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Preparation, Properties, Stability and Applications of Different Nanofluids: A Review

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Abstract - **In this paper, the attention is given on Preparation, characteristics, and applications of nanofluids in detail. It was found that the use of Nanofluids appears promising, but the development of the field faces several challenges like long term stability, pressure drop, erosion, power consumption, etc. In this paper, thermal physical properties of nanoparticles suspended in refrigerant and lubricating oil of refrigerating systems were reviewed. Several interesting properties of nanofluids have been detailed in this review.**
Keywords: **Nanoparticles, Refrigeration, Properties**

I. INTRODUCTION

The Refrigeration system maintains cold environment in selected space relative to surrounding. The selected space is maintained at temperature lower than surrounding atmosphere temperature. The major problems with refrigeration systems are higher amount of power consumption, lower freezing speed, lower rate of heat transfer and the main problem is, it causes the environmental problems like ozone layer depleting (ODP) and global warming potential (GWP). The refrigerants used in refrigerators and air conditioners do not easily decompose when they reach to atmosphere following emission. Thus they are responsible to earth's greenhouse effect, which resulting in change in climate or atmosphere around the world and effects to the ecosystem. So it is need for developing thermal systems which are energy efficient as well as they are nature friendly. The environmental problems can be reduced by proper selection of refrigerant in refrigeration system. Another problem of power consumption or freezing speed and heat transfer rate is solved by using of new modern type of fluid called nanofluids. The use of nanofluid will increases the rate of heat transfer and also it reduces the power consumption. Hence these increases in heat transfer and lower consumption of power results in increase of performance of system [1]. Nanofluid is a colloidal mixture in which the properties of both the nanoparticles and the base fluid contribute to the change in the transport and thermal properties of the base fluid [2], [3].

Compared to conventional solid–liquid suspensions for heat transfer intensifications, nanofluids possess the following advantages

1. High specific surface area and therefore more heat transfer surface between particles and fluids.
2. High dispersion stability with predominant Brownian motion of particles.

a. Reduced pumping power as compared to pure liquid to achieve equivalent heat transfer intensification.
b. Recently scientists used nanoparticles in refrigeration systems because of its remarkable improvement in thermo-physical, and heat transfer capabilities to enhance the efficiency and reliability of refrigeration and air conditioning system.

While evaluating performance of refrigeration system, effect of nanofluid preparation method, effect of various types of nanoparticle materials, variation of sizes of nanoparticles, variation of concentration of nanoparticles, variation of suspension concentration in refrigerant needs to be investigated.

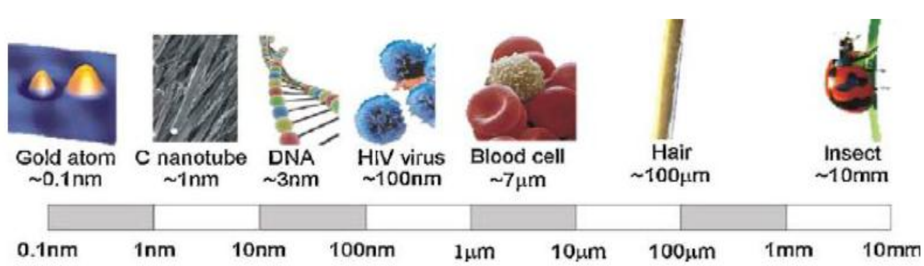

Fig. 1Nano scale

II. PREPARATION OF NANOFLUIDS

A. Single-Step Preparation Process

The single-step preparation process indicates the synthesis of nanofluids in one-step. Several single step methods have been arrived for nanofluid preparation. Akoh *et al.* [4] developed a single-step direct evaporation method. This process is familiar as VEROS (Vacuum Evaporation onto a Running Oil Substrate).But it was difficult to separate nanoparticles form fluids. Eastman *et al.* [5] developed a modified VEROS technique, in which Cu vapor is directly condensed into nanoparticles by contact with flowing low vapor-pressure ethylene glycol. Zhu *et al.*, [6] presented a single-step chemical process for the preparation of Cu nanofluids by reducing CuSO4 .5H2O with NaH2PO2 .H2O in ethylene glycol under microwave irradiation. This method also proved to be a good way to produce mineral oil based silver nanofluids. A suitable power source is required to produce an electric arc between 6000-12000^{0}C which melts and vaporizes a metal rod in the region where arc is created. The vaporized metal is condensed and then dispersed by de-ionized water to produce nanofluids. An advantage of one-step synthesis method is that nanoparticle agglomeration is minimized. But prime problem is that only low vapor pressure fluids are compatible with such a process.

B. Two-Step Preparation Process

Two-step preparation process is extensively usedin the synthesis of nanofluids by mixing base fluids with commercially available nanopowders obtained from different mechanical, physical and chemical routes such as milling, grinding, and sol-gel and vapor phase methods. An ultrasonic vibrator or higher shear mixing device is generally used to stir nanopowders with host fluids. Frequent useofultrasonicationor stirring is required to reduce particle agglomeration.

Eastman *et al.* [5], Lee *et al.* [6], Wang *et al.* [7-8] used two-step method to produce alumina nanofluids. Murshed *et al. [*8] prepared TiO_2-water nanosuspension by the same method.

Some authors suggested that two-step process is very suitable to preparation of fluids containing oxide nanoparticles than those containing metallic nanoparticles [9-11]. Stability is a big issue that inherently related to this operation as the powders easily aggregate due to strong van der Walls force among nanoparticles. In spite of such disadvantages this process is still popular as the most economic process for nano fluids production

C. Other Methods

Laser ablation is another much sought, single-step technique that simultaneously makes and disperses nanoparticles directly in the base fluids. A variety of nanofluids have been prepared by laser ablation method[10,11] by ablating solid metals, semiconductors, etc which are submerged in the base fluid (water, lubrication oils, etc).By creating a nanofluid in this way, stable nanofluids resulted without using any property-changing dispersants. This method is also useful for further splitting of nanoparticles present in the nanofluids to study effect of particle size on thermal conductivity. Microwave Irradiation[12], is a quick method of nanofluid synthesis. Submerged arc nano synthesis system(SANSS) is also used for preparing nanofluids [13]. A common difficulty encountered in nanofluid manufacture is nanoparticles tendency to agglomerate into larger particles, which limits the benefits of the high surface area nanoparticles.

Feng *et al.* [12] used aqueous organic phase transfer method for preparation of gold, silver, platinum nanoparticles. Phase transfer method can also be applied to prepare kerosene based Fe3O4 nanofluids which do not show time dependent thermal conductivity. Grafting of oleic acid onto the surface Fe_3O_4 makes it compatible with kerosene [13].Wei *et al.* [14] established a continuous flow micro fluidic microreactor to synthesize copper nanofluids. The microstructure and properties of nanofluids can appropriately be varied by adjusting parameters such as concentration, flow rate, additives. Moreover a novel preparation of aqueous CuO nanofluid can be done through novel precursor transformation method with the help of ultrasonic and microwave irradiation [15]. Here the precursor, Cu $(OH)_2$ is completely converted to CuO in water under that process.

III. PROPERTIES OF NANOFLUIDS

A. Thermal Conductivity

Since thermal conductivity is the most important properties responsible for enhanced heat transfer and many experimental works have been reported on this aspect. The experimental results have pointed out the improvement of thermal conductivity with the addition of nanoparticle [16].

Liu *et al.* [17] measured the thermal conductivity of nanofluids containing CNTs dispersed in ethylene glycol and synthetic engine oil. The increase of thermal conductivity is up to 12.4% for CNT–ethylene glycol suspensions at1.0vol% and30% for CNT-synthetic engine oil suspensions at2vol% .The higher thermal conductivities and the larger specific surface area of CNT have big impacts on thermal conductivity. The CNT dispersed in base fluid can form an xtensive three dimensional CNT networks that facilitate thermal transport. The highest thermal conductivity enhancement is seen in CNT nanofluids. Eastman *et al.* [18] reported an experimental study on the thermal conductivity of ethylene glycol-based nanofluids containing copper nanoparticles. The nanofluid exhibited an anomalously increase defective thermal conductivity. The thermal conductivity increased up to 40% for nanofluids consisting of 0.3% (by volume) of Cu nanoparticles of a mean diameter less than 10nm dispersed in ethylene glycol.

Jang *et al.* [19] proposed a theoretical model that involves the following four modes contributing to energy transfer for enhancing the thermal conductivity of nanofluids

1. Collision between the base fluid molecules
2. Thermal diffusion in nanoparticles,
3. Collision of nanoparticles with each other due to the Brownian motion.
4. Collision between the base fluid molecules and nanoparticles by thermal induced fluctuations. It still needs further research to develop a sophisticated theory to predict thermal conductivity of nanofluids [20].

B. Lubricity and Material Compatibility

A few investigations were carried out with nanoparticles in refrigeration systems to use advantageous properties of nanoparticles to enhance the efficiency and reliability of refrigerators.

For example, Wang and Xie [8] found that TiO_2 nanoparticles can be used as additives to enhance the solubility of the mineral oil in the hydro fluorocarbon (HFC) refrigerant.

C. Viscosity

Viscosity is a measure of the tendency of a liquid to resist 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 [21]. Einstein [22] was the first to calculate the effective viscosity of a suspension of spherical solids using the phenomenological hydrodynamic equations. Li *et al.* [23] measured the viscosity of water with CuO nanoparticles suspensions using a capillary viscometer. Results showed that the apparent viscosity of nanofluids decreased with increasing temperature. However, as they pointed out, the capillary tube diameter may influence the apparent viscosity for higher nanoparticles mass fractions, especially at lower temperatures.

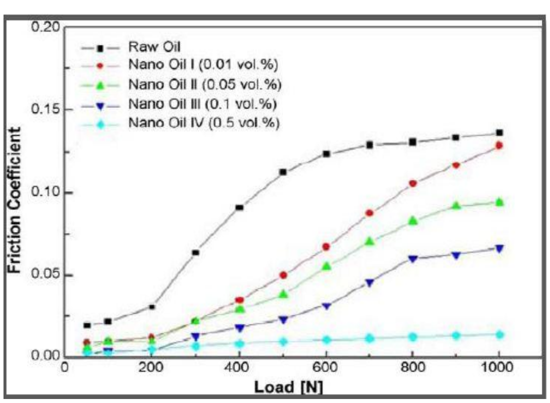

Fig. 2 Variation of friction coefficient vs load [24]

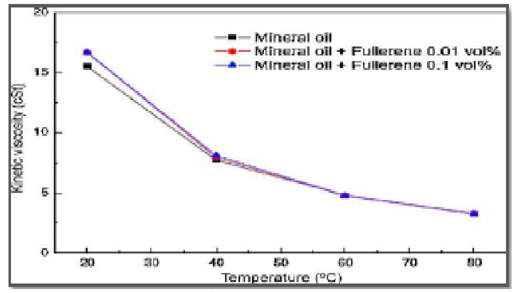

Fig. 3Variation of Kinetic viscosity vs particle concentration temperature [24]

IV. STABILITY OF NANOFLUIDS

The agglomeration of nanoparticles results in not only the settlement and clogging of microchannels but also the decreasing of thermal conductivity of nanofluids. So, the investigation of stability is also a key issue that influences the properties of nanofluids for application, and it is necessary to study and analyze influencing factors to the dispersion stability of nanofluids.

A. Stability Evaluation Methods for Nanofluids

1. Zeta Potential Analysis

Zeta potential is the potential difference between the dispersion medium and the stationary layer of fluid attached to the particle. The zeta potential indicates the degree of repulsion between adjacent, similarly charged particles in dispersion (Figure 4). So, colloids with high zeta potential (negative or positive) are electrically stabilized while colloids with low zeta potentials tend to coagulate or flocculate. Nanofluids with zeta potential from 40-60 mV are believed to have excellent stability. A lot of researchers have gone through zeta potential test of nanofluids. Kim *et al.* [25] used zeta potential analysis for Au nanofluids and found out standing stability. Zhu *et al.* [26] measured the zeta potential of Alumina-water based nanofluids under different pH values and different SDBS concentrations. The DLVO theory was applied to measure the attractive and repulsive potentials.

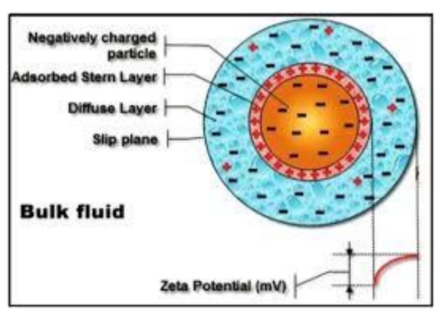

Fig. 3 Zeta potential of nanofluids

2. Sedimentation Method

Sedimentation method is the most elementary method for evaluation of nanofluids [27]. An external force field is applied to start the sedimentation of nanoparticles in the nanofluids. The weight of sediment or the volume of sediment indicates the stability of nanofluids. Nanofluids are generally considered to be stable if the concentration of the supernatant particles remains constant with time. Zhu *et al.* [28] used the principle of sedimentation method in his own experimental setup to measure the stability of graphite suspension. Use of camera has proven to be a suitable aid to capture sedimentation photographs for observing the stability of nanofluids [29].Waiting time for capturing photos links up with quality of nanofluids during preparation and well use of applied methods to make astable nanofluids. Wei *et al.* captured photographs of their samples within 24 hours after preparation. Wang *et al.* followed the path for testing sedimentation of alumina-water nanofluid [30].

3. Centrifugation Method

Sedimentation method is very time consuming as it requires a long period of observation. Sing *et al.* [31] used centrifugation method to evaluate the stability of silver nanofluid prepared by reducing AgNO3and selecting PVP as the stabilizer. An excellent stability of silver nanofluids was found due to the protective role of PVP because it decelerates the agglomeration of particles by steric effect.

B. Stability Enhancement Procedures

1. Addition of Surfactants in Nanofluids

Addition of surfactants lowers the surface tension of host fluids and increases the immersion of particles. Surfactants can be defined as chemical compounds added to nanoparticles in order to lower surface tension of liquids and increase immersion of particles. Several literatures talk about adding surfactant to nanoparticles to avoid fast sedimentation; however, enough surfactant should be added to particle at any particular case. In researches, several types of surfactant had been utilized for different kinds of nanofluids. Some important surfactants are: Sodium dodecyl sulfate (SDS) [32], Salt and oleic acid [33], Dodecyltrimethylammonium bromide (DTAB) [34], Hexadecyltrimethylammoniumbromide (HCTAB) [35], Polyvinylpyrrolidone (PVP)[36],Gum Arabic [37]. 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 hamper 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 [38].

2. Surface Modification Techniques

Injection of functional nanoparticles in the base fluids can provide long term stability of nanofluids. There are a number of examples of such modification techniques. As for example, Yang *et al.* [39] 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[40].Plasma treatment can be applied to modify the surface of diamond nanoparticles for improving their dispersion property in water [41].

3. Ultrasonic Agitation

After preparation of nanofluids, agglomeration might occur over the time which results in fast sedimentation of nanoparticles due to enhancement of downward body force. Manson *et al.* [42] investigated two different nanofluids; carbon black-water and silver-silicon oil and they utilized high energy of cavitation for breaking clusters among particles.

V.APPLICATIONS

A. Automobile

The addition of nanoparticles and nanotubes to the standard engine coolants (water mixture and ethylene glycol) and lubricants to form nanofluids can increase their thermal conductivity, and give the potential to improve the heat exchange rates and fuel efficiency. The above improvements can be used to reduce the size of the cooling systems or remove the heat from the vehicle engine exhaust in the same cooling system [43].

Heat transfer improvements can also be achieved by increasing the heat transfer coefficient h either by using more efficient heat transfer methods, or by improving the transport properties of the heat transfer material. For example, heat transfer systems which employ forced convection of a gas exhibit a greater heat transfer coefficient than systems which employ free convection of a gas. Alternatively, the heat transfer coefficient can be increased by enhancing the properties of the coolant for a given method of heat transfer. Additives are often added to liquid coolants to improve specific properties. For example, glycols are added to water to depress its freezing point and to increase its boiling point. The heat transfer coefficient can be improved via the addition of solid particles to the liquid coolant (i.e. nanofluids).[44-52]

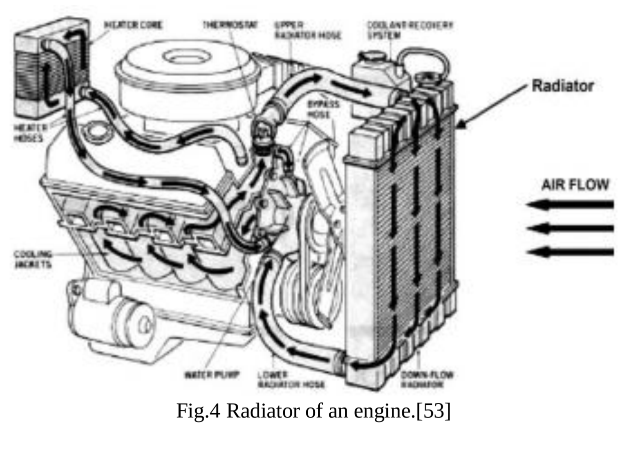

Fig.4 Radiator of an engine.[53]

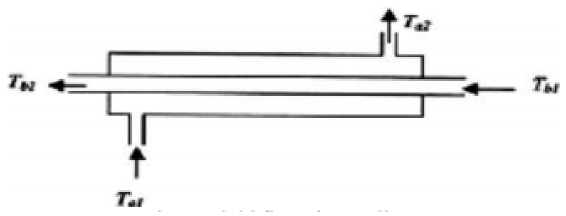

Fig.5 Fluid flows in a radiator.[53]

B. Solar

Taylor *et al.,* [54] compared a nanofluid-based concentrating solar thermal system with a convention alone. Their results show that the use of a nanofluid in the receiver can improve the efficiency by 10%. They also concluded that for10–100MW electric power plants, using graphite/therminolVP-1nanofluid with volume fractions approximately to 0.001% or less could be beneficial. The researchers estimated that combining a nanofluid receiver with a solar thermal power tower with the capacity of 100MW operating in a solar resource like Tucson, Arizona, could generate $3.5 million more per year. In a ridremoteregions in the world, the provision of freshwater is more critical. In these regions, solar desalination systems can solve part of the problem where solar energy is available. In developing countries, lack of safe and unreliable drinking water constitutes a major problem. Worldwide drought and desertification are expected to increase the drinking water shortage to become one of the big- gest problems facing the world [55]. Solar stills can be used to avoid the greenhouse gas emissions from the production of freshwater [6].

C. Electronic Applications

Advanced electronic devices face thermal management challenges from the high level of heat generation and the reduction of available surface area for heat removal. Recent researches illustrated that nanofluids could increase the heat transfer coefficient by increasing the thermal conductivity of a coolant. Jang *et al.* designed a new cooler, combined microchannel heat sink with nanofluids [56]. Higher cooling performance was obtained when compared to the device using pure water as working medium. Nanofluids reduced both the thermal resistance and the temperature difference between the heated micro channel wall and the coolant. Nguyen *et al.* designed a closed liquid-circuit to investigate the heat transfer enhancement of a liquid cooling system, by replacing the base fluid (distilled water) with a nanofluid composed of distilled water and Al_2O_3 nanoparticles at various concentrations [57]. Measured data have clearly shown that the inclusion of nanoparticles within the distilled water has produced a considerable enhancement in convective heat transfer coefficient of the cooling block. With particle loading 4.5 vol%, the enhancement is up IOSR Journal of Applied Physics (IOSR-JAP) e-ISSN: 2278-4861, PP 21-28 www.iosrjournals.org International Conference on Advances in Engineering & Technology – 2014 (ICAET-2014) 23 | Page to 23% with respect to that 15 of the base fluid. It has also been observed that an augmentation of particle concentration has produced a clear decrease of the junction temperature between the heated component and the cooling block.

D. Industrial Cooling Applications

The application of nanofluids in industrial cooling will result in great energy savings and emissions reductions. Experiments were performed using a flow-loop apparatus to explore the performance of polyalphaolefinnanofluids containing exfoliated graphite nanoparticle fibers in cooling [58]. 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. The thermal diffusivity was found to be 4 times higher for nanofluids. The convective heat transfer was enhanced by ~10% using nanofluids compared with using polyalphaolefin. Ma *et al.* proposed the concept of nano liquid-metal fluid, aiming to establish an engineering route to make the highest conductive coolant with about several dozen times larger thermal conductivity than that of water [59]. The liquid metal with low melting point is expected to be an idealistic base fluid for making super conductive solution which may lead to the ultimate coolant in a wide variety of heat transfer enhancement area. The thermal conductivity of the liquid-metal fluid can be enhanced through the addition of more conductive nanoparticles.

E. Heating Buildings and Reducing Pollution

Kulkarni *et al*,. evaluated how they perform heating buildings in cold regions. In cold regions, it is a common practice to 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 necessitate smaller heating systems, which are capable of delivering the same amount of thermal energy as larger heating systems, but are less expensive. This lowers the initial equipment cost excluding nanofluid cost. This will also reduce environmental pollutants because smaller heating units use less power, and the heat transfer unit has less liquid and material waste to discard at the end of its life cycle.

F. 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 another is the absorption properties of nanofluids.

G. Energy Storage

Latent heat storage is one of the most efficient ways of storing thermal energy. Wu *et al.* evaluated the potential of

Al_2O_3-H_2O nanofluids as a new phase change material (PCM) for the thermal energy storage of cooling systems. The thermal response test showed the addition of Al_2O_3 nanoparticles remarkably decreased the super cooling degree of water, advanced the beginning freezing time and reduced the total freezing time. Only adding 0.2 wt% Al_2O_3 nanoparticles, the total freezing time of Al_2O_3-H_2O nanofluids could be reduced by 20.5%.

H. Mechanical Applications

Nanoparticles in nanofluids form a protective film with low hardness and elastic modulus on the worn surface can be considered as the main reason that some nanofluids exhibit 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 utilizing the property magnetic properties of the magnetic nanoparticles in liquid.

VI. LITERATURE REVIEW

Xuan *et al.,* (2000) [60] carried out research on “Heat transfer enhancement of Nanofluids”. The paper presented a procedure for preparing a Nanofluid which is a suspension consisting of nano phase powders and a base liquid. By means of the procedure, some sample Nanofluids were prepared. The theoretical study of the thermal conductivity of Nanofluids was also introduced in the work and a hot-wire apparatus was used to measure the thermal conductivity of Nanofluids with suspended copper nano phase powders. The experiment showed that the volume fraction, shape, dimensions and properties of the nanoparticles affect the thermal conductivity of Nanofluids.

Kostic and Choi (2004) [61] carried out some analysis in a project on Nanofluids for Ultra-High-Performance Cooling. The work explored the basic concepts of Nanofluids. Also, materials for Nanoparticles (Oxide Ceramics e.g. Al_2O_3, CuO, Metal Carbides e.g. SiC) and base materials (Water, Ethylene, Oil, Bio-fluids) were discussed in detail. Furthermore, the work highlighted major methods for producing nanoparticle.

Bi *et al.,* (2008) [62] did some research on “Application of nanoparticles in domestic refrigerators”. The work experimentally investigated the reliability and performance of a domestic refrigerator with nanoparticles in the working fluid. Mineral oil with TiO_2nanoparticles mixtures were used as the lubricant instead of Polyol-ester (POE) oil in the 1, 1, 1, 2-tetrafluoroethane (HFC134a) refrigerator. The refrigerator performance with the nanoparticles was then investigated using energy consumption tests and freeze capacity tests. The results indicated that HFC134a and mineral oil with TiO_2nanoparticles works normally and safely in the refrigerator. The refrigerator performance was better than the HFC134a and POE oil system, with 26.1% less energy consumption used with 0.1% mass fraction TiO_2 nanoparticles compared to the HFC134a and POE oil system. The same tests with Al_2O_3nanoparticles showed that the different nanoparticles properties have little effect on the refrigerator performance. Thus, the work elucidated that nanoparticles can be used in domestic refrigerators to considerably reduce energy consumption.

Saidur *et al*., (2011)[63] did some work on “A review on the performance of nanoparticles suspended with refrigerants and lubricating oils in refrigeration systems”.In the paper, thermal–physical properties of nanoparticles suspended in refrigerant and lubricating oil of refrigerating systems were reviewed. Heat transfer performance of different nanorefrigerants with varying concentrations was reviewed and review results were then presented. Pressure drop and pumping power of a refrigeration system with nanorefrigerant were obtained from different sources and reported their review. Along with these, pool boiling heat transfer performance of Carbon Nanotubes (CNT) refrigerant was reported. The results indicated that HFC134a and mineral oil with TiO2 nanoparticles works normally and safely in the refrigerator with better performance. The energy consumption of the HFC134a refrigerant using mineral oil and nanoparticles mixture as lubricant was found to have saved 26.1% energy with 0.1% mass fraction TiO_2 nanoparticles compared to the HFC134a and POE oil system.

M.T. Naik and L. Syam Sundar(2011) [64] published a paper “Investigation into Thermo physical Properties of Glycol based CuO Nanofluids for Heat Transfer Applications”. They presented experimental work on thermal conductivity and viscosity of water-propylene glycol based CuO nanofluids at different temperatures for five different concentrations. They showed that thermal conductivity of CuOnanofluids increases with increase in the CuO nanoparticle concentration in the base fluid.

H. K *et al.,*(2012) [65] carried out research on “Nanofluids as a new media towards green environment”. The study discussed how nanofluids are synthesized by dispersing and stably suspending nanometre sized solid particles in conventional heat transfer fluids. The objective was to present a broad range of Nanofluid based current and future applications whilst highlighting some barriers and challenges for implementing the new class of working fluids. Some of the applications discussed include Applications in automotives, Nanofluids as coolants, Nanofluids in fuels, Applications in domestic refrigerator and Nanofluid in Brake fluids. In conclusion the work, it was found that the use of Nanofluids appears promising, but the development of the field faces several challenges.

Kumar *et al.* (2013) [66] did some research on “Heat transfer enhancement in domestic refrigerator using R600a/mineral oil/nano-Al_2O_3 as working fluid”. In the experiment, heat transfer enhancement was investigated numerically on the surface of a refrigerator by using Al2O3 nano-refrigerants, where Nanofluids could be a significant factor in maintaining the surface temperature within a required range. The addition of nanoparticles to the refrigerant resulted in improvements in the thermo physical properties and heat transfer characteristics of the refrigerant, thereby improving the performance of the refrigeration system. The experimental studies indicated that the refrigeration system with nano-refrigerant works normally. The experiment showed that freezing capacity is higher and power consumption reduces by 11.5 % when POE oil is replaced by a mixture of mineral oil and Aluminium oxide nanoparticles. Thus using Aluminium oxide nano lubricant in refrigeration system was shown to be feasible.

TABLE I LITERATURE REVIEW

S. No.	Author Name	Nanofluids and percentage	Concluding Remark
1	Xuan*et al.*,(2000)	nano phase powders and a base liquid.	The experiment showed that the volume fraction, shape, dimensions and properties of the nanoparticles affect the thermal conductivity of Nanofluids
2.	Kostic and Choi (2004)	Nanoparticles (Oxide Ceramics e.g.Al_2O_3,CuO,Metal Carbides e.g.SiC) and base materials (Water,Ethylene,Oil,Bio-fluids)	The work explored the basic concepts of Nanofluids. Furthermore, the work highlighted major methods for producing nanoparticles.
3.	Bi *et al.*, (2008)	HFC134a and mineral oil with TiO_2nano particles. 0.1% mass fraction TiO_2nano particles	Somenano particles showed that their different properties have little effect on the refrigerator performance. Thus, the work elucidated that nano particles can be used in domestic refrigerators to considerably reduce energy consumption.
4	Saidur*et al.*, (2011)	TiO_2nano particles 0.1% mass fraction TiO_2nano particles	In the paper, thermal–physical properties of nanoparticles suspended in refrigerant and lubricating oil of refrigerating systems were reviewed.
5	M.T. Naik and L. SyamSundar (2011)	CuO nanofluids	It was found that thermal conductivity of CuOnanofluids increases with increase in the CuOnano particle concentration in the base fluid.
6	H.K *et al.*, (2012)	Research on “Nanofluids as a new media towards green environment”	It was found that the use of Nanofluids appears promising, but the development of the field faces several challenges.
7	Kumar *et al.*, (2013)	R600a/mineral oil/nano-Al_2O_3	The experiment showed that freezing capacity is higher and power consumption reduces by 11.5 % when POE oil is replaced by a mixture of mineral oil and Aluminium oxide nanoparticles. Thus using Aluminium oxide nanolubricant in refrigeration system was shown to be feasible.
7.	Mahbubul I.M. *et al.*,(2015)	nanofluidsAl_2O_3nanoparticles	The results indicate that the thermal conductivity of nanorefrigerantAl2O3 increases on increasing temperature i.e. 8.12% to 28.58% for 208K to 308K
8	A.K.Singh	----------	They concluded that nanofluids have great potential for thermal management and control involved in a variety of applications such as electronic cooling, micro electro mechanical systems (MEMS) and spacecraft thermal management.

Mahbubul I.M. *et al.* (2015)[67] analyzed the thermo-physical properties and their effect on COP. 5% volume of Al_2O_3nanoparticles are added at temperature of 283-308 K. The results indicate that the thermal conductivity of nanorefrigerantAl_2O_3 increases on increasing temperature i.e. 8.12% to 28.58% for 208K to 308K. The density and viscosity of nanorefrigerant also increased by 13.68% and 11% for the same temperature rise. The variation in thermal conductivity, density and viscosity also increases the COP by 15%, 3.2% and 2.6%.

A.K.Singh [68] Defence Institute of Advanced Technology, Pune presented a paper on “Thermal Conductivity of Nanofluids”. This study provides a review of nanotechnology with focus on thermal conductivity studies of nanofluids. They concluded that nanofluids have great potential for thermal management and control involved in a variety of applications such as electronic cooling, microelectro mechanical systems (MEMS) and spacecraft thermal management.

Indranil Manna[69]in his paper “Synthesis, Characterization and Application of Nanofluid—An Overview” reviewed an update on the historical evolution of nanofluid concept, possible synthesis routes, level of improvements reported, theoretical understanding of the possible mechanism of heat conduction by nanofluid and scopes of application.

VII. CONCLUSION

This review paper has made to cover all the important information and investigations performed on the preparation, properties, stability and applications of nanofluids. We have come to know that two-step preparation method is accepted by the major portion of researchers as it is simple and economic.Nanofluides shows distinct properties which made it applicable in different processes. Further, we have found the steps involved in the stabilization process of these fluids. There is a wide range of applications where nanofluidsplay a very important role in refrigeration and air conditioning also it helps to improve COP of refrigeration system. Based on the literature review done on nanorefrigerants, it is observed that the thermal conductivity of a nanorefrigerant is higher than that of the base fluid. It is confirmed that the thermal conductivity increases with the volume concentration/mass fraction of nanoparticles in the working fluid. Based on the articles reviewed, it can be concluded that the use of nanorefrigerants in refrigeration systems can improve the performance of the systems. Nanoparticles can be used as nanorefrigerants in the base refrigerant or as nanolubricants in the lubricating oil. The results from the investigations indicate an improvement in the COP of the refrigeration system.

REFERENCES

[1] S. U. S.Choi, D. A. Singer and H. P. Wang. "Developments and applications of non-Newtonian flows." *ASME FED*, Vol. 66, pp. 99-105, 1995.

[2] E Serrano, G Rus and JG Martı´nez, "Nanotechnology for sustainable energy," *Renewable and Sustainable Energy Reviews*, Vol. 13, No. 9, pp. 2373–84, 2009.

[3] D. Elcock, "Potential impacts of nanotechnology on energy transmission applicationsand needs," *Environmental Science Division, Argonne National Laboratory,* 2007.

[4] 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.

[5] J.A. Eastman, U.S. Choi, S. Li, L.J. Thompson, 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.

[6] H.T. Zhu and Y.S. Yin, "A novel one-step chemical method preparation of copper nanofluids", *Journal of Colloid and Interface Science*, Vol. 227, No.1, pp. 100-130, 2004.

[7] 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.

[8] 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.

[9] *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.

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

[11] J. A. Eastman, S. U. S. Choi, S. Li, W. Yu and L. J. Thompson, "Anomalously increased effective thermal conductivities of ethylene glycol-based nano fluids containing copper nanoparticles," *Applied Physics Letters*, Vol. 78, No. 6, pp. 718–720, 2001.

[12] A.K. Singh and V.S. Raykar, "Microwave synthesis of silver nanofluids with polyvinyl pyrrolidone (PVP) and their transport properties; colloid and polymer science," Accepted for publication, 2008.

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

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

[15] 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.

[16] Kumar Tiwari Arun, Pradyumna Ghosh and Sarkar Jahar, "Investigation of thermal Conductivity and viscosity of Nanofluids," *J Environ ResDev,* Vol. 2, pp. 768–77, 2012.

[17] Liu MS, Ching-Cheng Lin M, HuangWang IT, "Enhancement of thermal conductivity with carbon nano tubes of nanofluids, " I*ntCommun Heat Mass Transf*, 2005, Vol. 32, No. 9, pp. 1202–10.

[18] JA Eastman, SUS Choi, LiS, W Yu and LJ Thomson., "Anomalously increased effective thermal conductivities of ethylene eglycol-based nanofluids containing copper nano particles," *ApplPhys Lett*, Vol. 78, pp. 718–20, 2001.

[19] S. P. Jang and S. U. S. Choi, "Effect of various parameters on nanofluid thermal conductivity," *J Heat Transf*, Vol. 129, pp. 617–23, 2007.

[20] Kakac Sadik, Pramuanjaroenkij Anchasa, "Review of convective heat transfer enhancement with nanofluids," *IntJofHeat and Mass Transf*; Vol. 52, pp. 3187– 96, 2009.

[21] S. Suresh, K. P. Venkitaraj, P. Selvakumar and M. Chandrasekar, "SynthesisofAl2O3– Cu/water hybrid nanofluids using two step method and its thermophysical properties," *Colloids Surf A: Physicochem EngAsp*, Vol. 388, pp. 41–8, 2011.

[22] A. Einstein, "Investigations on the theory of the Brownian motions," New York: Dover Publications; 1956.

[23] J. M. Li, Z. L. Li and B. X. Wang, "Experimental viscosity measurements for copper oxide nanoparticles suspensions," *TsinghuaSciTechnol*, Vol. 7, No. 2, pp. 198–201, 2002.

[24] P. Singh, "To Study the Application of Nanorefrigerant in Refrigeration System : A Review," *Int. J. of research in enng and technology, pp.* 2319–2322, 2015.

[25] H. J. Kim, I. C. Bang and J. Onoe, "Characteristic stability of bare Au-water nanofluids fabricated by pulsed laser ablation in liquids," *Optics and Lasers in Engineering*, Vol. 47, No. 5, pp. 532–538, 2009.

[26] D. Zhu, X. Li, N. Wang, X. Wang, J. Gao, and H. Li, "Dispersion behavior and thermal conductivity characteristics of Al2O3-H2O nanofluids," *Current Applied Physics*, Vol. 9, No. 1, pp. 131–139, 2009.

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

[28] H. Zhu, C. Zhang, Y. Tang, J. Wang, B. Ren, and Y. Yin, "Preparation and thermal conductivity of suspensions of graphit e nanoparticles," *Carbon*, Vol. 45, No. 1, pp. 226-228, 2007.

[29] 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.

[30] 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.

[31] 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.

[32] M. Chandrasekar, 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.

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

[34] 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.

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

[36] 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.

[37] 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: Physicochem. Eng. Aspects*, Vol. 358 No. 1-3, pp. 101-107, 2010.

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

[39] 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.

[40] L. Chen and H. Xie, "Surfactant-free nanofluids containing double- and single-walled carbon nanotubes functionalized by a

wetmechanochemical reaction," *ThermochimicaActa*, Vol. 497, No. 1-2, pp. 67–71, 2010.

[41] Q. Yu, Y. J. Kim and H. Ma, "Nanofluids with plasma treated diamond nanoparticles," *Applied Physics Letters*, Vol. 92, No. 10, Article ID 103111, 2008.

[42] 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.

[43] Shanthi R, Anandan Shanmuga Sundaram, Velraj R, "Heat Transfer Enhance-ment Using Nanofluids- An Overview," *Therm Sci*; Vol. 16, No. 2, pp. 423–44, 2012.

[44] Beck M, "Thermal conductivity of metal oxide nanofluids," PhD thesis. Georgia Institute of Technology, 2008.

[45] E Serrano, G Rus and JG Martínez., "Nanotechnology for sustainable energy," *Renew Sust Energy Rev*, Vol. 13, No. 9, pp. 2373–84, 2009.

[46] YM Xuan, W Roetzel, "Conceptions for heat transfer correlation of nanofluids," *Int J Heat Mass Transfer*, Vol. 43, pp. 3701–7, 2000

[47] SUS Choi, W Yu, JR Hull, ZG Zhang and FE Lockwood, "Nanofluids for vehicle thermal management," *Society of Automotive Engineers*, pp. 139–144, 2001.

[48] P Keblinski, SK Nayak and P. Zapol, "Charge distribution and stability of charged carbon nanotubes," *Phys Rev Lett*, Vol. 89, 2002.

[49] XQ Wang and AS.Mujumdar, "Review on nanofluids. Part II: experiments and applications," *Braz J ChemEng*, Vol. 25, pp. 631–48, 2008.

[50] KD. Sarit, "Nanofluids—the cooling medium of the future," *Heat Transfer Eng*, Vol. 27, No. 10, pp.1–2, 2006.

[51] S. Lee, SUS Choi, "Application of metallic nanoparticle suspensions", *ANL*, 1997.

[52] V Sridhara, BS Gowrishanka, Snehalatha and LN Satapathy, "Nanofluids a new promising fluid for cooling," *Trans Indian Ceram Soc*, Vol. 68, pp. 1–17, 2009.

[53] Wei Yu and Huaqing Xie, "A Review on Nanofluids: Preparation, Stability Mechanisms and Applications,"

[54] R. A. Taylor, P. E. Phelan, T. P. Otanicar, C. A .Walker, M. Nguyen, S. Trimble and R. Prasher, "Applicability of nanofluids in high flux solar collectors," *JRenewSustain Energy*, Vol. 3, No. 2, pp. 023104, 2011.

[55] O. Badran and M. M. AbuKhader, "Evaluating thermal performance of a single slope solarstill," *Heat Mass Transf*, Vol. 43, No. 10, pp, 985–95, 2007.

[56] S. P. Jang and S. U. S. Choi, *Appl. Therm. Eng.* Vol. 26, 2457, 2006.

[57] C.T. Nguyen, G. Roy, N. Galanis and S. Suiro, *Proceedings of the 4th WSEAS Int. Conf. on heat transfer, thermal engineering and environment,Elounda, Greece*, pp. 103-108, 2006.

[58] I.C. Nelson, D. Banerjee and R. Ponnappan, *J. Thermophys, Heat Transf.* Vol. 23, pp. 752, 2009.

[59] K.Q. Ma, J. *Liu, Phys. Lett. A* Vol. 361, pp. 252, 2007.

[60] Y. Xuan and Q. Li, "Heat transfer enhancement of nanofluids," *International Journal of Heat and Fluid Flow*, Vol. 58, 2000.

[61] M. Kostic, (2004), "Advanced Flow and Heat Transfer Fluids," Illinois, Chicago: Department of Mechanical Engineering, Northern Illinois University.

[62] S. s. Bi, L. Shi and L. Zhang, "Application of nanoparticles in domestic refrigerators", *Applied Thermal Engineering*, pp. 1834 – 1843, 2008.

[63] R. Saidur, S. Kazi, M. Hossain, M. Rahman and H. Mohammed, "A review on the performance of nanoparticles suspended with refrigerants and lubricating oils in refrigeration systems," *Renewable and Sustainable Energy Reviews*, pp. 310 – 323, 2011.

[64] M. Naik and L. Sundar, "Investigation into Thermophysical Properties of Glycol based CuONanofluid for Heat Transfer Applications," *World Academy of Science, Engineering and Technology*, pp. 3 – 7, 2011.

[65] H.K, G., G.D, A., and J, M., "An overview of nanofluids: a new media towards green environment," *International Journal of Environmental Sciences,* Vol. 3, 2012 doi:10.6088/ijes.20120301310 42.

[66] R. R. Kumar, K. Sridhar and M. Narasimha, "Heat transfer enhancement in domestic refrigerator using R600a/mineral oil/nano-Al," *International Journal of Computational Engineering Research,* Vol. 03, No. 4, pp. 2 – 9, 2013.

[67] I. M. Mahbubul, R. Saidur and M. A. Amalina, "Investigation of viscosity of R123-TIO2 Nanorefrigernt," *International Journal of Mechanical and Materials Engineering*, Vol. 7, pp. 146-151, 2015.

[68] A.K. Singh, Defence Institute of Advanced Technology, Pune "Thermal Conductivity of Nanofluids", *Defence Science Journal*, Vol. 58, No. 5, pp. 600-607, 2008.

[69] Indranil Manna, "Synthesis, Characterization and Application of Nanofluid An Overview," *Journal of the Indian Institute of Science*, Vol. 89, No. 1, Jan–Mar 2009.