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Research Article

Performance and fluid flow analysis of double pipe heat exchanger using AL_2O_3-nanofluid

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ABSTRACT

Heat exchangers play a vital important role in industries and processing equipment's. Among them, the double pipe heat exchanger facilitates the exchange of heat between two fluids through surface tubes. This study aimed to investigate various thermal performance parameters of baseline water and Aluminum oxide nanofluid at various volume concentrations and flow rates. The results were compared between baseline water and Aluminum oxide nanofluid using a test rig at the temperature range of 60 °C for industrial applications. The nanofluid sample was prepared by adding very small-sized (20nm) Al_2O_3 nanoparticles in the baseline water within the range of 0.10% to 0.175% using a standard two step method for the sterilization process. The nanoparticle and baseline water were under set by a hot plate mechanical stirrer for approximately 2 hours to ensure the proper dispersion before the tests, rendering the nanofluid stable for 12 hours. The Laminar-Transition flow double pipe heat exchanger (test rig) operated at flow rates ranging from 1.6×10^{-5}-3.3×10^{-5} m^3/sec (1-2 LPM) within the range of Reynolds number from 1700 to 3400 at volume concentration of 0.10% to 0.175% Moreover, an addition of 0.175% of Al_2O_3 nanoparticle in the baseline improved the average heat transfer coefficient from 140% to 155%, thermal conductivity of 21.6% and, 5.94% efficiency in counter flow direction and also showed higher friction factor i.e. 2.81% than baseline water. The results suggest that Al_2O_{3-}nanofluid at 0.175% could function very well as working fluid for industrial requirements compared to the conventional baseline water.

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INTRODUCTION

Different nanoparticles are used nowadays for enhancing various thermal properties of working fluids like heat transfer rate and thermal conductivity. These can be used directly in automobile radiators and heating and cooling devices. Heat transfer plays a vitally important role in engineering, science and various processing factories [1-3]. A

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nanoparticle is a nanosized solid particle consisting of metal and its oxides to be mixed in the baseline water to enhance the various properties of a nanofluid [4]. The size and dimension of nanoparticles play a vital role in their physiochemical properties. Whenever the size changes, the atom's arrangement and other structures of nanoparticles change. The thermal conductivity of Al_2O_3-nanofluid at various concentrations increases due to the smaller particle size. This is due to the larger surface-to-volume ratio of a small size particle (20nm) which is compared with a larger size particle (80nm) [5]. Kokateand Sonawane [6] revealed the effects of nanoparticle size on thermal conductivity. As particle size varied of mean diameters 15 nm and 60 nm, their thermal conductivities approximately decreased from 22% to 17%. Al_2O_3 nanoparticles have widely used in industries i.e. pharmaceutical, manufacturing and material industries because of their good thermal behaviour, characteristics and durability at high operating temperatures. Al_2O_3 nanoparticle is obtained by several methods like sputtering, pyrolysis and laser ablation techniques. Nanoparticles produced more stability when dispersed in baseline water for improving various properties NFs. Ali et al. [7] focused on various characteristics like stability and performance of nanofluids.

Murali Krishna and Sandeep Kumar [8] reflect that heat can be removed easily from electronic heat transfer equipment using water, Aluminum oxide-water, and Titanium oxide-water nanofluids as working fluids. Kaggwa and Carson [9] investigated performance parameters like heat transfer and thermal conductivity. Jassim and Ahmed [10] focused on investigating experimentally the effects of two different nanofluids, CuO and Al_2O_3-nanofluid passing through heating equipment at various vol. concentrations. Terese [11] showed that heat transfer characteristics increased in heat exchangers using nanofluid. Thus reduces the cost and size of the heat exchanger. Zheng et al. [12] found the impacts of Nano-sized particles and experimentally results showed that Reynolds and Russell number increased at 0.25-0.5% volume concentrations in the turbulent flow regime. Okonkwo et al. [4] focused on future recommendations for nanofluids in the various fields of engineering giving trends of nanofluids in various heat transfer devices and found various challenges for preparation, obtaining and applications of various nanofluids. Mansoury et al. [13] investigated the performance on double pipe, plate type and shell type HX using Aluminum oxide nanofluid at 0.2, 0.5 and 1% volume concentrations and found that double pipe heat exchanger offers better performance for enhancing the heat transfer coefficients than other types of heat exchanger. Barzegar et al. [14] experimentally described the overall HTC effects due to change in mass flow rate, weight concentrations and temperature and found that 1% Al_2O_3/CuO nanofluid shows better performance than other nanofluid. Barzegar et al. [14] investigated that the HTC was found experimentally on test equipment using a hybrid nanofluid as a coolant. These effects were calculated at different temperatures and mass flow rates. Singh et al. [15] showed that the overall thermal efficiency of single and multipass heat exchangers using aluminium oxide nanofluid was increased up to 12.64%. Jama et al. [16] showed that Nanofluid is a binary mixture of solid particles and liquid water which enhances thermal properties of nanofluid especially HTC and other properties. Azeez et al. [17] revealed and studied numerically HTC enhancement for the volume concentration of 1 to 4% using Al_2O_3-nanofluid. Singh et al. [18] investigation showed that aluminium and its oxide nanoparticles deposited in distilled water superb the thermal behaviour of nanofluid than ordinary fluid and found that HTC enhanced maximum value than ordinary distilled water. Aghayari et al. [19] investigated HTC at a volume fraction of 0.001-0.002 and the result showed that 8-10% heat transfer rate improved. Jamal-Abadi and Zamzamian [20] found that the value of thermal conductivity increased up than base fluid and calculated values of thermal's parameters enhanced for Cu-nanofluid than Al-nanofluid. Askar et al. [21] focused on stability and increasing of heat transfer using aluminium oxide-distilled water as nanofluid and showed that performance of such nanofluid was higher than water at given volume concentration. Asadi's [22] aim was to select such hybrid nanoparticles containing zinc oxide to enhance the heat transfer effectiveness at various concentrations i.e. 0.125-1%. Alawi et al. [23] showed numerical performance of turbulent flow to estimate the thermal behaviour using various Nano-sized materials like copper oxide, aluminium oxide, silicon dioxide and zinc oxide. Dew and Shrivastava [24] calculated various effects by using different nanooxide metals as nanofluids like aluminium oxide, iron oxide and copper oxide and found that copper oxide played a higher role than other nanofluids. Albadr et al. [25] focused towards various flowing characteristics and heat transfer coefficients using aluminium oxide nanofluid as coolant and was flowing towards two types of heat exchangers at various weight concentrations. Sulgani et al. [26] studied various Nano-sized hybrid particles i.e. iron oxide in the oil for cooling purposes and investigated their hybrid effects at various concentrations.Akhtari et al. [27] measured experimental effects using aluminium oxide nanofluid in both types of exchangers in laminar flow regimes and showed that the overall efficiency of shell type equipment is greater than double pipe heating equipment. Ranjbarzadeh et al. [28] revealed that heat transfer plays a vitally important role in different industries and other heating and cooling equipment. Matsunaga et al. [29] revealed that defects on the surface of nanoparticles play an important role of nanoparticles in the HX. There are various defects are produced in the nanoparticles like point and crystal defects but from this point defect surface is considered due to the molecular dissociation and transition effect. Point Defect imparts in both the chemical and physical behaviour of solid materials. This happens due to the missing of an atom or doping of an impurity in place of the normal atom. Kirm et al. [30] analyzed to examine intrinsic energies in aluminium oxide Al_2O_3 nanoparticles. Kuzovkov et al. [31] presented their study on electronic excitation and other properties of Al_2O_3 nanoparticles. Dresvyannikov et al. [32] focuses on finding the defects of Al_2O_3 nano powder and obtained the three types of electronic defects before the annealing process. Bouselsal et al. [33] presented their study on tube and shell type heat exchangers. The efficiency was maximized by altering either varying geometrical shape of heat exchanger pipe or using nanofluid. Water based Al_2O_3-MWCNT hybrid nanofluid is used as working fluid. The results showed that heat transfer enhanced due to increasing volume concentration and velocity of the fluid. Based upon this study, diamond shaped tube revealed better geometrical shape for producing good results in heat transfer rate. Ajeeb et al. [34] experimentally found performance of gasketted plate type HX. They used volume concentrations of Al_2O_3/water nanofluid at 0.10% to 0.20%. The enhancements in viscosity were observed 7.3%, 8.3% and 9.1% at 0.20% by vol. conc. DW and EG respectively. Heat transfer enhancement was done more using DW and EG. Mohamed et al. [35] focused on augmented heat transfer on double pipe HX. The work has used Al_2O_3-nanofluid as working fluid under turbulent flow regime. From results, it is concluded that Al_2O_3-nanofluid exhibited a significant enhancement compared to the baseline water with different mass flow rates and volume concentrations from 0.05% to 0.4%. Sahu et al. [36] presented their study on numerical simulation using Eulerian- Euleian two models. The results were compared to pure nanofluid flow (mixing of air and water with Al_2O_3 nanoparticles) and investigated the enhancement in density, viscosity, thermal conductivity and heat transfer rate. The result indicated that nanofluid (mixing of air and with Al_2O_3 nanoparticles) produced a significant effect than baseline water. Salameh et al. [37] numerically and experimentally investigated the heat transfer enhancement and friction factor of counter flow heat exchanger. They investigated the effects of copper oxide, titanium oxide, aluminum oxide and baseline water using different volume fractions 0.05% and 0.2%. The results illustrated that copper oxide exhibited highest performance index than other nanofluid and baseline water under Reynolds number of 2000 and 12000.

In previous investigations, the researchers only could found few thermal performance parameters like heat transfer rate, Reynolds number, thermal conductivity, density and viscosity either both fluids moving in parallel or counter flow regimes at different flow rates. Few researchers conducted various experiments on various types of heat exchangers using various nanofluids containing oxides of metals separately. Even few researchers found heat transfer rate of hot water and cold water. In this investigation, heat was transferred between hot fluid (Hydraulic oil) and cold fluid (Al_2O_{3-}nanofluid), and this is novelty of this investigation which could not found in any other's studies. This study was done to determine various thermal performance parameters containing performance index and loop efficiency under laminar to transition flow regime conditions from 1700 to 3400 at volume concentration from 0.10% to 0.175%. In this work, nanofluid and hot oil have been sent towards parallel and counter flow HX separately at flow rates of 1, 1.25, 1.5 and 2 (1.6×10^{-5} to 3.3×10^{-5} m^3/sec) when oil was heated at 60 °C.

The present study lacks in small pumping power consumptions. The pumping power in watt is required to transfer hot oil and nanofluid at various flow rates on double pipe heat exchanger. In addition, experimental measured density was compared with those calculated data of ASHRAE. Moreover, measured thermal conductivity ratio was calculated and compared with correlation equation. The results revealed and suggested that 0.175% volume concentration showed highest results in heat transfer rate than other percentages. This enhancement is due to the higher temperature difference between hot and cold fluid. This enhancement exhibits due to the better stability and other favorable characteristics. The present study yields better results at volume concentration 0.175% and are highly preferred for industrial applications.

MATERIALS AND METHODS

Basically, the mixing of 0.175% volume concentration of Al_2O_3 nanoparticles in baseline water showed optimum results compared to the other percentage and fluids [38]. This concentration enhances the thermal conductivity, temperature difference between hot and cold fluid and exhibits its optimum enhancements in stability and other favorable characteristics. Therefore, pumping power consumption, agglomeration of particles and pressure drop offers lesser obstacles during the movement of nanofluid in HX pipe. With the addition of 0.20% and 0.205% volume concentration of Al_2O_3 nanoparticles in baseline water also showed good results in heat transfer measurement. However, at the same time, pumping power consumption as well as the pressure drop measurements occurs more inside the pipe due to the development of agglomeration forces, which caused the higher obstacles across the heat exchanger. On other side, it also reduces the stability of nanofluid. Therefore, 0.175% volume concentration produces good result with lesser power consumption and agglomeration forces inside heat exchanger pipe as compared to 0.20% and 0.205%. Therefore, the volume concentration 0.175% yields better results and is highly preferred than the other values.

This research work described thermal performance using various volume concentration i.e. 0.10% to 0.175% Al_2O_3-nanofluid and baseline water at volume flow rate of 1.6×10^{-5}-3.3×10^{-5} m^3/sec (1-2 LPM). In this work, heat was transferred between Hydraulic oil ISO VG 64 and baseline water. Previous studies could only found results between hot and cold water. The present work focused on the solution of various problems faced by mechanical equipment's bearings (of large sizes) due to their over loading and overheating. For such condition, oil was treated and passed towards a double pipe heat exchanger for exchange their maximum heat to Al_2O_{3-}nanofluid. Moreover, by applying this Al_2O_{3-} nanofluid in heating equipment, the life of oil is saved by the addition of proper aluminium oxide nanoparticles in the baseline water. Moreover, heat was immediately transferred from hot oil to cold nanofluid. Therefore, Al_2O_3-nanofluid produced good and reliable results than baseline water and other nanofluids due to their good thermal conductivity. Additionally, in this study, very small-sized 20 nm [12] Al_2O_3 nanoparticles were mixed in the baseline water to superb the solution due to their availability in market and possessing good thermal characteristics compared to the other sizes. By investigating heat transfer rate through different flow regimes, the study likely aimed to determine transfer of heat, Reynolds number, Nu, pumping power, pressure drop and other parameters change as flow behavior from laminar to transition regimes. In this study, experimental investigation was conducted on both type of heat exchangers i.e. Parallel and Counter heat exchangers at various and fixed flow rates. This type of investigation is more valuable for optimizing heat exchanger design.

Aluminum oxide is widely used in an engineering field. Its powder is probably used in formation of nanofluid. Because of their low cost and high thermal properties these nanosized particles are mixed in baseline water and used in heat exchanger devices. Aluminum oxide nanoparticles have very good thermal properties at various ordinary temperatures than baseline water. Table 1 shows various thermal properties of nanoparticles.

From Table 1, it is clearly shown that Aluminum oxide possesses good thermal conductivity, density and specific heat and highly used in heat exchanger devices in order to absorb more heat generated from hot fluid. To overcome the problems faced in heating equipment's, a research study was based to analyze the effectiveness of heating device using baseline water and aluminum oxide nanofluid. Thus nanofluid was prepared and stirred by a hot plate mechanical stirrer for about 2 hours to ensure the proper dispersion before being used in the test. In this study, ISO VG 64 hydraulic oil was used as a hot fluid to carry out heat to the cold nanofluid. Due to this heat transfer was enhanced and the life of hot oil and cold fluid was saved using such nanofluid.

Preparation Method of Nanofluids

Nanofluid was produced by suspending aluminium oxide Al_2O_3 nanoparticles with particle size 20nm in the baseline water in a range of 0.100, 0.125, 0.150, and 0.175% by volume concentration. Moreover, when Al_2O_3 nanoparticles added in the baseline increased the heat transfer rate. Al_2O_3 nanoparticles in dry powder form with an average particle size of wire in baseline water according to the standard method given in the following [35].

$$\phi = \frac{\frac{W_p}{\rho_p}}{\frac{W_p}{\rho_p}+\frac{W_{bf}}{\rho_{bf}}} \times 100 \tag{1}$$

W_p= weight of nanoparticle (kg)
ρ_p= density of nanoparticle (kg/m^3)
W_{bf}= Weight of base fluid (kg)
ρ_{bf}= density of base fluid (kg/m^3)

Table 1. Thermal properties of Al_2O_3 nano powder [12]

Nanoparticle	Density (kg/m³)	Thermal Conductivity (W/m.K)	Specific heat Capacity (J/kg.K)	Appearance
aluminium oxide (Al_2O_3)	3960	40	773	White powder

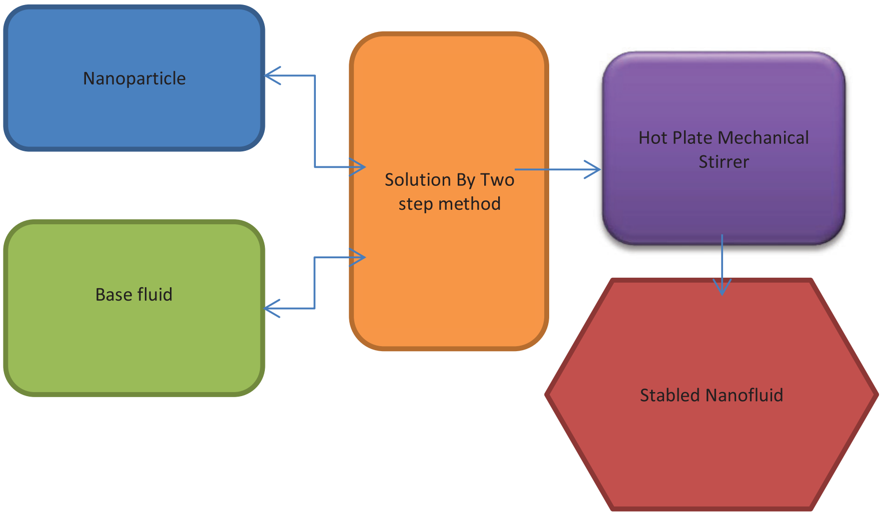

Figure 1. Preparation method of nanofluid.

Nanofluid was prepared through a Two-step method using suspending Al_2O_3 nanoparticles by volume concentration in the baseline water (Figure 1).

In this research, Al_2O_{3-}nanofluid is prepared using two-step method. The stability of Al_2O_{3-}nanofluid is assessed through Sedimentation method. This a common technique used to check the stability of nanofluid. In sedimentation and agglomeration analysis, settling of nanoparticles over time can indicate instability. Observing the suspension for particle's agglomeration or precipitation through visual inspection or by measuring sedimentation rates can provide insights into stability. The stability of Al_2O_3-nanofluid remains for 24 hrs. After applying stabilization process by hot plate mechanical stirrer, the nanoparticles were settled down in the bottom side of the nanofluids jar. Therefore, stability and instability were checked physically.

Selection of Nanoparticle

The selection of nanoparticle size in heat exchangers is a critical consideration. The choice of nanoparticle size is driven by following factors:

1. Surface Area: surface area plays an important role in heat transfer devices. Smaller nanoparticles possess a larger surface area per unit volume. This increased surface area allows better interaction to the particles of base fluid, to enhance heat transfer rate.
2. Availability in the market: This sized nanoparticle was easily accessed in the market and is more suitable for this study for increasing various thermal properties of nanofluid.

Stability of Nanofluid

The stabilization process is used to reduce agglomeration of the nanoparticles into the baseline water to get stable solution. The hot plate stirrer method was applied continuously up to two hours to produce good stability into the baseline water. In this study, the Sonication process did not evolve due to unavailability in the laboratory. Therefore, a hot plate agitator was employed for good stability of the nanofluid.

Indeed, an increase in volume concentration of Al_2O_3 nanoparticles (Figure 2) in baseline water ranging from 0.10% to 0.175% can increase density, viscosity, pressure drop which may subsequently increase consumption of pumping power. This consumption and pressure drop cannot be completely minimized and neglected during fluid flow but can be managed and regulated by passing highly stabilized nanofluid through the pipe. When highly stabilized nanofluid (Figure 3) is passed through heat exchanger pipe, it reduces the agglomeration and coherent forces. While these losses cannot be ignored completely but can be controlled in a proper way by utilizing more stable nanofluid. Therefore, a volume concentration of 0.10% to 0.175% Al_2O_{3-}nanofluid offers lesser obstacles compared to 0.20% and 0.205%.

Experimental Setup

The experimental device is located in Heat Transfer Laboratory shown in Figure 3. Test rig comprises two concentric pipes, one contains hot fluid and second cold fluid and both fluids are moving in the counter direction. It also consists of one oil storage tank with an oil pump, one gate valve and one ball valve for controlling both fluids. The device has a 0.91 m length of pipe made of copper material with diameters of 0.545 inch and 0.625 inch, respectively. To reduce the heat losses from tubes an insulating material is employed. Thermocouples are installed on HX pipes for measuring temperature. Detailed specifications are given in Table 2.

Thermal properties and structures of aluminium oxide Al_2O_3 nanoparticles were checked using chemical, electrochemical, X-ray diffraction, atomic emission spectroscopy

Figure 3. Sample of stabilized nanofluid (left) and Al_2O_3-nanoparticle (right).

Table 2. Components and specification of test rig

Component/specification	Unit	Quantity
Inner diameter	0.625 inch	1
Outer diameter	0.875 inch	1
Overall Length	36 inch	-
Type of material	Parallel pipe (copper inner tube)	-
Thermocouples	+0.9°F (0.5°C) °F and °C	5
Ball valve	GPM and LPM.	4
Gate valve	GPM and LPM.	2

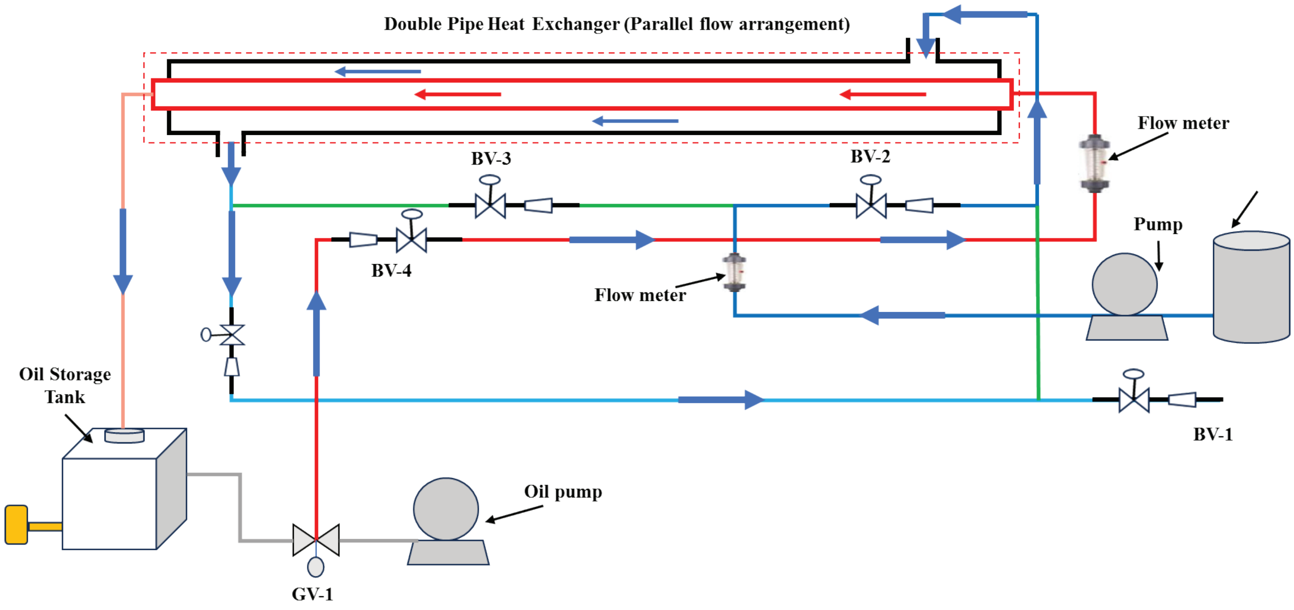

Figure 2(a). Schematic diagram of parallel flow heat exchanger unit (test rig).

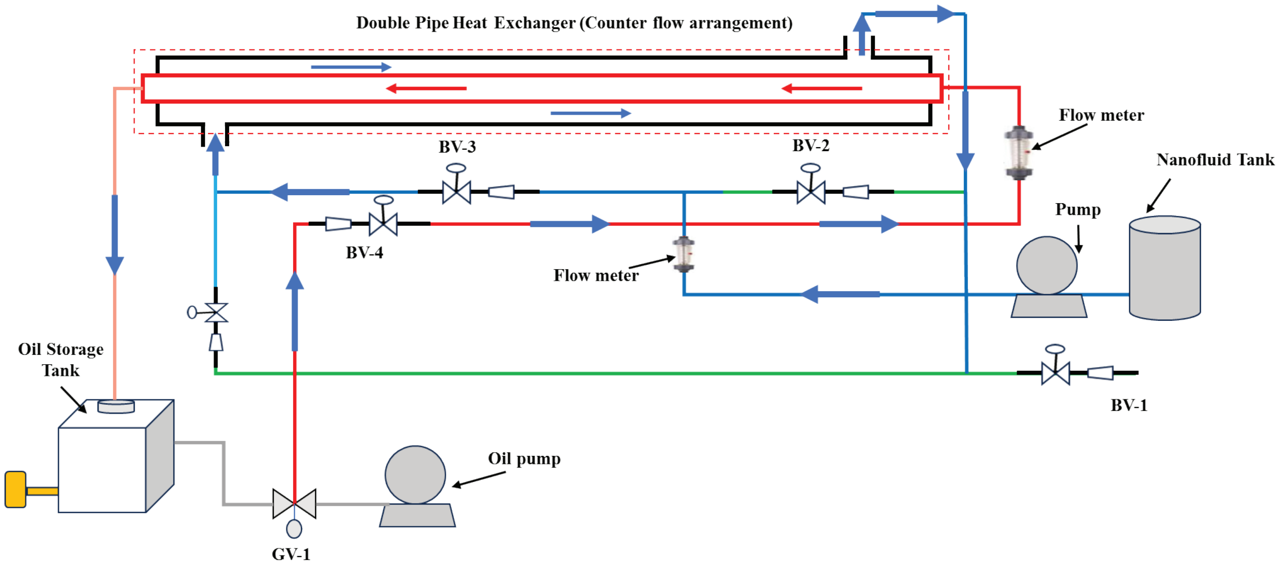

Figure 2(b). Schematic diagram of counter flow heat exchanger unit (test rig).

Figure 4. Actual view of experimental test rig.

and thermal analysis methods [32]. Figure 2 (a, b) is the experimental test rig shows the complete operation and the ways through which both fluids move.

The 20 liters tank made of stainless steel was used for storage of cold fluid i.e. aluminium oxide-water nanofluid. This nanofluid flows through the pump towards a double pipe heat exchanger for absorbing more heat from hot fluid i.e. hydraulic oil ISO VG-68 to cold nanofluid. During experimental work, flow rate, wall temperature of the Laminar- Transition flow HX (Test rig) were measured separately (Figure 4).

In this test, ISO VG-68 hydraulic oil was filled in the oil storage tank of the test unit up to standard level and oil was heated at 60°C [18]. The flow rate is controlled in the range of 1.6×10^{-5}-3.3×10^{-5} m^3/sec (1-2 LPM). In the end, oil and nanofluid samples were collected for measuring various thermal properties i.e. viscosity, density and Thermal conductivity through measuring devices. The measuring devices were first calibrated and were used to measure various thermal properties. Therefore, accurate results were obtained from measuring devices and can be compared theoretically through various correlations. In Table 3, various attached/installed devices of the test rig with their ranges are given. This table includes many devices with their units like thermocouples (°C), volt meters (V), ampere meters (I), flow meters (LPM, GPM) and gauge pressure (bar). Instruments with their Ranges of various parameters are given below:

Table 3. Instruments with their ranges of various parameters

Sr#	Instrument	Min-max range (un-certainty error)	Measured range
1	Thermocouple, °C, Wall temperature	0-100° (±0.1)	30-40°
2	Thermocouple, °C, hot fluid temperature	0-100° (±0.1)	50-80°
3	Thermocouple, °C, cold fluid temperature	0-100° (±0.1)	25-45°
4	Voltage, V	0-220 (±0.1)	210
5	Current, I	0-30 (±0.1)	7
6	Flow meter, LPM, GPM	0-4 (±0.1)	1-2
7	Pressure gauge, bar	0-3	1-2

Table 4. Summary of Uncertainty analysis of parameters and values

Sr. No.	Parameters	Uncertainty error (%)
1	Reynolds number, Re	0.0625
2	Heat transfer coefficient, HTC	0.0618
3	Loop Efficiency, ή	0.068
4	Thermal conductivity, K	2.25
5	Performance index	4.7

Uncertainty Analysis

Uncertainty analysis sometimes called as error analysis. It is statistical method used to determine the amount of uncertainties or errors present in an experimental data. The uncertainty is a deviation of the measured data to the true value and is calculated using the following equation 2 [39].

$$\Delta x = \frac{R}{2} \tag{2}$$

Where R is the range which is the difference of maximum value and minimum value of an experimental data (x).

$$R = xmax - Xmin \tag{3}$$

The uncertainty analysis between measured and true value can be determined as following equation [39]. The uncertainty analysis can be measured in percentage.

$$\text{uncertainty analysis (\%)} = \frac{\Delta x}{\bar{x}} \times 100 \tag{4}$$

Where x is the arithmetic or mean value of measured data.

The Uncertainty calculated with the maximum possible error for the experimental calculated values is given in Table 4.

In this research work, the uncertainty values are below 5%. Thus uncertainty value for this experimental work pertains to the accepted value. Accepted value for any experimental work should come below 5%. If uncertainty value comes lesser than 5%, it means more accurate results are obtained from an experimental work.

General Operating Conditions of Valve

Valves are used for controlling fluid flow within HX. The operating conditions for valves in a heat exchanger can vary depending on several factors, including type of fluids involved, and specific requirements of the system. Different types of valves, such as globe valves and ball valves are used in this study and condition is based upon direction of fluid flow either flow is moving in parallel or counter flow direction However, some general operating conditions are applied and given in Table 5.

Table 5. Closing and opening position of valve

Valve	Counter flow
BV-1	Closed
BV-2	Open
BV-3	Closed
BV-4	Open

Data Processing

Various thermo physical properties of nanofluid i.e. HTC, heat flux, Nusselt number, and Reynolds number at varying volume concentrations have been calculated. Thermal properties are calculated using wall temperature and bulk average temperature.

Heat transfer rate

Heat transfer equation consists of various principles used to determine transfer of heat between the two systems or within the systems. The heat transfer rate is used to determine energy transfer through a system involving specific heat, mass flow rate and temperatures at various points. It is amount of heat to be transferred in a unit area and time. Heat transfer rate mainly depends on various factors such as; mass flow rate in kg/sec, specific heat capacity in J/kg.K and temperature difference.

The heat transfer rate is calculated as;

$$Q = \dot{m} C_p (T_o - T_i) \tag{5}$$

Where *Q* is heat transfer rate in Watt, ṁ is mass flow rate in kg/sec, C_p is specific heat capacity in J/kg.°C and T_i, T_o are inlet and outlet temperatures in °C.

Heat flux

Heat flux equation is particularly used in heat exchanger devices, pipes and cylindrical vessels. However, this equation relates the total heat transfer to the surface area of the heat exchanger pipes.

$$q'' = \frac{Q}{\pi DL} \quad (W/m^2) \tag{6}$$

Where q'' is heat flux in W/m^2, Q is the heat transfer rate in Watt, D is the Diameter of pipe in meter, L is the Length of pipe in meter.

Convective heat transfer coefficient

Convective heat transfer coefficient describes how heat can be moved from solid surface to fluid medium and this is an important parameter used in designing and analyzing heat transfer devices. It defines as the ratio of heat flux to the temperature differences between wall and Bulk temperature in °C.

$$h_{av} = \frac{q''}{T_w - T_b} \qquad (7)$$

h_{av}= Average convective heat transfer coefficient, W/m^2.K, T_w & T_b = Wall and Bulk temperature, °C

Average HTC is the measurement of average rate of heat transfer per unit area on the surface of the heat exchanger pipe to determine the overall efficiency of the heat exchanger. The average heat transfer coefficient is used to determine the computational applications in heat exchanger devices. In this study, average heat transfer coefficient is used and measured to determine the accurate analysis of an experimental study. Moreover, average heat transfer coefficient is based upon the various factors, such as fluid velocity, temperature difference, thermal conductivity and viscosity. In this study, average values of surface temperature are measured to make accurate analysis of convective heat transfer coefficient and Nusselt number.

Nusselt number

Nusselt number describes how heat is being transferred by convection relative to conduction. Nusselt number is a ratio of average convective heat transfer coefficient to conductive heat transfer. The Nusselt number “Nu” depends upon various factors like convective heat transfer coefficient, characteristics length and thermal conductivity of fluid.

$$Nu_{av} = \frac{h_{av}.\ D}{K} \qquad (8)$$

Where h_{av} is average convective heat transfer coefficient in W/m^2.K, D is the diameter of pipe in meter; K is the thermal conductivity of fluid in W/m.K.

Friction factor

The friction factor is a non-dimensional number used in heat transfer devices to describe the resistance to fluid flow through a pipe. The fluid flow friction mainly depends upon the roughness of pipe and fluid flow’s velocity.

$$f = 0.316/(Re)^{1/4} \qquad (9)$$

Where f is friction factor and Re is Reynolds number

$$\text{Blasius formula}, f(th) = (100.Re)^{-1/4} \qquad (10)$$

$$\text{Filonenko model}, f(th) = (\ln.Re.0.790 - 1.64\ ) \quad (11)$$

Reynolds number

It is used to determine behavior of fluids properties. This is the most essential parameters applied in convective heat transfer applications especially used to determine either flow is laminar or turbulent.

$$\text{Reynolds number} = \frac{\rho V D}{\mu} \qquad (12)$$

Where ρ is density of fluid in kg/m^3, V is velocity of fluid, D is the diameter of pipe in meter and μ is

dynamic viscosity of fluid in Pa.sec.

For fluid flow in a pipe, Reynolds number has following ranges according to [40, 41] and is applied in this study:

Laminar flow: up to Re=2300

Transition flow: Re=2300-4000

Turbulent flow: Re>4000

In this study, Reynolds number was ranged from 1700 to 3400 for laminar-Transition flows which consist of Laminar and Transition flow regimes. However, in this study laminar as well as Transition flows may likely occur within this range.

Pumping power

Pumping power refers to the amount of power is needed to maintain the fluid flow inside the heat exchanger pipe. The Pumping power mainly depends upon the density, viscosity and fluid flow’s velocity. This relationship is based upon two different fluids i.e. base fluid and nanofluid and is influenced by the viscosity and density ratios between two fluids.

$$\text{Pumping power,} \quad \frac{W_{nf}}{W_{bf}} = \left(\frac{\mu_{nf}}{\mu_{bf}}\right)^{0.25} \left(\frac{\rho_{bf}}{\rho_{nf}}\right)^{2} \qquad (13)$$

Where ρ_{bf} , ρ_{nf} are densities of base fluid and nanofluid in kg/m^3 and μ_{bf} , μ_{nf} are the dynamic viscosities of base fluid and nanofluid in Pa.sec.

Loop efficiency

Loop efficiency is applied in heat transfer systems and heat exchangers to describe the effectiveness of heat exchanger processes within the system. Loop efficiency is a ratio of convective heat transfer coefficients of two fluids to the pumping power required of both fluids.

$$\text{Loop efficiency,}\ \eta = \frac{h_{nf}/h_{bf}}{W_{nf}/W_{bf}} \qquad (14)$$

Where h_{bf}, h_{nf} are convective heat transfer coefficients of base fluid and nanofluid in W/m^2.K

Performance index:

Performance index refers to investigate and compare HTC of two fluids to the Pressure drop occurs by both fluids across the heat exchanger pipe.

$$\text{Performance index,}\ \varepsilon = \frac{h_{nf}/h_{bf}}{\Delta P_{nf}/\Delta P_{bf}} \qquad (15)$$

Where $\Delta P_{nf,bf}$ are pressure drops of nanofluid and base fluid in Pascal.

RESULTS AND DISCUSSION

Density of Al_2O_3-nanofluid

It is an important parameter used in this study. More dense fluid imparts more pressure inside tubes but on heating expansion of nanofluid particles take place. By hearing the nanofluid at high temperature the density of nanofluids decreases down so temperature and density are inversely proportional with each other. By increasing temperature of nanofluid, its density is decreased and shown in Figure 5. By adding 0.10-0.175% volume concentration of Al_2O_3 nanoparticle in the baseline water, the density of Al_2O_{3}-nanofluid is increased than that of base fluid. Approximately 2.2% density of nanofluid is increased than water. In order to validate the experimental data, a comparison of viscosity of tested nanofluid with ASHRAE data has been conducted. From Figure 5, it is clear that experimental results meet the closeness with the ASHRAE data with minimum errors.

Effect of Volume Concentration and Temperature on Viscosity of Al_2O_3-nanofluid

It plays vital important role in heat transfer fields. Viscosity of nanofluid offers some internal resistance which produces internally due to cohesion and more attractive forces among particles. It depends upon many factors like pressure, temperature and fluids strain. Higher the fluid temperature causes the viscosity lower. The viscosity of Al_2O_{3}-nanofluidat particle concentration and temperatures is shown in Figures 6 and 7. When particles were suspended

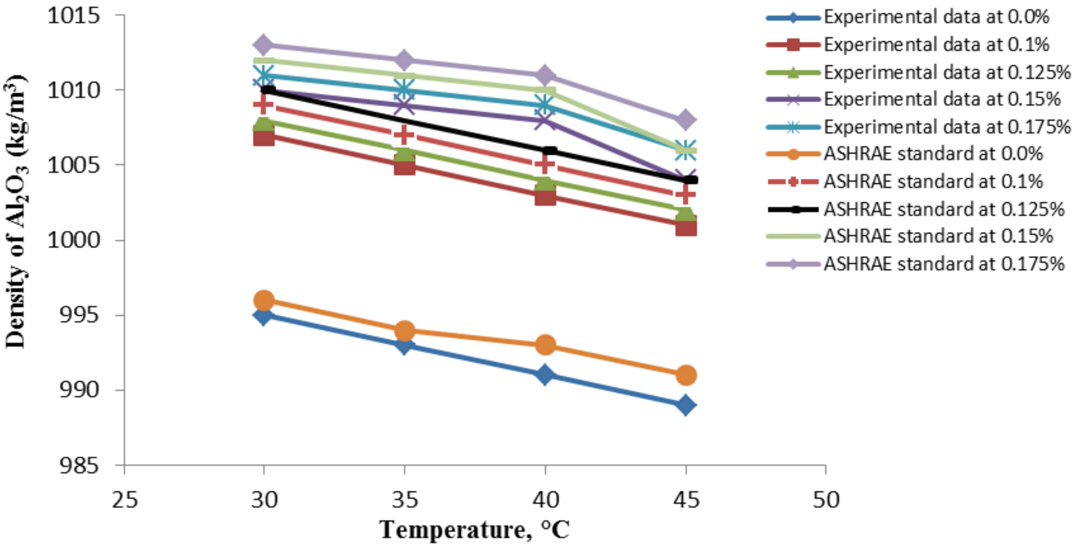

Figure 5. Density of Al_2O_3-nanofluid at various temperatures.

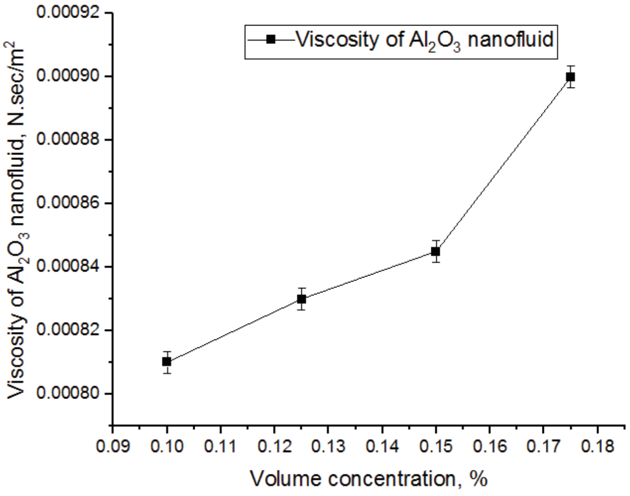

Figure 6. Viscosity of Al_2O_3-nanofluid at various concentrations.

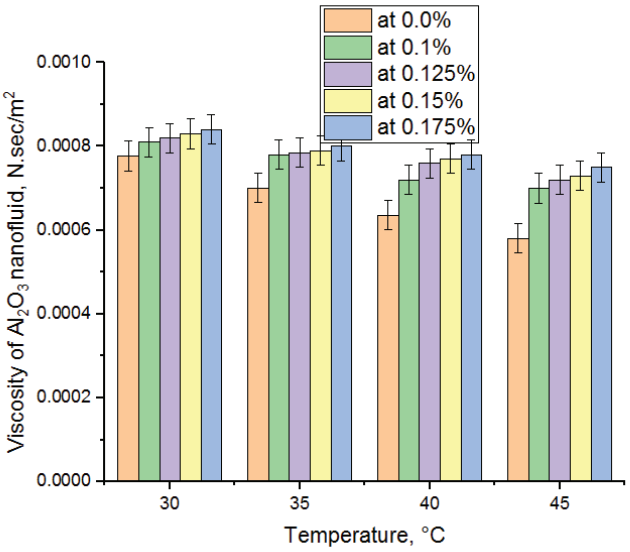

Figure 7. Viscosity of nanofluid at various temperatures.

in the baseline water, its dynamic viscosity increases than baseline water. The enhancement of viscosity is measured by 13.92% than baseline water at 0.175% volume concentration. From Figure 7 it is shown that as temperature of nanofluid increases its viscosity start to drops because in heating the nanofluid particles disclose with each other and make a small distance among them to produce less viscous nanofluid. This is due to the enhancement of absolute temperature.

Effect of Volume Concentration on Thermal Conductivity

Thermal conductivity is an important parameter for measuring heat transfer rate between hot and cold fluids. Thermal conductivity offers the nanofluid to transfer or conduct heat within region. It increases as the fluid temperature increases and mainly depends upon temperature and other factors such as moisture and density. Thermal conductivity of pure fluid is 0.6 W/m.K at normal operating temperature and is shown in Figure 8. Figure 8 shows the thermal conductivity of nanofluid in terms of volume concentration. From results, it is very clear shown that thermal conductivity is increased as volume concentration of the nanoparticle increases. Since the thermal conductivity of nanofluid is much higher than baseline water, these changes made higher thermal conductivity for nanofluid attributed to the nanoparticles. Another reason for increasing thermal conductivity is better stability and best mixing of nanoparticles in the base fluid which may cause higher heat transfer rate. The changes in thermal conductivity are also improved due to rise in temperature of working fluid. Moreover, suspended nanoparticles in the base fluid are also causing higher thermal conductivity. Furthermore, viscosity of nanofluid increased as nanoparticles mixed in the baseline fluid. This enhancement happened due to the agglomeration of nanoparticles in the baseline water. Therefore, the thermal conductivity of nanofluid was increased from 0.6 to 0.73 W/m.K due to increasing of nanoparticles concentrations and temperature also. The thermal conductivity also varies with particle size and shape. The thermal conductivity of base fluid and nanofluid was measured through Thermal conductivity apparatus which is located in Heat and mass transfer laboratory. Experimental work was carried out in Heat transfer laboratory, and three times results of Thermal conductivity were taken at temperature of 60°C. Than average value of Thermal conductivity was taken place as reference value. Aluminum oxide nanofluid showed an increasing drift in thermal conductivity with temperature and volume concentration.

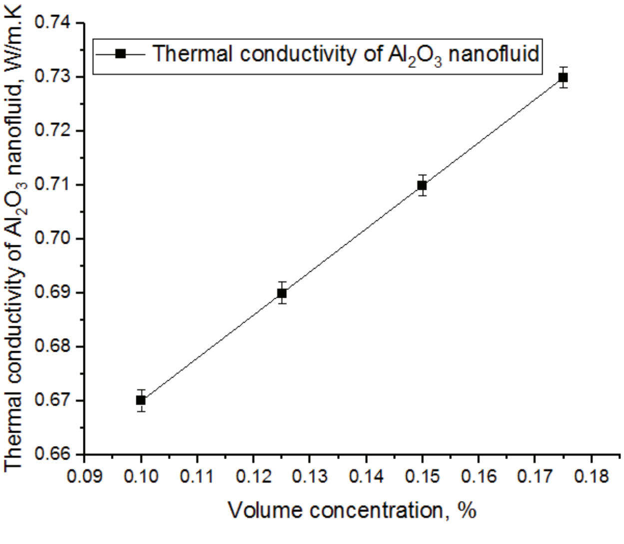

Figure 8. Thermal conductivity of Al_2O_3-nanofluid at various concentrations.

Thermal Conductivity Ratio

It is ratio of thermal conductivity of base fluid and nanofluid. By addition of nanoparticle in the baseline water in the range of 0.10-0.175% increased the thermal conductivity ratio and its effect due to various volume concentrations can be shown in Figure 9. By adding Al_2O_3 nanoparticle in the baseline water, thermal conductivity was increased due to increasing temperature of the nanofluid. As the temperature increases the Brownian motion was increased therefore its thermal conductivity was increased as compared to the baseline water. Temperature variation imparts a major role in enhancing the thermal conductivity of nanofluid. Therefore thermal conductivity of nanofluid was increased from 0.6 to 0.73 W/m.K due to increasing of nanoparticles concentrations and temperature also. The thermal conductivity also varies with particle size and shape. Basically, by mixing of volume concentration of Al_2O_3 nanoparticles in baseline water increases the thermal conductivity, improving the fluid's ability to conduct heat. This increase is typically observed as the concentration of nanoparticles rises within certain limits. However, there's a point where adding more nanoparticles can lead to a decrease in thermal conductivity or other adverse effects. This transition can be explained as follows:

Initial enhancement

Initially, as nanoparticles are added into the baseline water, increased the surface area and interaction between particles which enhanced the thermal conductivity. This effect is due to the higher thermal properties of nanoparticles, which could raise heat transfer rate compared to the base fluid.

Percolation threshold

As the concentration of nanoparticles continues to rise, there's a critical point known as the percolation threshold. Beyond this point, instead of improving thermal conductivity, the nanoparticles might start to agglomerate or cluster together. This clustering can increase barriers to effective heat transfer rate and thermal conductivity of nanofluid.

Agglomeration and hindered movement

Agglomeration of nanoparticles can hinder the movement of heat through the fluid. Instead of increasing heat transfer rate, these clusters can act as an insulating barrier, decreasing the fluid's ability to conduct heat. When Al_2O_3 nanoparticles with 0.20, 0.22, 0.24% volume concentration (Instead of adding 0.10-0.175%), will be added to a base fluid, it decreases the thermal conductivity because of increasing agglomeration and hindered movement of nanoparticles in the base fluid which can increase pumping power consumption and pressure drop across heat exchanger pipes. Therefore, this volume concentration will increase more consumption of power and is less economical than 0.10-0.175% volume concentration. Therefore, this percentage 0.10-0.175% is preferred more and is more economical than others.

$$\mathrm{TCR} = \frac{K_{nf}}{K_{bf}} = 1 + 0.4281\left(\frac{T}{100}\right)^{1.707} \times \phi^{0.8449} \tag{16}$$

Where K_{bf}, K_{nf} are thermal conductivities of base fluid and nanofluid in W/m.K and T is temperature in °C and ϕ is volume concentration.

This research is based upon an experimental study; a correlation model (16) is proposed to predict the thermal conductivity ratio of both nanofluid and water at 30°C using 0.1-0.175% volume concentration. From this figure it is clear shown that experimental and theoretical correlation meet their closeness values.

Empirical Correlation and Validiation of Experimental Results

The validiation of results is a major parameter to check the results using various euations. In this study, experimentally investigagtion was done at all cases. Nu increases as Re increased because of increasing thermal conductivity and HTC of nanofluid than basline water. The emprical correlation for nusselt number is shown in Figure 10. The development for correlation for Nusselt number is to minimize the uncertainity of experimental work and increase the precision of experimental work. It was observed that due to increase of volume concentration of Al_2O_3 nanoparticle in the baseline water, Nusselt number was increased. Nusslet number for experimental and theroritical work showed the least deviation of +10%. The boundary conditions were selected for nusslet numebr are 40 to 110. Figure 9 showed the less discripency and highest accuracy of correlation with experomental work. It is obviously clear that, correlation between Gryta et al. (1997) showed the least deviation than correlation of Acharya et al. (1992, 2001). The following correlations were used for differentiating the errors in the Nusselt number.

$$Nu = 0.298Re^{0.646}Pr^{0.316} \tag{17}$$

$$Nu = 0.1381Re^{0.75}\,Pr^{0.33} \tag{18}$$

Where Re is Reynolds number and Pr is Prandlt number

Effect of Reynolds Number and Volume Concentration on Heat Transfer Coefficient

The influence of nanofluid volume concentration has a major role in the heat transfer coefficient. As volume concentration of Al_2O_3 nanoparticle in the baseline water is increased its thermal properties of nanofluid improved. It is revealed from Figure 11 that heat transfer efficiency

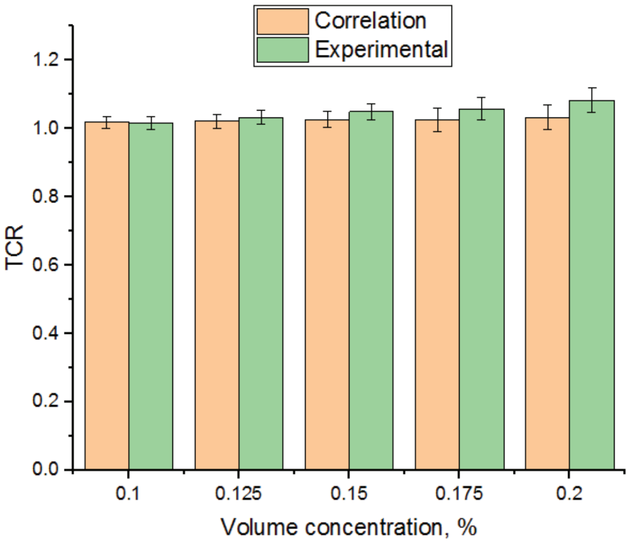

Figure 9. Thermal conductivity ratio at various volume concentrations.

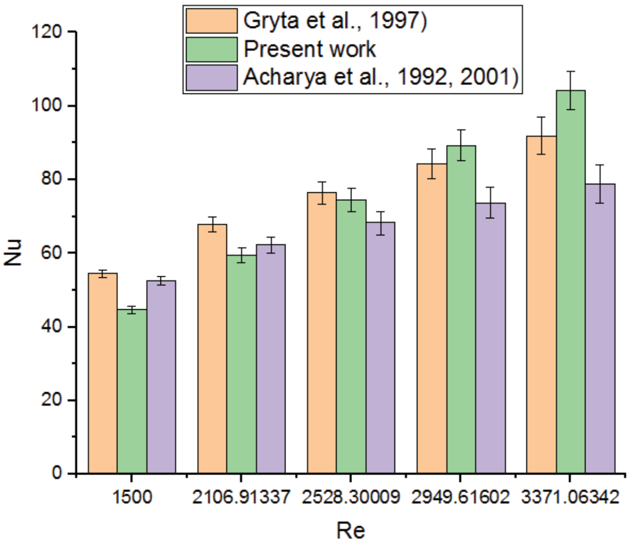

Figure 10. Comparison of experimental and emprical correlation for Nusselt number at various flows of Al_2O_3-nanofluid.

enhanced from 6053 W/m^2.K to 6372 W/m^2.K in parallel and counter flow directions. It is also shown in Figure 12 that average HTCs were measured from 4200 to 4900 W/m^2.K in parallel and counter flow direction by adding 0.175% of Al_2O_3 nanoparticle in the baseline water because the thermal conductivity of Al_2O_3 is higher than water. Meanwhile, counter flow direction has better performance than parallel flow arrangements because in the counter-flow direction, more difference of temperature is maintained between hot and cold fluid. Moreover, It is seen that HTC and Nu was increased with an increasing concentration of Al_2O_3 nanoparticle in the baseline water. The use of nanoparticles in the baseline water causes the enhancement of various thermal properties of nanofluid. Putting 0.175% volume concentration of Al_2O_3 nanoparticle in the baseline water showed the maximum HTC of 6372 W/m^2.K at a Re of 3066.

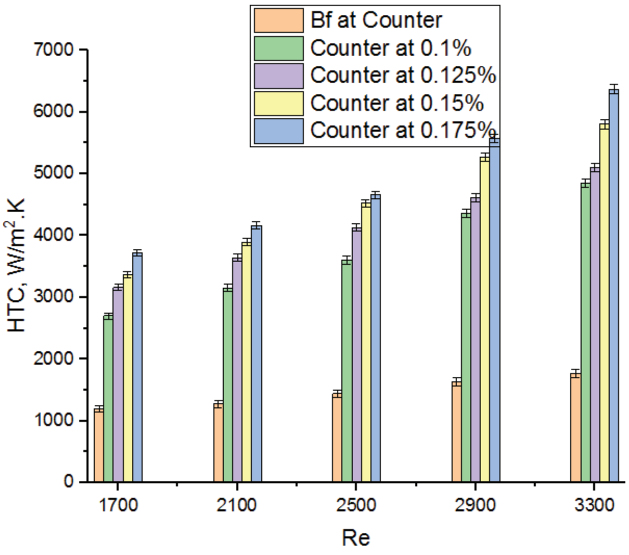

Figure 11. Variation of heat transfer coefficient with Reynolds number in counter flow.

Effect of Friction Factor on Volume Concentration at Various Flow Rates

Friction factor is a major important parameter measured and produced due to the movement of base fluid and nanofluid across the heat exchanger pipe. It offers some resistance as nanoparticle moves in the baseline water. The increase in volume concentration increases the friction factor because of the increasing density and viscosity of nanofluids. Figure 13 shows the variation of friction factor with respect to volume concentration. As volume concentration increases, agglomeration of nanoparticles increases which causes more friction in the nanofluid than baseline water. Figure 12, it was shown that by adding 0.175% of Al_2O_3 nanoparticle in the baseline water showed a 2.81% higher friction factor than baseline water because Al_2O_3-nanofluid has a higher density than water.

Effect of Friction Factor on Reynolds Number

The friction factor plays a vital role in enhancing the resistance and obstacles in the the path of moving fluid. In this study, various volume concentartions of Al_2O_3 nanoparticle were mixed in baseline water enhanced the friction factor due to their higher densities and viscosities of fluids. Thus fluid's friction imparts serious effects on pressure and pumping power loss. In order to decrease agglomeration of nanoparticles, the fluids motion can be increased due to higher velocities and flow rates across the test section. Therefore, friction losses may be reduced using greater movement and motion of fluid. Higher velocity of fluid causes higher Reynolds number but reduces the

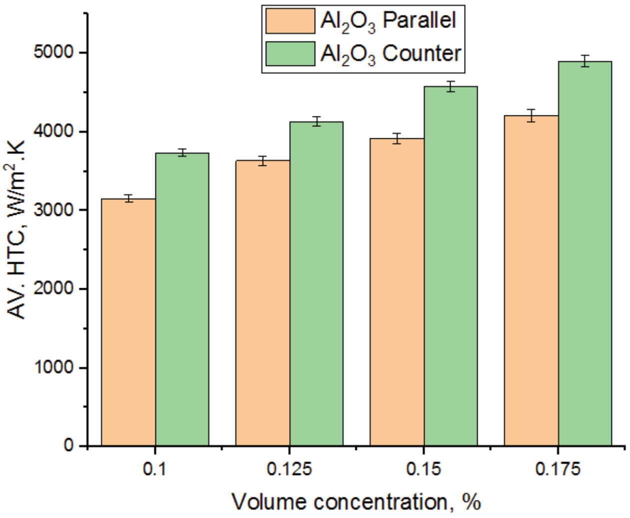

Figure 12. Effect of heat transfer coefficient on volume concentration in parallel and counter flows at various flow rates.

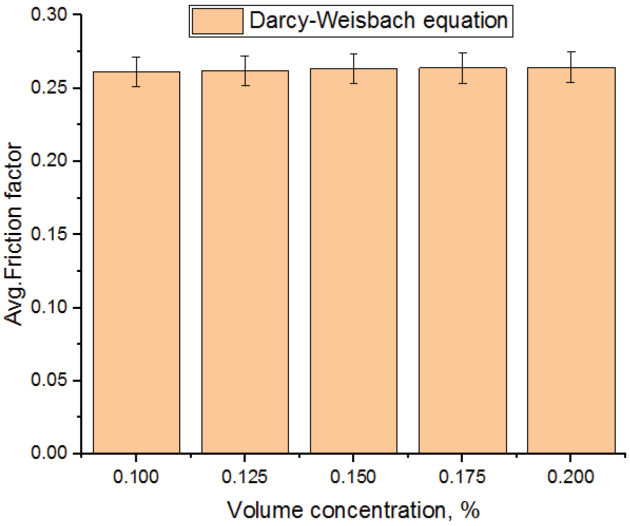

Figure 13. Effect of friction factor on volume concentration at various flow rates using Darcy-Weisbach equation.

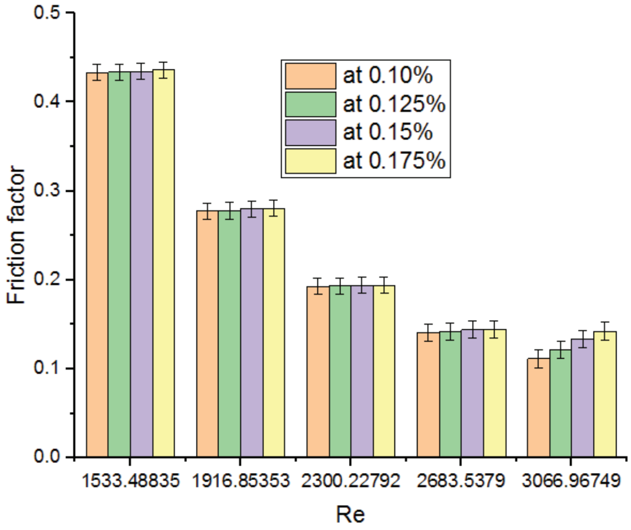

Figure 14. Effect of friction factor on various Reynolds number using Darcy-Weisbach equation.

friction among fluid particles which reduces the pumping power. The friction factor is increased as volume concentration increases and decreases as increasing of Reynolds number can be shown in Figure 14.

$$\Delta P = \left(\frac{L}{D}\right) \cdot \left(\frac{\rho V^2}{2}\right) . f \qquad (19)$$

Where L, D are Length and diameter of pipe in meter, V= velocity of fluid in m/sec, ρ = density of fluid in kg/m^2, f = friction factor, ΔP = pressure drop in pascals

In fluid mechanics, Darcy–Weisbach equation (19) is used to determine the pressure loss or loss of head and friction factor along a length of pipe during the fluid flow. In this study, friction factor has been calculated using Darcy–Weisbach equation. Meanwhile, pressure drop occurred across the length of the pipe measured directly with the help of calibrated pressure measuring device. Figure 14 illustrates the friction factor versus Reynolds number of Al_2O_3-nanofluid at volume concentration of 0.10-0.175%. When "Re" increases due fluids velocity causes the friction factor decrease. The maximum friction factor was recorded as 0.050 at a Reynolds number of 1630.

Effect of Volume Concentration on Performance Index and Loop Efficiency of Heat Exchanger

To measure performance of test rig, it is necessary to assess and evaluate the performance and efficiency of heat exchanger using Al_2O_3-nanofluid as a coolant. Performance evaluation is a major important parameter of heat exchangers which improves the life of heat exchangers using Al_2O_3-nanofluid at various volume concentrations. By using the volume concentrations at 0.10-0.175% performance and efficiency of the heat exchanger increased due to the higher thermal conductivity and heat transfer coefficients of nanofluids than baseline water. Figure 15 shows the variation of the performance index with the volume concentration of Al_2O_3-nanofluid in both directions at various flow rates. From Figure 16, it is revealed that the performance index and Loop efficiency were increased due to the addition of nanoparticles in the baseline water. A higher performance index indicates greater thermal efficiency of nanofluid. It is shown from the Figure 15 that the performance indices of Al_2O_3-nanofluids are greater than 1 indicating that Al_2O_3-nanofluid has a higher heat transfer coefficient than baseline water. Counter flow heat exchangers showed a good performance index than parallel flow heat exchangers at various flow rates because in counter

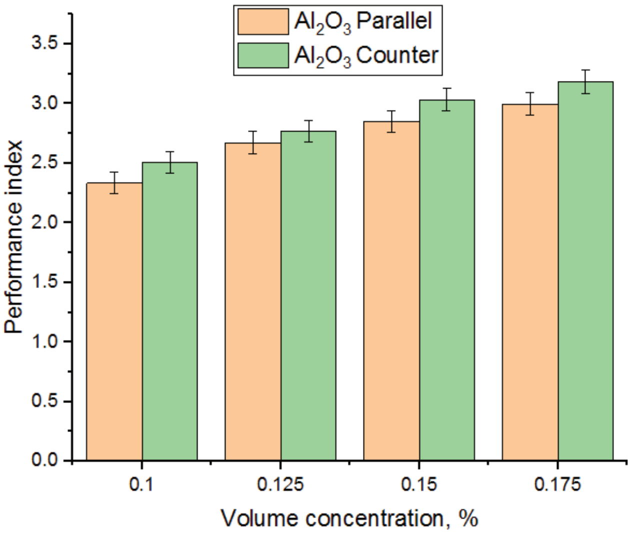

Figure 15. Effect of performance index on volume concentration at various flow rates.

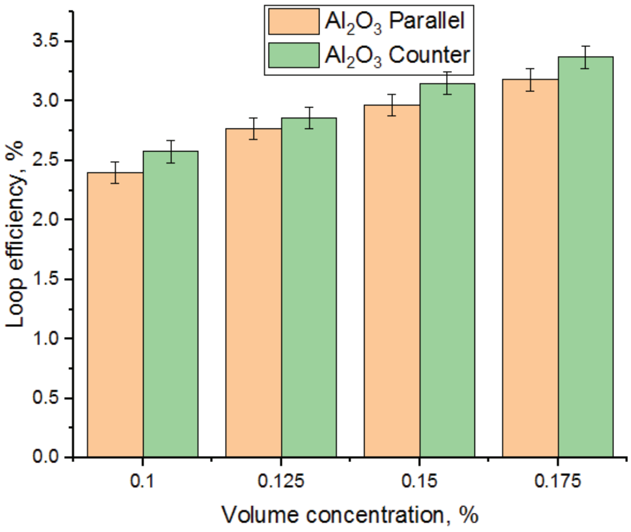

Figure 16. Effect of loop efficiency on volume concentration at various flow rates.

flow direction uniform and continuous temperatures are maintained across the heat exchanger. The performance index and loop efficiency of heat exchanger using Al_2O_3-nanofluid were measured using equations (14) and (15).

CONCLUSION

This study concluded that using small size 20 nm Al_2O_3 nanoparticles 0.10% to 0.175% by volume concentration at Reynolds number ranging from 1700 to 3400 resulted higher heat transfer coefficient, Nusselt number and friction factors compared to baseline water. This improvement seems higher density and best thermal conductivity for Al_2O_3-nanofluid compared to baseline water. Major findings of this research are summarized as follows:

The addition of 0.10% to 0.175% volume concentration of Al_2O_3 nanoparticle in the baseline water revealed higher density and viscosity for Al_2O_{3-}nanofluid. A superb enhancement in density was achieved of nanofluid 1022 kg/m3 at 0.175% volume concentration accompanied by a maximum enhancement of 2.2%. Additionally, maximum enhancement of 13.92% in viscosity was observed at 0.175% volume concentration. The thermal conductivity of Al_2O_3-nanofluid exhibited an increase from 0.61 to 0.67 W/m.K at various operating inlet temperatures 30-45°C when Al_2O_3 nanoparticles mixed in the baseline water. A remarkable enhancement i.e. 21.6% in thermal conductivity of nanofluid was observed by the addition of 0.175% volume concentration in the baseline water. An Approximate enhancement of 140% to 155% in average HTC was observed in parallel and counter flow directions upon adding 0.175% Al_2O_3 nanoparticles in the baseline water. This enhancement was observed due to the higher thermal conductivity of Al_2O_3 than water. Furthermore, it was noted that inclusion of 0.175% Al_2O_3 nanoparticle in the baseline water increased friction factor i.e. 2.81% than baseline water due to their higher density Al_2O_3-nanofluid than water.

The experimental and theroritical Nusslet numbers showed the least deviation of ±10%. Boundary conditions for Nusslet numebr are ranged from 40 to 110, attaributing highest accuracy and low discripency between theoritical and experomental values. It is thus obviously say that, correlation Gryta et al. (1997) exhibited low deviation compared to Acharya et al. (1992, 2001) and others. Further more, the performance index for Al_2O_3-nanofluid exhibited greater value than 1, signifying higher HTC. In counter flow HX, Al_2O_3-nanofluid at 0.10-0.175% volume concentration showed remarkable performance index ranging from 2.5 to 3.18. Moreover, an approximately 5.94% increase in efficiency was observed in counter flow direction at 0.175% Al_2O_3-nanofluid concentration. Thus increase in pressure drop and pumping power occurs in counter flow direction compared to the parallel flow direction.

Thus the results strongly suggest that Al_2O_{3-}nanofluid at 0.175% volume concentration functioned well as a working fluid for industrial requirement compared to the conventional baseline water. This enhancement in results was done due to the higher performance index and efficiency than baseline water. So, Al_2O_{3-}nanofluid can be preferred more in heat exchangers, solar collector, refrigeration, heating and cooling equipment's.

Limitations and Future Scope

The present study lacks in small pumping power consumptions. The pumping power in watt is required to transfer/move hydraulic oil ISO VG 68 and nanofluid at various flow rates on double pipe heat exchanger. This research is based upon an experimental study; only 0.175% volume concentration of aluminum oxide nanoparticle showed/produced good results for heat transfer rate so this is limitation of this study. Above addition of 0.175% volume concentrations of nanoparticle in the baseline water showed higher pressure drop and pumping power on HX pipe. Thus enhancement in pumping power and pressure drop across the heat exchanger pipe may cause serious problem and offering more consumption of power. Therefore, 0.175% volume concentration has s sufficient power consumption to sustain the load. This is a big challenge and scope of this study that may be faced during utilization of nanofluid. In future, hybrid nanofluid i.e. mixing of aluminum and zinc oxide may be mixed in the baseline water to enhance scope of heat transfer enhancement compared to the present study.

NOMENCLATURE

NP	Nanoparticle
NF	Nanofluid
HX	Heat exchanger
Al_2O_3	Aluminium oxide
nm	Nanometer
LPM	Liter per minute
GPM	Gram per minute
BV	Ball valve
GV	Gate valve
W_p	Weight of particle
ρ_{bf}	Density of base fluid
TCR	Thermal conductivity ratio
ISO VG	International standard organization viscosity grade
f	Friction factor
h_{bf}	convective heat transfer coefficient of base fluid
K	Thermal conductivity
°C	Degree Celsius
EG	Ethylene glycol
ή	Loop efficiency
Re	Reynolds number
T_{h1}	Temperature of hot fluid at inlet
T_{h2}	Temperature of hot fluid at outlet
T_{c1}	Temperature of cold fluid at inlet
T_{c2}	Temperature of cold fluid at outlet

CuO	Copper oxide
HTC	Heat transfer coefficient
Avg.	Average
Nu	Nusselt number
C_p	Specific heat capacity
T_w	Wall temperature
μ_{bf}	Dynamic viscosity of base fluid
T_b	Bulk temperature
Pr	Prandlt Number
ΔP_{nf}	Pressure drop of nanofluid
DW	Distilled water
φ	Volume concentration
έ	Performance index

AUTHORSHIP CONTRIBUTIONS

Authors equally contributed to this work.

DATA AVAILABILITY STATEMENT

The authors confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

CONFLICT OF INTEREST

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

ETHICS

There are no ethical issues with the publication of this manuscript.

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