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Research Article

Heat transfer performance of nanofluids in heat exchanger: a review

Rohinee BARAI[1,*], Devesh KUMAR[2], Atul WANKHADE[3]

[1]Research Scholar, Department of Mechanical Engineering, Poornima University, Jaipur, Rajasthan, 303905 India
[2]Department of Mechanical Engineering, Poornima University, Jaipur, Rajasthan, 303905, India
[3]Department of Chemistry, Visvesvaraya National Institute of Technology, Nagpur, Maharashtra, 440010, India

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ABSTRACT

Energy is a key aspect of any country's economic development. Improving heat transfer performance leads to saving energy. Nanotechnology has a key role to play in optimizing heat exchangers. Fluids containing nanosized particles are called nanofluids. Nanofluids have higher thermal conductivity than typical liquids. This paper outlines current research on convective heat transfer performance, thermophysical properties, particle size, and volume concentration effects in nanofluid studies. Measurement methods forth ermal conductivity and correlations used by earlier researchers to determine thermal conductivity are also encompassed. The main applications of nanofluids as libricants and radiator systems to improve the efficiency of heat removal from vehicle engines have also been emphasized. Results suggest that by using a larger size of particle some drawbacks include particle sedimentation, clogging, erosion, stability, and increasing pressure drop. Enhancing thermal conductivity with optimum volume concentration. Improving the efficiency of heat exchange systems is one of the possible ways to reduce energy consumption. The need for optimum concentration of nanofluids is required. The Problem of stability, corrosion, and erosion arrived by increasing the volume concentration of nanoparticles in a nanofluid.

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INTRODUCTION

Energy is a crucial aspect of any country's economic development. The most pressing task for thermal engineers today is to intensification the thermal efficiency of heat transport systems. System optimization is a popular approach in this direction, with an emphasis on miniaturization, size reduction, and, as a result, cost reduction. Improving heat transfer performance leads to saving energy via other heat transfer devices like heat exchangers, evaporators, condensers, and sinks. A heat exchanger is commonly used in air conditioning, space heating, cooling, power stations, plants of chemicals, plants of petrochemical, natural gas extraction, and wastewater treatment, and

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*Corresponding author.
*E-mail address: rohinee39@gmail.com

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many other heat applications [1]. The fundamental problem is the efficient heating and cooling within the heat exchangers of storage fluids. A radiator heat exchanger system is used in automobiles to extract heat from the engine's cooling system. The mechanism used for the process is conduction and convection. Nanoparticles are added to normal engine coolant; they could boost the automotive cooling efficiency of the engine. This is because when we use nanofluids the energy system becomes more thermally efficient. The thermal efficiency of the energy system is due to the large nanoparticles surface area per unit volume that allows more heat transfer between solid particles and base fluids. In recent years, a number of researchers have proposed techniques for increasing heat transfer through nanofluids, including the interface effect, Brownian motion, ballistic transport of energy carriers, and thermophoresis. [2]. By using nanofluids, this increase in the rate of heat removal can reduce the size of the heat exchanger and due to this lower fuel consumption and cost savings.

Technological advances in the automotive industry concentrate on improving the fuel efficiency of internal combustion engines. Fuel efficiency is improved by maintaining the engine temperature at an optimal value that involves extraction of engine heat by circulating common fluids around the engine, such as water, ethylene glycol, water, and so on [3].

Due to their low thermal conductivity, the possibility to progress the performance of traditional fluids as coolants is limited. Because nanoparticles have a higher thermal conductivity than normal fluids, the thermal conductivity of these fluids can be improved by introducing them [4]. Many factors are accountable for the augmentation of thermal conductivity viz. volume fraction of particle, size, shape, and material of particle, base fluid, temperature, the nanoparticle's Brownian motion, and nanoparticles aggregation [5].

Stability is the main problem in nanofluids because of the increase in nanoparticle volume concentration, which results in rapid sedimentation that could reduce the thermophysical properties of nanofluids. Therefore, the stability of nanofluids is of considerable importance to preserve their thermo-physical properties after manufacturing for a lengthy period. Ettefaghi et al. [6] studied the thermal properties by adding MWCNTs with a different concentration in engine oil. It has been investigated that, higher stability is achieved with lower concentration. Wadd et al. [7] metal (copper) and nonmetal (TiO_2) nanofluids were compared in terms of performance. The surfactant Sodium Lauryl Sulfate (SLS) ensured the stability of nanofluids. Meanwhile the thermal conductivity of copper nanoparticles is far advanced than that of TiO_2 nanoparticles, copper-based nanofluids had stronger thermal conductivity than TiO_2/water nanofluids. Since nonmetal nanoparticles have a lower density, they are more stable than metal nanoparticles. Asadi et al. [8] theoretically investigated (Al_2O_3-MWCNT) / (thermal oil hybrid) nanofluids as a new class of cooling liquid for heat transfer and energy management applications in the automotive industry and a heating fluid for strong concentration (from 0.125 to 1.5 percent) and temperature (from 25°C to 50°C) thermoelectric modules on the hot side. The stability of the produced nano-oil was investigated using Zeta's potential analysis. Except for solid concentrations of 1 and 1.5 percent in internal turbulent flow regimes, they discovered that using this nanofluid instead of the base fluid could be useful in all of the strong levels and temperatures investigated for turbulent and laminar flow regimes. Esfahani et al. [9] when the temperature was elevated from 60 to 65 degrees Celsius, the action of surfactant was diminished, resulting in a decrease in dispersed nanoparticle stability. Surfactants have various disadvantages, including contamination of heat transfer medium, high-temperature foam production, and higher thermal resistance. Selvam et al. [10] prepared by a non-covalent technique using experimentally measured thermal characteristics such as thermal conductivity and particular GnP / H_2O–EG nanofluid heat efficiency. The zeta potential analysis and UV-Vis absorption spectrum have been conducted to confirm the long-term stability of the prepared nanofluid dispersions.

The efficacy of using such suspensions with sizes of millimeters (or micrometers) has been investigated earlier and major disadvantages observed [11]. These limitations include particle sedimentation, channel well blockage, and increased pressure loss, all of which make them unsuitable for practical use. We can overcome such drawbacks by reducing the size of the particle to nanoscale [12]. Stabilizing the suspension of the nanoparticles is essential to get the desired properties of the nanofluids. Choi (1995), Nanoparticles formed and increased thermal conductivity with nanoparticles dispersed in conventional heat transfer fluids were reported [13]. The present paper summarizes the latest research in nanofluids studies to review the heat transfer performance and thermal conductivity in the heat exchanger application of nanofluids, and studies other challenging issues such as stability and optimum concentration.

Nanofluids

Continuous nanotechnology work contributes to the evolution of new fluids for increasing heat transfer rate and this kind of fluid is known as nanofluids. Figures 1 and 2 show different base fluids and nanoparticles. Prepared the nanofluids by dispersing nanometer-sized particles i.e.1-100nm in conventional fluids and having greater thermal conductivity than the traditional fluids [4].

Nanotechnology plays a major role in heat transfer optimization [14]. The thermal conductivity of heat transfer fluids plays a significant role in the development of energy-efficient heat transfer equipment. Inherently weak heat transfer fluids, however, traditional heat transfer fluids such as ethylene glycol, water, and oil. Because of the increasing global competition, there is a significant requisite for

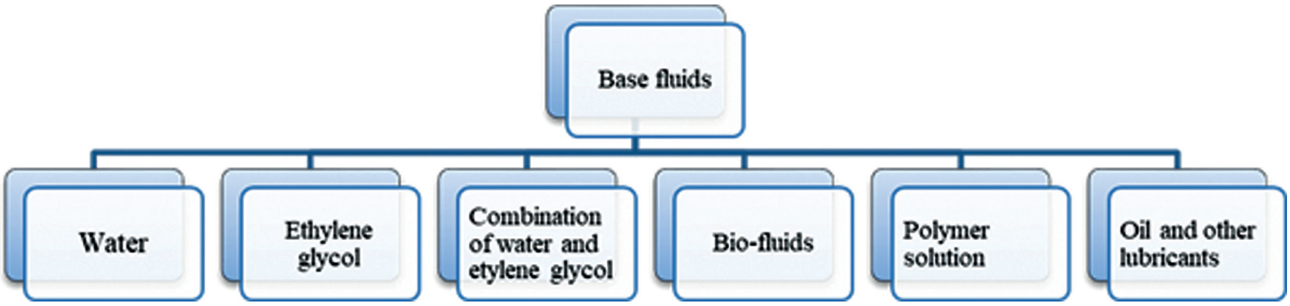

Figure 1. Different base fluids.

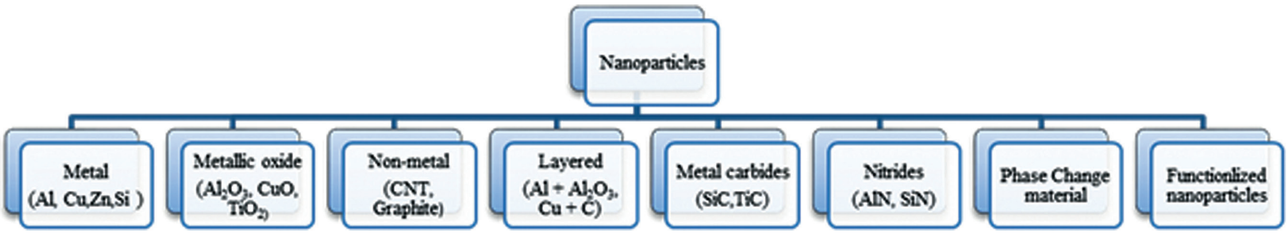

Figure 2. Different nanoparticles.

progressive fluids for heat transfer resulting in significant growth in greater thermal conductivity than currently available [15]. However, conventional fluids like ethylene glycol, water, etc., the application of conventional fluids as coolants are limited by their lower thermal conductivity. Figure 3 shows the thermal conductivity of different heat transfer materials. When incorporating nanoparticles, these particles can increase the thermal conductivity of these fluids have greater thermal conductivity than conventional fluids [16-17].

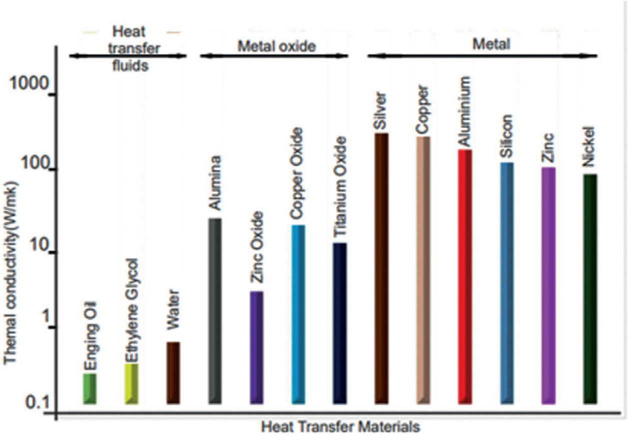

Figure 3. Thermal conductivity of different heat transfer materials.

Advantage of Nanofluids

- Nanoparticle have a larger surface area due to which heat transfer rate increases.
- The heat transfer rate is expanded because of the more prominent thermal Conductivity of nanoparticles.
- Due to the smaller size of particles, reduction in pressure drop.
- It reduces the size of the heat exchanger.

Nanofluids Preparation Process

Two processes listed below that are commonly used for the nanofluids preparation, which is shown in Figure 4.

Two-step preparation

Many physical and chemical techniques, such as chemical vapour deposition, pulse laser deposition, physical vapour deposition, sputtering, and ion implantation have been used to create nanoparticles in this form. Ultrasonic agitation, high-shear mixing, intensive magnetic force agitation, homogenizing, sol-gel vapour phase, or ball milling are then used to discretize the nanosized powder in the base fluid [18]. Nanoparticles have an affinity to accumulate in the second phase due to their high surface area and surface activity. As a result, the nanofluid's stability is harmed by this accumulation property.

Single-step preparation

To get a steadier nanofluid single-step planning measure is liked, as the name shows it is amalgamated in just one stage. This one-step method consists of making and dispersing nanoparticles in the base fluid at the same time [19-20]. A more stable nanofluid is prepared in single-step preparation, but it has limitations on high process costs, small-scale output, and residual reagents in the base fluid.

Thermophysical Properties of Nanofluids

It is fundamental to consider the thermophysical properties of nanofluids when using them in practical applications. To predict the thermo-physical properties of nanofluids, there is a range of basic formulas, and researchers investigate these. This research has both theoretically and experimentally studied the heat transfer activity of nanofluids [21]. Table 1 shows the thermo-physical properties of different nanomaterials. The convective heat transfer coefficient, which is a function of a variety of thermo-physical properties such as thermal conductivity, viscosity, specific heat, and density, expresses the heat transfer efficiency using nanofluids.

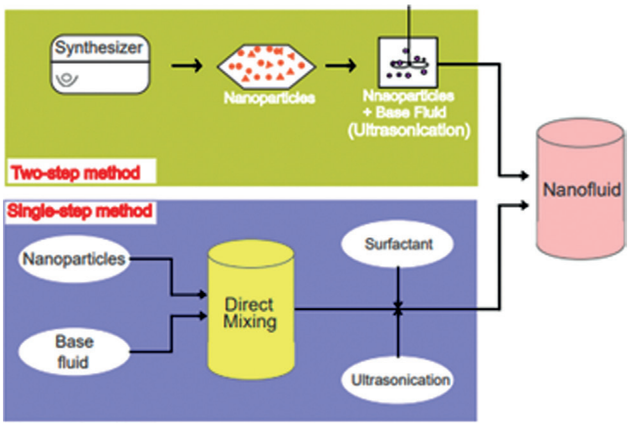

Figure 4. Nanofluids preparation methods (modified from [20]).

Impact on Thermal Conductivity by Volume Fraction and Particle Size

The influence of particle volume fraction on nanofluids thermal conductivity has received a lot of attention in the literature. Among the different nanoparticles and concentration forms used, metal oxides with particle volume concentration up to 4% are the most common, apparently due to their less price. The results and conclusions reported differing considerably. Ding et al. [22] analyzed the efficiency of a carbon nanotubes-containing nanofluid and stated that the coefficient of heat transfer could be 3.5 times higher than the standard fluids concerned.

Lee et al. [23] & Wang et al. [24] studied the effect of volume fraction of particles with 24 and 23nm CuO particles in a water (base fluid), and it was observed that at 10% volume fraction, the intensification in thermal conductivity grows linearly with higher particle volume fraction. The ratio of thermal conductivity increased by 34%. Masuda et al. [25] recorded thermal conductivity enhancement of nanofluid for volume concentration of 4.3% of alumina, silica, and other oxides in water. The Thermal conductivity of nanofluids increased by 30%.

Table 1. Thermophysical properties of different nanomaterials and base fluids

Material	Thermal conductivity (W/m K)	Specific heat (kJ/kg K)	Density (kg/m^3)
Alumina (Al_2O_3)	40	0.773	3960
Aluminium (Al)	237	0.903	2700
Aluminium nitride (AlN)	285	0.74	3260
Carbon nanotube (CNT)	2800 - 6000	-	1350
Copper (Cu)	401	0.385	8940
Copper oxide (CuO)	33	0.551	6000
Diamond	2200	0.509	3530
Gold(Au)	317	0.129	19300
Graphite	120	0.701	2160
Silicon(Si)	148	0.714	2320
Silicon carbide (SiC)	150	1.34	3370
Silver(Ag)	429	0.235	10490
Titanium oxide (TiO_2)	8.4	0.692	4230
Zirconia	3	0.418	5680
Ethylene glycol	0.261	2664	1076
Water	0.607	4180	1000

Xian et al. [26] studied an improvement in thermal conductivity for the same oxides considered by Masuda [25], not only in ethylene glycol but also in water. They stated that as the size of the particles decreases, the thermal conductivity improvement increases and is almost proportional to the volume fraction of the particles. When alumina particles for volume concentration of only 3 percent were used, there was a maximum increase of thermal conductivity of 12%. A significant finding from Xian et al. [26] is that there is a linear reliance of thermal conductivity on volume fraction. For alumina and copper oxide in water, Das et al. [27] noted the same linear pattern as [26]. However, the conductivity improvement pattern varies more like the temperature's square root as the particle volume fraction has increased.

To estimate the thermal conductivity of Al_2O_3 nanofluids, Xie et al. [28] used the transient hot-wire process and observed a significant increase in various volume fractions. Hwang et al. [29] investigated Al_2O_3 nanofluids and found a 4% increase in thermal conductivity at 1% volume concentration. Lee et al. [30] aqueous nanofluids prepared with a low volume concentration of nanoparticles Al_2O_3 and observed a 2% escalation in thermal conductivity for 35 nm-sized Al_2O_3 particles at a lower volume percentage. Li et al. [31] have studied the impact of volume fraction and temperature variations on thermal conductivity by applying 2, 4, 6, and 10 percent volume fractions of copper-aluminum oxide nanoparticles to the distilled water at different temperatures. Table 2 shows the summary of the influence of particle size, and volume fraction on thermal conductivity. The results suggested that the thermal conductivity of these suspensions was substantially influenced by the nanoparticle material, size, volume fraction, and bulk temperature.

Thermal Conductivity

Thermal conductivity is a very significant thermophysical property that decides the characteristics of the heat transfer of nanofluids. High thermal conversion leads to the efficiency of thermal equipment.

Measurement of Thermal Conductivity

There are different methods to measure the thermal conductivity of nanofluids experimentally and theoretically. Experimental methods are 3ω method, thermal constant analyzer, steady-state parallel plate method, and the transient hot wire method. During the transient hot-wire phase, a heat sensor is applied to the needle, and the temperature response on the adjacent needle is detected both during and after the heat pulse application. The response to temperature will depend on the material's thermal properties. Remarkable researchers [72-87] used thermal property analyzer KD2- pro which works on the main transient hot-wire method. The thermal constant analyzer operates on the transient plane source system theory [88]. The hot disc sensor raises the temperature in this operation, while the resistive thermometer keeps time. The steady-state parallel technique includes glueing the test sample between two parallel circular copper plates. The test sample inserted in the plates receives one-dimensional heat. Conduction equation is used to measure thermal conductivity. 3-omega method is very similar to the THW method. It also uses the same material as the heater and thermometer. However, the key difference is that the TWH approach uses time dependence response while 4using electrical current frequency (ω) dependence response.

According to the findings, the transient hotwire method is the most commonly used method for measuring thermal conductivity. Table 3 shows that the thermal conductivity of base fluid by using nanoparticles and was mostly measured by the transient hot-wire method. This measurement approach has gained popularity because the thermal conductivity of the liquid may be calculated instantly with a high degree of precision and repeatability. A few recommendations can be pointed out from the literature review. Many researchers used the transient hot-wire method for measuring the thermal conductivity of nanofluids have been reported. Some of the latest work here has been reviewed [101-108] used a KD2 Pro thermal analyzer device using the transient hot-wire method to characterize the nanofluids thermal conductivity by measuring the temperature of the nanofluids during the cooling and heating phases. Maheshwary et al. [107] for measurement of thermal conductivity used a more precise hot wire method manufactured in-house Figure 5. The setup consists of a chemically inert cylindrical hollow tube of Teflon with special configuration of wire and thermocouple.

A significant number of the proposed models of thermal conductivity. Table 4 shows the summary of the studies on the theoretical models for the thermal conductivity of nanofluids. Some of them take into account nanoparticle morphology, assuming that all particles are spherical and introducing a variety of (mostly empirical) constants.

Heat Exchanger

Heat exchangers are appliances that allow heat exchange at various temperatures in between a couple of fluids at the same time preventing mixing with each other. Usually, there is no external heat and work contact in heat exchangers. It differs from mixing chambers because it does not permit the mixing of the two involved fluids. In both cooling and heating methods, heat exchangers are used [18]. The heat exchanger is commonly used in air conditioning, space heating, cooling, power stations, plants of chemical, plants of petrochemical, natural gas extraction, and wastewater treatment, and many other heat applications [3]. The fundamental problem is the efficient heating and cooling within the heat exchangers of storage fluids. Figure 6 shows the Shell and Tube heat exchanger system. Many automobiles use a radiator heat exchanger system to extract heat from the engine's cooling system.

Table 2. Summary of the effect of particle size and volume fraction on thermal conductivity

Nanofluid type	Average particle size	Volume fraction	Thermal conductivity enhancement	References
CuO+ DW+ EG	8nm	1 vol.%	31.6%	Karthikeyan et al. [32]
CuO + EG	(10–30 nm)	<0.002 vol.%	54%	Kwak et al. [33]
CuO + DW	25 nm	0.3 vol.%	3 times greater than base fluid	Lee et al. [34]
Al_2O_3+DW	(15-50 nm)	0.4 wt. %	13%	Alawi et al. [35]
Graphite+ DW	106nm	2 vol.%	34%	Zhu et al.[36]
Cu_2O+ DW	200.5nm	0.01-0.05 vol.%	24%	Wei et al. [37]
Cu+ EG	10nm	0.3%	40%	Choi et al. [38]
Al_2O_3+W	Less than 50nm	1.5 vol.%	4.5%	Kole et al. [39]
GnP+DW	—	0.05wt.%	17%	Ghozatloo et al. [40]
Al_2O_3+DW, SiO_2+DW and ZrO_2+DW	40nm, 15nm, and 25nm	1%	10.13, 6.5 and 8.5%	Iqbal et al. [41]
CuO+W	30nm	2%	10%	Pantazali et al. [42]
Al_2O_3+ W: EG (40:60, 50:50 and 60:40)	13nm	0.2 to 1.0 percent	12.8 % at 40:60 (W: EG)	Chiam et al. [43]
CuO+W	4nm	6vol.%	31%	Sahooli et al. [44]
CuO/W, Al_2O_3/W, and Al_2O_3-CuO/ W	50nm 27nm	0.2%	6.1%, 8% and 9.8%	Senthilraja et al. [45]
Al_2O_3/CuO+ EG-W	14nm	0.05, 0.1 and 0.2	45%	Kannaiyan [46]
Al_2O_3 + W	30nm	0.01-0.03%	1.44%	Jang et al. [47]
Al_2O_3 + W	43nm	0.33-3%	9.7%	Chandrashekar et al. [48]
Fe_3O_4 + EG	25nm	0.01- 0.1%	20%	Khedkar et al. [49]
Al_2O_3 + W	38.4nm	1–4%	24%	Xie et al.[28]
CuO + W	8nm	1%	31%	Karthikeyan et al. [50]
Al_2O_3 + W	9nm	2-10%	29%	Minsta et al. [51]
Al_2O_3 + W	11-150nm	1-4%	47%	Chon et al. [52]
Al_2O_3 + W/EG	28nm	3-8%	41%	Das et al. [27]
Al_2O_3 + W/EG	53nm	1-10%	35%	Vajjha and Das [53]
Al_2O_3 + W/EG	60.4nm	5%	23%	Xie et al. [54]
Al_2O_3 + W/EG	8-282nm	1.86-4%	20%	Beck et al. [55]
Al_2O_3+ Transformer oil	650-1000nm	0.5-4%	20%	Choi et al. [56]
Cu+ EG	<10nm	0.01-0.05%	41%	Eastman et al. [57]
Cu+ DW	23nm	0.25%	40%	Bhanushali et al. [58]
Cu+ EG	5-10nm	0.3-0.5%	46%	Yu et al. [59]
Cu+ W	100-200nm	0.05%	12%	Liu et al. [60]
CuO + W	29nm	0-16%	24%	Minsta et al. [61]
CuO + W	100nm	7.5%	52%	Zhang et al. [62]
Ag+ EG	100-500nm	0.1-1%	18%	Sharma et al.[63]
Ag+ W	<100nm	0.3-0.9%	30%	Godson et al. [64]
MWCNT + W	5-10 (dia.) in µm and length 270nm	0.015%	32%	Karami et al. [65]
MWCNT + W	10-30(dia.)*(10-50)µm	1%	7%	Hwang et al. [66]
TiO_2 + W	15nm	0.5-5%	30%	Murshed et al. [67]
FeO_2 + EG	10nm	0.1-0.55%	18%	Hong et al [68]
SiO_2+ W	12nm	1-4%	23%	Jahanshashi et al. [69]
ZrO_2+W	20nm	0-2.2%	60%	Paul et al. [70]
SnO_2+ W	4.5-5.3nm	0.012-0.024%	7%	Habibzadeh et al. [71]

Table 3. Results of the thermal conductivity measurement of different type of nanofluids

Nanofluids	Measurement of thermal conductivity	Enhancement of thermal conductivity	References
CNT+W	3-ω method	19.4%	Choi et al. [89]
Al_2O_3+DIW+EG	Transient hot-wire method	7.6%	Xie et al. [90]
CuO + EG	Transient hot-wire method	1.0089%	Sahooli and Sabbaghi, [91]
Ag+DIW	Transient hot-wire method	69.3%	Asirvatham et al. [92]
Titanium+ DIW	Transient hot-wire method	10.60%	Naphon et al. [93]
CuO+W	Transient hot-wire method	22%	Pantzali et al. [94]
Al_2O_3+W		18%	
CNT+W		10%	
Al_2O_3+W	Transient hot-wire method	Increases	Nguyen et al. [95]
Al_2O_3+W	Transient hot-wire method	12.1%	Gherasim et al. [96]
Cu+EG	Transient hot-wire method	3.8%	Leong et al. [97]
Al_2O_3+W	Transient hot-wire method	40%	Hung et al. [98]
CuO+W	Transient hot-wire method	8%	Naraki et al. [99]
CNT	Transient hot-wire method	1.4%	Halelfadl et al. [100]
Al_2O_3+W+EG	KD2 Pro thermal analyzer	11.2%	Azmi et al. [101]
SiO2 + EG	Transient hot-wire method	9.6%	Guo et al., 2018[102]
SiO2 + DW		3.4%	
GnP+W+EG	KD2 Pro thermal analyzer	18%	Selvam et al., 2017[103]
ZnO+W+EG	KD2 Pro thermal analyzer	15%	Islam et al., 2017[104]
TiO_2+W	Transient hot-wire method	10%	Naphon and Nakharint, 2013[105]
Al_2O_3+EG	KD2 Pro thermal analyzer	21.1%.	Hamid et al., 2016[106]
TiO_2+W	hot-wire method	69.23%	Maheshwary et al.,2017[107]
MWCNT+ Engine oil	KD2 Pro thermal analyzer	22.7%	Ettefaghi et al., 2013[108]
Gn+W	A transient short hot-wire method	17%	Ghozatloo et al., 2013[109]
Al_2O_3+EG	Transient hot-wire method	11.25%	Kole and Dey, 2010[110]
Gn+EG+DW	Transient hot-wire method	15%	Kole and Dey, 2013[111]
Al_2O_3+EG+W	Transient hot-wire method	8.30%	Elias et al., 2014[112]

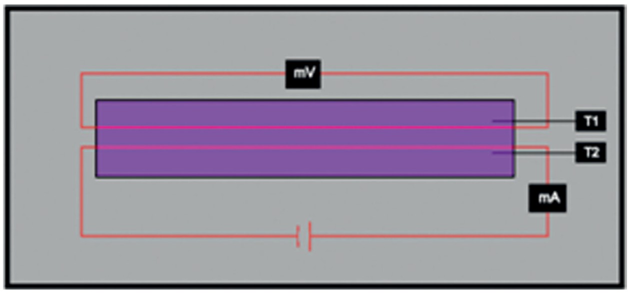

Figure 5. Schematic diagram of the hot-wire method to determine thermal conductivity of nanofluids (modified from [107]).

Application of Nanofluid in The Heat Exchanger

Nanofluids are effective fluids for transfer of heat applications in shipping, electronic cooling, industrial cooling, aerospace, and defense cooling systems and, more specifically, renewable energy and budding to increase the efficiency of heat transfer by increasing the quantity of energy needed to operate heat transfer fluid-related thermal systems [15, 134-139]. Nanofluid implementation will save energy and reduce emissions, the potential for global warming, and the impact of greenhouse gases. The heat exchanger is commonly used in air conditioning, space heating, cooling, power stations, and many other heat applications [1]. Selvam et al. [103] prepared by a non-covalent technique using experimentally measured thermal characteristics such as thermal conductivity and particular GnP / H_2O–EG nanofluid heat efficiency. The prepared nanofluid dispersions' stability has been verified using zeta potential analysis and UV-Vis absorption spectrum. The extreme enhancement of thermal conductivity obtained 18% at 0.45 vol. % of GnP. Raja et al. [140] explore the features of heat

Table 4. Summary of the studies on the theoretical models for thermal conductivity of nanofluids.

Author	Empirical model/ Correlation	Factor Considered	Used in study
Maxwell [127]	$K_{nf}=\dfrac{k_p+2k_{bf}-2\left(k_{bf}-k_p\right)\times\varnothing}{k_p+2k_{bf}-\left(k_{bf}-k_p\right)\times\varnothing}k_{bf}$	Low Volume concentration of spherical particle	Akbarzade 2014[113], Islam 2017[104], Goudarzi and Jamali 2017[114], Elias 2014[112]
Hamilton-Crosser [128]	$K_{nf}=\dfrac{k_p+(n-1)k_{bf}+(n-1)\left(k_p-k_{bf}\right)\varnothing}{k_p+(n-1)k_{bf}+(n-1)\left(k_p-k_{bf}\right)\varnothing}k_{bf}$	Shape factor(n)	Senthilraja 2017 [45], Ravisankar 2015 [115], Tijani 2018 [116], Ali 2015[117], Sandhya 2016[118], Hatami 2017[119], Peyghambarzadeh 2011[120], Elias2014[112]
Koo and Kleinstreuer [129]	$K_{nf}=\dfrac{k_p+2k_{bf}-2\left(k_{bf}-k_p\right)\varnothing}{k_p+2k_{bf}-2\left(k_{bf}-k_p\right)\varnothing}k_{bf}+5*10^4\beta\varnothing\rho_{bf}C_{pbf}\sqrt{\dfrac{KT}{\rho_p d_p}}f(T,\varnothing)$ $f(T,\varnothing)=\left(2.8217*10^{-2}*\varnothing+3.917*10^{-3}\right)\left(\dfrac{T}{T_0}\right)-\left(3.0669*10^{-2}\varnothing+3.91123*10^{-3}\right)$ $\beta=9.881(100\varnothing)^{-0.9446}$	Particle volume concentration, size and temperature	Vajjha 2010 [121], Naraki 2013[99], Peyghambarzadeh 2013[122] Sheikhzadeh 2011[123]
Timofeeva model [130]	$k_{nf}=(1+3\varnothing)k_{bf}$	-----	------
Yu and Choi [131]	$K_{nf}=\dfrac{k_p+2k_{bf}-2\left(k_{bf}-k_p\right)\varnothing(1+\beta)^3}{k_p+2k_{bf}-2\left(k_{bf}-k_p\right)\varnothing(1+\beta)^3}k_{bf}$	nanolayer	Chavan2014[124], Heris 2014[125], Duangthongsuk, and Wongwises [126]2009
Wasp [132]	$K_{nf}=\dfrac{k_p+2k_{bf}+2\left(k_{bf}-k_p\right)\varnothing}{k_p+2k_{bf}-\left(k_{bf}-k_p\right)\varnothing}k_{bf}$	----	----
Pak & choi [133]	$k_{nf}=(1+7.74\varnothing)k_{bf}$	Spherical and non-spherical	----

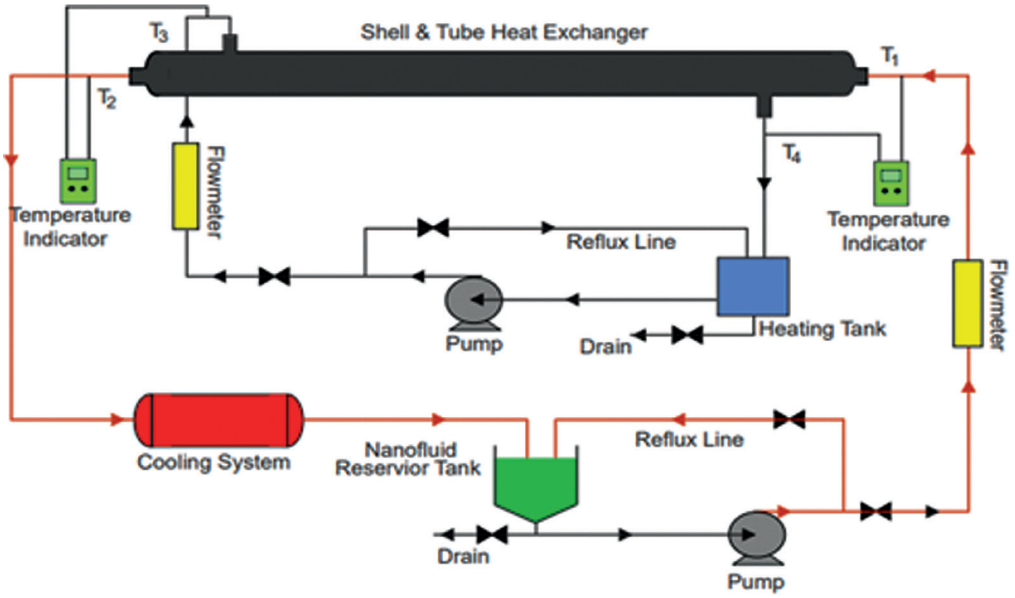

Figure 6. Shell and Tube heat exchanger system.

transfer, pressure drop, and NOx by using nanofluid Al_2O_3/water with a distinct volume fraction of 0.5, 1, 1.5, and 2% under the flow of laminar in shell and tube heat exchanger. The result shows that the reduction of NOx emission was 12.5% by using nanofluids. Zhong et al. [141] nanofluid heat transfer improved in a car heat exchanger (plate-fin oil cooler), using alumina nanofluids with distinct volume fractions was analyzed and it was found that the heat transfer deteriorates at high-volume nanoparticles fraction at 5 vol. % Compared to water. Teng et al. [142] the efficiency of heat dissipation nano coolant MWCNT in a motorcycle radiator has been studied. The maximum enhanced heat exchange of ratio, pumping power, and efficiency factor found that 12.8 percent, 4.9 percent, and 14.1 percent, respectively, compared to a combination of ethylene glycol and water.

Hajjar et al. [143] have studied the impact of convective coefficient of heat transfer in a shell and tube heat exchanger using the alkaline graphene oxide/H_2O nanofluid, by using different weight concentrations of Graphene nanoparticle 0.025 to 0.1percent. They found to be the heat transfer coefficient increases by 15.3% at 25°C and 23.9% at 38°C at the highest concentration. Ghozatloo et al. [109] investigated transfer of heat features in shell and tube heat exchanger using GnP- EG nanofluid for turbulent flow. With the addition of Graphene with different weight concentrations 0.1 to 0.15percent into EG. They found that thermal conductivity and coefficient of heat transfer 21.2 and 42.4 percent at 0.15wt. % increases by increasing the temperature and concentration of graphene. Tiwari et al. [144] compared experimentally the performance of heat transfer of the plate heat exchanger using different nanofluids such as TiO_2, CeO_2, and Al_2O_3 and SiO_2 with base fluid H_2O and determined the optimum concentration of nanofluids. CeO2/water shows better performance with comparatively low optimal concentration i. e. 0.75 vol. percentage within studied nanofluids. Ali et al. [145] Performance of the heat transfer performance of automobile radiator using ZnO/H_2O with different volume concentrations 0.01%, 0.08%, 0.2% & 0.3% nanofluid as a coolant. Flow rate varied in a range of 7 to 11 LPM and Reynolds number was 17,500 to 27,600. Enhancement of heat transfer was obtained to be 46% as compared to H_2O at 0.2 vol. percentage. Furthermore, it has been also reported that heat transfer enhancement was decreased beyond 0.2 vol. percentage of ZnO.

Chavan et al. [124] carried out experimental work on Al_2O_3/water as a coolant in the radiator and compared results with water. Concentration varied between 0-1percent by volume. The result shows that heat transfer quality can be improved by increasing the rate of fluid circulation. They also found that applying the low concentration nanofluid could increase the efficiency of heat transfer by up to 40–45 percent likened to pure water. Hussein et al. [146] Compared the performance of the radiator experimentally investigated using TiO_2, SiO_2 nanoparticles. The results of the analysis of variance (ANOVA) showed enhancement of Nusselts number found to be 22.5% and 11% for SiO_2 and TiO_2 respectively. The result showed that the performance of SiO_2 is better than TiO_2 nanoparticles. Ray et al. [147] comparison of the quality of three separate nanofluids Al_2O_3, CuO, and SiO_2 nanoparticles distributed in the same base fluid, 60/40 of W/EG by mass as a coolant in car radiators. The programming system has been implemented. Method of transfer unit efficiency number encoded in MATLAB. The SiO_2 nanofluid showed the three nanofluids lowest efficiency gain, but could still minimize the pumping power by 26.2% and area 5.2 percent.

Ahmadi et al. [148] studied the thermal properties by adding MWCNTs with a different concentration in engine oil. They found that thermal conductivity was 13.2% at 0.5 Wt. percentage. It has been investigated that, higher stability is achieved with lower concentration. M'hamed et al. [149] experimentally studied that water/ethylene glycol with MWCNT. Varying concentrations of the volume of nanoparticles (0.1, 0.25, and 0.50%) were prepared and tested in a blend of (50:50) water/ethylene glycol. The coefficient of heat transfer enhancement was obtained at 196.3 percent at 0.5percent concentration of the volume of nanoparticles. Zamzamian et al. [150] investigated growth in the overall coefficient of heat transfer of nanofluids CuO and Al_2O_3 with various volume fractions of and ethylene glycol used as a base fluid in the heat exchanger. The coefficient of heat transfer enhancement found that 37 percent of CuO and 26 percent of Al_2O_3. Elias et al. [112] nanoparticles of Al_2O_3 dispersed in water and coolant based on ethylene glycol used in vehicle radiators. Enhancement of nanofluids thermal conductivity for more volume concentration 8.3% but decreases specific heat.

Chougule et al. [151] experimentally studied the performance of radiators comparatively using functionalized MWCNT and surface treated MWCNT. They found that functionalized MWCNT shows 90.76% higher heat transfer than base fluid while at high-temperature heat transfer with surface treated MWCNT deteriorate. Shajahan et al. [152] Presented thermal conductivity at the same concentration in the volume of various deionized water-based nanofluids. The volume fraction of one percent nanoparticles, there was 10.13, 6.5, and 8.5 percent improvement in thermal conductivity for Al_2O_3, SiO_2, and ZrO_2 respectively. Many computational physics experts have become interested in recent technological breakthroughs in computers and computational techniques. Unlike traditional experiments, more detailed study can be carried out at a cheaper cost using computational or numerical forecasts. Numerical research on nanofluids has emerged as a viable alternative for demonstrating their improved performance over standard heat transfer fluids. Bozorgan et al. [153] numerically studied the use of CuO-water nanofluid as a coolant in the Chevrolet Suburban diesel engine radiator and the effects of the vehicle speed and the nanofluid

Table 5. Summary of experimental studies of nanofluids in heat exchanger

Nanoparticles	Base fluid	Concentration	Enhancement	Reference
Al_2O_3	EG	—	H=9% using wire coil Insert	Goudarzi et al. 2017[114]
Al_2O_3	Water / EG	0.1 to 0.4 vol. %	H=45.87%	Gulhane et al. 2017 [170]
Al_2O_3	Water/EG (60:40,50: 50 and 40:60)	1vol %	H=24.6% at 60:40 base fluid	Azmi et al. 2017[101]
Al_2O_3	Water/EG (55:45)	1 and 2vol%	H=57% & 106%	Yu et al. 2012[136]
Al_2O_3 and CNT	Water	1vol%	$H_{Al_2O_3}$ = 90.76% HT_{CNT} = 52.03%	Chougule et al. 2014[151]
Al_2O_3 and TiO_2	Water /EG (60:40)	1 vol.%	$H_{Al_2O_3}$ =23.8% at 70° C H_{TiO_2} =24.2%	Azmi et al. 2016 [171]
Cu	W/EG	1vol.%	HT= 15.34%	Sarkar et al. 2013[172]
SiC	W/EG		HT= 14.33%	
Al_2O_3	W/EG		HT= 14.02%	
TiO_2	W/EG		HT= 10.20%	
CuO	Water	0.5, 0.1 and 0.2 vol.%	SP. Fuel cons. 4 stroke DE, was reduce by 8.6,15.1 and 21.1%	Senthilraja et al. 2017[45]
CuO	Water	0.15 to 0.4 vol.%	H = 6 to 8%	Naraki et al. 2013[99]
MWCNT	Water	0.16 mass %	HT = Deterioration occurred at 0.16 percent of the mass	Oliveira et al. 2017 [173]
Al_2O_3, Cu, TiO_2	Water	4 vol. %	Cu/water shows superior heat transfer performance than Al_2O_3/water, TiO_2/water	Kilic and Abdulvahitoglu 2019 [174]
CeO_2	Water	0.5, 1.0, and 1.5 vol. %	Heat flux 10,15 and 20 KW/m^2	Gupta et al. 2019 [175]
CuO	water/EG	0.8 vol.%	H=55%	Heris et al. 2014[125]
TiO_2	Water	0.5 - 2.5wt%	Contribution towards enhancement of thermal conductivity for concentration, size and shape obtained 69.43%, 24.95%, 5.62%	Maheshwary et al. 2017[107]
TiO_2	40% EG and 60% water	0.5%	H=35%	Sandhya et al. 2016[118]
GnP	Water /EG (70:30)	0.001, 0.01, 0.05, 0.1, 0.15, 0.3 and 0.45 vol. %	18% increases thermal conductivity and 8% decreases specific heat	Selvam et al. 2017[103]
MWCNT	Water/EG (50:50)	0.4wt%	The maximum enhanced ratio of heat exchange 12.8%. Nano coolant with high MWCNT could not achieve maximum heat exchange ability.	Teng et al. 2013[142]
MWCNT	Water	0.5%	Increase in thermal conductivity of as much as 22.7%.	Ettefaghi et al. 2013[6]
SiO_2	Water	0.4 vol. %	HT = 9.3%	Akbarzade et al. 2014[113]
γ- Al_2O_3	Water	0.03,0.14 and 0.3 vol. %	Overall HT=5.4, 10.3 and 19.1%	Barzegarian et al. 2017 [176]

(*continued*)

Table 5. Summary of experimental studies of nanofluids in heat exchanger (*continued*)

Nanoparticles	Base fluid	Concentration	Enhancement	Reference
Al_2O_3	Water	2 and 4%	Average HT= 5.42 and 11.94%	Jafari et al. 2017 [177]
TiO_2	Water	1vol%	HT= 26%	Duangthongsuk and Wongwises 2010 [178]
γ- Al_2O_3	Water	0.2vol%	H= 7.32%	Aghayari et al. 2014 [179]
γ- Al_2O_3	Water	0.15 vol. %	HT= 23%	Raei et al. 2017 [180]
Fe_3O_4	Water	0.06vol%	H= 14.7%	Ravi Kumar et al. 2017 [181]
Ag	Water/EG (70:30)	0.45vol%	HT=42%	Selvam et al. 2016[10]
Al_2O_3	Water	0.65vol%	H= 7%	Chavan et al. 2014[124]
Al	Distilled water	0.2 and 0.3vol%	HT= 16.40 and 18.39%	Sharma et al. 1995 [182]
1) TiO_2, 2) TiO_2 doped with 0.1% Ag, 3) TiO_2 doped with 0.3% Ag, 4)TiO_2 doped with 0.1% Cu	EG/Water (50:50)	0.3, 0.5, 1 and 2%.	HT= Descending Order: 0.3%Ag doped > 0.1%Ag doped > TiO2 > 0.1%Cu doped	Soylu et al. 2019 [183]
TiO_2	Water	0.5, 1.0, and 1.5 vol. %	Thermal efficiency = 13.4% at 1 vol. %	Gupta et al. 2018[184]
Cu	Distilled water	0.3%, 0.6% and 1.0%	K = 57.51%	Mahay and Yadav 2019 [185]
Cu Al MWCNT	de-ionized (DI) water	0.3%	H = 29% H = 25% H = 40%	Akash et al. 2020 [186]
CuO	Water	0.5 and 1%	HT = 3% and 6.9%,	Kiani and Nadooshan 2019 [187]
Cu, NiO, CuO	Water	—	$K_{Cu/water} = 0.6684 W/m K$ $K_{NiO/water} = 0.6640 W/m K$ $K_{CuO/water} = 0.6621 W/m K$ $K_{water} = 0.5970 W/m K$	Abdulvahitoglu, 2019 [188]
CuO, Al_2O_3, Cu, TiO_2	Water	2-8 vol. %	Cu/water shows the preeminent heat transfer performance	Kilic and Ali 2019 [189]
CuO	Water	—	Optimum value of thermal efficiency, thermal resistance and wall temperatures has been obtained.	Gupta et al. 2020 [190]
TiO_2	Water/EG	0.35 vol. %	HT=10%	Jagadishwar et al. 2017 [191]
Al_2O_3	Distilled water	0.2%	H= 44.29%	Chaurasia et al. 2019 [192]
CuO	Water	1 vol. %	Maximum thermal efficiency = 66.5%	Gupta et al. 2020[193]
CuO, Cu, TiO_2	Water	—	Cu/water shows the highest heat transfer performance.	Kilic and Ullah 2021 [194]
Al_2O_3	Glycerin	0.05, 0.1, and 0.15 vol. %	H = 62%	Sundari et al.2020 [195]
Graphite	Water	0.2,0.5,0.8,1 and 1.5 vol. %	K = 39.72% at 1.5 vol. %	Yashawantha et al. 2021 [196]
Graphene	W/EG (60:40)	0.01%-0.09%	H = 236% at %	Madderla et al. 2021 [197]

amount of Reynolds number at various volume concentrations 0.1 to 2%. They found CuO-water nanofluid flowing through the flat tubes with Reynolds number of nanofluid was 6000 at 2 percent volume concentration while the automotive speed was 70 km/h, the average coefficient of heat transfers and pumping energy was about 10 percent and 23.8 percent higher than the base fluid. Li et al. [154] experimentally studied the silicon carbide (SiC) nanofluid thermal conductivity and viscosity dependent on motor coolants with a volume fraction of up to 0.5 vol. It has obtained thermal conductivity of nanofluids 53.81% for 0.5 vol. % nanofluid at 50°C. Oleic acids has been discovered to be an efficient nanofluid-based surfactant for nanofluids derived on vehicle motor coolant.

Fares et al. [155] have studied the characteristics of heat transfer of graphene/water nanofluids at 0.2 wt. % in vertical shell and tube heat exchanger. Maximum heat transfer coefficient and thermal efficiency were found to be 29% and 13.7%. Qasim et al. [156] carried out experimentally work on ZnO/water nanofluids in automobile engine radiators at different volume concentrations (0 to 0.3 vol. %). Enhancement in overall heat transfer coefficient, heat transfer rate, and Nusselt number found to be 50%, 41%, and 31% at concentrations of 0.2vol. %. Zheng et al. [157] investigated the enactment of nanofluid Al_2O_3/water in a double pipe counter flow heat exchanger with different volume concentrations. The results show that Nusselt numbers are 23.2 and 32.23 percent for inlet temperatures of 40o C and 50^{o}C. Gupta et al. [158] experimentally investigated that the thermal efficiency of heat pipe at different inclination angle, heat input and the volume of working fluid. It found that the maximum thermal efficiency was 69%.

Kumar et al. [159] studied the performance of tungsten trioxide nanofluid (WO_3/water) in automobile radiators. A higher heat transfer rate was observed to be 4.18% at 0.067 vol. % of (WO_3/water) nanofluid. Jarrah et al. [160] studied Ag/water nanofluids as coolants in a car radiator by using a low volume concentration of nanofluids. It was found to be heat transfer efficiency up to 30.2% in comparison to base fluid (water). Gupta et al. [161] studied the effect of mono (TiO_2/water) and hybrid ((TiO_2+MWCNT)/water) nanofluids in heat pipe. It was found that enhancement in thermal performance by using hybrid nanofluids. Verma et al. [162] have been studied the thermal components of solar energy conversion into thermal energy. Rathore et al. [163] analysis has been focuses on synergistic techniques, processes, design criteria, and developments in working fluids for solar collectors to attain maximum thermal and exergy efficiency. Rathore et al. [164] comprehensive assessment of numerous experimental trials (laboratory-based and real-world testing) that have been conducted utilizing solely MPCM to assess the true potential of MPCM in enhancing building thermal performance.

Zubair et al. [165] have studied the enhancement of heat transfer using TiO_2 nanoparticles and base fluid (25% ethylene glycol and 75% water) for different volume concentrations (0.01%, 0.03%, and 0.05%) in the radiator. The result shows that Maximum heat transfer enhancement was obtained 29.5% as compared to water at concentration 0.03 vol. % and volume flow rate 150 LPH. Verma et al. [166] experimentally studied inquiry into an innovative design and fabrication approach for analyzing the efficiency of flat plate solar collectors. In forced mode testing, a 21.94 percent improvement in thermal efficiency was achieved when compared to a typical flat plate collector design. Exergy efficiency has increased by 6.73 percent. Rathore et al. [167] studied composite mixtures of paraffin and expanded perlite (EP) with identical weight percents of 49.5 and 47.5, respectively, loaded with 1% and 5% graphene nanoplatelets. Rathore et al. [168] analysis of various parameters based on the indoor peak temperature, indoor thermal amplitude, time lag, and decrement factor to assess the indoor thermal behavior. Gupta et al. [169] have studied the thermal performance of Ce_2O nanoparticle coated wick heat pipe with base fluid water at different concentration. It found that nanoparticle coating was provided as a substitute for a nanofluid to evade the problem of stability. Table 5 shows the summary of experimental studies of nanofluids in the heat exchanger.

Throughout this literature, several studies are focused on the enhancement of heat transfer and thermal conductivity by utilizing different nanofluids in the heat exchanger. From this, it is observed that improving the efficiency of heat exchange systems is one of the possible ways to reduce energy consumption, and at the same time, the need for optimum concentration of nanofluids is required.

CONCLUSIONS

Based on prior literature numerous applications would have been more effective by using nanofluids. This paper reveals the heat transfer performance on the application of nanofluids in the heat exchanger. Several researchers carried out experimental and statistical investigations relevant to nanofluid's heat transfer performance. From this analysis, we need to understand the basics of heat transfer because it is important to develop nanofluids for an extensive range of applications for heat transfer and we can conclude as follows:

1. The majority of the investigations have been performed on metallic oxides. In the case of metallic nanoparticles, heat transfer enhancement is much greater and enhancement is significant even at a very low volume fraction. Exhaustive research is needed on low volume fraction, nanofluids with metallic and non-metallic nanoparticles.
2. Particle size had inversely related to thermal conductivity. Because of the increase in their collision rate, small size particles could move faster, achieving higher thermal conductivity.

3. The transient hot-wire method is more popular than most other techniques for measuring the thermal conductivity because of its speed, and most researchers have used it. To measure the thermal conductivity, a KD2-pro thermal analyzer system was used, which works on the theory of the transient hot-wire process.
4. The majority of the results from the authors' analysis are positive, indicating that nanoparticles increase the cooling ability or heat transfer efficiency of traditional heat transfer fluid in various heat transfer applications. In cases where there was a degradation in heat transfer, few researchers reported that the factor where agglomeration occurs is an excessive amount of nanoparticles. Very few of these indicated the best amount of nanoparticles before degradation of performance or thermal properties. Therefore, the need of optimum concentration of nanofluids is required.
5. Consequently, to achieve the optimum concentration repeated experimental work on similar nanoparticles and the same working parameters is required in the future. The best thermal efficiency for a device can be obtained by knowing the optimal amount of nanoparticles.
6. Nanofluid stability and price are major problems with nanofluid integration into day-to-day applications. Therefore, more work is needed for synthesis of nanoparticles at a low cost.

Results suggest that by using a larger size of particle some drawbacks include particle sedimentation, clogging, erosion, stability, and increasing pressure drop. Enhancing thermal conductivity with optimum volume concentration. Improving the efficiency of heat exchange systems is one of the possible ways to reduce energy consumption.Heat transfer efficiency of heat exchanger depends on temperature, flow rate, nanofluids Concentration, nanoparticle size, and shape.

NOMENCLATURE

DW	Deionized water
EG	Ethylene glycol
Nm	Nanometer
W	Water
T	Temperature
DE	Diesel engine
n	Shape factor
Nu	Nusselt number
Wt	Weight
H	Heat transfer coefficient
vol.	Volume
HT	Heat transfer rate
MWCNT	Multi walled carbon nanotubes
K	Thermal conductivity
K_p	Thermal conductivity of nanoparticle
K_{bf}	Thermal conductivity of base fluid
K_{nf}	Thermal conductivity of nanofluid

Greek symbols

Ø	Volume concentration or volume fraction
C_p	Specific heat
β	Extinction or attenuation coefficient

AUTHORSHIP CONTRIBUTIONS

Authors equally contributed to this work.

DATA AVAILABILITY STATEMENT

The authors confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

CONFLICT OF INTEREST

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

ETHICS

There are no ethical issues with the publication of this manuscript.

REFERENCES

[1] Kakac S, Liu H, Pramuanjaroenkij A. Heat Exchangers: Selection, Rating, and Thermal Design. 2nd ed. Florida: CRC Press; 2002.

[2] Gupta NK, Tiwari AK, Ghosh SK. Heat transfer mechanisms in heat pipes using nanofluids–A review. Exp Therm Fluid Sci 2018;90:84–100. [CrossRef]

[3] Sankar BR, Rao DN, Rao CS. Experimental investigation on stability of Al2O3-Water Nanofluid using response surface methodology. Int J Nanosci Nanotechnol 2012;3:149–160.

[4] Choi SUS, Eastman JA. Enhancing thermal conductivity of fluids with nanoparticles. In: Sheh M, Sherwood JA, editors. ASME International Mechanical Engineering Congress & Exposition; 1995 Nov 12-17; San Francisco, California: Amer Society of Mechanical; 1995. pp. 99–105.

[5] Gupta NK, Mishra S, Tiwari AK, Ghosh SK. A review of thermo physical properties of nanofluids. Mater Today Proc 2019;18:968–978. [CrossRef]

[6] Ettefaghi E, Ghobadian B, Rashidi A, Najafi G, Khoshtaghaza MH, Pourhashem S. Preparation and investigation of the heat transfer properties of a novel nanofluid based on graphene quantum dots. Energy Convers Manag 2017;153:215–223. [CrossRef]

[7] Wadd MS, Warkhedkar RM, Choudhari VG. Comparing performance of nanofluids of metal and nonmetal as coolant in automobile radiator. Int J Adv Eng Res Sci 2015;4:182–190.

[8] Asadi A, Asadi M, Rezaniakolaei A, Rosendahl LA, Afrand M, Wongwises S. Heat transfer efficiency of Al2O3-MWCNT/thermal oil hybrid nanofluid as a cooling fluid in thermal and energy management applications: An experimental and theoretical investigation. Int J Heat and Mass Transf 2018;117:474–486. [CrossRef]

[9] Esfahani NN, Toghraie D, Afrand M. A new correlation for predicting the thermal conductivity of ZnO–Ag (50%–50%)/water hybrid nanofluid: An experimental study. Powder Technol 2018;323:367–373. [CrossRef]

[10] Selvam C, Lal DM, Harish S. Thermal conductivity and specific heat capacity of water–ethylene glycol mixture-based nanofluids with graphene nanoplatelets. J Therm Anal Calorim 2017;129:947–955. [CrossRef]

[11] Das SK, Choi SUS, Patel HE. Heat transfer in nanofluids—A review. Heat Transf Eng 2006;27:3–19. [CrossRef]

[12] Nallusamy S, Babu AM, Prabu NM. Investigation on carbon nanotubes over review on other heat transfer nano fluids. Int J Appl Eng Res 2015;10:112–117.

[13] Choi SUS, Siginer DA, Wang HP. Development and application of Non-Newtonian flows. In: Sheh M, Sherwood JA, editors. ASME International Mechanical Engineering Congress & Exposition; 1995 Nov 12-17; San Francisco, California: Amer Society of Mechanical; 1995.

[14] Choi S. Nanofluids for improved efficiency in cooling systems. Int J Heavy Veh Syst 2006;18-20.

[15] Saidur R, Leong KY, Mohammad H. A review on applications and challenges of nanofluids. Renew Sustain Energy Rev 2011;15:1646–1668. [CrossRef]

[16] Wen D, Lin G, Vafaei S, Zhang K. Review of nanofluids for heat transfer applications. Particuology 2009;7:141–150. [CrossRef]

[17] Al-Sammarraie AT, Vafai K. Heat transfer augmentation through convergence angles in a pipe. Numer Heat Transf A 2017;72:197–214. [CrossRef]

[18] Neto ET, Filho EPB. Preparation methods of nanofluids to obtain stable dispersions. In: Filho EPB, Bansal P, Wen D, editors. 13th Brazilian Congress of Thermal Sciences and Engineering; 2010 Dec 5–10.

[19] Mukherjee S, Paria S. Preparation and stability of nanofluids-A review. J Mech Civ Eng 2013;9:63–69. [CrossRef]

[20] Kaggwa A, Carson JK. Developments and future insights of using nanofluids for heat transfer enhancements in thermal systems: A review of recent literature. Int Nano Lett 2019;9:277–288. [CrossRef]

[21] Sarkar J, Tarodiya R. Performance analysis of louvered fin tube automotive radiator using nanofluids as coolants. Int J Nanomanuf 2013;9:51–65. [CrossRef]

[22] Ding Y, Alias H, Wen D, Williams RA. Heat transfer of aqueous suspensions of carbon nanotubes (CNT nanofluids). Int J Heat Mass Transf 2006;49:240–250. [CrossRef]

[23] Manimaran R, Palaniradja K, Alagumurthi N, Sendhilnathan S, Hussain J. Preparation and characterization of copper oxide nanofluid for heat transfer applications. Appl Nanosci 2014;4:163–167. [CrossRef]

[24] Wang XW, Xu XF, Choi SUS. Thermal conductivity of nanoparticle-fluid mixture. J Thermophys Heat Trans 1999;13:474–480. [CrossRef]

[25] Masuda H, Ebata A, Teramae K. Alteration of thermal conductivity and viscosity of liquid by dispersing ultrafine particles (dispersion of-Al2O3, SiO2, and TiO2 ultra-fine particles). Netsu Bussei 1993;227–233. [CrossRef]

[26] Xian-Ju W, Xin-Fang L. Influence of pH on nanofluids' viscosity and thermal conductivity. Chinese Phys Lett 2009;26:056601. [CrossRef]

[27] Das SK, Putra N, Thiesen P, Roetzel W. Temperature dependence of thermal conductivity enhancement for nanofluids. J Heat Transf 2003;125:567–574. [CrossRef]

[28] Xie H, Wang J, Xi T, Liu Y, Ai F. Thermal conductivity enhancement of suspensions containing nanosized alumina particles. J Appl Phys 2002;91:4568–4572. [CrossRef]

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

[30] 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; 51:2651–2656. [CrossRef]

[31] Li CH, Peterson GP. Experimental investigation of temperature and volume fraction variations on the effective thermal conductivity of nanoparticle suspensions (nanofluids). J Appl Phys 2006;99:084314. [CrossRef]

[32] Karthikeyan NR, Philip J, Raj B. Effect of clustering on the thermal conductivity of nanofluids. Mater Chem Phys 2008;109:50–55. [CrossRef]

[33] Kwak K, Kim C. Viscosity and thermal conductivity of copper oxide nanofluid dispersed in ethylene glycol. Korea Aust Rheol J 2005;17:35–40.

[34] Lee D, Kim JW, Kim BG. A new parameter to control heat transport in nanofluids: Surface charge

state of the particle in suspension. J Phys Chem B 2006;110:4323–4328. [CrossRef]

[35] Alawi OA, Sidik NAC, Xian HW, Kean TH, Kazi SN. Thermal conductivity and viscosity models of metallic oxides nanofluids. Int J Heat Mass Transf 2018;116:1314–1325. [CrossRef]

[36] Zhu H, Zhang C, Tang Y, Wang J, Ren B, Yin Y. Preparation and thermal conductivity of suspensions of graphite nanoparticles. Carbon 2007;45:226–228. [CrossRef]

[37] Wei X, Zhu H, Kong T, Wang L. Synthesis and thermal conductivity of Cu2O nanofluids. Int J Heat Mass Transf 2009;52:4371–4374. [CrossRef]

[38] Choi SU, Yu W, Hull JR, Zhang ZG, Lockwood FE. Nanofluids for vehicle thermal management. SAE Trans 2002:38–43. [CrossRef]

[39] Kole M, Dey TK. Thermal conductivity and viscosity of Al2O3 nanofluid based on car engine coolant. J Phys D Appl Phys 2010;43:315501. [CrossRef]

[40] Ghozatloo A, Shariaty-Niasar M, Rashidi AM. Preparation of nanofluids from functionalized Graphene by new alkaline method and study on the thermal conductivity and stability. Int Commun Heat Mass Transf 2013;42:89–94. [CrossRef]

[41] Mohamed IS, Raj CS, Arul S, Rathnakumar P. Heat transfer intensification of zirconia/water nanofluid. J Adv Chem 2017;13:1–8. [CrossRef]

[42] Pantzali MN, Kanaris AG, Antoniadis KD, Mouza AA, Paras SV. Effect of nanofluids on the performance of a miniature plate heat exchanger with modulated surface. Int J Heat Fluid Flow 2009;30:691–699. [CrossRef]

[43] Chiam HW, Azmi WH, Usri NA, Mamat R, Adam NM. Thermal conductivity and viscosity of Al2O3 nanofluids for different based ratio of water and ethylene glycol mixture. Exp Therm Fluid Sci 2017;81:420–429. [CrossRef]

[44] Sahooli M, Sabbaghi S, Shariaty Niassar M. Preparation of CuO/water nanofluids using polyvinylpyrolidone and a survey on its stability and thermal conductivity. Int J Nanosci Nanotechnol 2012;8:27–34.

[45] Raja SS, Vijayakumar K, Gangadevi R. A comparative study on thermal conductivity of Al2O3/water, CuO/water and Al2O3–CuO/water nanofluids. Dig J Nanomater Biostructures 2015;10:1449–1458.

[46] Kannaiyan S, Boobalan C, Umasankaran A, Ravirajan A, Sathyan S, Thomas T. Comparison of experimental and calculated thermophysical properties of alumina/cupric oxide hybrid nanofluids. J Mol Liq 2017;244:469–477. [CrossRef]

[47] Jang SP, Hwang KS, Lee JH, Kim JH, Lee BH, Choi SUS. Effective thermal conductivities and viscosities of water-based nanofluids containing Al2O3 with low concentration. 2007 7th IEEE Conference on Nanotechnology (IEEE NANO); 2007 Aug 2-5; Hong Kong: IEEE; 2007. pp. 1011–1014.

[48] Chandrasekar M, Sivan S, Senthilkumar T. Mechanisms proposed through experimental investigations on thermophysical properties and forced convective heat transfer characteristics of various nanofluids – A review. Renew Sustain Energy Rev 2012;16:3917–3938. [CrossRef]

[49] Khedkar RS, Kiran AS, Sonawane SS, Wasewar K, Umre SS. Thermo–physical characterization of paraffin based Fe3O4 nanofluids. Procedia Eng 2013;51:342–346. [CrossRef]

[50] Karthikeyan NR, Philip J, Raj B. Effect of clustering on the thermal conductivity of nanofluids. Mater Chem Phys 2008;109:50–55. [CrossRef]

[51] Mintsa HA, Roy G, Nguyen CT, Doucet D. New temperature dependent thermal conductivity data for water-based nanofluids. Int J Therm Sci 2009;48:363–371. [CrossRef]

[52] Chon CH, Kihm KD, Lee SP, Choi SUS. Empirical correlation finding the role of temperature and particle size for nanofluid (Al2O3) thermal conductivity enhancement. Appl Phys Lett 2005;87:153107. [CrossRef]

[53] Vajjha RS, Das DK. Experimental determination of thermal conductivity of three nanofluids and development of new correlations. Int J Heat Mass Transf 2009;52:4675–4682. [CrossRef]

[54] Xie H, Wang J, Xi T, Liu Y, Ai F. Dependence of the thermal conductivity of nanoparticle–fluid mixture on the base fluid. J Mater Sci Lett 2002;21:1469–1471. [CrossRef]

[55] Beck MP, Yuan Y, Warrier P, Teja AS. The effect of particle size on the thermal conductivity of alumina nanofluids. J Nanoparticle Res 2009;11:1129–1136. [CrossRef]

[56] Choi C, Yoo HS, Oh JM. Preparation and heat transfer properties of nanoparticle-in-transformer oil dispersions as advanced energy-efficient coolants. Curr Appl Phys 2008;8:710–712. [CrossRef]

[57] Eastman JA, Choi SUS, Li S, Yu W, Thompson LJ. Anomalously increased effective thermal conductivities of ethylene glycol-based nanofluids containing copper nanoparticles. Appl Phys Lett 2001;78:718–720. [CrossRef]

[58] Bhanushali S, Jason NN, Ghosh P, Ganesh A, Simon GP, Cheng W. Enhanced thermal conductivity of copper nanofluids: The effect of filler geometry. ACS Appl Mater Interfaces 2017;9:18925–18935. [CrossRef]

[59] Yu W, Timofeeva EV, Singh D, France DM, Smith RK. Investigations of heat transfer of copper-in-Therminol 59 nanofluids. Int J Heat Mass Transf 2013;64:1196–1204. [CrossRef]

[60] Liu MS, Lin MCC, Huang IT, Wang CC. Enhancement of thermal conductivity with CuO

for nanofluids. Chem Eng Technol 2006;29:72–77. [CrossRef]

[61] Mintsa HA, Roy G, Nguyen CT, Doucet D. New temperature dependent thermal conductivity data for water-based nanofluids. Int J Therm Sci 2009;48:363–371. [CrossRef]

[62] Zhang X, Gu H, Fujii M. Experimental study on the effective thermal conductivity and thermal diffusivity of nanofluids. Int J Thermophys 2006;27:569–580. [CrossRef]

[63] Sharma P, Baek IH, Cho T, Park S, Lee KB. Enhancement of thermal conductivity of ethylene glycol based silver nanofluids. Powder Technol 2011;208:7–19. [CrossRef]

[64] Godson L, Raja B, Lal DM, Wongwises SJ. Experimental investigation on the thermal conductivity and viscosity of silver-deionized water nanofluid. Exp Heat Transf 2010;23:317–332. [CrossRef]

[65] Karami M, Bahabadi MA, Delfani S, Ghozatloo A. A new application of carbon nanotubes nanofluid as working fluid of low-temperature direct absorption solar collector. Sol Energy Mater Sol Cells 2014;121:114–118. [CrossRef]

[66] Hwang Y, Park HS, Lee JK, Jung WH. Thermal conductivity and lubrication characteristics of nanofluids. Curr Appl Phys 2006;6:e67–e71. [CrossRef]

[67] Murshed SMS, Leong KC, Yang C. Enhanced thermal conductivity of TiO2-water based nanofluids. Int J Therm Sci 2005;44:367–373. [CrossRef]

[68] Hong TK, Yang HS, Choi CJ. Study of the enhanced thermal conductivity of Fe nanofluids. J Appl Phys 2005;97:064311. [CrossRef]

[69] Jahanshahi M, Hosseinizadeh SF, Alipanah M, Dehghani A, Vakilinejad GR. Numerical simulation of free convection based on experimental measured conductivity in a square cavity using Water/SiO2 nanofluid. Int Commun Heat Mass Transf 2010;37:687–694. [CrossRef]

[70] Paul G, Chopkar M, Manna I, Das PK. Techniques for measuring the thermal conductivity of nanofluids: A review. Renew Sustain Energy Rev 2010;14:1913–1924. [CrossRef]

[71] Habibzadeh S, Kazemi-Beydokhti A, Khodadadi AA, Mortazavi Y, Omanovic S, Shariat-Niassar M. Stability and thermal conductivity of nanofluids of tin dioxide synthesized via microwave-induced combustion route. Chem Eng J 2010;156:471–478. [CrossRef]

[72] Sarviya RM, Fuskele V. Review on thermal conductivity of nanofluids. Mater Today Proc 2017;4:4022–4031. [CrossRef]

[73] Xie HQ, Wang JC, Xi TG, Liu Y. Thermal conductivity of suspensions containing nanosized SiC particles. Int J Thermophys 2002;23:571–580.

[74] Assael MJ, Metaxa IN, Arvanitidis J, Christofilos D, Lioutas C. Thermal conductivity enhancement in aqueous suspensions of carbon multi-walled and double–walled nanotubes in the presence of two different dispersants. Int J Thermophys 2005;26:647–664. [CrossRef]

[75] Abareshi M, Goharshadi EK, Zebarjad SM, Fadafan HK, Youssefi A. Fabrication, characterization and measurement of thermal conductivity of Fe3O4 nanofluids. J Magn Magn Mater 2010;322:3895–3901. [CrossRef]

[76] Liu MS, Lin MCC, Huang IT, Wang CC. Enhancement of thermal conductivity with carbon nanotube for nanofluids. Int Commun Heat Mass Transf 2005;32:1202–1210. [CrossRef]

[77] Arora N, Gupta M. Experimental investigations on thermo-physical properties and stability of diamond–alumina based hybrid nanofluids. J Dispers Sci Technol 2022;1–4. [CrossRef]

[78] Ding Y, Alias H, Wen D, Williams RA. Heat transfer of aqueous suspensions of carbon nanotubes (CNT nanofluids). Int J Heat Mass Transf 2006;49:240–250. [CrossRef]

[79] 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. [CrossRef]

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

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

[82] Zhang X, Gu H, Fujii M. Effective thermal conductivity and thermal diffusivity of nanofluids containing spherical and cylindrical nanoparticles. Exp Therm Fluid Sci 2007;31:593–599. [CrossRef]

[83] Zhu HT, Zhang CY, Tang YM, Wang JX. Novel synthesis and thermal conductivity of CuO nanofluid. J Phys Chem C 2007;111:1646–1650. [CrossRef]

[84] Murshed SMS, Leong KC, Yang C. Investigations of thermal conductivity and viscosity of nanofluids. Int J Therm Sci 2008;47:560–568. [CrossRef]

[85] Tugolukov E, Ali AJ. Review enhancement of thermal conductivity and heat transfer using carbon nanotube for nanofluids and ionanofluids. J Therm Eng 2021;7:66–90. [CrossRef]

[86] Buongiorno J, Venerus DC, Prabhat N, McKrell T, Townsend J, Christianson R, et al. A benchmark study on the thermal conductivity of nanofluids. J Appl Phys 2009;106:094–312. [CrossRef]

[87] 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;30:2213–2218. [CrossRef]

[88] Shende R, Sundara R. Nitrogen doped hybrid carbon based composite dispersed nanofluids as working fluid for low-temperature direct absorption solar collectors. Sol Energy Mater Sol Cells 2015;140:9–16. [CrossRef]
[89] Choi TY, Maneshian MH, Kang B, Chang WS, Han CS, Poulikakos D. Measurement of the thermal conductivity of a water-based single-wall carbon nanotube colloidal suspension with a modified 3-ω method. Nanotechnology 2009;20:315706. [CrossRef]
[90] 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;91:4568–4572. [CrossRef]
[91] Sahooli M, Sabbaghi S. Investigation of thermal properties of CuO nanoparticles on the ethylene glycol–water mixture. Mater Lett 2013;93:254–257. [CrossRef]
[92] Asirvatham LG, Raja B, Lal DM, Wongwises S. Convective heat transfers of nanofluid with correlations. Particuology 2011;9:626–631. [CrossRef]
[93] Naphon P, Assadamongkol P, Borirak T. Experimental investigation of titanium nanofluids on the heat pipe thermal efficiency. Int Commun Heat Mass Transf 2008;35:1316–1319. [CrossRef]
[94] Pantzali MN, Mouza AA, Paras SV. Investigating the efficacy of nanofluids as coolants in plate heat exchangers (PHE). Chem Eng Sci 2009;64:3290–3300. [CrossRef]
[95] Nguyen CT, Galanis N, Polidori G, Fohanno S, Popa CV, Le Bechec A. An experimental study of a confined and submerged impinging jet heat transfer using Al2O3–water nanofluid. Int J Therm Sci 2009;48:401–411. [CrossRef]
[96] Gherasim I, Roy G, Nguyen CT, Vo-Ngoc D. Experimental investigation of nanofluids in confined laminar radial flows. Int J Therm Sci 2009;48:1486–1493. [CrossRef]
[97] Leong KY, Saidur R, Kazi SN, Mamun AH. Performance investigation of an automotive car radiator operated with nanofluid-based coolants (nanofluid as a coolant in a radiator). Appl Therm Eng 2010;30:2685–2692. [CrossRef]
[98] Hung YH, Teng TP, Teng TC, Chen JH. Assessment of heat dissipation performance for nanofluid. Appl Therm Eng 2012;32:132–140. [CrossRef]
[99] Naraki M, Peyghambarzadeh SM, Hashemabadi SH, Vermahmoudi Y. Parametric study of overall heat transfer coefficient of CuO/water nanofluids in a car radiator. Int J Therm Sci 2013;66:82–90. [CrossRef]
[100] Halelfadl S, Maré T, Estellé P. Efficiency of carbon nanotubes water based nanofluids as coolants. Exp Therm Fluid Sci 2014;53:104–110. [CrossRef]
[101] Azmi WH, Usri NA, Mamat R, Sharma KV, Noor MM. Force convection heat transfer of Al2O3 nanofluids for different based ratio of water: Ethylene glycol mixture. Appl Therm Eng 2017;112:707–719. [CrossRef]
[102] Guo W, Li G, Zheng Y, Dong C. Measurement of the thermal conductivity of SiO2 nanofluids with an optimized transient hot wire method. Thermochim Acta 2018;661:84–97. [CrossRef]
[103] Selvam C, Lal MD, Harish S. Thermal conductivity and specific heat capacity of water–ethylene glycol mixture-based nanofluids with graphene nanoplatelets. J Therm Anal Calorim 2017;129:947–955. [CrossRef]
[104] Islam R, Shabani B, Andrews J, Rosengarten G. Experimental investigation of using ZnO nanofluids as coolants in a PEM fuel cell. Int J Hydrog Energy 2017;42:19272–19286. [CrossRef]
[105] Naphon P, Nakharintr L. Heat transfer of nanofluids in the mini-rectangular fin heat sinks. Int Commun Heat Mass Transf 2013;40:25–31. [CrossRef]
[106] Abdul Hamid K, Azmi WH, Mamat R, Usri NA. Thermal conductivity enhancement of aluminium oxide nanofluid in ethylene glycol. In: Khalid A, Manshoor B, Rahim EA, Siswanto WA, Abdullah K, editors. 5th International Conference on Mechanical and Manufacturing Engineering 2014 (ICME 2014); 2014 Oct 29–30; Bandung, Indonesia: Trans Tech Publications Ltd; 2014. pp. 730–734. [CrossRef]
[107] Maheshwary PB, Handa CC, Nemade KR. A comprehensive study of effect of concentration, particle size and particle shape on thermal conductivity of titania/water based nanofluid. Appl Therm Eng 2017;119:79–88. [CrossRef]
[108] Ettefaghi E, Rashidi A, Ahmadi H, Mohtasebi SS, Pourkhalil M. Thermal and rheological properties of oil-based nanofluids from different carbon nanostructures. Int Commun Heat Mass Transf 2013;48:178–182. [CrossRef]
[109] Ghozatloo A, Rashidi A, Shariaty-Niassar M. Convective heat transfer enhancement of graphene nanofluids in shell and tube heat exchanger. Exp Therm Fluid Sci 2014;53:136–141. [CrossRef]
[110] Kole M, Dey TK. Thermal conductivity and viscosity of Al2O3 nanofluid based on car engine coolant. J Phys D Appl Phys 2010;43:315501. [CrossRef]
[111] Kole M, Dey TK. Investigation of thermal conductivity, viscosity, and electrical conductivity of graphene based nanofluids. J Appl Phys 2013;113:084307. [CrossRef]
[112] Elias MM, Mahbubul IM, Saidur R, Sohel MR, Shahrul IM, Khaleduzzaman SS, et al. Experimental investigation on the thermo-physical properties of Al2O3 nanoparticles suspended in car radiator coolant. Int Commun Heat Mass Transf 2014;54:48–53. [CrossRef]
[113] Akbarzade S, Sedighi K, Farhadi M, Ebrahimi M. Experimental investigation of force convection

heat transfer in a car radiator filled with SiO2-water nanofluid. Int J Eng 2014;27:333–340. [CrossRef]
[114] Goudarzi K, Jamali H. Heat transfer enhancement of Al2O3-EG nanofluid in a car radiator with wire coil inserts. Appl Therm Eng 2017;118:510–517. [CrossRef]
[115] Ravisankar R, Venkatachalapathy VS, Alagumurthy N. Thermal performance improvement of tractor radiator using CuO/Water nanofluid. Heat Transf Asian Res 2017;46:61–74. [CrossRef]
[116] Tijani AS, Bin Sudirman AS. Thermos-physical properties and heat transfer characteristics of water/anti-freezing and Al2O3/CuO based nanofluid as a coolant for car radiator. Int J Heat Mass Transf 2018;118:48–57. [CrossRef]
[117] Ali M, El-Leathy AM, Al-Sofyany Z. The effect of nanofluid concentration on the cooling system of vehicles radiator. Adv Mech Eng 2014;6:962510. [CrossRef]
[118] Sandhya D, Reddy MCS, Rao VVR. Improving the cooling performance of automobile radiator with ethylene glycol water based TiO2 nanofluids. Int Commun Heat Mass Transf 2016;78:121–126. [CrossRef]
[119] Hatami M, Jafaryar M, Zhou J, Jing D. Investigation of engines radiator heat recovery using different shapes of nanoparticles in H2O/(CH2OH)2 based nanofluids. Int J Hydrog Energy 2017;42:10891–10900. [CrossRef]
[120] Peyghambarzadeh SM, Hashemabadi SH, Hoseini SM, Jamnani MS. Experimental study of heat transfer enhancement using water/ethylene glycol based nanofluids as a new coolant for car radiators. Int Commun Heat Mass Transf 2011;38:1283–1290. [CrossRef]
[121] Vajjha RS, Das DK, Namburu PK. Numerical study of fluid dynamic and heat transfer performance of Al2O3 and CuO nanofluids in the flat tubes of a radiator. Int J Heat Fluid Flow 2010;31:613–621. [CrossRef]
[122] Peyghambarzadeh SM, Hashemabadi SH, Naraki M, Vermahmoudi Y. Experimental study of overall heat transfer coefficient in the application of dilute nanofluids in the car radiator. Appl Therm Eng 2013;52:8–16. [CrossRef]
[123] Sheikhzadeh GA, Fakhari MM. Investigation of heat transfer in a flat tube of an automobile radiator using Al2O3 nanofluid. 7th International Conference on Computational Heat and Mass Transfer; 2011 Jul 18-22; Istanbul, Turkey, 2011.
[124] Chavan D, Pise AT. Performance investigation of an automotive car radiator operated with nanofluid as a coolant. J Therm Sci Eng Appl 2014;6:021010. [CrossRef]
[125] Heris SZ, Shokrgozar M, Poorpharhang S, Shanbedi M, Noie SH. Experimental study of heat transfer of a car radiator with CuO/ethylene glycol-water as a coolant. J Dispers Sci Technol 2014;35:677–684. [CrossRef]
[126] Duangthongsuk W, Wongwises S. Heat transfer enhancement and pressure drop characteristics of TiO2–water nanofluid in a double-tube counter flow heat exchanger. Int J Heat Mass Transf 2009;52:2059–2067. [CrossRef]
[127] Maxwell JC. A treatise on electricity and magnetism, Clarendon. Oxford 1881;314:1873.
[128] Hamilton RL, Crosser OK. Thermal conductivity of heterogeneous two-component systems. Ind Eng Chem Fundam 1962;1:187–191. [CrossRef]
[129] Koo J, Kleinstreuer C. A new thermal conductivity model for nanofluids. J Nanoparticle Res 2004;6:577–588. [CrossRef]
[130] Timofeeva EV, Gavrilov AN, McCloskey JM, Tolmachev YV, Sprunt S, Lopatina LM, et al. Thermal conductivity and particle agglomeration in alumina nanofluids: Experiment and theory. P Phys Rev E Stat Nonlin Soft Matter Phys 2007;76:061203. [CrossRef]
[131] Yu W, Choi SUS. The role of interfacial layers in the enhanced thermal conductivity of nanofluids: A renovated Maxwell model. J Nanoparticle Res 2003;5:167–171. [CrossRef]
[132] Wasp EJ, Kenny JP, Gandhi RL. Solid-liquid Flow Slurry Pipeline Transportation (Bulk Materials Handling). 1st ed. Switzerland: Trans Tech Publications; 1977.
[133] Pak BC, Cho YI. Hydrodynamic and heat transfer study of dispersed fluids with submicron metallic oxide particles. Exp Heat Transf 1998;11:151–170. [CrossRef]
[134] Shahrul IM, Mahbubul IM, Saidur R, Sabri MFM. Experimental investigation on Al2O3–W, SiO2–W and ZnO–W nanofluids and their application in a shell and tube heat exchanger. Int J Heat Mass Transf 2016;97:547–558. [CrossRef]
[135] Colangelo G, Favale E, Milanese M, De Risi A, Laforgia D. Cooling of electronic devices: Nanofluids contribution. Appl Therm Eng 2017;127:421–435. [CrossRef]
[136] Yu W, Xie H. A review on nanofluids: preparation, stability mechanisms, and applications. J Nanomater 2012;2012:1–17. [CrossRef]
[137] Wong KV, De Leon O. Applications of nanofluids: Current and future. Adv Mech Eng 2010;2:519659. [CrossRef]
[138] Mahian O, Kianifar A, Kalogirou SA, Pop I, Wongwises S. A review of the applications of nanofluids in solar energy. Int J Heat Mass Transf 2013;57:582–594. [CrossRef]
[139] Milanese M, Colangelo G, De Risi A, Laforgia D. High efficiency nanofluid cooling system for wind turbines. Therm Sci 2014;18:543–554. [CrossRef]

[140] Raja M, Vijayan R, Suresh S, Vivekananthan R. Effect of heat transfer enhancement and NOx emission using Al2O3/water nanofluid as coolant in CI engine. Indian J Eng Mater Sci 2013;20:443–449. [CrossRef]

[141] Zhong X, Yu XL, Wu J, Jiang PZ. Experimental investigation on alumina nanofluids in vehicle heat exchanger. J Zhejiang Univ Sci 2010;44: 761–764.

[142] Teng TP, Yu CC. Heat dissipation performance of MWCNTs nano-coolant for vehicle. Exp. Therm. Fluid Sci 2013;49:22–30. [CrossRef]

[143] Hajjar Z, Rashidi AM, Ghozatloo A. Enhanced thermal conductivities of graphene oxide nanofluids. Int Commun Heat Mass Transf 2014;57:128–131. [CrossRef]

[144] Tiwari AK, Ghosh P, Sarkar J. Performance comparison of the plate heat exchanger using different nanofluids. Exp Therm Fluid Sci 2013;49:141–151. [CrossRef]

[145] Ali HM, Ali H, Liaquat H, Maqsood HT, Nadir MA. Experimental investigation of convective heat transfer augmentation for car radiator using ZnO–water nanofluids. Energy 2015;84:317–324. [CrossRef]

[146] Hussein AM, Bakar RA, Kadirgama K, Sharma KV. Heat transfer enhancement using nanofluids in an automotive cooling system. Int Commun Heat Mass Transf 2014;53:195–202. [CrossRef]

[147] Ray DR, Das DK. Superior performance of nanofluids in an automotive radiator. J Therm Sci Eng Appl 2014;6:041002. [CrossRef]

[148] Ettefaghi EI, Ahmadi H, Rashidi A, Nouralishahi A, Mohtasebi SS. Preparation and thermal properties of oil-based nanofluid from multi-walled carbon nanotubes and engine oil as nano-lubricant. Int Commun Heat Mass Transf 2013;46:142–147. [CrossRef]

[149] M'hamed B, Sidik NAC, Akhbar MFA, Mamat R, Najafi G. Experimental study on thermal performance of MWCNT nanocoolant in *Perodua Kelisa* 1000cc radiator system. Int Commun Heat Mass Transf 2016;76:156–161. [CrossRef]

[150] Zamzamian A, Oskouie SN, Doosthoseini A, Joneidi A, Pazouki M. Experimental investigation of forced convective heat transfer coefficient in nanofluids of Al2O3/EG and CuO/EG in a double pipe and plate heat exchangers under turbulent flow. Exp Therm Fluid Sci 2011;35:495–502. [CrossRef]

[151] Chougule SS, Sahu SK. Thermal performance of automobile radiator using carbon nanotube-water nanofluid—experimental study. J Therm Sci Eng Appl 2014;6:041009. [CrossRef]

[152] Iqbal SM, Raj CS, Arul S, Rathnakumar P. Heat transfer intensification of Zirconia/water nanofluid. J Adv Chem 2017;13:1–8. [CrossRef]

[153] Bozorgan N, Krishnakumar K, Bozorgan N. Numerical study on application of CuO-water nanofluid in automotive diesel engine radiator. Mod Mech Eng 2012;2:130–136. [CrossRef]

[154] Li X, Zou C, Qi A. Experimental study on the thermo-physical properties of car engine coolant (water/ethylene glycol mixture type) based SiC nanofluids. Int Commun Heat Mass Transf 2016;77:159–164. [CrossRef]

[155] Fares M, Al Mayyahi M, Al Saad M. Heat transfer analysis of a shell and tube heat exchanger operated with graphene nanofluids. Case Stud Therm Eng 2020;18:100584. [CrossRef]

[156] Qasim M, Kamran MS, Ammar M, Jamal MA, Javaid MY. Heat transfer enhancement of an automobile engine radiator using ZnO water base nanofluids. J Therm Sci 2020;29:1010–1024. [CrossRef]

[157] Zheng M, Han D, Asif F, Si Z. Effect of Al2O3/water nanofluid on heat transfer of turbulent flow in the inner pipe of a double-pipe heat exchanger. Heat Mass Transf 2020;56:1127–1140. [CrossRef]

[158] Gupta NK, Tiwari AK, Ghosh SK. Experimental investigation of the thermal performance of mesh wick heat pipe. Heat Transf Res 2018;49:2049. [CrossRef]

[159] Kumar JV, Amarkarthik A, Santhosh T, Allenjudah RS, Sundreswaran U. Performance analysis of automobile radiator using tungsten trioxide nano-fluid. In: Kumaresan G, Shanmugam NS, Dhinakaran V, editors. ICAMR 2019: International Conference on Advances in Materials Research 2019; 2019 Dec 6-7; Sathyamangalam, India: Springer; 2019. pp. 1175–1181.

[160] Jarrah HT, Mohtasebi SS, Ettefaghi E, Jaliliantabar F. Experimental investigation of Silver/Water nanofluid heat transfer in car radiator. J Mech Eng Sci 2021;15:7743–7753. [CrossRef]

[161] Gupta NK. Effects of hybrid nanofluids on the thermal performance of heat pipe: An experimental investigation. In: Sikarwar BS, Sundén B, Wang Q, editors. Advances in Fluid and Thermal Engineering; 2020 Aug 5-7; Singapore: Springer; 2020. pp. 509–518. [CrossRef]

[162] Verma SK, Gupta NK, Rakshit D. A comprehensive analysis on advances in application of solar collectors considering design, process and working fluid parameters for solar to thermal conversion. Sol Energy 2020;208:1114–1150. [CrossRef]

[163] Rathore PKS, Gupta NK, Yadav D, Shukla SK, Kaul S. Thermal performance of the building envelope integrated with phase change material for thermal energy storage: An updated review. Sustain Cities Soc 2022;79:103690. [CrossRef]

[164] Rathore PKS, Shukla SK, Gupta NK. Potential of microencapsulated PCM for energy savings

in buildings: A critical review. Sustain Cities Soc 2020;53:101884. [CrossRef]

[165] Zubair MM, Seraj M, Faizan M, Anas M, Yahya SM. Experimental study on heat transfer of an engine radiator with TiO2/EG-water nano-coolant. SN Appl Sci 2021;3:1–9. [CrossRef]

[166] Verma SK, Sharma K, Gupta NK, Soni P, Upadhyay N. Performance comparison of innovative spiral shaped solar collector design with conventional flat plate solar collector. Energy 2020;194:116853. [CrossRef]

[167] Rathore PKS, Shukla SK, Gupta NK. Synthesis and characterization of the paraffin/expanded perlite loaded with graphene nanoparticles as a thermal energy storage material in buildings. J Sol Energy Eng 2020;142:041006. [CrossRef]

[168] Rathore PKS, Shukla SK, Gupta NK. Yearly analysis of peak temperature, thermal amplitude, time lag and decrement factor of a building envelope in tropical climate. J Build Eng 2020;31:101459. [CrossRef]

[169] Gupta NK, Tiwari AK, Verma SK, Rathore PKS, Ghosh SK. A comparative experimental study of thermal performance uncoated wick heat pipe using water, nanofluid and nanoparticles coated wick heat pipe using water. Heat Transf Res 2019;50:1767–1779. [CrossRef]

[170] Gulhane A, Chincholkar SP. Experimental investigation of convective heat transfer coefficient of Al2O3/water nanofluid at lower concentrations in a car radiator. Heat Transf Asian Res 2017;46:1119–1129. [CrossRef]

[171] Azmi WH, Hamid KA, Usri NA, Mamat R, Mohamad MS. Heat transfer and friction factor of water and ethylene glycol mixture based TiO2 and Al2O3 nanofluids under turbulent flow. Int Commun Heat Mass Transf 2016;76:24–32. [CrossRef]

[172] Sarkar J, Tarodiya R. Performance analysis of louvered fin tube automotive radiator using nanofluids as coolants Int J Nanomanuf 2013;9:51–65. [CrossRef]

[173] Oliveira GA, Contreras EMC, Filho EPB. Experimental study on the heat transfer of MWCNT/water nanofluid flowing in a car radiator. Appl Therm Eng 2017;111:1450–1456. [CrossRef]

[174] Kilic M, Abdulvahitoglu A. Numerical investigation of heat transfer at a rectangular channel with combined effect of nanofluids and swirling jets in a vehicle radiator. Therm Sci 2019;23:3627–3637. [CrossRef]

[175] Gupta NK, Barua A, Mishra S, Singh SK, Tiwari AK, Ghosh SK. Numerical study of CeO2/H2O nanofluid application on thermal performance of heat pipe. Mater Today Proc 2019;18:1006–1016. [CrossRef]

[176] Barzegarian R, Aloueyan A, Yousefi T. Thermal performance augmentation using water based Al2O3-gamma nanofluid in a horizontal shell and tube heat exchanger under forced circulation. Int Commun Heat Mass Transf 2017;86:52–59. [CrossRef]

[177] Jafari SM, Jabari SS, Dehnad D, Shahidi SA. Heat transfer enhancement in thermal processing of tomato juice by application of nanofluids. Food Bioprocess Technol 2017;10:307–316. [CrossRef]

[178] Duangthongsuk W, Wongwises S. An experimental study on the heat transfer performance and pressure drop of TiO2-water nanofluids flowing under a turbulent flow regime. Int J Heat Mass Transf 2010;53:334–344. [CrossRef]

[179] Aghayari R, Maddah H, Ashori F, Hakiminejad A, Aghili M. Effect of nanoparticles on heat transfer in mini double-pipe heat exchangers in turbulent flow. Heat Mass Transf 2015;51:301–306. [CrossRef]

[180] Raei B, Shahraki F, Jamialahmadi M, Peyghambarzadeh SM. Experimental study on the heat transfer and flow properties of γ-Al2O3/water nanofluid in a double-tube heat exchanger. J Therm Anal Calorim 2017;127:2561–2575. [CrossRef]

[181] Kumar NTR, Bhramara P, Sundar LS, Singh MK, Sousa ACM. Heat transfer, friction factor and effectiveness of Fe3O4 nanofluid flow in an inner tube of double pipe U-bend heat exchanger with and without longitudinal strip inserts. Exp Therm Fluid Sci 2017;85:331–343. [CrossRef]

[182] Sharma S. Fabricating an experimental setup to investigate the performance of an automobile car radiator by using aluminum/water nanofluid. J Therm Anal Calorim 2018;133:1387–1406. [CrossRef]

[183] Soylu SK, Atmaca I, Asilturk M, Dogan A. Improving heat transfer performance of an automobile radiator using Cu and Ag doped TiO2 based nanofluids. Appl Therm Eng 2019;157:113743. [CrossRef]

[184] Gupta NK, Tiwari AK, Ghosh SK. Experimental study of thermal performance of nanofluid-filled and nanoparticles-coated mesh wick heat pipes. J Heat Transf 2018;140:102403. [CrossRef]

[185] Mahay N, Yadav RK. An experimental investigation into heat transfer characteristics of aqua based Cu nanofluid for automobile radiator. In: Thakur L, editor. 2nd International Conference on New Frontiers in Engineering, Science & Technology (NFEST); 2019 Feb 18–22; Kurukshetra, Haryana, India: IOP Publishing; 2019. 012043. [CrossRef]

[186] Akash AR, Abraham S, Pattamatta A, Das SK. Experimental assessment of the thermo-hydraulic performance of automobile radiator with metallic and nonmetallic nanofluids. Heat Transf Eng 2020;41:235–251. [CrossRef]

[187] Kiani H, Ahmadi Nadooshan A. Thermal performance enhancement of automobile radiator using water-CuO nanofluid: An experimental study. J Power Energy Syst 2019;7:235–248.

[188] Abdulvahitoglu A. Using analytic hierarchy process for evaluating different types of nanofluids for

engine cooling systems. Therm Sci 2019;23:3199–3208. [CrossRef]

[189] Kilic M, Ali HM. Numerical investigation of combined effect of nanofluids and multiple impinging jets on heat transfer. Therm Sci 2019;23:3165–3173. [CrossRef]

[190] Gupta NK, Sharma A, Rathore PKS, Verma SK. Thermal performance optimization of heat pipe using nanofluid: Response surface methodology. J Braz Soc Mech Sci Eng 2020;42:590. [CrossRef]

[191] Jagadishwar K, Babu SS. Performance investigation of water and propylene glycol mixture based nano-fluids on automotive radiator for enhancement of heat transfer. Int J Mech Eng Technol 2017;8:822–833.

[192] Chaurasia P, Kumar A, Yadav A, Rai PK, Kumar V, Prasad L. Heat transfer augmentation in automobile radiator using Al2O3–water based nanofluid. SN Appl Sci 2019;1:257. [CrossRef]

[193] Gupta NK, Verma SK, Rathore PKS, Sharma A. Effects of CuO/water nanofluid application on thermal performance of mesh wick heat pipe. Heat Transf Res 2020;51:837–850. [CrossRef]

[194] Kilic M, Ullah A. Numerical investigation of effect of different parameter on heat transfer for a cross-flow heat exchanger by using nanofluids. J Therm Eng 2021;7:1980–1989. [CrossRef]

[195] Sundari KG, Asirvatham LG, Ninolin E, Surekha B, Marshal JJ. Feasibility of Glycerin/Al2O3 nanofluid for automotive cooling applications. J Therm Eng 2020;6:619–632. [CrossRef]

[196] Yashawantha KM, Vinod AV. Experimental investigation on thermal conductivity and stability of water-graphite nanofluid. J Therm Eng 2021;7:1743–1751. [CrossRef]

[197] Madderla S, Ramasamy D, Sudhakar K, Kadirgama K, Harun WS. Heat transfer performance of a radiator with and without louvered strip by using Graphene-based nanofluids. J Therm Eng 2021;7:1315–1328. [CrossRef]