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Optimization of AL_2O_3 concentration in water based nano fluid to enhance the heat transfer for solar application

Nano-fluid is a suspension of nano particles in the base fluids like water to enhance heat transfer. Nano-fluids is a class of fluids used for the cooling and heating process. This paper reports an investigation of the optimum concentration of Al_2O_3 in water for solar application based on stability checking using the zeta potential method. In this study, computational fluid dynamics analysis was performed using the Ansyss Fluent software for the different concentrations. Results are analyzed, and simulated result shows that heat transfer coefficient increases as concentration increase, and for a given geometry, Nusselt number rises as Reynolds number rises, which is used for the solar application.

Keywords: Nano-fluid, heat transfer, nussellt number, CFD, solar application.

1.0 Introduction

Nano-fluid is class of fluid or innovative fluid used for the heating and cooling process. Nano-fluid is suspension of nano particles in the base fluid like H_2O, ethylene glycol, oil, biofuels and distilled water etc. the thermal conductivity of the nano particles were high as that of the base fluid, hence they are used as heat transfer medium. Nano particles used in the present work is Al_2O_3 for high temperature application and suitable for water. Our research work has to be used for the application of solar system and geometry for the research work is real application to the solar water heater. White powder of nanometer sized Al_2O_3 particles used in the base fluid water to study the heat transfer distinctive and viscosity of the nano-fluid. The goal of this study is to show that as the concentration of Al_2O_3 in water grows, so does the heat transfer coefficient. In addition, Nusselt number increases for varying Reynolds number (4000 to 20,000). Vasheghani et al (2011), shows that with increase in concentration viscosity, density and thermal conductivity ratio of nano-fluid increases. Abdolbaqia et al (2016), investigated the variation of Nusselt number with varying Reynolds number in flat tube for Al_2O_3 water nano-fluid using Ansyss Fluent; for various concentrations, he discovered that the Nusselt number rises as the Reynolds number rises. O. Abdelrehim et al (2019), carried out investigation on Al_2O_3 nano-fluid for concentration 0 to 4%, shows that Nusselt number and average Nusselt number increases as concentration increase in water for different Reynold number varying from 100 to 200. In our research, we are using method called zeta potential to check the 20 nm sized Al_2O_3 nano particles stability in water exclusively for solar application. The concentration of nano particles in water varying from 0.01% to 5.5% for 20 nm size nano particles. The Reynold for our research work varying from 4000 to 24000 for optimized values of concentration. Ansyss Fluent software used to carry out the simulation for different concentration particularly for 20 nm sized Al_2O_3 nano particles and results were tabulated and compared to theoretical values with heat transfer coefficient and Nusselt number. Youngho Lee et al (2021), show that dispersion characteristics of oxide based nano-fluids Al_2O_3 having high absorbance values with respect to the concentration for solar application, in his investigation thermal absorption increases for the concentration 0.01, 0.1%, 1% by weight. Kong and Lee (2020), investigated the thermal performances of Al_2O_3 nano particles in water using circular tube under turbulence with three different concentrations and found that thermal conductivity and heat transfer coefficient of nano-fluid increased with increase in concentration in extend to this, he also shows that Nusselt number increases for Reynolds number 4000 to 24000. If the concentration of nano particles increases, viscosity and density also increases. As the viscosity of nano-fluid increases, it affects the heat transfer coefficient and pumping power. Hence, optimal values of oxide metal nano particle concentration is required for better stability to enhance heat transfer. Higher concentration of nano particles required more the pumping power, but pressure drop can be increased with increase in Reynolds number or volume flow rate for particular temperature. Abbasi and Baniamerian (2014) in their work shows variation of heat

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transfer coefficient and liquid film thickness for aluminum oxide with 2-phase nano-fluid in circular pipe and simulated analytically using correlations. Authors concluded in their study that Al_2O_3 and Cu are most commonly used nano particles to enhance heat transfer and construction of nano particles in nano-fluid depends on flow regimes and flow properties. Pathak and Sahu (2018) conducted the experiments for different concentration of Al_2O_3 nano particles and carried simulation in ANSYS for parallel, counter and cross flow heat exchanger. In his analysis, the overall heat transfer coefficient increased using triangular fins and nano-fluid. Azari et al (2014), in their paper discussed the experimental study and modelling of Al_2O_3 nano-fluid convective heat transfer performance using circular tube under laminar flow, he observed that enhance convective heat transfer and effective thermal conductivity.

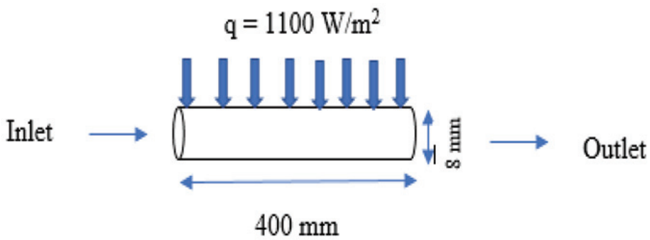
2.0 Methodolgy

In the present paper work has been carried out for Al_2O_3 nano particles in water for different concentration 0.01% to 5.5% by volume. The properties of Al_2O_3 nano particles and base fluid water is given in Table 1.

TABLE 1: Al_2O_3 NANO-PARTICLES AND WATER PROPERTIES

	Density (Kg/m^3)	Specific heat (J/kg K)	Thermal conductivity (W/m K)	Viscosity (Kg/ms)
Al_2O_3	3970	776	40	1.72e-5
Water	998	4182	0.613	0.001003

The nano-fluid method of preparation is a two-step approach, which is more economical than the one-step method to produce nano-fluids commercially.



Geometry of the pipe

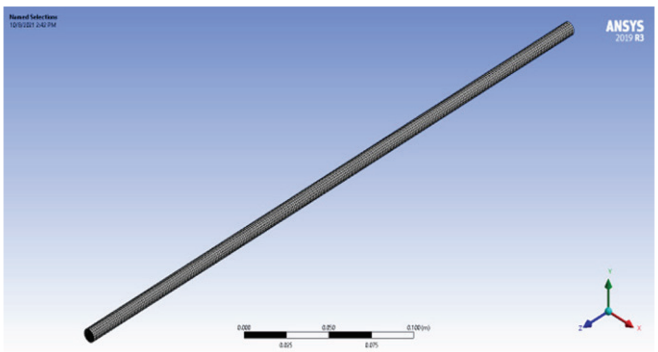


Fig.1: Geometry and meshing of the model

Ansys Fluent used for the modelling and to carry out the analysis. The geometry of the model and meshing as sown in Fig.1.

The geometry of the particular experimental set up developed for the solar applications. It consists of a cylindrical pipe with length L = 400 mm and diameter D = 8mm, heated with a uniform heat flux q_w = 1100 W/m^2 along the wall. Meshing have done using Ansys Fluent and checked the qualities. The number of elements are 53,465 and number of nodes 56,840.

The system of governing equation solved by control volume approach. A second order upwind scheme employed and pressure and velocity coupled using Simple. The boundary conditions are heat flux in wall at inlet, velocity, turbulence intensity and hydraulic diameter of 8 mm. At outlet fluid properties of nano-fluid mentioned and atmospheric pressure.

Theoretical module used for the calculation of the nano-fluid properties are as follows.

Pak and Cho developed model used to calculate density of the nano-fluid.

$$\rho_{nf} = \Phi\rho_p + (1-\Phi)\rho_f \quad \text{... (1)}$$

ρ_{nf} density of nano-fluid, ρ_p is density of nano particles, ρ_f density of base fluid and Φ percentage of concentration.

Specific heat of nano-fluid calculate using Pak and Cho developed model.

$$CPnf = \frac{\Phi\ \rho_p C_{Pnp} + (1-\Phi)\ \rho_f C_{Pf}}{\rho_{nf}} \quad \text{... (2)}$$

C_{Pnf} specific heat of nano-fluid, C_{Pf} specific heat of water, C_{Pnp} is specific heat of nano particles

Thermal conductivity of nano-fluid calculated using Pak and Cho developed model.

$$K_{nf} = K_{bf}\,(1+7.47\Phi) \quad \text{... (3)}$$

where, K_{nf} is thermal conductivity of nano-fluid and K_{bf} is thermal conductivity of water (base fluid).

Viscosity of nano-fluid calculated using Einstein model.

$$\mu_{nf} = (1+2.5\Phi)\,\mu_{bf} \quad \text{... (4)}$$

where, μ_{nf} is dynamic viscosity of nano-fluid and μ_{bf} is dynamic viscosity of base fluid like water.

Nusselt number calculation equation.

$$Nu = 0.023(Re_D)^{0.8}\,(P_r)^{n} \quad \text{... (5)}$$

$$Nu = hD/K_{nf} \quad \text{... (6)}$$

where, ReD is Reynolds number, Pr Prandtle number, Nu Nusselt number, h is heat transfer coefficient and D is hydraulic diameter of pipe.

In the present research, the stability analysis carried out using the zeta potential method. According to theory, elevating the zeta potential (electro kinetic potential) in a colloidal system leads to increased nano particle suspension stability in water. Electrostatic repulsion between the same particles is also known to raise the zeta potential value. The stability analysis of 20 nm sized Al_2O_3 nano particles dispersed in water carried out for the different concentration of Al_2O_3 from 0.01% to 5.5%. Concentration of nano particles optimized based on the stability, which gives highest zeta potential values.

3.0 Result and discussion

3.1 Optimization of concentration using Zeta Potential Stability Method

Wang et al. using zeta potential test have inspected stability of Al_2O_3 nano particles by volume concentration in water. Table.2 shows the various zeta potential (mV) values and nano particle suspension stability criteria in any given zeta potential value.

The Table 3 shows the zeta potential and pH values of different concentration with different sonication time and addition of acid

Present research work of Al_2O_3 – water nano-fluid stabilized at 0.5 % concentration of Al_2O_3 Nano particles in water. Thus, for solar application, it is concentration to absorb the all types of radiation and also 20 nm sized diameter of the nano particles best suited for solar application hence the optimized concentration is 0.5% and optimized size is 20 nm for the solar application.

3.2 TEM (Transmission Electron Microscopy)

TEM measurements was perform to identify the mean particle size, purity and shape of the Al_2O_3 nano powder. TEM images are for the aluminum oxide powder, which was mentioned before and observed that the nano particles were much agglomerate and form large group due to the strong Van der Waals forces. It was expecting because no ultra-sonication was performed and the nano powder was initially in agglomeration form. Fig.2 depicts both size and shape of the Al_2O_3 nano particles and in the figure it is seen that the identified ultra-fine particles look like nano clay flakes and spheres with mean diameter of 20 nm. Apart from this, the material composition was measure and verified using TEM.

Table 2: Zeta potential absolute values and stability

Zeta potential (absolute values mV)	Stability
0	Stability is scarce or absent.
15	There is some stability, but it is settling slowly.
30	Stability is moderate to medium.
45	Stability is good, but there is little chance of settling
60	Excellent stability with little chance of settling

Table 3: Zeta potentials values with different experimental mixture

Concentration (vol. %)	Sonication time (minutes)	Addition of acid/base	pH value	Zeta potential (mV)
0.01	60	Acid	2.48	40.36
0.1	180	Acid	3.38	43.40
0.5	180	Acid	3.03	50.07
0.8	180	Acid	3.17	45.61

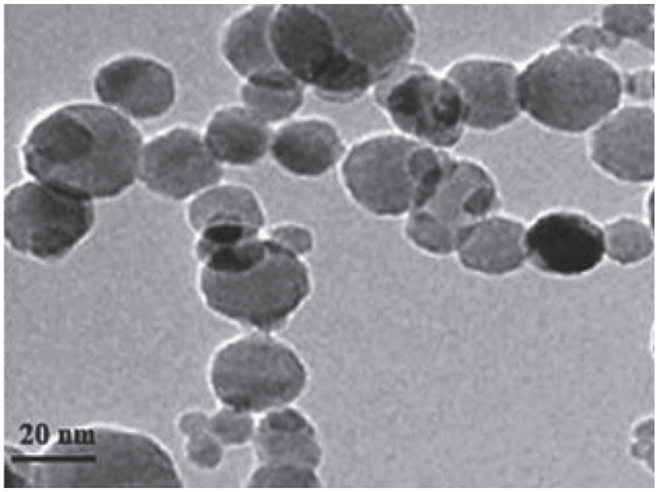


Fig.2: TEM images of Al_2O_3 nano-particles dispersed in water

3.3 Density and Viscosity

The density of nano-fluid increases as the concentration of Al_2O_3 in water increase as shown in the Fig.3. The viscosity of nano-fluid is also increases as concentration

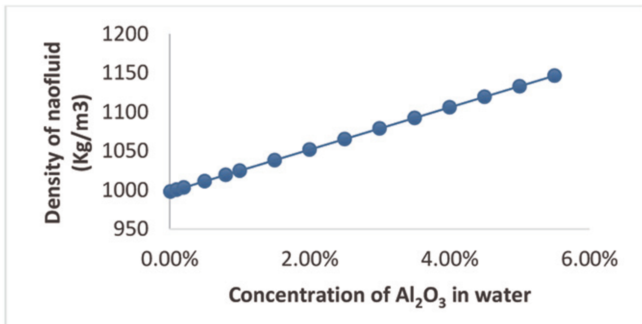


Fig.3: Variation of density with concentration

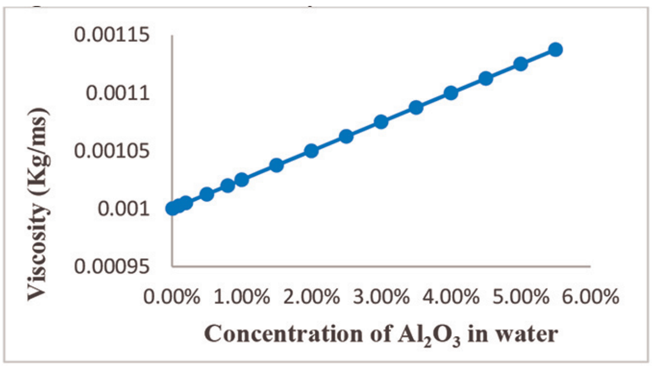


Fig.4: Variation of viscosity with concentration

increase shown in the Fig.4, both density and viscosity related to each other.

If the density and viscosity of the nano-fluid increases then shear stress also increases, it in turn increases the pumping power, but viscosity decreases as the nano-fluid temperature increases. The density and viscosity of nano-fluid calculated using the Pak and Cho model.

3.4 Thermal Conductivity

Thermal conductivity of nano-fluids calculated using the Pak and Cho model. The thermal conductivity of a nano-fluid is a function of both temperature and the concentration of A_2O_3 nano particles in water; when the concentration of Al_2O_3 in water rises, the thermal conductivity of the nano-fluid rises as well, as illustrated in Fig.5. The thermal conductivity is also function of temperature; hence, it increases with increase in temperature. Thermal conductivity is material properties that depend upon the type of nano material used in nano-fluid and it depends upon the size of the nano particles used and base fluid.

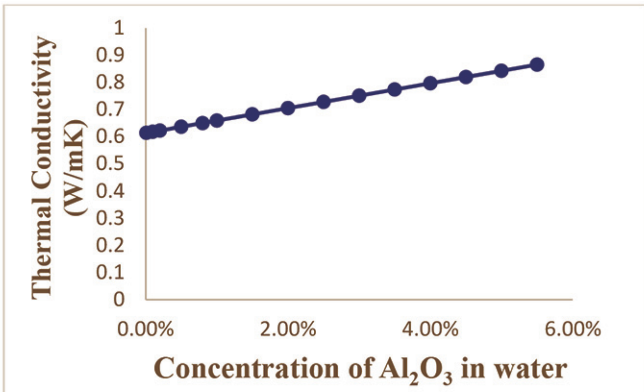


Fig.5: Variation of thermal conductivity with concentration

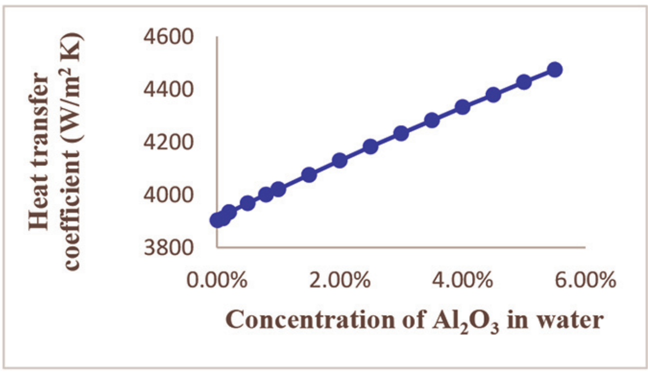


Fig.6: Effective thermal conductivity with different concentration

3.5 Effective Thermal Conductivity

Using Maxwell relations, the effective thermal conductivity of Al_2O_3–H_2O nano-fluids was estimated. The effective thermal conductivity is the ratio of the nano-fluid's thermal conductivity to the base fluid's thermal conductivity. The thermal conductivity ratio, or effective thermal conductivity of nano-fluid, is affected by viscosity and density, as shown in Fig.6. The thermal conductivity ratio, or effective thermal conductivity of nano-fluid, rises as the concentration of Al_2O_3 in water rises. The effective thermal conductivity values obtained from simulation software.

3.6 Heat Transfer Coefficient

The coefficient of heat transfer is proportionality constant in convection heat transfer and this data tabulated from the simulation software in the present work. This is dependent on the shape of the surface, the base fluid, nano particle characteristics and nano particle concentration in water. The mass flow rate (Reynolds number) play very important. The heat transfer coefficient increases when the concentration of Al_2O_3 in water increases, as is seen in Fig.7. Hence, the nano-fluid are the best innovative fluid used as heat transfer fluid in many of the heat transfer application to enhance heat transfer. Hence, nano-fluid are best suited for the solar application to enhance heat transfer.

3.7 Variation of Nusselt Number (Nu) and heat transfer coefficient with reynolds number (Re)

Fig.8 shows that Nusselt number goes on increases with Reynolds number varying 4000, 8000, 12000, 16000, 20000 and 24000 for the optimized concentration 0.5% of 20 nm sized Al_2O_3 nano particles in water. Similarly, Fig.9 indicates,

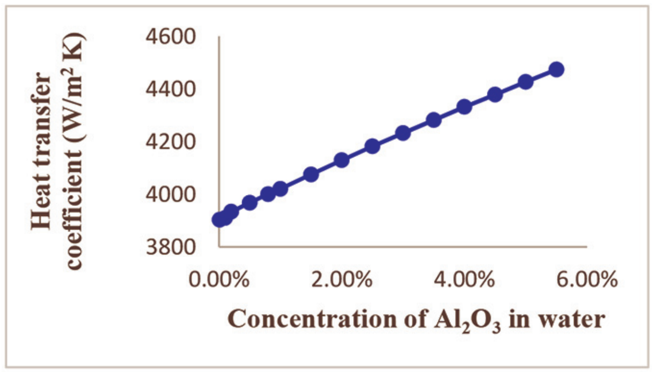


Fig.8: Reynolds number v/s. nusselt number

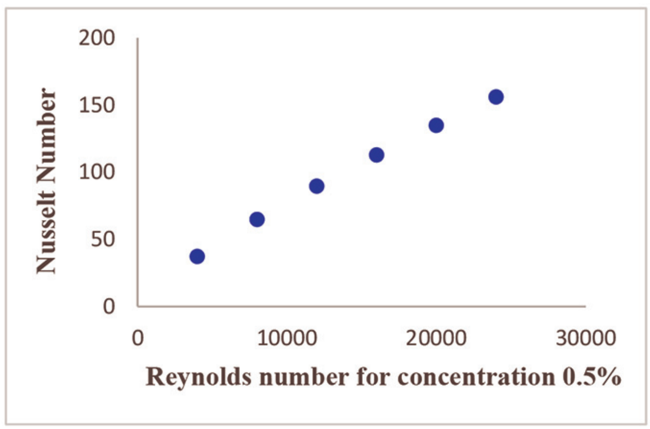


Fig.7: Heat transfer coefficient with concentration of Al_2O_3 in water

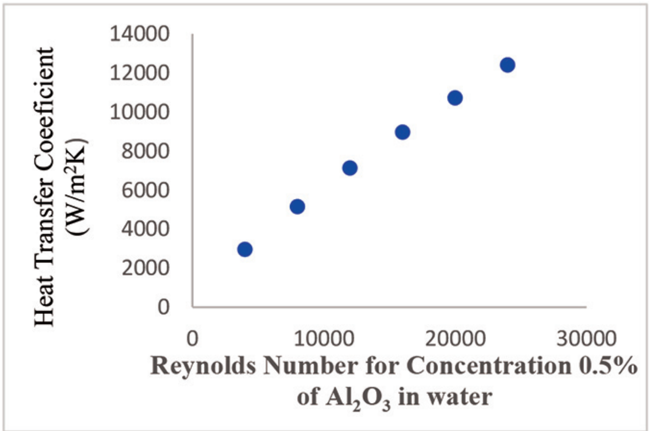


Fig.9: Reynolds number v/s heat transfer coefficient

coefficient of heat transfer is also increases with the same varying Reynolds number for optimized concentration 0.5% of 20 nm diameter Al_2O_3 nano particles in H_2O. Therefore, for optimized concentration of 20 nm sized Al_2O_3 nano particles in water the Nusselt number and coefficient of heat transfer increases for different Reynolds number, hence the 0.5% concentration and 20 nm diameter Al_2O_3 nano particles in water suitable for the solar applications.

4.0 Conclusions

The main conclusion of the present work are:

As the concentration of Al_2O_3 nano particles in the water rises, so does the density and viscosity of the Al_2O_3 water nano-fluid.

Optimization of Al_2O_3 nano particles in water done based on the stability method to enhance the heat transfer.

Thermal conductivity, effective thermal conductivity, and heat transfer coefficient all rise as the concentration of Al_2O_3 nano particles in water increases.

Heat transfer coefficient (h) and Nusselt (Nu) number increases with varying Reynolds number.

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