Experimental analysis of heat transfer enhancement within tube in tube heat exchanger by using nano fluid and jagged twisted tape inserts

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Abstract

Heat transfer & friction factor characteristics of CuO/water nanofluid have been experimentally inspected within tube in tube counter flow heat exchanger. The CuO/water nanofluid with nanopartical 0.1% by volume was engaged in circular tube equipped with full-length square jagged copper twisted tape inserts as a turbulators. Square jagged twisted tape inserts having twist ratios 4, 6 and 7 were used alternately by keeping the 0.1 vol% constant concentration of nano particles. The experimentation were performed and different readings for different set were recorded in turbulent regime with Reynolds number in between 2700 and 54000, to assessment of heat transfer increment and the friction factor. The attained results release that Nusselt number intensifies with increase in Reynolds number and shrinkage in twist ratio of twisted tape inserts. The synchronized use of square jagged twisted tape insert with twist ratio 4 and CuO/water nanofluid gives significant increase in Nusselt number value than that of the plain tube in tube heat exchanger.

Keywords : Heat transfer enhancement, Nanofluids, Tube in tube heat exchanger, Square jagged twisted tape inserts, Twist ratio.

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1. Introduction

A variety of strategies has been used to decrease the size of the heat exchanger, running costs and to increase heat transfer rate. In different fields for excellent heat transfer performance, nanofluids are used as heat transfer medium. Most of the investigators measured thermal conductivity [1-3], as well as developed some imperial relations for thermal conductivity [4-7]. The literature delivers a more thorough analysis of the study on the preparation processes and thermal property parameters of nanofluids [8]. Additionally, a selection criteria for nanofluids has been researched for use in practical applications of nanofluids [9]. Free convection and forced convection are two essential heat transfer techniques in the world of heat exchange equipment. Numerous studies on free convection have been documented in the literature. Shi et al. [10] used experimental and numerical modelling techniques to conduct research on the free convection of Fe_3O_4@CNT nanofluids in a rectangular cavity under magnetic field conditions. The results showed that the magnetic field's direction can control how well nanofluids conduct heat. Selimefendigil et al. reports [11, 12], the free convection of CNTwater nanofluids in a two-dimensional enclosure with a corrugated partition and three different types of nanofluids in a three-dimensional cavity with rotating circular cylinders were both studied using numerical methods. It was found that the rotational direction of circular cylinders also significantly affects heat transfer, and that the thermal performance of nanofluids diminishes with the height of the triangle waves in the two-dimensional enclosure. A numerical simulation research on the free convection of MWCNT-Fe_3O_4/water nanofluids in a square cavity full of porous media was given by Sajjadi et al. [13]. Results indicated that the thermal performance can be improved by raising the Darcy number and porosity. Numerous studies have been done on the natural convection of nanofluids in different cavities.

The application of CuO nanofluids within a tube in tube heat exchanger with twisted tape is the attention of the current effort. A set of square jagged twisted tape inserts (y/w = 4, 6, and 7) were used with only one concentration of nano particles as 0.1% by volume, and Reynolds numbers between 2700 and 54,000.

2. Experimentation

2.1. Nanoparticles concentration calculation & Nanofluid preparation

CuO nanoparticles with an average size of <80 nm and a density of 6349 kg/m^3 are purchased from Intelligent Materials Pvt. Ltd., which works in association with Nanoshel LLC, a corporation with its headquarters in the United States.

Figure-1: Photograph of CuO nanoparticles

The law of mixture formula is used to determine how much CuO nanoparticles are needed to prepare nanofluids. The CuO nanoparticles are extremely precisely weighed using a sensitive scale with a 0.1 mg resolution. The following relation is used to determine the weight of the nanoparticles needed to prepare 100 ml of CuO nanofluid at a specific volume concentration using distilled water as the base fluid:

$$\%volume\,concentration = \frac{\left[\dfrac{W_{CuO}}{\rho_{CuO}}\right]}{\left[\dfrac{W_{CuO}}{\rho_{CuO}} + \dfrac{W_{bf}}{\rho_{bf}}\right]}$$

Table-1 Volume concentrations of CuO nanoparticle with corresponding weight

Sr. No.	Volume concentration (φ) (%)	Weight of nanoparticles (W_{CuO}) (Grams)
1	0.1	0.60872
2	0.2	1.21865

Nanofluids can be prepared using either by a one-step method or by a two-step method. A two-step approach is used to create a CuO/Distilled water-based nanofluid with a volume concentration of 0.1%. Nanoparticles are mixed with distilled water during processing. For an hour, a magnetic stirrer is utilised in the homogenise mixer to dissolve accumulations.

Figure-2: Sample CuO/water nanofluid

2.2. Experimental apparatus

The tube in tube heat exchanger experimental setup is represented in Figure 3 and 5, respectively, along with its schematic layout and actual experimental setup. The experimental setup consists of a test section having inner tube of copper having inside diameter 19.8 mm and outer diameter of inner tube is 25.4 mm. Outer tube is of stainless steel having inner diameter 32 mm and outer diameter is 38 mm. In order to minimise heat losses to the atmosphere, the exterior pipe is effectively insulated with 15mm thick asbestos rope. Cold water and hot nanofluid flow rates are measured using two rotameters, each with a flow range of 100-1000 LPH. Two centrifugal pumps of ½ HP of capacity 2000 LPH are used. Four flow control valves are used. and collection tanks are used. For the purpose of measuring the pressure drop, two pressure tapings—one at the test section's inlet and the other at its outlet are offered and connected by pipes to the inverted U-tube manometer. Through a multipoint digital temperature indicator, four-temperature sensors (RTD) PT-100 3-wire are utilised to detect the intake & exit temperatures of hot nanofluid and cold water (i.e., Th1, Th2, Tc1, and Tc2). A hot nanofluid tank is equipped with 1500-watt electric heater. CuO-water nanofluid and different twisted tape inserts are used.

Figure-3: Experimental set up

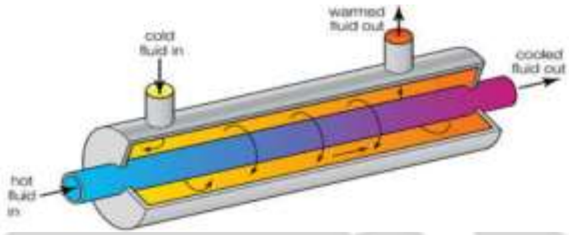

Figure-4: Cut section model of test section

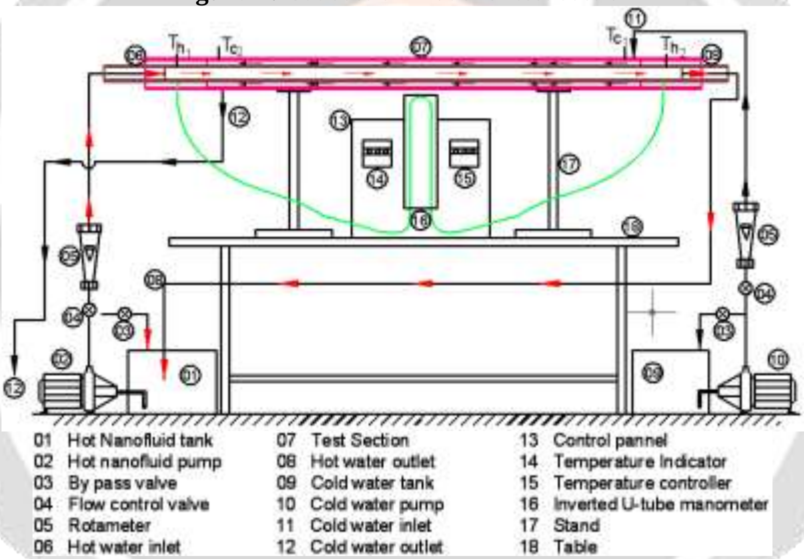

Figure-5: Schematic of experimental set up

2.3. Experimental Process

Place the nanofluids in the hot nanofluid tank, and set the temperature to the desired value i.e. 70^0C. Open every valve, flow metre, and pump in the experimental system, start the two loops of working fluids, and thoroughly inspect the experimental system for leaks. Open transmitters of U-tube differential manometer. For different hot water flow rates, such as 300, 400, 500, 600, 700, 800, and 900 LPH, note all the readings. Repeat the same process for all sets (i.e. plane tube with base fluid, nanofluid with different sets of twisted tape inserts, shown in the figure-5, 6, and 7). After completion of testing, turn off the pumps, the water heater, and the thermometer. Finally turn off the main power.

Figure-6: Square jagged copper twisted tape insert (twist ratio, y/w=7)

Figure-7: Square jagged copper twisted tape insert (twist ratio, y/w=6)

Figure-8: Square jagged copper twisted tape insert (twist ratio, y/w=4)

3. Experimental data processing

3.1. Water Properties

i) Mean bulk temperature of nanofluid hot water

$$T_{bh} = \frac{Th_2 + Th_1}{2}$$

ii) Properties of cold water

$$T_{bc} = \frac{Tc_2 + Tc_1}{2}$$

3.2. Heat given by hot nanofluid

$$Q_h = [m\,C_p\,(T_{h1} - T_{h2})]_h$$

3.3. Heat given by cold water

$$Q_c = [m\,C_p\,(T_{c2} - T_{c1})]_c$$

3.4. Average heat transfer

$$Q_{avg.} = \frac{Q_c + Q_h}{2}$$

3.5. Heat transfer coefficient (Overall)

$$Q_{average.} = A_s \Delta Tm\, U$$

i) Heat transfer surface area of tube

$$A_s = L\,\pi d_i$$

ii) LMTD (Logarithmic mean temperature difference)

$$\Delta T_m = \frac{\Delta T_1 - \Delta T_2}{\ln\left(\frac{\Delta T_1}{\Delta T_2}\right)}$$

Where,

$$\Delta T_1 = T_{h1} - T_{c2}$$

$$\Delta T_2 = T_{h2} - T_{c1}$$

3.6. Nusselt Number for cold water flowing through the annular space.

$$Nu_o = 0.023\,(R_{eo})^{0.8}\,(P_r)^{0.3}$$

$$Re_o = \frac{U_o\,D_h\,\rho}{\mu}$$

Where, $D_h = D_i - d_o$

Continuity equation

$$m_c = A_o\,U_o\,\rho$$

3.7. Cold water heat transfer coefficient flowing through the annular space between two tubes.

$$Nu_o = \frac{h_o\,D_h}{K}$$

$$h_o = \frac{Nuo\;K}{D_h}$$

3.8. Hot water heat transfer coefficient flowing through the inner tube.

$$\frac{1}{U} = \frac{1}{h_o} + \frac{1}{h_i}$$

$$\text{Where, } h_i = \frac{1}{\left(\frac{1}{U} - \frac{1}{ho}\right)}$$

3.9. Hot water Nusselt Number of flowing through the inner tube- experimental.

$$Nu_i = \frac{h_i d_i}{K}$$

3.10. Theoretical Nusselt Number by Dittus-Boelter equation of hot nanofluid flowing through the inner tube

$$Nu_i = 0.023(R_{ei})^{0.8} (P_r)^{0.3}$$

3.11. Friction Factor (Experimental)

(i) $\Delta P = h \varrho g$

(ii) $\Delta_P = \frac{f\ L\ \rho\ U_i^2}{2\ d_i}$

Where, $f = \frac{2\ g\ d_i\ h}{L\ U_i^2}$

3.12. Friction Factor (Theoretical)

$$f = 0.0055 \left(1 + \left(50 + \left(\frac{10^6}{\mathrm{Re}_i}\right)\right)^{0.33}\right)$$

3.13. Performance evaluation criteria

$$PEC = \eta = \left(Nu) \frac{\frac{Nu}{p_i}}{\frac{f_3}{f_p}} \right)$$

4. Results and discussions

By conducting initial experiments using simple tube in tube heat exchanger, it was possible to discover the precision with which the Nusselt number and friction factor could be experimentally calculated using the current experimental setup. The outcomes are contrasted with established empirical relationships and earlier studies on turbulent flow. The goal was to evaluate the apparatus's dependability.

4.1. Theoretical and experimental heat transfer for plain smooth tube

The correlation between Reynolds number and Nusselt number is represented in Figure-9. The graph reveals the correlation between Nusselt number and Reynolds number. With a maximum 20% difference, the numbers closely match the Dittus-Boelter equation.

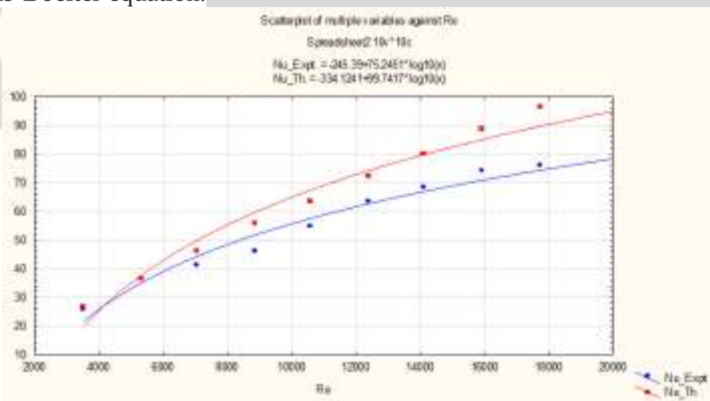

Figure-9: Nusselt number v/s. Reynolds number for plain smooth tube

4.2. Theoretical and experimental and friction factor for plain smooth Tube

The association among Reynolds number and friction factors for turbulent flow in a plain smooth tube is showed in figure-10. The attained findings are relatively nearby to theoretic values. This exhibits that the experimental test rig is authenticated and allowing for the conduct of more further experiments.

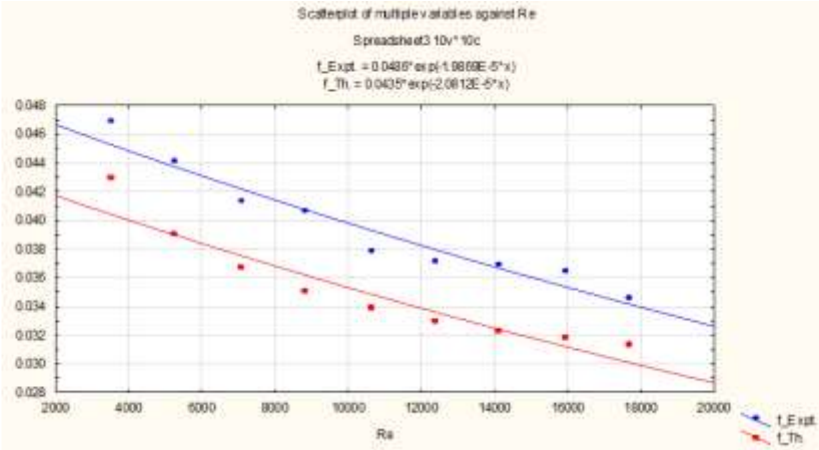

Figure-10: Friction factor v/s. Reynolds number for smooth plain tube

4.3. "Smooth Plain Tube" Vs. "Tubes with various twisted tape inserts"

The correlation between Nussult number and Reynolds number for smooth plain tubes and tubes with different inserts is described in Figure-11. According to the following graph, Nusselt number is a function of Reynolds number. When Reynolds numbers increase, the Nusselt number also rises. Therefore, a higher Reynolds number results in a greater rate of convective heat transfer.

Furthermore, it can be comprehended that for a given Reynolds number, twisted tapes with a smaller twist ratio provide the largest Nusselt numbers. Twisted tape inserts with a lower twist ratio have a improved rate of heat conduction.

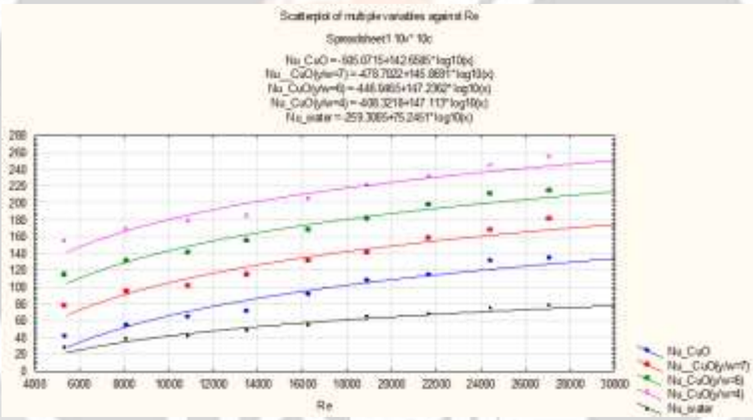

Figure-11: Nussult Number v/s. Reynolds number graph for (Y = 7, 6, 4), CuO, and water

The correlation between Reynolds number and friction factor for smooth plain tubes and tubes with altered inserts is shown in Figure-12. The graph specifies that for a plain tube, friction is minimal. For a given Reynolds number, the friction factor keeps growing as the twist ratio shrinkages.

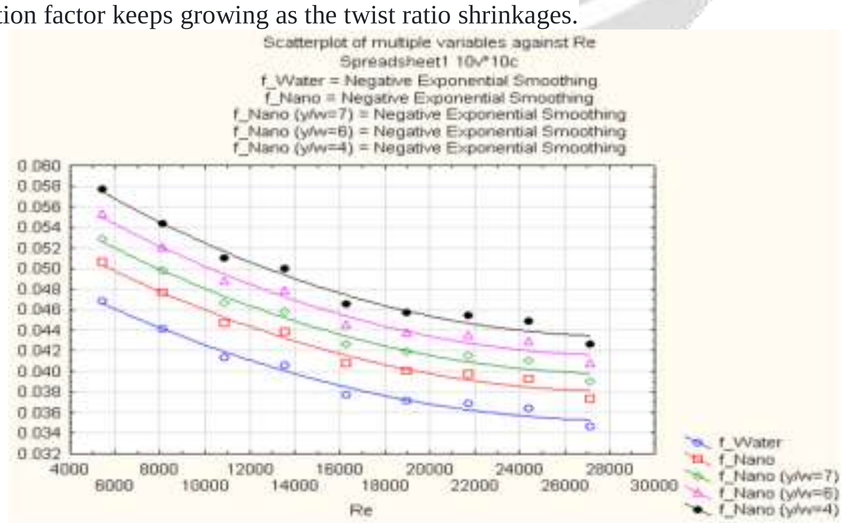

Figure-12: Friction factor v/s. Reynolds number graph for (Y = 7, 6, 4), CuO, and water

5. Conclusion

In the present work, CuO-water nanofluid with different twist ratios and a circular tube equipped with full-length square jagged twisted tape inserts have been studied experimentally for Nusselt number and friction factor. The outcomes are distinguished with those of a plain tube filled with base fluid. CuO/water nanofluid with square jagged twisted tape insert with twist ratio=4 can produce a maximum Nusselt number of 72%, which is higher than that of the base fluid. The results showed a considerable improvement in heat transfer, and the performance of the proposed nanocomposite for improving the thermal performance of heat exchangers in the chemical and petroleum industries was superior with smaller twist ratios.

References

[1] Sajid MU, Ali HM. Thermal conductivity of hybrid nanofluids: a critical review. Int J Heat Mass Transf 2018;126:211–34.

[2] Ranjbarzadeh R, Moradikazerouni A, Bakhtiari R, Asadi A, Afrand M. An experimental study on stability and thermal conductivity of water/silica nanofluid: Ecofriendly production of nanoparticles. J Clean Prod 2019;206:1089–100.

[3] Asadi A, Pourfattah F. Heat transfer performance of two oil-based nanofluids containing ZnO and MgO nanoparticles; a comparative experimental investigation. Powder Technol 2019;343:296–308.

[4] Esfahani NN, Toghraie D, Afrand M. A new correlation for predicting the thermal conductivity of ZnO-Ag (50%–50%)/water hybrid nanofluid: an experimental study. Powder Technol 2018;323:367–73.

[5] Esfe MH, Esfandeh S, Afrand M, Rejvani M, Rostamian SH. Experimental evaluation, new correlation proposing and ANN modeling of thermal properties of EG based hybrid nanofluid containing ZnO-DWCNT nanoparticles for internal combustion engines applications. Appl Therm Eng 2018;133:452–63.

[6] Safaei MR, Hajizadeh A, Afrand M, Qi C, Yarmand H, Zulkifli NWBM. Evaluating the effect of temperature and concentration on the thermal conductivity of ZnO-TiO2/EG hybrid nanofluid using artificial neural network and curve fitting on experimental data. Physica A 2019;519:209–16.

[7] Asadi A, Asadi M, Rezaniakolaei A, Rosendahl LA, Wongwises S. An experimental and theoretical investigation on heat transfer capability of Mg (OH)2/MWCNT-engine oil hybrid nano-lubricant adopted as a coolant and lubricant fluid. Appl Therm Eng 2018;129:577–86.

[8] Asadi A, Aberoumand S, Moradikazerouni A, Pourfattah F, Żyła G, Estelle P, et al. Recent advances in preparation methods and thermophysical properties of oil-based nanofluids: a state-of-the-art review. Powder Technol 2019;352:209–26.

[9] Asadi A. A guideline towards easing the decision-making process in selecting an effective nanofluid as a heat transfer fluid. Energy Convers Manage 2018;175:1–10.

[10] Shi L, He Y, Hu Y, Wang X. Thermophysical properties of Fe3O4@CNT nanofluid and controllable heat transfer performance under magnetic field. Energy Convers Manage 2018;177:249–57.

[11] Selimefendigil F, Oztop HF. Corrugated conductive partition effects on MHD free convection of CNT-water nanofluid in a cavity. Int J Heat Mass Transf 2019;129:265–77.

[12] Selimefendigil F, Oztop HF. Mixed convection of nanofluids in a three dimensional cavity with two adiabatic inner rotating cylinders. Int J Heat Mass Transf 2018;117:331–43.

[13] Sajjadi H, Delouei AA, Izadi M, Mohebbi R. Investigation of MHD natural convection in a porous media by double MRT lattice Boltzmann method utilizing MWCNTFe3O4/water hybrid nanofluid. Int J Heat Mass Transf 2019;132:1087–104.

[14] S. Liu, M. Sakr.: A compressive review on passive heat transfer enhancements in pipe exchangers, pp. 64-81 (2013)

[15] Khwanchit Wongcharee, Smith Eiamsa- ard.: Enhancement of heat transfer using CuO/water nanofluid and twisted tape with alternate axis, pp. 742-748 (2011)

[16] S. Suresh, M. Chandrasekar, S. Chandra Sekhar.: Experimental studies on heat transfer and friction factor characteristics of CuO/water nanofluid under turbulent flow in a helically dimpled tube, pp. 542-549 (2011)

[17] Milad Tajik Jamal-Abad, Amirhossein Zamzamian, MaziarDehghan.: Experimental studies on the heat transfer and pressure drop characteristics of Cu–water and Al–water

nanofluids in a spiral coil, pp. 206-212 (2013)

[18] 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, pp. 37-44 (2012)

[19] Khwanchit Wongcharee, Smith Eiamsa-ard.: Heat transfer enhancement by using CuO/water nanofluid in corrugated tube equipped with twisted tape, pp. 251-257 (2012)

[20] S. Eiamsa-ard, K. Wongcharee.: Single-phase heat transfer of CuO/water nanofluids in micro-fin tube equipped with dual twisted-tapes, pp. 1453-1459 (2012)

[21] Manglik R.M and Bergles A.E.: Application of twisted tape inserts in tubular heat exchangers, Heat and Mass Transfer, Vol. 27, pp. 249-257, No. 4

[22] Tanzila Hayat, S. Nadeem.: Heat transfer enhancement with Ag–CuO/water hybrid nanofluid, T. Hayat, S. Nadeem / Results in Physics 7, pp. 2317–2324 (2017)

[23] Chirag Maradiya, Jeetendra Vadher, Ramesh Agarwal.: The heat transfer enhancement techniques and their Thermal Performance Factor, Beni-Suef University Journal of Basic and Applied Sciences xxx (2017)

[24] Naser Ali,Joao A. Teixeira,and AbdulmajidAddali.: A Review on Nanofluids: Fabrication, Stability, and Thermophysical Properties, Hindawi Journal of Nanomaterials Volume Article ID 6978130, 33 pages (2018)

[25] EdaFeyza Akyürek, KadirGelis, BayramSahin, Eyüphan Manay.: Experimental Analysis for Heat Transfer of Nanofluidwith Wire Coil Turbulators in a Concentric Tube Heat Exchanger, Results in Physics, PII: S2211-3797(18)30156-6 (2018)

[26] Izza Adillah Ismail, Mohd Zamri Yusoff, Firas Basim Ismail, and Premm Gunnasegaran. Heat transfer enhancement with nanofluids: A review on recent applications andexperiments, 6th International Conference on Production, Energy and Reliability. AIP Conf. Proc. 2035, 040006-1–040006-18; Published by AIP Publishing. 978-0-7354-1761-8/$30.00 (2018)

[27] N.N.M. Zawawi, W.H. Azmi, A.A.M. Redhwan, M.Z. Sharif.: Thermo-Physical Properties of Metal Oxides Composite Nanolubricants, Journal of Mechanical Engineering Vol SI 5(1), pp. 28-38 (2018)