Experimental Analysis of Heat Transfer Enhancement Using Al_2o_3/Water Nanofluid

Mr. Rahul N. Khachane
Assistant Professor
Smt. KashibaiNavale College of Engineering, Pune-41

Abstract- *Nanofluids refer to a new kind of heat transfer fluids with suspended high conductivity metal nanoparticles and can be employed to increase heat transfer rate in various applications. In this paper effect of nanoparticle material and its concentration in water on heat transfer is studied.The concentration of nanoparticle to be use in this experiment is 0.2 %, 0.4% and 0.6% Vol. with base fluid as water.The result shows that addition of* Al_2O_3 *nanoparticle into the water has great effect on heat transfer coefficient and the Nusselt number.*

Keywords- Nanofluid, Heat Transfer Enhancement, Nano Particle, Heat Transfer Coefficient.

I. INTRODUCTION

Heat transfer fluids (HTFs) have many industrial and civil applications, including in transport, energy supply, air-conditioning and electronic cooling, etc. Traditional HTFs, such as water, oils, glycols and fluorocarbons, however, have inherently poor heat transfer performance due to their low thermal conductivities. Research and development activities are being carried out to improve the heat transport properties of fluids. Solid metallic materials, such as silver, copper and iron, and non-metallic materials, such as alumina, CuO, SiC and carbon nanotubes, have much higher thermal conductivities than HTFs. It is thus an innovative idea trying to enhance the thermal conductivity by adding solid particles into HTFs since Maxwell initiated it in 1881.The situation changed when S.U.S. Choi and J. Eastman in Argonne National Laboratory revisited this field with their nanoscale metallic particle and carbon nanotube suspensions .Choi and Eastman have tried to suspend various metal and metal oxides nanoparticles in several different fluids and the results are promising, however, many things remain elusive about these suspensions of nano-structured materials, which have been termed “nanofluids” by Choi and Eastman.

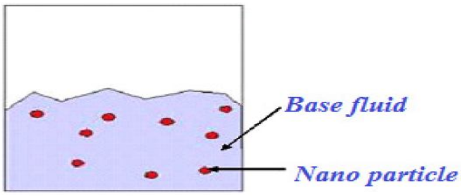

Fig. 1.1 Principle of Nanofluid

Base fluids mostly used in the preparation of nanofluids are the common working fluids of heat transfer applications; such as, water, ethylene glycol and engine oil. In order to improve the stability of nanoparticles inside the base fluid, some additives are added to the mixture in small amounts.

1.1 Properties of Material

In present study, Al_2O_3 types of nano particles used. The various properties of the nanoparticle are given in Table 1.

Table 1: Properties of Al_2O_3 nanoparticles

Property/Material	Al_2O_3
Shape of Particle	Spherical
Avg. Size of Particles (nm)	55
Density (Kg/m3)	3900
Sp. Heat (KJ/Kg.K)	0.88
Thermal Conductivity(W/m-K)	35

Table 2: Properties of PCM (Paraffin C27 Wax) and Base fluid (Water)

Property	PCM(Paraffin C27 Wax)	Base Fluid(Water)
Melting Temperature (°C)	58 – 60 °C	0°C
Density (Kg/m3)	897	1000
Sp. Heat (KJ/Kg-K)	2.88 (Solid) & 2.24 (Liquid)	4.18
Latent Heat of solidification (KJ/Kg)	189	334.774
Thermal Conductivity (W/m-K)	0.21	0.613

II. LITERATURE SURVEY

In the last decade, a significant amount of experimental and theoretical research was made to investigate the thermos-physical behaviour of nanofluids. In these studies, it was observed that a high thermal conductivity enhancement could be obtained with nanofluids, even in the case of very small particle volume fractions. Wang et al. wereused Al_2O_3 and CuO nanoparticles to prepare nanofluids with several base fluids; water, ethylene glycol, vacuum pump fluid, and engine oil. With Al_2O_3 nanoparticles, the highest thermal conductivity ratio was observed when ethylene glycol was used as the base fluid. For the particle volume fraction of 3.5%, 40% increase in viscosity was observed. Lee et al.studied the room temperature thermal conductivity of nanofluids by dispersing Al_2O_3 (38.5 nm) and CuO (23.6 nm) nanoparticles. They obtained 20% enhancement with 4 vol.% CuO (23.6 nm)/ethylene glycol nanofluid & 15% enhancement with 4 vol.% Al_2O_3 (38.4 nm)/ethylene glycol nanofluid. J. A. Eastman et al. studied effect of Copper and copper oxide nanoparticle on thermal conductivity. The effective thermal conductivity of ethylene glycol is shown to be increased by up to 40% for a nanofluidconsisting of ethylene glycol containing approximately 0.3 vol% Cu nanoparticles of mean diameter <10 nm. Xie et al. investigated the thermal conductivity of SiC/distilled water and SiC/ethylene glycol nanofluids. It was found that 4.2 vol.% water-based nanofluid with spherical particles had a thermal conductivity enhancement of 15.8%, whereas 4 vol.% nanofluid with cylindrical particles had a thermal conductivity enhancement of 22.9%.

Das et al. Studied the temperature dependence of the thermal conductivity of Al_2O_3 (38.4 nm)/water and CuO (28.6 nm)/water nanofluids. It was seen that for 1 vol. % Al_2O_3/water nanofluid, thermal conductivity enhancement increased from 2% at 21°C to 10.8% at 51°C. Temperature dependence of 4 vol. % Al_2O_3nanofluid was much more significant. From 21 to 51°C, enhancement increased from 9.4 to 24.3%. A linear relationship between thermal conductivity ratio and temperature was observed at both 1 and 4 vol. % cases.

Pak and Choinvestigated the convective heat transfer of Al_2O_3 (13 nm)/water and TiO_2 (27 nm)/water nanofluids in the turbulent flow regime (values in parenthesis indicate particle diameter). Heat transfer enhancement as high as 75% was obtained by using Al_2O_3/water nanofluid with a particle volume fraction of 2.78%. It was indicated that the heat transfer enhancement obtained with Al_2O_3 particles is higher than that obtained with TiO_2 particles. P. C.

Michael Saterlie et al. done theoretical work on the effect of Particle size on the thermal conductivity enhancement of copper-based nanofluids. Nanofluids were prepared using water as the base fluid with copper nanoparticle concentrations of 0.55 and 1.0 vol.%. He found that the 0.55 vol.% Cu nanofluids exhibited excellent dispersion in the presence of sodium dodecyl benzene sulfonate. In addition, a dynamic thermal conductivity setup was developed and used to measure the thermal conductivity performance of the nanofluids. The 0.55 vol.% Cu nanofluids exhibited a thermal conductivity enhancement of approximately 22%. In the case of the nanofluids prepared from the powders synthesized in the presence of cetyl trimethyl ammonium bromide, the enhancement was approximately 48% over the base fluid for the 1.0 vol.% Cu nanofluids.

Mukesh Kumar et al. carried out Experimental investigation on convective heat transfer and friction factor in a helically coiled tube with Al_2O_3 / water nanofluid. They found The enhancement of tube side experimental Nusselt numbers were found to be 17%, 23% and 28% at 0.1%, 0.4% and 0.8% Al_2O_3 / water nanofluid respectively when compared with water. The increase in friction factor are 3%, 9% and 18% at 0.1%, 0.4% and 0.8% volume concentration, respectively, when compared with water at the tube side Reynolds of 8532.

V. L. Bhimani et al. done Experimental Study of Heat Transfer Enhancement Using Water Based Nanofluids as a New Coolant for Car Radiators. The presence of TiO_2 nanoparticle in water can enhance the heat transfer rate of the automobile radiator. The degree of the heat transfer enhancement depends on the amount of nanoparticle added to pure water. Ultimately, at the concentration of 1 vol. %, the heat transfer enhancement of 40-45% compared to pure water was recorded. Increasing the flow rate of working fluid enhances the heat transfer coefficient for both pure water and nanofluid considerably.

G. Kumaresan et al. experimentally studied the enhancement in heat transfer characteristics of a copper sintered wick heat pipe with surfactant free CuO nanoparticles dispersed in DI water. He found that the enhancement in HTC for 0.5%, 1.0% and 1.5% by wt. is 46.6%, 63.5% and 55.9% respectively.

III. EXPERIMENTALSETUP AND PROCEDURE

A. Experimental Setup

In this experimental study shell and tube latent heat storage system is used. The experimental apparatus is composed of a test unit, constant temperature storage tank set at different temperatures (above and below the melting/ solidification temperature of the PCM) and pumps supplying fluid from the constant temperature containers to the test unit.

i. Shell and tube type heat exchanger

- **Inner copper tube**: I.D= 33 mm; O.D= 36 mm; Length= 1000 mm
- **A shell**: I.D= 128 mm; O.D= 136 mm; Length= 1000 mm; material = Stainless Steel (S.S).
- **Insulation**: Glass-wool insulation is used in order to minimize loss of heat from PCM to surrounding of thickness 50 mm.

ii. Temperature measuring system

- **Temperature Indicator:** The 14 port digital temperature indicator is used for indication of temperature of PCM. The 14 in numbers, Pt-100 thermocouples are connected to it via wire. The range of it various from 0 to 199^0 C with accuracy of +/- 0.2^0 C.
- **Thermocouples:** Pt-100 type thermocouples (PtRh-Pt), 14 in number are used of temperature range 0 to 199^0 C with accuracy +/- 0.2^0 C.

iii. Secondary Counter Flow Heat Exchanger

Inner Tube- 10mm OD and 8mm ID made up of copper tube. Outer Tube- 28 mm OD and 24mm ID made up of Iron.Tube Length- 6 meter. B.V. - Ball Valve, F- vol. flow meter, T-Thermocouple, PCM – Phase change material.

Table 3: Radial and axial position of thermocouple placed inside the shell

Thermo-Couple	1	2	3	4	5	6	7	8	9	10	11	12
Radial Position(mm)	128				82				36			
Axial Position(mm)	50	350	650	950	50	350	650	950	50	350	650	950

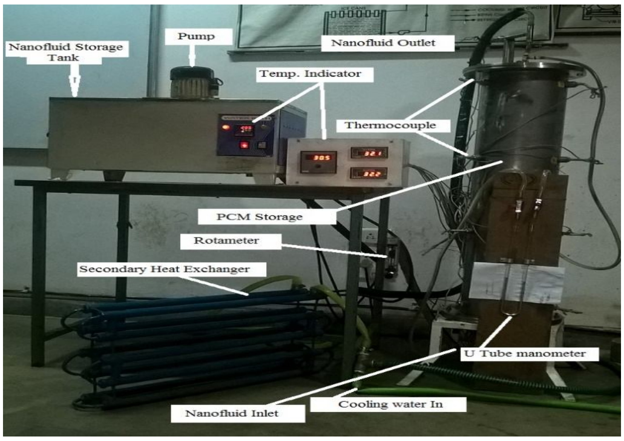

Fig. 3.1 Experimental setup

B. Experimentation

Preceding the experiments, the PCM tube to be fill up with the paraffin wax up to 75%. Experiments start at room temperature and the paraffin wax is in the solid phase. Initial conditions for melting will establish by the circulating water from the low temperature container at environmental temperature. Initial conditions to be establish when all thermocouples inside the paraffin were recording the same temperature. Cold water is then quickly drained from the HTF tube.

First the experiment was performed by using pure water as HTF. Water from the hot temperature container at a required temperature, over the melting range, started to circulate and data collection began. The mass flow rate of the water will constant. Temperature data for all thermocouples to be collected at particular time interval. When all measured PCM temperatures will reach above the melting temperature range and when they reached the same temperature (near to the water temperature in the HTF tube), the melting experiment then finished. The solidification experiment will then start with established initial conditions. Hot water to be drained from the HTF tube and water from the cold temperature container, with a constant flow rate and temperature below the solidification temperature range, started to circulate. Temperature distributions in the PCM will measure and recorded with measuring inlet and outlet temperature of water at the same time interval as in the melting experiment. A solidification experiment as completed when all thermocouples within the paraffin will reached the same temperature.The input operating parameters are concentration of nanoparticle in base fluid, Material of nanoparticle putting the volume flow rate and inlet temperature constant.

Same experiments is performed by replacing water by nanofluid as HTF with 0.2%, 0.4% & 0.6% concentration of nanoparticle in base fluid, measurement is taken for same time interval. Total seven experiment on charging mode and seven experiment on discharging mode are done. During the discharging process the hot nanofluid is passed through secondary counter flow heat exchanger to remove the heat from nanofluid and recirculate at constant inlet temperature. To compare the result, all the experiments were done at same flow rate (2 LPM) and same inlet temperature (About 80^o – Charging mode and 35^o – Discharging mode). The temperature reading of secondary counter flow heat exchanger is also note down at various inlet nanofluid temperature to calculate the overall heat transfer coefficient and effectiveness of heat exchanger.

IV. RESULTS AND DISCUSSION

The results show that the heat transfer coefficient is depend on material and volumetric concentration used. The details comparison for each parameter and its effect on properties of fluid is discuss below.

Experiments are performed under following conditions;

- Inlet Temperature
  Charging mode- 80^{o}C
  Discharging mode- 35^{o}C
- Nanoparticle Material- Al_2O_3
- Nanoparticle concentration by volume- 0.2%, 0.4% and 0.6%.
- Level of PCM filled- 75%

Data Reduction

While doing the result analysis, the properties of nanofluid and performance parameter like Nusselt number, heat transfer coefficient, overall heat transfer coefficient, effectiveness of heat exchanger is calculated by using following formulae

Density of nanofluid,

$$\sigma_{nf} = \Phi\sigma_p + (1-\Phi)\sigma_f \qquad 4.1$$

Where, nf = nanofluid, p= nanoparticle, f= Base fluid, Φ= volume fraction,
Specific heat of nanofluid,

$$Cp_{nf} = \frac{\Phi\sigma_p Cp_p + (1-\Phi)\sigma_f Cp_f}{\sigma_{nf}} \qquad 4.2$$

Thermal conductivity of nanofluid,

$$\frac{k_{nf}}{k_f} = \frac{(k_p+2k_f)+2\varphi(k_p-k_f)}{(k_n+2k_f)-\varphi(k_n-k_f)} \qquad 4.3$$

Heat transfer rate,

$$Q = m_{nf}Cp_{nf}(T_{in} - T_{out}) \qquad 4.4$$

Heat transfer coefficient,

$$h = \frac{m_{nf}Cp_{nf}(T_{in}-T_{out})}{A_s(T_b-T_s)} \qquad 4.5$$

Where, As = surface area of tube, Tb=Bulk mean temp. Of nanofluid, Ts = Average Tube surface temp.

Nusselt number for nanofluid,

$$Nu = \frac{h\,D_h}{K_{nf}} \qquad 4.6$$

V. RESULTSAND DISCUSSION

5.1 Effect of particle concentration on Nusselt number

Various experiments are carried out to study the effect of particle volume concentration in water on the heat transfer coefficient (h) or Nusselt number (Nu). Nusselt number is main parameter regarding heat transfer characteristics. Hence the Nusselt number is calculated for each reading and compare with another reading. The result is plotted with concentration 0.2%, 0.4% & 0.6% by vol. and it compare with pure water for the same time interval. Fig. 4.1 shows that as increase in particle concentration of Al_2O_3 in water helps to increase the Nusselt number. The nanofluid having 0.4 % Al_2O_3 particle concentration shows maximum enhancement of 47% as compare to pure water. Similarly, 0.2% & 0.6 % concentration shows enhancement of 31% & 42% respectively. Fig. also shows that enhancement is decreased as time period increased. It means that the enhancement in Nusselt number is occur at the beginning of experiment.

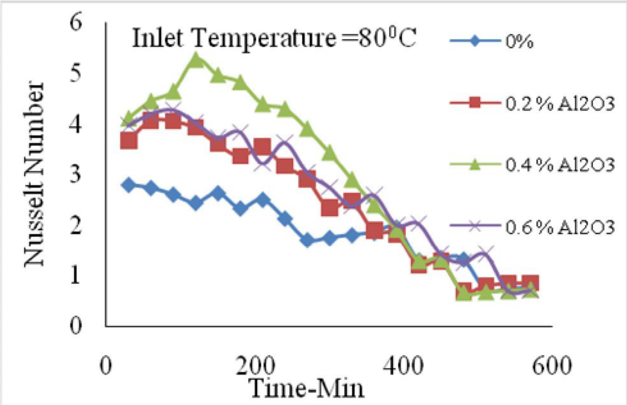

Fig. 5.1 Effect of Al_2O_3 nanoparticle concentration on Nusselt number

5.2 Effect on total heat transfer

The fig. 4.6 shows that the total heat transfer into phase change material in given time is highest in case of 0.4% Al_2O_3 and then decreases with 0.6% Al_2O_3, 0.2% Al_2O_3 and pure water.

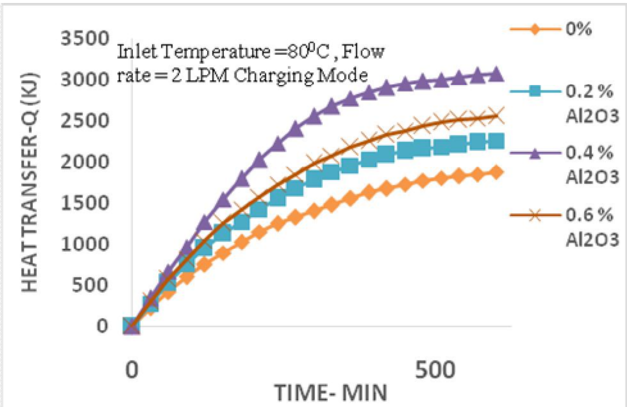

Fig. 5.2 Effect of nanoparticle on total heat transfer at various concentration

VI. CONCLUSIONS

Heat transfer is key phenomenon in every thermal related process. It is very important that the heat transfer fluid must have better thermal properties. Basically, the base fluid like water, ethylene glycol and heat transfer oil have lower thermal conductivity. By the addition of nanoparticle having high thermal conductivity in to the base fluid is an efficient way to increase the thermal properties of base fluid.

During the experiment various parameter are noted down by changing the types and concentration of nanofluid.

Result shows that addition of 0.4% Al_2O_3 nanoparticle in water enhance the Nusselt number by 47%. The result also shows that further increased in concentration of nanoparticle cause decreased in enhancement. The reason behind this phenomenon is as concentration of nanoparticle in water increases its viscosity also goes increases and increased in viscosity resist the movement of particle in water which is responsible for enhancement.

It concludes that successfully used nanofluid in closed heat transfer system. It is best replacement for fluid having low thermal conductivity. It increases the performance of the system.

REFERENCES

[1] Choi S. U. S., 1995, Enhancing Thermal Conductivity of Fluids with Nanoparticles, ASME International Mechanical Engineering Congress & Exposition. November 12-17, San Francisco, CA.

[2] Ozerinc S., 2010, Heat Transfer Enhancement with Nanofluids, Thesis Submitted to The Graduate School of Natural And Applied Sciences Of Middle East Technical University.

[3] Kavitha T., Rajendran, Durairajan, Shanmugam, 2012, Heat Transfer Enhancement Using Nano Fluids And Innovative Methods - An Overview, International Journal Of Mechanical Engineering And Technology (IJMET), Volume 3, Issue 2, Page. 769-782.

[4] Wang X., Choi S. U. S., Xu X., 1999, Thermal Conductivity of Nanoparticle - Fluid Mixture, Journal Thermo-physics Heat Transfer, 13, Page. 474-480.

[5] Lee S., Choi S. U. S., Li S., Eastman J. A., 1999, Measuring Thermal Conductivity of Fluids Containing Oxide Nanoparticles, Journal Heat Transfer, 121, Page. 280-289.

[6] Eastman J. A., Choi S. U. S., Li S., Yu W., Thompson L. J., 2001, Anomalously Increased Effective Thermal Conductivities of Ethylene Glycol-Based Nanofluids Containing Copper Nanoparticles, Applied Physics Letters, 78, Page. 718-720.

[7] Xie H., Wang J., Xi T., Liu Y., 2002, Thermal Conductivity of Suspensions Containing Nanosized SiC Particles, International Journal of Thermo-physics, 23, Page. 571-580.

[8] Das S. K., Putra N., Thiesen P., Roetzel W., 2003, Temperature Dependence of Thermal Conductivity Enhancement for Nanofluids, Journal Heat Transfer, 125, Page. 567-574.

[9] Pak B. C., Cho Y. I., 1998, Hydrodynamic and Heat Transfer Study of Dispersed Fluids with Submicron Metallic Oxide Particles, Experimental Heat Transfer, A Journal of Thermal Energy Generation, Transport Storage, and Conversion, 11:2, Page. 151-170.

[10] Michael S., Huseyin S., Barkan K., Yanming L., Olivia G.,2011, Particle size effects in the thermal conductivity enhancement of copper-based nanofluids, Nanoscale Research Letters, 6:217. Page. 1-7.
[11] Mukesh Kumar P. C., Kumar J., Suresh S., 2013, Experimental investigation on convective heat transfer and friction factor in a helically coiled tube with Al2O3 / water nanofluid, Journal of Mechanical Science and Technology 27, Page No. 239-245.
[12] Bhimani V. L., Dr. P. P. Rathod P.P., Prof. Sorathiya A.S., 2013, Experimental Study of Heat Transfer Enhancement Using Water Based Nanofluids as a New Coolant for Car Radiators , International Journal of Emerging Technology and Advanced Engineering Volume 3, Issue 6, Page 295-302.
[13] Kumaresan G., Venkatachalapathy S., Asirvatham L.G., 2014, Experimental investigation on enhancement in thermal characteristics of sintered wick heat pipe using CuO nanofluids , International Journal of Heat and Mass Transfer 72, Page. 507–516.