IMPROVED EFFICIENCY OF NANO COOLANTS

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Abstract: Nowadays, the demand of nanotechnology is increasing day by day. So it has become a huge challenge for the automobile industry to produce an efficient engine. Nanofluids are potential heat transfer agents. Earlier air radiators and water radiators have been used for the cooling system but both have merits and demerits. As nanotechnology is emerging, nanofluids have developed and researchers found these nanofluids offering high thermal conductivity as compared with the conventional fluids. Theoretically the cooling efficiency of the cooling engine can be increased by 50-60% by using nanofluids as cooling agents. In this paper a comprehensive literature on increased efficiency of nanofluids as better heat transfer agent and challenges for nanofluids. Nanofluid have a much higher and strongly temperature dependent thermal conductivity at very low particle concentration than conventional fluids. It is because of these high thermal properties it can be directly applicated to industrial purposes.
Keywords: nanofluids, thermal properties, conductivity

I. INTRODUCTION

According to NSF (Nano Science & Foundation) prediction the market for nanotech products and services will exceed about $ 1 trillion in the U.S. alone by 2015. [1]

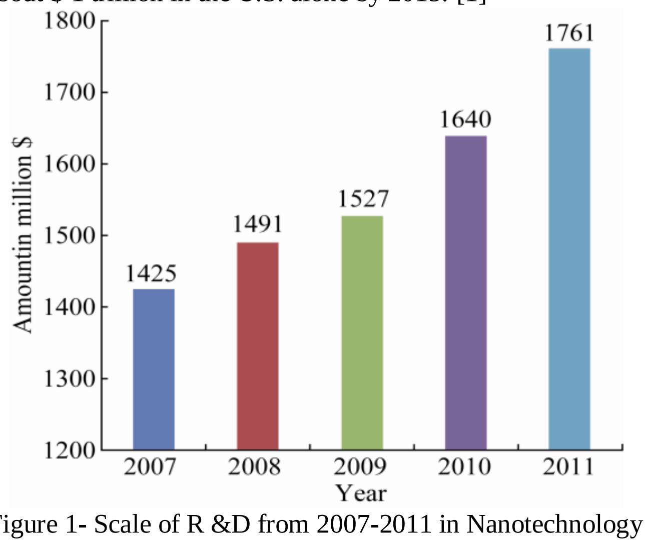

Figure 1- Scale of R &D from 2007-2011 in Nanotechnology [1]

Nanotechnology is the technology which deals with the structures in nanometer range and due to their smaller size and dimensions the physical and chemical properties can be manipulated and deeply studied over all properties. About a decade ago USA based researcher lab started to prepare a special kind of fluid by suspending particle with diameter 1-100 nm in base fluid such as water, ethylene glycol etc. This fluid is named as Nanofluid. [2] In the past one decade engine efficiency, power dissipation, chip power consumption and heat flux in electronics devices created a need for improvement methods of cooling them. Nanofluid as a coolant can be used as coolant for these kinds of machines and devices. The use of nanofluids as coolant would allow for smaller size and better positioning of the radiators. Owing to fact that there would less fluid due to higher efficiency, coolant pumps would be strong and truck engines would be operated at higher temperature allowing for more horsepower while still meeting stringent emission standards.[3][4]

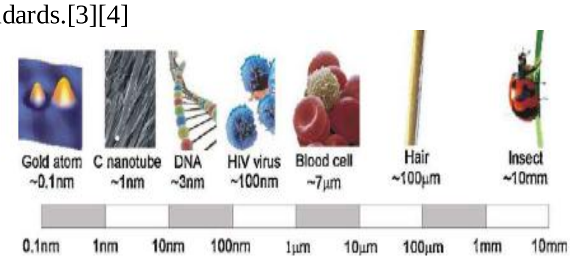

Figure 2-range of sizes with various examples

Nanofluids prevailed over water and ethylene glycol due to two main obstacles. The poor heat transfer property of common fluids like water is a primary obstacle and results in high compactness and effectiveness of heat exchangers. The second obstacle is in case of automobiles is the role of air cooled heat exchangers which has strong impact on aerodynamic behaviour. [4]

The addition of nanoparticles (i.e. nanofluids) improves the thermal efficiency of coolants while maintaining other coolant parameters i.e. viscosity and foaming dominated over two primary challenges. Nanofluids have the ability to generate nanoparticles in large volumes and to suspend particles in base coolant such that they don't coagulate.

Eastman et al. [5] report that thermal conductivity of ethylene glycol of nanofluids containing 0.3% volume fraction of copper particles can enhance thermal properties by 40% compared to that of EG (Ethylene Glycol) base fluid. Huwang et al. [6] found that thermal conductivity of nanofluids depends on the volume fraction of particles and thermal conductivity of base fluids and particles.

The other properties of nanofluids as nanocoolants is forced convective heat transfer. Enhancement of convective heat transfer was reported by Zeinali Heris et al. [7], Kim et al. [8] and Jung et al. [9]. Presently in radiators there are four possible methods in nanofluids which may contribute to thermal conduction.

- Brownian motion of nanoparticles
- Liquid layering at liquid/particle interface
- Ballistic nature of heat transport in Nano particle
- Nano particle clustering in Nanofluids

Brownian motion of nanoparticles is too slow to transfer heat through a Nanofluid. This mechanism works well when the particle clustering has both positive and negative effect of thermal conductivity which is obtained directly through convection. [10]

A. Types of Nanofluids

There are different types of metallic, non metallic nanoparticles and Multiwalled carbon Nano tubes (MWCNT) which are used as nanofluids. Generally the mixture of (Al_2O_3 + Water), (CuO + Water), (TiO + Water), (CH_3CH_2OH + Water), (ZnO + EG) are used in industries for preparation of nanofluids. Due to use of Nano coolants, coolants pump would be shrunk. So, the 65% of total energy from the energy output of a truck is expanded in overcoming the aerodynamic drag would be reduced and overcome the wind resistance on road. But the development and applications of nanofluids may be hindered by several factors such as long term stability, increase pumping power pressure drop, nanocoolants thermal performance in turbulent flow and fully developed region, lower specific heat of nanofluids and higher production cost of nanofluids.

B. Benefits of using Nanofluids

1) Absorption of solar energy will be maximized with change of the size, shape, material, and volume fraction of the nanoparticles.
2) The suspended nanoparticles increase the surface area and the heat capacity of the fluid due to the very small particle size.
3)The suspended Nanoparticles enhance the thermal conductivity which results improvement in efficiency of heat transfer systems.
4) Heating within the fluid volume, transfers heat to a small area of fluid and allowing the peak temperature to be located away from surfaces losing heat to the environment.
5) The mixing fluctuation and turbulence of the fluid are intensified.
6) The dispersion of nanoparticles flattens the transverse temperature gradient of the fluid.
7) To make suitable for different applications, properties of fluid can be changed by varying concentration of nanoparticles.

II. OVERVIEW OF APPLICATIONS OF NANOFLUIDS

In an automobile, fuel and air produce power within the engine through combustion. Only a portion of the total generated power actually supplied to the automobile with power, the rest is wasted in the form of exhaust and heat. If this excess heat is not removed, the engine temperature becomes too high which results in overheating and viscosity breakdown of the lubricating oil, metal weakening of the overheated engine parts which decrease the efficiency & life term of engine. Out of cooling system components, the radiator and fins are the most prominent part of the system as it transfers heat. As coolant travels through the engine's cylinder block, it accumulates heat. Once the coolant temperature increases above a certain threshold value, the vehicle's thermostat triggers a valve which forces the coolant to flow through the radiator. As the coolant flows through the tubes of the radiator, heat is transferred through the fins and tube walls to the air by conduction and convection [4] and fins are used to increase heat transfer area on the air side, since the air has the largest influence on the overall heat transfer rate, mass flow rate of air, pitch of tube [13]. For a heat transfer system in automobiles many methods are available to improve heat transfer in processes. The flow of heat in a process can be calculated based on [12]

$$Q = hA\blacktriangle T \quad .....(2.1)$$

Where, Q is the heat flow, h is the heat transfer coefficient, A is the heat transfer area and ▲T is the temperature difference that results in heat flow. So for better heat transfer following condition must be achieved:

- Increasing (▲T) => A greater temperature difference will increase the heat flow. Increased ▲T can only be achieved by decreasing the temperature of the coolant.
- Increasing (A) => maximizing the heat transfer area A is a common way to improve heat transfer. However, this strategy cannot be regulated in microprocessors and Micro Electro Mechanical Systems (MEMS) because the area cannot be increased.
- Increasing (h) => Heat transfer improvements can also be achieved by increasing the heat transfer coefficient (h) either by using more efficient heat transfer methods or by enhancing the properties of the coolant for a given method of heat transfer. For example Additives are often added to liquid coolants to improve specific properties. Such as 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). [12].

In past times , water was the heat transfer medium but due to demand of higher efficiency engines in market, there would be either change in coolant structure or fluids being used or reducing Radiator size to lose weight was the only solution or increasing the number of fins used but they can't be used after certain limit. So Researchers used the term Nanoparticles. Since the thermal conductivity of solids is greater than liquids, dispersion of solid particles in a given fluid is bound to increase thermal conductivity. However, dispersion of millimeter or micrometer sized particles is prone to sedimentation, clogging and erosion of pipes and channels. In contrast, Nanofluid is a stable colloidal suspension of solid particles dispersed in conventional heat transfer fluids to offer a dramatic enhancement in thermo physical properties of the fluids. [1] Existence of agglomerates and close packing of the dispersed phase as well as the presence and type of the dispersants can negatively influence the increase of the thermal conductivity. Many parameters are responsible for the unique thermal behavior of nanofluids which are: the particle size and shape, the length-to-diameter ratio, homogenization time, volume fraction of the dispersed phase, interfacial resistance, the ordered structure of the liquid at the solid-liquid interfaces and the Brownian motion of the Nanoparticles enabling the formation of loosely packed clusters and convection-like effects at the Nanoscale (Assael etal., 2006). [14] Smaller the size the greater the stability of colloidal dispersion and the greater the stability of colloidal dispersion the greater the probability of interaction and collision among particles and collision among particles and fluid and the greater the effective heat energy transport inside the liquid (Xue 2003).[15]

Thermal conductivity enhancement ratio K(effective)= K(nanofluid)/ K(basefluid) and the parameters that most affect the thermal conductivity of nanofluids are:

1- Particle volume fraction
2- Particle material
3- Base fluids
4- Particle size
5- Temperature

Heat transfer contains several modes and one of them is convection that is the heat transfer from a fluid to the wall or at opposite direction. It is very important to know that enhancement in thermal conductivity of Nanofluid necessarily does not increase the heat transfer capability of it. The physical properties of nanofluids compared to pure fluid such as viscosity, heat capacity, density and stability of nanoparticles in the fluid maybe deteriorated. Convection having divided into two types i.e. natural convection and force convection. Natural convection is the type of convection which the flow is generated by buoyancy force during cooling or heating of the fluid and Force convection is the convection in which the flow is due to external forces such as pump, fan, compressor and etc. (Raj Kemal et al, 2007). The law of convection is Fourier's conduction law (Incropra 2002)[16]:-

$$Q = hA\,(T_W - T_f) \quad \ldots.(2.2)$$

Where Q is the amount of heat transfer between the wall and the fluid in motion, A is the solid-liquid interface area, T_W is the wall temperature and T_f is the fluid temperature.

$$q=Q/A= h\,(T_W - T_f) \quad \ldots\ldots(2.3)$$

This gives the picture of newton's law of cooling, which states that convective heat flux is directly proportional to the temperature difference between the wall and the fluid.

Here, h= heat transfer coefficient ($W/m^2.K$)

Where, h depends on number of factors such as fluid and its properties, flow geometry, flow regime (laminar or turbulent flow), flow velocity and thermal boundary conditions at the wall. Nanofluids can be used for wide variety of industries, ranging from transportation to energy production and in electronics system like microprocessors and MEMS. Recently the number of companies that observe the potential of Nanofluids technology and their focus for specific industrial applications is increasing. Kostic reported that nanofluids can be used in the following areas. [17]

- Heat transfer nanofluids
- Process/extraction nanofluids
- Tribiological nanofluids
- Chemical nanofluids
- Medical nanofluids (drug delivery and tissue-cell interaction)
- Environmental (pollution cleaning) nanofluid

III. LITERATURE REVIEW

M. Naraki [18] found that thermal conductivity of CuO/water nanofluids much higher than that of base fluid/water and observed that overall heat transfer coefficient increases with the enhancement in the nanofluid concentration from 0 to 0.4 volume %. Conversely, the implementation of nanofluid increases the overall heat transfer coefficient up to 8% at nanofluid concentration of 0.4 volume % in comparison with the base fluid. Liu et al. [19], investigated the thermal conductivity of copper–water nanofluids produced by chemical reduction method. Results showed 23.8% improvement at 0.1% volume fraction of copper particles. Higher thermal conductivity and larger surface area of copper nanoparticles are attributed to this improvement. It is also noted that thermal conductivity increases with particles volume fraction but decreases with elapsed time. Lee et al. [20] revealed thermal conductivity of nanofluids is affected by pH level and addition of surfactant during nanofluids preparation stage. Better dispersion of nanoparticles is achieved with addition of surfactant such as sodium dodecyl benzene sulfonate. Optimum combination of pH and surfactant leads to 10.7% thermal conductivity enhancement of 0.1% Cu/H2O nanofluids. Thermal conductivity of ethylene glycol based ZnO nanofluids measured by transient short hot wire technique is found to be increased non-linearly with nanoparticles volume fraction. Ollivier et al. [21] numerically investigated the possible application of nanofluids as a jacket water coolant in a gas spark ignition engine. Pure ethylene glycol is a poor heat transfer fluid compared to a 50/50 mixture of ethylene glycol and water, but the addition of nanoparticles will improve the situation. If the resulting heat transfer rate can approach the 50/50 mixture rate, there are important advantages. Perhaps one of the most prominent is the low pressure operation of an ethylene-glycol-based nanofluids compared with a 50/50 mixture of ethylene glycol and water. This nanofluid also has a high boiling point, which is desirable for maintaining single-phase coolant flow. More heat rejection allows a variety of design enhancements including engines with higher horsepower. Ollivier et al. found that found that the more concentrations of the nanoparticles, the more enhancement of the engine heat dissipating capacity. When the concentration of nanofluid reaches 5%, the heat dissipating capacity is increased by 44.1%. With a remarkable enhancement on heat-transfer capability, the workload of the pump of engine cooling system only increased by 6%, which could be acceptable. Kole et al. prepared car engine coolant (Al2O3 nanofluid) using a standard car engine coolant (HPKOOLGARD) as the base fluid, and studied the thermal conductivity and viscosity of the coolant. The prepared nanofluid, containing only 3.5% volume fraction of Al2O3 nanoparticles, displayed a fairly higher thermal conductivity than the base fluid, and a maximum enhancement of 10.41% was observed at room temperature [22]. Duangthongsuk and Wong wises [23] reported that heat transfer coefficient of TiO2–water nanofluids is higher than base fluid. This property increases with the increase of Reynold's number and particle concentrations ranging from 0.2% to 2%. Although the study revealed that 26% enhancement can be observed for nanofluids with 1% of TiO2 nanoparticles, it showed contradictory results at 2.0% volume fraction. Study indicated that heat transfer coefficient of nanofluids at this condition was 14% lower than base fluid. Eastman et al found [24] that a "nanofluid" consisting of copper nanometer-sized particles dispersed in ethylene glycol has a much higher effective thermal conductivity than either pure ethylene glycol or ethylene glycol containing the same volume fraction of dispersed oxide nanoparticles. Thermal conductivity of ethylene glycol can be increased by 40 % for a nanofluids consisting of ethylene glycol containing approximately 0.3 volume % Cu nanoparticles of mean diameter <10 nm. Leong et al. [25] reported that about 3.8% of heat transfer enhancement and almost 18.7% reduction of air frontal area is achieved by adding 2% copper nanoparticles at Reynold's number of 6000 and 5000 for air and coolant respectively. Their analyses showed substantial increase in the average heat transfer coefficient with concentration. The simulation of cooling effects of water, TiO2 nanofluid, Al2O3 nanofluid and CuO nanofluid have done by Peng et al. [26]. They showed that compared to water by using TiO2, Al2O3 and CuO nanofluid, the average surface heat transfer coefficient is increased by 10.82%, 8.43% and 11.24%, and correspondingly the pump power is increased only by 1.06%, 1.30% and 1.98%, respectively. Raja, S Suresh observed that heat transfer coefficient of Al2O3 nanofluid increases with volume concentration. The maximum was observed for 2% volume concentration which is about 25%. For peclet number 3000, the enhancement at 0.5%, 1%, 1.5% and 2% nano particle volume concentration are about 11%, 18%, 23%, 25% respectively. [27] Thermal conductivity of zinc dioxide ethylene glycol (ZnO + EG) based nanofluids was investigated by Yu et al .They obtained about 26.5% enhancement of thermal conductivity by adding 5% volume fraction of zinc dioxide nanoparticles in ethylene glycol and also conducted heat transfer experiments of nanofluids containing 170-nm silicon carbide particles at 3.7% volume concentration. The results showed that heat transfer coefficients of nanofluids are 50-60% greater than those of base fluids at a constant Reynolds number. [28]. Rahul A. Bhogare, B. S. Kothawale observed that with increase in the concentration of the Al2O3 particle in the base fluid .It showed increment in the thermal conductivity. The thermal conductivity of the mixture of EG + water (50/50) combination increases by adding the volume fraction of the Al2O3 particle in nanofluids. The percentage increase in thermal conductivity by adding the 1% volume fraction of Al2O3 particle in the base Fluid is 3.03%. [4] Nguyen et al. [29] performed their experiments in the radiator type heat exchanger and at 6.8 vol. % Al2O3 in water obtained 40% increase in heat transfer coefficient. Sharma et al. [30] implemented 12.5 vol.% Al2O3 in water in a horizontal tube geometry and concluded that at (Pe) number of 3500 and 6000 up to 41% promotion in heat transfer coefficient compared to pure water may be occurred. Wang et al. [31] dispersed 28-nm-sized Al2O3 nanoparticles in different base fluids and prepared nanofluids by mechanical blending, coating particles with polymers and filtration method. The thermal conductivity enhancement was 16% for 5.5 volume % and 12% for 3% volume faction. Xie et al. [32] used 60.4-nm-sized particles, observed higher thermal conductivity enhancement for larger nanoparticles in ethylene glycol-based nanofluids. In the case of Xie et al. , the researchers used 60.4-nm-sized Al2O3 dispersed in water and prepared stable solution by adjusting pH. The nanoparticles are de-agglomerated by using an ultrasonic disrupter after mixing with a base fluid and were homogenized by using magnetic force agitation. The enhancement observed was 21% for 5% volume fraction and 14% at 3.2% volume fraction.

Scientists	**Base Fluid**	**Nano particle**	**Conc. in Volume (%)**	**Thermal Conductivity (TC)/ Heat Transfer Coefficient (HTC)**	**Particle size**	**REF.**
M. Naraki	Water	CuO	0 to 0.4	8%(HTC)		[18]
Liu et al.	Water	Cu	0.1	23.8%(TC)		[19]
Lee et al.	Water	Cu	0.1	10.7%(TC)		[20]
Olliver et al.	Water	Cu	Less than 5%	15%(TC)		[21]
	Water	Cu	5%	44.1%(TC)		
Kole et al.	[HP KOOLGARD]	Al_2O_3	3.5%	10.41%(TC)	<50nm	[22]
Duang thongsuk & Wong wises	Water	TiO_2	1%	26%(TC)		[23]
Eastman et al.	Ethylene glycol	Cu	0.3%	40%(TC)	< 10nm	[24]
Leong et al.	Water	Cu	2%	3.8% (HTC)		[25]
Peng et al.	Water	TiO_2	-	10.82%(HTC)		[26]
	Water	Al_2O_3	-	8.43%(HTC)		
	Water	CuO	-	11.24%(HTC)		

M. Raja S. Suresh	Water	Al_2O_3	0.5%	11% (HTC)		[27]
	Water	Al_2O_3	1%	18% (HTC)		
	Water	Al_2O_3	1.5%	23% (HTC)		
	Water	Al_2O_3	2%	25% (HTC)		
Yu et al.	EG	ZnO	5%	26.5%(TC)		[28]
	Water	170nm SiC	3.7%	50-60%(HTC)		
B.S. Kothawale, Amol Gawali	EG : Water (50:50)	Al_2O_3	1%	3.03%(TC)		[4]
Nguyen et al.	Water	Al_2O_3	6.8%	40%(HTC)		[29]
Sharma et al.	Water	Al2O3	12.5%	41%(HTC)		[30]
Wang et al.	Nanofluids	Al_2O_3	5.5%	16%(TC)	28nm	[31]
			3%	12%(TC)		
Xie et al.	Ethylene Glycol	Al_2O_3	-	30%(TC)	15& 60.4nm	[32]

Table 1- Effect of Nanofluids on Thermal Conductivity

IV. APPLICATIONS

Today, many industries facing thermal challenges and have a great need for ultrahigh-performance cooling. However, conventional coolants are inherently poor heat transfer fluids. Although particle-in-liquid suspensions or slurries are frequently used in industry but they are not suitable for heat transfer applications, due to severe problems caused by large particles (agglomeration) in those suspensions or slurries. The major problem with traditional suspensions containing millimeter or micrometer-sized particles is the rapid settling of these particles (stability). If the fluid were kept circulating to prevent much settling, the micro particles would damage the walls of the pipe and make them thin. Other problems include large increase in pressure drop and clogging, particularly in small thermal control systems. Because nanoparticles are so small, they remain in suspension almost indefinitely and dramatically reduce erosion and clogging compared with the suspension of larger particles. Also, their larger surface area may improve heat transfer. Therefore, nanofluids are not only of academic interest but also of industrial interest. Nanofluids can be used to improve heat transfer, thermal conductivity and energy efficiency in many ways. Cooling is a top technical challenge facing high-tech industries such as microelectronics, transportation, manufacturing, and metrology. Cooling is required to maintain various electronic products at selected temperatures for proper functioning and long life. Powerful chips are at the heart of electronic products and heat ejection is the real problem. Air cooling, consisting of a heat sink and a fan, is the most common method for cooling electronics. Some new techniques have emerged to extend the useful range of air cooling, such as piezofans (Acikalin et al) [33] and synthetic jet cooling (Glezer and Mahalingam)[34]. Air cooled aluminum heat pipes developed at Intel can remove a total power of 200 W with a heat flux up to 200 W/cm^2. For heat fluxes below 100 W/cm^2, air cooling may remain the cooling method of choice but drawback is that it creates a lot of noise. With the advances in computing technology over the past few decades, electronics have become faster, smaller and more powerful. In most cases, the chips are cooled using forced air flow. However, when dealing with a component that contains billions of transistors working at high frequency, the temperature can reach a critical level where standard cooling methods are not sufficient and there is requirement of removal of high heat flux removal. So MCHS (Micro Channel Heat Sinks) was come in discussion because of its ability to produce high heat transfer coefficient rather than having small size and volume per heat load and small coolant requirements. This concept was proposed by (Tuckerman and Pease,) [35]. It contains a large number of parallel micro channels with a hydraulic diameter ranging from 10 to 1000 mm. A coolant is forced to pass through these channels to carry the heat away from a hot surface. Since then, MCHS is under study by researchers. Unique methods are investigated by using different substrate materials and channel dimensions to achieve the desired objective of developing a design which increase MCHS performance.

A. Vehicle Cooling

Nanoparticles can be dispersed not only in coolants and engine oils, but in transmission fluids, gear oils, and other fluids and lubricants means have a great use in automobile sector. These nanofluids may provide better overall thermal management and better lubrication. Tzeng et al. (2005) [36] was the first to apply nanofluid research in cooling a real-world automatic power transmission system. They dispersed CuO and Al2O3 nanoparticles into automatic transmission oil to investigate the optimum possible compositions of a nanofluid for higher heat transfer process.

B. Nanofluid as Coolant

In a study done by Saidur et al (2011) [37] have shown that the use of nanofluids in radiators can lead to a reduction in the frontal area of the radiator by up to 10%. This reduction in aerodynamic drag can lead to a fuel saving of up to 5%. Ethylene glycol based nanofluids have attracted much attention in the application as engine coolant [7-9], due to the low pressure operation compared with a 50/50 mixture of ethylene glycol and water, which is the universally used automotive coolant. The nanofluids has 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 [38] and also contributed to a reduction in friction and wear. It is conceivable that greater improvement of savings could be obtained in the future but with time nanofluids degrade radiator material and Erosion of radiator material will be there. Choi studied on the development of energy efficient nanofluids and smaller and lighter radiators. A major goal of the nanofluids project is to reduce the size and weight of the HV cooling systems by >10% thereby increasing fuel efficiency by >5%. Nanofluids enable the potential to allow higher temperature coolants and higher heat rejection in HVs. A higher temperature radiator could reduce the radiator size by perhaps 30%. This translates into reduced aerodynamic drag and fluid pumping and fan requirements, leading to perhaps a 10% fuel savings.

C. Nanofluid as Fuel Additives

Due to depletion of natural resources like natural gas, oil and water at faster rate and due to trends toward faster speeds it is need to improve the efficiency and the performance of automobile by using different methods. If this rate is continued, then we are at verge of extinction. Many methods like reducing the vehicle weight, improving the engine performance have been used and also under investigation. In the recent research it has been found that we can use the nanoparticles as fuel additives to improve the fuel economy as well as to reduce the exhaust emissions and also combustion stability. The scientists in nano science and technology council in USA have achieved to increase 10-25% combustion efficiency by adding 0.5% of aluminum nanoparticles to a rocket's solid fuel [49]. Also the combustion speed has been increased because of nanoparticle additives.

Due to the use of Aluminum nanoparticles in base fluid, it serves as the catalyst to decompose water and fuel consumption can be reduced [50]. When diesel fuel mixed with aqueous aluminum nanofluid, pure Al increased decomposition of hydrogen from water during the combustion process and resulted in increase of the total combustion heat and decreasing the concentration of smoke and nitrous oxide[52]. Cerium oxide nanoparticles were used in base fluid such as diesel and bio-diesel mixture and found the improvement and reduction in the exhaust emission by using a cerium oxide nano particle catalyst. The cerium oxide acted as an oxygen donating catalyst and provides oxygen for the oxidation of CO or absorbs oxygen for the reduction of NOx [51].

D. Nanofluid as Braking Fluid

During the process of braking, A vehicle's kinetic energy is dispersed through the heat produced during the process of braking and this is transmitted throughout the brake fluid in the hydraulic braking system , the produced heat causes the brake fluid to reach its boiling point, a vapor lock is created that retards the hydraulic system from dispersing the heat caused from braking. It will create a brake malfunction and poses a safety hazard in vehicles. Copper-oxide and aluminum-oxide based brake nanofluids were manufactured using the arc-submerged nanoparticles synthesis system and the plasma charging arc system [39, 40]. The two kinds of nanofluids both have enhanced properties such as a higher boiling point, higher viscosity, and a higher conductivity than that of traditional brake fluid. By yielding a higher boiling point, conductivity, and viscosity, the nanofluid brake oil will reduce the occurrence of vapor-lock and offer increased safety while driving.

E. Nanofluid as Lubricant

In automobile lubrication nanoparticles dispersed in mineral oils were reported to be effective in reducing wear & enhancing load carrying capacity [41]. Recently lots of researchers show their interest to enhance the tri biological properties (such as load carrying capacity, wear resistance and friction reduction) of nanoparticle suspended lubricants. The vehicle life time as well as the performance will be increased by using the nanoparticle suspended lubricants. Osorio et al. investigated the tribological properties of CuO suspended lubricant. They suspended 30-50 nm sized CuO nanoparticles in polyalphaolefin (PAO6) and came to conclusion that the addition of CuO nanoparticles to the polyalphaolefin (PAO6) reduces friction with respect to base oil and also the nanoparticles could react with the surfaces forming antifriction compounds and deposit on the wear surfaces by tribosinterization [42]. The Mu-Jung Kao et al. have used the TiO2 nanoparticles as additives to reduce the friction between the two pieces of cast iron. They suspended the TiO2 nano particles in paraffin oil, studied the characteristics of nanofluids and also studied the tribiological properties. They concluded that the nanoparticles could fill rough cracks in a metal wall surface to reduce the coefficient of friction [43].

F. Nanofluid as Shock Absorber

Shock absorbers used for the comfortable ride in vehicles ranging from sports car to pick-up trucks. The hydraulic shock absorbers were used in modern automobiles to reduce the space and to improve the performance of shock absorber by absorbing more vibrations. The researchers prepared special kind of fluid by suspending a magnetic nanoparticle with the base fluid. The above prepared fluid is known as Magneto Rheological nano fluid or Electro Rheological nanofluid. Shock absorbers based on magnetic fluids are used in the modern automobiles like "Audi Le mans Quattro".

V. PROPERTIES

Nanoparticles having peculiar properties such as

(a) Size dependent physical properties (color, conductivity)

(b) Large surface area (the specific surface area 3 times greater than micro particles),

(c) High density (for given mass there are greater number of particles as the size decreases),
(d) Surface structure (nanoparticles have approx 20%) of their atom near the surface allowing them to absorb & transfer heat more efficiently
(e) Small size (improve stability of suspension).

These made researchers mind to investigate on them thoroughly. So these are used in base fluids in definite proportion to improve stability, efficiency and thermal conductivity. They possess enhanced thermo physical properties such as thermal conductivity, thermal diffusivity, viscosity and convective heat transfer coefficients compared to those of base fluids like oil or water. In general, nanofluids operating at higher temperature, there is decrease in viscosity of nanofluids & with increase in nanoparticle volume concentration, there is small increase in nanofluid dynamic viscosity & density of nanoparticle in base fluid. For particles in the nanometer range, the surface forces become predominant and the interactions are controlled by short range forces like Vander Waals attraction force. These interactions lead to the formation of agglomerates and led to increase the viscosity of the fluids [56]. Therefore the friction factor and the pressure drop must be increased. Hence, nanofluids generally require the greater pumping power than their base fluid [57]. The nanofluids have high boiling point, used to increase the normal coolant operating temperature, and then reject heat through existing coolant system and enables the potential to allow higher temperature coolants and higher heat rejection in heavy vehicles.

Specific heat plays a pivotal role in determining the characteristics of nanofluids as along with Thermal conductivity; specific heat is the property which differentiates the liquid cooling system over air cooling. The specific heat describes the amount of heat required to increase the temperature of the sample by a given amount. As expected, the specific heat increases with increasing the temperature and decreases with increasing the solid content i.e. nanoparticle volume concentration [58].

Heat transfer rate can be calculated as follows:

$$\mathbf{Q=mc_p(T_{in}-T_{out})\ldots\ldots\ldots\ldots(a)}$$

In Radiator, heat transfer rate can be calculated as:-

$$Q=m_{nf}.c_{p,nf}(T_1-T_2)\ \ldots\ldots(b)$$

Where *nf* and *air* denote the parameters of nanofluid coolant and airflow.

Heat transfer enhancement depends on number of factors:-Thermal conductivity and Brownian motion. Due to the enhancement of the thermal conductivity of the nanofluids, the convective heat transfer coefficient of the nanofluids increases. The enhancement of convective heat transfer coefficient of a nanofluid in an internal flow has been reviewed by Wang et.al.[59] in both laminar and turbulent regimes. The primary factor is suspension of nanoparticles which will increase the surface area. As a result of which, there are more collisions and interactions between working fluid, the particles and the flow passages which causes more disorder, integration, within the working fluid & there will increase in effective thermal conductivity and enhancement in heat transfer property of nanofluids. Due to this, Lubricating performance of coolant can also be enhanced [28].By suspending nano phase particles in heating or cooling fluids, the heat transfer performance of the fluid can be significantly improved. The main reasons behind this is: A) The mixing fluctuation and turbulence of the fluid are intensified and B) The dispersion of nanoparticles flattens the transverse temperature gradient of the fluid. Patel et al. (2008) [60] investigated the mechanisms of conduction in liquids and conduction through solid nanoparticles and the micro-convective heat transfer to the nanoparticles due to their Brownian motion in the liquid. These investigations show that nanofluids have higher heat transfer relative to conventional fluids and also a better stability compared to fluids with suspended micro particles, making nanofluids useful. Several factors such as gravity, Brownian motion, layering at the solid/liquid interface, ballistic phonon transport between the particles and nanoparticle clusters and the friction between the fluid and the solid particles contributes to the increase in nanofluid heat transfer. With a very small volume fraction of nanoparticles, thermal conductivity and convective heat transfer capability are enhanced significantly without the problems encountered in common slurries such as clogging, erosion, sedimentation, and large increases in pressure drop. Suspended nanoparticles have higher thermal conductivity than base-fluids, so the effective thermal conductivity of the nanofluids increases. The enhancement of thermal conductivity increases with the solid content i.e. volume fraction in Base fluid, due to the higher number of particles present in the suspension and the higher number of contacts between them. Choi et al [2] showed that the addition of a small amount of nanoparticles (less than 1% by volume) to base fluid would increase the thermal conductivity of the fluid up to approximately two times. But thermal conductivity having the most important property is not easy to determine accurately by a single formula, but there are some experimental relations that could be used to estimate it. With increase in temperature, there is increase in thermal conductivity but there is abnormal behavior of the thermal conductivity at high temperatures which is related to the solubility of the nanoparticles. In the nanometrical size range, kinetics of dissolution of particles is enhanced due to the small size according to the Kelvin equation. The dissolution increases with temperature, degree of dispersion and time. So, at high temperature, more solid is dissolved and the conductivity decreases. This decrease becomes higher and higher for better dispersed nanofluids. Silver nano rods of 55±12 nm diameter and 12.8 µm average length at 0.5 vol.% increased the thermal conductivity of water by 68%, and 0.5 vol.% of silver nano rods increased thermal conductivity of ethylene glycol used coolant by 98%. Hwang et al. [6] found that thermal conductivity of the nanofluids depends on the volume fraction of particles and thermal conductivity of base fluid and particles. Mintsa et al. [61] investigated the effect of temperature, particle size and volume fraction on thermal conductivity of water based nanofluids of copper oxide and alumina. Authors found that the smaller the particle size, the greater the effective thermal conductivity of the nanofluids at the same volume fraction. Contact surface area of particles with fluid and Brownian motion can be increased when smaller particles are used in the same volume fraction. This consequently increased thermal conductivity of nanofluids.

Due to use of nanofluids as coolants in radiators, it found that there is significant increase in the critical heat flux of the base fluids. Alumina nanoparticles at 0.1% can increase the critical heat flux of water by as much as 70%. Nanofluids have great potentials to improve engine cooling rates by increasing the efficiency, lowering the weight, reducing the complexity of thermal management systems. As, this cooling rate can remove more heat from higher HP engines with same size of cooling system effectively.

VI. FUTURE CHALLENGES AND LIMITATIONS

The use of nanofluids seems attractive in a broad range of applications as reported in the previous section. But the development in the area of nanofluid application is hindered by many factors in which long term stability of nanofluid in suspension is major reason. So, this paper focuses many important challenges that should be solved in the near future. The following are the most pressing issues.

A. Poor long term stability of suspension

Due to agglomeration, settlement and clogging of nanoparticles, there is decrease in thermal conductivity of nanofluids. Long term physical and chemical stability of nanofluids is an important practical issue because of aggregation of nanoparticles, due to very strong Vander Waals interactions so the suspension is not homogeneous. Physical or chemical methods have been applied to get stable nanofluids such as

(i) Addition of surfactant;
(ii) Surface modification of the suspended particles;
(iii) Applying strong force on the clusters of the suspended particles.

Stability evaluation methods for nanofluids

Since today many methods have taken into account for stability but a few has become quite effective. One of the simplest and earliest methods is sedimentation. In this method, the sediment weight or volume of nanoparticles in nanofluids under an external force field is the indication of stability of particular nanofluid & nanofluid as coolants is assumed to be stable when the concentration or particle size of sedimented particle is constant[53]. Zhu et al used a sedimentation balance method to measure the stability of graphite suspension [54]. There is the limitation for this method as it requires long term observation. So, centrifugal method came into effect. Singh et al applied this method to observe the stability of silver nanofluids prepared by microwave synthesis in ethanol by reduction of AgNO3 with PVP as stabilizing agent [55]. Results obtained are that nanofluids are stable for more than 1 month in stationary state and more than 10 hour under centrifugation at 3000 rpm without sedimentation. It is because of the use of PVP as it retards the growth and agglomeration of nanoparticles by steric effect. The ways to enhance the stability of nanofluids

Surfactants used in nanofluids also known as dispersants, even small quantity of dispersants can affect the surface characteristics. Dispersants consists of hydrophobic tail portion, usually long chain hydrocarbon and a hydrophilic polar head group, which helps in increasing the contact of two materials and process is known as wettability. According to composition of head, surfactants are divided into four classes:- (a) non-ionic surfactants without charge groups in its head (include polythene oxide and alcohol etc.), (b) anionic surfactants with +vely charged head group, (c)cationic surfactants with +vely charged head group and (d) amphoteric surfactants with zwitter ionic head group.

For selection of dispersants, when base fluid is a polar solvent, we should select water soluble surfactants, otherwise we select soluble ones. For non ionic surfactants, we can evaluate the stability through the term hydrophilic/liophilic balance stability (HLB). Lower the HLB number, the more oil soluble surfactants is and the higher the HLB number, the more water soluble surfactant is. But there is the drawback of using dispersants that addition of dispersants can contaminate heat transfer media and may produce foams in heating and cooling process of heat exchange systems.

Stability mechanism

In the radiator, particles in dispersion may adhere together and form aggregates of increasing size and this cause in settlement of particles due to gravity means stability is inverse to agglomeration. This rate is determined by the frequency of collisions and probability of cohesion during collision. DVLO presented a theory which dealt with colloidal stability which suggests that the stability of a particle in a solution is determined by the sum of Vander Waals attractive and electrical double layer repulsive forces that exist between particles when they approach each other due to Brownian motion among the particles of fluid. If the attractive forces are larger than repulsive forces, two particles will collide and suspension is not stable and if particle have sufficient high repulsion, the suspension will exist in stable state. So, repulsive force must be dominant for the stability. According to types of repulsion, the fundamental mechanisms that affect colloidal stability are divided into two groups:- (a) Steric repulsion, (b) Electrostatic (charge) repulsion. For Steric repulsion, polymer plays important role in suspension systems, they will absorb on particle surface, producing an additional steric repulsive force. Ex- ZnO nanoparticles modified by PMAA have good compatibility with polar solvents. For electrostatic stabilization, surface charge will be developed through many mechanisms:-Preferential absorption of ions, dissociation of surface charged species, isomorphic substitution of ions, accumulation or depletion of electrons at surface, physical adsorption of charged species onto surface.

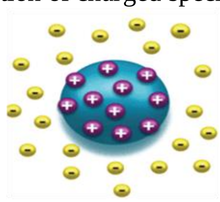

Figure 3- Steric stabilization

Figure4-Electrostatic stabilization

Generally, long term stability of nanoparticles dispersion is one of the basic requirements of nanofluids applications. Stability of nanofluids has good corresponding relationship with the enhancement of thermal conductivity. As a result of this, thermal conductivity of nanofluids is eventually affected. Eastman et al. [25] 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 measured twice: first was within 2 days and second was two months after the preparation. It was found that fresh nanofluids exhibited slightly higher thermal conductivities than nanofluids that were stored up to two months. This might due to reduced dispersion stability of nanoparticles with respect to time. Nanoparticles may tend to agglomerate when kept for long period of time. Due to particle settlement it may lead clogging of coolant passages.

B. Increased pressure drop and pumping power

Pressure drop developed during the flow of coolant is one of the important parameter determining the efficiency of nanofluids application. There are few properties which could influence the coolant pressure drop i.e. flow rate, density and viscosity. The flow rate has linear relationship with pressure drop. For a particular flow rate the pressure drop of water was lower and it increased for nanofluid with increased concentration. Since the density remains constant, the dispersing behavior in pressure drop of nanofluid may be due to viscosity which is mainly influenced by formation of particle cluster and defragmentation of the cluster. It is expected that coolants with higher density and viscosity experience higher pressure drop. This has contributed to the drawbacks of nanofluids application as coolant liquids. Lee et al. [21] and Yu et al. [45] investigated viscosity of water based Al2O3 nanofluids and ethylene glycol based ZnO nanofluids. Results clearly show, viscosity of nanofluids is higher than base fluid. Namburu et al. [46] in their numerical study reviewed that density of nanofluids is greater than base fluid. Both properties are found proportional with nanoparticles volume fraction. Vasu et al. [47] studied the thermal design of compact heat exchanger using nanofluids. In this study, it is found that pressure drop of 4% Al2O3 +H2O nanofluids is almost double of the base fluid. Pantzali et al. [48] reported there was substantial increase of nanofluids pressure drop and pumping power in plate heat exchanger. About 40% increase of pumping power was observed for nanofluids compared with water. In another study, observed that the measured viscosity of the suspension (i.e. nanofluids) exhibits a twofold increase compared to water. This leads to a significant increase in the measured pressure drop and consequently in the necessary pumping power when the nanofluids are applied. Authors calculated that the pumping power increased about 40% compared to water for a given flow rate.

C. Lower specific heat

From the literatures, it is found that specific heat of nanofluids is lower than base fluid. An ideal coolant should possess higher value of specific heat which enables the coolant to remove more heat. Namburu et al. [46] reported that CuO/ethylene glycol nanofluids, SiO2/ethylene glycol nanofluids and Al2O3/ethylene glycol nanofluids exhibit lower specific heat compared to base fluids.

D. High cost of nanofluids

Nanofluids are prepared by either one step or two step methods. Both methods require advanced and sophisticated equipments and great attention. This leads to higher production cost of nanofluids. Therefore high cost of nanofluids is drawback of nanofluid applications. . Lee and Mudawar [44] and Pantzali et al. [48] stressed that high cost of nanofluids is among the drawback of nanofluids applications.

E. Higher viscosity

The viscosity of nanoparticle–water suspensions increases in accordance with increasing particle concentration in the suspension. So, the particle mass fraction cannot be increased unlimitedly. Pantzali et al. [48] concluded that in industrial heat exchangers, where large volumes of nanofluids are necessary and turbulent flow is usually developed, the substitution of conventional fluids by nanofluids seems impossible.

F. Difficulties in production process

Since nanofluids are manufactured either by one step or two step process, there is always involvement of reduction reactions or ion exchange. Since, the base fluids also contain other ions and reaction products so it is very difficult or impossible to separate from the fluids. Another difficulty encountered in nanofluid use at large scale is nanoparticles' tendency to agglomerate into larger particles, the effective surface area to volume ratio decreases, thus reducing the effective area of thermal interaction of particles causing a decrease in the thermal conductivity of the fluid. But due to the addition of particle dispersion additives to the base fluid this can be cured. Unfortunately, this practice can change the surface properties of the particles, and nanofluids prepared in this way may contain unacceptable levels of impurities.

VII. FUTURE WORK

After studying extensive uses of nanofluids in automobiles as vehicle cooling, we have also got some points which are to be deeply studied. Stability of suspensions is an important issue for scientists and also for practical applications i.e. in automobiles and refrigerators means stability for long term and stability after thousands of cycles is a great issue. Performance of nanofluids at higher temperature is also the primary obstacle as higher temperature may accelerate the degradation of surfactants used as dispersants in nanofluids and may result in production of foams and also increase in viscosity by use of nanofluids is important drawback to increase in pumping power. Many properties like thermal conductivity, Brownian motion, particle path and migration, thermo physical properties changing with temperature must be considered with convective heat transfer and study is required to identify the reasons for and effects of particle deposition. One appealing possibility is to create fluids whose thermal properties can be engineered and set as specific task demands, but till now, basic facts about nanoparticles remain unclear. Eastman et al, for example, would like to know why the molecules of a base fluid keep nanoparticles suspended so well, since nanoparticles are still dramatically larger than individual molecules and after having so much of research, its conclusion or process it is still unclear, why nanofluids conduct heat so effectively. Eastman speculates that it may be related to the increased surface interaction. "Since for a given volume of material, there are a greater number of particles as their size decreases, perhaps there is more opportunity for the nanoparticles to conduct the heat. Nanofluids are so much expensive because of manufacturing equipments used as they are one of a kind. So to bring the cost down and to make affordable for widespread use, there applications and properties must be studied deeply. Development of nanofluids is hindered by (a) Lack of agreements in results produced by different researchers. (b) Poor characterization of suspensions (c) Lack of theoretical understanding in mechanisms responsible for changes in properties. Future work has to be on the synthesis, stability, thermal properties and also at applicable places so that our ecosystem is more efficient, smaller, healthier and eco-friendly.

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