heat transfer coefficient is much higher than the increase in the thermal conductivity.

Khanafer et al. (2003)-The heat transfer behavior of nanofluids in a two-dimensional horizontal enclosure was numerically investigated. Where the nanofluids were assumed as a single phase and with no slip condition between base fluid and particles. And it was found that the heat transfer rate increased with the particle concentration at any given Grashoff number.

Nguyen et al. (2007)-The heat transfer enhancement of an Al_2O_3/water nanofluid inside a closed system was experimentally investigated. This is used for cooling of micro-electronic components. And by introducing the nanoparticles into distilled water, it was found that there was a considerable enhancement convective heat transfer coefficient of the cooling block.

Bang and Chang (2005)-The boiling of Al_2O_3-water nanofluids on a 100 mm square surface at high heat fluxes was studied and it was observed that the surface roughness increased after boiling with nanoparticle concentration. But the critical heat flux was increased to 32% and 13% for a horizontal flat surface and a vertical flat surface, respectively.

Lee and Mudawar (2007)-A microchannel cooling using Al_2O_3/water nanofluids was prepared. And it was found that the high thermal conductivity of nanoparticles was only enhanced the single-phase heat transfer coefficient, for laminar flow only and higher heat transfer coefficients were achieved mostly in the entrance region of the microchannels, and it was weaker in the fully developed region.

M. Akbari (2011)-The analysis of single and three different two-phase models (volume of fluid, mixture, Eulerian) for CFD studies of Al_2O_3/water nanofluid heat transfer was compared. And it was found that the single-phase and the two-phase models had almost same hydrodynamic fields but different thermal fields, three two-phase models were also identical and the two-phase models give closer value of the convective heat transfer coefficient to the experimental data than the single-phase model.

Conclusion

This paper represents an overview of the recent developments in the study of heat transfer using different nanofluids with different sizes of nanoparticles and different volume concentrations of the nanofluid. Many important, complex and interesting phenomena involving nanofluids have been reported in this review literature. It is clear that researchers have given more attention to the thermal conductivity of the fluids rather than the heat transfer characteristics. The thermal conductivity of nanofluids largely depends on the volume concentration, size of the nanoparticles and the bulk temperature. With the use of nanofluids, thermal conductivity and heat transfer characteristics increases where as pressure drop and entropy generation or exergy loss increases, which is the main challenge for the researchers. The use of nanofluids in a wide range of applications gives a new concept towards the enhancement of heat transfer characteristics, but the development of this field faces several challenges, such as, the poor performance of suspensions of nanoparticles in base fluid and lack of theoretical understanding of the mechanisms. Further theoretical and experimental research and investigations are required for better understanding of the heat transfer characteristics of nanofluids.

References

[1] Ahmad Ghozatloo, Alimorad Rashidi, Mojtaba Shariaty-Niassar (**2014**). Convective heat transfer enhancement of graphene nanofluids in shell and tube heat exchanger. Experimental Thermal and Fluid science, 53.

[2] Akoh, H., Tsukasaki, Y., S.Yatsuya, and Tasaki, (**1978**). A. Magnetic properties of ferromagnetic ultrafine particles prepared by vacuum evaporation on running oil substrate. Journal of Crystal Growth, 45, 495–500.

[3] Arun Kumar Tiwari, Pradyumna Ghosh, Jahar Sarkar (**2013**), Performance comparison of the plate heat exchanger using different nanofluids. Experimental Thermal and Fluid science, 49.

[4] Bang I. C. and Chang, S. H. (**2004**). Boiling heat transfer performance and phenomena of Al2O3-water nanofluids from a plain surface in a pool. In Proceedings of ICAPP. Pitterburgh, US.

[5] Bang I. C. and Chang, S. H. (**2005**). Boiling heat transfer performance and phenomena of Al2O3-water nano-fluids from a plain surface in a pool. International Journal of Heat and Mass Transfer, 48, no. 12, 2420–2428.

[6] Chien, H.-T., Tsai, C.-I., Chen, P.-H., and Chen, P.-Y. (**2003**). Improvement on thermal performance of a diskshaped miniature heat pipe with nanofluid. ICEPT 2003. Fifth International Conference on Electronic Packaging Technology. Proceedings. (IEEE Cat. No.03EX750), 389. IEEE, Shanghai, China.

[7] Choi SUS (**1995**). Enhancing thermal conductivity of fluids with nanoparticles. In: Signer DA, Wang HP (eds) Developments applications of non newtonian flows, FED-vol. 231/MD-vol. 66, ASME, New York, pp 99–105.

[8] Das, S. K., Putta, N., Thiesen, P., and Roetzel, W. (**2003**). Temperature dependence of thermal conductivity enhancement for nanofluids. ASME Trans. J. Heat Transfer, 125, 567–574.

[9] Ding, Y., Alias, H., Wen, D., and Williams, R. A. (**2005**). Heat transfer of aqueous suspensions of carbon nanotubes (CNT nanofluids). International Journal of Heat and Mass Transfer, 49, no. 1-2, 240–250.

[10] Dustin R. Ray, Debendra K. Das, Ravikanth S. Vajjha (**2013**). Experimental and numerical investigations of nanofluids performance in a compact minichannel plate heat exchanger. International communications in Heat and Mass Transfer, 71.

[11] Eastman, J. A., Choi, U. S., Li, S., Thompson, L. J., and Lee, S. (**1997**). Enhanced thermal conductivity through the development of nanofluids. Volume 457 of Materials Research Society Symposium-Proceedings, 3–11. Materials Research Society, Pittsburgh, PA, USA, Boston, MA, USA.

[12] Eastman, J. A., Choi, S. U. S., Li, S., Yu, W., and Thompson, L. J. (**2001**). Anomalously increased effective thermal conductivities of ethylene glycol-based nanofluids containing copper nanoparticles. Applied Physics Letters, 78, no. 6, 718–720.

[13] E.V. Timofeeva, W. Yu, D.M. France, D. Singh, J.L. Routbort, (**2011**). Nanofluids for heat transfer: an engineering approach, Nanoscale Research Letters 6 (1).

[14] F.S. Javadi, S. Sadeghipour, R. Saidur, G. BoroumandJazi, B. Rahmati, M.M. Elias, M.R. Sohel (**2013**). The effects of nanofluid on thermophysical properties and heat transfer characteristics of a plate heat exchanger. International communications in Heat and Mass Transfer, 44.

[15] Gabriela Huminic and Angel Huminic (**2011**). Heat transfer characteristics in double tube helical heat exchangers using nanofluids.. International Journal of Heat and Mass Transfer, 54.

[16] H. Xie, J. Wang, T. Xi, Y. Liu, F. Ai, Q. Wu, (**2002**). Thermal conductivity enhancement of suspensions containing nanosized alumina particles, Journal of Applied Physics 91.

[17] Heris, S., Etemad, S. G., and Esfahany, M. (**2006**). Experimental investigation of oxide nanofluids laminar flow convective heat transfer. International Communications in Heat and Mass Transfer, 33, no. 4, 529–535.

[18] Hong, T.-K., Yang, H.-S., and Choi, C. J. (**2005**). Study of the enhanced thermal conductivity of Fe nanofluids. Journal of Applied Physics, 97, no. 6, 1–4.

[19] Hwang, Y. J., Ahn, Y. C., Shin, H. S., Lee, C. G., Kim, G. T., Park, H. S., and Lee, J. K. (**2005**). Investigation on characteristics of thermal conductivity enhancement of nanofluids. Current Applied Physics, 6, no. 6, 1068–1071.

[20] Kanjirakat Anoop, Jonathan Cox, Reza Sadr-(**2013**). Thermal evaluation of nanofluids in heat exchangers.. International Journal of Heat and Mass Transfer, 49.

[21] Khanafer, K., Vafai, K., and Lightstone, M. Bouyancy-(**2003**). Heat transfer enhancement in a two-dimensional enclosure utilizing nanofluids. International Journal of Heat and Mass Transfer, 46, 3639–3653.

[22] Lee, S. and Choi, S. U. S. (**1996**). Application of metallic nanoparticle suspensions in advanced cooling systems. In 1996 International Mechanical Engineering Congress and Exhibition. Atlanta, USA.

[23] Lee, S., Choi, S. U. S., Li, S., and Eastman, J. A. (**1999**). Measuring thermal conductivity of fluids containing oxide nanoparticles. Journal of Heat Transfer, 121, 280–289.

[24] Lee, J. and Mudawar, I. (**2007**). Assessment of the effectiveness of nanofluids for single-phase and two-phase heat transfer in micro-channels. International Journal of Heat and Mass Transfer, 50, no. 3-4, 452–463.

[25] Li, C. H. and Peterson, G. P. (**2006**). Experimental investigation of temperature and volume fraction variations on the effective thermal conductivity of nanoparticle suspensions (nanofluids). Journal of Applied Physics, 99, no. 8, 084,314.

[26] Li, J. M., Li, Z. L., and Wang, B. X. (**2002**). Experimental viscosity measurements for copper oxide nanoparticle suspensions. Tsinghua Sci. Tech., 7, no. 2, 198–201.

[27] Liu, M.-S., Ching-Cheng Lin, M., Huang, I. T., and Wang, C.-C. (**2005**). Enhancement of thermal conductivity with carbon nanotube for nanofluids. International Communications in Heat and Mass Transfer, 32, no. 9, 1202–1210.

[28] Lo, C.-H., Tsung, T.-T., and Chen, L.-C. (**2005**). Shape controlled synthesis of Cu-based nanofluid using submerged arc nanoparticle synthesis system (SANSS). Journal of Crystal Growth, 277, no. 1-4, 636–642.

[29] Lo, C.-H., Tsung, T.-T., and Chen, L.C-(**2006**). Ni nanomagnetic fluid prepared by submerged arc nano synthesis system (SANSS). JSME International

Journal, Series B: Fluids and Thermal Engineering, 48, no. 4, 750–755.

[30] M.A. Khairul, M.A. Alim, I.M. Mahbubul, R. Saidur, A. Hepbasli and A. Hossain-(**2014**). Heat transfer performance and exergy analyses of a corrugated plate heat exchanger using metal oxide nanofluids. International Journal of Heat and Mass Transfer, 50.

[31] M.A. Khairul, R. Saidur, M.M. Rahman, M.A. Alim, A. Hossain, Z. Abdin-(**2013**). Heat transfer and thermodynamic analyses of a helically coiled heat exchanger using different types of nanofluids. International Journal of Heat and Mass Transfer, 67.

[32] M. Akbari, N. Galanis, A. Behzadmehr-(**2011**). Comparative analysis of single and two-phase models for CFD studies of nanofluid heat transfer.. International Journal of Thermal Science, 50.

[33] M.M. Elias, I.M. Shahrul, I.M. Mahbubul, R. Saidur, N.A. Rahim-(**2014**). Effect of different nanoparticle shapes on shell and tube heat exchanger using different baffle angles and operated with nanofluid.. International Journal of Heat and Mass Transfer, 70.

[34] Murshed, S. M. S., Leong, K. C., and Yang, C. (**2005**). Enhanced thermal conductivity of TiO2 – Water based nanofluids. International Journal of Thermal Sciences, 44, no. 4, 367–373.

[35] N. Kannadasan, K. Ramanathan, S. Suresh-(**2012**). Comparison of heat transfer and pressure drop in horizontal and vertical helically coiled heat exchanger with CuO/water based nano fluids. Experimental Thermal and Fluid science, 42.

[36] Nguyen, C. T., Roy, G., Gauthier, C., and Galanis, N. (**2007**). Heat transfer enhancement using Al2O3-water nanofluid for an electronic liquid cooling system. Applied Thermal Engineering, 27, no. 8-9, 1501– 1506.

[37] Patel, H. E., Das, S. K., Sundararagan, T., Nair, A. S., Geoge, B., and Pradeep, T. (**2003**). Thermal conductivities of naked and monolayer protected metal nanoparticle based nanofluids: Manifestation of anomalous enhancement and chemical effects. Applied Physics Letters, 83, 2931–2933.

[38] Pradyumna Ghosh, Arun Kumar Tiwari, Jahar Sarkar**-(2013).** Heat transfer and pressure drop characteristics of CeO2/water nanofluid in plate heat exchanger. Applied Thermal Engineering, 57.

[39] Shive Dayal Pandey, V.K. Nema-(**2012**). Experimental analysis of heat transfer and friction factor of nanofluid as a coolant in a corrugated plate heat exchanger. Experimental Thermal and Fluid science, 38.

[40] T. Srinivas, A. Venu Vinod-(**2013**). Performance of an agitated helical coil heat exchanger using Al2O3/water nanoflui. Experimental Thermal and Fluid science, 51.

[41] Wang, X., Xu, X., and Choi, S. U. S. **(1999).** Thermal conductivity of nanoparticle-fluid mixture. Journal of Thermophysics and Heat Transfer, 13, no. 4, 474–480.

[42] Wagener, M., Murty, B. S., and Gunther, B. **(1997).** Preparation of metal nanosuspensions by highpressure DC-sputtering on running liquids. In Komarnenl, S., Parker, J. C., and Wollenberger, H. J. (Editors), Nanocrystalline and Nanocomposite Materials II, volume 457, 149– 154. Materials Research Society, Pittsburgh PA.

[43] W. Yu, D.M. France, J.L. Routbort, S.U.S. Choi, **(2008).** Review and comparison of nanofluid thermal conductivity and heat transfer enhancements, Heat Transfer Engineering 29 (5).

[44] X. Wang, X. Xu, S.U.S. Choi, **(1999).** Thermal conductivity of nanoparticle–fluid mixture, Journal of Thermophysics and Heat Transfer 13 (4)

[45] Xuan, Y. and Li, Q. **(2000).** Heat transfer enhancement of nanofluids. International Journal of Heat and Fluid Transfer, 21, 58–64.

[46] Zan Wu, Lei Wang, Bengt Sundén**-(2013).** Pressure drop and convective heat transfer of water and nanofluids in a double-pipe helical heat exchanger. Applied Thermal Engineering, 60.

[47] Zhang, X., Gu, H., and Fujii, M. **(2007).** Effective thermal conductivity and thermal diffusivity of nanofluids containing spherical and cylindrical nanoparticles. Experimental Thermal and Fluid Science, 31, no. 6, 593–599.

[48] Zhu, H., Lin, Y., and Yin, Y. **(2004).** A novel one-step chemical method for preparation of copper nanofluids. Journal of Colloid and Interface Science, 227, 100–103.