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Experimental Investigation of Diameter effect of Al_2O_3 nano fluid on Shell and tube heat exchanger in laminar flow regime

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Abstract

In this paper the experimental study performed to investigate the convective heat transfer characteristic of Al_2O_3–water nano fluid in laminar flow regime. The diameter effect of nano particle on convective heat transfer studied at nano particles volume concentration of 0.012 by volume. The experimental apparatus is horizontal shell and tube counter flow heat exchanger. The nano particles of $Al_2O_3$with average diameter of 20, 40, 60, 80 nm is dispersed in distilled water as base fluid. The result indicates the higher heat transfer coefficientand Nusselt number for all nano fluid compare to base fluid. The result shows that nano fluid with 20 nm diameter has highest heat transfer coefficient and friction factor over rang of mass flow rate.

1. Introduction

In the development of energy-efficient heat transfer equipment, the thermal conductivity of the heat transfer fluid plays a vital role. However, traditional heat transfer fluids such as water, oil, and ethylene glycol mixtures, are inherently poor heat transfer fluids. With increasing global competition, industries have a strong need to develop advanced heat transfer fluids with significantly higher thermal conductivities than are presently available. It is well known that at room temperature, metals in solid form have higher thermal conductivities than those of fluids. Suspended nano particles (vary from 1-100 nm) in conventional fluids are called nano fluids. Recent development of nanotechnology brings out a new heat transfer coolant called 'nano fluids. These fluids exhibit larger thermal properties than conventional coolants. Nano fluids can be considered to be the next-generation heat transfer fluids because they offer exciting new possibilities to enhance heat transfer performance compared to pure liquids. Micrometer-sized particle-fluid suspensions exhibit no such dramatic enhancement. Nanofluids are expected to have superior properties compared to conventional heat transfer fluids, as well as fluids containing micro-sized metallic particles. The much larger relative surface area of nano particles, compared to those of conventional particles, not only significantly improves heat transfer capabilities, but also increases the stability of the suspension.Different types of nanoparticles, such as metallic, ceramics, ceramic oxides, ceramic nitrides, semi conductivematerial and carbon nanotubes (CNTs) can be used as solid.Many experimental studies have been done by researchers. They reported that nanofluids have shown special advantages, such as better stability, greater thermal conductivity, and lowerpressure drop. Although all of these benifits might does not occurat the moment. Some of these studies are expressed as follows.

B.A. Bhanvase et al.**[1]** worked on TiO_2 nano particles having a particle size below 100 nm in a base fluid which is binary mixture of EG 40% and water 60% in test section of copper pipe and heater with volume fraction of TiO_2 between 0 to 0.5 %. They found enhancement in heat transfer coefficients with increase in volume fraction of TiO_2 nano particles. The maximum enhancement of 105% in heat transfer coefficients was observed for the nano fluid with solid volume fraction of 0.5 %. They also found that with increase in inlet temperature of fluid Nusselt number is also increase which attributes the reduction in agglomeration of solid particles.

Ehsan B. Haghighi et al.**[2]**worked on Al_2O_3,ZrO_2,TiO_2 nano particles with average particle size of 20,30 and 20 nm respectively in water as base fluid in test section of horizontal steel tube with heater at 9% wt. of solid particles. They found that at equal Reynolds number the heat transfer enhancement is 23%,8%, 15% in laminar flow and 51%, 13%, 41% in turbulent flow in Al_2O_3,TiO_2,ZrO_2 respectively. At equal pumping power they found decrement in heat transfer coefficient of 63%, 17%, and 52% for Al2O3, TiO2, and ZrO2respectively.

L. Syam Sunder et al.**[3]** worked on MWCNT–Fe_3O_4nano particles with average particle size of 10-30 nm, in distilled water as base fluid in test section of horizontal copper tube with heater with particles varied from 0.1% to 0.3%. The objectiveof the present investigation is to determine experimentally the Nusseltnumber, conductivity, viscosity and friction factor in the turbulent flow and they conclude that thermal conductivity is enhanced by 29% and viscosity is enhancedby 1.5-times with 0.3% vol.The enhancement in Nusselt number for 0.1% particle concentration is 9.35% and 20.62%, for 0.3% concentration and enhancement in friction factor for 0.3%concentration is 1.11-times compare to base fluid.

M.Ghanbarpour et al.[4] investigated thermal conductivity and viscosity of Al_2O_3/water nano fluid with average particle size of 75 nm with concentration varied from 3 to 50 mass concentration and temperature ranging from 293 K to 323 K. They conclude that the thermal conductivity and viscosity enhancement are in the range of 1.1–87% and 18.1–300%, respectively, for mass concentration in the range of 3–50%.

Mohammad Salami Mojarrad et al.[5] investigated thermal conductivity viscosity, convective heat transfer coefficient, pressure drop in alumina/water and alumina/water–ethylene glycol nano fluids with solid particle size 20-30 nm and volume concentration of 0%, 0.25%, 0.5%, 0.7% and Reynolds number between650 to 2300 in the thermal entrance region of a circular tube with constant wall temperature. They conclude that the maximum enhancement in heat transfer coefficient of 8%, 16% and 19% were observed for 0.25%, 0.5% and 0.7% volume concentrations of alumina/water at Re = 2300, respectively. Where these were 13%, 19% and 24% for 0.25%, 0.5% and 0.7% alumina/WEG50 volume concentrations at same Reynolds number. They also conclude that with adding nano particle to the base fluid thermal conductivity viscosity, and pressure drop is increased.

L. Godson et al.[6]investigated LMTD, effectiveness, convective heat transfer coefficient and pressure drop of silver/water nano fluids in a shell and tube heat exchanger with particle size of 54 nm and Reynolds number varying between 5000 and 25,000, with particle volume concentrations of 0.01%,0.03% and 0.04%.They conclude that enhancement in heat transfer coefficient is 9.2%, 10.87% and 12.4% and decrease in LMTD is 1.86%, 2.4%, 3.21% for concentration of 0.01%,0.03% and 0.04% respectively, at Re=25,000. They also observed increase in effectiveness and pressure drop about 0.73, 0.75, 0.76 and 11.15%, 12.84%, 16.2% for 0.01%, 0.03%, 0.04% respectively.

Jaafar Albadr et al[7]experimentally investigated the forced convective heat transfer and flow characteristics of Al_2O_3/water nano fluid of 30 nm particle size and different volume concentration 0.3 % to 2 % in horizontal shell and tube heat exchanger in turbulent condition. They observed that enhancement in overall heat transfer coefficient is up to 57% and Nusselt number is 62.6% for 2% volume concentration with nano fluid. They also conclude that with increase in particle volume concentration viscosity is increased which result increase in friction factor.

N. Kannadasan et al[8] Experimentally investigated heat transfer and pressure drop characteristics of CuO/water nano fluids in the turbulent flow regimes in helically coiled heat exchanger held in horizontal and vertical positions with 0.1% and 0.2% volume concentrations. They conclude that increase in Nusselt number for 0.1% and 0.2% volume concentration, is 36% and 45% in horizontal position, where in vertical position it is 37% and 49% respectively. The increase in friction factor at 0.1% and 0.2% concentration is 7% and 21% in horizontal position and for vertical position it is 12% and 25% respectively.

A.A. Abbasian Arani et al [9] experimentally investigated effect of mean diameter of TiO_2 nano particles on the convective heat transfer and pressure drop with 10,20,30,50 nm particle size and 0.01 to 0.02 volume concentration in horizontal double tube counter flow heat exchanger with distilled water as base fluid. They conclude that all nano fluids, showed higher Nusselt number than the base fluid. The maximum thermal performance factor of 1.9 is found with the simultaneous use of the TiO_2–water nano fluid with 0.02% volume, Reynolds number of 47,000 and nano particle diameter size of 20 nm.

Amirhossein Zamzamian et al [10] experimentally investigated effect of forced convective heat transfer coefficient of Al_2O_3/EG and CuO/EG nano fluid with 20 nm solid particle size in turbulent flow using a double pipe and plate heat exchangers. They varied the weight concentration 0.1% to 1.0% of Al_2O_3 and CuO in ethyl glycol and conclude that heat transfer enhancement for double pipe heat exchanger is maximally 26% for aluminium oxide and 37% for copper oxide at 1.0% weight concentration in ethylene glycol. In the plate heat exchanger it is 38% and 49%, respectively.

B. Farajollahi et al[11] experimentallyinvestigated heat transfer characteristics of γ-Al_2O_3/water and TiO_2/water nano fluids in a shell and tube heat exchanger under turbulent flow condition having particle size 25 and 10 nm and volume concentration 0.3% to 2% and 0.15% to 0.75% respectively. They conclude that heat transfer characteristics of nano fluids improve with Peclet number significantly and addition of nano particles to the base fluid enhances the heat transfer performance and results in larger heat transfer coefficient than that of the base fluid at the same Peclet number.

S. Zeinali Heris et al[13]experimentally investigated the convective heat transfer of Al_2O_3/water nano fluid at particle size 20 nm with 0.2%, 0.5%, 1.0%, 1.5%, 2.0% and 2.5% volume concentration. They carried out experiment in circular tube with constant wall temperature in laminar flow regime and conclude that heat transfer co efficient of nano fluids increases with Peclet number as well as nano particles concentration.

2. Experimental Setup

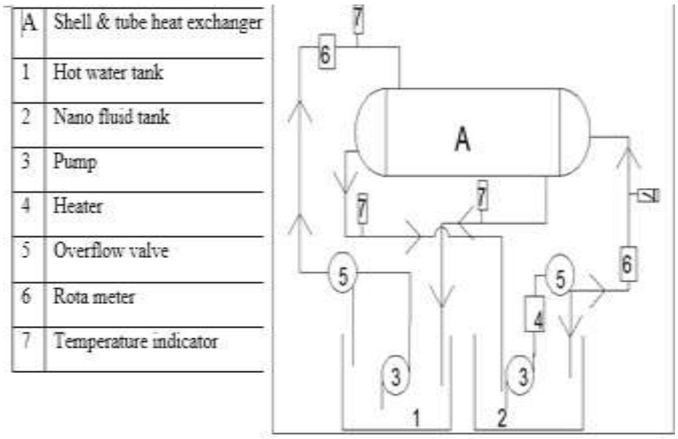


Fig.1 Schematic diagram of Experimental Setup

Table 1. Specification of Heat exchanger

Shell MOC	S.S. 304
Shell Dimension	150(D) X 600(L) mm
Tube MOC	Copper
Tube Dimension	22 (D) X 400(L) mm
No of tubes	24
Water tank MOC	S.S.304
Capacity	80 litre
Pump MOC	S.S. body
Pump Capacity	0.5 HP

The schematic of experiment is shown in fig.1.The set up have nano fluid collection tank, heater, pump with bypass line, shell and tube heat exchanger to heat the cold water. The heat exchanger shell is made of stainless steel and tubes are made of copper. The four J- type thermocouple are placed at inlet and outlet to measure temperature of test section. Two rotameter are used to measure the flow rate of nano fluid and water. The nano fluid is heated and it flows inside tubes where the cold water is made to flow in shell in counter flow arrangement.

3. Preparation of nano fluid

In order to prepare nano fluid by dispersing the nano particles in base fluid two methods are used as, Single step and two step method. Due to economical consideration Two step method is widely used. It is followed by two step, one is production of dry nano powder and in second step it is directly dispersed in base fluid with the help of high speed steering, ultrasonic vibration, intensive magnetic force agitation.In Present Study nano fluid is prepared by two step method. The Al_2O_3 nano power of different average particle size of 20,40,60,80 nano meter is obtain from Nano Labs-Jamshedpur. The Al_2O_3nano powder is directly dispersed in pure water. The Nano fluid of Average particle size 20,40,60,80 nano meter with concentration of 0.012 % vol. Is prepared. Due to higher density of nano particles it tends to agglomerate at the bottom level. To break this agglomeration it is followed byhigh speed stirring for 120 min.The majority of particles is well dispersed in liquid and settle out of liquid.

Fig.2 Dry Al_2O_3 nano powder

Table.2. Specification of Al_2O_3 nano powder

Al_2O_3 Average Particle size	20,40,60,80 nm
Thermal Conductivity	40 W/m^2.K
Specific Heat	0.880 KJ/kg K
Density	3920 kg/m^3

4. Data analysis[9]

4.1 Density and Specific heat

The density of nano fluid is given by

$$\rho nf = \varphi(\rho p) + (1-\varphi)\rho f \qquad (1)$$

The specific heat of nano fluid is given by

$$Cp,nf = \frac{\varphi(\rho Cp)p+(1-\varphi)(\rho Cp)f}{\rho nf} \qquad (2)$$

4.2 Thermal conductivity and viscosity

Thermal conductivity of nano fluid is,

$$\frac{Knf}{Kf} = 1 + 4.4\,(Re)p^{0.4} Prf^{0.66} (\frac{T}{Tfr})^{10} (\frac{Kp}{Kf})^{0.03} \varphi^{0.66} \qquad (3)$$

whereReynolds is particle Reynolds number

$$(Re)p = \frac{\rho f * Ub * dp}{\mu f} = \frac{2\rho f * Kb * T}{\pi * \mu f 2 * dp} \qquad (4)$$

K_b is Boltzmann constant, (1.38066 x 10^{-23} J/K)

Viscosity of nano fluid is given by,

$$\frac{\mu nf}{\mu f} = \frac{1}{1-34.87(\frac{dp}{df})^{-0.3}\varphi^{1.03}} \qquad (5)$$

whered_f is equivalent diameter of molecules of base fluid, (3.85 x 10^{-10} m)

4.3 Heat transfer rate

Heat transfer rate of nano fluid,

$$Q_h = m_{nf} * Cp_{nf} * (Tnf_i - Tnf_o) \qquad (6)$$

Heat transfer rate of cold water

$$Q_c = m_c * Cp_c * (Tc_o - Tc_i) \qquad (7)$$

The average heat transfer rate can be calculated by $Q_{avg} =$

$$\frac{Q_c+Q_{nf}}{2} \qquad (8)$$

4.4 Nusseltnumber ,convective heat transfer coefficient and friction factor[16]

$$Nu = 0.031\,(Re * \mathrm{Pr})^{0.68}(1+\varphi)^{95.73} \qquad (9)$$

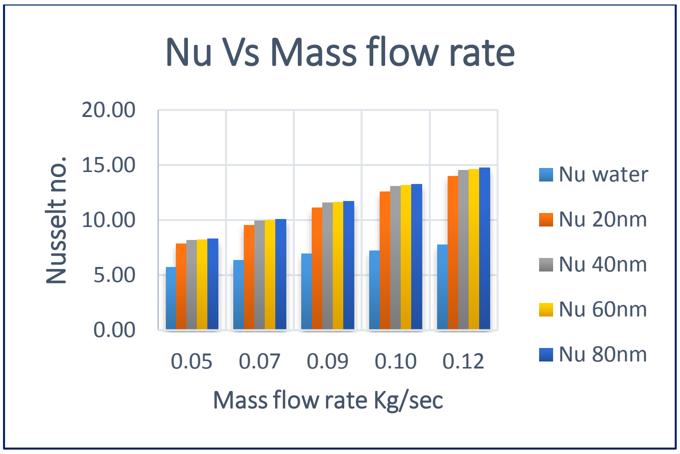
$$Nu = \frac{hi*d}{knf} \quad (10)$$

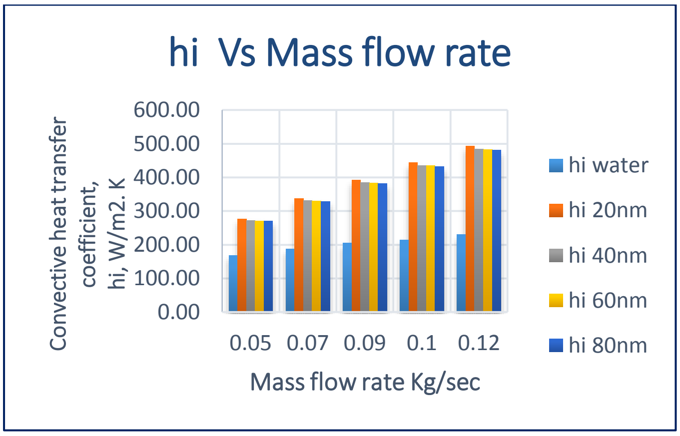
Friction factor of nano fluid is given by,

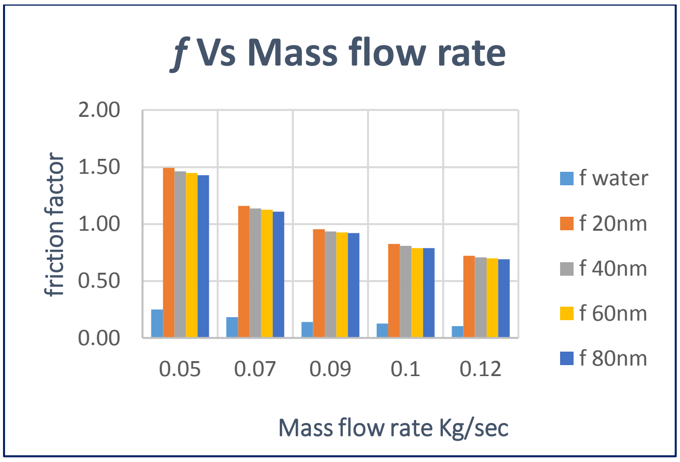
$$f = 26.4Re^{-0.8737}(1+\varphi)^{156.23} \quad (11)$$

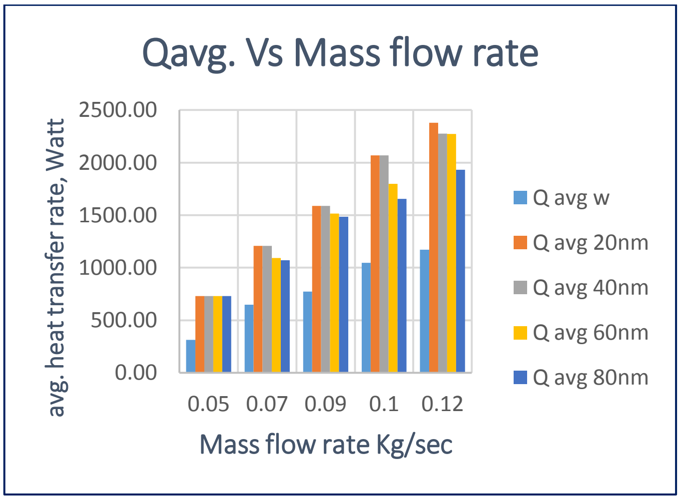
5. Results and conclusion

The experiment were carried out using Al_2O_3/water nano fluid using particle diameter of average 20,40,60,80 nano meter with concentration of 0.012 by volume in laminar flow regime.









It is seen that by decreasing the diameter of nano particles the thermal conductivity of fluid is increased and due to higher thermal conductivity the convective heat transfer coefficient is also increased. The major drawback of the nano fluid is that it increase friction factor too. The experiment is performed with four different particle size at particle concentration of 0.012 by vol. It is found that 20 nm particle size gives better heat transfer and also higher friction factor among all the particles being used.

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