# Effect of Nanoparticle Size on Heat Transfer Intensification

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## ABSTRACT

***Properties that mainly determine the thermal performance of a liquid for heat transfer applications are the thermal conductivity, viscosity, specific heat and density. Fluids such as air, water, ethylene glycol, and mineral oils are typically used as heat transfer media in applications such as power generation, chemical production, automobiles, air conditioning and refrigeration. However, their heat transfer capability is limited by their very low thermal conductivity. For enhancement of thermal conductivity of these fluids, much attention has been paid in the past decade to a new type of composite material i.e. nanofluids. Nanofluids are the suspensions of nanoparticles in base fluids. Nanoparticles have unique features different from conventional solids liquid mixtures in which mm or micrometer sized particles of metals and non-metals are dispersed. Due to their excellent characteristics nanofluids find wide applications in enhancing heat transfer. A nanoparticles suspension is considered as a three phase system including the solid phase (Nanoparticles), the liquid phase (fluid media), and the interfacial phase, which contributes significantly to the system properties because of their extremely high surface-to-volume ratio in nanofluids.***

***This study provides an experimental review on the effect of nanoparticle size on convective heat transfer. The researchers focused on the measuring and modeling the heat transfer characteristics of nanofluids and they did experiment on the $SiO_2$ and $Al_2O_3$ nanoparticles. The nanoparticle size ranges from 10 nm to 100 nm. It was seen that adding nanoparticles to the coolant significantly influences the heat transfer coefficient in turbulent flow regime.***

***Keywords:** Nanoparticles size, Heat Transfer Enhancement, Nanofluids, heat transfer coefficient.*

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## 1. INTRODUCTION

The enhancement of convective heat transfer and the related experimental and theoretical research become at present an independent, important and rapidly developing field of heat transfer theory. High heat flux removal is a major consideration in the design of many machines, equipment and technologies, and can be accomplished using various kinds of heat transfer equipment. The urgency of this problem is determined by driving to enhance the performance of heat exchange devices, reduce energy costs and achieve maximum compactness with minimum material consumption. One of the solutions to the problem of heat transfer performance enhancement could be the use of so called nanofluids, which are fluids containing nanoparticles of various composition[1].

Very small particles suspension in saturated liquids (water, ethylene glycol, engine oil) is defined as nanofluids may constitute a very interesting alternative for advanced thermal applications. It has been found that important heat transfer enhancement may be achieved while using nanofluids compared to the use of conventional fluids; some oxide nanoparticles exhibit an excellent dispersion properties in traditional cooling liquids [2]. The nanolayer acts as a thermal bridge between a solid nanoporticle about less than in dimension 100nm and a bulk liquid and so is key to enhancing thermal conductivity. Nanofluids are dilute liquid suspensions of nanoparticle. The thermal behavior provide a basis for an enormous innovation for heat transfer intensification the nanofluid structure consisting of nanoparticles, Bulk liquid, and nanolayers at solid liquid interface[3]. Scientists have been quite active in the past few decades in the search of novel approaches to increase heat dissipation of various cooling devices. Heat transfer through a fluid medium is important in several engineering applications including heat exchangers, refrigerators, automobiles, and power plants. The ability of a fluid medium to transfer heat across a small temperature difference enhances the efficiency of energy conversion and improves the design and performance of automobile engines, heat transfer devices, and micro-electro-mechanical systems (MEMS). In recent years, modern technologies have permitted the manufacturing of a new class of fluids, called nanofluids.

## 2. LETERATURE REVIEW:

A.V. Minalov [1]. The paper briefly explains the effect of various parameters on heat transfer intensification. These parameters are particle concentration particle size, nanoparticle material, temperature. This paper also focusses the particle effectiveness of the nanofluid. This paper gives the experimental results. Extensive experimental studies of turbulent convective heat transfer in annular channel for several water based nanofluids containing $Al_2O_3$ and $SiO_2$ particles is carried out in this paper.

Prof. A.M. Meshram[2]. This paper is to presents the broad range of nanofluid based current and future applications. This gives a brief description of how heat transfer enhances using Nanofluids. And its application in various fields viz. heat transportation, military applications, medical, etc. This paper focuses one explaining the basic mechanisms of improvement in heat transfer by addition nano particles. It is an overview of systematic studies that address the complexity of nanofluid systems and advances the understanding of nanoscale contributions to viscosity, thermal conductivity, and cooling efficiency of nanofluids is presented. A nanoparticle suspension is considered as a three phase system including the solid phase (nanoparticles), the liquid phase (fluid media), and the interfacial phase, which contributes significantly to the system properties because of their extremely high surface-to-volume ratio in nanofluids.

Cong Q [3] The effects of two kinds of base fluid (H2O and Ga) and three different nanoparticle radiuses (20 nm, 40 nm and 80 nm) on the natural convection heat transfer of a rectangular enclosure filled with $Al_2O_3$–water and $Al_2O_3$-GA nanofluid at different Rayleigh numbers (Ra = $10^3$and Ra = $10^5$) are discussed based on a two-phase lattice Boltzmann method in this paper. This paper does comparative study of heat transfer characteristics between $H_2O$ based and GA based nanofluids.It is seen that $Al_2O_3$-GA nanofluid shows a better heat transfer enhancement than$Al_2O_3$–water nanofluid. Al2O3–Ga and nanofluid with the same smallest radius (r = 20 nm) can enhance the heat transfer by 86.0% and 24.5% compared with water respectively. It is also found that$Al_2O_3$–Ga nanofluid at low Rayleigh number (Ra = 10 showsthebiggest heat transfer enhancement (shows a 4.4% increase for every nanoparticle radius decreasing 20 nm) compared with $Al_2O_3$–water nanofluid. The enhancement ratio at low Rayleigh number is about 3–10.8% and 23.5–28.8% more than that at high Rayleigh number for$Al_2O_3$–water and $Al_2O_3$-GA nanofluid respectively. In addition, the nanoparticle fraction distributions in the enclosure are also investigated.

F. M. Ali [4] This paper studies the effect of particle size and volume fraction concentration on the thermal conductivity and thermal diffusivity of $Al_2O_3$ nanofluids. This study presents new data for thermal conductivity enhancement in four nanofluids containing 11, 25, 50, 63 nm diameter aluminium oxide nanoparticle in distilled water. The result shows that the thermal conductivity and thermal diffusivity enhancement of nanofluids increases as the particle size increases. This enhancement attributed to the many factors such as, ballistic energy, nature of heat transport in nanoparticle, and interfacial layer between solid/fluids.

Valtteri Mikkola [5]. In this Master's Thesis, impacts of concentration, particle size and thermal conductivity of particle material on convective heat transfer of nanofluids are experimentally examined. It covers key areas of heat transfer characteristics such as stability, aggregation, zeta potential, density, specific heat, viscosity.

## 3. TYPES OF NANOFLUIDS :

The range of potentially useful combinations of nanoparticle and base fluids is enormous. Nanofluids can be classified broadly by the type of particles into four groups:
1. Ceramic
2. Pure metallic
3. Alloy
4. Some allotropes of carbon or carbon-based nanofluids.

**Nanoparticle Materials:**

1. Oxide ceramics – $Al_2O_3$, CuO
2. Metal carbides – SiC
3. Nitrides – AlN, SiN
4. Metals – Al, Cu
5. Non-metals – Graphite, carbon nanotubes

ISSN: 2321-8169
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6. Layered – Al + $Al_2O_3$, Cu + C

**Base Fluids:**

1. Water
2. Ethylene- or tri-ethylene-glycols and other coolants
3. Oil and other lubricants
4. Bio-fluids
5. Polymer solution

## 3.1 EFFECT OF SOME PARAMETERS ON THERMAL CONDUCTIVITY OF NANO-FLUIDS:

1. Particle Size
2. Particle Volume Fraction
3. Particle Material
4. Particle Shape
5. Particle Material and Base Fluid
6. Temperature
7. Effect of Acidity (PH)

## 4. EFFECT OF PARTICLE SIZE IN $SiO_2$ NANOFLUIDES:

Further the effect of nanoparticles diameter on the heat transfer characteristics in turbulent regime of nanofluids containing silica particles was investigated. The particles diameter ranged from 10 to100 nm, all other experimental conditions were similar. Fig.1 presents the dependence of the average heat-transfer coefficient on flow rate of the 2% nanofluid with particles of different size. As is obvious, at a fixed fluid flow rate the heat transfer coefficient definitely increases with increasing particle size. It is found that the viscosity of nanofluid decreases with increasing particle size, while the thermal conductivity, on the contrary, increases. It should be noted that currently in the literature there is no consensus regarding the dependence of transfer coefficients of nanofluids on the particle size. The available data are rather contradictory. This is especially true for the thermal conductivity of nanofluid. Many works indicate that the thermal conductivity coefficient increases with increasing particle size. Though, the fact that the viscosity decreases with increasing particles size is ascertained more reliably. Recall that the average heat transfer coefficient in the turbulent regime at a fixed fluid flow rate is proportional to the complex of $\mu^{-0.37}k^{0.57}$.With the increase in particle size, thermal conductivity of nanofluids increases, whereas the viscosity, on the contrary, decreases and, as a consequence, heat transfer unambiguously enhances. This is shown in Fig.1.

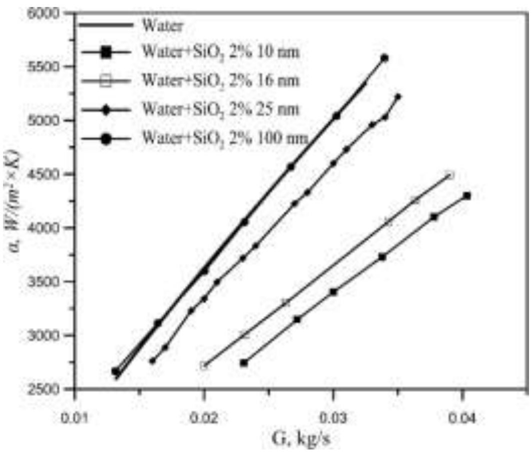


**Fig.1. Heat transfer coefficient versus flow rate for various sizes of SiO2 nanoparticles at a bulk concentration of 2%[1].**

Now it was found thatat a fixed Reynolds number the heat transfer coefficient has a maximum at particle size of 25 nm. The reason for this non-monotonic behavior again lies in the effect of nanoparticle size on the transfer coefficients of nanofluids. According to Mikheev's formula, at a fixed Reynolds number, the heat transfer coefficient is proportional to the complex of $\mu^{-0.37}k^{0.57}$.In this case, with increasing particle size, we are faced with two competing tendencies, namely, the viscosity decreases while the thermal conductivity increases. Therefore the dependence of the heat transfer coefficient on the particle size has a maximum. In this particular case it falls on the particle size of 25 nm. This non-monotonic behavior of heat transfer coefficient is probably the main reason for such wide variations and in consistency in the experimental data on turbulent heat transfer of

ISSN: 2321-8169
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nanofluids, found in the literature, because, as is obvious, the heat transfer coefficient depends not only on particles concentration but also, in a complex way, on particles size, as well as criterion which was taken for comparative analysis.
Thus, it was revealed that at a fixed flow rate of a nanofluid, the heat transfer coefficient increases with increase in nanoparticles size, and has a certain maximum at a fixed Reynolds number.

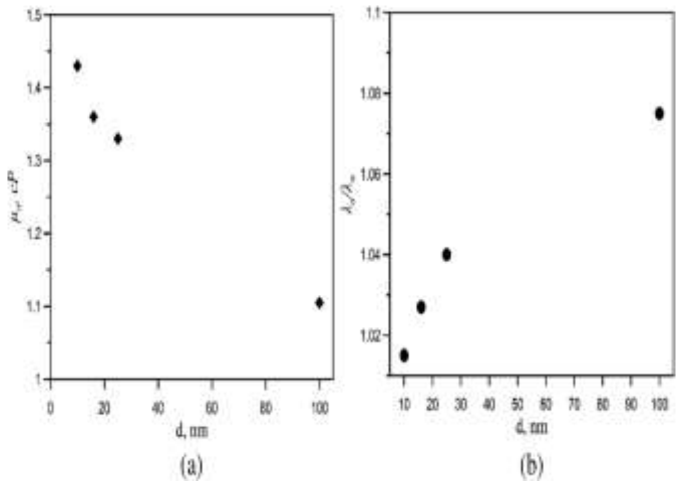


**Fig.2 Viscosity (a) and thermal conductivity (b) of nanofluids versus SiO2 nanoparticles sizes at a bulk concentration of 2%[1].**

| D , nm | $\mu_n$ , cP | $k_n / k_w$ |
|---|---|---|
| 10 | 1.43 | 1.015 |
| 16 | 1.36 | 1.04 |
| 25 | 1.33 | 1.027 |
| 100 | 1.11 | 1.075 |

**Table 1: Viscosity and thermal conductivity of nanofluids versus SiO2 nanoparticles sizes at a bulk concentration of 2%.cf[1].**

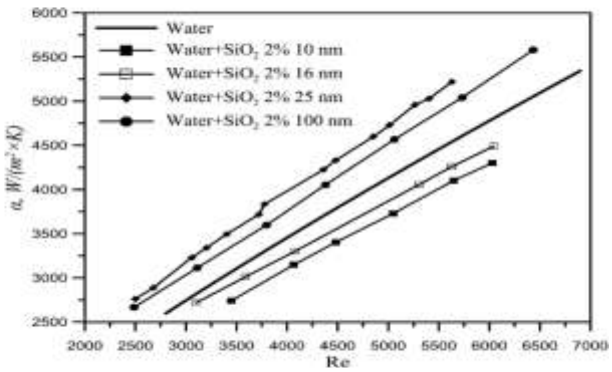


**Fig.3. Heat transfer coefficient versus Reynolds number for various SiO2 nanoparticles sizes at a bulk concentration of 2% [1].**

## 5. EFFECT OF PARTICLE SIZE IN $Al_2O_3$ NANOFLUIDES:

The thermal conductivity of nanofluids measured at different volume fractions from 1.4 to 0.225% and particle sizes ranging from 11 to 63 nm are presented in Table1.2 and Figure1.5. All measurements were made at room temperature. The samples consisted of $Al_2O_3$ nanoparticles dispersed in distilled water. Figure 8 displayed the thermal conductivities for Al2O3 nanofluids as a function of particle size. Moreover, it displayed the dependence of the thermal conductivity and thermal diffusivity on the particle size, as well as, note that the slope increases as the particle size increase. The thermal conductivity values of these nanofluids generally increase nonlinearly with increases particle size[5].

| Particles size (nm) | Thermal conductivity (W/m.K) | Enhancement in thermal conductivity (%) |
|---|---|---|
| 11 | 0.676 | 9.56 |
| 25 | 0.681 | 10.37 |
| 50 | 0.689 | 11.6 |
| 63 | 0.705 | 14.26 |

**Table.2.Variation of thermal conductivity of $Al_2O_3$nanofluid with particle size obtained for 1.4 % volume fraction[5].**

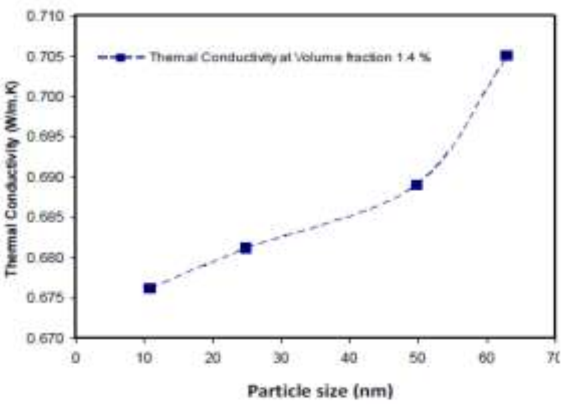


**Fig-4.Variation of thermal conductivity of $Al_2O_3$ nanofluid with particle size obtained for 1.4 % volume fraction[4].**

Furthermore, the thermal conductivity of the smallest nanoparticles are lower than that of the largest nanoparticles. This would be attributed to phonon scattering at the solid–liquid interface. The phonon mean free path in small particles may be reduced by phonon–phonon scattering, scattering at the boundaries between nanoparticle and molecules, as well as, lattice imperfections. However, the relationship between the particle size and its thermal conductivity nonlinearly dependent for the particle size as shown in Figure 8. The lattice imperfections in smaller nanoparticles cannot remarkably affect the thermal conductivity. This indicates that, the phonon– phonon scattering at the boundary between nanoparticle and fluid interfacial can be more remarkable than that at the lattice imperfections. Though lattice imperfections are readily formed in small particles, the thermal conductivity and thermal diffusivity of nanoparticles is mainly subject to its size. Therefore, the results suggest that, the thermal conductivity of nanofluid is subject to a size-dependent effect. The results show that, the enhancement in thermal conductivity were 9.56, 10.37, 11.6, 14.26% at particle size 11, 25, 50, and 63 nm at volume fraction 1.4% respectively. These results indicate that, the enhancement thermal conductivities of Al2O3 nanoparticle suspension in distilled water have increased with increase in the particle size of nanoparticles. The results are listed in the Table.2.

The heat transfer coefficient depends on the coefficient of thermal conductivity of nanofluids.

The relation is given by:

$$h=k/\delta$$

where, $\delta$ – the thickness of boundary layer

As the coefficient of thermal conductivity increases heat transfer coefficient also increases. But heat transfer coefficient also depends on 1)fluid flow rate 2)viscosity 3)fluid's specific heat 4) Temperature difference between the bulk fluid and the heat transfer surface 5)Gravitational acceleration 6) fluid's coefficient of thermal expansion 7)Fluid's latent heat of vaporization 8)

Nature of heat transfer surface 9) Fluid's density 10) Geometrical setup and dimensions. So, the total increase in heat transfer coefficient is less than the thermal conductivity.

The Nusselt Number is given by,

$$Nu=hd/k$$

So, the overall Nusselt Number decreases as the particle size and thermal conductivity increases.

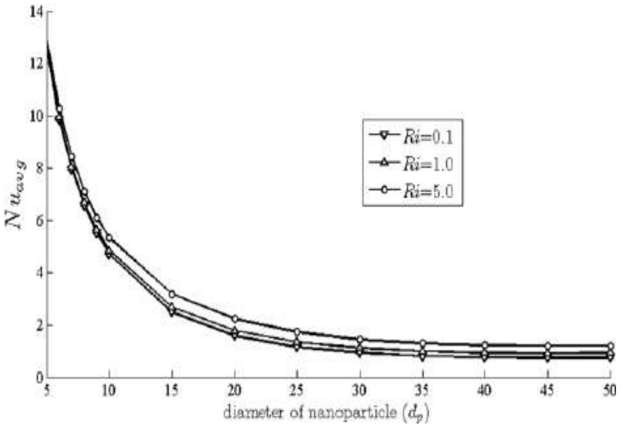


**Fig.5. Variation of the average Nusselt number with particle size[5]**

Nanofluid with small radius can enhance the heat transfer. Nusselt number of nanofluid increases with the decreasing nanoparticle radius.

## 6. APPLICATIONS:

1) Heat transfer in microelectronics
2) Pharmaceutical processes
3) Hybrid-powered engines
4) Engine cooling
5) Domestic refrigerator
6) Nuclear reactor coolant
7) Grinding machining
8) Space technology Boiler flue gas temperature reduction.

## 7. CONCLUSION:

1. The analysis of the literature shows that in the available works there is neither quantitative nor qualitative consensus in terms of turbulent heat transfer performance of nanofluids. In the meantime, almost all scientists note that the effect of nanoparticles on the heat transfer in the turbulent flow regime is much more complicated than that in laminar flow regime. This circumstance requires additional systematic experimental study of turbulent heat transfer of nanofluids.
2. For $SiO_2$ nanofluid, The heat transfer coefficient increases with the particle size.
3. The heat transfer coefficient increases with decreasing the average nanoparticle diameter in $Al_2O_3$ nanofluid.
4. Overall, the majority of results seems to indicate the small particle size to be beneficial for nanofluids, but no widespread consensus concerning the effect or its magnitude exists.
5. Consequently, the final practical aim of improving convective heat transfer performance of fluids is to decrease the power of pumps or alternatively the size and financial cost of heat exchangers.

## ACKNOWLEDGEMENT

A sincere thanks to our guide Asst. Prof. V.L. Bhanavase for giving an opportunity to prepare a paper on effect of nanoparticle size on heat transfer intensification and supporting on every stage.

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