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Research Article

A Study of Heat Transfer with Nanofluids

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Abstract

The seminar report gives an overview of history and evolution of nanofluids, synthesis and preparation methods, the rationale behind nanofluids, mechanisms of heat transfer, their types– about carbon nanotube nanofluids, their applications, and advantages. Nanofluids are suspensions of nanoparticles in fluids that show significant enhancement of their properties at modest nanoparticles concentrations. The available models of physical mechanisms of heat transfer intensification and suppression in nanofluids are presented. The thermal conductivities of different types of nanofluids when compared, carbon nanotubes (CNTs) appear as the promising nanomaterials and have particularly attracted attention from researchers due to their superior thermal features.

Keywords: *Nanomaterials, Nanotubes, Heat Transfer mechanisms, Features of Nanofluids, Carbon Nanotubes,*

1. Introduction

1.1 *Background: Discovery and Evolution*

The term Nanofluids was suggested by Sir Stephen Choi (the year 1995) in Argonne national laboratory, USA. Since then the discovery nanofluids have been explored for their heat transfer characteristics.

When nanoparticles are suspended in a suitable base fluid, the nanofluids thus prepared have superior thermal and electrical properties in comparison to their base fluids. The enormous heat transfer capacities of nanofluids have motivated the researchers to explore the properties.

Since the last few decades, there has been an enormous growth in technologies ranging from electronics and communication, and computers. The need to attend to the thermal management problems in these areas gives the researchers a reason to find better, efficient cooling systems. Nanofluids with their superior thermal and electrical properties can find their applications in these areas.

Several materials have been used to develop different kinds of nanofluids and have been tested for the thermal properties that they offer. Nanomaterials such as copper oxide, copper, aluminum oxide, silicon dioxide, carbon nanotubes etc., have been used for developing nanofluids for the thermal properties that they offer. The carbon nanotube nanofluids have been studied to find out that their significantly superior features shall be useful in many areas.

Nanofluids are quasi-single phase medium which forms a stable colloidal dispersion of nanometric metallic, ceramic or carbon nanotubes nanoparticles in a given base fluid. Nanofluids are characterized by an enrichment of base fluid like Water, Ethylene glycol, or oil with nanoparticles of various types mentioned above.

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2. Synthesis and Preparation methods

The first step in experimental studies with nanofluids is synthesis and preparation. In the synthesis, there are two main techniques which are used to produce nanofluids: the single step and the two-step technique.

2.1 Single Step Method

The single step simultaneously makes and disperses the nanoparticles directly into a base fluid; best for metallic nanofluids. The problem of clustering can be reduced to a good extent by using a direct evaporation-condensation method.

2.2 Two-Step Method

The two-step method is the most widely used method for preparing nanofluids. In this method, nanofibers are first produced as dry powders by using chemical or physical methods. The obtained nanosized powder will be diffused into a base fluid in the second processing.

2.3 Stability of nanofluids so prepared

For the formation of a perfectly stable, it is required that the particles are dispersed with minimum agglomeration. There are various methods, including electrical, physical, or chemical in order to do this. The commonly used dispersion techniques use an ultrasonic or stator-rotor method. Stabilizing agents may also be used during dispersion. However, the best way to produce them may be by a single-step method where, instead of nanoparticles, nanofluids are produced directly, thus reducing the chance of agglomeration.

3. The Rationale behind Nanofluids

The thermal properties that all liquid coolants used today as heat transfer fluids have extremely poor thermal conductivity. For example, water which is often used as a coolant has roughly three orders of magnitude poorer in heat conduction than in copper just as in the case of engine coolants, lubricants, and organic coolant.

There are several means to increase heat transfer by increasing surface area, increasing turbulence, etc. However, they are ultimately limited by the innate thermal conductivity of the fluid. Thus it is better to increase the thermal conduction behavior of the nanofluid itself. Although the suspension of solids is an idea that came to several minds more than a century ago, all of those studies were limited to the suspensions of micro- to macro- sized particles. These suspensions bore the following major disadvantages:

1. The particles settle rapidly, forming a layer on the surface and reducing the heat transfer capacity of the fluid.
2. If the circulation rate of the fluid is increased, sedimentation is reduced, but the erosion of the heat transfer devices, pipelines, etc., increases rapidly.
3. The large size of the particles tends to clog the flow channels, particularly if the cooling channels are narrow.
4. The pressure drop in the fluid increases considerably.
5. Finally, conductivity enhancement based on particle concentration is achieved (i.e., the greater the particle volume fraction is, the greater the enhancement—and greater the problems).

Later, however, with the advent of advanced technology, came the ability to produce nanometric particles. Thus nanofluid technology could then be studied with nanometric sized particles which opened a vista for further research in the field.

4. Features of Nanofluids

When the particles are properly dispersed, these features of nanofluids are expected to give the following benefits:

1) *Higher heat conduction*: The nanoparticles have a large surface area which allows more heat transfer. Due to their tiny size, they are mobile and may bring about micro convection. The abnormal increase in thermal conductivity of nanofluids can be attributed to the above reasons.
2) *Stability*: The problem of sedimentation is resolved because the particles are small, they weigh less, thus making the chances of sedimentation less. Reduced sedimentation can help overcome one of the major drawbacks of suspensions.
3) *Reduced chances of erosion*: Nanoparticles are very small hence the momentum they impart on a solid wall is very small. This causes reduced erosion of materials they are in contact with.
4) *Reduction in pumping power*: To increase the heat transfer in a conventional fluid by a factor or two, pumping power must be increased by a factor of ten. In the case of nanofluids, the required increase in pumping power will be very moderate unless there is a very sharp increase in viscosity.

5. Mechanisms of Heat Transfer In Nanofluids

The researchers have been analyzing several mechanisms, in order to analyze the increase in heat transfer. Listed below are the possible mechanisms:

(a) Liquid-layering
(b) Particle aggregation
(c) Particle Brownian motion
(d) Brownian-motion-induced convection

In order to understand the enhancement of thermal conductivity of nanofluids, it is necessary to create a dynamic condition for evaluating its usage and the performance of nanofluids in convective environments. There are two static mechanisms available including liquid-layering at the particle–liquid interface as a heat transfer bridge, as shown in Fig. (a). The particle aggregation has formed chain shape like a thermal transport path, as shown in Fig.(b). Also, there are two dynamic mechanisms including the particle Brownian motion as shown in Fig. (c). The convection in base fluid induced by the particle Brownian motion, as shown in Fig. (d)

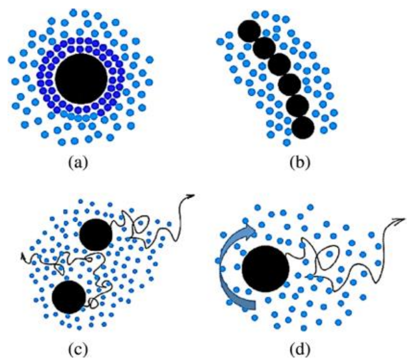


Fig 1 Sketch of four potential mechanisms responsible for the reported conductivity enhancement: (a) liquid-layering, (b) particle aggregation, (c) particle Brownian motion and (d) Brownian-motion-induced convection

The reasons for an increase in thermal conductivity of nanofluids may be explained by the researchers by several main mechanisms. These include the Brownian motion of nanoparticles, the formation of highly heat-conductive fluid layer (thickness is at the molecular level) at the Fluid-particle interface, ballistic transfer of heat energy inside a separate nanoparticle and between nanoparticles, when they contact, and the effect of nanoparticle clustering. [Fig 1]

5.1 Static Mechanisms:

The concept of separation interphase layer at fluid-solid body interface can be used to explain the increase in thermal conductivity in nanofluids. The arranged structure can be the mechanism of thermal conductivity increase, particularly, because there is a change in the volume of nanoparticles (efficient volume concentration of nanoparticles).

It was suggested to modify the Maxwell model, which considers an intermediate molecular layer around particles; they have come to conclusion that the presence of even fine layers with the nanometric thickness can increase significantly the efficient volume concentration of a solid fraction and thermal conductivity of nanofluid, especially when the particle diameter is < 10 nm. The suggested model predicts up to eight-fold increase in thermal conductivity of nanofluid in comparison with data obtained on the basis of Maxwell model without consideration of the intermediate layer.

The last mechanism relates to nanoparticle splitting or their restructuring in the basic fluid. As a result, the effective volume of particles and their effective concentration, respectively, are determined incorrectly. The importance of this mechanism consideration at the calculation of real volume concentration of particles is proved by experimental data and theoretical studies of fluids. Authors have shown that the size of nanoparticles in nanofluids is approximately 3.5 times larger than the size of initial particles. According to (Keblinski, 2008), to explain all available experimental material on thermal conductivity of nanofluids, it is sufficient to consider only particle clustering without the involvement of any other mechanisms.

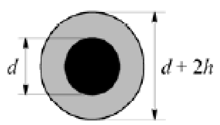


Fig 2 Formation of a transitional molecular layer on the surface of nanoparticles

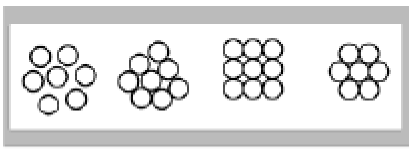


Fig 3 Separation and formation of new nanoparticles clusters

5.2 Dynamic Mechanisms

Brownian motion of nanoparticles bring a contribution to thermal conductivity by two ways: firstly, directly via nanoparticle diffusion and secondly, indirectly via intensification of micro-convection of fluid around separate nanoparticles. On the basis of experiments carried out by Keblinski, the authors conclude that the direct contribution of Brownian motion to total heat transfer by nanofluid is negligibly small.

In contrast to the direct influence, the indirect effect of Brownian motion on nanofluids thermal conductivity can be considerable. According to the taken theoretical model on the basis of flow visualization, each nanoparticle makes local periodic movements together with ordinary Brownian motion because of interaction with the basic medium. Results of this study illustrate that micro-convection and mixing stimulated by nanoparticle oscillations can affect significantly the macroscopic transport properties of nanofluids.

The calculated dependences of a distance between particles on their size and volume concentration are shown in Fig.5 It can be seen that in the case of fine particles the distance between them even at low concentration can be very small.

Moreover, due to Brownian vibrations of particles, the effective distance between them can be even less. Thus, we can suppose that the nonlinear thermal waves are the reason for the high thermal conductivity of nanofluids. The wave mechanism of heat transfer is also suggested. According to the authors' opinion, the heat waves generated in nanofluids can resonate and change the value of thermal conductivity considerably.[3]

6. The Classification of Nanofluids

The enhancement of the thermal conductivity of nanofluids depends on the selection of nanomaterial and the base fluid. Until now, the base fluids used include water, ethylene glycol, transformer oil, and toluene.

The nanoparticles that are used can be broadly divided into three groups:
1) Ceramic
2) Pure metallic particles
3) Carbon nanotubes (CNTs).
Different combinations of the above particles and fluids give different nanofluids.

6.1 Ceramic nanofluids

The first type of nanofluid investigated by the ANL group was ceramic nanoparticle nanofluid. The first research in this area showcased conductivity measurements on fluids that contained Al2O3 and CuO nanoparticles in water and ethylene glycol.

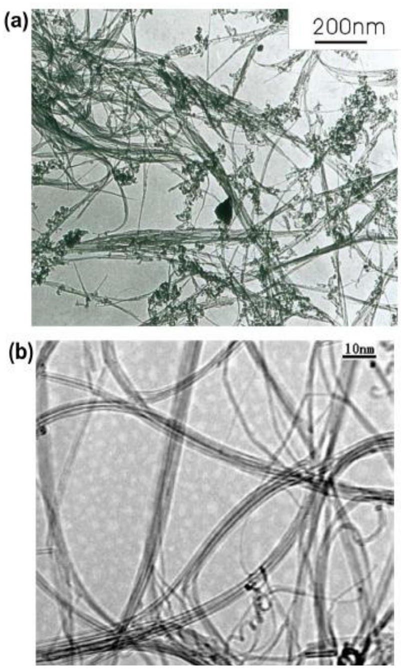
6.2 Metallic nanofluids

The potential of nanofluids was explored from the experiments carried out with ceramic nanofluids. However, with the emergence of metallic particle-based nanofluids was a crucial step. However, the real breakthrough came when the ANL group reported a 40% enhancement of conductivity with only 0.3% concentration of 10 nm-sized copper particles suspended in ethylene glycol. When gold and silver were used for the first time to prepare nanofluids, the most important observation in their study was a significant enhancement in thermal conductivity for even small concentrations.

6.3 Carbon Nanotube nanofluids

The greatest enhancement of thermal conductivity was achieved when Carbon nanotubes and polymer nanotubes were used with suitable base fluids. They were found to be most promising nanomaterials for their superior thermal features. CNTs have a very high aspect ratio and thus have extraordinary heat transfer properties.

The thermal conductivity of nanofluids depends on the thermal conductivity of the base fluid, the characterizations of the dispersed nanomaterial (structure, shape, and size), the concentration, additives, and interactions between the nanomaterials and base fluid etc. These dependence factors affect the thermal conductivity enhancement of CNTs-nanofluids with different contributions. Currently, there are two main types of carbon nanotubes: single-walled nanotubes (SWNTs) and multiwalled nanotubes (MWNTs) that can be used to make nanofluids with different base fluids. Their different structures and sizes, create differences in aspect ratios thus enhancing the thermal conductivity enhancement of CNTs-nanofluids.[Meibo Xing, *et al,* 2015] obtain higher thermal conductivity values than that of the base fluid.



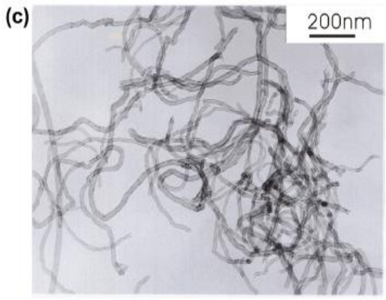


Fig 4 The TEM images of (a))S-SWNTs, (b)L-SWNTs, (c)MWNTs

6.3.1 Advantages of Carbon Nanotube Nanofluids

The advantages of using CNT suspensions in practical applications is that we can control the properties and applications by changing the size and concentration of the CNT, synthesizing any number of walls, and surface treatment of CNT.

CNT-nanofluids have better stability which prevent sedimentation and reduce clogging in the walls of heat transfer devices.

High thermal conductivity, convective and boiling heat transfers of nanofluids show a promise of high energy efficiency, better performance, and lower operating costs.

They can reduce energy consumption for pumping heat transfer fluids and can enhance the performance of solar energy technologies and devices.

Thus, compared to traditional fluids and suspensions of milli- & micro-sized, the advantages of CNT-nanofluids can be summarized as high heat transfer and stability due to large aspect ratio and specific heat transfer surface areas of dispersed CNT, micro-channel flow and cooling without clogging, miniaturized systems, and reduction in pumping power.

Conclusion

We can conclude that nanofluids show great promise for use in cooling and related technologies. Oxide nanoparticle-based nanofluids are relatively lesser promising in the enhancement of thermal conductivity of fluids. With the increase in particle size, the enhancement increases rapidly. Metallic nanoparticles enhance thermal conductivity rapidly, with very large enhancement at very low volume fraction. This discovery opens the possibility of increasing thermal conductivity enhancement without making significant changes in viscosity, which can erode the gain in convective conditions. Maximum enhancement at small volume fraction was observed with carbon nanotubes dispersed. However the researchers are still unclear about the theoretical perspective of the mechanism of thermal conductivity enhancement. The potential thermal conductivity should be thus exploited in the next generation heat transfer fluids.

References

A.L. Subramaniyan, R.Ilangovan,(2015), A report on the latest trends in nanofluids research, *Int. J. Nano Dimens., 6(3): 323-328.*

B.N.Kharad, G.P.Bhagat, R.M.Ghodke, A.P.Avhad, (2014), Heat Transfer Enhancement Using Nanofluids- An Overview, *International Journal of Innovative Research in Science, Engineering and Technology An ISO 3297: 2007 Certified organization, Volume 3, Special Issue 4.*

V.I.Terekhov, S.V. Kalinina, V.V.Lemanov, (2010) The mechanism of heat transfer in nanofluids: state of the art (review), Part 1.Synthesis and Properties of Nanofluids, *Thermophysics, and Aeromechanics, Vol. 17,No.1.*

Sarit Kumar Das, Stephan U. S. Choi, Hrishikesh E. Patel, (2006), Heat Transfer in Nanofluids- A Review, *Heat Transfer Engineering.*

Kavitha T., Rajendran A., Durairajan A., Syedabuthahir M., Advanced Heat Transfer enhancement using TiO2 water based nanofluids.

Kaufui V. Wong, Omer De Leon, (2010), Review article Applications Of Nanofluids: Current and Future, *Hindawi Publishing Corporation Advances in Mechanical Engineering, Volume 2010, Article ID 519659.*

Emad Sadeghinezad, Mohammad Mehrali, R. Saidur, Mehdi Mehrali, Sara Tahan Latibari, Amit Reza Akhiani B, Hendrik Simon Cornerlis Metselaar,(2016), A comprehensive review on graphene nanofluids: Recent Research, development and applications, *Energy Conversion and Management 111,pp.466-487.*

S.M. Sohel Murshed n, C. A. Nietode Castro,(2014,) Superior thermal features of nanotubes-based nanofluids- A Review, *Renewable and Sustainable Energy Reviews 37,*pp.155-167.

Meibo Xing, Jianlin Yu, Ruixiang Wang, (2015), Experimental study on the thermal conductivity enhancement of water based nanofluids using different types of carbon nanotubes, *International Journal of Heat and Mass Transfer 88* 609-616