

## Nanofluid Heat Transfer-A Review

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### ABSTRACT

Heat transfer rate is considered as critical aspect for the design of rapid heating and cooling environment. The convective heat transfer can be enhanced passively by changing the flow geometry, boundary conditions, or by enhancing the thermal conductivity of the fluid. Researchers tried to increase the heat transfer rate by increasing the thermal conductivity of the fluid. The thermal conductivity of the fluid can be boosted by the use of nanopowder in the base fluid (uniformly suspended). Nanofluids are termed as the next generation heat transfer elements. Nanofluids cause drastic change in the properties of the base fluid. The mass concentration of nanoparticles is proportional to the rate of heat transfer within critical limit. The Reynolds number, mass concentration of the powder, and size of the particles are the basic parameters controlling the heat transfer of the fluid. The increase in the Nusselt and Peclet number results in the increase in the heat transfer coefficient of the fluid which leads to higher heat transfer rate.

**Keywords:** *Nanofluids, Nanoparticles, Heat Transfer, Heat Transfer coefficient, Thermal Conductivity*

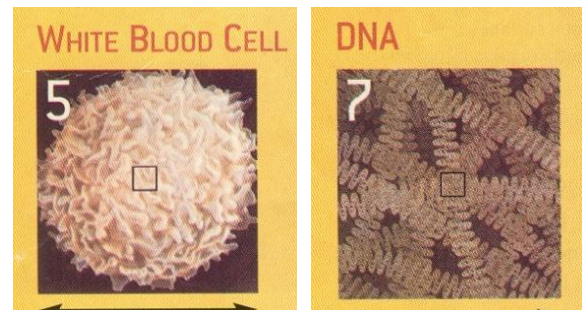
### 1. INTRODUCTION

The rate of heat transfer is considered as an important parameter for the design of any mechanical, electrical or electronic component. The heat transfer rate of the element is governed by the surface area, surface roughness, thermal conductivity of the element and the temperature gradient. Researchers tried to increase the thermal conductivity of the fluid so as to increase the heat transfer rate. The thermal conductivity of the fluid can be increased by the nanofluids. Fluids with nanoparticles suspended in them are called as nanofluids, a term coined by Choi in 1995 of the Argonne National Laboratory, U.S.A. (diameter less than 50nm). Suspended nanoparticles in the various base fluids can alter the fluid flow and heat transfer characteristics of the base fluids. The main objective of this study is to enhance the heat transfer rate using nanofluids as the working medium. The base fluid is usually water, ethylene glycol, and toluene or engine oil. The uniform suspension of the nanoparticles plays an important role in the heat transfer capability of the fluid. The uniform suspension is achieved by the use of ultrasonic mixer or ultrasonic homogenizer, which perform the task of mixing the nanofluid in the conventional fluid. The ultrasonic mixer are available in the various frequency ranges from 20 to 40KHz. The use will depend upon the volume concentration and the particle diameter of the nanofluid. The fine grade of nanoparticles will suspend uniformly with the higher surface area and less pressure drop across the test section. The various parameters which governed the heat transfer rate are Nusselt number, Peclet number, and Reynolds

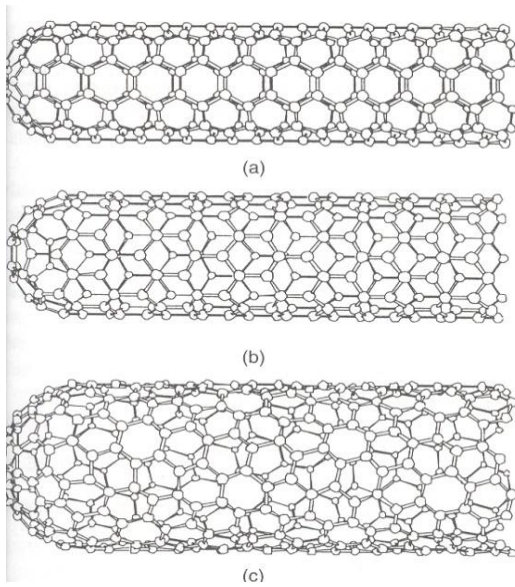
number. The higher the Nusselt and Peclet number will tend to increase the heat transfer coefficient and increase the heat transfer rate of the nanofluid. The various authors developed the relation for the effective thermal conductivity of the nanofluid for the particular boundary condition. The boundary layer phenomenon and the Brownian motion of the particles plays an important role in the rate of heat transfer enhancement. The Nusselt number rises considerably by increase in the volume concentration of the nanofluid.

### 2. NANOTECHNOLOGY HISTORY

The term nanotechnology is new, but its existence of the functional devices and structure of nanosized devices are not new in this world. In 1905, experimental data on the diffusion theory showed that the molecule has nanometer diameter, which is considered as the notable landmark in the scientific history of nanotechnology.



In 29 December 1959: Visionary statement by Prof.R.P.Feynman, "There is enough space at the bottom".



Some common structure of carbon nanotubes (CNT)

### 3. NEED OF NANOFLUID

- Due to nano size particles, pressure drop is minimum.
- Higher thermal conductivity of nano particles will increase the heat transfer rate.
- Successful employment of nanofluid will lead to lighter and smaller heat exchanger.
- Drastic change in the properties of the base fluid, by suspending nanofluids.
- Heat transfer rate increases due to large surface area of the nano particles in the base fluid.
- Nanofluids are most suitable for rapid heating and cooling systems.
- Due to nano size particles, fluid is considered as integral fluid.

Considering the heat transfer point of view, one of the most important challenge faced by the experts is the necessity to increase the heat flux and to reduce the size of the heat exchanger for the efficient use of the energy. Nanotechnology is being considered for use in many applications to provide cleaner, more efficient energy utilization.

Maximizing the heat transfer area  $A$  is a common strategy to improve the heat transfer and many heat exchangers such as radiators and plate and frame heat exchanger designed to maximize the heat transfer area. This strategy cannot be applied to the microelectromechanical systems (MEMS).

Nanofluids can be used for the wide variety of industries, ranging from transportation to energy production and in electronics systems like microprocessor. The novel and advanced concept of coolant offer intriguing heat transfer characteristics compared to conventional fluid.

Application of the nanofluids in the industries may be hindered by the several factors such as long term stability, increase pumping power and pressure drop, nanofluids thermal performance in turbulent and fully developed region, lower specific heat of nanofluids and higher production cost of nanofluids.

### 4. APPLICATIONS

Nanofluids can be used to cool automobile engines and welding equipments and to cool high heat flux device such as high power microwave tubes, and high power laser diode array. Nanofluid could flow through the tiny passage in MEMS to improve the efficiency. In the transportation industry, nanocars, General Motors (GM), Ford among others are focusing on nanofluid research projects.

Some common applications are:-

- Engine cooling
- Engine transmission oil
- Boiler exhaust flue gas recovery
- Cooling of electronics circuits
- Nuclear system cooling
- Solar water heating
- Refrigeration (domestic and chillers)
- Defence and Space applications
- Thermal storage
- Bio-medical applications
- Drilling and lubrications

The measurement of nanofluid critical heat flux (CHF) in a forced convection loop is useful for the nuclear applications. If nanofluid improve the chiller efficiency by 1%, a saving of 320 billion KWh of electricity or equivalent 5.5 million barrel of oil per year would be release in US alone. The nanofluids finds the potential for deep drilling operations. A nanofluid can also be used for increasing the dielectric strength and life of transformer oil by dispersing nanodiamonds particles.

### 5. LITERATURE SURVEY

Jongwook Choi and Yuwen Zhang [1] performed simulation of laminar forced convection heat transfer of  $Al_2O_3$  - water in pipe with return bend. A straight pipe of dimensionless diameter 1 and dimensionless length of 10 is considered. The grids on pipe consists of nodal points 5226 and elements of 4875 for the Finite Element Method (FEM), and nodal points of 292800 and elements 301701 for CFX with fine mesh to obtained more accurate

solution. In total 25 cases have been simulated in the concentration of 0.0%, 2.5%, 5.0%, 7.5% and 10% and Reynolds number of 10, 25, 50, 75, 100. The result shows that the average Nusselt number increases with the rise of the Reynolds number and the particle concentration. The heat transfer enhancement in the return section is more than the inlet and the outlet section of the pipe, due to the secondary flow.

S.M.Fotukian and M.Nasr Esfahany [2] experimentally investigated turbulent convective heat transfer of dilute  $\text{Al}_2\text{O}_3$ /water inside circular tubes. The nanofluid  $\text{Al}_2\text{O}_3$ /water with dilute loading of 0.03%, 0.054%, 0.135% were studied. The Reynolds number was varied from 6000 to 31000. The experimental results indicated that addition of small amount of nanoparticles to pure water improves the heat transfer performance significantly. The maximum value of 48% increase in the heat transfer coefficient compared to pure water for 0.054% volume concentration at Reynolds number of 10000 was observed. Increasing the particle concentration did not show much heat transfer enhancement in the turbulent region. The ratio of convective heat transfer coefficient of nanofluid to that of pure water decreases with the Reynolds number. The pressure drop of the nanofluid with 0.135% volume concentration with showed 30% increase at Reynolds number of 20000 compared to pure water.

Sharjeel Tahir and Manu Mital [3] performed numerical investigation of laminar alumina–water nanofluid laminar forced convection heat transfer in circular channel. The effect of particle diameter, Reynolds number, and concentration are investigated. The fluid is treated as continuous media and the flow field is solved by Navier-Stokes Equations. The validated numerical model is used for formulating a three factorial design matrix with each of the three independent variables at three levels. The matrix considers the particle size (50nm, 75nm, and 100nm), Reynolds number (250, 750 and 1250), and particle volume fraction (1, 2.5, and 4%). The effect of these variables were studied by developing three level, three factorial design with average heat transfer coefficient along the tube axis. It is seen that almost all the variation in the heat transfer coefficient is due to the change in these parameters. The Reynolds number is the most significant parameter in the heat transfer coefficient, while the particle volume fraction is the least significant.

M.Nasiri et al. [4] experimented heat transfer of nanofluid through annular duct. The nanofluids were  $\text{Al}_2\text{O}_3$  and  $\text{TiO}_2$  with water as the base fluid. The range of the Reynolds number for both the nanofluids were 4000 and 13000. The volume concentration for both fluids was 0.1, 0.5, 1.0, and 1.5% of  $\text{Al}_2\text{O}_3$  and  $\text{TiO}_2$ . Both nanofluids shows higher Nusselt number than those of the base fluids and enhancement increases with the particle concentration. At Peclet number about 24400, the enhancement of Nusselt number for  $\text{Al}_2\text{O}_3/\text{H}_2\text{O}$  nanofluid

with concentration of 0.1%, 0.5%, 1.0%, 1.5% are 2.2%, 9%, 17% and 23.8% respectively. For  $\text{TiO}_2/\text{H}_2\text{O}$  nanofluid, at Peclet number 53200 the increment in the Nusselt number with particle concentration of 0.1, 0.5, 1.0, and 1.5% are 1%, 2%, 5.1%, and 10.1%. Relative enhancement in the heat transfer coefficient is increased by increasing in the nanoparticle concentration for both nanofluids. This may be due to thermal conductivity of the nanofluid, the presence of the Brownian motion, nanoparticle migration in nanofluid, possible slip at the wall, and thinner boundary layer thickness. Comparison shows similar properties for both nanofluids with the particle concentration are same. This can be related to the higher thermal conductivity and lower particle size of  $\text{Al}_2\text{O}_3$  nanoparticles in  $\text{Al}_2\text{O}_3$ -water nanofluid.

Javad Bayat and Amir Hossein Niksereht [5] studied numerically the thermal performance and the pressure drop of nanofluids in turbulent forced convection. The study involves the axisymmetric steady, forced turbulent convective flow of nanofluid through the circular tube having diameter  $D=1$  cm and length  $L=1$ m, by mathematical modeling. The set of coupled non-linear Navier-Stokes differential equations have been discretized using finite volume technique. The experimentation was performed on water/ Ethylene Glycol (60:40) by mass with  $\text{Al}_2\text{O}_3$  for wide range of Reynolds number of  $10^4 < \text{Re} < 10^5$  and constant wall heat flux condition. The result shows that the volume fraction has great impact on heat transfer, pressure drop, Prandtl number, pumping power. There is large difference in the pressure drop by using the nanofluid and the base fluid for same pumping power. Nanofluids provide higher thermal enhancement at higher Reynolds number but not recommended for the practical application in the turbulent regimes, as pumping power is considerable.

M. A. Akhavan-Behabadi and M.Fakoor [6] investigated heat transfer of nanofluids inside vertical helically coiled tubes at uniform wall temperature. In addition to the nanofluid Multi-Walled Carbon Nano Tubes (MWCNT) were used as additives. The nanoparticles with weight concentration of 0.1%, 0.2% and 0.4% were prepared along MWCNT. The performance was observed for straight tubes and for helical coils. The results shows that the Nusselt number increased upto 45% and the corresponding heat transfer coefficient was 80% more than the base fluid. For the helical coils, reducing the coil to diameter ratio or increasing the coil pitch to tube diameter ratio leads to augmentation of heat transfer rate. In helical coils, the Nusselt number for base fluid were 3 to 7% higher than straight tubes, and Nusselt number for helical coils is further 60% more. The combination of the two methods has a high capacity to enhance the heat transfer. The Nusselt number for the helical coil with nanofluid is 10 times higher than that of the conventional fluid.

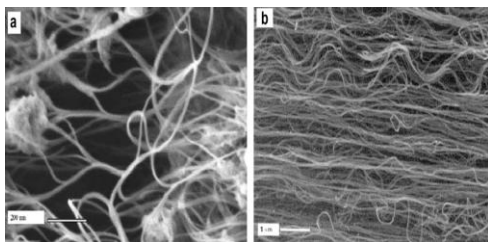


## Properties of Nanofluids

Particle	Mean Diameter (nm)	Density Kg/m <sup>3</sup>	Thermal Conductivity w/m-K	Sp.Heat (J/gm-K)
Al <sub>2</sub> O <sub>3</sub>	20	3700	46	880
TiO <sub>2</sub>	10	3840	11.7	710
Fe <sub>3</sub> O <sub>4</sub>	36	5180	80.4	670

M.Saedinia et al. [7] studied heat transfer and pressure drop of nanofluids flow in horizontal coiled wire inserted tube at constant heat flux. The nanofluid is prepared by dispersion of CuO in base oil. Particles volume fraction ranging from 0.07% to 0.3% is used. Five coiled wires having pitch of 25-35 mm and wire diameter 0.9-1.5 mm were put one by one in the test section. Effects of different parameters such as Reynolds number, wire diameter, coil pitch, particle concentration were studied. Results shows that the increase in 45% for heat transfer coefficient and penalty of 63% in the pressure drop was observed for the coiled tubes. Nanofluids have better heat transfer performance when they flow inside the tubes with wire coil inserts instead of flowing through plain tubes. For 0.3% vol. concentration for the highest wire diameter 40.2% enhancement in the heat transfer is achieved.

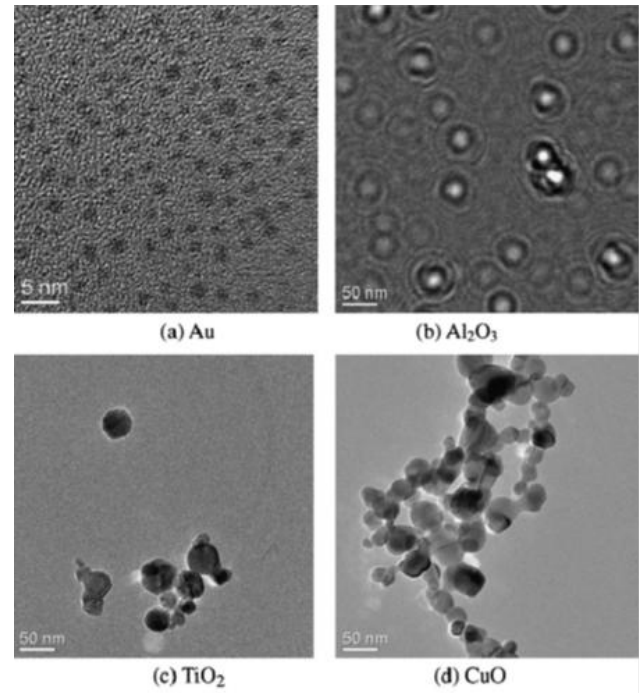
D.Ashtiani et al. [8] investigated effect of MWCNT inside flattened tubes at uniform wall temperature condition. The test section consists of copper tube surrounded by a steam chamber to keep temperature of the wall constant. Weight fraction of 0.0%, 0.1%, 0.2%, 0.4% were selected. Copper tube of 14.5 mm ID and test section of oblong shape with inside height of 13.4mm, 11.7mm, 10.6mm, 8.6mm were used. The heat transfer without the nanofluid is carried out so as to compare it with nanofluids. The results shows that the Nusselt number rises suddenly by 132% at the Peclet number of 420000 for 0.4wt.% whereas the corresponding value for the 0.2 wt. % nanofluid is approximately 58% for the same range of Peclet number. It can be concluded that the Nusselt number and hence the heat transfer rate goes up by increasing the nanoparticle weight fraction.



SEM( Scanning electron microscope) images of (a) Single wall CNT and (b) Multi-wall CNT

S.M.Hashemi and M.A.Akavan-Behabadi [9] empirically studied the heat transfer and pressure drop for CuO-base oil nanofluid in horizontal helically coiled tubes for constant heat flux. The nanofluids with mass concentration of 0.5%,1% and 2% were selected. The apparatus consists of helical coils with four turns with 14.37 mm inner diameter and wall thickness of 0.75 mm.

The coil had a stretched length of 4.073m. The effects of different parameters such as Reynolds number, fluid temperature, nanofluid particle concentration on the heat transfer and pressure drop were observed. The nanofluids were dispersed uniformly by ultrasonic processor generating ultrasonic pulses of 400W at 24KHz frequency. The heat transfer enhancement of about 18.7% and 30.4% were observed with the basefluid for the case of straight tube and helical tube respectively.



TEM photographs of Au, Al<sub>2</sub>O<sub>3</sub>, TiO<sub>2</sub> and CuO particles and carbon nanofiber

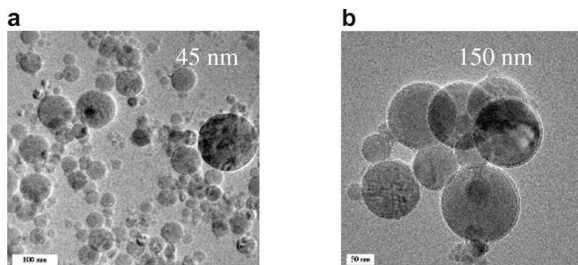
S. Zeinali Heris et al [10] performed experimental investigation of convective heat transfer of alumina/water nanofluid in circular tubes. The test section consists of 6 mm diameter tube of 1m length with 0.5 mm thickness. Nanofluids flows inside the tubes while saturated steam entered the annulus section in order to maintain the constant wall temperature. The Nusselt number were obtained for the different particle concentration as well as various Peclet and Reynolds number. The experimental results were compared to the theoretical values by the use of Seider-Tate equation. The increase in the heat transfer rate is due to the higher thermal conductivity of the nanoparticles. Some other factors are dispersion and chaotic movements of nanoparticles. The Brownian motion and migration of the particles plays an important role in the heat transfer enhancement.

S.Suresh et al. [11] compared the thermal characteristics of Al<sub>2</sub>O<sub>3</sub>/ water and CuO/ water nanofluid in transition flow through straight tube fitted with helical screw taper inserts. The twist ratio in screw tape inserts were 1.78, 2.44, 3. Using 0.1% volume concentration for both the

nanofluids. The average enhancement in the Nusselt number at the given twist ratio were 156.24%, 122.16%, 89.22%. The average increase in the Nusselt number for  $\text{Al}_2\text{O}_3$  were 166.84%, 128.67% and 89.22%. In case for CuO the enhancement was 179.82%, 144.29%, 105.63%. The thermal performance based on the constant pumping power criteria shows that helical screw taper inserts give better thermal performance when used with CuO/water nanofluid than with  $\text{Al}_2\text{O}_3$ /water nanofluid.

Massimo Corcione et al. [12] studied the heat transfer in turbulent pipe flow theoretically. The main idea is base that the concept that the nanofluid behave like a single phase fluid than like conventional solid-liquid mixture if the thermo-physical properties are provided at particular temperature. The author in regard suggested two empirical equations based on the data reported for the evaluation of the effective thermal conductivity and dynamic viscosity. Experimentation performed at the constant power and constant heat transfer rate for the different operating conditions, nanoparticles diameter and solid- liquid combination. The fundamental result obtained is the existence of optimal particle loading for either maximum heat transfer at constant driving power or minimum cost of operation at constant heat transfer rate. It is found the optimal concentration of the nanofluid increases as the bulk mean temperature increases and the Reynolds number of the base fluid also increased.

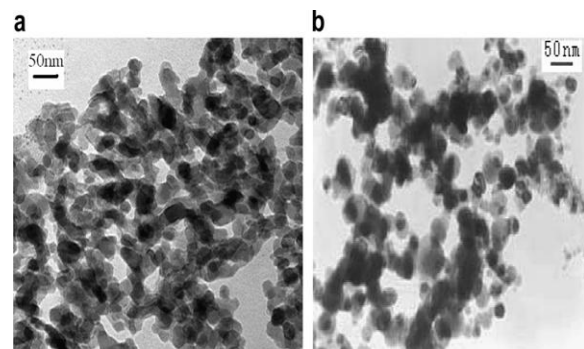
K.B. Anoop et al. [13] studied experimentally the effect of particle size on the convective heat transfer in nanofluid in the developing region. The nanofluid used was  $\text{Al}_2\text{O}_3$ /water. The particle size selected was 45 nm and 150 nm. It is found that both the fluid shows higher heat transfer characteristics than that of the base fluid, while the 45 nm shows higher heat transfer rate and heat transfer coefficient than of other fluid. It is observed that at  $x/D=147$ , for 45 nm particle based nanofluid (4 wt%) with  $Re = 1550$ , the enhancement in heat transfer coefficient was around 25% whereas for the 150 nm particle based nanofluids it was found to be around 11%. It is also observed that in 4 wt% nanofluid with average particle size 45 nm, at  $Re=1550$ , the enhancement in heat transfer coefficient was 31% at  $x/D = 63$ , whereas it was 25% and 10% at  $x/D = 147$  and 244, respectively.



The Scanning Electron Microscope (SEM) images of  
a)  $\text{TiO}_2$  and b) CuO

A.A. Abbasian Arani et al. [14] studied experimentally the effect of  $\text{TiO}_2$ -water nanofluid on heat transfer and pressure drop. The particle size selected was of 30 nm. The experimentation was performed for the volume fraction of 0.002 and 0.02, the Reynolds number was in between 8000 to 51000. The apparatus was in the form of horizontal double tube counter-flow heat exchanger. It is observed that by increasing the Reynolds number or nanoparticle volume fraction, the Nusselt number increases. Meanwhile all nanofluids have a higher Nusselt number compared to distilled water. It is observed that by use the nanofluid at high Reynolds number (say greater than 30,000) more power compared to low Reynolds number needed to compensate the pressure drop of nanofluid, while increments in the Nusselt number for all Reynolds numbers are approximately equal. Therefore using nanofluids at high Reynolds numbers compared with low Reynolds numbers, have lower benefits. It is also seen that, the maximum thermal performance factor of 1.8 is found with the simultaneous use of the  $\text{TiO}_2$ -water nanofluid with 0.02% volume and at Reynolds number of 47,000.

L. Syam Sundar, K.V. Sharma [15], studied experimentally the heat transfer enhancements of low volume concentration of  $\text{Al}_2\text{O}_3$  nanofluid and with longitudinal strip inserts in a circular tube. The main aim is to study the convective heat transfer and friction factor for  $\text{Al}_2\text{O}_3$ /water nanofluid with different aspect ratio. Experiments are conducted with water and nanofluid in the range of  $3000 < Re < 22,000$ , particle volume concentration  $0 < u < 0.5\%$  and longitudinal strip aspect ratios of  $0 < AR < 18$ . The friction factor of 0.5% volume concentration nanofluid with longitudinal strip insert having  $AR = 1$  is 5.5 times greater at 3000 Reynolds number and 3.6 times at 22,000 Reynolds number when compared to water or nanofluid flowing a tube. The heat transfer coefficient of 0.5% volume concentration  $\text{Al}_2\text{O}_3$  nanofluid with longitudinal strip insert having  $AR = 1$  is 50.12% and 55.73% greater at Reynolds number of 3000 and 22,000, respectively compared to the same fluid and 76.20% and 80.19% greater compared to water flowing in a plain tube.



TEM (Transmission Electron Microscope) image of (a) nano-alumina and (b) nano-copper

## 6. DISCUSSION

The various authors have performed the experimentation related to the heat transfer enhancement by using oxide form nanofluid such as CuO, Al<sub>2</sub>O<sub>3</sub>, TiO<sub>2</sub>, ZnO. Amongst all Al<sub>2</sub>O<sub>3</sub> and CuO are frequently used due to the ease of suspension in the basefluid. The use of proper ultrasonic mixer is essential for the uniform mixing of the nanoparticles. Proper care has to be taken while handling the nanoparticles in order to avoid the oxidation. The use of the nanofluid with higher concentration provides considerably higher thermal performance for all Reynolds number.

## 7. CONCLUSIONS

1. The higher the nanoparticles weight fraction, the more the rate of heat transfer enhancement.
2. The heat transfer rate is directly proportional to Nusselt and Peclet number of the fluid.
3. The fine grade of nanoparticles increases the surface area which results in increase in the heat transfer rate.
4. Nanofluid stability and its production cost are major factors that hinders the commercialization of the nanofluids. By solving these challenges, it is expected that nanofluid can make substantial impact as coolant in heat exchanging devices.
5. There has been considerable pressure drop by the use of nanofluid, but can overcome to some extent if extremely fine powder is used (less than 20 nm).

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