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A Glanceon Preparation, Stability, Properties and Applications of Nanofluids

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Abstract- **Nanofluids are colloidal suspension engineered by dispersing nanometersized metallic or non-metallic particles (nanoparticles, nanotubes, nanowires, nanosheets or droplets) in a base fluid. The nanofluid enhances properties of the base fluid. Nanofluids have extraordinary properties that make them potentially useful in many applications. Even though the nanofluid has lots of advantages, its applications are limited due to poor stability over long-term, high-pressure drop, particle collection, low specific heat, high cost. In this review, an attempt has been made to explain the method of preparation, stability, properties, and applications of nanofluids.**

Keywords: **Nanofluids, Preparation, Stability, Properties, Thermal Conductivity, Applications**

I. INTRODUCTION

Previously only CFC refrigerants were used in the refrigeration system until 2002 which causes global warming and they are harmful to the ozone layer. After that, HFC based refrigerants were used but further, it was replaced by R134a refrigerant which is a mixture of hydrocarbon refrigerant like R600a and R290 etc. Now due to the advancement of technologies, it is possible to increase the efficiency of refrigerators and safe to the environment by using nanofluids. Nanoparticles are nearly-spherical particles with the size of its diameter in nm. Nanoparticles are between 1 and 100 nanometers (1×10^{-9} to 1×10^{-7}m) size [1].The properties of nanoparticles usually highly dependent on their size. Nanofluids are the new class of fluids engineered by dispersing nanometer-sized particles (nanoparticles, nanotubes, nanowires, nanosheets or droplets)[2]. They are colloidal suspensions of ultra-fine metallic or non-metallic particles (organic/inorganic) in given fluid [3]. Nanofluids are the two-phase system with the solid phase in the liquid phase. The nanoparticles used in nanofluids are typically made of metals, oxides, carbides, or carbon nanotubes. They exhibit enhanced thermal conductivity and the convective heat transfer coefficient compared to the base fluid. Common base fluids include water, ethylene glycol, oil and conventional fluid mixtures. The metallic nanofluids are prepared by using metals like copper, aluminium, nickel, gold, silver etc. and the non-metallic particles like metal oxides ceramics such as titanium, zinc, aluminium and iron oxides and various allotropes of carbon such as graphite, CNT [3].It is proved that chemical, physical and mechanical behaviours of material considerably change at the nanoscale, which encourages the use of such enhanced behaviour of nanomaterials for new generation technology [4]. The nanofluid enhances properties like thermal conductivity, viscosity, heat transfer coefficients and friction factor. Heat transfer depends on the thermal conductivity of nanofluids, and compressor energy efficiency depends upon viscosity and friction factor [5]. A nanoparticle increases the thermo-physical capability and heat transfer capability in many applications. Nanofluids have extraordinary properties that make them potentially useful in many applications in heat transfer, including microelectronics, fuel cells, pharmaceutical processes and hybrid-powered engines, engine cooling/vehicle thermal management, domestic refrigerator, chiller, heat exchanger, in grinding, machining, solar applications and in boiler flue gas temperature reduction.

In general refrigerant’s performance normally suffers from its poor heat transfer properties. The earlier studies on the use of microscale solid particles in the fluid as refrigerant showed major problems [4].

1. Rapid settling of the solid spherical particles at the base in the fluids.
2. Blockage of microchannels and surface cut.
3. Agglomeration of particles.

Incorporation of nanoparticles in refrigerants gives assurance to overcome these problems. It was experimentally proved that stability of nanoparticles can be increased by developing proper dispersants in fluids and ultrasonication process. Hence the heat transfer performance of such fluids can be significantly improved [4].Even though the nanofluid has lots of advantages, its applications are limited due to poor stability over long-term, high-pressure drop, particle agglomeration, low specific heat, high cost. Thus it is important to find an appropriate method of preparation for the stability of nanofluids.

II. PREPARATION OF NANOFLUIDS

The preparation of nanofluids can be considered as the key step in the study of nanofluids. The preparations of nanofluids require mixing of nanoparticles with the oil with the even distribution of these particles with lubricating oil for stable and durable mixture [6]. In the synthesis of nanofluids, agglomeration is a major problem [7]. The delicate preparation of a nanofluid is important because nanofluids need special requirements such as an even dispersion, stable suspension, low agglomeration of particles and no chemical change of the fluid[8]. There are two basic methods to prepare nanofluids.

1. one step method 2. Two-step method

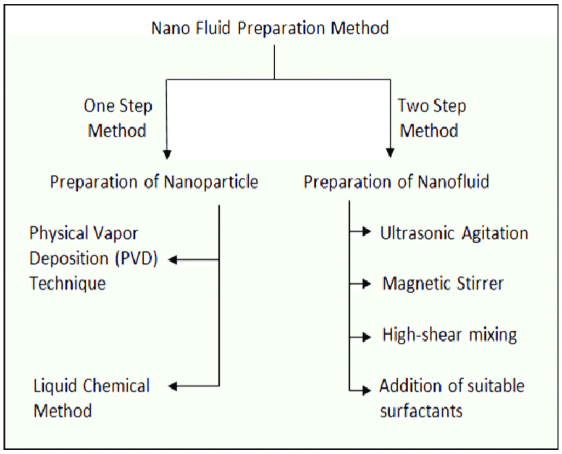

Chart 1: Methods of Preparation of Nanofluids.

A. One Step Method

The single step method indicates the synthesis of nanofluids in one step. i.e. here production of nanoparticles and their dispersion in the base fluid is done in a single step. The one-step process consists of simultaneously making and dispersing the particles in the fluid. In this method, the processes of drying, storage, transportation, and dispersion of nanoparticles are avoided, so the agglomeration of nanoparticles is minimized, and the stability of fluids is increased [9]. Many single step methods have been used for the preparation of nanofluids. Akoh *et al.* [10] has developed single step direct evaporation method which is known as VEROS (Vacuum Evaporation onto a Running Oil Substrate).In this method, nanofluid is produced by the solidification of the nanoparticles, which are initially in a gaseous phase, inside the base fluid[11]. As it was difficult to separate nanoparticles from fluids, a VEROS technique was developed by Eastman et al.[12] in which copper vapour is directly condensed into nanoparticles by reduction of CuSO4 .5H2O with NaH2PO2 .H2O in ethylene glycol under microwave radiations. Another one step method is laser ablation method which has been used to produce alumina nanofluids [13]. This method was also used by Zhu *et al.* [14] for producing nanofluids of copper nanoparticles in ethylene glycol as the base fluid. Preparation method for CuO, Cu2O and Cu based nanofluids with different dielectric liquids is developed by Lo *et al.*,[15] which is known as vacuum based submerged arc nanoparticle synthesis system (SANSS). The different morphologies are mainly influenced and established by various thermal conductivity properties of the dielectric liquids that are used to prepare nanofluids. The nanoparticles prepared display needle-like, polygonal, square, and circular morphological shapes. In this method, an electric arc with an appropriate power source is required to generate a temperature between 6000-12000°C to melt and vaporize the metal rod in the region of the arc. The vaporized metal is condensed and then dispersed by deionized water to produce nanofluids [3]. The nanoparticle agglomeration is minimized due to single-step preparation method. But the main problem with this process is only low vapour pressure fluids are suitable for it.method. The most important limitation is that the residual reactants are left in the nanofluids due to incomplete reaction or stabilization. Thus it is difficult to interpret the nanoparticle effect without eliminating this impurity effect.

B. Two Step Method

It is the most widely used method for preparation of nanofluids using the available commercial nanopowders supplied by several companies. In this method, nanoparticles are first produced and then dispersed in the base fluids [11]. First, the nano-sized powder (nanoparticles, nanotubes, nanofibers, nanorods or other nanomaterials) is produced by mechanical chemical or physical methods such as milling, grinding, and sol-gel and vapour phase methods. Then, the nanosized powder will be dispersed into a fluid in the second processing step with the help of intensive magnetic force agitation, ultrasonic agitation, high-shear mixing, homogenizing, and ballmilling[2]. An ultrasonic vibrator or higher shear mixing device is generally used to stir nanopowders with host fluids. Frequent use of ultrasonication or stirring is required to reduce particle agglomeration.

Eastman et al [12], Lee *et al.* [16], Wang *et al.* [17] used this method to produce alumina nanofluids. Murshed*et al.* [18] made TiO2-water nanosuspension by the same method. Nanofluids of water and transformer oil with Cu nanoparticles prepared by Xuan*et al.* [19], he used commercially available copper nanoparticles for the preparation. Kim *et al.* [20] used the two-step method to prepare nanofluid of CuO nanoparticles and ethylene glycol by sonication without using any stabilizers. Two-step method can also be used for the synthesis of carbon nanotube based nanofluids. Single-walled and multi-walled carbon nanotubes are first produced by pyrolysis method and then suspended in base fluids with or without the use of surfactants [21, 22, and 23].

Jeena *et al.*[24] prepared nanocomposites from chemically prepared reactant mixtures by hydrogen reduction technique in distilled water using two-step method. Nanofluid was prepared by using an ultrasonic vibrator by dispersing the nanoparticles in deionized water with sodium lauryl sulfate (SLS)as dispersant[25]. The two-step process is very suitable in the preparation of nanofluids containing oxide nanoparticles than those containing metallic nanoparticles. It is the most economical method in the production of nanofluids in a large scale. As a result of the high surface area and surface activity, nanoparticles tend to aggregate.

Surfactants are used to enhance the stability of nanoparticles. But the surfactants are of no use for high-temperature applications. The stability of nanofluids prepared by the two-step method is a big concern as the powders easily aggregate due to strong van der Walls force among nanoparticles, hence several enhanced techniques are developed to produce nanofluids.

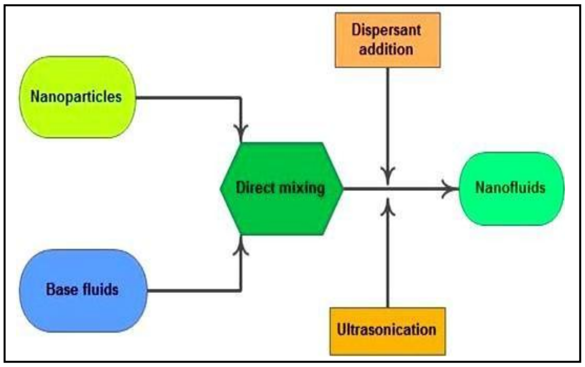

Fig.1Two-step preparation process of nanofluids[101]

C. Other Methods

Wei *et al.* developed a continuous flow microfluidic microreactor to synthesize copper nanofluids [2]. Copper nanofluids can be continuously synthesized by this method, and their microstructure and properties can be adjusted by varying parameters such as reactant concentration, flow rate, and additive. CuOnanofluids with high solid volume fraction (up to 10 vol%) can be synthesized through a novel precursor transformation method with the help of ultrasonic and microwave irradiation [26]. The precursor $\mathrm{Cu(OH)_2}$ is totally converted into CuO nanoparticle in water under microwave irradiation. The growth and aggregation of nanoparticles is prevented by ammonium citrate, which results in a stable CuO aqueous nanofluid with higher thermal conductivity than the nanofluids prepared by other dispersingmethods. Phase-transfer method is also a facile way to obtain monodisperse noble metal colloids [27]. The aqueous formaldehyde is transferred to the cyclohexane phase via reaction with dodecylamine in a water cycle-hexane two-phase system, to form reductive intermediates in cyclohexane. These intermediates are proficient to form dodecylamine-protected silver and gold nanoparticles in cyclohexane solution by reduction silver or gold ions in aqueous solution at room temperature. Feng et al.[28] used the aqueous organic phase transfer method for preparing gold, silver, and platinum nanoparticles on the basis of the decrease of the PVP's solubility in water with the temperature increase [28]. Stable kerosene based$\mathrm{Fe_3O_4}$nanofluids are also prepared by phase transfer method. Oleic acid is successfully embedded on to the surface of $\mathrm{Fe_3O_4}$ nanoparticles by chemisorbed mode, which allows $\mathrm{Fe_3O_4}$nanoparticles have good compatibility with kerosene. These $\mathrm{Fe_3O_4}$ nanofluids do not show the previously indicated "time dependence of the thermal conductivity characteristic". It's a challenge to prepare nanofluids with controllable microstructure. We know that the properties of nanofluids especially depends on the structure and shape of nanomaterials. The recent research shows that nanofluids synthesized by chemical solution method have both higher conductivity enhancement and better stability than those produced by the other methods[29]. This method differs from the others by its controllability. The nanofluid microstructure can be varied and controlled by adjusting parameters such as temperature, acidity, ultrasonic and microwave irradiation, types and concentrations of reactants and additives, in its synthesis and the sequence in which the additives are added to the solution. The microstructure and properties of nanofluids can appropriately be varied by adjusting parameters such as concentration, flow rate, additives.

III. STABILITY OF NANOFLUID

The agglomeration of nanoparticles results in not only the agreement and clogging of microchannels but also the falling of thermal conductivity of nanofluids. So, the investigation on strength is also a key issue that influences the properties of nanofluids for application, and it is necessaryto study and study influencing factors to the dispersionstability of nanofluids[2]. This section contains the stability development methods and stability enhancement processes along with a detail[3].

A. Stability Evaluation Methods for Nanofluids

1. Zeta Potential Analysis

Zeta potential is the potential variation between the dispersion medium and the fixed layer of fluid attached to the particle. The zeta potential indicates the degree of repulsion between adjacent, also charged particles in dispersion[3]. So, colloids with high zeta potential (negative or positive) are electrically stabilized, while colloids with low zeta potentials tend to set or flocculate. In general, a value of 25mV (positive or negative) can be taken as the random value that separates low-charged surfaces from extremely charged surfaces. The colloids with zeta potential from 40 to 60 mV are supposed to be good stable, and those with more than 60 mV have superb stability [2].

2. Sedimentation Method

Sedimentation method is the simple method for evaluation of nanofluids [30]. An external force field is useful to start the sedimentation of nanoparticles in the nanofluids. The weight of sediment or the volumes of sediment specifies the stability of nanofluids. Nanofluids are generally considered to be steady if the attention of the supernatant particles remains constant with time. Zhu *et al.* [31] used the principle of sedimentation method in his own experimental setup to measure the stability of graphite suspension. Use of camera has confirmed to be a suitable aid to capture sedimentation photographs to examine the stability of nanofluids [32]. Waiting time for capturing photos links up with the feature of nanofluids during preparation and well use of applied methods to make stable nanofluids. Wei *et al.* captured photographs of their samples within 24 hours after preparation. Wang *et al.* follow the path for testing the sedimentation of alumina-water nanofluid [33].

3. Centrifugation Method

Centrifugation method is developed because sedimentation method is very time-consuming as it requires a long period of observation. So the centrifugation method is developed for stability evaluation. Sing *et al.* [34] used centrifugation method to calculate the stability of silver nanofluid prepared by reducing AgNO3 and selecting PVP as the stabilizer. An excellent stability of silver nanofluids was established due to the protective role of PVP because it decelerates the agglomeration of particles by the steric effect.

4. Spectral Analysis Method

Spectral analysis via UV- vis spectrophotometer is another useful way to calculate the stability of nanofluids. The advantage of UV-vis spectroscopy gives quantitative results equivalent to the concentration of nanofluids. Hwang *et al.* [35] analyzed the stability of MWNT nanofluids by measuring the UV-vis absorption of MWNT at different sediment time. If the nanomaterials dispersed in fluids have feature absorption bands in the wavelength 190–1100 nm, it is an easy and dependable method to evaluate the stability of nanofluids using UV-vis spectral analysis[2].

5. 3ωMethod

In this method, the stability of suspensions can be evaluated considering thermal conductivity growth caused by the nanoparticle sedimentation in a wide nanoparticle volume fraction range [36]. A new literature has found using this method to check the stability of nanofluids [37].

B. Stability Enhancement Procedure

1. Addition of Surfactants

Surfactants or dispersants are generally useful to stabilize the nanofluids. Addition of surfactants lowers the surface tension of host fluids and raise the attention of particles. Surfactants can be defined as chemical compounds added to nanoparticles in order to lower the surface tension of liquids and raise immersion of particles. Some works of literature talk about the addition of surfactant to nanoparticles to avoid quick sedimentation; however, enough surfactant should be added to a particle in any particular case. In researches, several types of surfactant had been utilized for different kinds of nanofluids. Some essential surfactants are: Sodium dodecyl sulfate (SDS)[38], Salt and oleic acid [39], Dodecyl trimethyl ammonium bromide (DTAB) [40], Hexadecyltrimethyl ammonium bromide (HCTAB) [41], Polyvinylpyrrolidone (PVP)[42],Gum Arabic [43]. It should be noted that this technique cannot be applicable for nanofluids working in high temperature on account of probable damage of bonding between surfactant and nanoparticle. Additionally, surfactants may obstruct heat transfer produce foam when heating. Furthermore, surfactants may increase the thermal resistant between the nanoparticle and the base fluids which may lead diminish the enhancement in the thermal conductivity [44].

2. Surface Modification Techniques

This segment presents the surfactant-free method. Injection of functional nanoparticles in the base fluids can provide long-term stability of nanofluids. There are lotof examples of such modification techniques. As for example, Yang *et al.* [45] grafted silanes directly to the surface of silica nanoparticles in the original nanoparticle solutions.A special feature of those nanofluids was no deposition layer formed on the heated surface after a pool boiling process. The stability of carbon nanotubes can be increased by introducing hydroxyl groups onto the surface of CNTs [46]. Plasma treatment can be applied to modify the surface of diamond nanoparticles for improving their dispersion property in water [21]. Details of surface modification techniques can be found in the reference [44].

3. pH Control of Nanofluids

Stability of nanofluid is directly related to its electro-kinetic properties; therefore, pH control of them can increase stability due to strong repulsive forces.As for example, simple acid treatment could cause nice stability of CNT in water [47]. Lee et al.[33]investigated various pH values for Al2O3 nanofluid and observed decrease or increment of agglomeration by changing pH. Finally, for alumina, copper, and graphite dispersed in water are around 8, 9.5 and 2, respectively [21].

4. Ultrasonic Agitation

After preparation of nanofluids, agglomeration might occur over the time which results in fast sedimentation of nanoparticles due to development of downward body force. Manson *et al.* [48] investigated two different nanofluids; carbon black-water and silver-silicon oil and they utilize the high energy of cavitations for breaking clusters with particles.

IV. PROPERTIES OF NANOFLUID

The properties of nanofluids mainly based on five parameters: thermo fluids, heat transfer, particles, colloid, and lubrication. Thermo fluid property includes temperature, viscosity, density, specific heat, and enthalpy. Based on the heat transfer are thermal conductivity, heat capacity, Prandtl number and pressure drop[11]. The every heat transfer applications are constrained by the finite values of thermophysical properties in any heat transfer media. These properties play a vital role in deciding the magnitude of heat transfer. The parameters based on particles are size, shape, BET (Surface area analysis) and a crystalline phase. Based on the colloidal properties are suspension stability, Zeta potential, and pH. The final properties based on lubrication were viscosity, viscosity index, friction coefficient, wear rate and extreme pressure[11]. The active or passive method is mostly used to vary the heat transfer performance. The active method consists of a mechanical process like vibrations and related process. The passive method consists of customization of fluid properties and varying the surface area and shape. The passive method is inexpensive, suitable, and more effective compared to the active method. The passive method enhances the heat transfer performance of nanoparticles which is suspended in a base fluid. In recent times, there have been many kinds of research to improve the heat transfer performance in refrigeration systems by using nano refrigerants and nanolubricants. The thermophysical properties of nanofluids are quite different from the base fluid. The main properties of nanofluids are discussed in detail.

1. Thermal Conductivity

As thermal conductivity is the most important properties responsible for enhanced heat transfer and many experimental works have been details on this aspect. Nanofluid has higher thermal conductivity as compared to base fluid[49]. By suspending nanoparticles in working fluid result in an improved thermal conductivity of the fluid and hence improvement in freezing speed, therefore, this is one of the most important key parameters for improving the performance of system[50]. Thermal conductivity is the capability of the material to conduct or transmit heat. It plays a very important role in the improvement of the efficient thermal energy system. If thermal conductivity improved and heat transfer coefficient also improved[51]. The experimental results have pointed out the improvement of thermal conductivity with the addition of nanoparticle [52]. Thermal conductivity was measured by using a thermal analyzer in the temperature range between 10-40°C [53].

A benchmark experimental study on thermal conductivity of nanofluids "International Nanofluids Property Benchmark Exercise (INPBE) [54] was carried out by a group of more than 30 organizations using a different experimental method. The research shows that the different measurement method can affect the measured value of thermal conductivity. For example, in thermal hot wire (THW) equipment with or without insulation can give different thermal conductivity value due to current leakage into the fluid [55]. Though, very few notable investigations conducted experimentally and numerically on the thermal conductivity of nano refrigerants. The Maxwell model was the first model to find out the thermal conductivity of liquid-solid suspensions. The model is valid for statistically homogeneous and low volume fraction liquid-solid suspensions with random dispersed, uniformly sized, and non-interacting spherical particles. The effective thermal conductivity is [52].

$$Keff = \frac{\mathrm{Kp+2Kf+2(kp-Kf)}\emptyset}{\mathrm{Kp+2Kf-(Kp-Kf)}\emptyset}\mathrm{kf}$$

Several researchers have conducted an experimental study using Al2O3Nano particles and lubricants of R134a refrigeration system as a base fluid[56]. It has been observed that thermal conductivity enhances by 2.0%, 4.6% and 2.5% for 1.0, 1.5 and 2.0 wt.% of Al2O3 at 40°C and Nanofluids show better effects for high temperature[57]. Significant researches have been carried out on this subject matter. It might point out that it is a driving factor that leads to an idea of allowing for nanofluids as a refrigerant. Eastman et al.[58]found that a thermal conductivity of 0.3% copper nanoparticles of ethylene glycol nanofluids is increased up to 40% compared to base fluid. The author stressed that this property plays a vital role in the construction of efficient energy heat transfer equipment. Peng *et al.* [59] have experimentally investigated the thermal conductivity of a nano-refrigerant and proposed a model to predict the thermal conductivity. The authors used spherical nanoparticles with a mean diameter in R-113 refrigerant are as followings: copper-25nm, aluminum-18nm,nickel-20nm, copper oxide-40nm, and aluminum oxide-20nm. The authors concluded that with an increase in nanoparticle concentration, the thermal conductivity enhances sharply and adding up, they noticed that for the same volume concentration, the thermal conductivity values for different types of nanoparticles showed somewhat variation. The thermal conductivity of nanofluid can be improved in two ways one is to use nanoparticles with higher thermal conductivity and other is to increase the concentration of nanoparticles in base fluid [60].

2. Viscosity

Viscosity is also one of the most important factors to be considered in the case of refrigerants. Variation in viscosity affects the pressure drop, Thus it affects the pumping capacity of the compressor. Viscosity is a measure of the tendency of a liquid to oppose flow. It is the ratio of the shear stress to shear rate. When the viscosity is constant at different values of shear rate, the liquid is known as Newtonian while that varies as a function of shear rate then the liquid is known as Non-Newtonian [61]. Einstein [62] was the first to calculate the effective viscosity of a suspension of spherical solids using the phenomenological hydrodynamic equations.

Mehbubul *et al.* [63] investigated the variation in viscosity of TiO2/R123 nano-refrigerant by varying the temperature from 5 to 20 °C, and volume concentration from 0 to 2%. The authors bring to a closed that viscosity increased with the higher volume concentration of nanoparticles, and decreased as the temperature was increased. Volume and temperature have a major effect over the viscosity of Nano-fluids. It was primed by using TiO2Nano particles and measured the viscosity it has been found that the viscosity of the base fluid increases by adding nanoparticles. Nanofluid was prepared using a mechanical stirrer and ultrasonic agitation for 70 minutes[64]. The viscosity of nanofluid was predictable by using Redwood viscometer. It has been found that predominant in lower temperature range [65].

Garg, Poudel, Chiesa *et al.* [66] conducted an experiment to test the viscosity of copper nanoparticles in ethylene glycol and found that the increase in viscosity was about four times of that predicted by the Einstein law of viscosity given by,

$$\frac{\mu}{\mu bf} = 1+2.5\Psi$$

Where μ the viscosity of the nanofluid, μbf is the viscosity of the base fluid, and φ is the nanoparticle volume fraction. An experimental study was conducted on Al2O3/R141b Nanorefrigernt and measured the viscosity of nano refrigerants using LVDT series ultra-programmable viscometer [67]. The viscosity of Al2O3/R141b nano-refrigerant was estimated using the Brinkman Model and Found that adding of nanoparticles on volume basis increases viscosity and decreases with an increase of temperature [68].

This review indicates that the viscosity of nanofluid depends on lots of parameters such as base fluid properties particle volume fraction, particle shape, particle size, temperature, pH value, surfactants, dispersion method, particle size allocation, particle aggregation, and temperature. The viscosity models discussed here are commonly applied to measure the viscosity of nanofluids. Though, the criterion for confirming their results with experimental results and restrictions still need more attention. Additional work is required to verify new models for the viscosity of nanofluids with different materials and to recognize the effect of viscosity variation on natural convection heat transfer.

3. Density

For proper lubrication performance of a compressor, the viscosity and density of the nano lubricant are important. The density of nanofluid is relative to the volume ratio of solid (nanoparticles) and liquid (base fluid) in the system, As the density of solids, is higher than that of the liquids, usually, the density of nanofluid is found to increase with the addition of nanoparticles to the fluid. In the absence of experimental data, the density of the nanofluids has been reported to be consistent with the mixing theory [69] given by,

$$\rho nf = (1-\phi)\ \rho bf + \phi\ \rho s$$

whereρnf is the density of nanofluid, ρbf is the density of the base fluid, ρs is the density of solid particles, ϕ is the volume concentration. Sommers and Yerkes [70] measured the density of the Al2O3/ propanol nanofluid at room temperature using two methods and compared them. In the primary method, a hydrometer was used to calculate the specific gravity of a fluid sample. In the next method, a fluid sample of known volume was taken and then weighed on a high precision balance. Data collected using these two methods were then averaged and a virtually linear relationship between density and particle concentration was observed.

4. Specific Heat

Zhou and Ni [71] have presented an experimental investigation of the specific heat of water-based Al2O3 nanofluid with a differential scanning calorimeter. Their result shows that the specific heat of nanofluid decreases progressively as the nanoparticle volume concentration increases. The relationship among them exhibits good conformity with the forecast from the thermal equilibrium model while the simple mixing model fails to forecast the specific heat of nanofluid. In an experimental work, the specific heat is calculated as

$$Cpnf = \frac{\phi\ \rho(Cp)p + (1+\phi)\rho Cpf}{\rho nf}$$

where, (ρCp)p is the density and specific heat of particle, (ρCp)f is the density and specific heat of fluid, (ρCP) nf is the density and specific heat of nanofluid. Sekhar and Sharma [72] mentioned that more studies on temperature-dependent specific heat capacity over a wide range of nanoparticle size and concentration combinations have to be conducted to get the results.

5. Pressure Drop

Razi *et al.* [73] conducted an experimental investigation on the pressure drop and thermal characteristics of CuO-base oil nanofluid under laminar flow in flattened tubes at constant heat flux. For a certain flattened tube and at same flow conditions, there is a visible enlarge in heat transfer coefficient as well as pressure drop of nanofluids compared to that of base liquid. Sajadi and Kazemi [74] were experimentally investigated turbulent heat transfer behavior of TiO2/water nanofluid in a circular pipe under the fully developed turbulent regime for various volumetric concentrations. Their measurements illustrated that the pressure drop of nanofluid was somewhat higher than that of the base fluid and increased with increasing the volume concentration.

Recent experimental investigation on viscous pressure loss characteristics of alumina-water and zirconia–water nanofluids in laminar flow regime by Rea *et al.* [75] also showed that their test results were in good agreement with a prediction from conventional correlation for laminar flow. More methodical experiments are to be carried out to develop correlations of friction factor and heat transfer for the flow of nanofluids through tubes. Moreover, the effect of the tube geometry (e.g., flat, elliptical or circular)on the hydrodynamics and heat transfer in a tube and heat exchanger required to be understood.

V. CHALLENGES OF NANOFLUIDS

Nanofluid has a perspective to become a promising coolant in many various industrial processes. However, that opportunity faces several challenges that need to be solved through a long road of nanofluid research programs. Several interesting properties of nanofluids have been detailed in the review. In the earlier studies, thermal conductivity has received the maximum consideration, but many researchers have recently started studies on other thermo-physical properties also. The use of nanofluids in a large variety of applications appears promising. But the advancement of the field is delayed by (i) lack of agreement of results obtained by different researchers; (ii) poor characterization of suspensions; (iii) lack of theoretical understanding of the mechanisms responsible for changes in properties. [1] Hence, this paper illustrated u some important issues that should receive greater consideration in the upcoming future.

1. Long Term Stability of Nanoparticles Dispersion

Preparation of homogeneous suspension leftovers a technical challenge because the nanoparticles always form combined due to very strong Vander Waals interactions. To obtain stable nanofluids, physical or chemical action have been conducted such as an addition of the surfactant, surface modification of the suspended particles or applying strong force on the group of the suspended particles. Stability of nanofluids has a good corresponding relationship with the enhancement of thermal conductivity where the better dispersion behavior, the higher thermal conductivity of nanofluids [76]. Dispersing agents, surface-active agents, have been used to disperse fine particles of hydrophobic materials in aqueous solution [77]. On the other hand, if the heat exchanger operates under laminar conditions, the use of nanofluids seems advantageous, the only disadvantages so far being their high price and the potential instability of the suspension [78]. Usually, the long-lasting stability of nanoparticles dispersion is one of the basic requirements of nanofluids applications. The dispersion behavior of the nanoparticles could be prejudiced by a period of time. So, the thermal conductivity of nanofluids is ultimately affected. Stability of nanofluids has a good corresponding relationship with the enhancement of thermal conductivity where the better the dispersion behaviour, the higher the thermal conductivity of nanofluids [79]. Eastman *et al.* [80] Revealed that thermal conductivity of ethylene glycol-based nanofluids containing 0.3% copper nanoparticles is decreased with time. In their study, the thermal conductivity of nanofluids was calculated two times: earliest was within two days and next was two months after the preparation. It was found that fresh nanofluids displayed slightly higher thermal conductivities than nanofluids that are stored up to two months. This might due to reduced dispersion stability of nanoparticles with respect to time. Nanoparticles may tend to agglomerate when reserved for a long period of time.

Choi *et al.* [81] reported that the excess quantity of surfactant has a harmful effect on viscosity, thermal property, chemical stability, and thus it is strongly recommended to control the addition of the surfactant with great care. On the other hand, the addition of surfactant would make the particle surface coated, thus resulting in the screening effect on the heat transfer performance of nanoparticles.

2. Increased Pressure Drop and Pumping Power

Pressure drop developed during the flow of coolant is one of the significant parameter finding the efficiency of nanofluids application. Pressure drop and coolant pumping power are closely related with each other. There are a few properties which could influence the coolant pressure drop: density and viscosity. It is estimated that coolants with higher density and viscosity experience higher pressure drop. This has contributed to the drawback of nanofluids application as coolant liquids. Leeetal. [82] and Yu *et al.* [83] Investigated the viscosity of water-based Al2O3 nanofluids and ethylene glycol based ZnOnanofluids. The viscosity of the nanofluids is higher than the base fluid, it was clearly showed. Nam- buru*et al.* [84] in their numerical study reviewed that density of nanofluids is greater than base fluid. Both properties are found relative with nanoparticles volume fraction. Peng*et al.* [83] Reported that the frictional pressure drop of refrigerant-based nanofluids flow boiling inside the horizontal smooth tube is larger than that of pure refrigerant, and increases with the increase of the mass fraction of nanoparticles.

Several kinds of literature have shown that there is a major increase in nanofluids pressure drop compared to base fluid. An important parameter in the application of nanofluids in heat exchanging equipment is the pressure drop developed during the flow through the Plate Heat Exchanger (PHE) [84]. This guides to a significant increase in the measured pressure drop and as a result of the necessary pumping power when the nanofluids are applied.

3. The High Cost of Nanofluids

The higher production cost of nanofluids is also the reasons that may delay the application of nanofluids in industry. Nanofluids can be created by either one-step or two-step methods. However, both methods require highly developed and sophisticated equipment. Lee and Mudamawar [85] and Pantzali *et al.* [85, 86] stressed that the high cost of nanofluids is among the drawback of nanofluids applications.

4. Difficulties in the Production Process

Preceding efforts to manufacture nanofluids have often employed either by a single step that simultaneously makes and disperses the nanoparticles into base fluids or by a two-step method that involves generating nanoparticles and then dispersing them into a base fluid. Using one of these two methods, nanoparticles are inherently produced from processes that involve reduction reactions or ion exchange. Also, the base fluids contain other ions and reaction products that are difficult or impractical to separate from the fluids. Another complexity encountered in nanofluid manufacture is nanoparticles’ tendency to agglomerate into bigger particles, which restricted the benefits of the high surface area nanoparticles. To oppose this tendency, particle dispersion additives are often added to the base fluid with the nanoparticles. Unfortunately, this practice can change the surface properties of the particles, and nanofluids prepared in this way may contain undesirable levels of impurities. Most studies to date have been restricted to sample sizes less than a few hundred milliliters of nanofluids. This is problematic since larger samples are needed to test many properties of nanofluids and, in particular, to assess their potential for use in new applications [87].

VI. APPLICATIONS OF NANOFLUIDS

The advanced concepts of nanofluids offer absorbing heat transfer characteristics compared to conventional heat transfer fluids. There are considerable researches on the excellent heat transfer properties of nanofluids especially on thermal conductivity and convective heat transfer. Nanofluids can be used in the following specific areas [88],

1. Electronic Application

Due to the higher density of chips, the design of electronic components with more compact makes heat dissipation more difficult. Advanced electronic devices face the high level of heat generation and the reduction of obtainable surface area for heat deduction. So, the reliable thermal management system is essential for the smooth operation of the advanced electronic devices. In general, there are two approaches to get better the heat removal for electronic equipment. One is to find an optimum geometry of cooling devices; another is to raise the heat transfer capacity. Nanofluids with higher thermal conductivities are predicated convective heat transfer coefficients compare to those of base fluids. Recent researches illustrated that nanofluids could increase the heat transfer coefficient by increasing the thermal conductivity of a coolant [2]. Jang and Choi designed a new cooler, combined microchannel heat sink with nanofluids [89]. The high cooling performance was obtained when compared to the device using pure water as a working medium. Nanofluids compact both the thermal resistance and the temperature difference between the heated microchannel wall and the coolant. A combined microchannel heat sink with nanofluids had the potential as the next-generation cooling devices for remove ultrahigh heat flux [2].

2. Transportation

Nanofluids have huge potentials to improve automotive and heavy-duty engine cooling rates by increasing the efficiency, lowering the weight and dropping the complexity of thermal management systems. The enhanced cooling rates for automotive and truck engines can be used to remove more heat from higher horsepower engines with the same size of a cooling system[2]. On the other hand, it is useful to design a more compact cooling system with smaller and lighter radiators. Ethylene glycol-based nanofluids have concerned much attention in the application as engine coolant [91–93] due to the low-pressure operation compared with a 50/50 mixture of ethylene glycol and water, which is the most commonly used automotive coolant. The nanofluids have a high boiling point, and it can be used to increase the normal coolant operating temperature and then reject more heat through the existing coolant system [95].In the USA, car manufacturers GM and Ford are running their own research programs on nanofluid applications. A C8.3 million FP7 project, named NanoHex (Nanofluid Heat Exchange), began to run. It involved 12 organizations from Europe and Israel ranging from Universities to SMEs and major companies. NanoHex is overcoming the technological challenges faced in the development and application of reliable and safe nanofluids for more sophisticated, energy efficient and environmentally friendly products and services [96].

3. Industrial Cooling Application

The nanofluids also applicable for Industrial cooling will result in great energy savings and emissions reductions. For US industry, the replacement of cooling and heating water with nanofluids has the potential to conserve 1 trillion Btu of energy [97, 98]. Experiments were performed using a flow-loop apparatus to explore the performance of polyalphaolefinnanofluids containing exfoliated graphite nanoparticle fibres in cooling [99]. It was observed that the specific heat of nanofluids was found to be 50% higher for nanofluids compared with polyalphaolefin, and it increased with temperature.

4. Heating Buildings and Reducing Pollution

Nanofluids can be useful in the building heating systems. Kulkarni *et al.* evaluate how they perform heating buildings in cold regions [99]. In cold regions, it is a commonly use ethylene or propylene glycol mixed with water in different proportions as a heat transfer fluid. So, 60: 40 ethylene glycol/water (by weight) was selected as the base fluid. The results showed that using nanofluids in heat exchangers could reduce volumetric and mass flow rates, resulting in an overall pumping power savings. Nanofluids require smaller heating systems, which are able of delivering the same amount of thermal energy as larger heating systems but are less costly. The initial equipment cost excluding nanofluid cost lowers. This will also decrease environmental pollutants, as smaller heating units use less power, and the heat transfer unit has less liquid and material waste to remove at the end of its life cycle [2].

5. Space and Defence

Due to the limitation of space, energy, and weight in space station and aircraft, there is a strong requirement for a highly efficient cooling system with a smaller size. You *et al.* [90] and Vassalo *et al.* [100] have reported the order of magnitude increases in the critical heat flux in pool boiling with nanofluids compared to the base fluid alone. Advance research of nanofluids will lead to the development of next generation of cooling devices that incorporate nanofluids for ultrahigh-heat-flux electronic systems, presenting the opportunity of raising chip power in electronic components or simplifying cooling requirements for space applications. A number of military devices and systems require high-heat flux cool to the level of tens of MW/m2. At this level, the cooling of military devices and system is essential for the reliable operation. Nanofluids with high critical heat fluxes have the potential to provide the required cooling in such applications as well as in other military systems, including military vehicles, submarines, and high-power laser diodes. Therefore, nanofluids have wide application in space and defense fields where power density is very high and the components should be smaller and weightless.

6. Energy Applications

For energy applications of nanofluids, two remarkable properties of nanofluids are utilized, one is the higher thermal conductivities of nanofluids, enhancing the heat transfer, and second is the absorption properties of nanofluids.[2]

7. Mechanical Applications

Nanoparticles in nanofluids form a protecting film with low hardness and elastic modulus on the damaged surface can be considered as the main reason that some nanofluids show excellent lubricating properties. Magnetic fluids are kinds of special nanofluids. Magnetic liquid rotary seals operate with no maintenance and extremely low leakage in a very wide range of applications, and it utilizes the property magnetic properties of the magnetic nanoparticles in the liquid.

8. Biomedical Application

Nanoparticles have antibacterial or drug-delivery properties, so the nanofluids containing these nanoparticles will exhibit some relevant properties. For some special kinds, these nanofluids are used for the biomedical applications.

VII. LITERATURE REVIEW

Many researchers have investigated and studied on VCR system with nano-refrigerant and also nano lubricant on the performance of VCR system. Some of that literature is as discussed below.

Bi *et al.* 2007[102] conducted studies on a domestic refrigerator using Nano refrigerants. Authors used R134a as the refrigerant and a mixture of mineral oil with TiO2 nanoparticles additives as the lubricant. They found that the refrigeration system with the Nano refrigerant worked normally and efficiently and the energy feeding reduces by 26.1%. When compared with R134a/POE oil system.

Jwo *et al.* 2009[103] conducted studies on a refrigeration system replacing R-134a refrigerant and polyester lubricant with a hydrocarbon refrigerant and mineral lubricant. Their studies showed that the 60% R-134a and 0.1 wt. % Al2O3 nanoparticles were optimal. Under these conditions, the power consumption was reduced by about 2.4%, and the coefficient of performance was increased by 4.4%.

Henderson *et al.* 2010 [104] conducted an experimental analysis of the flow of the boiling heat transfer of R134a based Nanofluids in a horizontal tube. They found an excellent scattering of CuO nanoparticle with R134a and POE oil. The heat transfer coefficient increased more than 100% over baseline R134a/POE oil.

Subramani&Prakash, 2011 [105] Conducted experiment studies on a VCR system it the use of nano-refrigerant. They state that the nanoparticles added into the refrigerant result in enhanced thermo-physical properties and heat transfer rate of refrigerant. This results in improved performance VCR system. The refrigerant used for this purpose was R134a. Stable nano lubricant was prepared for the experimental study. For experimental study, there were three cases considered. The compressor filled with (1) pure POE oil, (2) mineral oil (3) mineral oil with Al2O3 nanoparticles and the mass fraction of nanoparticles in lubricant was 0.06%. It is found in mineral oil with Al2O3 nanoparticles used in the system then the system works normally and gives the best result. The power consumption reduced by 25% and the freezing capacity is also higher with mineral oil and alumina nanoparticles. The improvement in COP of the system was 33% when nano-refrigerant was used.

Shengshan Bi *et al.* 2011 [106] conducted an experimental study on the performance of a domestic refrigerator using TiO2-R600a Nano refrigerant as working fluid. They showed that the TiO2-R600a system worked normally and efficiently in the refrigerator and observed energy saving of 9.6%. They too cited that the freezing velocity of Nano refrigerating system was more than that with pure R600a system.

Kumar & Elansezhian, 2012 [107] Studied on experimental work of nano-refrigerant. An experimental test rig of VCR system was designed and fabricated in which R134a as a refrigerant and PAG oil as a lubricant was used Al2O3 nanoparticles were used. The nanoparticles were mixed with PAG (Poly Alkylene Glycol) lubricating oil. The concentration of nanoparticles in lubricant was 0.2% of the volume. The result shows that system with R134a and PAG oil with Al2O3 nanoparticles as works normally and safely. The performance of the system with nano-refrigerant was better than pure lubricant with R134a as working fluid with 10.32% less energy consumption and improvement in coefficient in performance up to 3.5. The uses of nano-refrigerant also reduce the length capillary tube.

Kotu& Kumar, 2013 [108] Investigated the performance of the domestic refrigerant with mineral oil and R134a system was compared with mineral oil, nano-refrigerant and R134a, mineral oil and double pipe heat exchanger (DPHE) experimentally. The aluminum oxide with average size up to 50nm and mass fraction in lubricant was 0.06%. These nanoparticles were added into compressor oil or lubricant. The result shows that the use of mineral oil, nano-refrigerant and R134a, mineral oil and DPHE works normally and safely. The power consumption of R134a, Mineral oil and DPHE system was decreased by 30% and also power consumption was reduced 26% when R134a, mineral oil and Al2O3 nanoparticles were used. The performance of R134a, Mineral oil and DPHE system increased by 10% and increased by 6% when R134a, mineral oil and Al2O3 nanoparticles were used.

VIII. CONCLUSION

Many studies tried the Performance Enhancement of Simple Vapor compression system by using nanofluids either in the form Nano-refrigerant or Nano-lubricant. It is clear that Nano-refrigerants have higher thermal conductivity than traditional refrigerants. Increasing of Nanoparticle concentration on volume basis thermal conductivity also increases. Temperature, particle size, constancy and dispersion are the important factors to determining thermal conductivity of Nanofluids. Increasing of nanoparticles results of increase viscosity and decreases with increasing of temperature.

REFERENCES

[1] R. Saidur, *et al.*, “A review on the performance of nanoparticles suspended with refrigerants and lubricating oils in refrigeration systems,” *Renewable and Sustainable Energy Reviews*, Vol. 15, No.1, pp. 310-323, 2011.

[2] Yu, Wei and Huaqing Xie, “A review on nanofluids: preparation, stability mechanisms, and applications,” *Journal of nanomaterials*, Vol. 1, 2012.

[3] Mukherjee, Sayantan and Somjit Paria, “Preparation and stability of nanofluids-a review,” *IOSR Journal of Mechanical and civil engineering*, Vol. 9, No. 2, pp. 63-69, 2013.

[4] Doshi Sachindra J, “Review on Enhancement of CoP of Refrigeration System by Inclusion of Nano particles in Refrigerant,” *SJIF*, Vol. 4, No. 8, 2017.

[5] Majgaonkar and Amey, “Use of Nanoparticles In Refrigeration Systems: A Literature Review Paper,” 2016.

[6] R.K Adyanshee Pattanayak, Nilamani Sahoo and Prasheet Mishra, “Performance Analysis of a Domestic Refrigerator using Al2O3 Nanoparticles”, *IOSR-JMCE*, Vol. 12, No. 4, Ver.4,pp. 12-16,2015.

[7] Wang Xiang Qi, S. Mujumdar Arun, “A review on nanofluids—Part II: theoretical and numerical investigations,” *Braz J ChemEng*, Vol. 25, No. 04, pp. 613–30, 2008;.

[8] S Lee, SUS Choi, S Li and J A., “Eastman Measuring thermal conductivity of fluids containing oxide nanoparticles,” *ASME J Heat Transf*, Vol. 121, pp.280–9, 1999.

[9] Y. Li, J. Zhou, S. Tung, E. Schneider and S. Xi, “A review on development of nanofluid preparation and characterization,” *Powder Technology*, Vol. 196, No. 2, pp. 89–101, 2009.

[10] H. Akoh, Y.Tsukasaki, S.Yatsuya and A.Tasaki, “Magnetic properties of ferromagnetic ultrafine particles prepared by vacuum evaporation on running oil substrate,” *Journal of Crystal Growth*, Vol. 45, pp. 495–500, 1978.

[11] Dhinesh Kumar Devendiran, Valan Arasu Amirtham, “A review on preparation, characterization, properties and applications of nanofluids,” *ELSEVIER Renewable and Sustainable Energy Reviews*, Vol. 60, pp. 21-49, 2016.

[12] J.A. Eastman, U.S. Choi, S. Li, L.J. Thompson and S. Lee, “Enhanced thermal conductivity through the development of nanofluids”, *Materials Research Society Symposium-Proceedings, Materials research Society, Pittsburgh, PA, USA, Boston, MA, USA*, Vol. 457, pp.3-11, 1997.

[13] PX Tran and Y. Soong, “Preparation of nanofluids using laser ablation in liquid technique”, *In: ASME applied mechanics and material conference, Austin, Texas USA*, 2007.

[14] H Zhu, Y Lin and Y Yin, “A nove one-step chemical method for preparation of copper nanofluids,” *J Colloid Interface Sci*, Vol. 227, pp. 100–3, 2004.

[15] C–H. Lo, T-T. Tsung, L-C. Chen, C.-H. Su and H.-M. Lin, “Fabrication of Copper Oxide Nanofluid Using Submerged Arc Nanoparticle Synthesis System (SANSS),” *Journal of Nanoparticle Research*, Vol. 7, pp. 313–320, 2005.

[16] S. Lee, S. U.S. Choi, S. Li and J. A. Eastman, “Measuring thermal conductivity of fluids containing oxide nanoparticles,” *Journal of Heat Transfer*, Vol. 121, No. 2, pp. 280–289, 1999.

[17] X. Wang, X. Xu and S. U. S. Choi, “Thermal Conductivity of Nanoparticle-Fluid Mixture,” *Journal of Thermophysics and Heat Transfer*, Vol. 13, pp. 474 480, 1999.

[18] S. M. S. Murshed, K. C. Leong and C. Yang, “Enhanced Thermal Conductivity of TiO2 Water Based Nanofluids,” *International Journal of Thermal Sciences,* Vol. 44, pp. 367–373, 2005.

[19] Y. Xuan and Q. Li, “Heat transfer enhancement of nanofluids,” *International Journal of Heat and Fluid Flow*, Vol. 21, No. 1, pp. 58-64, 2000.

[20] K. Kwak, C. Kim and Kor.-Austr. *Rheol. J.*, Vol. 17, No. 35, 2005.

[21] Q. Yu, Y. J. Kim and H. Ma, “Nanofluids with plasma treated diamond nanoparticles,” *Applied Physics Letters*, Vol. 92, No. 10, 2008.

[22] P. Keblinski, J. A. Eastman and D. G. Cahill, “Nanofluids for Thermal Transport,” *Materials Today*, pp. 36-44, 2005.

[23] M-S. Liu, M. C-C. Lin, I-T. Huang and C.-C.Wang, “Enhancement of thermal conductivity with carbon nanotube for nanofluids,” Vol. 32, No. 9, pp.1202-1210, 2005.

[24] PK Jeena, EA Brocchi and MS Motta, “In- situ formation of Cu–Al2O3 nanoscale composites by chemical routes and studies on their microstructures,” Mater Sci Eng A, Vol. 313, pp.180–6, 2001.

[25] JH Lee, KS Hwang, SP Jang, BH Lee, JH Kim, SUS Choi and CJ. Choi, “Effective viscosities and thermal conductivities of aqueous nanofluids containing low volume concentrations o Al2O3 nanoparticles,” *Int J Heat Mass Transf* , Vol. 51, pp. 2651–6, 2008.

[26] H. T. Zhu, C. Y. Zhang, Y. M. Tang and J. X. Wang, “Novel synthesis and thermal conductivity of CuOnanofluid,” *Journal of Physical Chemistry C*, Vol. 111, No. 4, pp. 1646–1650, 2007.

[27] Y. Chen and X. Wang, “Novel phase-transfer preparation of monodisperse silver and gold nanoparticles at room temperature,” *Materials Letters*, Vol. 62, No. 15, pp. 2215–2218, 2008.

[28] X. Feng, H. Ma, S. Huang *et al.*, “Aqueous-organic phase-transfer of highly stable gold, silver, and platinum nanoparticles and new route for fabrication of gold nanofilms at the oil/water interface and on solid supports,” *Journal of Physical Chemistry B*, Vol. 110, No. 25, pp. 12311–12317, 2006.

[29] L. Wang and J. Fan, “Nanofluids research: key issues,” *Nanoscale Research Letters*, Vol. 5, No. 8, pp. 1241–1252, 2010.

[30] X. Wei and L.Wang, “Synthesis and thermal conductivity of microfluidic copper nanofluids,” *Particuology*, Vol. 8, No. 3, pp. 262–271, 2010.

[31] H. Zhu, C. Zhang, Y. Tang, J. Wang, B. Ren and Y. Yin, “Preparation and thermal conductivity of suspensions of graphite nanoparticles,” *Carbon*, Vol. 45, No. 1, pp. 226–228, 2007.

[32] X. Wei, H. Zhu, T. Kong and L. Wang, “Synthesis and thermal conductivity of Cu2O nanofluids,” *International Journal of Heat and Mass Transfer*, Vol. 52, No.19-20, pp.4371-4374, 2009.

[33] Y. Fovet, J. Y. Gal and F. Toumelin-Chemla, “Influence of pH and fluoride concentration on titanium passivating layer: stability of titanium dioxide, Talanta,” Vol. 53, No. 5, pp. 1053–1063, 2001.

[34] A. K. Singh and V. S. Raykar, “Microwave synthesis of silver nanofluids with polyvinylpyrrolidone (PVP) and their transport properties,” *Colloid and Polymer Science*, Vol. 286, No. 14-15, pp. 1667–1673, 2008.

[35] Y. Hwang, J. K. Lee, C. H. Lee *et al.*, “Stability and thermal conductivity characteristics of nanofluids,” *ThermochimicaActa*, Vol. 455, No. 1-2, pp. 70–74, 2007.

[36] B.R. Munson, D.F. Young, T.H. Okiishi, *Fundamentals of Fluid Mechanics*, John Wiley & Sons Inc., 1998.

[37] D. W. Oh, A. Jain, J. K. Eaton, K. E. Goodson and J.S. Lee, “Thermal Conductivity Measurement and Sedimentation Detection of Aluminum Oxide Nanofluids by Using the3ωMethod,” I*nternational Journal of Heat and Fluid Flow*, ISSN: 0142-727X, Vol. 29, No. 5, pp. 1456-1461, 2008.

[38] M. Chandrasekhar, S. Suresh and A. Chandra Bose, “Experimental investigations and theoretical determination of thermal conductivity and viscosity of Al2O3/water nanofluid,” *Exp. Therm. Fluid Sci.*, Vol. 34, No. 2, pp. 210-216, 2010.

[39] Y. Hwang, J-K. Lee, J-K. Lee, Y-M. Jeong, S-i.Cheong, Y-C. Ahn, S.H. Kim, “Production and dispersion stability of nanoparticles in nanofluids,” *PowderTechnol*, Vol. 186, No. 2, pp.145-153, 2008.

[40] X.F. Li, D.S. Zhu, X.J. Wang, N. Wang, J.W. Gao and H. Li, “Thermal conductivity enhancement dependent pH and chemical surfactant for Cu-H2O nanofluids,” *Thermochim.Acta*, Vol. 469, No. 1-2, pp. 98-103, 2008.

[41] W. Yu, H. Xie, L. Chen and Y. Li, “Enhancement of thermal conductivity of kerosene-based Fe3O4 nanofluids prepared via phase-transfer method,” *Colloids and Surfaces A*, Vol. 355, No. 1–3, pp. 109–113, 2010.

[42] M.N. Pantzali, A.A. Mouza and S.V. Paras, “Investigating the efficiency of nanofluids as coolants in plate heat exchangers (PHE),” *Chem. Eng. Sci.*, Vol. 64, No. 14, pp. 3290-3300, 2009.

[43] I. Madni, C.-Y. Hwang, S.-D. Park, Y.-H. Choa and H.-T. Kim, “Mixed surfactant system for stable suspension of multiwalled carbon nanotubes,” *Colloids Surface A: Physicochemical. Eng. Aspects*, Vol. 358, No. 1-3, pp.101-107, 2010.

[44] W. Yu and H. Xie, “A Review on Nanofluids: Preparation, Stability Mechanisms, and Applications,” *Journal of Nanomaterials*, pp.1-17, 2012.

[45] X.Yang and Z. H. Liu, “A kind of nanofluid consisting of surface-functionalized nanoparticles,” *Nanoscale Research Letters*, Vol. 5, No. 8, pp. 1324–1328, 2010.

[46] L. Chen and H. Xie, “Surfactant-free nanofluids containing double- and single-walled carbon nanotubes functionalized by a wet-mechanochemical reaction,” *ThermochimicaActa*, Vol. 497, No. 1-2, pp. 67–71, 2010.

[47] D. Wen, G. Lin, S. Vafaei and K. Zhang, “Review of nanofluids for heat transfer applications,” *Particuology*, Vol. 7, No. 2, pp. 141–150, 2009.

[48] X. J. Wang and X. F. Li, “Influence of pH on nanofluids‘ viscosity and thermal conductivity,” *Chinese Physics Letters*, Vol. 26, No. 5, Article ID 056601, 2009.

[49] O.A. Alawi, N Sidik and M Beriache, “Applications of nanorefrigerant and nanolubricants in Refrigeration air-conditioning and heat pump systems: A review,” *Int. Commun. Heat Mass Transf*, pp. 91–97, 2015.

[50] Jayendra, Sanket, Sagar, Vinesh, Yuken, Kaushal, “Effect Of Nanorefrigerant On Performance of Vcr System A Review,” Vol. 3, No.6, 2017.

[51] K Guo and Z Liu, “Performance of a domestic refrigerator using TiO2-R600a nano-refrigerant as Working fluid,” *2011 Energy Convers*. pp. 733–737

[52] Kumar Tiwari Arun, Pradyumna Ghosh. Sarkar Jahar, “Investigation of thermal Conductivity and viscosity of Nanofluids,” *JEnvironResDev*, Vol. 2, pp. 768–77, 2012.

[53] M Youbi and J Bonjour, “The effect of oil in refrigeration: Current research issues and criticalreview of thermodynamic aspects,” I*nt. J. Refrig*, pp.165–179, 2008.

[54] J. Buongiorno, D.C. Venerus and N. Prabhat, T. McKrell, J. Townsend, R. Christianson, Y.V. Tolmachev, P. Keblinski, L.-W. Hu J.L.Alvarado,;*et al.*, “A benchmark study on the thermal conductivity of nanofluids,” *J. Appl. Phys.*, Vol. 106, 2009.

[55] Mahesh Suresh Patil, *et al, “*Review of the thermo-physical properties and performance characteristics of a refrigeration system using refrigerant-based nanofluids,” *Energies*, Vol. 9, No. 1, pp. 22, 2015.

[56] D.S. Kumar and Elansezhian, “Experimental Study on Al 2 O 3 - R134a Nano Refrigerant inRefrigeration System,” *Int. J. Mod. Eng. 3927–3929*, 2012.

[57] V. Nair, R.P. Tailor and A.D. Parekh, “Nano refrigerants: A comprehensive review on its past, present and future,” *Int. J. Refrig. 290–307*, 2016.

[58] JA Eastman, SUS Choi, S Li, W Yu, LJ Thompson, “Anomalously increased effective thermal conductivities of ethylene glycol-based nanofluids containing copper nanoparticles,” *Applied Physics Letters*, Vol. 78, No. 6, pp. 718–20, 2001.

[59] W. Jiang, G. Ding, H. Peng, Y. Gao and K.Wang, “Experimental and model research on nanorefrigerant thermal Conductivity,” *HVAC&R Res.*, Vol. 15, pp. 651–669, 2009.

[60] J M Jones, P Satheesh, and L.N. Raj, “Preparation and Performance Test of Tio 2 - R600a in a Domestic Refrigerator,” I*nt. J. of mechanical engg.* Vol. 1–6, 2016.

[61] S Suresh, K P Venkitaraj, P Selvakumar and M.Chandrasekhar, “Synthesis of Al2O3–Cu/water hybrid nanofluids using two step method and its thermophysical properties,” *Colloids Surf A: PhysicochemEng Asp*, Vol. 388, pp. 41–8, 2011.

[62] A. Einstein, *Investigations on the theory of the Brownian motions*, New York: Dover Publications, 1956.

[63] I.M. Mahbubul, R. Saidur and M.A.Amalina, “Investigation of viscosity of R123-TiO2 nanorefrigerant,” *Int. J. Mech. Mat. Eng.*, Vol. 7, pp. 146–151, 2012.

[64] Krishna R Sabareesh, Goliath N, Sajith V, Das V and Sobhan C.B., “Application of TiO2 nanoparticles as a lubricant-additive for vapor compression refrigeration systems – An experimental investigation,” *Int. J. Refrig.*, pp. 1989–1996, 2012.

[65] C.I Rivera-Solorio, L.A Payán-Rodríguez, A.J. García-Cuéllar, E.D. Ramón-Raygoza, N.L Cadenade-la-Peña and D Medina-Carreón, “Formulation techniques for nanofluids,” *Recent Pat. Nanotechnol.* Vol. 208–15, 2013.

[66] J Garg, B Poudel, M Chiesa, J Gordon, JJ Ma, JB Wang, ZF Ren, YT Kang, H Ohtani, Nanda, J Mc Kinley, G.Chen GH, “Enhanced thermal conductivity and viscosity of copper nanoparticles in ethylene glycol nanofluid,” *J ApplPhys*, Vol. 103, No. 7, 074301, pp. 1–6, 2008.

[67] V. P. Mohod and N. W. Kale, “A Review on Heat Transfer Enhancement Using Nanoparticles Suspended With Refrigerants / Lubricating Oils in Refrigeration Systems,” *Int.conf on engg. Andiinovations*, pp. 191–194, 2015.

[68] BC Pak and Y.Cho, “Hydrodynamic and heat transfer study of dispersed fluids with submicron metallic oxide particle,” *Exp Heat Transf*, Vol. 1, pp. 151–70,1998.

[69] AD Sommers and KL Yerkes, “Experimental investigation in to the convective heat transfer and system-level effects of Al2O3 propanol nanofluids,” *J Nanopart Res*, Vol. 12, pp. 1003–14, 2010.

[70] SQ Zhou and R Ni, “Measurement of the specific heat capacity of water-based Al2O3 nanofluid,” *ApplPhysLett*, Vol. 92, pp. 093123, 2008.

[71] YR Sekhar and KV Sharma, “Study of viscosity and specific heat capacity characteristics of water-based Al2O3 nanofluids at low particle concentrations,” *J Exp Nanosci*, pp. 1–17, 2013.

[72] P Razi, MA Akhavan-Behabadi, M. Saeedinia, “Pressure drop and thermal characteristics of CuO-base oil nanofluid laminar flow in flattened tubes under constant heat flux,” I*nt Commun Heat Mass Transf*, Vol. 38, pp. 964–71, 2011.

[73] AR Sajadi and MH Kazemi, “Investigation of turbulent convective heat transfer and pressure drop of TiO2/water nanofluid in circular tube,” *Int Commun Heat Mass Transf*, Vol. 38, pp. 1474–8, 2011.

[74] U Rea, T McKrell, L Hu, J. Buongiorno, “Laminar convective heat transfer and viscous pressure loss of alumina–water and zirconia–water nanofluids,” *Int J Heat MassTransf*, Vol. 52, No. 7–8, pp. 2042–8, 2009.

[75] D Wen, G Lin, S Vafaei and Zhang, “Review of nanofluids for heat transfer applica- tions,” *Particuology*, Vol. 7, No. 141–50, 2009.

[76] L Godson, Raja, D Mohan Lal and S. Wongwises, “Enhancement of heat transfer using nanofluids: An overview,” *Renew Sust Energy Rev* 2009, doi:10.1016/j.rser.2009.10.004.

[77] H. Y. Wang, H. S. Park, J. K. Lee and W. H. Jung, “Thermal conductivity and lubrication characteristics of nanofluids,” *CurrApplPhys*, Vol. 6, No. S1, pp. 67–71, 2006.

[78] D Guoliang, P Hao, J Weiting and G.Yifeng, "The migration characteristics of nanoparticles in the pool boiling process of nanorefrigerant and nanorefrigerant–oil mixture," *International Journal of Refrigeration*, Vol. 32, pp.114–23, 2009.

[79] JA Eastman, SUS Choi, S Li, W Yu and LJ.Thompson, "Anomalously increased effective thermal conductivities of ethylene glycol-based nanofluids containing copper nanoparticles," *ApplPhysLett*, Vol. 78, No. 6, pp. 718–20, 2001.

[80] J Lee and I Mudawar, "Assessment of the effectiveness of nanofluids for single- phase and two-phase heat transfer in micro-channels," *Int J Heat Mass Transfer*, Vol. 50, No. 3–4, pp. 452–63, 2007.

[81] C Choi, H S Yoo and JM Oh, "Preparation and heat transfer properties of nanoparticle in transformer oil dispersions as advanced energy efficient coolants," CurrApplPhys, Vol. 8, pp. 710–2, 2008.

[82] H LeeJ, H KS wang , S P Jang, B H Lee, JH Kim, SUS Choi, *et al*, "Effective viscosities and thermal conductivities of aqueous nanofluids containing low volume concentrations of Al2O3 nanoparticles," *Int J Heat Mass Transfer*, Vol. 51, No. 11–12, pp. 2651–6, 2008.

[83] W Yu, DM France, SUS Choi, JL Routbort, "Review and assessment of nanofluid technology for transportation and other applications", *Energy Systems Division, Argonne National Laboratory*, 2007.

[84] N. ao, L. Gahane and S. Ranganayakulu, "Synthesis, applications and challenges of nanofluids–review," *IOSR Journal of Applied Physics*, pp. 21-28, 2014:.

[85] J Lee and I. Mudawar, "Assessment of the effectiveness of nanofluids for single phase and two-phase heat transfer in micro-channels," *International Journal of Heat and Mass Transfer*, Vol. 50, No. 3–4, pp. 452–63, 2007.

[86] MN Pantzali, AA Mouza and SV Paras, "Investigating the efficacy of nanofluids as coolants in plate heat exchangers (PHE)," *Chemical Engineering Science*, Vol. 64, pp. 3290–300, 2009.

[87] The energy lab. NETL, 2009

[88] P Sivashanmugam, "Application of nanofluids in heat transfer An Overview of Heat Transfer Phenomena," *InTech*, 2012.

[89] S. P. Jang and S. U. S. Choi, "Cooling performance of a microchannel heat sink with nanofluids," *Applied Thermal Engineering*, Vol. 26, No. 17-18, pp. 2457–2463, 2006.

[90] S.M. You, J.H. Kim and K.H. Kim, *Appl. Phys. Lett.* Vol. 83, pp. 3374, 2003.

[91] H. Xie and L. Chen, "Adjustable thermal conductivity in carbon nanotube nanofluids," *Physics Letters Section A*, Vol. 373, No. 21, pp. 1861–1864, 2009.

[92] H. Xie, W. Yu and Y. Li, "Thermal performance enhancement in nanofluids containing diamond nanoparticles," J*ournal of Physics D,* Vol. 42, No. 9, Article ID 095413, 2009.

[93] W. Yu, H. Xie, L. Chen and Y. Li, "Investigation of thermal conductivity and viscosity of ethylene glycol based ZnO nanofluid," *ThermochimicaActa,* Vol. 491, No. 1-2, pp. 92–96,2009.

[94] W. Yu, D. M. France, S. U. S. Choi and J. L. Routbort, "Review and assessment of nanofluid technology for transportation and other applications," *Tech. Rep.*, Vol. 78, ANL/ESD/07-9, Argonne National Laboratory, 2007.

[95] www.labnews.co.uk/featurearchive.php/5449/5/keeping it-cool.

[96] K. V. Wong and O. de Leon, "Applications of nanofluids: current and future," *Advances inMechanical Engineering*, Vol. 2010, Article ID 519659, pp. 11, 2010.

[97] J. Routbort *et al.*, Argonne National Lab, Michellin North America, St. Gobain Corp., 2009, http://www1.eere.energy-.gov/industry/nanomanufacturing/pdfs/nanofluidsindusttrialcooling.pdf.

[98] I. C. Nelson, D. Banerjee and R. Ponnappan, "Flow loop experiments using polyalphaolefinnanofluids," *Journal ofThermophysics and Heat Transfer,* Vol. 23, No. 4, pp. 752–761, 2009.

[99] D. P. Kulkarni, D. K. Das, and R. S. Vajjha, "Application of nanofluids in heating buildings and reducing pollution," Applied Energy, Vol. 86, No. 12, pp. 2566–2573, 2009.

[100] P. Vassallo, R. Kumar and S.D. Amico. *Int. J. Heat Mass Transf.* Vol. 47, pp. 407, 2004.

[101] K. T. Pawale1, A. H. Dhumal2, G. M. Kerkal3 123 Asst. Prof. Dr. D. Y. "Performance Analysis of VCRS with Nano-Refrigerant," 2017.

[102] S. Bi, L. Shi and L. Zhang, "Performance study of a domestic refrigerator using R134a/mineral oil/nano-TiO2 as working fluid. ICR07-B2-346, 2007..

[103] Jwo *et.al.*, "Effect of Nano lubricant on the performance of Hydrocarbon refrigerant system," *J. Vac. Sci. TechNo. B.*, Vol.27, No. 3, pp.1473-1477, 2009.

[104] Henderson *et al.*, "Experimental analysis on the flow boiling heat transfer of R134a based nanofluids in a horizontal tube," *IJHMT*. pp. 944-951, Vol. 53, 2010..

[105] N. Subramani and M. J. Prakash, "Experimental studies on a vapour compression system using nanorefrigerants", *International Journal of Engineering, Science and Technology*, pp. 95-102, 2011.

[106] Shengshan Bi, "Performance of a Domestic Refrigerator using TiO2-R600a nano-refrigerant as working fluid," *Int. Journal of Energy Conservation and Management*, Vol. 52, pp 733-737, 2011.

[107] D. S. Kumar, and R. Elansezhian, "Experimental studay on Al2O3 -R134a Nano Refrigerant in Refrigeration System", *International Journal of Modern Engineering Research*, pp. 3927-3929, 2012.

[108] T. B. Kotu and R. R Kumar, "Comparison of Hat Transfer Performance in Domestic Refrigerator Using Nanorefrigerant and Double Pipe Heat Exchanger," *International Journal of Mechanical and Industrial Engineering*, pp. 67-73, 2013.