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# A REVIEW OF EXPERIMENTAL STUDIES OF HEAT TRANSFER CHARACTERISTICS OF NANO FLUIDS

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**ABSTRACT**
Nanofluids are fluids in which nanoparticles (less than 100 nm) are suspended in the conventional base fluids. These dispersed solid nanoparticles metallic or non-metallic changes the thermal properties of the base fluid like thermal conductivity, viscosity, specific heat, and density, etc. This paper summarizes the important articles published on the enhancement of the heat transfer characteristics in heat exchangers using nanofluids. In the first part of this article the experimental studies and results for the effective thermal conductivity, viscosity and the Nusselt number reported by several authors are discussed. And the second part is focused on application of nanofluids in different types of heat exchangers.

**KEYWORDS:** Nanofluids, Thermal Conductivity, Heat Transfer, Heat Exchangers

## INTRODUCTION
Nanofluids have the characteristics to enhance the heat transfer rate because of its inbuilt thermo physical properties and hence these properties make nanofluids use in the devices for increased performance rates. Various types of powders such as metallic, non-metallic and polymeric particles can be suspended into fluids. The thermal properties of fluids with suspended particles are expected to be higher than that of common fluids. Compared to the conventional fluids with solid suspensions for heat transfer intensifications, nanofluids have the following advantages: [1]

- High specific surface area and heat transfer surface between particles and fluids.
- High dispersion stability with predominant Brownian motion of particles.
- Reduced pumping power as compared to pure liquid to achieve equivalent heat transfer intensification.
- Reduced particle clogging as compared to conventional slurries, thus promoting system miniaturization.
- Adjustable properties, including thermal conductivity and surface wettability, by varying particle concentrations to suit different applications.

These advanced concepts of nanofluids offer exciting heat transfer characteristics compared to conventional fluids. There are considerable researches on the superior heat transfer properties of nanofluids especially on thermal conductivity and convective heat transfer. It is also expected that performances of these identified applications can be improved further.

## EXPERIMENTAL INVESTIGATIONS
### 2.1 MEASUREMENT OF THERMAL CONDUCTIVITY
As we know the thermal conductivity is the most significant parameter responsible for heat transfer enhancement many authors have done experimental works on this aspect. The various techniques like steady-

state parallel-plate technique [2], the transient hot wire method [3], and the temperature oscillation technique [4] are used to measure the thermal conductivity of nanofluids. The oscillation method was proposed by **Roetzel et al. [5]** and further developed by **Czarnetski and Roetzel [6].** This method is based on the pure thermal techniques and hence there is no electrical component in the apparatus, which results in no effect of ion movement, on the measurement. Many researchers used the Alumina ($Al_2O_3$) and Copper oxide (CuO) nanoparticles for experimental investigations as they are the most common and inexpensive. All the experimental results have shown the enhancement of the thermal conductivity by addition of nanoparticles. **Eastman et al. [7]** measured the thermal conductivity of nanofluids containing $Al_2O_3$, CuO, and Cu nanoparticles with two different base fluids: water and HE- 200 oil. A 60% improvement of the thermal conductivity was achieved as compared to the corresponding base fluids for only 5 volume % of nanoparticles. They also showed that the use of Cu nanoparticles (using the one-step method) results in larger improvements than that of CuO (using the two-step method).

**Lee et al. [8]** in their study suspended CuO and Al2O3 (18.6 and 23.6 nm, 24.4 and 38.4 nm respectively) with two different base fluids: water and ethylene glycol (EG). They formed four different combinations of nanofluids: CuO in water, CuO in EG, Al2O3 in water and Al2O3 in EG. The results obtained showed that nanofluids have higher thermal conductivities than the base fluids without nanoparticles.

**Xuan and Li [9]** in this study used Cu particles of comparatively large size (100 nm) and smaller (36nm) with water. They found the enhanced the thermal conductivity of water using Cu particles for the both sizes.

**Li and Peterson [10]** have conducted an experimental investigation on the thermal conductivity of nanofluid (CuO of 29nm and Al2O3 of 36nm with water) for the analysis of the effects of temperature and volume fraction. The results obtained shown that the parameters like nano material sizes, its volume fraction and temperature have considerable effects on the thermal conductivity.

Further investigations on nanofluids are necessary to clarify the current predicament.

## 2.2 MEASUREMENT OF VISCOSITY

From the different experimental studies in the literature it is observed that as compared to the studies on thermal conductivity of nanofluids, there are limited studies on rheological properties. **Li et al. [11]** in their study by using a capillary viscometer measured the viscosity of water with CuO nanoparticles suspensions. They observed with increase in the temperature the apparent viscosity of nanofluids decreased. **Wang et al. [12]** measured the relative viscosity of $Al_2O_3$–water and $Al_2O_3$–ethylene glycol nanofluids. The results shown that; with increase in solid volume fraction of the two nanofluids there is increase of relative viscosity. It means that the desirable heat transfer increase may be due to the undesirable increase in pressure drop. **Das et al. [13]** in their experimentation measured the viscosity of $Al_2O_3$–water nanofluids against shear rate. The results have shown an increase of viscosity with increase in particle concentrations. They concluded the strong possibility of nanofluid being non-Newtonian; and may be viscoelastic in some cases.

**Ding et al. [14]** measured the viscosity of CNT–water nanofluids as a function of shear rate. From the results they observed that with increasing CNT concentration the viscosity of nanofluids increased and with decrease in the temperature.

From the literature we can conclude that the nanofluids have better fluid flow performance because of the higher shear rates at the wall, due to lower viscosity.

## 2.3 CONVECTIVE HEAT TRANSFER

In the last two decades significant research has been done on the forced convective heat transfer characteristics of the nanofluids. From the experimental study of Lee and Choi [45] for the heat transfer behavior in parallel channels using an unspecified nanofluid it is found that nanofluids offer less thermal resistance by a factor of 2.

**Wen and Ding [15]** carried out experiments for the analysis of convective heat transfer of $\gamma$ -$Al_2O_3$ (27–56 nm) /water based nanofluids flowing through a copper tube (D = 4.5 mm, L = 970 mm) in laminar regime. From the results is is concluded that the $Al_2O_3$ particles enhanced the convective heat transfer coefficient. Heat transfer coefficient increases with particle concentrations and Reynolds number.

**Xuan and Li [16]** investigated flow and convective heat transfer characteristics for Cu–water based nanofluids experimentally in a straight tube with a constant heat flux at wall. From the observed results it is found that nanofluids have enhanced heat transfer rate as compared to pure water.

**Heris et al. [17]** in their investigation on laminar flow of CuO/water and $Al_2O_3$/water nanofluids in a tube in tube heat exchanger made from 1 m annular copper tube with 6 mm inner diameter and with 0.5 mm thickness and 32 mm diameter outer stainless steel tube. The saturated steam was circulated to create constant wall temperature boundary condition rather than constant heat flux condition by other researchers. The experimental results shown enhanced heat transfer coefficient with increase in volume fraction of nanoparticles as well as Peclet number.

**Tsai et al. [18]** used gold nano particles of various sizes (2–35 nm & 15–75 nm) with aqueous solutions prepared by the reduction of HAuCl4 with trisodium citrate and tannic acid. They observed a large decrease in thermal resistance of the heat pipe with nanofluids as compared with de-ionized water. The thermal resistance of the circular heat pipe ranged from 0.17 to 0.215 K/W for different nanoparticle solutions. They concluded that nanofluids have high potential to replace the conventional fluids in heat pipes.

**Chien et al. [19]** experimentally investigated miniature disk shaped heat pipe of 9mm diameter and 2mm height with gold (17nm)/water nanofluids flowing through it. The results have shown that thermal resistance of heat pipe decreases with increase in nanoparticle concentration.

From the available results in the literature it is clear that the heat transfer phenomenon for the nanofluids is very complex. The effective thermal conductivity should not be considered as a major criterion for the application of nanofluids. The other factors such as particle size, shape and distribution, micro-convection, pH value, and the particle–fluid interactions etc should be considered as they affect the heat transfer rates of the nanofluids in natural convective heat transfer.

## 2.4 BOILING HEAT TRANSFER

**Das et al. [20]** studied the pool boiling performance in tubes of small diameter (4, 6.5 mm) with the bubble size and tube diameter of the same order. They observed that deterioration for the narrow tubes was lower than that in the large tube (D = 20 mm). The small tube results in a large curvature of the surface to induce direct departure rather than sliding of larger bubbles.

**Das et al. [13]** carried out an experimental investigation on the pool boiling characteristics of $Al_2O_3$ nanofluids under atmospheric conditions in a tube with 20mm diameter. It is found that the insertion of nanoparticles decreased the boiling performance and increased the wall superheat for a given heat flux. The drop in boiling performance increased with increasing particle concentration and surface roughness.

**Tu et al. [21]** observed significant enhancement in pool boiling heat transfer using Al2O3/water nanofluids.

**Wen and Ding [22]** carried out experiments by using $\gamma$ -$Al_2O_3$–water nanofluids to study the pool boiling heat transfer. They found that alumina nanofluid enhanced the boiling heat transfer, by around 40% for a 1.25 wt% particle concentration. The more studies should be carried out for the observation of interaction between the nanofluids (wettability) and surface.

From the observed literature the inconsistencies indicate that understanding of the thermal behavior of nanofluids related to the boiling heat transfer is still poor. Further in-depth investigations on boiling of nanofluids should be carried out for understanding the phenomena.

## APPLICATION OF NANOFLUIDS

The convective heat transfer is a major factor considered while investigating the nanofluids to observe the heat transfer characteristics in many engineering applications.

From the literature review it is observed that the nanofluids have greater potential for heat transfer enhancement and are highly suited to application in different types of heat exchangers.

In this section various application of nanofluids in heat exchangers used in industries, like shell-and- tube heat exchangers, plate type heat exchangers, double-pipe heat exchangers and compact heat exchangers are reviewed.

### 3.1 SHELL AND TUBE HEAT EXCHANGERS

**Khoddamrezaee et al. [23]** investigated heat transfer characteristics of an $Al_2O_3$/ethylene glycol nanofluid and ethylene glycol fluid in a cross rectangular arrangement of tubes in a shell and tubes heat exchanger. The variables like stagnation point, separation point, heat transfer coefficient and shear stress for nanofluid and pure fluid were determined and compared. From the results it is found that by using of nanofluids, the stagnation and separation points of flow were delayed and the heat transfer coefficient and shear stress increased.

**Lotfi et al. [24]** conducted an experimental investigation on heat transfer enhancement of multi-walled carbon nanotube (MWNT)/water nanofluid) in a horizontal shell and tube heat exchanger. The test section of the heat exchanger has 14 tubes with 7mm inside diameter and lenght580mm. The coolant flows in shell with 101mm diameter. The carbon Nanotubes were prepared by the use of catalytic chemical vapor deposition (CCVD) method over Co–Mo/Mg On a catalyst. From the results it is seen that the presence of multi-walled Nanotubes enhanced the heat transfer rate the heat exchanger.

**Farajollahi et al. [25]** studied heat transfer characteristics of nanofluids in a shell and tube heat exchanger with turbulent flow. The nanofluids used were $\Upsilon$-$Al_2O_3$/water and $TiO_2$/water. They observed enhancement in the heat transfer rate and heat transfer coefficients by using nanofluids that the base fluids. $TiO_2$/water nanofluid showed better performance for lower concentrations whereas $\Upsilon$-$Al_2O_3$/water with higher concentrations.

**Leong et al. [26]** investigated the application of nanofluids as working fluids for a biomass heating plant with shell and tube heat recovery exchangers. The results showed that the overall and convective heat transfer coefficient increased with the application of nanofluids compared to ethylene glycol or water based fluids.

### 3.2 PLATE TYPE HEAT EXCHANGERS

**Pantzali et al. [27]** instigated numerically and experimentally the performance of a miniature plate heat exchanger with modulated surface with nanofluids. It is observed that at lower rates the heat transfer rate was more as compared to the higher flow rates. Form the results it is concluded that nanofluids has low volumetric flow as compared to base fluid for the same heat transfer.

**Mare´ et al. [28]** investigated the thermal performances of two types of nanofluids ($Al_2O_3$/water and aqueous suspensions of Nanotubes of carbons) in two plate heat exchangers. The results showed a large heat transfer enhancement in laminar flow in the heat exchanger. For the same Reynolds number, alumina and carbon Nanotubes has convective heat transfer coefficient of about 42% and 50% respectively compared to that of pure water. The results shown that alumina and carbon Nanotubes have a better thermal–hydraulic performance as compared to water in terms of a competition between heat transfer enhancement and pumping power loss.

**Pandey and Nema [29]** have done study on corrugated plate heat exchanger using nanofluid ($Al_2O_3$ / water) with different concentrations and water in turbulent flow. It is observed that the heat transfer characteristics enhanced with increase in Reynolds and Peclet number and with decrease in nanofluid concentration. The pumping power increased with increase in nanofluid concentration for the same heat load. Both heat transfer rates and power consumption were lower for water in comparison to the nanofluid. For same heat load the nanofluid required lower flow rate but suffered higher pressure drop as compared to water.

**Kwon et al. [30]** have done experimental analysis of heat transfer characteristics pressure drop of the ZnO and $Al_2O_3$ nanofluids. The results shown that with Reynolds number for 6 vol% $Al_2O_3$ the overall heat transfer coefficient increased to 30%. At a given volumetric flow the performance was not changed.

### 3.3 DOUBLE PIPE HEAT EXCHANGERS

**Chun et al. [31]** experimentally analyzed a double pipe heat exchanger system under laminar flow regime for a convective heat transfer coefficient of nanofluids (Al nanoparticles and transformer oil). The experimental results showed that the average heat transfer coefficient of fluid increased due to addition of nanoparticles in laminar flow regime. The increase in heat transfer coefficient may be due to the nanoparticles concentration. The surface properties of nanoparticles, particle loading, and particle shape are major factors for enhancing the heat transfer properties of nanofluids.

**Zamzamian et al. [32]** have done experimental investigation of double pipe heat and plate heat exchanger with $Al_2O_3$ nanoparticles and CuO nanoparticles in ethylene glycol to analyze heat transfer coefficient with turbulent flow. The dimensions of the heat exchanger used for this analysis were inner pipe was made of copper with 12mm diameter and 1mm thickness, with a heat exchange length of 70cm. The shell was made of green pipes, 50.8mm in diameter. The plate heat exchanger has 40cm in height and 60cm in length. The results showed the enhancement in forced convective heat transfer with homogenously dispersed and stabilized nanoparticles. The greatest and smallest increases in our experiments were 49% and 3%, respectively.

**Demir et al. [33]** carried out numerical investigation of $TiO_2$ and $Al_2O_3$ nanoparticles in water in heat exchanger with forced convection flow and constant wall temperature. Numerical results have shown that the use of nanofluids significantly increased heat transfer capabilities foe small as well as higher particle volume fractions. Nanofluids with higher volume concentration have higher heat transfer enhancement and also have higher pressure drop.

**Godson Asirvatham et al. [34]** investigated experimentally the convective heat transfer coefficient of silver/water nanofluids in a tube-in-tube counter flow heat exchanger with 4.3 mm inside diameter. The silver nanoparticles of 0.9 vol% in water enhance the heat transfer coefficients by 69.3%.The suspended nanoparticles increased the heat transfer performance of the water, under the same Reynolds number.

### 3.4 COMPACT HEAT EXCHANGERS

Compact heat exchangers are distinct and special types of heat exchangers having a large heat transfer area per unit volume. They are widely used in various applications in thermal fluid systems like automotive thermal fluid systems. In addition, flat tubes are more popular in automotive applications due to the lower drag profile compared to round tubes.

**Vasu et al. [35]** studied the $Al_2O_3$/water nanofluid as coolant for thermal design of flat tube plain fin compact heat exchanger with the e-NTU rating method. The results showed that the pressure drop of 4% nanoparticles of $Al_2O_3$ is almost double of the base fluid.

**Leong et al. [36]** have investigated the application of ethylene glycol based copper nanofluids in an automotive cooling system. The results showed that, overall heat transfer coefficient and heat transfer rate in engine cooling system increased with the usage of nanofluids base fluid.

It is observed that, with the addition of 2% copper particles in a base fluid, about 3.8% of heat transfer enhancement could be achieved at the Reynolds number of 6000 and 5000 for air and coolant, respectively.

**Vajjha et al. [37]** have carried out numerical investigation to observe the cooling performance of a flat tube of a radiator under laminar flow with two different nanofluids, $Al_2O_3$ and CuO, in ethylene glycol and water mixture. Numerical results showed that at a Reynolds number of 2000, the percentage increase in the average heat transfer coefficient over the base fluid for a10% $Al_2O_3$ nanofluid is 94% and that for a 6% CuO nanofluid is 89%.

**Peyghambarzadeh et al. [38]** have investigated the $Al_2O_3$/water and $Al_2O_3$/ethylene glycol nanofluids as the coolants inside flat aluminum tubes of the car radiator for the convective heat transfer enhancement. The considerable increase heat transfer rate is observed with addition of nanoparticles than that of the base fluids.

**Huminic [39]** numerically investigated nanofluids cooling performance in an automobile radiator under laminar flow. The heat transfer enhancement is observed with Cu-ethylene glycol (2 vol %) nanofluid by 8% as compared with ethylene glycol.

## CONCLUSIONS

In this paper an overview of recent developments in the field of nanofluids for the application of heat transfer and heat exchangers is presented. It is observed that the Researchers have given more attention on the investigation of thermal conductivity and heat transfer characteristics. The further investigations are suggested to understand the heat transfer characteristics of nanofluids and discover new and exclusive applications for these fields.

The heat transfer enhancement capability of nanofluids makes them suitable in heat exchangers an interesting option, which leads better system performance and the resulting advantage in energy efficiency. But nanofluids stability and its production cost are major factors that hamper the commercialization of nanofluids.
Theoretical and experimental researches for investigations on the effective thermal conductivity and viscosity are needed to be carried to demonstrate the potential of nanofluids for heat transfer characteristics in new application fields.

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