ENHANCEMENT OF THERMAL CONDUCTIVITY OF LIQUID BY DISPERSING ULTRAFINE PARTICLES OF FLY ASH

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Abstract-The design of energy-efficient heat transfer equipment, as well as the research for enhancing the thermal capability of conventional fluids, contributes to the effort for better energy management. An apparatus is designed and fabricated with heat transfer fluid by an ultrafine particle of fly ash to measure the Effective thermal conductivity of liquids under various temperature ranges. Natural convection heat transfer has been experimentally investigated to find out the heat loss to the atmosphere.
The apparatus is a completely different form of thermal conductivity apparatus which has been widely applied in the normal laboratory The objective of the present work is to prepare HT fluid of FLY ASH and nano/microparticles with distilled water as a base fluid, measurement of thermo-physical properties (thermal conductivity, viscosity and density), FLY ASH/distilled water HT fluid, working principles of various instruments like KD2 Pro, Ubbelhode viscometer and Pycnometer have been discussed.
Description of the experimental setup for measurement of heat transfer coefficient with its schematic diagram, experimental procedure and equations used to calculate the heat transfer coefficient are also discussed. For the preparation of FLY ASH/distilled water with a surfactant, Gum Arabic is used as a surfactant. This surfactant was added in distilled water first and then FLY ASH nano/ were added in it and sonicated for 2.5 hours continuously. But still, the nano/ were not dispersed properly. It remains stable for 1-2 hours only and then nano/ start to settle down. Results show that the thermal conductivity of alumina/distilled water HT fluid increases up to 2.40% for 0.1 volume% and 0.328% for 0.5 volume% of alumina/distilled water as compared to distilled water.

1. INTRODUCTION

Heat Transfer Fluid (HT) fluid is the term proposed by Choi [1] to describe stable colloidal suspensions of nano-sized (1–100 nm) solid particles in common base fluids such as water and ethylene glycol. HT fluids prepared by dispersing nano/ into conventional heat transfer fluids are proposed as the next generation heat transfer fluids as they offer exciting new possibilities to enhance heat transfer performance compared to conventional fluids. Therefore, HT fluids have attracted great interest due to their potential benefits for numerous applications such as microelectronics, energy supply, transportation and HVAC.
From experimental investigations reported by various researchers in the past decade, HT fluids were found to exhibit substantially higher thermal properties particularly thermal conductivity even when the concentrations of suspended nano/microparticles are very low [2 and 3].Nano/microparticles are defined as particulate dispersions or solid particles with a size in the range of 10-100 nm [6].
At these length scales, materials begin to exhibit distinct properties that affect biological, chemical, and physical behaviours. A wide variety of nano/microparticles exists with organic or inorganic composition, most being metals. Examples include silica (SiO_2), silver, iron nano/microparticles, carbon black, aluminium, zinc oxides, titanium dioxide (TiO_2), polystyrene and nano clays etc.

1.1 Nano/Microparticles vs Microparticles

The surface area of nano/microparticles is 1000 times higher than that of microparticles. The high surface area of nano/microparticles enhances the heat conduction of HT fluid since heat transfer occurs on the surface of the particle. Nano/microparticles are very small in size so they reduce erosion, clogging, decreases pumping power, reduce the inventory of heat transfer fluid, and significantly save energy.
Comparison of nano/microparticles and microparticles is shown in table 1.1. Nano/ stay suspended much longer as compared to microparticles; therefore, these unique properties of nano/microparticles lead to developing HT fluids with a combination of the two features most highly desired for heat transfer systems: extreme stability and ultrahigh thermal conductivity.

1.2 Base Fluid

Base fluids mostly used in the preparation of HT fluids are the common working fluids of heat transfer applications include water, organic liquids (e.g. ethylene, tri-ethylene- glycols, refrigerants, etc.), oils and lubricants, bio-fluids, polymeric solutions and other common liquids

Table-1.1 Comparison between Micro and Nano Particle

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S. No.	Description	Micro-Particle	Nano-Particle
1.	Stability	Settle	Stable (remain suspended for a long time)
2.	Surface to volume ratio	1	1,000 times larger than that of
3.	Thermal Conductivity	Low	High
4.	Clogging	Yes	No

2. METHODS

2.1 Preparation of HT Fluids

For the present work FLY ASH and carbon nanotubes (CNT), is used for the preparation of the HT fluid and distilled water is used as base fluid. Work is done on two-volume fractions i.e. 0.1% and 0.5%. FA/water HT fluid is prepared without the use of any surfactant while for the CNT/water HT fluid surfactant has been used.
Required for preparing HT fluids

- FLY ASH nano/microparticles
- Carbon Nanotubes (Multiwall)
- Distilled water Gum
- Arabic (GA)

Aluminium oxide (Al_2O_3) commonly referred to as alumina, white crystalline powder as balls or lumps of various mesh sizes, possesses strong ionic interatomic bonding giving rise to its desirable material characteristics. Alumina is the most cost-effective and one of the most versatile of refractory ceramic oxides. The raw materials from which this high performance technical grade ceramic is made are readily available and reasonably priced, resulting in good value for the cost in fabricated alumina shapes [1]. With an excellent combination of properties and an attractive price, it is no surprise that fine-grain technical grade alumina has a very wide range of applications like gas laser tubes, wear pads, seal rings, high temperature and high voltage electrical insulators etc.

2.2 FA/Water HT Fluid

The size of alumina nano/microparticles is 40-45 nm as it was mentioned by the company. HT fluid is prepared by the two-step process. First of all, weigh the exact amount of alumina nano/microparticles as per volume fraction i.e. 0.1% and 0.5% with the help of digital weighing balance machine. Then, take 50 ml distilled water in a beaker, and pour the calculated amount of alumina nano/microparticles in the beaker very gently, avoiding the sticking of nano/microparticles on the beaker wall. Then place this beaker in an ultrasonicator for at least 2-3 hours for proper mixing. The prepared FA/water HT fluid for both of the concentrations is shown in Fig. 2.1

2.3 CNT/Water HT Fluid

As carbon nanotubes are very much hydrophobic two different surfactants have been used for stable suspension of CNT in water. Weigh the calculated amount of CNT as per volume fraction i.e. 0.1% and 0.5% with the help of digital weighing balance machine.

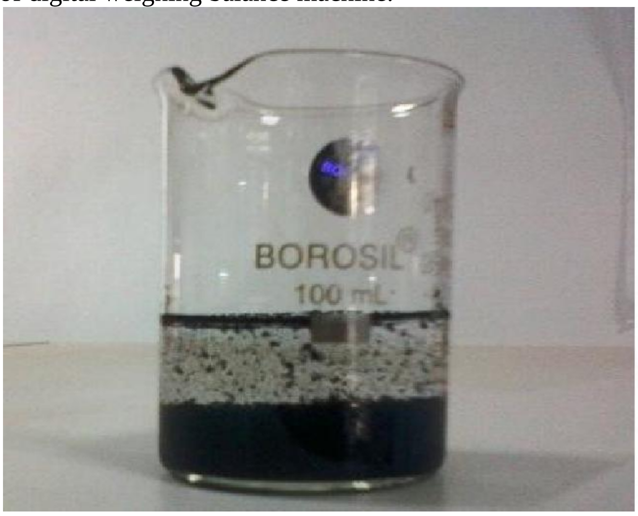

Fig. 2.1 the prepared CNT/water HT fluid without using any Surfactant and with using Surfactant Respectively

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Then, take 50 ml distilled water in a beaker, add the surfactant and pour CNT in the beaker very gently, avoiding the sticking of nano/microparticles on the beaker wall. Then place this beaker in an ultra sonicator for at least 2-3 hours for proper mixing.

2.2 Theory

Uniform cooling of water is done by the natural convection process to air from the top of the cylinder. By applying

$$hA_s(T_a\text{-}T_s) = \frac{2\,\pi L\,k\,(T_1\text{-}T_2)}{\ln(r_2/r_1)}$$

the energy balance, That is, the rate at which energy is transferred to the air by convection from the water surface must equal the rate at which energy reaches the water surface by conduction from the cylinder wall. That mean heat lost to air was equal to the heat gained by water All the water properties are calculated at mean film temperature by Yunus [9]

$$T_f = \frac{T_s + T_w}{2}$$

Nusselt number $\overline{Nu}_L = \frac{hL}{k}$

Where h is the coefficient of convection. In case of free convection from horizontals surfaces if the characteristic length is defined as, L=A_s / P. Then for the top surface of a hot object in a colder environment or bottom surface of a cold object in a hotter environment, $\overline{Nu}_L = 0.54 Ra_L^{1/4} \rightarrow 10^4 \leq Ra_L \leq 10^7$ The average values of surface temperature and bulk water temperature can be evaluated as:

$$\overline{T_s} = \frac{T_{s1} - T_{s2}}{ln\frac{T_{s1}}{T_{s2}}}$$

$$\overline{T_w} = \frac{T_1 - T_2}{ln\frac{T_1}{T_2}}$$

The Grashof, Prandle and the Raleigh numbers can be calculated as

$$Gr_L = \frac{g\beta(T_s - T_\infty)L^3}{\nu^2} \sim \frac{\text{buoyancy force}}{\text{viscous force}}$$

$$\overline{Pr\frac{\mu C_p}{k}}$$

$$Ra_L = Gr_L\,Pr = \frac{g\beta(T_s - T_\infty)L^3}{\nu\alpha}$$

All the physical properties (C_p, ρ, β, μ and k) of air were evaluated at average film temperature. The rate of heat transfer by free convection from the water level to the room is given by Newton's law of cooling and by radiation,

$$Q_{con} = \bar{h}A_s(T_s\text{-}T_\infty)$$

$$Q_r = \varepsilon A\sigma(T_s^4\text{-}T_{sur}^4),$$

Emissivity, ε for water was taken as 0.94 and Stefan-Boltzmann constant, σ for water was taken as 5.67 x 10^{-8} The total heat lost from water surface to air by both convection and radiation is given by, $Q_T = Q_{con} + Q_r$ And Heat transfer in case of the cylindrical coordinate system by conduction is given by,

$$Q = \frac{2\,\pi L\,k\,(T_1\text{-}T_2)}{\ln(r_2/r_1)}$$

3. THERMAL CONDUCTIVITY MEASUREMENT

An apparatus is designed and fabricated to measure the effective thermal conductivity of liquids under various temperature ranges. The uniform heat flux has been applied radially inward by placing heating element at the outer surface of the test cylinder circumferentially. Natural convection heat transfer has been experimentally investigated to find out the heat loss to the atmosphere. The apparatus is a completely different form of thermal conductivity apparatus which has been widely applied in the normal laboratory. Uniform cooling of water is carried out by natural convection to air. The temperature distribution along the radial distance concerning the time was recorded. The thermal conductivities of distilled water were measured using the system and the results obtained were compared with the standard values. The results obtained certified the aim of the work which was to develop the thermal conductivity measurement apparatus suitable for data collection and experimental experience in an economic way.

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3.1 Materials and Method

The procedures employed include the design stage, construction and testing of the sample. The materials used were Ferrites Stainless Steel, thermal insulators (Asbestos rope and Plaster of Paris), heating system, and variable voltage power supply (variance), thermocouple (K-type).

3.2 Design Stage

The experimental setup consists of three parts viz; the heating unit sample holder cylinder and the cold-end point (Figure 3.1). The heating unit consists of a band heater with an electrical power supply system. The outer portion was fitted with thermal insulators to control and conserve much of the heat generated by the heater. The heat was allowed to flow into the vertical cylinder to create a temperature gradient along with the test sample. Ferritic Stainless-Steel cylindrical chamber of 64mm diameter was used to hold the test sample.

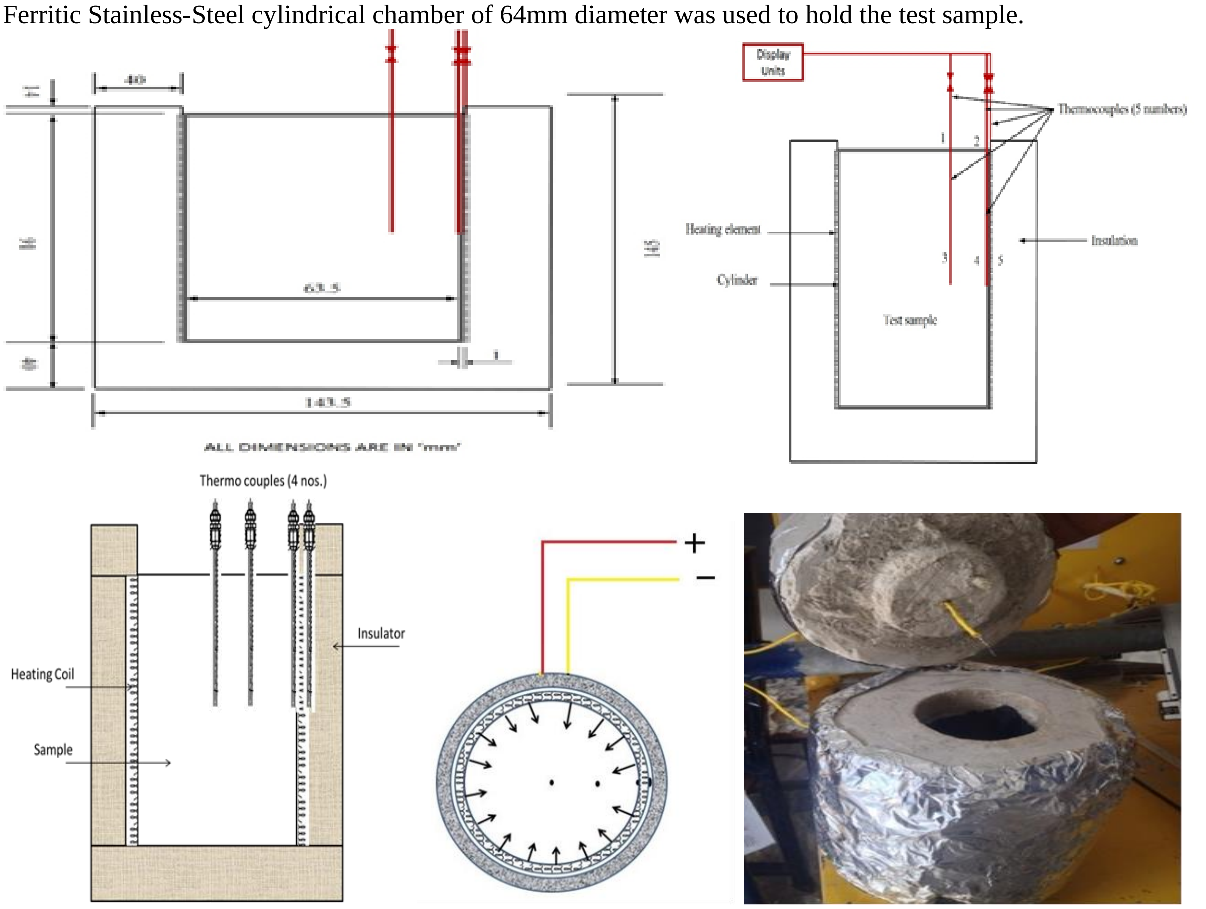

Fig. 3.1 Schematic Diagram of the Experimental Setup

3.3 Experimentation

Uniform heat was supplied to water. Temperatures were recorded for all locations. Film temperature was calculated from the above formula by considering the air temperature and average water surface temperature. Prandle numbers were calculated by considering the properties of air. Grashof, and the Raleigh numbers were calculated from their respective relation. Nusselt numbers were calculated from the relation between Nusselt number and Raleigh numbers. Raleigh numbers were found to be in the range between 10^4-10^7. Coefficient of convection was calculated from the relation between Nusselt number and Coefficient of convection. After knowing the values of coefficient of convection Q_{con} were calculated and Q_r were calculated from the above relation. Total heat loss was calculated and from that thermal conductivity of water were calculated from the heat transfer equation for cylindrical co-ordinate. In this work, heat transfer was not calculated from the relation P = V x I, because this relation gives accurate values when the heater is immersed in water i.e. in case of heat transfer radially outward.

4. RESULTS

Radial heat transfers were validated by calculating temperature distribution in a radial direction. To validate radial heat transfer in the model, the heat flux along the height of the cylinder at the different radial positions has been examined. Heat flux along the z-axis is also calculated. The result was confirmed when examining the temperature distribution in the radial direction at height z=0.0455 m, which will be the height of the thermocouples in the specimen. The theoretical temperature distribution and the actual temperature distribution have a perfect match, as shown in Figure. The theoretical values were determined by solving the heat transfer equation for cylindrical co-ordinate for T_1, where the T_2 is the cold point temperature, Q is 0.7726 W and the radial position r_1 is varied. From these examinations, it was safe to conclude that the 0.7726 W propagates

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radially in the test specimen when no heat losses were taken into account. By taking different values of heat the graph between temperature distribution vs radial position was established as shown in the figure: 3. The results of this experiment were tabulated below.
FA/Water HT Fluid

- Alumina nano/microparticles dispersed in distilled water by sonicating it for 2.5 hours continuously, without adding any surfactant. It remains stable for 3 weeks after that nanoparticle started to settle down, the alumina/distilled water HT fluid is shown in Fig
- Firstly, the FLY ASH/distilled water HT fluids were prepared without the use of any surfactant, but FLY ASH was not dispersed properly due to the hydrophobic nature of carbon nanotubes. the FLY ASH/distilled water HT fluid without the use of any surfactant is shown in Fig.
- For the present work alumina (Al_2O_3) and carbon nanotubes (CNT) nanoparticles are used for the preparation of the nanofluid and distilled water is used as base fluid. Work is done on two-volume fractions i.e. 0.1% and 0.5%. Alumina/water nanofluid is prepared without the use of any surfactant while for the CNT/water nanofluid surfactant has been used.

as balls or lumps of various mesh sizes, possesses strong ionic interatomic bonding giving rise to its desirable material characteristics. Alumina is the most cost-effective and one of the most versatile of refractory ceramic oxides. The raw materials from which this high performance technical grade ceramic is made are readily available and reasonably priced, resulting in good value for the cost. For the preparation of FLY ASH/distilled water with a surfactant, Gum Arabic is used as a surfactant. This surfactant was added in distilled water first and then FLY ASH nano/microparticles were added in it and sonicated for 2.5 hours continuously. But still the nano/microparticles were not dispersed properly. It remains stable for 1-2 hours only and then nano/microparticles start to settle down. The FLY ASH/distilled water HT fluid with surfactant is shown in Fig 2.1.

Table-4.1 Heat Transfer Coefficient, Re and Nu

S. No.	Surface Temp (^{0}C)	Air Temp (^{0}C)	P_r	Gr	Ra	Nu	h	Q_c	Q_r	Q_t	k
1	54.48	27	0.7	1.21 x 10^4	8.41 x 10^3	5.2	8.73	0.7712	1.418 x 10^{-3}	0.7726	0.6247
2	56.48	29	0.7	1.21 x10^4	8.36 x 10^3	5.2	8.72	0.7703	1.6224 x 10^{-3}	0.7719	0.6242
3	58.48	30	0.7	1.25 x 10^4	8.62x 10^3	5.2	8.79	0.8048	1.860 x 10^{-3}	0.8066	0.6523
4	57.48	30	0.7	1.20 x 10^4	8.33 x10^3	5.2	8.71	0.7695	1.730 x 10^{-3}	0.7712	0.6236
5	57.48	29	0.7	1.25 x10^4	7.65 x10^3	5.2	8.79	0.804	1.74 x 10^{-3}	0.8065	0.6522
6	57.48	28	0.7	1.30 x10^4	8.97 x10^3	5.3	8.87	0.840	1.765 x 10^{-3}	0.8417	0.6810
7	60.48	31	0.7	1.28 x10^4	8.89 x10^3	5.2	8.85	0.838	2.130 x 10^{-3}	0.8401	0.6790
8	55.48	28	0.7	1.21 x10^4	8.39 x10^3	5.2	8.73	0.7712	1.518 x 10^{-3}	0.7727	0.6251
9	59.48	30	0.7	1.29 x10^4	8.91 x10^3	5.2	8.86	0.8397	2.005 x 10^{-3}	0.8417	0.6806
10	59.48	31	0.7	1.24x10^4	8.60 x10^3	5.2	8.78	0.8039	1.98 x 10^{-3}	0.8050	0.6516

Table-4.2 Temperature and Thermal conductivity.

S. No.	Temperature (°C)	Thermal conductivity (W/m-K)
1	30	0.601
2.	35	0.602
3.	40	0.602
4.	45	0.601
5.	50	0.605

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6.	55	0.613
7.	60	0.621
8.	65	0.628

The thermal conductivity of 0.1% and 0.5% volume fractions of alumina/distilled water HT fluids at different temperatures is given in Table 4.2 and Table 4.3. The variation of thermal conductivity with temperature is shown in Fig.4.1.

Table-4.3 Temperature and Thermal conductivity

S. No.	Temperature (°C)	Thermal conductivity (W/m-K)
1.	30	0.66
2.	35	0.664
3.	40	0.673
4.	45	0.691
5.	50	0.707
6.	55	0.766
7.	60	0.768
8.	65	0.77

Table-4.4 Thermal conductivity of DI water

S. No.	Temperature (°C)	Thermal conductivity (W/m-K)
1	30	0.65
2	35	0.658
3.	40	0.679
4.	45	0.693
5.	50	0.699
6.	55	0.712
7.	60	0.718
8.	65	0.722
9.	30	0.734

Table-4.5 Thermal Conductivity of DI water (5%)

S. No.	Temperature (°C)	Thermal conductivity (W/m-K)
1.	30	0.66
2.	35	0.664
3.	40	0.673
4.	45	0.691
5.	50	0.707
6.	55	0.766
7.	60	0.768
8.	65	0.77

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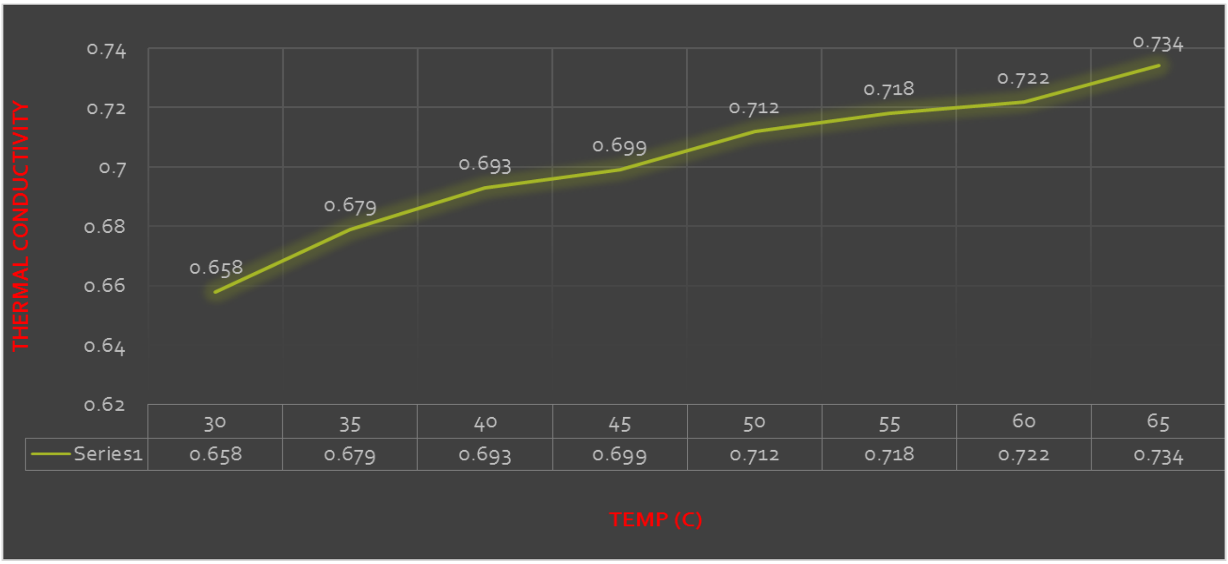

Fig. 4.1 Thermal Conductivity Variation with Temperature

Table-4.6 Thermal conductivity of DI + FA (5%) water

S. No.	Temperature (°C)	Thermal conductivity (W/m-K)
1	30	0.65
2	35	0.658
3.	40	0.679
4.	45	0.693
5.	50	0.699
6.	55	0.712
7.	60	0.718
8.	65	0.722
9.	30	0.734

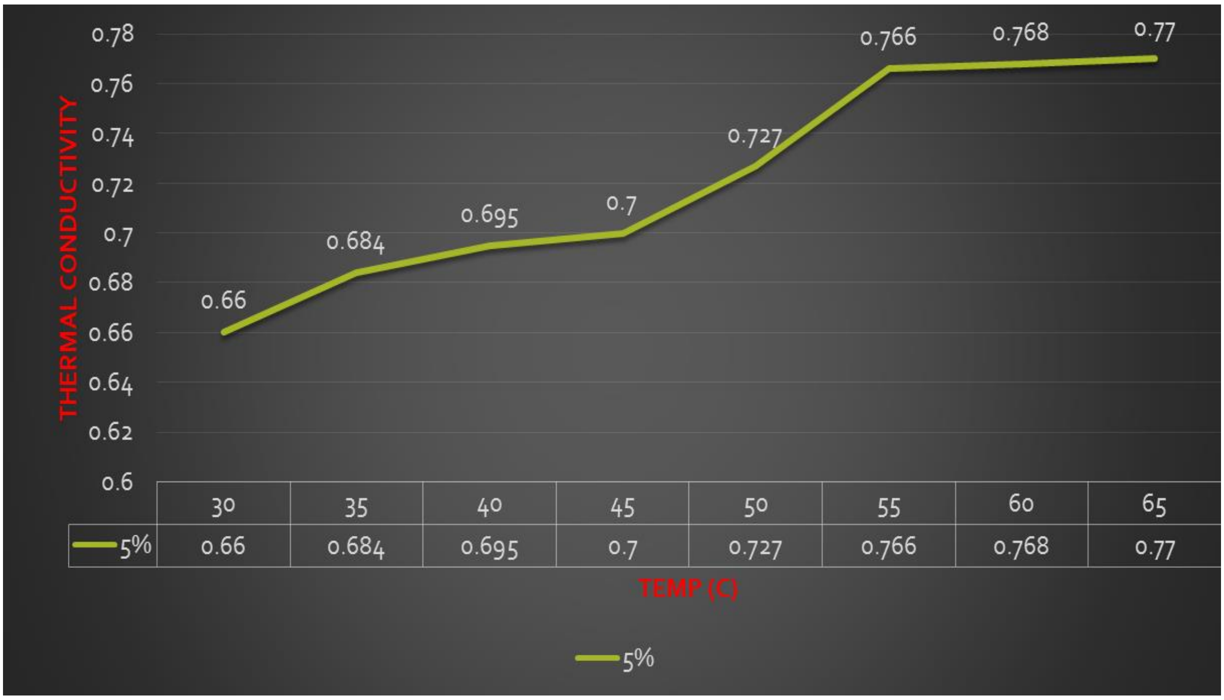

Fig. 4.2 Thermal Conductivity Variation with Temperature

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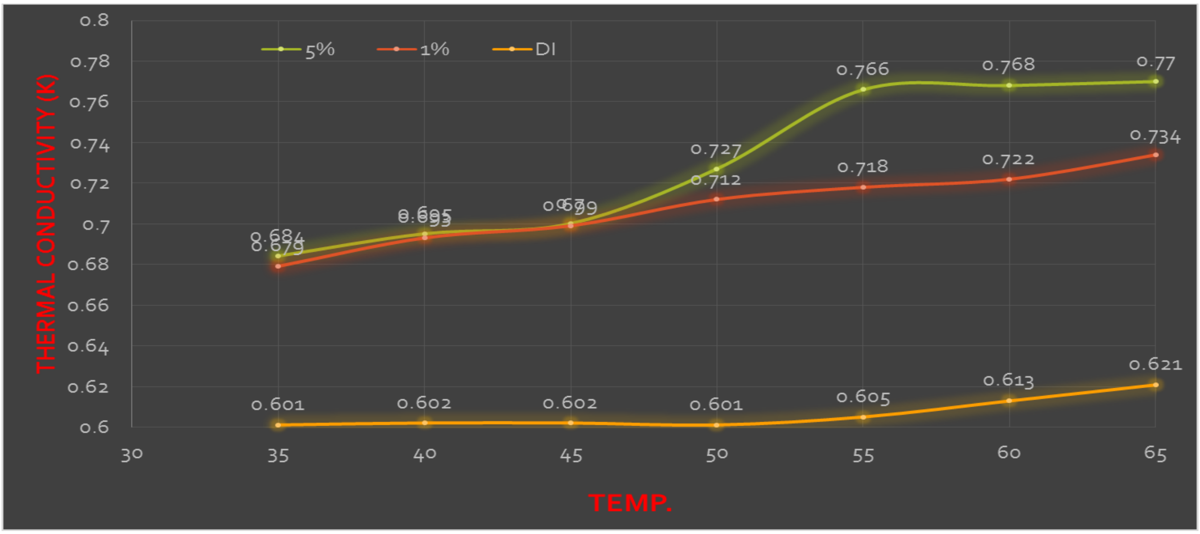

Fig. 4.3 Thermal Conductivity Variation with Temperature

The average time is taken to cover the distance between two ring-shaped calibrated marks for the distilled water, and 0.1% and 0.5% volume fraction of alumina /distilled water nanofluids.

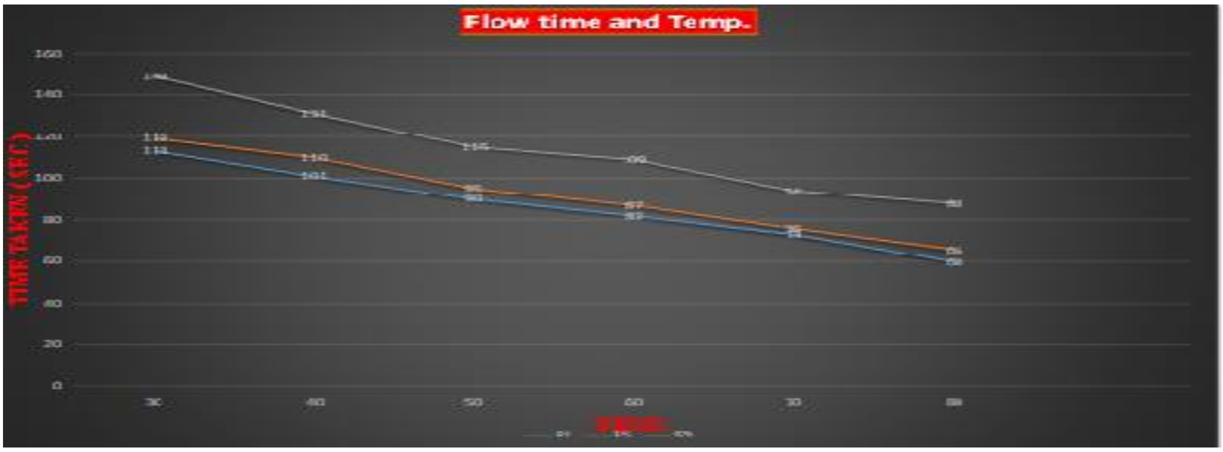

Fig. 4.4 Flow Time Variation with Temperature

CONCLUSION

- HT fluids are prepared by two-step process i.e. dispersing the nano/microparticles into base fluids. An ultra sonicator is used to disperse the particles properly and to minimize particle agglomeration to get a uniform stable suspension. Surfactant is also used to prepare FLY ASH/ water HT fluids.
- Results show that the thermal conductivity of alumina/distilled water HT fluid increases up to 2.40% for 0.1 volume% and 0.328% for 0.5 volume% of alumina/distilled water as compared to distilled water.
- The density of alumina/distilled water HT fluid is increased as compared to distilled water and it also increases with an increase in particle concentration at a particular temperature. But as temperature increases density decreases. At 0.1 volume% concentration of alumina in distilled water, an increment of 5.58% and an increment of 7.754% at 0.5 volume % are found.
- Viscosity results are also in an increasing pattern. Alumina/distilled water HT fluid for both concentrations have shown higher viscosities than distilled water. At 0.1 volume % there is an increment of 3.34 % and at 0.5 volume % increment of 30.1 % is found.
- Viscosity results are also in an increasing pattern. Alumina/distilled water HT fluid for both concentrations have shown higher viscosities than distilled water. At 0.1 volume % there is an increment of 3.34 % and at 0.5 volume % increment of 30.1 % is found.
- The temperatures and pressure drop of HT fluids, as well as pipe surface temperatures, are measured at steady state by using an experimental setup at different flow rates and power inputs.
- Results show that the heat transfer coefficient of 1 volume % and 5 volume % of alumina/distilled water HT fluid, at a particular flow rate is much higher than that of distilled water.

ACKNOWLEDGEMENTS

The author would like to extend her deepest gratitude and gratefulness to teachers for providing with the right ways of thinking and concepts of this research. The author wishes deeply thankful to her beloved parents and

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hubby who fulfil whatever she needs and gives her never-ending love and encouragement which have been helpful in my research to attain the destination without any trouble.

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