International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 6 Issue 05, May - 2017

Variation in the Properties of Nanofluids due to Change in Temperature and Concentration of Nanoparticles

Himanshu Saini*
Department of Mechanical Engineering
Global Institute of Technology,
Jaipur, India

Dr. V. N. Shukla
Department of Mechanical Engineering
Global Institute of Technology,
Jaipur, India

***Abstract*—Various materials have been developed by the researchers in the field of engineering. Nano materials are the one of the examples of such materials that occupies a major area in engineering. Now many researchers are concentrating on nanofluids. Nanofluids are the suspension of nana sized particles in the conventional fluid. These fluids are environmental friendly and provides better performance than currently using fluids. Nanofluids plays a vital role in many thermal applications such as heat transfer enhancement, automotive industries, nuclear reactors as well as food, biomedicines as it exhibits with superior thermal properties over conventional fluids. Heat exchangers are widely used in industries for transferring heat from one medium to another. The design of heat exchanging system largely depends upon the selection of suitable heat transfer fluid for heat dissipation. Improving the thermal conductivity is the key idea to improve the heat transfer characteristics of conventional fluids. Because solids have larger value thermal conductivity than a conventional fluid hence suspension of metallic solid fine particles into the fluid is expected to improve the thermal conductivity of that fluid. Nanofluids are special kind of fluids containing a small quantity of nana sized particles (usually less than 100nm) that are uniformly and stably suspended in a base liquid. Commonly used nanomaterials are Al_2O_3, TiO_2, CuO, ZnO, carbon nana tubes, single-walled carbon nana tubes (SWCNT), multi-walled carbon nana tubes (MWCNT) etc. The aim of this review articles is to present the open literature describing the recent advancement in nanofluids technology including the application of nanofluids in the various areas of industries.**

Keywords*—Nanofluids, Heat exchangers, Thermal conductivity, Heat transfer enhancement, Carbon nanotubes.

I. INTRODUCTION

Heat transfer is one of the most common process in power generation systems, refineries, IC engines, used for numerous purpose such as cooling, heating and chemical process. In many thermal applications conventional fluid water, engine oil, ethylene Glycol are used but these fluids possess limited capabilities in terms of thermo-physical properties hence imposes several restrictions on the use of conventional fluids. In order to improve the thermal properties of conventional fluids many strategies have employed and various researches have been conducted. As the solids have high value of thermal conductivity then fluids hence the value of thermal conductivity can be expected to increase by suspending some metallic particles in the base fluids.

Nanofluid is a colloidal suspension of nana- particles in the conventional fluids which possess enhanced thermo-physical properties such viscosity, thermal conductivity, thermal diffusivity and heat transfer coefficient compared the conventional fluids water, oil [1-8]. The conventional fluids can be water, ethylene glycol, mixture of water and EG, diethylene glycol, engine oil, vegetable oil, paraffin, kerosene, pump oil [9-11]. To reduce the friction and enhance the anti-wear properties carbon based nana particles can be used to prepare nanofluids [12]. In this field Novoselov et al. discovered graphene which is most studied [13]. Graphene is a single layer of carbon atoms bonded by sp^2 hybridization and forms hexagonal structure [14-16]. Macro-sized particles possess problems such as chocking, sedimentation, scale-sludge which is not in case of nanofluids. Because of high surface to volume ratio the nanofluids have good heat transfer enhancement compared to conventional fluids [17]. According to Eastman et al. water based nanofluid with 5% CuO nanoparticle can enhanced the thermal conductivity approximately 60% [18]. Masuda et al. investigated the thermo-physical properties of Al_2O_3 and TiO_2 suspended water based nanofluids and reported that the thermal conductivity increased 32% and 11% respectively as compared to base fluid [19]. Das et al. studied the temperature dependent behaviour of thermal conductivity of $Al_2O_3$and CuO suspended nana particles in water between the range of 21^0C to 51^0C and concluded that the value of thermal conductivity increases with the particle concentration as well as temperature of nanofluid [20]. Kole and Dey etal. concluded the better dispersion and fragmentation of ZnO nana particles in ethylene-glycol nana fluids. They reported 40% thermal conductivity enhancement by 3.5% (volume) suspension of ZnO nana particles at 30^0C [21]. Abdolbaqi et al. studied the water based TiO_2 nanofluid in the temperature range 30^0C to 80^0Cwith different concentration range and concluded that the thermal conductivity decreases with increasing temperature and increases with the increase of concentration [22]. Khdher et al. performed experiment to determine the electrical and thermal conductivity BioGlycol based Al2O3 nanofluids with the different concentration in the temperature range of 30^0C to 80^0C and observed that as the temperature and concentration of nana particles increases the electrical conductivity also increases. The electrical conductivity at

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 6 Issue 05, May - 2017

0.5 volume % concentration is measured to be 154 µS/cm [23]. Mohammad Rafiqul Islam et al. investigated the thermal and electrical conductivity if 50/50 water ethylene-glycol based TiO_2 nanofluid and concluded that the thermal conductivity increases with the increase of both temperature and particle concentration. They measured the electrical conductivity at .05% concentration and 0.5% concentration from 20^0C to 70^0C and found the enhancement 91% and 52% respectively [24]. This article summarize the properties of nanofluids and enhancement of heat transfer with the application of nanofluid. This article presents a comparative study of the effect of various nana particles and different concentration on thermal conductivity.

Table 1. Thermal conductivity of various materials in w/mk

Sr. No.	Material	Specification	Thermal Conductivity (w/mk)
1.	Metallic solids	Silver	429
2.		Gold	317
3.		Aluminum	237
4.		Copper	401
5.	Nonmetallic solids	Silicon	148
6.		Alumina	35
7.		CNT	2000
8.		Diamond	600
9.	Nonmetallic liquids	Water	0.613
10.		Ethylene Glycol	0.253

II. PREPARATION OF NANOFLUIDS

Nanofluids are the colloidal suspension of nana particles in the conventional fluid. Here it must be clear that the nanofluid is not only the simple mixing and dispersion of nana particles in the base fluid. It is the most significant stage in the use of nana particles or any nanostructured materials to enhance the thermal characteristics of conventional heat transfer fluids. If the nana particles are not prepared properly then agglomeration of solid particle can take place which in turns results poor thermos-physical properties. Some dispersive agents can be added to improve the stability of nanofluids but it reduces the thermal conductivity of nanofluids.

Nanofluids can be prepared by two methods first one is one step method and another is two step method. Preparation of nanofluid by one step method comprise the preparation of nana particles and fabrication of nanofluid simultaneously [33-34]. One step nanofluid preparation reduces the chances of agglomeration because the steps of dispersion of particles, drying, storage and transportation in the base liquid media are combined. Preparation of nanofluid highly depends upon the dispersion of nana particles. Proper dispersion can be achieved by either ultrasonic vibration till proper dispersion or mixing the nana particles first with distilled water [35]. The two step method for nanofluid preparation is a common technique in which nana particles are fabricated initially as a dry powders by physical or chemical method and after that they are dispersed in the base fluid [36-37]. N.A. Usri et al. prepared nanofluids by two step method taking distilled water and ethylene glycol in 60-40 ratio with alumina nana particles. The average size of alumina particles were 13nm in diameter [30]. K. Abdul Hamid et al. prepared nanofluid with Al_2O_3 nana particles with average particle size 13nm in water ethylene glycol base fluid. In order to improve the dispersion of nana particles Sonication process was employed for two hours [38]. Xuefeng Shao et al. fabricated TiO_2 –H_2O nanofluids by mixing certain amount of TiNTs and TiNSs powder with deionized water. This suspension was subjected to magnetic stirrer for 30 minutes and ultrasonic cleaner for one hour to improve its stability [39]. Saritkumar das et al. explained some methods to improve the stability of nanofluids. By addition of surface activators, proper dispersion of nana particles in base fluid and control of pH, the sedimentation can be avoided [40].

III. PROPERTIES OF NANOFLUIDS

In order to evaluate the effectiveness and efficiency of and nanofluid in heat transfer applications one must determine the thermo-physical properties of nanofluid such as thermal conductivity, heat transfer coefficient, density and viscosity etc.

Thermal conductivity of a fluid is the ability to transfer or conduct heat. This is very important thermos-physical property that must be demonstrated to evaluate the capability of fluid for heat transfer applications. Hence higher thermal conductivity of nanofluids is desired for heat transfer applications. The thermal conductivity of nanofluids depends upon some parameters such as particle size, concentration of nana particles, temperature etc. Yoo et al. reported enhancement of thermal conductivity of Al_2O_3 nanofluid with the control of pH and found maximum value of thermal conductivity at pH value 10.94 [41]. Lee et al. studied the effect of pH on thermal conductivity of water based CuO nanofluids and concluded that as the pH of dispersion decreased the thermal conductivity enhancement increases [42]. Assael MJ et al. concluded that addition appropriate surface modifier in proper amount results in enhanced thermal conductivity [43]. Moosavi et al [44], Xie et al [45] and Timofeeva et al [46] showed the high thermal conductivity enhancement for the NFs with low thermal conductivity base liquids than that with higher thermal conductivity [44-46]. Thermal conductivity enhancement of nanofluid depends upon the geometrical shape of the particles. Research shows that the thermal conductivity enhancement for cylindrical shaped particles is more than spherical [47]. Gahdimi et al. investigated water based TiO_2 nanofluids with SDS surfactant and two ultrasonic process, horn and bath. Maximum value of thermal conductivity was observed in bath type ultrasonic in the presence of SDS [48]. Researchers have also reported the effect of particle crystal structure and concentration of particles on the thermal conductivity. Higher thermal conductivity as well as good viscosity is required for heat transfer applications. Viscosity is defined as internal resistance among the layers of fluid which possess fluid flow which plays a significant role in thermal application of nanofluids [49]. Mahbubul et al. reported that the that the viscosity increases linearly as the concentration of nana particles increases but some other researchers found non-linear behaviour of viscosity and nanoparticles concentration [50]. Drzazga et al. investigated the effect of surfactant on the viscosity. They added nonionic surfactant in water based CuO nanofluids and concluded that the addition of surfactant increases the viscosity of nanofluids [51].

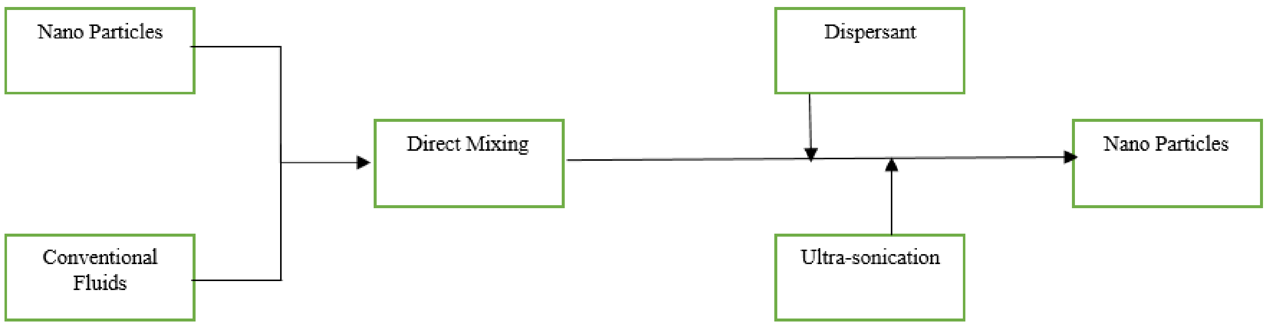

Fig 2.1 Schematic for nana fluid preparation

Table 2. Effect of temperature range on thermal conductivity enhancement

Sr. No.	Nano particle	Base fluid	Concentration (Vol. %)	Enhancement in TC (%)	Reference
1.	Al_2O_3	Water	-	32	19
2.	TiO_2	Water	-	11	19
3.	CuO	Water	3.5	14	25
4.	ZnO	Ethylene glycol	3.5	40	21
5.	Al_2O_3	50:50 W:EG	.5	5.8	27
6.	Al_2O_3	60:40 W:EG	.5	4	27
7.	Al_2O_3	40:60 W:EG	.5	8.9	27
8.	CuO	Water	3.5	40	26
9.	CuO	W-EG	5	23	28
10.	Graphene	EG	5	86	29
11.	Al_2O_3	W-EG	.2	6.9	30
12.	Al_2O_3	W-EG	.4	7.3	30
13.	Al_2O_3	W-EG	.6	14.6	30
14.	TiO_2	60:40 W:EG	.2	1.94	31
15.	TiO_2	60:40 W:EG	1	4.38	31

Table 3. Effect of various nana materials and concentration on thermal conductivity enhancement

Sr. No.	Nano particle	Temperature (^0C)	Concentration (vol. %)	Enhancement in TC (%)	Reference
1.	TiO_2	20-70	0.05	5.19	24
2.	TiO_2	20-70	0.1	4.5	24
3.	TiO_2	20-70	0.5	4.08	24
4.	CuO	15-50	0.8	15.6-24.56	32
5.	Al_2O_3	15-50	0.8	9.81-17.89	32

IV. APPLICATIONS OF NANOFLUID

Nanofluids have wide range of applications in the different fields such as lubrication, surface coatings, biomedical applications and thermal applications. In industries cooling and heating is most essential task hence heat transfer applications have gained more importance. SM Peyghambarzadeh et al. reported the application of nanofluids in transport systems such as automobile radiators [52]. Recent trends are showing the application of nanofluids in solar collectors. The conventional direct absorption solar collector is well known technology however the efficiency is limited by the absorption capacity of working fluids. Li et.al investigated the performance of tubular solar collector using Al_2O_3/water, ZnO/water & MgO/water nanofluids and concluded that 95% of incoming radiation can be absorbed with the volume fraction of nanofluids less than 10 ppm [53]. Khullar et al. studied aluminum based nanofluids on concentric parabolic solar collectors. The nanofluid was prepared by suspending 0.05% volume of aluminum in therminal VP-1 base fluid and compared the results with conventional collectors they found 5-10% enhancement in thermal efficiency [54]. Otanicar et.al reported the effect of nanofluids on the efficiency and concluded enhancement up to 5%. They found that while using graphite based nanofluids with 30 nm particle size the thermal efficiency can be increased 3% and 5% increment in thermal efficiency can be obtained by silver nana particles of 20 to 40 nm [55]. C. Paul et al. concluded that heat capacity of Al2O3 based nanofluid increased by 23% and by using silicon nana particles the enhancement was found 26% [56].

M.Faizaletal. investigated the flat plate solar collector by using MWCNT based nanofluids. They studied on the size of flat plate collector and reported 37% reduction in size with MWCNT based nanofluids [57].Donzelli et al. concluded that some special nanofluids can be used as smart materials to control the flow of heat [58]. Kim et al. performed experiments to check the feasibility of nanofluids in nuclear reactor application [59]. Nanofluids can also be used as coolant in radiators which allows better positioning and smaller size of radiators. Singh et al concluded that the use of high thermal conductive nanofluids leads up to 5% fuel saving and up to 10% reduction in frontal area of radiator [60]. Nano fluids also have applications in the field of electronic for microchip cooling and in the field of biomedical nanofluids can be used in Nano drug delivery, Cryopreservation and cancer therapy.

V. CONCLUSION

Nanofluids are the best alternatives to the conventional fluids and shows better performance and thermo-physical properties than conventional fluids.

- Stability of nanofluid can be increased by the addition of surfactants and ultra-sonication.
- Electrical conductivity of nanofluids are higher than base fluids.
- Thermal conductivity of conventional fluid can be increased by using nana particles.
- Thermal conductivity of nanofluids depends upon the geometrical shape and size of particles as well as on the concentration of nana particles.
- Heat transfer coefficient increases as the temperature increases.
- Efficiency of solar collector can be enhanced by using nanofluids instead of conventional fluids.

REFERENCES

[1] S. U. S. Choi, “Nanofluids: from vision to reality through research,” Journal of Heat Transfer, 131, no. 3, 2009, pp. 1–9.
[2] T. Tyler, O. Shenderova, G. Cunningham, J.Walsh, J. Drobnik, and G. McGuire, “Thermal transport properties of diamond based nanofluids and nanocomposites,” Diamond and Related Materials, 15, no. 11-12, 2006, pp. 2078–2081.
[3] M.-S. Liu, M. C.-C. Lin, I.-T. Huang, and C.-C. Wang, “Enhancement of thermal conductivity with carbon nanotube for nanofluids,” International Communications in Heat and Mass Transfer, 32, no. 9, 2005, pp. 1202–1210.
[4] W. Yu, D. M. France, J. L. Routbort, and S. U. S. Choi, “Review and comparison of nanofluid thermal conductivity and heat transfer enhancements,” Heat Transfer Engineering, 29, no. 5, 2008, pp. 432–460.
[5] S. K. Das, S. U. S. Choi, and H. E. Patel, “Heat transfer in nanofluids—a review,” Heat Transfer Engineering, 27, no. 10, 2006, pp. 3–19.
[6] S. U. S. Choi, Z. G. Zhang, and P. Keblinski, “Nanofluids Encyclopedia of Nanoscience and Nanotechnology”, H. S. Nalwa, Ed., vol. 6, pp. 757–737, American Scientific, Los Angeles, Calif, USA, 2004.
[7] M.H.U. Bhuiya, R. Saidur, M.A. Amalina, R.M. Mostafizur, AKMS Islam, “Effect of nanoparticles concentration and their sizes on surface tension of nanofluids”, Procedia Engineering, 105, 2015, pp. 431 – 437.
[8] S. Eiamsa-ard, K. Kiatkittipong, W. Jedsadaratanachai, “Heat transfer enhancement of TiO2 /water nanofluid in a heat exchanger tube equipped with overlapped dual twisted-tapes”, Engineering Science and Technology an International Journal, 18, 2015, pp. 336-350.
[9] S M Alves, B S Barros, M F Trajano, K S B Ribeiro, E Moura, “Tribological behavior of vegetable oil based lubricants with nanoparticles of oxides in boundary lubrication conditions” Tribology International, 65, 2013, pp. 28 - 36 ·
[10] R S Khedkar, A S Kiran, S SSonawane, K Wasewar, S SUmre, “Thermo – Physical Characterization of Paraffin based Fe3O4 Nanofluids” Procedia Engineering, 51, 2013, pp. 342-346.
[11] M N Rashin, J Hemalatha, “Viscosity studies on novel copper oxide–coconut oil nanofluid” Experiment Thermal Fluid Science, 48, 2013, pp. 67-72.
[12] ShuyingGu, Yihan Zhang, Beibei Yan, “Solvent-free ionic molybdenum disulfide (MoS2) nanofluids with self-healing lubricating behaviors”, Materials Letters, 97, 2013, pp.169-198.
[13] Novoselov KS, Geim AK, Morozov SV, Jiang D, Zhang Y, Dubonos SV, Grigorieva , Firsov AA. “Electric field effect in atomically thin carbon films, Science, 306(5696), 2004, pp. 666-9.
[14] Mehrali M, Latibari ST, Mehrali M, Mahlia TMI, Metselaar HSC, Naghavi MS, et al. , “Preparation and characterization of palmitic acid/graphene nana platelets composite with remarkable thermal conductivity as a novelshape-stabilized phase change material”, Applied Thermal Engineering, 61, 2013, pp.633–40.
[15] Emad Sadeghinezhad, Mohammad Mehrali , R. Saidur , Mehdi Mehrali , Sara TahanLatibari, Amir Reza Akhiani, Hendrik Simon CornelisMetselaar, “A comprehensive review on graphene nanofluids: Recent research, development and applications” , Energy Conversion and Management, 111, 2016, pp. 466–487.
[16] Mehrali M, Latibari ST, Mehrali M, IndraMahlia TM, Metselaar HS Cornelis, “Preparation and properties of highly conductive palmitic acid/graphene oxide composites as thermal energy storage materials”, Energy, 58, 2013, pp. 628–34.
[17] Yimin Xuan, Qiang Li, “Heat transfer enhancement of nanofluids”, International Journal of Heat and Fluid Flow, 21, 2000, pp. 58-64.
[18] Eastman, J.A., Choi, U.S., Li, S., Thompson, L.J., Lee, S., “Enhanced thermal conductivity through the development of Nanofluids”, In: Komarneni, S., Parker, J.C., Wollenberger, H.J. (Eds.), Nanophase and Nanocomposite Materials II. MRS, Pittsburg, 1997, pp. 3-11.
[19] Masuda, H., Ebata, A., Teramae, K., Hishinuma, N., “Alteration of thermal conductivity and viscosity of liquid by dispersing ultra-fine particles Dispersion of Al2O3, SiO2 and TiO2 ultra-fine particles”, NetsuBussei, 7, 1993, pp. 227 233.
[20] Das, S.K., Putra, N., Thiesen, P., Roetzel, W., “Temperature dependence of thermal conductivity enhancement for nanofluids”, Journal of Heat Transfer, 125, 2003, pp. 567-574.

[21] Kole M and Dey T., “Investigation of thermal conductivity, viscosity, and electrical conductivity of graphene based nanofluids”, Journnal of applied Physics, 113, 2013: 084307.
[22] Abdolbaqi MK, Sidik NAC, Aziz A, Mamat R, Azmi WH, Yazid MNAWM, and Najafi G, “ An experimental determination of thermal conductivity and viscosity of Bioglycol/water based TiO2 nanofluids”, International Communications in Heat and Mass Transfer, 77, 2016, pp. 22-32.
[23] Khdher AM, Sidik NAC, Hamzah WAW, and Mamat R, “An experimental determination of thermal conductivity and electrical conductivity of bio glycol based Al2O3 nanofluids and development of new correlation” International Communications in Heat and Mass Transfer, 73, 2016, pp. 75-83.
[24] Mohammad Rafiqul Islam, Bahman Shabani, 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, pp. 101 – 108.
[25] Lee, S., Choi, S.U.S., Li, S., Eastman, J.A., “Measuring thermal conductivity of fluids containing oxide nanoparticles”, Journal of Heat Transfer, 121, 1999, pp. 280 289.
[26] Eastman, J.A., S. C., J. Thompson, Proc. Symp. Nanophase Nanocomp. Materials, 1999, pp. 3-11.
[27] N. A. Usri, W. H. Azmi, RizalmanMamat, K. Abdul Hamid, G. Najafi, “Thermal Conductivity Enhancement of Al2O3 Nanofluid in Ethylene Glycol and Water Mixture”, Energy Procedia, 79, 2015, pp. 397 – 402.
[28] Khedkar, R. S., Sonawane, S. S., Wasewar, K. L., “Influence of CuO nanoparticles in enhancing the thermal conductivity of water and monoethylene glycol based nanofluids”, International Communications in Heat and Mass Transfer, 39, 2012, pp. 665-66.
[29] Yu, W., Xie, H., Wang, X., Wang, X., Significant thermal conductivity enhancement for nanofluids containing graphene nanosheets, Physics Letters, A 375 (10), 2011, pp. 1323-1328.
[30] N. A. Usri, W. H. Azmi, RizalmanMamat, K. Abdul Hamid, G. Najafi, “Heat Transfer Augmentation of Al2O3 nanofluid in 60:40 Water to Ethylene Glycol Mixture”, Energy Procedia, 79, 2015, pp. 403 – 408.
[31] Reddy MCS and Rao VV., “Experimental studies on thermal conductivity of blends of ethylene glycol-water-based TiO2 nanofluids”, Int. Commun. Heat Mass Transfer, 46, 2013, pp. 31-36
[32] Sundar LS, Farooky MH, Sarada SN, and Singh MK. Experimental thermal conductivity of ethylene glycol and water mixture based low volume concentration of Al2O3 and CuO nanofluids. Int. Commun. Heat Mass Transfer, 41, 2013, pp. 41-46.
[33] G.-J. Lee, C.K. Kim, M.K. Lee, C.K. Rhee, S. Kim, C. Kim, “Thermal conductivity enhancement of ZnO nanofluid using a one-step physical method”, ThermochimActa, 542, 2012, pp. 24–27.
[34] J A Eastman, S U S Choi, S Li, W Yu, L J Thompson, “Anomalously increased effective thermal conductivities of ethylene glycol-based nanofluids containing copper nanoparticles”, Applied Physics Letters, 78, 2001, pp. 718.
[35] R. Dharmalingam, K.K. Sivagnanaprabhu, B. Senthilkumar, R. Thirumalai, “Nano materials and nanofluids: An innovative technology study for new paradigms for technology enhancement”, Procedia Engineering, 97, 2014, pp. 1434 – 1441.
[36] A.A. AbbasianArani, J. Amani, “Experimental study on the effect of TiO2–water nanofluid on heat transfer and pressure drop”, Exp. Therm. Fluid Sci., 42, 2012, pp. 107–115.
[37] W Yu, H Xie, L Chen, Y Li, “Investigation of thermal conductivity and viscosity of ethylene glycol based ZnO nanofluid”, ThermochimicaActa, 491 (1), 2009, pp. 92-96.
[38] K. Abdul Hamid, W.H. Azmi, RizalmanMamat, N.A. Usria and G. Najafi, “Investigation of Al2O3 Nanofluid Viscosity for Different Water/EG Mixture Based”, Energy Procedia, 79, 2015, pp. 354 – 359.
[39] Xuefeng Shao, Ying Chen, Songping Mo, Zhengdong Cheng, Tao Yin, “Dispersion Stability of TiO2-H2O Nanofluids Containing Mixed Nanotubes and Nanosheets”, Energy Procedia, 75, 2015, pp. 2049 – 2054.
[40] Sarit Kumar Das, Nandy Putra, Peter Thiesen, WilfriedRoetzel, “Temperature dependence of thermal conductivity enhancement for nanofluids”, Journal of heat transfer, 125(4), 2003, pp.567-574.
[41] Dae-Hwang Yoo, KS Hong, TE Hong, JA Eastman, Ho-Soon Yang, “Thermal Conductivity of Al2O3-Water Nanofluids”, J. Korean Phys. Soc, 51 (12), 2007, pp. S84-S87.
[42] D Lee, J W Kim, B G Kim, “A new parameter to control heat transport in nanofluids: surface charge state of the particle in suspension”, J Phys Chem B, 110, 2006, pp. 4323-8.
[43] M J Assael, I N Metaxa, J Arvanitidis, D Christofilos, C Lioutas, “Thermal Conductivity Enhancement in Aqueous Suspensions of Carbon Multi-Walled and Double Walled Nanotubes in the Presence of Two Different Dispersants ”, International Journal of Thermophysics, 26, 2005, pp. 647-664.
[44] M Moosavi, EK Goharshadi, A Youssefi, “Fabrication, characterization, and measurement of some physicochemical properties of ZnO nanofluids”, International journal of heat and fluid flow, 31 (4), 2010, pp. 599-605.
[45] H.Q. Xie, J.C. Wang, T.G. Xi, Y. Liu, F. Ai, “Dependence of the thermal conductivity of nanoparticle-fluid mixture on the base fluid”, J. Mater. Sci. Lett., 21, 2002, pp. 1469–1471.
[46] E V Timofeeva, W Yu, D M France, D Singh, J L Routbort, “”,Base fluid and temperature effects on the heat transfer characteristics of SiC in ethylene glycol/H2OH2O and H2OH2O nanofluids, Journal of Applied Physics, 109, 2011, pp. 014914.
[47] H Xie, J Wang, T Xi, Y Liu, “Thermal Conductivity of Suspensions Containing Nanosized SiC Particle”, International Journal of Thermophysics, 23(2), 2002, pp. 571–580.
[48] A Ghadimi, I H Metselaar , “The influence of surfactant and ultrasonic processing on improvement of stability, thermal conductivity and viscosity of titania nanofluid”, Exp. Therm. Fluid Sci., 51, 2013, pp. 1–9.
[49] C T. Nguyen, F. Desgranges, G. Roy, N. Galanis, T. Mare, S. Boucher and H.A. Mintsa, "Temperature and particle-size dependent viscosity data for water-based nanofluids-hysteresis phenomenon," Int. J. Heat Fluid Flow, 28, 2007, pp. 1492.
[50] I M Mahbubul, R Saidur, M AAmalina, “Latest developments on the viscosity of nanofluids”Int J Heat Mass Transfer, 55, 2012, pp. 874-885.
[51] M Drzazga, A Gierczycki, G Dzido, M Lemanowicz, “Influence of nonionic surfactant addition on drag reduction of water based nanofluid in a small diameter pipe” Chinese Journal of Chemical Engineering, 21(1), 2013, pp. 104-108.
[52] SM Peyghambarzadeh, SH Hashemabadi, MS Jamnani, SM Hoseini, “Improving the cooling performance of automobile radiator with Al2O3/water nanofluid”, Applied Thermal Engineering, 31(10), 2011, pp. 1833-1838.
[53] Li Y, Xie H, Yu W, Li J., “Investigation on heat transfer performances of nanofluids in solar collector”, Material Science Forum, 694, 2011, pp. 33–36.
[54] Vikrant Khullar, Himanshu Tyagi, Todd P. Otanicar, Patrick E. Phelan, Harjit Singh, Robert A. Taylor, “Solar energy harvesting using nanofluids-based concentrating solar collector”, ASME digital collection, 2012, pp. 259-267.
[55] Otanicar TP, Phelan PE, Prasher RS, Rosengarten G, Taylor RA., “Nanofluid based direct absorption solar collector. Journal of Renewable and Sustain”, Energy, 2, 2010; 033102.
[56] Titan C.Paul, Morshed AKM M, Jamil A.Khan., “Nanoparticle enhanced ionic liquids (NEILS) as working fluid for the next generation solar collector” ,Procedia Engineering, 56, 2013, pp. 631 -636.
[57] Faizal M, Saidur R, Mekhilef S., “Potential of size reduction of flat-plate solar collectors when applying MWCNT nanofluid”, Earth and Environmental Science, 16, 2013,: 012004.
[58] G. Donzelli, R. Cerbino, and A. Vailati, “Bistable heat transfer in a nanofluid,” Physical Review Letters, 102, no. 10, 2009 Article ID 104503, 4 pages.
[59] S. J. Kim, I. C. Bang, J. Buongiorno, and L. W. Hu, “Study of pool boiling and critical heat flux enhancement in nanofluids,” Bulletin of the Polish Academy of Sciences—Technical Sciences, 55, no. 2, 2007, pp. 211–216.
[60] D. Singh, J. Toutbort, G. Chen, et al., “Heavy vehicle systems optimization merit review and peer evaluation,” Annual Report, Argonne National Laboratory, 2006.