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Nano materials and nanofluids: An innovative technology study for new paradigms for technology enhancement

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Abstract

Various nano materials are being developed in the field of engineering. In present days nano material occupies the major area in engineering field. There are many present researches concentrates on nanofluids containing different nano particles with various volume concentration and size used in heat transfer applications. Nano fluid is an environmental friendly and also provides better efficiency than the fluids using currently. Nano fluid is a colloidal mixture of nano sized particles in a base fluid to enhance the heat transfer characteristics suited for practical application. This article summarizes the recent research in experimental and mathematical studies on heat transfer in nanofluids, their physical and chemical properties and analysing the challenges and opportunities of nanofluids in future research work.

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Keywords: Heat transfer; Nanofluid; Solar radiation; Efficiency.

1.Introduction

In many industrial applications the primary requirement is transfer of heat from source to sink or one point to other point. Improving heat transfer efficiency is much important in telecommunication system. More than 50% of the total electrical energy is consumed for thermal management in case of electronic cooling system [1]. Very high heat removal rate of the order of 2000W/cm^2 is required in electronic systems like optical devices, X-rays and laser applications [2]. The performance of the system and devices can be altered or improved by rate of water, engine oil,

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ethylene glycol, formamide etc., which are being used. For more energy efficiency requires advanced heat transfer technologies. Now a day some latest inventions explain the utilisation of nano particles in heat transfer applications. Nano fluid is the dispersion of nano size metallic particles in the conventional heat transfer fluids. The drawback of using micro-sized particles (upto 10^{-6}m) is formation of sediment along the flow path which leads to erosion in path way. But nano fluid gives solution to the above said problem by complete mixing of base fluids with non-agglomerated particles. Enhancing of heat transfer more than 50% is achieved by using this colloidal mixture of nano-particles with base fluids. But past researchers tested with volume ratio of nano particles is less than 0.3% with base fluid [3]. Micro sized particles helps to improve thermal conductivity and convective heat transfer of liquids when mixed with base fluids [4]. Meanwhile the fluid path is disturbed and high pressure drop occurred due to sedimentation, excessive wear, and clogging due to micro-sized particles. These problems are overcoming and improvements in thermal properties are achieved by using nano fluids. In nano fluids the nano particles of (1-100nm) and base fluid mixed thoroughly is identified by Choi in the year 1995[5][6] at the Argonne National Laboratory. This is the first mile stone in nano fluid heat transfer technology which provides better thermal properties than micro-sized particles. Nano fluids have been used as lubricant in engines, collant and cutting fluids in manufacturing sectors, and hydraulic fluids in industrial automation as the nano particles have the advantages such as larger relative surface area, high mobility less particle momentum, better stability under suspended condition and improved thermal conductivity of the mixer than micro sized particles. Nano fluids are available in various forms such as metals, metal oxides, ceramics, semiconductors and carbon nano tubes. Jacob Eapen et al [7], stated that carbon nano tubes has better heat transfer characteristics but synthesis processing of carbon nano tubes is complicated and also manufacturing cost is high. Table 1 gives thermal conductivity values of some nano materials.

Nomenclature

ρ_{nf}	density of the fluid
ρ_p	density of the nanoparticles
ρ_w	density of water
μ	viscosity
k	thermal conductivity
c_p	specific heat
φ	volume concentration of nanofluid

1.1. Preparation of nanofluids

Sarit kumar Das et al,[8] explained three mechanisms that could be controlled while preparing nano fluid. (1) Proper dispersion of nano particles in the base fluid. (2) Control of p^H value. (3) Addition of surface activators to avoid sedimentation there by stability of the colloidal mixture can be attained. Disperse the nano particle in base fluid was achieved by ultrasonic vibration after adding surface activators. Nanophase Technologies Corporation was produced nano particles using vapour synthesis method. A Nano particle loose agglomerates and becomes micrometer sized particles as shown in figure 1. However they can be dispersed in the fluids quite successfully which results in breaking of the agglomerates to some extent giving particles of nanometer range. The particles of the nanopowder show a lognormal size distribution. The size distribution of typical sample is shown in figure 2. The average value of particle diameter for Al_2O_3 was 38.4mm and for CuO was 28.6mm by volume weighted approach. Complete dispersion of nano particles in the base fluid can be confirmed by viewing smaller nano particles after dispersion.

Table 1 Thermal conductivity values for some nano materials

S.No	Nano materials	K (w/mk)	Temperature(^{0}C)
1.	Water	0.61	25^0C
2.	Ethylene glycol(EG)	0.26	25^0C
3.	Al_2O_3	35	25^0C
4.	CuO	20	25^0C
5.	ZrO_2	2	25^0C
6.	SiO_2	1.4	25^0C
7.	Fe_3O_4	9.7	25^0C
8.	Au	317	25^0C
9.	Ag	429	25^0C
10.	Al	237	25^0C
11.	Fe	80.2	25^0C
12.	Carbon nanotubes	2000	25^0C
13.	Diamond	600	25^0C

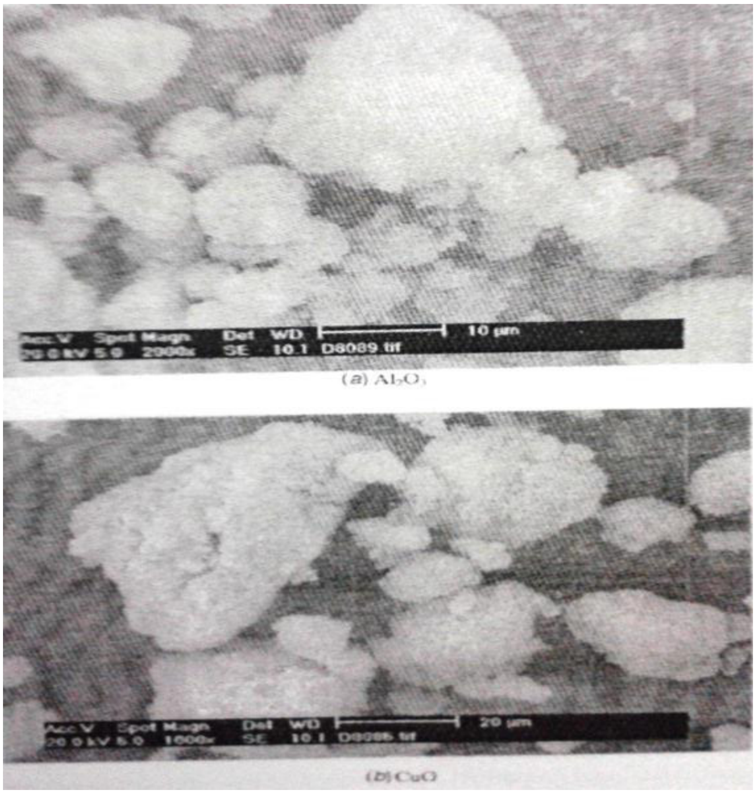

Figure 1 TEM photographs of agglomerated of nanoparticles

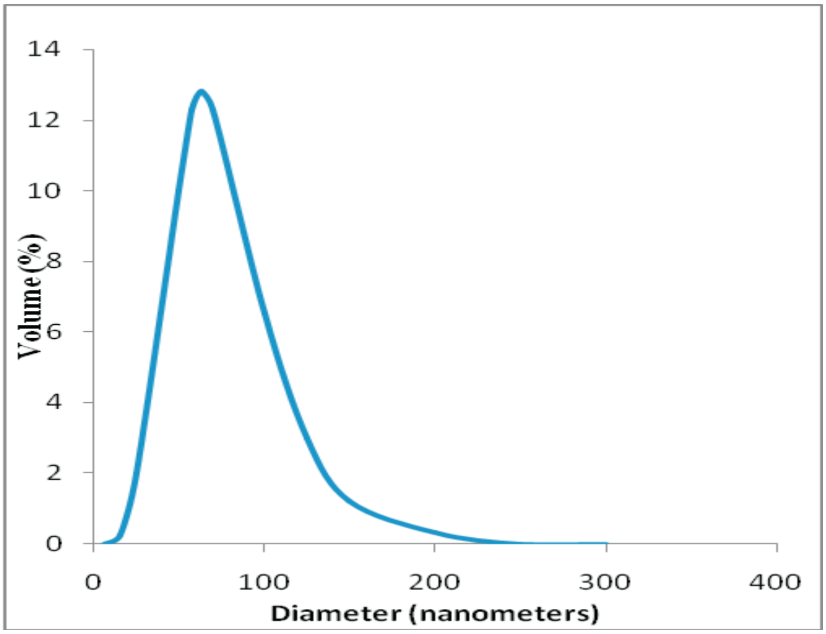

Figure 2 Volume weighted particle size distribution for Al_2O_3 particles

Proper dispersion was achieved by (1) First mixing nano powder with distilled water. (2) Using ultrasonic vibration until proper dispersion is obtained. The volume of the solid mixed with the base fluid was determined by (1) Considering true density to find equivalent weight of the solid (2) That weight was used to made the suspension. (3) Then ultrasonic vibration was given for 12 hours to get complete dispersion. For about next 12 hours no sedimentation was observed and thereafter it was proved that no sedimentation was observed for 1% and 2% volume suspensions. But minor sedimentation was observed in the case of 3% and 4% volume suspensions. But in practical applications it is not possible to stabilize the particles without any third agent like oleic acid or laurate salts. But even the thermal conductivity of the base fluid may be influenced due to the addition of third agent. But the authors have conducted experiment with in 1.5 to 2 hours with no sedimentation without adding any third agent. They have estimated the thermal conductivity is based on energy equation for conduction is given by

$$\frac{1}{\alpha}\frac{\partial T}{\partial t} = \nabla^2 T \qquad (1)$$

The experiment was conducted on Al_2O_3 and CuO nano particles with water as base fluid at various particle volume concentrations. Room temperature was maintained throughout the experiment and the result is represented in figure 3. Subsequently the temperature was altered with different particle concentration of Al2O3-water and CuO-water nano fluids. Comparison was made for 1% and 4% volume concentrations. But only about 2% enhancement was observed at 210C with 1% particle concentration but at 510C the enhancement value was increased about 10.8%. They concluded that the heat transfer depends on the addition of nano particles.

When temperature increases from room temperature the dynamic viscosity of a base fluid is decreased and Brownian motion of nano particles is increased. The nano convection term is increased resulting from the above two facts and also decreasing of nano particles size which increases Brownian motion. Due to these factors the effectiveness of the thermal conductivity is high.

L.Godson et al(10) analyzed heat transfer characteristics in a shell and tube heat exchanger using nano fluid contains silver nano particles. Turbulent flow was maintained throughout the experiment in the range of 5000 to 25000 with various particle concentrations i.e. 0.01%, 0.03% and 0.04%. Solar flat plate collector was used to provide the heat flux from 800W/m2 to 1000W/m2. The heat transfer characteristics such as convective heat transfer coefficient, effectiveness LMTD and pressure drop were studied under the influence of mass flow rate, inlet temperature and volume concentration of the nano particles. Xuan and Roetze(12) calculated viscosity of nano fluid by using Einstein's equation(11)

$$(\mu nf)/(\mu w)= (1.005+0.497\varphi-0.1149\varphi 2) \quad (2)$$

Pak and Cho(13) has calculated the thermal conductivity and density as follows

$$\frac{Knf}{Kw}= (0.9692\varphi+0.9508) \quad (3)$$

$$\rho_{nf} =\varphi\rho_p+(1-\varphi)\rho_w \quad (4)$$

$$\mu_{nf} = (1+2.5\varphi)\mu_w \quad (5)$$

$$(\rho c_p)_{nf} = \varphi(\rho c_p)_p +(1-\varphi)(\rho c_p)_w \quad (6)$$

The experimental Nusselt number values were compared with the predicted Nusselt number Dittus-Boelter correlation [10] shown in figure 4 and deviation of ±9.2% was observed which confirms the experimental test facility. The exit temperature of the hot fluid coming out from the heat exchanger increases as the mass flow rate increases and the exit temperature inversely decreases with the increase in the particle volume concentration. The authors also has observed the following (1) Nusselt number increases with the increase in particle concentration. (2) Logarithmic Mean Temperature Difference (LMTD) decreases as the volume concentration and Reynolds number increases. (3) The overall heat transfer coefficient is found to be increased when silver nano particle concentration varies upto 0.04%. (4) Pressure drop also found increases along with heat transfer characteristics when volume concentration of silver nano particle increases. And also higher pressure drop was found in silver nano fluid when compared to that of pure water. More pumping power is required to compensate pressure drop which leads to poor efficiency of the system.

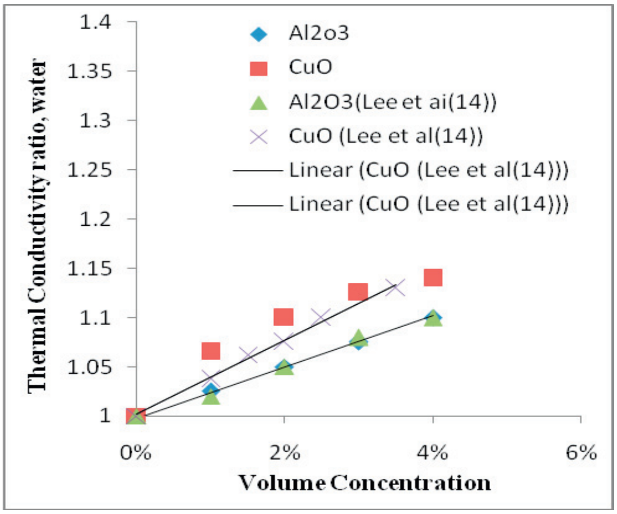

Figure 3 Enhancement of thermal conductivity at room temperature.

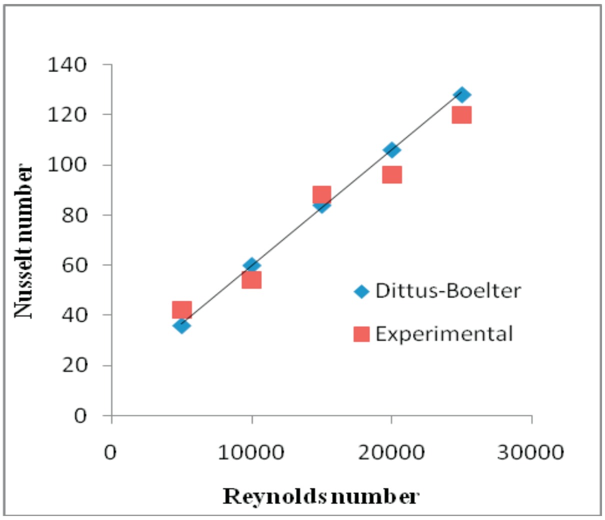

Figure 4 comparison of Experimental Nusselt number with Dittus-Boelter correlation

Classical problem in fluid mechanics was analysed by K.Hiemenz who have used similarity transformation to reduce the Navier-strokes equations governing the flow into an third order ordinary differential equation and non-linear equations were treated numerically using boundary conditions. The heat transfer is very important in many engineering applications such as condenser, evaporator, solar radiation, design of bearings, radial diffuser etc, involves boundary layer flow. Massoudi et al [16] solved heat transfer in stagnation point flow of non-Newtonian fluid. But it can be used only for the small values of the parameter to determine the behaviour of non-Newtonian fluid. And also in their later research [17] a new solution was found for all values of non-Newtonian fluid using Pseudo-similarity solution by computing flow characteristics numerically. Hazem Ali Attia [18] studied the heat transfer of incompressible two dimensional, non-Newtonian, stagnation point flow through a porous medium under laminar flow. It was found that porosity in the porous medium increases the wall shear stress there by heat transfer is increased.

Due to solar energy the thermal stratification over a porous wedge sheet of unsteady state Hiemenz flow of copper nano fluid was studied by R.Kandasamy et al, [19] by using Lie group transformation. Temperature variation due to radiation depends on angle of inclination of porous wedge. The buoyancy force due to thermal diffusion decreases by a factor of cos $\Omega/2$ as the angle of inclination increases, where Ω is angle of inclination of wedge. When the angle of inclination increases it affects the fluid flow thereby the temperature absorption is more as the density of nanofluid is higher than the pure water. The unsteady parameter directly influence the Prandtl number within the boundary layer. As the velocity of the flow decreases the nanofluid temperature increases with increase of unsteady parameter. As the porous medium contains porosity which increases the fluid resistance thereby velocity of the flow is abruptly reduced imitations of using nano fluid

The major limitation in using nanofluid is poor long term stability of nano particle in suspension. Some of limitations while using nanofluid in practical applications are reviewed here.

2.1 Poor long term stability of suspension

Because of strong vander walls interaction between the nano particles the non-homogeneous suspension is formed due to agglomeration of nano particles. Stability can be controlled by using either physical means i.e. surface modification of the suspended particles or chemical methods i.e. adding some surfactant or applying strong force on the clusters of the suspended particles. Particles settling must be examined carefully since it may lead to clogging in flow paths.

2.2 Increased pressure drop and pumping power

More pumping power is to be provided to avoid pressure drop decreases the nanofluid efficiency. Higher density and viscosity leads to higher pressure drop and pumping power. Further researches are required to control the pressure drop.

2.3 Lower specific heat

The important requirement of ideal heat transfer fluid is high specific heat to exchange more heat. But nanofluid exhibits lower specific heat than base fluid. It limits the use of nanofluid application.

2.4 High cost of nanofluids

Nano fluids are prepared either one step or two step methods. Both methods require advanced and sophisticated equipments. This leads to higher production cost of nanofluids. Therefor high cost of nanofluids is drawback of nanofluid applications.

Conclusion

The base fluids such as water, ethylene glycol etc., have been used by different authors with different proportion for various nano particles. Temperature plays a major role in heat transfer characteristics of nano fluids along with nano particle size and concentrations. As the suspended nano particles increase the surface area thereby heat transfer efficiency of the system is improved and absorption of solar energy is increased. Various heat transfer characteristics depend on particle volume concentration, mass flow rate and velocity of the fluid. The scope of the research on nano fluid is widely increased because of the wide application of nano fluid such as automotive system, domestic refrigerator, industrial cooling system, solar device etc. This paper reviewed about nano fluid, latest research and development in nano fluids, its important heat transfer mechanisms. Even though many heat transfer mechanisms has explained, still the usage of nano fluid in practical application is critical because of sedimentation formation and clogging in flow path.

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