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Review on Nanofluids as Potential Heat Transfer Fluid

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ABSTRACT
An automotive engine cooling system takes out of excess heat produced during engine operation. A vehicle cooling system regulates engine surface temperature for engine most optimal efficiency. Recent advancements and improvements in an engine for power forced engine cooling machine to develop new techniques to improve its overall performance efficiency and also to reduce fuel consumption. Nanofluid is a suspension of nanoparticles that is a promising heat transfer fluid inside the heat transfer enhancement having an excess of applications because of its advanced thermal conductivity and rheological properties. This paper points out the previous studies and recent progress in the field of improvement in heat transfer with the usage of nanofluid. The latest progress on preparation and enhancement of stability had been reviewed. Thermophysical properties, heat transfer characteristics of nanofluid, and various factors together with particle size, form, surfactant, temperature, and many others on thermal conductivity were presented. The present study discloses potential applications by nanofluid which include heat exchanger, transportation cooling, refrigeration, electronic system cooling, transformer oil, commercial cooling, nuclear device, machining operation, solar electricity and desalination, defense, and many others. Few barriers and challenges had been also addressed. The comprehensive review also covers the most recent investigations on the application of nanofluids in heat transfer enhancement of automotive radiators.

Keywords – Nanoparticle, synthesis method, characterization, thermal conductivity, heat transfer coefficient (HTC)

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I. INTRODUCTION

Radiator are the heat exchangers which are generally used to transfer thermal energy or heat from one medium to another medium in order to serve the purpose of heating and cooling and it is the most important part of heating and cooling system. The coolant around the engine flows through the radiator, and the coolant is cooled and returned to the system. The size of the radiator is adjusted by the thermal load and the packaging area availability. Cited above are heat transfers to convert heat / thermal energy from one medium to another for cooling and heating. Automobile radiators are used to reduce the temperature of an automotive engine.

If radiator is not used in automotive engine various problem will occur like cylinder deformation, knocking, piston deformation etc. can occur but if the radiator of the automotive engine works properly the engine performance of the vehicle will increase. Radiators are generally used for cooling the internal combustion (IC) engine usually in automobiles but also in railway locomotives, piston engine aircraft, concrete plant, etc. use of an engine. They are regularly cool down through the passing of liquid (coolant) via engine block, where it is generally heated from their it passes to the radiator where its losses heat to the surrounding, from there it passes again to the engine and remains in this close loop. The coolant used in the engine is generally water based with some additives generally oil. It is not unusual to use a water pump and an axial fan so that the coolant and air get pressurized for more heat tranfer. [1], [2]

Nanofluids are new generation fluids that are generally engineered by diffusing nanometer-sized particles such as nanotubes, nanorods, droplets, nanowires, nanofibers, nanotubes, etc. are mixed into base fluid. In different words, nanofluids are generally nanoscale colloidal suspensions that contain condensed nanomaterials. These are basically two-phase systems with one phase generally known as solid phase and another as liquid phase. Nanofluids had been found to keep increased thermophysical properties for example viscosity, thermal conductivity, convective and thermal diffusivity heat transfer coefficients compared to base fluids like water or oil. Many fields had made a demonstration of great potential application. There are some very important issues with the two-phase system which we have to face. One of the most significant problem is the stability of the nanofluids, and one of the most important problem is the stability of nanofluids,which remains a massive venture to acquire the stability of nanofluids. In this paper, we will review the new progress in the methods for preparing stable nanofluids and recapitulate the stability mechanisms. Today, nanofluids require more and more attention. Most of the functions of nanofluid analysis come from a wide range of applications.

Although a few evaluation articles related to the development of nanofluid research had been posted withinside the years [3-8], maximum of the critiques are involved with the experimental and theoretical research of the thermophysical properties or the convective heat transfer of nanofluids. This work is based on the knowledge of new practical strategies and balancing mechanisms, mainly the new useful development of nanofluids and the heat transfer characteristics of nanofluids. The incorporation of nanoparticles dramatically improves the thermophysical properties of traditional heat transfer fluid which increases the heat transfer coefficient. These thermophysical properties are density, specific heat, thermal conductivity, and dynamic viscosity. The degree of enhancement of heat transfer depends on the quantity of nanoparticles which is suspended in the base fluid. Metal oxides (Al_2O_3, CuO, TiO_2, ZnO, MgO, SiC, etc.) are preferred as nanoparticles that have high thermal conductivity. Nitride ceramics (AlN, SiN), carbon ceramics (SiC, TiC) are also used as nanoparticles. Commonly used base fluids are water (H_2O), ethylene glycol (EG), engine oil (EO) etc. **Table 1** demonstrates the thermal conductivity of different types of nanoparticles.

Table 1 Thermal conductivity of different nanoparticles

Nanoparticles	Thermal conductivity [W/(m·K)]	References
Diamond	3300	[9]
MWCNT	2000–3000	[10]
SiC	490	[11]
Ag	429	[12]
Cu	398	[13]
Au	315	[13]
Al	247	[13]
Si	148	[9]
MgO	54.9	[14]
Al2O3	40.0	[15]
CuO	32.9	[9]
ZnO	29.0	[16]
TiO2	8.4	[16]

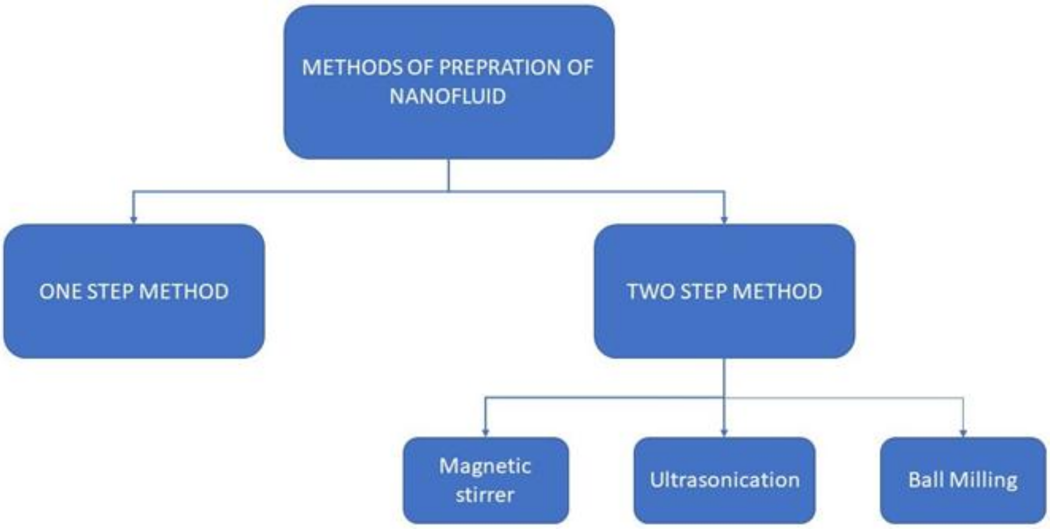

Fig. 1 Classification of Nanofluid preparation methods.

II. PREPARATION OF NANOFLUID

The preparation of nanofluids is the primary key step in experimental research with nanofluids.

Nanofluids are produced via dispersing nanometer-scale strong particles into base liquids inclusive of water, ethylene glycol (EG), oils, and so on. In the synthesis of nanofluids, agglomeration is the main trouble [17]. The delicate preparation of a nanofluid is essential due to the fact nanofluids need unique necessities which include a good suspension, stable suspension, low agglomeration of particles, and no chemical alteration of the fluid [18]. Xuan and Li [19] suggested strategies used for stabilizing the suspensions: (i) converting the pH fee of suspension, (ii) using floor activators and/or dispersants, (iii) using ultrasonic vibration. These techniques can change the surface residences of the suspended particles and may be used to suppress the formation of particle clusters to obtain stable suspensions.

The usage of these strategies depends on the required application of the nanofluid. The selection of appropriate activators and dispersants depends particularly upon the properties of the solutions and particles. It should be mentioned that the addition of dispersant/surfactant affects the thermophysical properties of nanofluids. The stability of nanoparticle spreading in a base fluid is indicated by zeta potential value, high zeta potential value (+/-) indicates good stability. There are two fundamental methods to prepare nanofluids which are one-step and two-step. For the preparation of hybrid nanofluid, most researchers adopted a two-step method. Classification of nanofluid preparation methods is shown in **Fig 1**.

2.1 One- step method

In this method, some processes are avoided like drying, storage, transportation, and dispersion of nanoparticles. Stable nanofluid is prepared by the Physical Vapor Deposition (PVD) technique in which direct evaporation and condensation of nanoparticles are carried in the base fluid. Pure and uniform nanoparticles are produced by this method. Hence the accumulation of nanoparticles is reduced.

The primary drawbacks of the one-step method are that the residual reactants are left in the nanofluids and additionally the cost is high. Zhu et al. [20] organized Cu nanofluid one-step method.

2.2 Two- step method

This is the most economic method for the large-scale preparation of nanofluid. In the two-step method, the nanoparticles are obtained by different methods and then these nanoparticles are dispersed into the base liquid for the desired nanofluid. This production process is inexpensive and massive. The main drawback of the two-step method is the aggregation of nanoparticles. Because of instability, a surfactant is used. This is the commercial method to prepare nanofluid. Most researchers prefer this method in the preparation of nanofluid for research. Zhu et al. [21] used a two-step method to prepare Al_2O_3/water nanofluid. **Fig.2** demonstrates the two-step method.

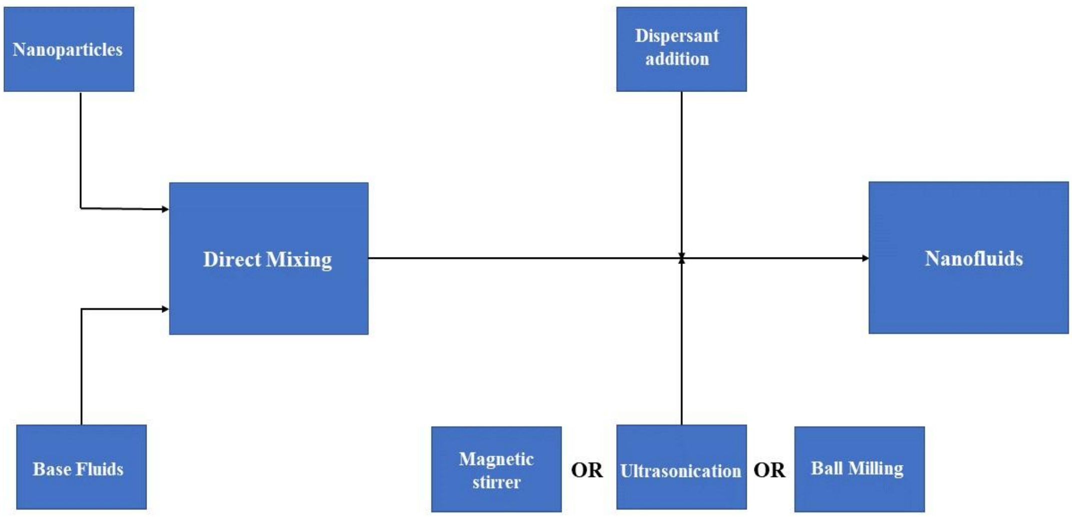

Fig.2 Schematic representation of steps in Two-step Method

III. STABILITY OF NANOFLUID

The stability of nanofluid is important to get uniform thermophysical properties. The stability of nanofluid is related to electrical double layer repulsive force and Vander Waals attractive force. Electrical Double Layer Repulsive Force (EDLRF) must be higher than the Vander Waals attractive forces to get stable nanofluid. Vander Waals attractive forces between nanoparticles cause to get clustered because of attraction forces. If this force is high, nanoparticles get separated from the base fluid and these clustered nanoparticles settle down at the bottom of the vessel because of gravitational force. On the other hand, EDLRF acts as opposite to Vander Waals's attractive force which separates the particles from each other. **Fig.3** demonstrates the sedimentation of Al2O3 nanoparticles without stabilizer at a different time from the preparation of nanofluid.

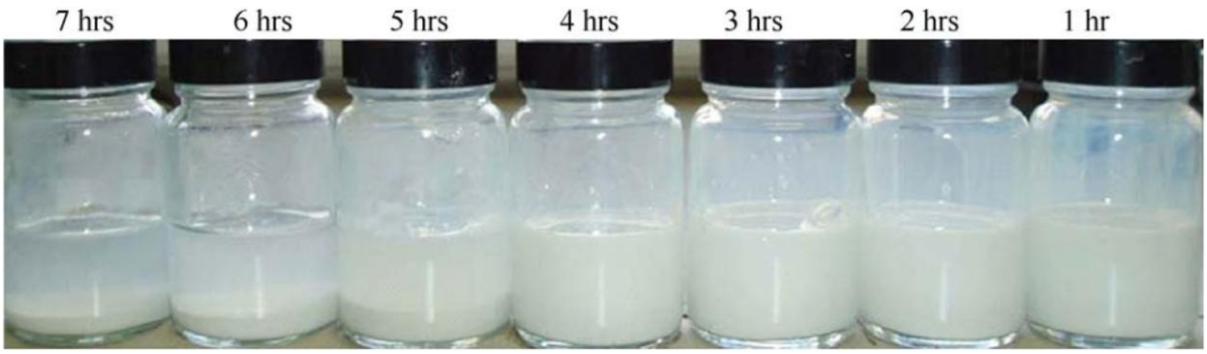

Fig.3 Sedimentation of Al_2 O_3 nanoparticles without stabilizer [86]

IV. CHARACTERIZATION OF NANOFLUID

The nanofluids are characterized by the following techniques: SEM, TEM, XRD, FT-IR, DLS, TGA Raman and Zeta potential analysis. SEM (Scanning Electron Microscopy) analysis is carried to study the micro structure and morphology of nanoparticles or nanostructured materials. TEM (Transmission Electron Microscopy) is similar to SEM but it has much higher resolution than SEM. Images taken by XRD (X-ray Diffraction) technique are help full to identify and study the crystal behavior of nanoparticles. FT-IR (Fourier-Transform Infrared Spectroscopy) is used to study the surface chemistry of solid particles and solid-liquid particles, DLS (Dynamic Light Scattering) analysis is performed to estimate the average size of nanoparticles dispersed in the base liquid media. TGA (Thermo-gravimetric Analysis) is used to study the influence of heating and melting on the thermal stabilities of nanoparticles. Raman spectroscopic technique is used to provide a structural fingerprint by which molecules can be identified. Zeta potential value is related to the stability of nanoparticles in base fluid [22]. Factors on which the heat transfer and pressure drop characteristics depend in radiators are shown in **Fig. 4**.

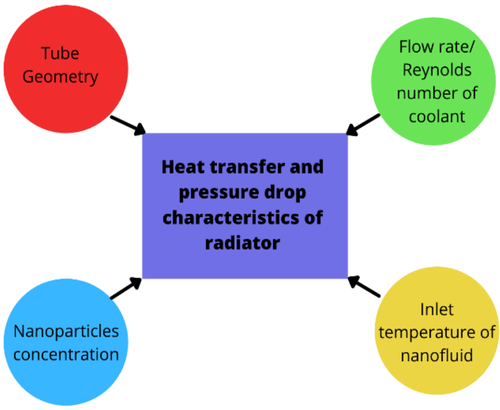

Fig. 4 Factors on which the heat transfer and pressure drop characteristics depend in radiators

V. ADVANTAGES OF NANOFLUID

Heat transfer improves much for the addition of a small volume fraction of nanoparticles. Researchers are still investigating the benefits of nanofluid and the cause of this heat transfer enhancement. Many researchers inferred as follows [23-27].

• The thermal conductivity of the fluid gets improved by the dispersion of nanoparticles. Effective thermal conductivity is dependent on nanoparticle volume. It improves with the increase in the volume of nanoparticles.

• Interactivity between base fluid & nanoparticles greatly improves due to the increase in surface area of particles.

• The dispersed nanoparticles generate Brownian motions which in turn increase interactivity and collision between particles and fluids.
• Mixing fluctuation and turbulence increase due to the dispersion of nanoparticles.
• The pumping power is relatively less in comparison to the base fluid for equivalent heat transfer.
• Absorption of solar energy increases with the help of nanofluid.
• Stability is better than another colloid suspension.

VI. REVIEW ON APPLICATION OF NANOFLUIDS

6.1 Application in Automotive Radiator

Engine cooling in automotive vehicles through different nanofluids is the current topic of discussion. Researches on the performance of the thermo-hydraulic nanofluids in radiators of circular tubes type are presented:

Naraki et al [28] studied a nanofluid (water-based copper oxide nanofluid) to calculate the rate of heat transfer of a nanofluid in a radiator. The result showed that the OHTC of nanofluid was relatively higher in comparison to that of water. HTC was inversely proportional to the temperature of nanofluids and directly proportional to that of nanofluid concentration. HTC was calculated using Qualitek-4 software with the help of the Taguchi method. Heris et al. [29] measured the thermal efficiency of nanofluids in a car radiator using a water-EG mixture consisting of CuO nanoparticles. They concluded that the Nusselt number increased with an increment in Reynolds number and concentration of nanoparticles in a nanofluid. Also, the Nusselt number showed an increment with an increase in the inlet temperature of nanofluid in the radiator. Ebrahimi et al. [30] showed the characteristic of heat transfer with the help of various concentrations of water-based SiO2 nanofluid in a car radiator. By using nanofluid the heat transfer performance shown was much better in comparison to that of water. As stated by an investigation done by Sheikhzadeh et al. [31], Nusselt number gets enhanced with an increase in the flow rate, the inlet temperature of nanofluid and nanoparticle. A numerical analysis of the performance of the automobile radiator employing Cu/EG nanofluid was done. Escalation in HTC was found after a rise in the flow rate and nanoparticle concentration. Bhogare and Kothawale [32] investigated the thermal characteristics of Al2O3 based nanofluid in an automobile radiator. Their conclusions showed that with increment in nanoparticle loading and rate of flow of nanofluids, HTC gets enhanced, subsequently. Ramaraju et al. [33] summarized the experiment of the intensification in the heat transfer rate of a car (Suzuki-800 cc) radiator with the help of MWCNT based nanofluid. With the help of nanofluids based on EG, there was sign remarkable improvement in heat transfer rate observed even for a very negligible increase in nanoparticle concentration. Samira et al. [34] used different nanoparticle concentrations of CuO nanofluid for enhancing the performance of car radiator. With increasing the nanoparticle concentration, pressure drop increased at lower temperatures. Though, at a higher temperature, pressure drop considerably decreased due to a decrease in nanofluid viscosity Nambeesan et al. [35] showed the enhancement in HTC in an automobile radiator with the help of alumina-based nanofluids. From the results, it can be concluded that heat transfer efficiency was relatively less when using the EG-water mixture as a coolant as compared to performance with adding nanoparticles in it. Dhale et al. [36] deduced the thermal efficiency of nanofluid (Al2O3/water) in the cooling system of an engine. Senthilraja et al. [37] experimentally boost the efficiency of a radiator using aluminium based nanofluids and oxides of copper. They discovered that with a rise in the rate of fluid circulation the heat transfer performance also improved. From the results, it could be concluded that CuO/water nanofluid produced better thermal performance in comparison to the Al2O3/water nanofluids.

Salamon et al. [38] illustrated experimentally the characteristics related to heat transfer in an automobile radiator using TiO2 nanofluid.

According to the results, increasing the flow rates, let to an increase in the Nusselt number. Nanofluid generated better heat transfer efficiency at relatively high inlet temperatures thus helping in radiator size reduction.

Contreras et al. [39] analyzed the thermo-hydraulic efficiency of an automotive cooling system in a cross-flow heat exchanger with the help of graphene and silver-based nanofluids.

The heat transfer properties of nanofluid calculated experimentally and compared with correlations of similar literature. Silver nanoparticles based nanofluid showed a better rate of heat transfer rather than graphene-based nanofluid.

A novel investigation performed by Goudarzi and Jamali [40] in which they introduced wire coil inserts and nanofluid (Al2 O3/EG) together in a car radiator for heat transfer enhancement. Nusselt number showed greater value with the use of wire coil insert than without wire coil insert. The enhancement in heat transfer was observed 9% higher with wire coil insert compared to that of without wire coil insert. Above discussed studies are summarized in Table 2.

Automotive and heavy-duty engines are associated with a plethora of heat. Engine may get damaged if this unwanted heat is not dissipated rapidly. The common coolant used in automotive cooling system is Ethelene glycol based HTF containing the volumetric ratio of EG to water of 60/40, 50/50. Ethelene glycol mixed with water increases the freezing temperature of pure water. More efficient and compact cooling system can be designed by using nanofluid. For the first time, Choi [41] suggested to use nanofluid in automotive cooling system. Al2O3/water nanofluid enhances heat transfer up to 45% in the car radiator than pure water [42, 43]. Heris et al. [44] found 55% enhancement of heat transfer coefficient in case of CuO/ EG-water nanofluid compared with EG-water base fluid. Samira et al. [45] also investigated CuO/ EG-water nanofluid in car radiator and found that incorporation of nanoparticle increases heat transfer rate though pressure drop increases at the same time.

Various kinds of heat exchangers including shell and tube, plate type, microchannel type, compact are generally used in the heavy industry, processing industry.

Researchers are working their best to improve the heat transfer efficiency of the heat exchanger by replacing traditional heat transfer fluid with nanofluid [46].

Lotfi et al. investigated MWNT/water nanofluid in shell and tube type heat exchanger by [47] and found incredible heat transfer enhancement because of the presence of multi-walled nanotube particles.

Farajollahi et al. [48] investigated the effects of volume concentration of nanoparticles and Peclet number of Al2 O3/water and TiO2/water nanofluids in shell and tube type heat exchanger. They found a higher heat transfer coefficient in the case of nanofluid. Pintail et al. [49] performed experimental and CFD analysis of CuO/water nanofluid in the plate heat exchanger. The investigation showed higher thermal conductivity of nanofluid. Asirvatham et al. [50] found a 69.3% increase in heat transfer coefficient using silver nanofluid in double pipe heat exchanger because of the 0.9% volume fraction of nanoparticles. Also, a compact heat exchanger was analyzed with the help of nanofluid by Leong et al.

[51], Huminic [52], and Vasu et al. [53] and found improvement in heat transfer performance. Nanoparticles can also be used for water desalination in the solar heat exchanger. The rate of evaporation and condensation increases if nanoparticles are used in the solar system which is more cost-effective [54]. Taghizadeh-Tabari et al. [55] analysed the efficiency of TiO2 nanofluid using a heat exchanger(plate type) which is used in the milk pasteurization industry. All volume fraction of TiO2 nanofluid showed a much better heat transfer rate.

Table 2 Summary of reviewed studies of nanofluids for circular tube car radiators.

Researcher(s)	Type of study	Nanofluid	Nanoparticle concentration	Flow Regime (Re)	Maximum HTC enhancement
Naraki et al. [28]	Experimental	CuO/water	0–0.4 vol%	Laminar (100–1000)	8% for 0.4 vol% of nanofluid
Heris et al. [29]	Experimental	CuO/(EG: water:: 60:40)	0.05, 0.1, 0.3, 0.5 and 0.8 vol%	Turbulent (2000–8000)	55% for 0.8 vol% of nanofluid
Ebrahimi et al. [30]	Experimental	SiO2/water	0.1, 0.2 and 0.4 vol%	Turbulent (11,000–23000)	3.8% for 0.4 vol% nanofluid
Sheikhzadeh et al.[31]	Numerical	Cu/EG	0-5 vol%	Turbulent (4000–6000)	26.16% for 5 vol% of nanofluid
Bhogare and Kothawale [32]	Experimental	Al2O3/EG-water	0-1 vol%	Turbulent (84,391 and 39,343)	36% for 1 vol% of nanofluid
Ramaraju et al. [33]	Experimental	MWCNT/ (EG: water: 40:60)	0.02 vol%	Laminar and turbulent (1000–7500)	30%
Samira et al. [34]	Experimental	CuO/ (EG: water: 60:40)	0.05, 0.1, 0.3, 0.5 and 0.8 vol%	Transient (2000–4300	–
Nambeesan et al. [35]	Experimental	Al2O3/EG-water	0.1 vol%	–	37%
Dhale et al. [36]	Experimental	Al2O3/water	1.2 vol%	Mass flow rate - 0.167 kg/s	40%
Senthilraja et al. [37]	Experimental	CuO/water and Al2O3/water	0-1 vol%	Flow rate (2–5 L/min)	55.53% and 40.08% for 0.15 vol% of CuO/water and Al2O3/water nanofluids
Salamon et al. [38]	Experimental	TiO2/ (PG: water: 70:30)	0.1 and 0.3 vol%	Flow rate (3–6 L/min)	8.5% for 0.3 vol% of nanofluid
Contreras et al. [39]	Experimental	Graphene/ (EG: water: 50:50);Ag/ (EG: water: 50:50)	0.01, 0.05 and 0.1 vol %	Mass flow rate - 0.08 and 0.11 kg/s	4.4% for 0.1 vol% of Ag based nanofluid and 4.1% for 0.1 vol% of graphene based nanofluid
Goudarzi and Jamali [40]	Experimental	Al2O3/EG	0.08, 0.5 and 1 vol%	Turbulent (18,500–22700)	9% with wire coil insert and 14% with wire coil insert and nanofluid

6.2 Miscellaneous Applications

Defense Applications

Most of military vehicles and equipment have heavy duty engines resulting production of much heat where high heat flux coolant is required. Defense equipment including submarine, fighter jet etc. must be compact with a good cooling system. Nanofluids have a great potential application in this equipment.

Refrigeration

The performance of CNT, gold, and HAuCl4 nanoparticles suspended in Polyalkylene Glycol lubricant was investigated by Mohan et al. [56] in Vapor Compression Refrigeration System (VCRS). The outcome of their research was tremendous in the nanofluid research in refrigeration. Compression work reduces with the increase in volume fraction of nano-lubricant which enhances the COP. The COP increased by 31.7% with the incorporation of 0.1% gold with 0.005% CNT in Polyalkylene Glycol lubricant and exergy loss reduced by 8% at the same time. Wang et al. [57] investigated R22 refrigerant with Al2O3 nanoparticles and observed enhanced heat transfer characteristics. The height of the boundary layer decreases because of the addition of nanoparticles in the refrigerant which enhances the flow boiling heat transfer [58]. Sheikholeslami et al. [59] carried an experimental investigation using R600a/oil/CuO nano-refrigerant. Their investigation reveals that boiling heat transfer increases with the increase in nanoparticle concentration.

Electronics equipment

In the power generation industry, transformer cooling is important. Kulkarni et al. [60] applied Al2O3 nanofluid as jacket water coolant in a diesel-electric generator to dissipated excess heat. Researchers are relentlessly giving their effort to reduce transformer size and weight by enhancing cooling systems. Nanofluid can be a potential alternative by improving the properties of conventional transformer oil [61]. Chips of electronic equipment produce much unnecessary heat which must be dissipated rapidly for the long lifespan of electronic equipment. Jang and Choi [62] recently designed a microchannel heat sink where nano- fluid was used as HTF. Their investigation gave a satisfactory result than pure water. Much electricity can be saved by improving the efficiency of the chiller with the help of nanofluid. Thermosyphon is now used for cooling the internal components of a computer including the processor. Researchers investigated different nanofluids in thermosyphon [63]. The heat transfer performance of thermosyphon largely depends on the thermal conductivity of the working fluid. If the thermal conductivity of the working fluid of the thermosyphon increases, the boiling heat transfer also increases in the nucleate boiling regime [64]. Sardarabadi et al. [65] investigated Na-MWCNT/water and K- MWCNT/water nanofluid in TPCT for electronic chip cooling. Na-MWCNT/water nanofluid showed higher thermal efficiency than K- MWCNT/water nanofluid.

Transformer oil

Transformer oil based nanofluids are promising because of their higher thermophysical properties than conventional transformer oil. Carbon nanotubes (CNTs) have enhanced thermophysical properties than other materials [66-69] Beheshti et al. [70] investigated oxidized MWCNTs nano- fluid based on transformer oil. The investigation shows that incorporation of oxidized MWCNT in transformer oil enhances both free and forced convective heat trans- ferrate. Also, flash point increases by 4.6% because of the incorporation of 0.001 mass percentage of oxidized MWCNT nanoparticles.

Industrial cooling

Heavy-duty machinery running all day in the production of goods produces a large amount of unwanted heat which must be removed rapidly to avoid damage to the machinery. Nanofluids can be used as HTF in these types of machinery. Again, much energy can be saved associated with nanofluid in industrial applications like cooling and heating of water resulting in less carbon dioxide emission to the environment [71]. About one trillion Btu energy can be saved by altering conventional HTF with nanofluid in the USA [72].

Cooling of nuclear system

The power density is much high in nuclear systems. Nanofluid has potential application as the main reactor coolant for Pressurized Water Reactors (PWR), Emergency Core Cooling Systems (ECCS), etc. [73].

Machining operation

Nanofluid demonstrates better results than conventional cutting fluid for machining operation which prevents the burning of the tool and workpiece [74, 75]. A large amount of heat generates during the grinding machining operation such as grinding, drilling, tapering, etc. This excess heat must be dissipated rapidly to protect the workpiece from phase transformation, thermal distortion, and residual stress. The crack may initiate If the excess heat is not dissipated rapidly. The Critical Heat Flux (CHF) of coolant can be enhanced by substituting nano-coolant. Nanocoolants with high CHF protect from the thermal damage of the workpiece [74]. Salimi-Yasar et al. [75] used TiO2/ soluble oil nanofluid as cutting fluid during drilling and found that nanofluid causes less amortization and temperature of drilling.

Geothermal energy extraction

Geothermal energy is a renewable and sustainable energy resource. The estimated equivalent power of geothermal energy is 42 million MW which is expected to last for billion years. Nanofluid can extract more geothermal energy and can produce more power in the Rankine cycle. The efficiency of the system can be increased by using nanofluid in geothermal boreholes and heat exchangers. Dene- ship our and Rafee [76] carried an investigation of Al2O3/ water and CuO/water nanofluids as circuit fluid in the geothermal borehole heat exchanger. The extracted heat by CuO/ water nanofluid was higher than Al2O3/water nanofluid. The extraction of heat increases with the increment of volume fraction.

Solar energy and desalination

There have been several investigations in the field of the solar collector based on nanofluid that demonstrates better result than the base fluid [77–80]. Saffariana et al. [81] found a 78.25% increase in heat transfer by using CuO/ water nanofluid in wavy pipes solar collectors. Li et al. [82] used EG-based SiC-MWCNTs hybrid nanofluid indirect absorption solar collectors (DASC). Their investigation found 48.6% higher solar-thermal conversion efficiency than pure EG in DASC. Choudhary et al. [83] found an increase in thermal efficiency by 16.36% using MgO nanofluid than EG/DW in the solar collector.

Many researchers investigated solar thermal desalination systems using nanofluids which give more potable drinking water by increasing efficiency [84,85]. Parsa et al. [86] experimentally studied a solar desalination system with silver nanofluid. Their study reveals that the incorporation of silver nanoparticles increases the rate of heat transfer and at the same time, silver nanoparticles act as an anti-bacterial agent.

VII. CONCLUSION

From the review of literature, it is concluded that nano fluid has emerged as a potential alternative to the conventional fluid in terms of heat transfer enhancement. From the literature survey, different findings are concluded as:

i. The heat capacity dissipation and the efficiency factor (EF) of Nano coolant (NC) are higher than ethyl glycol-water (EG/W), and the TiO2 NC is higher than Al2O3 NC. The overall heat transfer coefficient increases with enhancing the volumetric flow rate of the Nanofluid significantly. Cooling capacity and effectiveness increase with an increase in mass flow rate of air and coolant. Also increasing the inlet liquid temperature decreases the overall heat transfer coefficient. The overall heat transfer coefficient decreases with the increasing inlet temperature of the Nanofluid. Nanofluid offers higher heat-transfer properties compared to that of conventional automotive engine coolant. The requirement of pumping power reduces with the use of Nanofluid in the radiator. The heat transfer behavior of the Nanofluid was highly dependent on the particle concentration, the flow condition, and depended on temperature.

ii. Preparation of nanofluid is costly. Hence, efforts are required to identify cost-effective techniques for the nanofluid preparation.

iii. Stability is the main challenge of nanofluid which is crucial in the application as heat transfer fluid. More research on adoption of techniques for enhancing the stability of nanofluid are required. The optimum time of sonication and magnetic stirring is not determined yet for different types of nanofluid. Moreover, optimum concentration of surfactant is also not determined in most f the researches.

iv. The combination of different nanoparticles is not popularly used by the researchers. Hence, effort can be made to find out the thermophysical properties of hybrid nanofluid. MWCNT demonstrates high thermal conductivity but very few studies have been carried out regarding the thermophysical properties and heat transfer characteristics of MWCNT. Research can be carried out for MWCNT nanofluid.

v. Correlations for the thermophysical properties and heat transfer characteristics of different nanofluid are not yet been formulated. Researchers can carry out investigation in order to formulate new correlation of different nanofluid.

vi. There are many potential applications of nanofluid. Researchers have applied nanofluid in different fields such as heat exchanger, industrial cooling, automotive cooling system, nuclear systems, solar absorption, etc. More researches should be carried out before the application of nanofluid in nuclear system and some other fields.

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