An Updated Assessment on Performance and Application of Mixed Nanofluids in Heat Transfer Units

CH. Subramanyam[1], and G. Jayachandra Reddy [2]

[1] *(Department of Mechanical Engineering, Y.S.R Engineering College of Yogi Vemana University, AP, India-516360,)*

[2] *(Department of Mechanical Engineering, Y.S.R Engineering college of Yogi vemana university, AP, India-516360,)*

Abstract

The mixing of nano-particles in regular base solutions receiving additional consideration of investigators and examiners because of its distinctive thermal output in diverse area of sciences and engineering. Nano-fluid output was good and resulted satisfactory in heat convey phenomenon which fascinated scientists to mix dissimilar blends of nano-particles which titled as “hybrid nano-fluid”. From the pilot explorations it is established that the rate of heat transport is superior for hybrid nano-fluid as contrast to single nano-fluid. Depending on the above inspiration the current review is paying attention.

Bearing in mind the problems of power cutback and surroundings security, the output of refrigeration units needs to be developed. In latest days, nanofluids have fascinated really notice from the investigators because of their exceptional thermal properties. In this study, available data on the preparation and characterization of nanofluids have been conferred at initial. Besides, the key thermo-physical properties of nanofluids, such as thermal conductivity, viscosity, specific heat and density have been recapitulated. It is summarized that mixed nanofluids as refrigerant, lubricant or secondary fluid have extensive possible uses in refrigeration units.

Keywords: *Characterization, hybrid-nanofluid, nano-particles, refrigeration units, thermal properties.*

I. Introduction

These days, by fast expansion of population requirement for power also raises. Till date, the globe’s power requirement is fulfilled with the utilization of nonrenewable oils. The elevated employment of nonrenewable oils generates most of the troubles in surroundings which openly raise the temperature and also influence the creature comfort. To decrease this consequence changing in the direction of the renewable energy is extremely essential. It is only the trust to come out from this varying atmosphere situation. Worldwide heating is exceptionally big trouble these days and as per to information from the *International Energy Agency (IEA)* the 49% of primary energy fabrication is amplified over the past 20 years which consequence the raise of 43% of CO_2 emission. Currently all over the globe tries to crack this tough concern by emergent innovative technologies to cut the reliance on old oil and routinely boost the effectiveness of energy, and cut the harmful bang on surroundings.

The fresh power production plant establishment is significant which operate with the assist of renewable power. Sun energy is one of the most plentiful resources of power in globe and also a hygienic and sound free power. Conventional refrigerator unit uses electricity, which is usually created from conventional resource of energy. The accessibility of nonrenewable source of energy is declining at exceptionally shocking pace and mandatory interchange source and sun energy is one of them. By providing sun energy straight in the form of heat to the vapor absorption refrigeration (VAR) unit can play key job to diminish worldwide heating outcome. Additional make inquiries are compulsory in solar absorption refrigeration system so that it can be well-organized and trustworthy.

There is about 15% of the whole power creation is devoted to the *vapor compression refrigeration system (VCRS)* due to its necessity of high power to operate the entire unit. The accessibility of the electrical energy in most of the region is insignificant. To accomplish the necessity of current the employ of alternating energy sources plays an extremely vital function. In the perspective to this, the solar is the most capable un-conventional source of power. Sun power can be employed in the refrigeration unit to execute the obligations of those regions where current does not voluntarily exist.

VCRS is employed from the earlier period several years. The gasses used for this unit such as CFC, HCFC are injurious for the surroundings and reason several healthiness-associated troubles. The VCRS in which compressor is the chief element to influence the complete unit and also this is employed in the domestic refrigerator and marketable and bulky trade refrigerator unit. The VAR is superior in the situation where current is not obtainable willingly and more expenditure and the sound of compressor is problematical. The unit is missing its significance due to its little COP which is about one fifth of the VCRS.

Sun power is the superior preference for near energy crisis and declining of conventional resources. At the moment, the sun/solar refrigeration unit is the major center of attention end for the entire planet. The *solar vapour absorption refrigeration system (SVARS)* utilizes the refrigerant such as ammonia, water, lithium bromide etc. which generate not much destruction for the surroundings and also necessitate little temperature as compared to the other vapor compressor refrigerants. In the current revise, SVARS have been conferred and assorted methods employed to improve its performance have been also stated in following segments.

Ii. Preparation And Characterization Of Nano-Fluids

The phrase ‘‘nano-fluid’’ was initially coined by Choi and Eastman [1] before 26 years ago. Formerly, the word portrayed nano metre-sized copper particles scattered in water to get better its thermal conductivity. Now, a nano-fluid can be further precisely described as an engineered colloidal suspension of nano-particles into a base fluid. The application span of nano-elements is normally amid 0.01 wt% and 5 wt% and the average element extent is typically varied from 10 to 100 nm. The nano-particles/elements can be metals, metallic oxides, carbides, or carbon materials. Common base fluids are water and mineral oils.

Nano-fluids show a great prospective in numerous areas: in *solar applications*, to boost the heat-transfer coefficient of solar water heaters or to advance the capability of thermal energy storage units; and in the region of refrigeration, to boost the performance of refrigeration units. Regardless of the noteworthy strength of nano-fluids [2], their application as a *heat-transfer fluid (HTF)* or refrigerant is still not extremely regular. Conversely, the application of nano-fluids in solar-heat collectors has turn into a trendy subject matter of investigation through the previous decade. The innovation can be seen in Fig. 1.

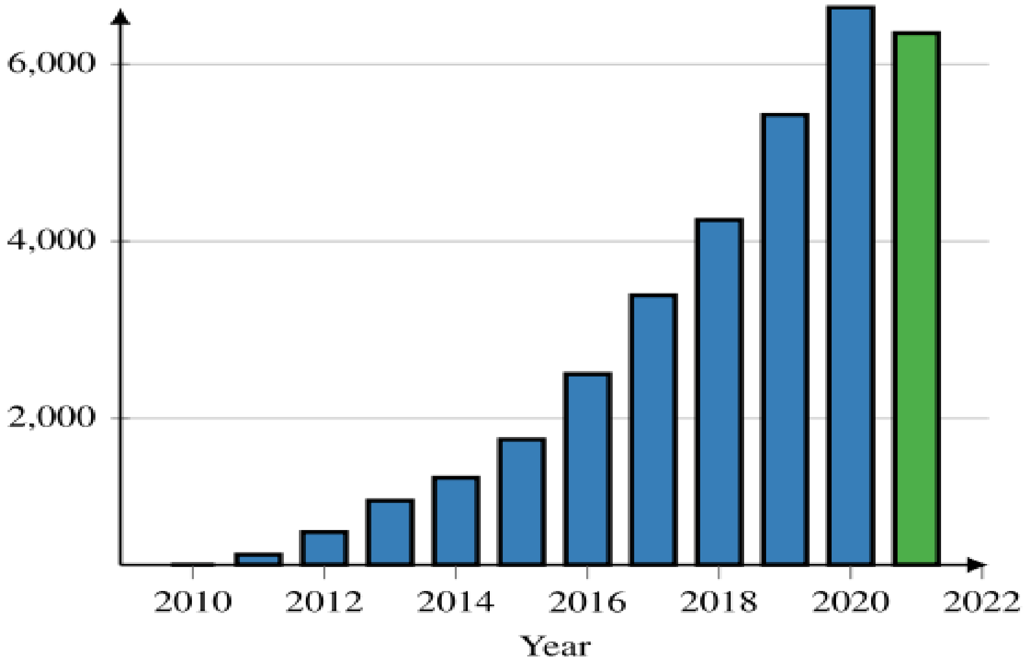

Figure. 1 The reputation of nano-fluids for exploit in solar areas calculated in the amount of published papers. The information is composed from Google Scholar for the search phrase nano-fluid solar heat. The entirety number of papers found in the given time is 34 230. The bar for 2021 is green to designate that this is the existing year. (The statistics was gathered on 2021-08-11).

The sun-heat collectors that function at dissimilar predictable temperature spans are numerous types. The major types comprise flatplate collectors (FPC) (up to 100°C), evacuated tube collectors (ETC) (up to 200°C), parabolic-trough collectors (PTC) (up to 500°C), and linear Fresnel collectors (LFC) (up to 600°C) [3]. How the solar radiation is collected will be key distinctions among these above. In FPCs and ETCs, the heat is gathered at the gripping surfaces directly. In PTCs and LFCs, sun waves are reflected and spotlighted onto receiver tubes. PTCs and LFCs are examples of concentrated-solar power (CSP) systems. CSPs are used both to generate power and to offer manufacturing development heat. In this study, only latter purpose was considered.

In every collector kinds, sun radiation is captivated and transported to HTF (heat transfer fluid) that later transmits the energy out of collector. For well-organized heat transport, the HTF is usually dispersed at moderately elevated stream rates to make sure turbulence. The variety of HTF is typically elected to maximize output efficiency. Water is often used for temperatures below 100°C, as it is inexpensive, has good transportation characteristics and a elevated heat capability. Above 100°C, like for PTCs and LFCs, pressurized water must be used, which raises complication and fee. Mineral liquids are employed because of their elevated vapour pressure[4].

2.1 Nanofluid preparation

Bulk characteristics at room temperature of some regular nano-particle substances are tabulated in Table 1. Considering the characteristics of nano-particles are not same to bulk substances, however depending on their dimension and profile [5]. Likewise, Table 2, catalogs several regular standard fluids employed as HTFs and their characteristics at elevated temperatures and at room temperature. Fig. 2 demonstrates a mapping of diverse nano-particle kinds to standard fluids.

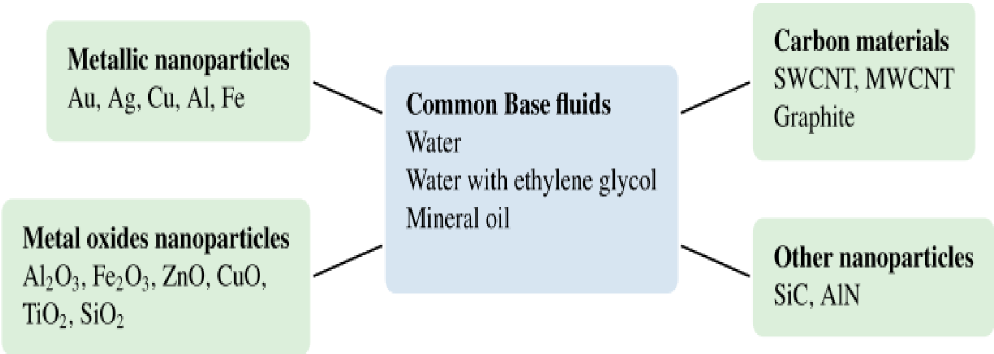

Figure. 2 Mapping of diverse standard fluids and nano-particles.

In the subsequent, mainly appropriate nano-fluid groundwork methods, and then regular nano-fluid and standard fluids applicable at more-temperatures considered.

Table. 1 Material characteristics of metallic and non-metallic solids at room temperature. The densities were all gathered from [6]. The characteristics are bulk substances, excluding for MWCNT and Graphene which were calculated as nano-powder substances. It is not capable to find the specific heat of graphene.

Material	ρ (kg/m^3)	k (W/(m K))	c_p (J/(kg K))	references
Au	19 320	320	128	[7]
Ag	10 500	430	235	[7]
Cu	8933	400	380	[7]
Al	2800	235	900	[7]
MgO	3580	42 [8]	918 [100]	
CuO	6000	30 [8]	528 [100]	
Fe_2O_3	5180	7 [10]	670 [9]	
TiO_2	4230	8.4[11]	710 [11]	
Al_2O_3	3960	36 [11]	765 [11]	
SiO_2	2200	1.4 [11]	745 [11]	
SiC	3100	490 [11]	675 [11]	
Graphene	2267	3000 [8]	nil	
MWCNT	1700–2100	2000 [8]	1200 [11]	

Table. 2 Characteristics of regular HTFs at diverse temperatures.

Fluid	T (°C)	ρ (kg/m^3)	μ (mPa s)	k (W/(m K))	c_p (kJ/(kg K))
Water (10 bar) [100]	20 160	998 917	1.00 0.17	0.598 0.608	4.18 4.33
EG/ water (20 vol%) [13]	20 100	1030 997	1.65 0.409	0.512 0.550	3.90 4.02
Therminol VP-1 [14]	20 200 300	1064 913 817	4.290 0.395 0.221	0.136 0.114 0.096	1.546 2.048 2.314
Syltherm 800 [15]	20 200 300	934 773 671	10.0 1.05 0.47	0.135 0.107 0.082	1.608 1.916 2.086

Nano-fluids are created by diffusing nano-particles into a standard fluid to structure a even mix. Clustering is a key opposition in amalgamation of nano-fluids. The composition is thus intimately linked to subject of steadiness, which is additional conferred in the subsequent part.

It is ordinary to split devising procedures into 2 chief styles: 1-step and 2-step techniques [16–18]. A easy indication of these styles is as subsequent. 1-step techniques are means where nano-particles and consequential nano-fluid are formed at the same time. This typically escorts to minimize clustering. The permanence of nano-fluids primed via these ways is consequently better contrasted to 2-step techniques [17]. There are supplementary benefits, registered in Table 3. Yet, 1-step techniques are tricky to balanceup.

The mainly regular 1-step means comprise physical vapour condensation, laser ablation in liquid (LAL), microwave radiation, and ultrasonic-aided submerged arc. Here, physical vapour condensation is depends on straight condensation of metallic vapour into nano-particles by get in touch with flowing, little vapour -pressure fluid like in Eastman et al. [19]. LAL is a way where nano-particles are formed quickly from uncomplicated pioneer substances by spotting powerful laser beam into a fluid or onto a solid–liquid boundary. The nano-particles are hence free from the solid plane and diffused into the fluid [20]. Microwave radiation interfere a microwave irradiation of a pioneer mix in existence of a reducing agent. The microwave irradiation supplies force for heating mixture and speeds up the nucleation procedure [21]. Lastly, ultrasonic-aided submerged arc takes help of a bulk metal substance as an electrode submerged into a dielectric liquid integrated with an ultrasonic vibrator [22]. In this procedure, metal is vaporized and condensed in dielectric liquid by submerged arc. Even though procedure seems supplementary composite contrast to former 3 methods, it has been establish to be benefiters.

2-step techniques, on other side, are schemes where nano-particles are formed initial and afterward scattered into a base solution. These ways are familiar and can be utilized with marketable nano-powders. The scattering of the nano-particles into base fluid is the vital pace. The dispersal may be enhanced and preserved by chemical means (electrostatic, steric, or electrosteric) [23]. For exemplar, when assimilation Cu nano-particles and water, surfactants are included to attain unwavering mix. Though, taken as a whole devising, it is critical to apply motorized routines to smash touching among particles and circumvent clustering. The motorized ways are exterior intercessions that should be functional occasionally to construct certain suspension is correctly distributed. Some of the mainly applicable methods contain ultrasonication, ball milling, mechanical or magnetic stirring, and high pressure homogenizer. Extra particulars concerning these methods can be instituted in the subsequent studies: [24]. A research on production of dissimilar metal and non-metal nano-fluids is specified by Devendiran and Amirtham.

Table. 3 Assessment among 1-step and 2-step ways for nano-fluid production. The tabulation is depended on record of advantages and disadvantages given by [17]

Techniques	1-step	2-steps
Advantages	· amalgamation and distribution are made simultaneously. · exposure to air of nano-particles is circumvented. · permits steady nano-fluids with no stabilizers. · consequential nano-fluids lean to be highly stable than through 2-steps.	· perfect for extensive and fee-effective manufacture.
Disadvantages	· Nano-fluids can merely be produced in unit - type approach and little magnitude. · elevated creation charge. · unresponded molecules in producing solutions can reason troubles in practice.	· aeration of particles is necessary. · clustering may arise while preparation.

2.2 Nanofluid steadiness description

The review of nano-fluid steadiness essentially based on our capability to describe or assess consistency. General assessment ways comprise ordinary sedimentation, Zeta potential calculation, 3-omega system, UV–VIS-spectrophotometer, optical spectrum analysis, centrifugation, electron microscopy (SEM and TEM) and dynamic light scattering. These ways are soundly portrayed in [25]. Meticulously, emphasized several applicable exemplars of description at elevated temperatures.

Hordy et al. [26] and Hordy [102] exercised numerous of the above stated techniques to estimate stability past heating to a definite temperature. For instance, Hordy et al. [26] heated a unit of nano-fluids portions in a insecurely lidded vial arranged on a temperature-regulated pot for 1 hr at 85% of the boiling temperature of base solution. Since the vial was closed, this trial outcome in no net failure of base solutions. The solution amount per model was less, around 10 mL, therefore restraining thermal stratification. The models past heating were then calculated with UV–VIS spectrometer to estimate their firmness. Hordy et al. [26] also calculated permanence of dried out models to guesstimate how permanence was influenced by the failure of efficient sets fastened to carbon nano-tubes (CNTs) at temperatures more than 170°C. They then produced aqueous mixes at room temperature by means of the heated arid models. The models were then assessed with UV VIS spectrometer and natural sedimentation. Even though their advancement for nature permanence of nano-fluid is incredibly realistic, since there is no necessitate for highly developed instrumentation, the nano-fluid nature and behavior might be customized throughout cooling or drying procedure.

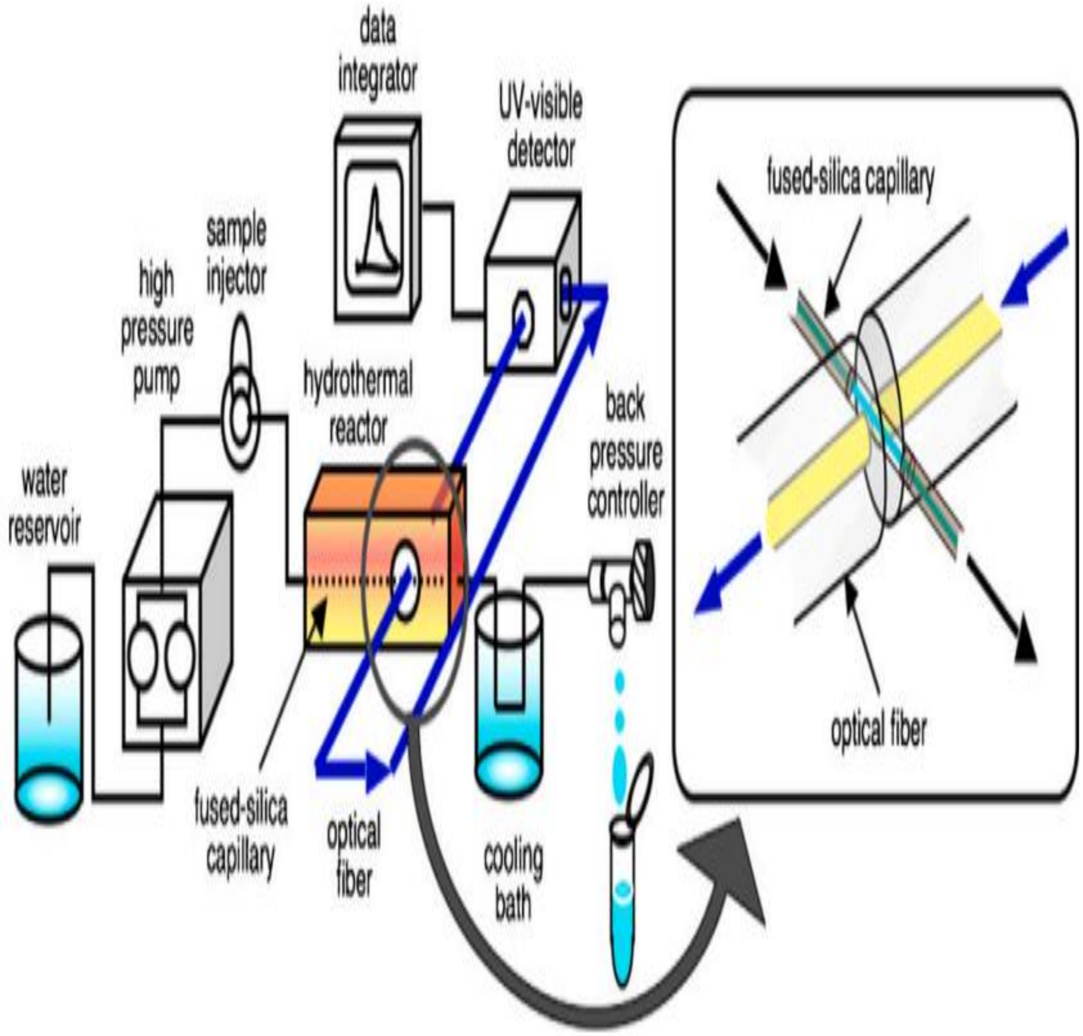

Figure. 5 Capillary-flow hydrothermal UV–VIS spectrometer. ***Source:*** **Kawamura et al. [27].**

Supervising thermal firmness of nano-fluids at elevated temperature can be completed by means of elevated temperature reactors attached to definite apparatus. For example Kawamura [28] done in-situ Supervising of batches up to 400°C by UV–VIS spectrometer. The batches were placed into a high-temperature narrow-piping reactor and permitted speedy heating and revelation with a small dwelling time. For UV–VIS evaluation, it is suggested to employ fused-silica capillary as a material for piping reactor since of its huge heat-transport pace and elevated clearness in the UV–visible area. A drawing of their system is represented in Fig. 5. Likewise, Navarrete et al. [29] established a traveler dynamic light scattering equipment to determine steadiness of nano-particles up to 300°C in molten salts gratitude to a devoted cuvette. Additionally, Milanese et al. [30] computed absorption natures of numerous gas-formed nano-fluids up to 500°C in a devoted arrangement.

Iii. Thermo-Physical Properties Of Nano-Fluids

One of the main motives for increasing concentration in nano-fluid exploration can be endorsed to the advancement of pioneering machineries for manufacturing of materials of nano-meter dimension. This progress has provided researchers and technocrats with influential gears to fabricate materials with outstanding behaviors, advanced than their bulk equivalents. Numerous materials are judged as probable preferences for heat transport amplification [31–34]. For exemplar, metals (aluminum, copper, gold, iron, silver, etc), metal oxides (alumina, ceria, copper, magnetite, zinc, etc), semiconductors (silica, titania, tin, etc), metal nitride (aluminum nitride), metal carbide (silicon), carbon nano-tubes (single-walled and multi-walled), graphene (multi-layer and oxide), etc. are employed to augment thermal transfer natures of operational solutions. As emphasized in writing [35,36], picking of nano-fluid for manufacturing purpose based on their thermo-physical behaviors. For case, ethylene-glycol leans to be a favored standard solution in glacial province owed to its anti frosty nature. Thus ethylene glycol-water (EG-water) combination is universally exercised as a standard solution in frosty climatic surroundings [37, 38]. Revisions on nano-fluids for diverse manufacturing purpose have been acknowledged in assess-manuscripts [39–42].

3.1 Affect of base solution

Numerous examiners have revealed reliance of knf (thermal conductivity of nanofluid) on inherent conductivity of the standard solution kbf [43]. The reference value of kbf (thermal conductivity of base fluid) for ordinary heat transport solutions at 300K are listed in Table4. The examiners examined superior enrichments with EG as contrasted to DIW. Hence, it can be assumed that standard fluid with superior thermal conductivity require not be choosing aspect for getting superior augmentation in thermal conductivity as the improvement is associated to scattered nano-particle. Thus, a steady nano-fluid of definite net electric charge reflected through zeta potential in the range between 740 & 760 mV might provide improved thermal transfer abilities.

Table. 4 Thermo-physical properties of various elected conventional cooling fluids at 300K.

Base fluid	Thermal conductivity	Density	Specific heat	Thermal diffusivity $x10^{-8}$	Reference
Deionized water (DIW)	0.607	998	4200	14.55	Sattler et al. [101]
Ethylene glycol (EG)	0.255	1111	2400	9.385	Sattler et al. [101]
Engine oil (EO)	0.145	884	1900	8.740	Sattler et al.

					[101]

Synopsis of tools exercised by different examiners for quality of nano-fluids is tabulated in Table 5.

Table. 5 Materials and characterization equipments

Thermophysical property	Equipment type	Dispersed nanopowder	Reference
Density	DA-505 (KEM, Japan)	Al_2O_3	[44]
	DA-130 N (KEM, Japan)	Al_2O_3	[45]
	Stabinger Viscometer (SVM 3000, Anton Paar GmbH) vibrating tube densimeter, (DMA512 P/60, Anton Paar)	Al_2O_3	[46]
Specific heat	DSC (200F3-Maia, NETZSCH GmbH)	CuO	[46]
	DSC (Q20, TA Instruments, USA)	Al_2O_3	[45]
	DSC (DSC 7, PerkinElmer Inc, USA)	Al_2O_3	[47]
	DSC (C80D, Setaram, France)	Al_2O_3	[48]
	DSC (Q2000, TA Instruments, USA)	Al_2O_3, CuO, TiO_2	[49]
	DSC (Setaram, France)	SiO_2, ZnO	[91]
Thermal conductivity	KD2 Pro (Decagon devices, Inc., USA)	Al_2O_3; Ag/MgO; Al_2O_3/Cu; CuO; Fe_2O_3; ND/CO_3O; SiO_2; TiO_2.	[44,46,52, 60,61,64,66, 71,72,74,75, 80,83,86, 91–94]
	Lambda system, (1, F5 Technology GmbH)	SiO_2	[91]
	Transient plane-source (2500 s, Hot Disk Sweden)	Fe_2O_3; SiO_2; TiO_2	[80;[87,94]
	Steady state Cut-bar Apparatus	Al_2O_3, CuO	[56]
	Transient Hot-wire Apparatus	Al_2O_3; CuO; Fe_3O_4; Fe_2O_3; SiC;	[59,53–55, 57,58,60–63,67-70,

		SiO_2; TiO_2	89,77–82, 84]
	Transient Short-wire Apparatus	Al_2O_3; CuO, SiO_2, TiO_2	[51,76]
	1D Steady-state parallel-plate Apparatus 3ω Hot-wire	Al_2O_3	[50] [73]
Viscosity	Concentric viscometer (VT550, Gebruder HAAKE Gmbh, Germany)	TiO_2	[93]
	Oscillation-type viscometer (VM-10A CBC Co. Ltd.)	Al_2O_3	[85]
	Piston-Type Couette flo viscometer (ViscoLab450, Cambridge Applied Sys-tems, Massachusetts, USA)	Al_2O_3	[84]
	Rolling ball viscometer, (AMV 200, Anton Paar)	CuO	[89]
	Rotational rheometer (AR-G2, TA Instruments Inc., USA)	TiO_2	[94]
	Rotational viscometer (DV IþPRIME C/P, Brookfield, Inc., USA)	Ag/MgO; Al_2O_3/Cu	[96,97]
	Rotational viscometer (DV IIþLV, Brookfield, Inc., USA)	Al2O3; CuO; SiO; TiO_2	[44,59,66, 71,92,95]
	Rotational rheometer (DV IIIþLV Ultra, Brookfield, Inc., USA)	TiO_2	[86]
	Rotational rheometer(cone-and-plate), (Paar Physica UDS 200, Anton Paar)	Al_2O_3	[88]
	Rotational rheometer (MCR 301, Anton Paar GmbH)	Ag, Fe_2O_3	[80]
	Rotational rheometer (parallel-plate), (MCR 101, Anton Paar GmbH)	Al_2O_3	[73]
	Rotational viscometer (coaxial cylinder), (OFITE-900, OFI Testing Equipment Inc., USA)	CuO	[65]

	Rotational rheometer (MCR 3000, Anton Paar GmbH)	SiO_2	[61]
	Rotational rheometer (Parallel-plate), (Gemini 200HR Nano, Malvern–Bohlin Instruments, UK)	TiO_2	[55]
	Ubbelohde capillary viscometer	ZnO; SiO_2	[90,91]
	U-tube (reverse-flow) capillary viscometer (Petrotest Instruments GmbH & Co. KG)	Al_2O_3	[46]
	Vibro-viscometer (SV-10, A&D, Japan)	ND/CO_3O	[98]

The explorations with single material nanofluid (SmNf) illustrate that traditional equations formulated for density & specific heat might be utilized to forecast behavior of compound nano-fluids. The universal equations of thermal conductivity & viscosity formulated for SmNf depicted by Eqs. (49), & (50) correspondingly can be employed to guess values of compound nano-fluids. The equations are authenticated with restricted trial information presented in the writing. On the other side, natures of CNf are to be decided from trials in order to institute further precise equations [99].

IV. Conclusions

Initially, there is extremely deciding shortage of trial toil on nano-fluids at elevated temperatures, both in universal and for employ in sun collectors. Mainly of accessible investigation on elevated-temperatures purposes are hypothetical review depend on numerical reproductions and guess. Hence, it is obvious that extra investigational examination is desirable on elevated-temperature employ of nano-fluids. The major confront at elevated temperatures is to produce and guarantee steady nano-fluids. On this subject, following conclusions are made: On steadiness at elevated temperatures.

• Steadiness is the mainly serious feature of nano-fluids, specially at elevated temperature. Numerous investigators have exercised surfactants to stabilizing nano-particles scattering into base fluids. Yet, at elevated temperatures, utilize of surfactants is a vital factor because to numerous reasons. Initially, surfactants can degrade/decompose at a temperature of just about 70°C. next, the interchange among surfactants and nano-particles alter as a function of temperature, and surfactants can generate foam through heating and cooling of structure. These instruments modify thermo-physical natures of nano-fluids and lessen their achievement.

• Surface alteration of the nano-particles appears to be a capable stabilization technique for elevated temperatures. This technique includes altering the surface of nano-particles by covalent functionalization with molecules like hydroxyl and carboxyl grafted on surface of nano-particle. Nano-fluids formed with this procedure have been experienced by number of examiners, but they are principally utilizing various kinds of carbon nano-tubes. Additional reviews are required utilizing other nano-particles like Al_2O_3 or Cu, which are economical to create, and reiews on the long-standing consistency for functionalized nano-fluids must also be done.

• Oxidation of nano-fluid constituents is a serious parameter for steadiness. It is keen that the chemical & physical worsening of nano-fluids at elevated temperature is due to- existence of oxygen. Additional revisions are required to distinguish what are the apparatus and techniques to overcome oxidation.

Thermo-physical natures of nano-fluids at elevated temperature:

• There has been a lot of research on mastery and identifying the natures of nano-fluids. To a little level, the thermo-physical natures are finely realized, & have been investigationally confirmed at temperatures up to 90°C. There does not present a solo reproduction or association for thermal conductivity that suitable to every trial. For several groupings of base fluids and nano-particle kinds, e.g. Al_2O_3 in water or oil, there are associations that are adequately excellent for guessing.

• It is established that a particular trial revise of thermal conductivity at elevated temperatures. The compromise from exploration at lesser temperatures is that raise in temperature will direct to amplified conductivity. But, there present proof to the opposing at lower temperatures, but most significantly, the single trial outcome identified at elevated temperatures also depicts the conflicting. Hence, additional trial test is essential on characterizing thermal conductivity of nano-fluids at elevated temperatures.

The application of nano-fluids for sun collectors is fetching a well-liked region of exploration. The writing on how nano-fluids influenced the thermal efficiency of PTCs, specially at working temperature above 100°C. Our main findings are:

• There are numerous of PTC works through nano-fluids in writing. But, they typically worked on water-based nano-fluids and temperatures below 100°C.

• Most of PTC trails are depend on numerical reproductions and guessing, and at elevated temperatures there is no sole trial test. The mainly regular nano-particles utilized are Cu and Al_2O_3. From numerical reviews, it can be scrutinized that Al_2O_3 distribution in Therminol-VP1 resulted the uppermost thermal efficacy improved of 15%. Though, it must be observed that numerical papers repeatedly offer dissimilar outputs on thermal efficacies.

• Additional trial tests to inspect thermal efficacy of oil-based nano-fluids are needed at temperatures over 100°C. Steadiness works, such as ageing reviews and experiments of ruggedness not in favor of thermal cycling, necessitate being involved to decide entire strength of nano-fluids.

• Trial effort must too tackle oxidation, corrosion, abrasion, and clogging influences of nano-fluids on constituents and mechanisms at elevated temperatures.

It is moreover found from above that mixed nano-fluids as refrigerant, lubricant or secondary fluid have broad strength purpose in refrigeration units also need to be explored.

V. References

[1] S.U.S. Choi, J.A. Eastman, Enhancing Thermal Conductivity of Fluids with Nanoparticles, Technical Report ANL/MSD/CP-84938; CONF-951135-29, Argonne National Lab., IL (United States), 1995, URL: https://www.osti.gov/biblio/196525.

[2] R. Taylor, S. Coulombe, T. Otanicar, P. Phelan, A. Gunawan, W. Lv, G. Rosengarten, R. Prasher, H. Tyagi, Small particles, big impacts: A review of the diverse applications of nanofluids, J. Appl. Phys. 113 (2013) 011301, http://dx.doi.org/10.1063/1.4754271.

[3] G. Barone, A. Buonomano, C. Forzano, A. Palombo, Chapter 6 - Solar thermal collectors, in: F. Calise, M.D. D'Accadia, M. Santarelli, A. Lanzini, D. Ferrero (Eds.), Solar Hydrogen Production, Academic Press, 2019, pp. 151–178, http: //dx.doi.org/10.1016/B978-0-12-814853 2.00006-0.

[4] Elvia Anabela Chavez Panduro, Francesco Finotti, Grégory Largiller, Karl Yngve Lervåg. A review of the use of nanofluids as heat-transfer fluids in parabolic-trough collectors. Applied Thermal Engineering 211 (2022) 118346. https://doi.org/10.1016/j.applthermaleng.2022.118346.

[5] P. Warrier, A. Teja, Effect of particle size on the thermal conductivity of nanofluids containing metallic nanoparticles, Nanoscale Res. Lett. 6 (2011) 247, http://dx.doi.org/10.1186 /1556-276X-6-247.

[6] AMERICAN ELEMENTS, The Advanced Materials Manufacturer, 2021, Accessed Online 2021-01-15. URL: https://www.americanelements.com.

[7] Periodic-table.org, Gold — Specific heat capacity, 2021, Accessed Online 2021-03-10. URL: https://www.periodic-table.org/specific-heat-capacityof-chemical-elements/.

[8] S. Simpson, A. Schelfhout, C. Golden, S. Vafaei, Nanofluid thermal conductivity and effective parameters, Appl. Sci. 9 (2018) 87, http://dx.doi.org/10.3390/app9010087.

[9] E. Bellos, Z. Said, C. Tzivanidis, The use of nanofluids in solar concentrating technologies: A comprehensive review, J. Cleaner Prod. 196 (2018) 84–99, http://dx.doi.org/10.1016/ j.jclepro. 2018.06.048.

[10] W. Chamsa-ard, S. Brundavanam, C. Fung, D. Fawcett, G. Poinern, Nanofluid types, their synthesis, properties and incorporation in direct solar thermal collectors: A review, Nanomaterials 7 (2017) 131, http://dx.doi.org/10.3390/nano7060131.

[11] T.L. Bergman, A.S. Lavine, Fundamentals of Heat and Mass Transfer, eighth ed., Wiley, 2017, URL: https://lccn.loc.gov/2016053414.

[12] M.A. Marcos, N.E. Podolsky, D. Cabaleiro, L. Lugo, A.O. Zakharov, V.N. Postnov, N.A. Charykov, S.V. Ageev, K.N. Semenov, MWCNT in PEG-400 nanofluids for thermal applications: A chemical, physical and thermal approach, J. Molecular Liquids 294 (2019) 111616, http://dx.doi.org/10.1016/j.molliq.2019.111616.

[13] CERN/P.BONNEAU, Properties of mixture water/glycol, 1997, URL: https:// detector cooling.web.cern.ch/data/Table%208-3-1.htm.

[14] THERMINOL, THERMINOL VP-1, heat transfer fluid, 2019, URL: http://www.cspfocus.cn/ueditor/net/upload/2019-08-16/148c7ad8-4be7-462a-868e-39dea39f1dd.pdf.

[15] Dow, SYLTHERM 800, Heat transfer fluid, Product technical data, 1997, URL:https://www.dow.com/content/dam/dcc/documents/en-us/app-techguide/176/176-01435-01syltherm-800-heat-transfer-fluid.pdf?iframe=true.

---

[16] A. Ghadimi, R. Saidur, H.S.C. Metselaar, A review of nanofluid stability properties and characterization in stationary conditions, Int. J. Heat Mass Transfer 54 (2011) 4051–4068, http://dx.doi.org/10.1016/j.ijheatmasstransfer.2011.04.014.

[17] S. Chakraborty, P.K. Panigrahi, Stability of nanofluid: A review, Appl. Therm.Eng. 174 (2020) 115259, http://dx.doi.org/10.1016/j.applthermaleng.2020.115259.

[18] N. Ali, J.A. Teixeira, A. Addali, A review on nanofluids: Fabrication, stability, and thermophysical properties, J. Nanomater. 2018 (2018) 1–33, http://dx.doi.org/10.1155/2018/6978130.

[19] 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, Appl. Phys. Lett. 78 (2001) 718–720, http://dx.doi.org/10.1063/1.1341218.

[20] D. Zhang, Z. Li, K. Sugioka, Laser ablation in liquids for nanomaterial synthesis: diversities of targets and liquids, J. Phys.: Photonics 3 (2021) 042002, http://dx.doi.org/10.1088/2515-7647/ac0bfd.
[21] H.-t. Zhu, Y.-s. Lin, Y.-s. Yin, A novel one-step chemical method for preparation of copper nanofluids, J. Colloid Interface Sci. 277 (2004) 100–103, http://dx.doi.org/10.1016/j.jcis.2004.04.026.

[22] H. Chang, C.S. Jwo, P.S. Fan, S.H. Pai, Process optimization and material properties for nanofluid manufacturing, Int. J. Adv. Manuf. Technol. 34 (2007) 300–306,http://dx.doi.org/10.1007/s00170-006-0597-0.

[23] D.K. Devendiran, V.A. Amirtham, A review on preparation, characterization, properties and applications of nanofluids, Renew. Sustain. Energy Rev. 60(2016) 21–40,http://dx.doi.org/10.1016/j.rser.2016.01.055.

[24] S. Mukherjee, P.C. Mishra, P. Chaudhuri, Stability of heat transfer nanofluids – a review, ChemBioEng Rev. 5 (2018) 312–333, http://dx.doi.org/10.1002/cben.201800008.

[25] F. Yu, Y. Chen, X. Liang, J. Xu, C. Lee, Q. Liang, P. Tao, T. Deng, Dispersion stability of thermal nanofluids, Prog. Nat. Sci.: Mater. Int. 27 (2017) 531–542, http://dx.doi.org/10.1016/j.pnsc.2017.08.010.

[26] N. Hordy, J.-L. Meunier, S. Coulombe, Thermal stability of plasma generated oxygenated functionalities on carbon nanotubes, Plasma Process. Polym. 12(2015) 533–544,http://dx.doi.org/10.1002/ppap.201400195.

[27] K. Kawamura, H. Nagayoshi, T. Yao, In situ analysis of proteins at high temperatures mediated by capillary-flow hydrothermal UV– vis spectrophotometer with a water-soluble chromogenic reagent, Anal. Chim. Acta 667 (2010) 88–95, http://dx.doi.org/10.1016/j.aca.2010.04.013.

[28] K. Kawamura, Development of micro-flow hydrothermal monitoring systems and their applications to the origin of life study on earth, Anal. Sci. 27 (2011) 675, http://dx.doi.org/10.2116/analsci.27.675.

[29] N. Navarrete, A. Gimeno-Furió, J. Forner-Escrig, J.E. Juliá, R. Mondragón, Colloidal stability of molten salt – based nanofluids: Dynamic light scattering tests at high temperature conditions, Powder Technol. 352 (2019) 1–10, http://dx.doi.org/10.1016/j.powtec.2019.04.045.

[30] M. Milanese, G. Colangelo, A. Cretì, M. Lomascolo, F. Iacobazzi, A. de Risi, Optical absorption measurements of oxide nanoparticles for application as nanofluid in direct absorption solar power systems – part ii: Zno, ceo2, fe2o3 nanoparticles behavior, Sol. Energy Mater. Sol. Cells 147 (2016) 321–326, http://dx.doi.org/10.1016/j.solmat.2015.12.030, URL: https://www.sciencedirect.com/science/article/pii/S0927024815006789.

[31] Suresh S, Venkitaraj K, Selvakumar P, Chandrasekar M. Effect of Al2O3–Cu/ water hybrid nanofluid in heat transfer. Exp Therm Fluid Sci 2012;38:54–60.

[32] Halelfadl S, Maré T, Estellé P. Efficiency of carbon nanotubes water based nanofluids as coolants. Exp Therm Fluid Sci 2014;53:104–10.

[33] Mehrali M, Sadeghinezhad E, Latibari ST, Kazi SN, Mehrali M, Zubir MNBM, et al. Investigation of thermal conductivity and rheological properties of nanofluids containing graphene nanoplatelets. Nanoscale Res Lett 2014;9:1–12.

[34] Madhesh D, Parameshwaran R, Kalaiselvam S. Experimental investigation on convective heat transfer and rheological characteristics of Cu–TiO2 hybrid nanofluids. Exp Therm Fluid Sci 2014;52:104–15.

[35] Trisaksri V, Wongwises S. Critical review of heat transfer characteristics of nanofluids. Renew Sustain Energy Rev 2007;11:512–23.

[36] Kakaç S, Pramuanjaroenkij A. Review of convective heat transfer enhancement with nanofluids. Int J Heat Mass Transf 2009;52:3187–96.

[37] Sahoo BC, Vajjha RS, Ganguli R, Chukwu GA, Das DK. Determination of rheological behavior of aluminum oxide nanofluid and development of new viscosity correlations. Pet Sci Technol 2009;27:1757–70.

[38] Sahoo BC, Das DK, Vajjha RS, Satti JR. Measurement of the thermal conductivity of silicon dioxide nanofluid and development of correlations. J Nanotechnol Eng Med 2012;3:041006.

[39] Wen D, Lin G, Vafaei S, Zhang K. Review of nanofluids for heat transfer applications. Particuology 2009;7:141–50.

[40] Saidur R, Leong K, Mohammad H. A review on applications and challenges of nanofluids. Renew Sustain Energy Rev 2011;15:1646–68.

[41] Huminic G, Huminic A. Application of nanofluids in heat exchangers: a review. Renew Sustain Energy Rev 2012;16:5625–38.

[42] Taylor R, Coulombe S, Otanicar T, Phelan P, Gunawan A, LV W, et al. Small particles, big impacts: a review of the diverse applications of nanofluids. J.Appl. Phys. 2013;113:011301.

[43] Gowda R, Sun H, Wang P, Charmchi M, Gao F, Gu Z, et al. Effects of particle surface charge, species, concentration, and dispersion method on the thermal conductivity of nanofluids. Adv Mech Eng 2010;2:807610.

[44] Ho C, Liu W, Chang Y, Lin C. Natural convection heat transfer of aluminawater nanofluid in vertical square enclosures: an experimental study. Int J. Therm Sci 2010;49:1345–53.

[45] Teng TP, Hung YH. Estimation and experimental study of the density and specific heat for alumina nanofluid. J Exp Nanosci 2014;9:707–18.

[46] Heyhat MM, Kowsary F, Rashidi AM, Alem Varzane Esfehani S, Amrollahi A. Experimental investigation of turbulent flow and convective heat transfer characteristics of alumina water nanofluids in fully developed flow regime. Int Commun Heat Mass Transf 2012;39:1272–8.

[47] Zhou SQ, Ni R. Measurement of the specific heat capacity of water–based Al2O3 nanofluid. Appl Phys Lett 2008;92:093123.

[48] Barbés B, Páramo R, Blanco E, Pastoriza-Gallego MJ, Piñeiro MM, Legido JL, et al. Thermal conductivity and specific heat capacity measurements of Al2O3 nanofluids. J. Therm Anal Calorim 2013;111:1615–25.

[49] O′Hanley, H, Buongiorno, J, McKrell, T, Hu, L-w. Measurement and model correlation of specific heat capacity of water-based nanofluids with silica, alumina and copper oxide nanoparticles. In: ASME 2011 international mechanical engineering congress and exposition; 2011, p. 1209–14.

[50] Wang X, Xu X, Choi SUS. Thermal conductivity of nanoparticle-fluid mixture. J. Thermophys Heat Transf 1999;13:474–80.

[51] Zhang X, Gu H, Fujii M. Experimental study on the effective thermal conductivity and thermal diffusivity of nanofluids. Int J Thermophys 2006;27:569–80.

[52] Chandrasekar M, Suresh S, Chandra Bose A. Experimental investigations and theoretical determination of thermal conductivity and viscosity of Al2O3/ water nanofluid. Exp Therm Fluid Sci 2010;34:210–6.

[53] Kim SH, Choi SR, Kim D. Thermal conductivity of metal-oxide nanofluids: particle size dependence and effect of laser irradiation. J Heat Transf 2007;129:298–307.

[54] Patel HE, Sundararajan T, Das SK. An experimental investigation into the thermal conductivity enhancement in oxide and metallic nanofluids. J Nanopart Res 2010;12:1015–31.

[55] Duangthongsuk W, Wongwises S. Measurement of temperature-dependent thermal conductivity and viscosity of TiO2 water nanofluids. Exp Therm Fluid Sci 2009;33:706–14.

[56] Calvin H. Li; G. P. Peterson, Experimental investigation of temperature and volume fraction variations on the effective thermal conductivity of nanoparticle suspensions J Appl Phys 2006;99:084314.

[57] Jahanshahi M, Hosseinizadeh S, Alipanah M, Dehghani A, Vakilinejad G. Numerical simulation of free convection based on experimental measured conductivity in a square cavity using Water/SiO2 nanofluid. Int Commun Heat Mass Transf 2010;37:687–94.

[58] Yiamsawasd T, Dalkilic AS, Wongwises S. Measurement of the thermal conductivity of titania and alumina nanofluids. Thermochim Acta 2012;545:48–56.

[59] Kang HU, Kim SH, Oh JM. Estimation of thermal conductivity of nanofluid using experimental effective particle volume. Exp Heat Transf 2006;19:181–91.

[60] Hussein AM, Bakar R, Kadirgama K, Sharma K. Experimental measurement of nanofluids thermal properties. Diamond 2013;7:850–63.

[61] Ferrouillat S, Bontemps A, Ribeiro JP, Gruss JA, Soriano O. Hydraulic and heat transfer study of SiO2/water nanofluids in horizontal tubes with imposed wall temperature boundary conditions. Int J Heat Fluid Flow 2011;32:424–39.

[62] Hwang Y, Park H, Lee J, Jung W. Thermal conductivity and lubrication characteristics of nanofluids. Curr Appl Phys 2006;6:67–71.

[63] Sundar LS, Sharma K. Experimental determination of thermal conductivity of fluid containing oxide nanoparticles. Int J Dyn Fluids 2008;4.

[64] Khedkar RS, Sonawane SS, Wasewar KL. Influence of CuO nanoparticles in enhancing the thermal conductivity of water and monoethylene glycol based nanofluids. Int Commun Heat Mass Transf 2012;39:665–9.

[65] Minakov AV, Rudyak VY, Guzei DV, Lobasov AS. Measurement of the heat transfer coefficient of a nanofluid based on water and copper oxide particles in a cylindrical channel. High Temp 2015; 53:246–53.

[66] Saleh R, Putra N, Wibowo RE, Septiadi WN, Prakoso SP. Titanium dioxide nanofluids for heat transfer applications. Exp Therm Fluid Sci 2014;52:19–29.

[67] Xie H, Wang J, Xi T, Liu Y, Ai F, Wu Q. Thermal conductivity enhancement of suspensions containing nanosized alumina particles. J Appl Phys 2002;91:4568–72.

[68] Murshed SMS, Leong KC, Yang C. Enhanced thermal conductivity of TiO2-water based nanofluids. Int J Therm Sci 2005;44:367–73.

[69] Yoo DH, Hong K, Yang HS. Study of thermal conductivity of nanofluids for the application of heat transfer fluids. Thermochim Acta 2007;455:66–9.

[70] Williams W, Buongiorno J, Hu LW. Experimental investigation of turbulent convective heat transfer and pressure loss of alumina/water and zirconia/ water nanoparticle colloids (nanofluids) in horizontal tubes. J Heat Transf 2008;130:042412.

[71] Timofeeva EV, Routbort JL, Singh D. Particle shape effects on thermophysical properties of alumina nanofluids. J Appl Phys 2009;106:014304.

[72] Shalkevich N, Shalkevich A, Bürgi T. Thermal conductivity of concentrated colloids in different states. J. Phys. Chem. C. 2010;vol. 114:9568–72.

[73] Hong J, Kim D. Effects of aggregation on the thermal conductivity of alumina/water nanofluids. Thermochim Acta 2012;542:28–32.

[74] Mintsa HA, Roy G, Nguyen CT, Doucet D. New temperature dependent thermal conductivity data for water-based nanofluids. Int J Therm Sci 2009;48:363–71.

[75] Teng TP, Hung YH, Teng TC, Mo HE, Hsu HG. The effect of alumina/water nanofluid particle size on thermal conductivity. Appl Therm Eng 2010;30:2213–8.

[76] Kazemi-Beydokhti A, Heris SZ, Moghadam N, Shariati-Niasar M, Hamidi AA. Experimental investigation of parameters affecting nanofluid effective thermal conductivity. Chem Eng Commun 2014;201:593–611.

[77] Xie HQ, Wang JC, Xi TG, Liu Y. Thermal conductivity of suspensions containing nanosized SiC particles. Int J Thermophys 2002;23:571–80.

[78] Hwang Y, Park HS, Lee JK, Jung WH. Thermal conductivity and lubrication characteristics of nanofluids. Curr Appl Phys 2006;6(Supplement 1):e67–71.

[79] Zhu H, Zhang C, Liu S, Tang Y, Yin Y. Effects of nanoparticle clustering and alignment on thermal conductivities of Fe3O4 aqueous nanofluids. Appl Phys Lett 2006;89:3123.

[80] Shima PD, Philip J. Role of thermal conductivity of dispersed nanoparticles on heat transfer properties of nanofluid. Ind Eng Chem Res 2014;53:980–8.

[81] Yoo DH, Hong K, Hong T, Eastman J, Yang HS. Thermal conductivity of Al2O3/water nanofluids. J Korean Phys Soc 2007;51:S84–7.

[82] Hays, A, Marsh, CP, Alvarado, J, Franks, R. The effect of nanoparticle agglomeration on enhanced nanofluidic thermal conductivity. Presented at the international refrigeration and air conditioning conference; 2006.

[83] Zhu H, Han D, Meng Z, Wu D, Zhang C. Preparation and thermal conductivity of CuO nanofluid via a wet chemical method. Nanoscale Res Lett 2011;6:1–6.

[84] Nguyen C, Desgranges F, Roy G, Galanis N, Mare T, Boucher S, et al. Temperature and particle-size dependent viscosity data for water-based nanofluids–hysteresis phenomenon. Int J Heat Fluid Flow 2007;28:1492–506.

[85] Lee JH, Hwang KS, Jang SP, Lee BH, Kim JH, Choi SUS, et al. Effective viscosities and thermal conductivities of aqueous nanofluids containing low volume concentrations of Al2O3 nanoparticles. Int J Heat Mass Transf 2008;51:2651–6.

[86] Azmi W, Sharma K, Sarma P, Mamat R, Anuar S, Dharma Rao V. Experimental determination of turbulent forced convection heat transfer and friction factor with SiO2 nanofluid. Exp Therm Fluid Sci 2013;51:103–11.

[87] Nikkam N, Saleemi M, Toprak M, Li S, Muhammed M, Haghighi E, et al. Novel nanofluids based on mesoporous silica for enhanced heat transfer. J Nanopart Res 2011;13:6201–6.

[88] Anoop K, Kabelac S, Sundararajan T, Das SK. Rheological and flow characteristics of nanofluids: Influence of electroviscous effects and particle agglomeration. J Appl Phys 2009;106:034909.

[89] Pastoriza-Gallego M, Casanova C, Legido J, Piñeiro M. CuO in water nanofluidinfluence of particle size and polydispersity on volumetric behaviour and viscosity. Fluid Phase Equilibria 2011;300:188–96.

[90] Jeong J, Li C, Kwon Y, Lee J, Kim SH, Yun R. Particle shape effect on the viscosity and thermal conductivity of ZnO nanofluids. Int J Refrig 2013;36:2233–41.

[91] Ferrouillat S, Bontemps A, Poncelet O, Soriano O, Gruss J-A. Influence of nanoparticle shape factor on convective heat transfer and energetic performance of water-based SiO2 and ZnO nanofluids. Appl Therm Eng 2013;51:839–51.

[92] Wamkam CT, Opoku MK, Hong H, Smith P. Effects of pH on heat transfer nanofluids containing ZrO2 and TiO2 nanoparticles. J Appl Phys 2011;109:024305.

[93] Tseng WJ, Lin K-C. Rheology and colloidal structure of aqueous TiO2 nanoparticle suspensions. Mater Sci Eng: A 2003;355:186–92.

[94] Bobbo S, Fedele L, Benetti A, Colla L, Fabrizio M, Pagura C, et al. Viscosity of water based SWCNH and TiO2 nanofluids. Exp Therm Fluid Sci 2012;36:65–71.

[95] Rohini Priya K, Suganthi KS, Rajan KS. Transport properties of ultra-low concentration CuO–water nanofluids containing non-spherical nanoparticles. Int J Heat Mass Transf 2012; 55:4734–43.

[96] Suresh S, Venkitaraj KP, Selvakumar P, Chandrasekar M. Synthesis of Al2O3–Cu/water hybrid nanofluids using two step method and its thermo physical properties. Colloids Surf A: Physicochem Eng Asp 2011;388:41–8.

[97] Hemmat Esfe M, Abbasian Arani AA, Rezaie M, Yan W-M, Karimipour A. Experimental determination of thermal conductivity and dynamic viscosity of Ag–MgO/water hybrid nanofluid. Int Commun Heat Mass Transf 2015;66:189–95.

[98] Takabi B, Salehi S. Augmentation of the heat transfer performance of a sinusoidal corrugated enclosure by employing hybrid nanofluid. Adv Mech Eng 2014; 2014.

[99] Suleiman Akilu, K.V. Sharma, Aklilu Tesfamichael Baheta, Rizalman Mamat. A review of thermophysical properties of water based composite nanofluids. Renewable and Sustainable Energy Reviews 66 (2016) 654–678. http://dx.doi.org/10.1016/j.rser.2016.08.036.

[100] P. Linstrom, W. Mallard (Eds.), NIST Chemistry WebBook, in: NIST Standard Reference Database, Number 69, National Institute of Standards and Technology, Gaithersburg MD, 20899, 2021, Accessed Online 2021-01-15, URL: https://doi.org/10.18434/T4D303.

[101] Sattler KD. Handbook of nanophysics: nanoparticles and quantum dots. Florida, Boca Raton, USA: CRC Press; 2010.

[102] N. Hordy, Plasma Functionalized Carbon Nanotubes Suspensions for High Temperature Direct Absorption Solar Thermal Energy Harvesting (PhD's Thesis), McGill University, Department of Chemical Engineering, Montreal, Quebec, Canada, 2014.