Nanofluids: A Review on Current Scenario and Future prospective

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Abstract. The use of additives in the base fluid is one of the techniques to strengthen the heat transfer. With the amelioration in the field of nanotechnology, a new class of heat transfer fluids has been engineered, a base fluid (host) in which nano particles (guests) are dispersed and suspended stably. Researches have showed that these fluids exhibit higher thermal conductivity than the base fluid. As a result, the study of nanofluids has materialized as a new field of scientific interest and innovative application. This paper focuses on the recent advancements in the study of nanofluids such as preparation methods, stability of nanofluids and presents the extensive area of applications.

1. Introduction
Heat transfer enhancement is an important concern in the field of thermal engineering. Many efforts have been taken to improve the heat transfer rate of different thermal systems. For decades, adding additives to the Coolant was the practice for enhancing the heat transfer. It was found that while adding additives improved the heat transfer problem of fouling, thereby reducing the life of the components. However, the development in the field of Nano technology enabled the discovery of new category of Coolants namely the Nano-Coolants (Coolant with dispersed Nano particles), where a concept of guest and host arises. The nano particles which is preferably called as guest is dispersed into the host, which is the base fluid. It was found that there was enhancement in thermo physical properties when compared to the base fluid and it increased as the concentration of nano particles in the base fluid increased. Devi Reddy et al.[1] performed an experiment on automobile radiator using ethylene glycol and water based TiO2 nanofluid as the Coolant at different concentration levels of nano particles. The results showed that there is enhancement in heat transfer coefficient compared to the base fluid to an extent of 17.77-34.12%. Das et al.[2] studied the viscous behavior of alumina-water nano fluid and concluded that viscosity increases with increase in particle concentration. Das et al.[2] conducted experiment using Al2O3-water nano fluid and CuO water nano fluid when it has been observed that nano fluid containing smaller CuO particles showed enhancement in thermal conductivity with temperature. The effect of particle concentration was observed more for Al2O3 - water nano fluids. Ju et al.[3] measured the thermal conductivity of aqueous alumina nano particle using hot wire setup for 20nm 30nm and 45nm upto a volume concentration of 10% and observed that there is an anomalous enhancement in thermal conductivity. Shyam Sundar et al.[4] performed investigation using Ni-Diamond nano particles in different proportions of ethylene glycol water mixture and water alone and concluded that the thermal conductivity was maximum for nanoparticles dispersed in water and ethylene glycol mixture. Abdul Hamid et al.[5] conducted an experiments using ethylene glycol-TiO2 and TiO2 - ethylene glycol(60:40). The first nanofluid was a commercial grade and second one was prepared by dilution method and it was found that for ethylene glycol- TiO2 the enhancement in heat transfer coefficient was 28.9% and for TiO2 - ethylene glycol(60:40) mixture only reduction in viscosity was observed due to increase in temperature. Murali krishna et al.[6] conducted an experiment using ZnO- water nanofluid prepared by sol-gel method...
and it was passed through concentric heat exchanger when it was observed that overall heat transfer coefficient increased by 11% for a volume fraction of 0.5%. Meena et al.[7] investigated the tribological behaviour of titanium oxide nano particle in an engine oil. It was observed that the coefficient of friction was reduced by 86% with 0.3% concentration by weight of the oil as compared to the oil without TiO$_2$ nanoparticles for load of 4 kg. M. Tajik Jamal-Abadi et al.[8] measured the thermal conductivity of Cu-water and Al-water nano fluids experimentally by thermal property analyzer. It was concluded that thermal conductivity enhancement rise from 12% to 26% (for Cu-water at 2000 ppm) and 11% to 22% (for Al-water at 2000 ppm). From the above result, it can be said that particle concentration is an important parameter, as particle concentration increases thermal conductivity of nanofluids increases.

Leong et al.[9] used ethylene glycol-Cu nanofluid and it was experimented in an automobile radiator. It was found that there was an enhancement in overall heat transfer coefficient by 3.8% for an addition of 2% of copper nano particles for a Reynolds number of 5000 and 6000. Ismat et al.[10] used CuO-PVA nanofluid using Thermo gravimetric analysis (TGA) and differential thermal analysis (DTA). Thermal stability and weight loss of the CuO NPs were studied and experimentally it was concluded that as temperature increases the viscosity decreases. Senthiraja et al.[11] performed an investigation on double pipe heat exchanger using CuO-water nanofluid at volume concentration of (0.1&0.3%) at room temperature when it was found that there was an huge increase in overall heat transfer coefficient for a Reynolds number of 25000. Wesley Williams et al.[12] used horizontal tubes were Zirconia-water nanofluid was allowed to flow at different flow rates and it was found that there was no abnormal increase in heat transfer rate. Heat transfer performance of an automobile radiator was conducted by S.M. Peyghambazardeh et al.[13] using Fe$_2$O$_3$-water nano particles at concentrations of 0.15,0.4 and 0.65vol% and it was found that there was an enhancement in overall heat transfer coefficient by 9% for Reynolds number of(500-1000). Two sets of experiments were conducted by R. Aghayari et al.[14] in a double pipe heat exchanger using iron oxide-water nanofluid where the concentration ranged from (0.12-0.2)% by volume. It was observed that there was an increase in Nusselt number by 132.5% (Re=2500). Bhaskar et al.[15] used silicon dioxide-water nanofluid and compared the experimental result with Hamilton and Crosser model and it was found that the model was unable to predict the thermal conductivity of the nanofluids. Wenhua Yu et al.[16] performed a heat transfer experiment with SiC-water nanofluid at constant pumping power, constant velocity and constant Reynolds number(3300 13000) and observed that there was an increase in heat transfer coefficient by (50-60)% . Xin Fang et al.[17] used silver nano particles measured thermal conductivity from 100$^\circ$C - 300$^\circ$C with an increment of 50$^\circ$C. Here nano particles of different shapes are used such as nano wires (NWs), nano fiber (NFs) and nano spheres (NSs), these nano particles are mixed with ethylene glycol. It was found that NFs and NSs nanofluids did no show much enhancement in thermal conductivity but presence of nano wires increased the viscosity of the ethylene-glycol suspension. S. Iyahraj et al.[18] prepared nanofluid by dispersing polyvinyl pyrrolidone coated silver nanoparticles in distilled water. The thermal conductivity of the nanofluid was measured by thermal analyzer. The experiment was conducted from 30$^\circ$C - 60$^\circ$C and was observed that there was an increase in thermal conductivity up to 69%.

2. Preparation of NanoFluids

Preparation of nanofluid is one of the major step that uses nano particles which helps to improve the thermal conductivity of the base fluid. Dispersion of the nano particles in a uniform manner and suspending them in the base fluid is critical in producing high quality nanofluid. Two methods are being followed for the preparation of nanofluids - one step and two step methods. Many one step and two step methods have been developed for the preparation of the nanofluids. These processes can be briefly explained:
One Step Method: In one step method, synthesis and dispersion of nano particles occurs simultaneously. Siva Eswara et al. [19] used sol-gel method for the preparation of alumina nanofluid. Eastman et al.[20] used one step method which involves direct condensation of the metallic vapour into the nano particles with a flowing low pressure liquid. Akanksha et al.[21] used direct evaporation method or the producing a stable nanofluid. Hai-tao et al. [22] used one step method for preparation of nanofluid by reducing CuSO₄·5H₂O with NaH₂PO₂·H₂O in ethylene glycol under micro wave radiation. Lo et al.[23] used Submerged Arc Nano particle Synthesis System (SANSS) to prepare CuO based nano particles where it is directly dispersed into deionized water. The advantage of one step method is that agglomerations of the particles are avoided. Diagrammatic representation of one step method is shown in figure 1.

Two Step Method: In this method, the nano particles are prepared as dry powder separately using physical or chemical method then dispersed into the base fluid with the help of magnetic force agitation, ultrasonic agitation and high-shear mixing. This method of producing nano particles tend to be cheaper, since they are produced in large scale. However due to large surface area these particles will have a tendency to agglomerate. So in order to attain stable suspension sonication, addition of stabilizer or adjustment of pH may be required. Akanksha et al.[21] used two step method to prepare wherein alumina nanoparticles were dispersed into the base fluid (water). 15gms of alumina nanoparticles were added to 10 liters of water. Micha et al. [26] prepared copper oxide nano fluid by mixing the nano powder with water and stabilizers, sonication was performed with an ultrasonic mixture. It can be concluded from the literatures that by two-step method it is difficult to obtain a stable nanofluid, this is where one-step method has an upper hand. Diagrammatic representation of two step method is shown in figure 2.

3. Stability of Nanofluids

Sometimes the particles that have been dispersed may adhere together and can form particles of larger size which may settle due to the effect of gravity. Stability means particles do not aggregate at a significant rate. The rate of aggregation is determined by the frequency of the collisions and the chance of cohesion during collision. It can be said that the theory the stability of the solution is determined by the van der Waals attractive and electrical double layer repulsive forces as the particle approach each other due to Brownian motion phenomenon, if the attractive forces is greater than the repulsive force the two particles will collide and the suspension is not stable. For the nanofluid to be stable the repulsive force
must dominate the attractive force [27]. The agglomeration of nano particles not only cause sedimentation but it also blocks the fluid passage and decreases the thermal conductivity of the nanofluids. Understanding about the stability is important since it has great influence on the properties of nanofluids. Different methods have been developed to evaluate the stability of nanofluids. Li et al.[28] used a sedimentation technique wherein copper nano suspensions were made and different dispersants were added and was kept under observation. State of sedimentation was observed every 24hrs. The following conclusions were made:

- Use of dispersant
- Use of ultrasonic Vibration
- Changing the pH value of the Suspension

All the above mentioned techniques provided a stable suspension. This was mainly because the technique improved the surface properties of the suspended particle. K singh et al.[29] studied about the stability of silver nanofluid under room condition and found that under stationary condition it was stable for 1 month and under the action of centrifugal force at 3000rpm it was stable for 10hrs without sedimentation. Ho jin et al.[30] prepared gold nanofluid using pulsed laser ablation technique. It was found that the nanofluid showed outstanding stability even after one month without using any dispersant. This was mainly due to large negative zeta potential of gold nanoparticles in water. Sebt et al.[31] produced colloidal solution of FePt nano particles by dispersing it into hexane and found that adding surfactants with centrifugation increased the stability of the solution. Shaoooli et al.[32] prepared CuO-water based nanofluid using PolyVinylPyrolidone (PVP) as dispersant. Zetapotential and absorbency were measured at different pH values and PVP concentrations. It was concluded that excellent stability was shown at the pH value of 8. Hwang et al.[33] estimated the stability of nanofluids using UV-vis spectrophotometer. It was concluded that the stability of the nanofluid was influenced by the characteristics between fluid and the suspended nano particles.

Surfactants that are added in the nanofluids are called dispersants. Since nanofluids is a two phase system, adding Surfactants is an economical way to enhance its stability. Surfactants consist of hydrophobic tail portion, mostly hydrocarbon chain and a hydrophilic polar head group. According to the composition of head, Surfactants are divided into four classes: nonionic surfactants, ionic surfactants, cationic surfactants and amphoteric surfactants. Hwang et al. used hydrophilic functional groups on nano tubes by mechananochemical reaction. Li et al.[34] used wet mechanochemical reaction to prepare surfactant-free nanofluid which contained singled walled and double walled CNT. Quing et al[35] used diamond nano particles with water for better dispersion characteristics. In water the nano particles were treated with plasma. Later it was observed that the stability of the nano fluid was increased. Johni et al.[36] used a bead milling process to get a stable dispersion of titania nanoparticles in an organic solvent of diethylene glycol diethylmether. Here the surface modification was done with silane coupling agent. For increasing the stability of titania nano fluid surface modification was carried during the centrifugal bead mill process.

4. Application of Nanofluids

As nanofluids exhibits enhanced thermo-physical properties, it’s application is limitless as a heat transfer fluid. These enhanced properties are mainly due to the Brownian motion which gives it an advantage over the conventional fluids used. The application is not only limited to the area of heat transfer system, but also extended to medical arena.
4.1 Heat Transfer Fluid
The potential of nanofluid to improve the efficiency of an automotive is tremendous. This improvement in efficiency can be done by decreasing the weight of the system along with thermal management. With increasing the cooling rate of an engine, more amount of heat can be removed with same size of the cooling system. The compactness that can be brought into the design of the radiator in turn increases the fuel economy of an automobile. Bhogare et al. [37] reviewed the application of Alumina nano particles with Engine oil (HP KOOLGARD) as the base fluid and concluded that there was a thermal conductivity enhancement by 10.41% for a volume fraction of 3.5% of nano particles in the base fluid. Sandeesh et al. [38] used MWCNT-water nano fluid to perform an investigation on automobile radiator and it was found that there was tremendous enhancement in heat transfer. An enhancement of 350% was observed for a volume concentration of 0.5%. Naraki et al.[39] used CuO-water nanofluid. Use of nanofluids not only help in increasing the efficiency and economic performance of an automobile but also miniaturizes the radiator helping it to be kept elsewhere in the automobile, which in turn helps to design it more aerodynamically.

4.2 Solar Energy
Solar energy is one of the widely used renewable energy which has least environmental impact. Otanicer et al.[40] investigated both numerical and experimental results of CNT, graphite and silver nanoparticles. Comparison between the DAC and conventional solar collectors were made and found that the efficiency was 10% higher. Tyagi et al.[41] conducted an investigation on direct absorption solar collectors (DASC) and compared it with a flat plate collector. A mixture of aluminum and water nano particles were used and found that the rate of absorption of radiation was nine times that of the pure water due to the presence of nano particles. Y. He et al.[42] conducted an experiment using water-carbon nanotubes and water-TiO$_2$ in a vacuum tube solar collector and it was found that water-CNT nanofluid at a weight concentration of 0.5% had better light conversion rate than the water-TiO$_2$ nanofluid. Li et al.[43] used three different nanofluids, MgO-water, Al$_2$O$_3$-water and ZnO-water on a tubular solar collector and it was found that ZnO-water nanoluid with 0.2% volume concentration showed the best result. Khullar et al.[44] theoretically investigated nanofluid based parabolic solar collector and compared it with the conventional concentrating parabolic solar collector operated under similar condition, aluminum nano particles were used with a concentration of 0.05%. It was found that nanofluid based parabolic solar collector had 5-10% efficiency higher compared to conventional concentrating parabolic solar collector.
4.3 Cooling of Electronic Components

Basically two approaches can be made to improve the heat transfer rate, one is to find out the optimum geometry and another one is to improve the heat transfer rate. Nanofluids which exhibit enhanced thermal conductivity helps to obtain higher heat transfer coefficient. Jang et al.[45] conducted a cooling performance investigation using micro channel heat sink with diamond-water nanofluid and it was found that the cooling performance was enhanced by 10% when compared with water based micro channel heat sink. Use of nanofluid caused a reduction in thermal resistance and the temperature difference between the heated micro channel wall and the coolant. Nguyen et al.[46] conducted an investigation on closed liquid-circuit to understand the enhancement of a liquid cooling system where water, the base fluid, was replaced by Al₂O₃-water nanofluids at various concentration levels and it was found that there was an enhancement in convective heat transfer coefficient by 23% for a volume concentration of 4.5%. Considering the thermal management in personal computers has become an important aspect as the energy dissipation rates increase tremendously, use of different heat transfer methods has become substantial. One solution is use of heat pipes. Nanofluids employed with heat pipes showed higher thermal performance, than the use of conventional water in heat pipes. Tsia et al.[47] used aqueous solution of nanoparticles in heat pipe at different concentration. It was found that the thermal resistance of heat pipe reduced when compared with DI water. Chen et al.[48] used flat heat pipe with silver nanofluid using different particle concentration and it was concluded that decrease in thermal resistance is owing to reduction in the boiling limit due to increase in effective liquid conductance and the effective thermal conductivity of the wick structure in heat pipes. Shung et al.[49] used silver-water nanofluid used as a working fluid in sintered circular heat pipe. It was observed that the temperature difference decreased 0.56-0.65 compared to DI water at an input power of 30-50 W. These results are encouraging the researchers to develop nanofluids in this area of application.

Fig.3. Schematic of nanofluid-based concentrated parabolic solar collector (NCPSC).[41]
5. Conclusions
The properties of nanofluids are found to be interesting and many are yet to be found out. This paper provides an overview on the recent developments in the field of nanofluids, their preparation methods, stability analysis, methods to maintain stable solution and their application in various engineering fields. Even though nanofluids exhibit tremendous applications, some obstructions are still being faced. Firstly, several experiments have been done especially in the field of Automotive Radiator. Some of them do not hold well, which gives rise to demand for further experimental studies. Secondly, the stability of oxide based nanofluids has been found to be more than that of the metal based nanofluids which hinders the use of metal based nanofluids. Studies and experiments have to be done to improve the stability of metallic based nanofluids and also to attain more stable solution for metal oxide based nanofluids. Thirdly, the use of nanofluids will surely increase the pumping power. Research must be carried for the development of nanofluids with low viscosity. There is no much study done on nanofluids under high temperature application, which is because there is a chance for the surfactants to breakdown. It was found that some nanofluids were prepared without using surfactants or changing pH, since it may change the thermophysical properties. The major advantage with nanofluid is it’s enhanced thermal conductivity due to which many studies has to be conducted to develop nanofluids for specific application. The cost of production of nanofluid has become a barrier for its commercialization. Prioritizing the problems and finding solutions accordingly will help to solve the challenges and will help nanofluids to make a promising impact in various applications

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