Nanofluids for Heat Transfer

Supreeti Das

Dept. of Physics, Gargi College, Delhi University
E-mail: supreeti25@gmail.com

Abstract—*In the last decade there has been a sudden interest in the thermal properties of nano fluids which are a class of suspensions with a base fluid containing nanoparticles . The high heat transfer due to the presence of nanoparticles makes such fluids very important as coolants in the transportation industries, electronic devices, manufacturing industries and wherever there is a requirement for an efficient removal of heat. We propose to investigate the heat transfer mechanisms resulting in this enhancement of thermal conductivity of nanofluids. Nanofluids have the special characteristic that their thermal properties can be contolled by changing the size, shape and concentration of the nanoparticles. Thus designing nanofluids for thermal efficiency appears as an innovative technology for energy saving mechanisms. In recent experimental studies it has been observed that the there is an anomalous increase in thermal conductivity at low concentrations and thermal conductivity appears to be a nonlinear function of the temperature. The enhancement is explained in terms of both static and dynamic mechanisms. The former assumes that the particles are stationary and form nanolayers and aggregate while the latter assumes a random motion like Brownian motion, thermophoresis and convection for the nanoparticles even if the bulk fluid may be stationary. In the static mechanism it is assumed that a nanolayer is formed around the particle and there appears more order in comparison to the bulk fluid and this nanolayer moves with the nano particle due to Brownian motion. A combination of static and dynamic model best explains the high heat transfer in the presence of nanoparticles in the fluid.*

1. INTRODUCTION

Nanofluid was a term coined by Choi in 1995 [1] . It represents a dilute suspension of nanometer size particles dispersed in a liquid. Typical dimension of the nanoparticles range from 1nm to 100 nm. They are synthesized by dispersing and stably suspending the particles in the conventional fluids. The fluid considered is called the base fluid . Usually we consider water, ethylene-glycol and oils as the base fluid. The particles which are added to such fluids are metals like Copper(Cu), Silver(Ag) , Gold(Au)and metal oxides like CuO, Al_2O_3,TiO_2 [2]. The most important characteristic of the nanofluids is an enhancement in the thermal conductivity in comparison to the base fluid. In todays technological developments , these nanofluids have emerged as efficient and innovative energy saving materials. In most of the industries , removal of heat i.e. an efficient cooling system is of paramount importance for their maintenance and optimal performance. . Since the particles employed are small in size , it does not pose a problem of clogging channels or settling of the particles. Since these particles are small and light therefore they cause much smaller erosions of the walls of pipes through which they move and therefore the wear and tear of components of heat exchangers and pipes are quite reduced in comparison to the micro-particle suspensions. In the electronics industry where miniaturization is resulting in high heat generation ,nanofluids can be used for efficient removal of heat. Thus microelectronics and several diverse industries like transportation industry, manufacturing industries, petroleum industries, solar cells, food processing and air conditioning systems can use nanofluids as energy efficient heat transfer material. Studying the mechanisms which result in such anomalous enhancements of thermal conductivity is therefore very significant for designing efficient nanofluids.

2. HEAT TRANSFER MECHANISMS

Cooling has been recognized as one of the challenges of modern technology . Conventional methods involve circulation of cooling fluids which require high pumping powers for the circulation of these fluids. An efficient heat removal therefore requires high power consumption. The other conventional method involves external fins for higher surface area for efficient heat removal. In this study our working fluid is a nanofluid. As discussed earlier, addition of nanoparticles to the conventional fluid enhances the heat transfer capacity of the fluid enormously. In this paper we study the various mechanisms that cause this anomalous enhancement.[4],[5].

The models under consideration are

a) stationary model and b)Dynamic model

a**) Stationary model** assumes that the nanoparticles remain stationary in the fluid.

b) **Dynamic Model**

In the present paper we focus on the dynamic model which assumes that the nanoparticles are in motion within the fluid and produce a convection effect within the fluid even if the fluid is not considered in motion.

We use the model proposed by Jang and Choi [6] .

1. Brownian Motion : The Brownian motion given by the the Einstein Stokes equation is represented by the coefficient $D_o = k_b T/ 3\pi\mu d_p$ with D_o as the nanoparticle diffusion coefficient, k_b is the Boltzmann constant ,μ is the viscosity of the base fluid and d_p is the diameter of the

nanoparticle under consideration. Brownian motion plays a very important role in heat transfer mechanisms.Rapid motion of particles results in transfer of energy.It induces a nanoscale convection. The motion of particles is in the direction from high to low concentration

2. Thermophoresis: This is the phenomena of movement of particles due to a temperature gradient. Any kind of movement results in the transfer of energy. Here the motion of particles is from hot to the cold region.
3. These effects which are significant at nanoscale introduce nonlinear effects in the transport of energy.
4. A recent experimental study shows that molecules of base fluids close to a solid surface organize into layered structures and this aids in the transfer of energy at the interface of solid and base fluid. Our knowledge of solid and liquid structures tell us that the atomic layers of solids are more ordered than that of liquids. Ordered solids like crystalline solids have higher thermal conductivity. In analogy we can therefore conclude that the thermal conductivity at the interface increases as compared to the rest of the base fluid.
5. Local clustering can also be a means of transport of energy. It can increase the rate of heat transfer. However , the flip side of clustering is that it can result in sedimentation which affects the stability of nanofluids.

3. VISCOSITY

We explore the thermophysical properties of nanofluids. Addition of nanoparticles to the base fluid, certainly results in increasing the viscosity of the fluid however the nanofluids are dilute resulting in a very marginal increase in the viscosity of nanofluids in comparison to the base fluids.

The effective dynamic viscosity of the nanofluid is given by several formula. We choose the following simple expression for nanofluids which is alos called the Brinkman model

$\mu_{nf} = \frac{\mu_f}{(1-\varphi)^{2.5}}$ with μ_{nf} as the dynamic viscosity of the nano fluid, μ_f as the viscosity of the base fluid and φ as the volume fraction of the nano particle. For the volume fractions investigated, 1% to 8% [3] we find that the change in viscosity is from .001 to .0012 Pa s. Thus there is an increase in viscosity with volume fraction. Viscosity of nanoparticles decreases with increase in temperature.

4. THERMAL CONDUCTIVITY

Dependence of thermal conductivity on temperature , concentration and particle size is studied which can help in altering the thermal properties by manipulating the size, shape and concentration of nano particles. Thermal dispersion and thermal conductivity's dependence on particle size are opposite . This results in a complex dependence of heat transfer on particle size. In general smaller the size higher the surface area and higher the thermal conductivity. Thermal conductivity is a non linear function of volume fraction. As opposed to microparticle suspensions, the distance between the particles is considered as lower and the particle particle interaction seems to result in nonlinear dependence of thermal conductivity on volume fraction at high concentrations[6]. Thermal conductivity of nanofluids has also been found to be a function of temperature as is the viscosity of nanofluids [7]. Temperature affects the Brownian motion of the nanoparticles.The material of nanoparticle and base fluid also determine the thermal conductivity of nanofluids.

5. DENSITY

Density of nanofluids is another thermophysical property which determines the heat transfer characteristics. The density of nano fluids is a function of the density of nanoparticles, density of base fluids and is also dependent on the volume fraction of the nano particles.

$\rho_{nf} = \varphi\rho_p + (1-\varphi)\rho_f$ where φ represents the volume fraction, and ρ_p and ρ_f respectively represent the density of the nanoparticles and the base fluid[8]

6. CONSTRAINTS OF USING NANOFLUIDS

Microparticles being replaced by nanoparticles can certainly result in an enhancement of heat transfer. It also

reduces the blocking of microchannels through which they flow when used as a coolant in various industries due to their small size. However an important limitation of using nanofluids is that of agglomeration of particles. This is due to the Vander Waals forces. As a result the clusters have a tendency to settle down instead of remaining suspended.

This results in a decrease in the thermal conductivity due to a decreased surface area used for heat transfer. For metal oxide nanoparticles, this effect appears more pronounced as the volume concentration requirement is higher in comparison to metal nanofluids for the same enhancement. Larger concentration of nano particle results in a higher clustering[9] Therefore for practical applications of nanofluids in the long term , the problem of agglomerations needs minimization. There is, therefore a need for developing techniques which will keep the particles suspended and dispersed over a long duration. Adding surfactants to the fluid can decrease the agglomeration[10] Once this is overcome, nanofluids have the potential to become an energy saving material in all industries which have a requirement of energy efficient heat transfer technology.

7. CONCLUSIONS

In this paper we have discussed the various mechanisms of heat transfer at nanoscale which causes an anomalous enhancement in thermal conductivity. Nonlinear effects arise at the nanoscale due to Brownian motion and thermophoresis. The chaotic movement of nanoparticle has been found to increase the heat transfer. Very often the experimental results are not in agreement with the theoretical predictions. For a better agreement we need to develop methods for synthesis and dispersion which will characterize them with respect to size, volume fraction, shape and their distribution in the fluid and facilitate the study of the transport properties .

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