EXPERIMENTAL STUDY OF THERMOPHYSICAL PROPERTIES OF NANOFLUIDS FOR HEAT TRANSFER APPLICATIONS

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ABSTRACT: There is a strong need to develop advanced heat transfer fluids, with significantly higher thermal conductivities and improved heat transfer characteristics than are presently available.1 or 2 lines about importance of heat transfer, then importance of nanofluids. The Nano particles used in nanofluids are typically made of metal oxides, carbides and carbon nanotubes. Nano fluids have novel properties that make them potentially useful in many applications in heat transfer. Nanofluid is a fluid obtained by suspending nano sized particles in base fluid. Nanofluid is a promising heat transfer fluid to enhance heat transfer due to its superior thermal conductivity and rheological properties. This paper projects the theoretical and experimental investigations of different physical and heat transfer characteristics of nanofluid such as density, dynamic viscosity, specific heat and thermal conductivity are performed by varying volume concentrations of nanofluids. The attained theoretical and experimental results of thermophysical properties of Al_2O_3, SWCNT and MWCNT nanofluids have been analysed. The results show that among all the three nanofluids Al_2O_3 has better thermophysical properties leading to superior heat transfer characteristics. The present study reveals the potential applications by utilizing nanofluid such as heat exchangers, refrigeration, industrial cooling, solar energy and defence etc.

1.INTRODUCTION

Nanofluids are a promising class of heat transfer fluids that have gained attention inrecent years due to their superior thermal conductivity and rheological properties. They are suspensions of nanoparticles in base fluids such as water or ethylene glycol.The useof nanofluids has been shown to improve heat transfer rates, reduce frictional loss, and minimize pressure drop in heat transfer devices. Nanofluid technology was developed in

1993, and it has been applied in a number offields, including defence, nuclear power plants, and automotive cooling systems [1]. To create nanofluids, the process entails dispersing nanoparticles in the base fluid. Theone-step and two-step physical methods are the two fundamental ways to preparenanofluids. One-step involves drying, storing, transporting, and dispersing nanoparticles,while the two-step method involves obtaining nanoparticles using distinct techniques and dispersing them into the base liquid[2]. Carbon ceramics, nitride ceramics, and metal oxide nanoparticles that conduct heatare frequently employed. The nanofluid's stability is essential to obtaining the samethermophysical characteristics. Centrifugation, electron microscopy, zeta potential, and sedimentation photograph methods are some of the methods used for assessment [3]. Heat exchangers, refrigeration systems, electronics, transformer oil, industrial cooling,nuclear system cooling, machining, solar energy, desalination, geothermal energyextraction, and the defense sector are just a few of the industries that use nanofluids extensively.

2. LITERATURE REVIEW

Tuckerman first becomes familiar with microchannel technology in 1981. Twelve yearslater, in 1992, Argonne National Laboratory begins working on nanofluid, which Choi andEastman eventually dubbed "nano fluid" in 1993.Lee and colleagues (1999) [2] examined the oxide nanoparticles thermal conductivity when they were scattered in the base fluid. Eastman et al. [3] discovered an increase in the thermal conductivity of copper nanoparticle-containing ethylene glycol-based nanofluids. Choi et al. [4] investigated thermal conductivity of nanotube suspension. In 2007, Dasetal.[5] authored the first book on nanofluids, "Nanofluids: Science and Technology," which Wiley published. Choi [6[6]] recommended using nanofluid in the cooling system of automobiles. The world's largest research project (€8.3 million) on the application of nanofluid, called Nano Hex, was started by twelve European businesses and research centres[7] Xuan and Roetzel [7] recommended that the velocity formulation take into account Brownian motion. The base fluid's random motion of the nanoparticles causes the thermal boundary layer to recede [8[8]]. Gupta et al. [9] concluded that the enhancement of heat transfer can be attributed topercolation, Brownian motion, and micro-level convection. By dispersing nanoparticles in the base fluid, nanofluids are created. A suitabledispersion is required before applying nanofluid. One-step and two-step physical methods are the two basic ways to prepare nanofluids. One-step method: This method avoids some steps, such as the drying, storing,transporting, and dispersingofthe nanoparticles.

By using the Physical Vapor Deposition (PVD) technique, which involves carryingnanoparticles in the base fluid through direct evaporation and condensation, stablenanofluid is created.Using this technique, pure and homogenous nanoparticles arecreated. As a result, there is less nanoparticle accumulation. The primary disadvantagesof the one-step method are its high cost and the residual reactants that remain in the nanofluids. Zhuetal.[11[11]]prepared Cu nanofluid one-step method.

The most cost-effective technique for producing nanofluid on a large scale is the two-step method.The two-step method involves obtaining the nanoparticles using distincttechniques and dispersing them into the base liquid to create the desired nanofluid.This production method is large-scale and low-cost. The aggregation of nanoparticles isthe primary disadvantage of the two-step method. The use of surfactant is due toinstability.

Thisisshownanofluidispreparedcommercially.Whenpreparing nanofluidforresearch,this method is preferred by the majority of researchers.Zhu et al. [[12]] used two stepmethodtoprepareAl2O3/waternanofluid.Figure3demonstratesthetwo-stepmethod.Heat-conductive metal oxide nanoparticles (Al_2O_3, CuO, TiO_2, ZnO, MgO, SiC, etc.) arethe ones that are favoured. As nanoparticles, nitride ceramics (AlN, SiN) and carbon ceramics (SiC, TiC) are also employed. Base fluids such as water (H_2O), ethylene glycol(EG), engine oil(EO),etc.arefrequentlyused.

Stability of nanofluid is important to get the same thermophysical properties. Stabilityof nanofluid is related to electrical double layer repulsive force and Van der Waalsattractive force.Electrical Double Layer Repulsive Force (EDLRF) must be higher than the Vander Waals attractive forces to get stable nanofluid. Several assessment methods have been used by researchers to look into the stability ofnanofluid.They are the centrifugation method, electron microscopy method, zetapotential, and sedimentation photograph method. Different methods have been developed in enhancing nano fluid stability. They are: Dispersant method: By lowering the surface tension of the base fluid, the addition ofdispersants or surfactants is a popular technique for improving the stability of nanofluidand preventing the agglomeration of nanoparticles. However, overuse of dispersant canharm the thermophysical characteristics of nanofluid, such as lowering its thermal conductivity and compromising its chemical stability [23[23]].

Examples:Sodium dodecyl benzene sulfonate (SDBS), Gumarabic, Sodium dodecylsulphate

(SDS), Polyvinylprolidone (PVP) etc. Magnetic stirring: A magnetic stirrer is used in laboratories to reduce sediment andincrease homogeneity of nanofluid by means of a revolving magnetic field. A magneticstirrer or magnetic mixer typically has two knobs: a left knob and a right knob. The knobon the left controls the rate of stirring. Conversely, the right knob regulates the heating. Some researchers use the magnetic stirring technique prior to sonication. [24, 25-26].

Sonication: Compared to magnetic stirring, the sonication method provides betterdispersion and a lower chance of particle agglomeration. The sonication method appliesultrasonic waves through a nanofluid. To create a more homogenised suspension, sonication is helpful. Sonication using a probe type performs better than sonication using a bath type, when sonication process is applied, the agglomerated nanoparticles are vibrated by the ultrasonic waves. Sonication creates cavitation bubbles that expand until they reach a critical state. The combination of extremely high local pressure and temperature creates hotspots. Hotspots are produced when the situation is critical. These hot spots break down the lumped particles [27-28]. The benefits of nanofluid and the mechanisms underlying this improvement in heat transfer are still being studied. Numerous researchers came to the following conclusion: [22,29-32].

The distributed nanoparticles raise the fluid's effective thermal conductivity. Afunction of the volume fraction of nanoparticles is the effective thermal conductivity. Itrises as the volume fraction of nanoparticles increases. The enhanced specific surfacearea of the particles causes an increase in the interaction between the base fluid and nanoparticles. Brownian motions produced by the dispersed nanoparticles enhance fluid-particlecollisionandinteraction.Thescatterednanoparticlesincreasethemixingfluctuationandturbulence.In comparison to base fluid, the pumping power required for equivalent heattransferislower.

Cons: The production of nanoparticles requires sophisticated machinery. Therefore,the cost of producing nanofluid is high.Nanofluid stability is low in the absence of surfactant. As the density and viscosity of the fluid increase, so do the pressure drop and pumping power. The nanofluid has substantially higher density and viscosity than thebase fluid. As a result, the nanofluid has a greater pressure drop and pumping power than the base fluid. The nano fluid as a lower specific heat than the base fluid.

Heat exchangers, refrigeration systems, electronics equipment, transformer oil, industrial cooling, nuclear system cooling, machining operations, geothermal energyextraction, solar energy and desalination, and defence are just a few of the many uses for nano fluids.

3. EXPERIMENTAL SETUP

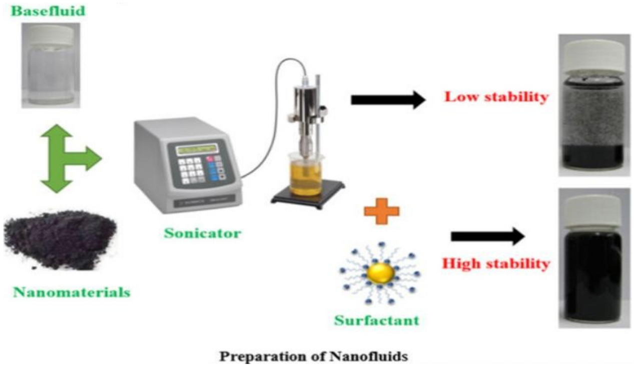

Fig.1: Preparation of nano fluid [33]

Nano fluidis prepared by the dispersion of nanoparticles into conventional fluids. In the figure the stability of the nano fluid is enhanced primarily by application of sonicator using sonic waves. Then surfectant is which increases or enhances the stability of the nano fluids evenmore.

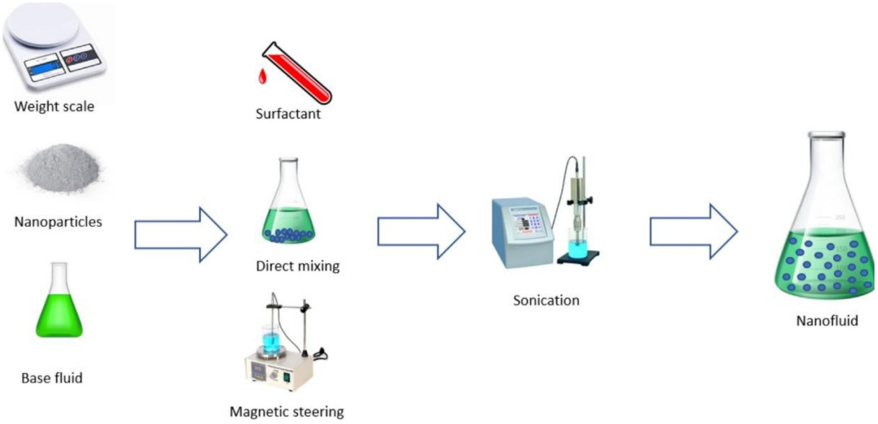

Fig.2:two step method [10]

By weighing the weights of both nanoparticles and conventional fluids mixing of themtakes place. Then we enhance the properties of the formed nanofluid by application ofmagnetic stirrer and surfactant. The resultant nanofluid passes through a sonicator resulting in a greater stability nano fluid.

4. RESULTS AND DISCUSSIONS:

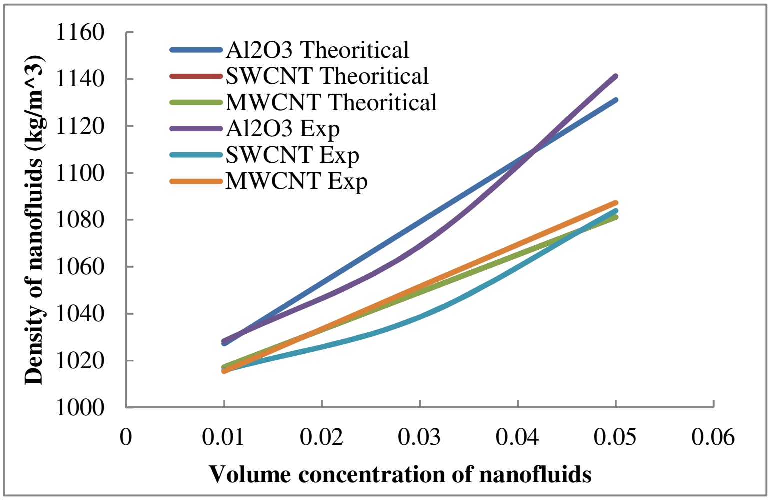

Fig.3: Density versus volume concentrations of nanofluids

Increased density results in increased heat transfer from the Figure.3, it is observed that the theoretical density of all the three nanofluids varies linearly with increased volume concentration, further the experimental density value is same as the theoretical density value at lower concentrations. But, with the gradual increase in concentration the density first decreased to an optimum value and then increased to a high value compared to experimental value. From the above figure 3 that density of Al_2O_3 is more compared to other nanofluids both theoretically and experimentally.

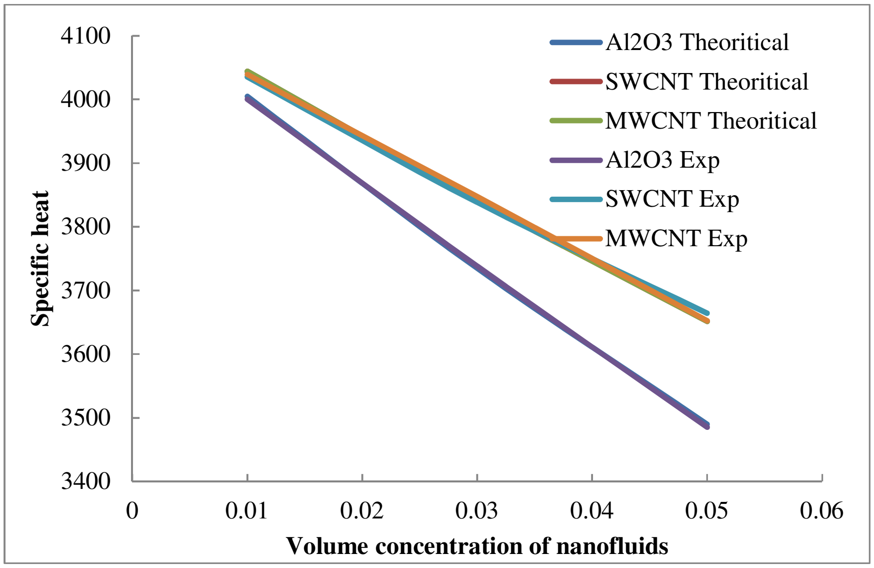

Fig.4: Specific heat versus volume concentrations of nanofluids

The above figure 4 shows the comparison of specific heat for different volume concentration of nanofluid. From the above Figure.4. it can be concluded easily that by using theoretical Al_2O_3 the specific heat decreases compare to the other nanofluids SWCNT, MWCNT, also it can be noticed from the above graph that specific heat of Al_2O_3 is less compared to other nanofluids both theoretically and experimentally.

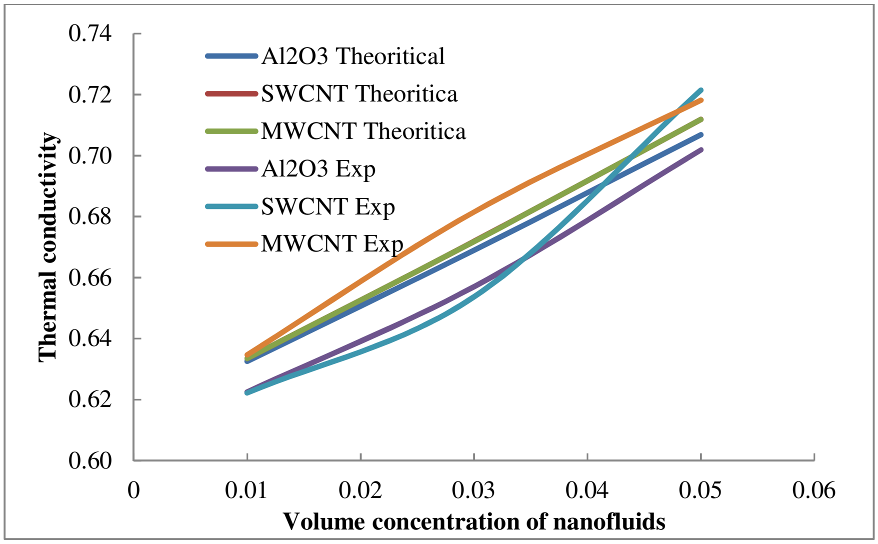

Fig.5: Thermal conductivity versus volume concentrations of nanofluids

The above Figure.5 shows the comparison of thermal conductivity and volume concentration of nanofluids. It can be concluded easily that by using theoretical Al_2O_3 nanofluid the thermal conductivity varies linearly when compared to the other nanofluids.

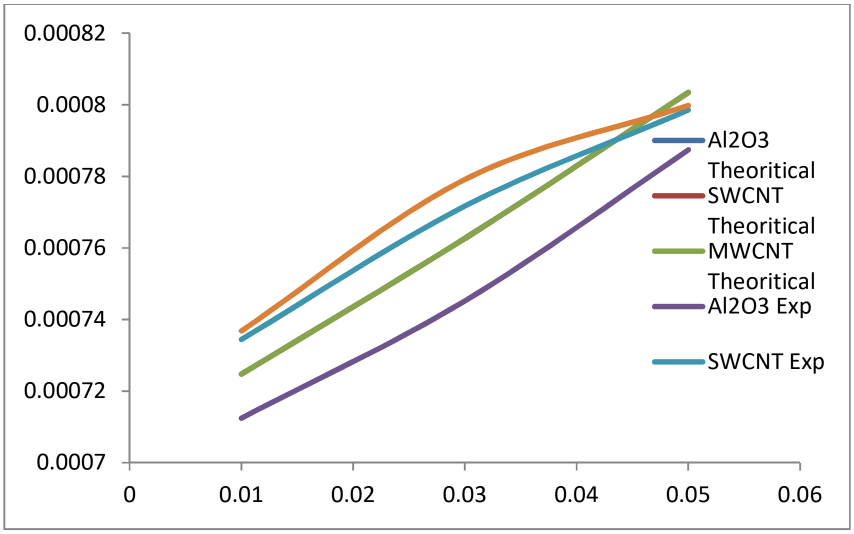

Fig.6: Dynamic viscosity versus volume concentrations of nanofluids

The above Figure.6 shows the comparison of dynamic viscosity and volume concentrations of nanofluids from the above figure.6 it can be concluded easily that by using Al_2O_3 nanofluid the dynamic viscosity increased compared to the experimental Al_2O_3 and other experimental nanofluids.

CONCLUSIONS: Researchers are relentlessly working to enhance heat transfer rate, thermal conductivity. A new type of Heat transfer fluid is engineered which provides improved thermal properties for heat transfer which is called as nanofluid. Nano fluids are expected to exhibit superior properties relative too those conventional heat transfer fluids and fluids containing micro meter sized particles. In this research paper physical properties of nanofluids are measured and compared with available literatures. In this study with the increase in concentration the density of fluid decreased up to an optimum value of 0.03 volume concentration. Further increase in volume concentration of nanofluid results in increased density, specific heat, thermal conductivity and dynamic viscosity. The experimental density of nanofluid is more than the theoretical density at higher concentrations. Among all the three fluids the density, specific heat, thermal conductivity and dynamic viscosity is more compared to other fluids both experimentally and theoretically.

References

[1] John H. Merkin, Ioan Pop, Yian Yian Lok, Teodor Gros an, Chapter 4 -Nanofluids, Similarity Solutions for the Boundary Layer Flow and Heat Transfer ofViscous Fluids, Nanofluids, Porous Media, and Micropolar Fluids, Academic Press,2022,ISBN9780128211885.

[2] (https://www.sciencedirect.com/science/article/pii/B9780128211885000059).

[3] Wang XJ, Zhu DS (2009) Investigation of pH and SDBS on enhancement of thermalconductivityin nanofluids.ChemPhysLett 470:107–111.

[4] Lee S, Choi S, Li S, Eastman JA (1999) Measuring thermal conductivity of fluidscontaining oxidenanoparticles.JHeatTransfer121:280–289.

[5] Eastman JA, Choi SUS, Li S et al (2001) Anomalously increased effective thermalconductivities of ethylene glycol-based nanofluids containing copper nanoparticles.ApplPhysLett78:718–720.

[6] Choi SUS, Zhang ZG, Yu W et al (2001) Anomalous thermal conductivity enhancementin nanotube suspensions. Appl Phys Lett 79:2252–2254.

[7] Das SK, Choi SU, Yu W, Pradeep T (2007) Nanofluids: science and technology. Wiley,NewYorkChoi S (2006) Nanofluids for improved efficiency in cooling systems. Heavy Veh SystRev18–20.

[8] TheProject.https://www.nanohex.org/the-project.Accessed8Aug2020.

[9] Xuan Y, Roetzel W (2000) Conceptions for heat transfer correlation of Nanofluids. Int JHeatMassTransfer43:3701–3708.

[10] Kakaç S, Pramuanjaroenkij A (2009) Review of convective heat transfer enhancementwithnanofluids.IntJHeatMassTransfer52:3187–3196.

[11] Sen Gupta S, Manoj Siva V, Krishnan S et al (2011) Thermal conductivity enhancementofnanofluidscontaininggraphene nanosheets.JApplPhys110:084302.

[12] Ali, A.R.I., Salam, B. A review on nanofluid: preparation, stability, thermophysicalproperties, heat transfer characteristics and application. SN Appl. Sci. 2, 1636 (2020).

[13] Zhu HT, Lin YS, Yin YS (2004) A novel one-step chemical method for preparation ofcopper nanofluids.JColloidInterface Sci277:100–103.

[14] Zhu D, Li X, Wang N (2009) Dispersion behavior and thermal conductivitycharacteristicsofAl2O3–H2Onanofluids.CurrAppl Phys9:131–139.

[15] SarkarJ(2011)A criticalreviewonconvectiveheattransfercorrelations ofnanofluids.RenewSustainEnergyRev15:3271–3277.

[16] Hwang Y, Park HS, Lee JK, Jung WH (2006) Thermal conductivity and lubricationcharacteristicsofnanofluids.CurrApplPhys6:67–71.

[17] Lee SW, Park SD, Kang S et al (2011) Investigation of viscosity and thermalconductivity of Sic nanofluids for heat transfer applications. Int J Heat Mass Transfer54:433–438.

[18] Bobkov V, Fokin L, Petrov E et al (2018) Thermophysical properties of materials fornuclear engineering: a tutorial and collection of data. Int At Energy Agency,

Vienna,Austria.

[19] ChungDDL(2001)Materialsforthermalconduction.ApplThermEng21:1593–1605.

[20] Hofmeister AM (2014) Thermal diffusivity and thermal conductivity of single-crystalMgO and Al_2O_3 and related compounds as a function of temperature. Phys ChemMiner41:361–371.

[21] Shackelford JF, Alexander W (2000) CRC materials science and engineering handbook,vol.3. CRCPress,BocaRaton.

[22] Kim SH, Choi SR, Kim D (2007) Thermal conductivity of metal-oxide nanofluids:particlesizedependenceandeffectoflaserirradiation.JHeatTransfer129:298–307.

[23] Wen D, Lin G, Vafaei S, Zhang K (2009) Review of nanofluids for heat transferapplications.Particuology7:141–150.

[24] Choi C, Yoo HS, Oh JM (2008) Preparation and heat transfer properties ofnanoparticle-in-transformer oil dispersions as advanced energy-efficient coolants.CurrApplPhys8:710–712.

[25] Asadi A, Asadi M, Siahmargoi M et al (2017) The effect of surfactant and sonicationtime on the stability and thermal conductivity of water-based nanofluid containingMg(OH)$_2$ nanoparticles: an experimental investigation. Int J Heat Mass Transfer108:191–198.

[26] Saleh R, Putra N, Wibowo RE et al (2014) Titanium dioxide nanofluids for heattransfer applications. Exp Therm Fluid Sci 52:19–29.

[27] Chakraborty S, Sarkar I, Behera DK et al. (2017) Experimental investigation on theeffect of dispersant addition on thermal and rheological characteristics of TiO2nanofluid.PowderTechnol307:10–24.

[28] Choudhary R,KhuranaD,Kumar A,SubudhiS(2017)StabilityanalysisofAl_2O_3/water nanofluids. J Exp Nanosci 12:140–151.

[29] Afzal A, Nawfal I, Mahbubul IM, Kumbar SS (2019) An overview on the effect ofultrasonication duration on different properties of nanofluids. J Therm Anal Calorim135:393–418.

[30] Cheng L, Bandarra Filho EP, Thome JR (2008) Nanofluid two-phase flow and thermalphysics: a new research frontier of nanotechnology and its challenges. J NanosciNanotechnology8:3315–3332.

[31] Shanbedi M, Heris SZ, Amiri A (2015) Synthesis of aspartic acid-treated multi-walledcarbonnanotubes-basedwatercoolantandexperimentalinvestigationofthermal and hydrodynamic properties in circular tube. Energy Convers Manag105:1366–1376.

[32] Heris SZ, Mohammadpur F, Mahian O, Sahin AZ (2015) Experimental study of

twophase closed thermosyphon using cuo/water nanofluid in the presence of electricfield.ExpHeatTransfer28:328–343.

[33] Huminic G, Huminic A (2013) Numerical study on heat transfer characteristics ofthermosyphon heat pipes using nanofluids. Energy Convers Manag 76:393–399.

[34] Zafar Said, L. Syam Sundar, Arun Kumar Tiwari, Hafiz Muhammad Ali, MohsenSheikholeslami, Evangelos Bellos, Hamza Babar,Recent advances on the fundamentalphysical phenomena behind stability, dynamic motion, thermophysical properties,heat transport, applications, and challenges of nanofluids,Physics Reports,Volume946,2022,Pages1-94,ISSN0370-1573.

[35] MohammadAlhuyi Nazari,MohammadH. Ahmadi,MiladSadeghzadeh,Mohammad Behshad Shafii, Marjan Goodarzi, A review on application of nanofluid invarious types of heat pipes,Journal of Central South University, 2019, 26(5): 1021–1041.

[36] H.Ma,OscillatingHeatPipes,DOI10.1007/978-1-4939-2504-9_7.

[37] SURESHKUMAR R, MOHIDEEN S T, NETHAJI N. Heat transfer characteristics ofnanofluids in heat pipes: A review [J]. Renew Sustain Energy Rev, 2013, 20: 397–410.

[38] SCHREIBER M, WITS W W, TE RIELE G J. Numerical and experimental investigation of acounter-current two-phase thermosyphon with cascading pools [J]. Appl Therm Eng,2016, 99: 133–146.

[39] DAIMARU T, YOSHIDA S, NAGAI H. Study on thermal cycle in oscillating heat pipes bynumerical analysis [J]. Appl Therm Eng, 2017, 113: 1219–1227.

[40] SHEWALE S P, SAHU S K, CHOUGULE S S, PISE A T. A review of heat pipe withnanofluid for electronic cooling [C]/ Int Conf Adv Eng Technol. 2014, ICAET.

[41] LATAOUI Z, JEMNI A. Experimental investigation of a stainless steel two-phase closedthermosyphon [J]. Appl Therm Eng, 2017, 121: 721–727.

[42] ARABNEJAD S, RASOULIAN R, SHAFII M B, SABOOHI Y. Numerical investigation of theperformance of a U-shaped pulsating heat pipe [J]. Heat Transfer Eng, 2010, 31(14):1155–1164.

[43] EBRAHIMI M, SHAFII M B, BIJARCHI M A. Experimental investigation of the thermalmanagement of flat-plate closed-loop pulsating heat pipes with interconnectingchannels [J]. Appl Therm Eng, 2015, 90: 838–847.

[44] SHAFII M B, FAGHRI A, ZHANG Y. Analysis of heat transfer in unlooped and loopedpulsating heat pipes [J]. Int J Numer Methods Heat Fluid Flow, 2002, 12(5): 585–609.

[45] HOLLEY B, FAGHRI A. Analysis of pulsating heat pipe with capillary wick and

varyingchannel diameter [J]. Int J Heat Mass Transfer, 2005, 48(13): 2635–2651.

[46] XU D, LI L, LIU H. Experimental investigation on the thermal performance of heliumbased cryogenic pulsating heat pipe [J]. Exp Therm Fluid Sci, 2016, 70: 61–68.

[47] JIAO A J, MA H B, CRITSER J K. Experimental investigation of cryogenic oscillating heatpipes [J]. Int J Heat Mass Transfer, 2009, 52(15, 16): 3504–3509.

[48] LIU Y, GUO K. A novel cryogenic power cycle for LNG cold energy recovery [J]. Energy,2011, 36(5): 2828–2833.DOI: 10.1016/j.energy.2011.02.024.

[49] CAO Y, FAGHRI A. Closed-form analytical solutions of high-temperature heat pipestartup and frozen startup limitation [J]. J Heat Transfer, 1992, 114(4): 1028.

[50] RAMEZANIZADEH M, ALHUYI NAZARI M, AHMADI M H, AÇIKKALP E. Application ofnanofluids in thermosyphons: A review [J]. J Mol Liq, 2018, 272: 395–402.