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A review on thermal conductivity of ethylene glycol/water based nanofluid

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Abstract:

This review article discusses the historical background of Ethylene Glycol (EG)/water Nanofluids. The primary focus of this work is to study salient research work done on Nanofluid in which main focused was on ethylene glycol and water with nanomaterial. Now a day's augmentation of transfer of heat is one of the most significant requirements of current time, which can be improved with the help of the nanofluid. A lot of research has been done on Nanofluid in the last few years. Most of them have noticed that the main drawback of Nanofluid is its stability. Since water is not suitable to work below freezing point so ethylene glycol and water proportion can be used to work at low temperature. Ethylene glycol increasing proportion allows to work at a lower temperature. Stability of ethylene glycol is more comparable to the water-based Nanofluid. So EG could be an alternative of water in case of Nanofluid. Several mathematical models are suggested to quantify nanofluid thermal conductivity but none of them gave an accurate result. It was observed that the heat transfer enhancement during experimentation is more than the numerical result. Many researchers have done a number of experiments on Nanofluid and most of them found the augmentation in thermal conductivity, Nusselt number, heat transfer coefficient, but it was also observed that the increase in viscosity which result increases in pump power, low stability, agglomeration, settling, clogging, segregations, and erosion due to the nanoparticle. In many engineering applications such as heat exchangers, vehicles, electronics, solar equipment, nuclear reactor coolants, nanofluids are used. Nanofluid has its own advantages and disadvantages so further research has been carried out to make it more efficient for commercial use.

Keywords- Nanofluid; Water; Ethylene glycol; Nanoparticle; Heat transfer

1. Introduction

"Nanofluids can be defined by the dispersion of nano sized material in the base fluid" [1,20]. Nanoparticle are of various types of nanomaterial available for nanofluid, in which "nanoparticles, nanofibers, nanotubes, nanowires, nanorods, nanosheet, or droplets" [1]. Nowadays coolant is one of the most important required due to ever-increasing heat generation in the micro and macro instrument.[2].

Thermal properties of fluid like water, ethylene glycol (EG), engine oil etc. are a major area of research nowadays. Since the conventional heat transfer fluid have low heat transfer capacity [3], so it needs to improve it by dispersion of high thermal conductivity nanoparticles. To enhance the thermal conductivity of conventional fluid different types of method are applied. [4]. Adding millimeter sized particle to the conventional fluid is one of the best techniques to augment heat transfer performance by increasing thermal conductivity of the conventional fluid. [50,76].

Masuda et al.[5] studied dispersed nanoparticle in base fluid in 1993. Then S. Choi in 1995 coined the term nanofluid, and observed upsurge of thermal conductivity for nanofluid [6]. Yu et al. [7] reviewed on nanofluid preparation and stability mechanism and also discussed few methods for nanofluid preparations. Since stability was a major problem in nanofluid the calculation method of stability are sedimentation and centrifugation method, zeta potential method, spectral absorbency analysis method in which zeta potential method was mostly used and observed that nanoparticle synthesis by chemical solution has higher thermal conductivity and stability.

Mohamad et al. [8] examined nanofluid and found that why many researchers found a diminution in the heat transfer performance in nanofluid. Calculation was done for copper water based nanofluid and noticed Segregations, Agglomeration, and erosion due to nanoparticles are major problems, the addition of nanoparticle with high density decreases buoyancy forces cause a reduction in natural convection. Increase in viscosity also causes an adverse effect on forced convection. The thermal conductivity of copper 400W/mK added to water having the thermal conductivity of 0.6 W/mK. By adding 5% volume fraction results in 20.57 W/mk thermal conductivity for nanofluid.

Xu et. al. [9] investigated alumina-water-ethylene glycol nanofluid for estimation of thermal conductivity and viscosity. Agglomeration was a measured problem observed in this research. Kabeel et al. [10] considered consequence of alumina-water nanofluid concentration on sharp edge orifice flow characteristics. Numerical approach method was used by the governing equation with standard K-ε model, applied boundary condition and compared with the experimental data. Variation relative to the experimental result was under limit.

Srikanth et al. [11] investigated heat transfer considering viscosity and thermal conductivity. Mathematical model finite element method used in one dimensional with 100 elements for copper–water

Nanofluid. And observed that the heat transfer was affected by magnetic field and inclination angle.

Coquard et al. [12] investigated conductive heat transfer inside nanostructure silica of porous structure for nanofluid and develops a numerical model of Boltzmann equation using Monte Carlo simulation and observed that the nanoscopic effect relatively limited for a particular diameter of 10nm. Nanostructured silica permits to reach effective conductivity levels lower than air due to small porosity size. Heat exchanger efficiency increases by increasing volume fraction of nanoparticle. Hosseinian et. al.[13] study heat transfer augmentation due to vibration in the double heat exchanger. With increasing vibrational amplitude, mass flow rate, temperature of nanofluid, and nanoparticle fraction, the coefficient of heat transfer increases. The vibrational effect increases with increasing nanofluid temperature.

Sakr et al. [14] examined heat transfer enhancement of alumina-water nanofluid for nano phase material. Increase in volume fraction result in increment in Stefan number and decrement in Rayleigh number. Increase in heat transfer was influence by Rayleigh number more than volume fraction. Boutra et al [15] investigated hydrodynamic and thermal characteristics in a cubical enclosure. Numerical approach by Boltzmann method and finite difference method used for Ag-water based nanofluid. Enhancement of heat transfer observed relative to the mass concentration of nanoparticle. Yang et al. [16] review of TiO_2 with water, ethylene glycol, R141b, Aqueous electrolytes, R134a, and mineral oil propylene glycol. One step and two steps are reviewed for nanofluid preparation. Most of the researcher facing problem of nanoparticle aggregation, clustering, increase in viscosity. Bhattacharya model has more efficient than other types of model for spherical shape TiO_2 based nanofluid for calculating thermal conductivity. Features that influences thermal conductivity of TiO_2 based nanofluid are particle loading, temperature, thermal conductivity, particle size and shape, surfactant, ultrasonic vibration, the geometry of flow channel, boiling heat transfer, forced or natural convection.

Eslami et al. [17] study effect of coulomb force on forced convection. Fe_3O_4-Ethylene glycol nanofluid study with CVFEM analysis. The effect of the electric field on the improvement of forced convection was more sensible for a lower number of Reynolds. Ilyas et al. [18] carried thermal conductivity enhancement experimentations of alumina-thermal oil based nanofluid observed that by increasing volume fraction of nanoparticle the Nusselt number decreases, viscosity increases, improve thermal conductivity. Purohit et al. [19] done a numerical study for thermal conductivity of nanofluid with different nanoparticle by keeping Reynolds number and mass flow rate constant. It measures the increase in the coefficient of heat transfer and the decrease in the performance factor.

2. Ethylene glycol nanofluid

Ethylene glycol nanofluid have some advantages over water-based Nanofluid in terms of stability and low freezing point. “Ethylene glycol also known as ethane 1,2-diol according to IUPAC. Ethylene glycol Molecular weight is 62.06g/mol and molecular formula $C_2H_6O_2$”[20]. Ethylene glycol is a colorless, syrupy liquid which produced by the reaction of ethylene oxide and water. [21]. Ethylene glycol is soluble in water, its color when used as automotive antifreeze is yellow-green. Agency named “toxic substances and disease registry” said that it is poisonous fluid harmful for human health. [22].

H K Dawood et al. [23] carried out studied in condensed elliptic annular, heat transfer increase using ethylene glycol dependent nanofluid. In this numerical investigation Al_2O_3, CuO, SiO_2, ZnO are used as nanoparticle with diameter variation 20,40,60,80 nm. In which SiO_2 based nanofluid have uppermost Nusselt numbe. Other nanofluid Al_2O_3, ZnO, CuO have Nusselt number in decreasing order respectively. Suleiman Akilu et al. [24] used SiO_2–CuO hybrid nanofluid for augument solar energy transportation with fluid Glycerol and ethylene glycol in the ratio of 60:40. Thermal conductivity enhancement of 26.9% observed for SiO_2 nanofluid and 6.9% for SiO_2-CuO/C at 2% volume fraction and at temperature 303.15K. Reduction in Viscosity of 33.5% for SiO_2-CuO/C and 14.9 % for SiO_2 at 2% volume were noticed.
Sani et al. [25] study for solar collector used 0.0025-0.01 % concentration of nanoparticle with base fluid ethylene glycol in laminar flow. High potential of heat absorption for solar collector with nanofluid is observed. Xiaoke li et al. [26] conducted an experiment with SiC-ethylene glycol nanofluid and observed 44% enhancement in viscosity. Omid Soltani et al. [27] studied with ethylene glycol nanofluid with MgO-MWCNT nanoparticle and found enhancement of 168% viscosity for 1 % concentration. Gawel Zyla et al. [28] conducted an experiment with boron nitride nanoparticle with base fluid ethylene glycol and found huge enhancement of 260 % in thermal conductivity for 12% volume concentration of nanoparticle. Zyla et al. [29] studied nano diamond-water nanofluid and observed thermal conductivity lower than the theoretical value. Krishnakumar T.S. et al. [30] studied alumina-ethylene glycol nanofluid and observed 20 % enhancement in thermal conductivity for 1% concentration of nanoparticle, it has been also observed that nonionic surfactant can show better effect than an ionic surfactant. Zyla et al. [31] conducted an experiment on SiO_2 –EG Nanofluid with particle diameter 7-14nm and found that

thermal conductivity linearly increasing up to 3.31% for 5% concentration of nanoparticle.

Akilu et al. [32] studied with Silicon oxide-EG nanofluid and observed enhancement of 11.5% in thermal conductivity for 2% nanoparticle mass concentration. Zyla et al. [33] conducted an experiment with nanoparticle graphite and nano diamond with different percentage of ash content and observed that thermal conductivity was linearly increasing and maximum at 0.023% nanoparticle concentration and it was 5.8%. Variation in ash content was also done but variation in thermal conductivity was negligible. Jafarimoghaddam et. al. [34] done experimental study for laminar flow with nanoparticle copper of diameter 20nm with base fluid EG in a concentric annular tube and observed an augmentation of Nusselt number and heat transfer coefficient. Leong et. al. [35] Study on laminar flow for copper nanoparticle in a car radiator and found 3.8 % augmentation in Nusselt number for 2% volume fraction of nanoparticles. Nusselt number heat transfer coefficient and pressure drop also increased by increasing the volume concentration of nanoparticle.

Li et. al. [36] conducted an experiment with SiC nanoparticle having 30nm diameter with base fluid and found 16.21 % enhancement in thermal conductivity for 1 % volume concentration of nanoparticle. Gawel Zyla et. al. [37] conduct experimental studies with ethylene glycol as base fluid and aluminum nitride as nanoparticle with volume concentration 5-20 % and found 25% enhancement in thermal conductivity for 0.1 volume fraction of nanoparticle. Electrical conductivity also improved with increment of mass concentration of nanoparticles.

3. Water ethylene glycol mixture based Nanofluid

Water is the best fluid that uses in the heat exchanger as coolant due to its high thermal conductivity, low viscosity compares to other fluid, it is available in large quantity. Water freeze and boil at extreme temperature [38].

Water is generally mixed with ethylene glycol to avoid freezing of coolant when it is too cold. Peyghambarzadeh [39] experiment show that a mixture of EG:W ratio 60:40 can avoid freezing up to -45^{0}C.

Diglio et. al.[40] done a numerical study for a borehole heat exchanger with Nanofluid as the heat carrier. Used nanoparticles are Cu, Ag, Al, Alumina, CuO, Graphite, SiO_2 with varying volume concentration up to 1 % and found an increase in heat transfer coefficient and 5 times increase in pressure drop for Ag nanofluid. Copper shows highest borehole thermal resistance reduction of 3.8%.

Cu and CuO are lowest volumetric heat capacity reduction and graphite shows highest heat capacity reduction.

Islam et al [41] For TiO_2 compare the experimental result with a mathematical model and found that Maxwell model was unable to find electrical conductivity of Nanofluids. Maxwell model predict a decrease in electrical conductivity but in experimental result, electrical conductivity increases. Cho et al [42] investigated alumina and titanium oxide nanoparticle with water nanofluid for a circular pipe and found decrement in heat transfer coefficient by increasing VF of nanoparticle due to increase in viscosity. And then discovered an empirical formula for calculation of Nusselt number. Subhedar et. al[43] studied with W:EG ratio of 50:50 with alumina nanoparticle for car radiator application and observed 93% enhancement in Nusselt number. Gao et al. [44] studied with DW:EG equal ratio with graphene nanoplatelet. Compared to other models, the Chu model provides the best result because it considers significant variables such as interfacial thermal resistance, weight, thickness and average nanoparticle flatness ratio. The new model also explained which give more accurate result and closest to the experimental result.

Suganthi [45] studies ZnO with EG:W of ratio 1:1 and observed 33.4% augmentation in thermal conductivity for 4% mass concentration of nanoparticle and reduction in viscosity of 39.2 % and 17.34 % at a nanoparticle mass concentration of 4 % and 2% respectively. Guo et. al. [46] done an experiment variation of EG:W ratio of 0-100%. By increasing, Ethylene Glycol reduction in thermal conductivity was detected. Leong et. al. [47] studied nanofluid with EG:W ratio 50:50 and nanoparticle copper and titanium. Three types of surfactant were used in this experiment and observed that by adding SDBS surfactant Titanium oxide having the highest thermal conductivity and hybrid nanofluid thermal conductivity close to this one. By adding PVP highest thermal conductivity observed in hybrid Nanofluid and Titanium oxide Nanofluid thermal conductivity was closed to this one. And by adding GA Titanium oxide Nanofluid has the highest thermal conductivity and other shows much lower thermal conductivity than this one.

Selvam et. al. [48] done an experimental study with EG:W ratio of 1:1 with graphene nanoplatelet having 5-10mm thickness and 15μm diameter and observed 21% enhancement in thermal conductivity for 0.5% volume fraction of nanoparticle. Strandberg et. al. [49]conduct an experiment with W:EG ratio of 60:40 with nanoparticle alumina having a 44nm diameter and copper having a 29nm diameter. Rectangular fin was used for experiment up to 4% of nanoparticle and observed an augumentation in Nusselt number by improving volume fraction. Peyghambarzadeh [50] conduct experiment for different ratio of W:EG ratio with turbulent flow. Alumina nanoparticle was used of diameter 20nm. The volume fraction of nanoparticle in base fluid up to 1% was used. The experiment was conducted in car radiator and observed to increase in Nusselt number and heat transfer coefficient. Yu et. al. [51] conduct an experiment with W:EG ratio of 45:55 with nanoparticle alumina having 30nm diameter up to 3% volume fraction. Car radiator was chosen for experiment and found an increase in Nusselt number and heat transfer coefficient. Enhancement in thermal conductivity of 11.7% for 3% volume fraction of nanoparticle was also observed.

Chiam et. al. [52] conduct an experiment with different proportion of EG:W ratio as the base fluid. Nanoparticle alumina was added in between 0.2-1.0 % having diameter 13nm. Heat transfer coefficient increases for increasing nanoparticle volume ratio. Maximum thermal conductivity was measured at 1% volume fraction of 40:60 W:EG ratio was 12.8%. Hu et. al. [53] conduct an experiment with W:EG ratio of 60:40 and nanoparticle graphene nanosheet up to 0.1% volume fraction. For stability magnetic stirrer for 36 hours and ultrasonication for 4 hours. Heat transfer coefficient augmentation with the improving volume fraction of nanoparticle. Sandhya et al. [54] conduct experiment with titanium oxide nanoparticle with fluid water to ethylene glycol proportion of 60:40 and found 35 % enhancement in heat transfer rate for 0.5 % volume concentration of nanoparticle. Reddy et al. [55] studied on EG:W ratio of 0:100, 40:60, 50:50 with the nanoparticle TiO_2 of diameter 21 nm and found augmentation in thermal conductivity for every case and proposed a correlation to calculate thermal conductivity of TiO_2based Nanofluid for the temperature range of 30-70^o and it was concluded that nanoparticles temperature and volume concentration have a major effect on nanofluid thermal conductivity enhancement. Hamid et. al. [56] studies W:EG ratio of 60:40 with TiO_2 nanoparticle. Volume concentrations of nanoparticle in base fluid were 0.5 to 1.5 % and found enhancement in pressure drop and friction factor. At 30^{o}C experienced low heat transfer enhancement up to 1.17% volume fraction of nanoparticle. Li. Et. al. [57] performed an experiment with EG:W ratio of 50:50 as a base fluid and ZnO nanoparticle of diameter 29±26nm with the volume fraction of 0-5% and found 4.64% enhancement in density, 13.62% enhancement in dynamic viscosity, 3.77% enhancement in thermal conductivity.

Azmi [58] perform an experiment with W:EG ratio of 60:40 with TiO_2 as nanoparticle with the fraction in limits of 0.5-1.5 % and found that maximum augmentation in thermal conductivity obtained was 15.4 % at 1.5% volume concentration at a temperature of 60^{o}C. Relative viscosity fluctuates/range observed was 4.6-33.3%. He et. al. [59] conduct experiment with EG and water mixture as a base fluid and ZnO as nanoparticle in a cylindrical vessel and found enhancement in HTC and CHF with an increasing volume concentration of nanoparticle and also find that Nanofluid with ZnO mass fraction up to 7.25% can augment boiling heat transfer rate.

3. Conclusion

The present study has critically reviewed the heat transfer rate of Nanofluid and factors that affect it. Following conclusion can be made with that

1. Heat transfer rate generally increases for most of the researcher for Nanofluid with base fluid EG /EG-W.

2. Most of the researcher found common problem of low stability, agglomeration, clogging in settling, segregation, erosion due to the nanoparticle, increase in viscosity, increase in the rate of vaporization, moment decrease and affected by the magnetic field and inclination angle.

3. None of the mathematical models are able to give an accurate result, for a different combination of nanoparticle and base fluid different mathematical was more accurate, for some specific combination researcher was able to give new formula to calculate thermal conductivity which was more accurate than other models.

4. The heat transfer rate of the different researcher was different from each other. It depends upon many factors like ultra-sonication time, magnetic stirrer time, suitable selection of surfactant, by varying these parameters different result can be obtained. By increasing ultra-sonication time, a researcher found to decrease in viscosity of the base fluid.

5. This field of research needs more research to find the best method to get maximum thermal conductivity, we don't know the optimal VF needed to add to get the best result.

6. By increasing particle size heat transfer rate increases, surfactant decreases thermal conductivity at the same time they lead to agglomeration, settling so we need to find optimal particle size and surfactant for Nanofluid.

7. Water thermal conductivity is more than EG but it can’t work under low temperature, by adding EG we can work at -55^{0}C for EG:W ratio of 60:40. EG is the best fluid for working at low temperature.

References

1. Fuskele, Veeresh, and R. M. Sarviya. "Recent developments in nanoparticles synthesis, preparation, and stability of Nanofluids." *Materials Today: Proceedings* 4.2 (2017): 4049-4060.

2. Hussien, Ahmed A., et al. "Experiment on forced convective heat transfer enhancement using MWCNTs/GNPs hybrid Nanofluid and mini-tube." *International Journal of Heat and Mass Transfer* 115 (2017): 1121-1131.
3. Sundar, L. Syam, et al. "Hybrid Nanofluids preparation, thermal properties, heat transfer and friction factor–A review." *Renewable and Sustainable Energy Reviews* 68 (2017): 185-198.
4. Sharma, S. K., and Shipra Mital Gupta. "Preparation and evaluation of stable Nanofluids for heat transfer application: a review." *Experimental Thermal and Fluid Science* 79 (2016): 202-212.
5. Masuda, Hidetoshi, Akira Ebata, and Kazumari Teramae. "Alteration of thermal conductivity and viscosity of liquid by dispersing ultra-fine particles. Dispersion of Al2O3, SiO2 and TiO2 ultra-fine particles." (1993): 227-233.
6. S. Choi, Enhancing thermal conductivity of fluid with nanoparticles, Dev. Appl. Non-Newtonian Flows (1995) 99-105
7. Yu, Wei, and Huaqing Xie. "A review on Nanofluids: preparation, stability mechanisms, and applications." Journal of nanomaterials 2012 (2012): 1.
8. Mohamad, A. A. "Myth about nano-fluid heat transfer enhancement." International Journal of Heat and Mass Transfer 86 (2015): 397-403.
9. Xu, Jinghai, Krisanu Bandyopadhyay, and Dohoy Jung. "Experimental investigation on the correlation between nano-fluid characteristics and thermal properties of Al2O3 nano-particles dispersed in ethylene glycol–water mixture." International Journal of Heat and Mass Transfer 94 (2016): 262-268.
10. Kabeel, A. E., and Mohamed Abdelgaied. "Study on the effect of alumina nano-fluid on sharp-edge orifice flow characteristics in both cavitations and non-cavitations turbulent flow regimes." Alexandria Engineering Journal 55.2 (2016): 1099-1106.
11. Srikanth, G. V. P. N., G. Srinivas, and B. Suresh Babu. "Characterization of chemical reaction on heat transfer through the nano fluid." Procedia Materials Science 10 (2015): 10-18.
12. Coquard, Remi, et al. "Modelling of the conductive heat transfer through nano-structured porous silica materials." Journal of Non-Crystalline Solids 363 (2013): 103-115.
13. Hosseinian, A., AH Meghdadi Isfahani, and E. Shirani. "Experimental investigation of surface vibration effects on increasing the stability and heat transfer coeffcient of MWCNTs-water Nanofluid in a flexible double pipe heat exchanger." *Experimental Thermal and Fluid Science* 90 (2018): 275-285.

14. Sakr, R. Y., et al. "Heat transfer enhancement during freezing process of Nano Phase Change Material (NPCM) in a spherical capsule." *Applied Thermal Engineering* 125 (2017): 1555-1564.
15. Boutra, Abdelkader, et al. "Free Convection Heat Transfer of Nanofluids into Cubical Enclosures with a Bottom Heat Source: Lattice Boltzmann Application." *Energy Procedia* 139 (2017): 217-223
16. Yang, Liu, and Kai Du. "A comprehensive review on heat transfer characteristics of TiO2 Nanofluids." *International Journal of Heat and Mass Transfer* 108 (2017): 11-31.
17. Sheikholeslami, M., and M. M. Bhatti. "Active method for Nanofluid heat transfer enhancement by means of EHD." *International Journal of Heat and Mass Transfer* 109 (2017): 115-122.
18. Ilyas, Suhaib Umer, Rajashekhar Pendyala, and Marneni Narahari. "An experimental study on the natural convection heat transfer in rectangular enclosure using functionalized alumina-thermal oil-based Nanofluids." *Applied Thermal Engineering* 127 (2017): 765-775.
19. Purohit, Nilesh, Varun Anand Purohit, and Kamlesh Purohit. "Assessment of Nanofluids for laminar convective heat transfer: A numerical study." *Engineering Science and Technology, an International Journal* 19.1 (2016): 574-586.
20. Azmi, W. H., et al. "Heat transfer augmentation of ethylene glycol: water Nanofluids and applications—a review." International Communications in Heat and Mass Transfer 75 (2016): 13-23.
21. Stellman, Jeanne Mager, ed. Encyclopaedia of occupational health and safety. Vol. 1. International Labour Organization, 1998.
22. Colborn, Theo, et al. "Natural gas operations from a public health perspective." Human and ecological risk assessment: An International Journal 17.5 (2011): 1039-1056.
23. Dawood, H. K., et al. "Heat transfer augmentation in concentric elliptic annular by ethylene glycol based Nanofluids." International Communications in Heat and Mass Transfer 82 (2017): 29-39.
24. Akilu, Suleiman, et al. "Properties of glycerol and ethylene glycol mixture based SiO2-CuO/C hybrid Nanofluid for enhanced solar energy transport." Solar Energy Materials and Solar Cells 179 (2018): 118-128.
25. Sani, Elisa, et al. "Graphite/diamond ethylene glycol-Nanofluids for solar energy applications." Renewable Energy126 (2018): 692-698
26. Li, Xiaoke, et al. "Rheological behavior of ethylene glycol-based SiC Nanofluids." International journal of heat and mass transfer 84 (2015): 925-930.

27. Soltani, Omid, and Mohammad Akbari. "Effects of temperature and particles concentration on the dynamic viscosity of MgO-MWCNT/ethylene glycol hybrid Nanofluid: experimental study." Physica E: Low-dimensional Systems and Nanostructures 84 (2016): 564-570.
28. Żyła, Gaweł, et al. "Huge thermal conductivity enhancement in boron nitride–ethylene glycol Nanofluids." Materials Chemistry and Physics 180 (2016): 250-255.
29. Żyła, Gaweł, et al. "Nanodiamonds–ethylene glycol Nanofluids: experimental investigation of fundamental physical properties." International Journal of Heat and Mass Transfer121 (2018): 1201-1213.
30. Krishnakumar, T. S., S. P. Viswanath, and Sajin Mathew Varghese. "Experimental studies on thermal and rheological properties of Al2O3–ethylene glycol Nanofluid." International Journal of Refrigeration 89 (2018): 122-130.
31. Żyła, Gaweł, and Jacek Fal. "Viscosity, thermal and electrical conductivity of silicon dioxide–ethylene glycol transparent Nanofluids: an experimental studies." Thermochimica Acta 650 (2017): 106-113.
32. Akilu, Suleiman, et al. "Rheology and thermal conductivity of non-porous silica (SiO 2) in viscous glycerol and ethylene glycol based Nanofluids." International Communications in Heat and Mass Transfer 88 (2017): 245-253.
33. Żyła, Gaweł, Jacek Fal, and Patrice Estellé. "The influence of ash content on thermophysical properties of ethylene glycol based graphite/diamonds mixture Nanofluids." Diamond and Related Materials 74 (2017): 81-89.
34. Jafarimoghaddam, A., and S. Aberoumand. "An empirical investigation on Cu/Ethylene Glycol Nanofluid through a concentric annular tube and proposing a correlation for predicting Nusselt number." Alexandria Engineering Journal55.2 (2016): 1047-1052.
35. Leong, K. Y., et al. "Performance investigation of an automotive car radiator operated with Nanofluid-based coolants (Nanofluid as a coolant in a radiator)." Applied Thermal Engineering 30.17-18 (2010): 2685-2692.
36. Li, Xiaoke, et al. "Stability and enhanced thermal conductivity of ethylene glycol-based SiC nanofluids." *International Journal of Heat and Mass Transfer* 89 (2015): 613-619.
37. Żyła, Gaweł, and Jacek Fal. "Experimental studies on viscosity, thermal and electrical conductivity of aluminum nitride–ethylene glycol (AlN–EG) Nanofluids." Thermochimica Acta 637 (2016): 11-16.
38. Parker, Barry. The Isaac Newton School of Driving: Physics and Your Car. JHU Press, 2004.
39. Yu, Wei, et al. "Experimental investigation on the heat transfer properties of Al2O3 Nanofluids using the mixture of ethylene

glycol and water as base fluid." Powder Technology 230 (2012): 14-19.

40. Diglio, Giuseppe, et al. "Borehole heat exchanger with Nanofluids as heat carrier." Geothermics 72 (2018): 112-123.
41. Islam, Mohammad Rafiqul, Bahman Shabani, and Gary Rosengarten. "Electrical and thermal conductivities of 50/50 water-ethylene glycol based TiO2 Nanofluids to be used as coolants in PEM fuel cells." Energy Procedia 110 (2017): 101-108.
42. Pak, Bock Choon, and Young I. Cho. "Hydrodynamic and heat transfer study of dispersed fluids with submicron metallic oxide particles." *Experimental Heat Transfer an International Journal*11.2 (1998): 151-170.
43. Subhedar, Dattatraya G., Bharat M. Ramani, and Akhilesh Gupta. "Experimental investigation of heat transfer potential of Al2O3/Water-Mono Ethylene Glycol Nanofluids as a car radiator coolant." Case Studies in Thermal Engineering 11 (2018): 26-34.
44. Gao, Yuguo, et al. "Measurement and modeling of thermal conductivity of graphene nanoplatelet water and ethylene glycol base Nanofluids." International Journal of Heat and Mass Transfer 123 (2018): 97-109.
45. Suganthi, K. S., V. Leela Vinodhan, and K. S. Rajan. "Heat transfer performance and transport properties of ZnO–ethylene glycol and ZnO–ethylene glycol–water Nanofluid coolants." Applied energy 135 (2014): 548-559.
46. Guo, Yufeng, et al. "Experimental investigation of thermal and electrical conductivity of silicon oxide Nanofluids in ethylene glycol/water mixture." International Journal of Heat and Mass Transfer 117 (2018): 280-286.
47. Leong, Kin Yuen, et al. "Thermal conductivity of an ethylene glycol/water-based Nanofluid with copper-titanium dioxide nanoparticles: An experimental approach." International Communications in Heat and Mass Transfer 90 (2018): 23-28.
48. Selvam, C., D. Mohan Lal, and Sivasankaran Harish. "Thermal conductivity enhancement of ethylene glycol and water with graphene nanoplatelets." Thermochimica Acta 642 (2016): 32-38.
49. Strandberg, Roy, and Debendra K. Das. "Finned tube performance evaluation with Nanofluids and conventional heat transfer fluids." International Journal of Thermal Sciences 49.3 (2010): 580-588.
50. Peyghambarzadeh, S. M., et al. "Experimental study of heat transfer enhancement using water/ethylene glycol based Nanofluids as a new coolant for car radiators." International Communications in Heat and Mass Transfer 38.9 (2011): 1283-1290.
51. Yu, Wei, et al. "Experimental investigation on the heat transfer properties of Al2O3 Nanofluids using the mixture of ethylene

glycol and water as base fluid." Powder Technology 230 (2012): 14-19.

52. Chiam, H. W., et al. "Thermal conductivity and viscosity of Al2O3 Nanofluids for different based ratio of water and ethylene glycol mixture." Experimental Thermal and Fluid Science 81 (2017): 420-429.
53. Hu, Yanwei, et al. "Role of nanoparticles on boiling heat transfer performance of ethylene glycol aqueous solution based graphene nanosheets Nanofluid." International Journal of Heat and Mass Transfer 96 (2016): 565-572.
54. Devireddy, Sandhya, Chandra Sekhara Reddy Mekala, and Vasudeva Rao Veeredhi. "Improving the cooling performance of automobile radiator with ethylene glycol water based TiO2 Nanofluids." International communications in heat and mass transfer 78 (2016): 121-126.
55. Reddy, M. Chandra Sekhara, and V. Vasudeva Rao. "Experimental studies on thermal conductivity of blends of ethylene glycol-water-based TiO2 Nanofluids." International Communications in Heat and Mass Transfer 46 (2013): 31-36.
56. Hamid, K. Abdul, et al. "Experimental investigation on heat transfer performance of TiO2 Nanofluids in water–ethylene glycol mixture." International Communications in Heat and Mass Transfer 73 (2016): 16-24.
57. Li, Yanjun, et al. "Experimental investigation on heat transfer and pressure drop of ZnO/ethylene glycol-water Nanofluids in transition flow." Applied Thermal Engineering 93 (2016): 537-548.
58. Azmi, W. H., et al. "Effects of working temperature on thermo-physical properties and forced convection heat transfer of TiO2 Nanofluids in water–Ethylene glycol mixture." Applied Thermal Engineering 106 (2016): 1190-1199.
59. He, Yurong, et al. "Boiling heat transfer characteristics of ethylene glycol and water mixture based ZnO Nanofluids in a cylindrical vessel." International Journal of Heat and Mass Transfer 98 (2016): 611-615.