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THERMAL ANALYSIS AND PERFORMANCE CHARACTERISTICS OF DOUBLE PIPE HEAT EXCHANGER USING ALUMINIUM OXIDE AL_2O_3 AND IRON OXIDE FE_2O_3 NANOFLUID

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ABSTRACT

Heat exchangers are widely used in industrial applications. The aim of this study was to investigate the thermal conductivity, heat transfer coefficient, Nusselt number, and Reynolds number of baseline water, Fe_2O_3, and Al_2O_3 nanofluids at different volume concentrations and flow rates using a double-pipe heat exchanger. The results were compared between baseline water and the two nanofluids. The test rig was operated at a temperature of 60 °C, suitable for industrial applications. Experiments were conducted at flow rates ranging from 1 to 2 L/min, corresponding to Reynolds numbers between 1500 and 3400, with volume concentrations from 0.10% to 0.175%.

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The study showed that increasing the nanoparticle volume concentration enhanced the density, viscosity, thermal conductivity, heat transfer rate, and convective heat transfer coefficient of the Nano fluids at different flow rates. The density and viscosity of Al_2O_3 and Fe_2O_3 Nano fluids increased by 2.2%, 3.32% and 13.92%, 25.5%, respectively, compared to baseline water. The average heat transfer coefficient improved by approximately 28% to 37% in counter-flow configuration when using iron oxide and aluminum oxide nanofluids. This improvement is attributed to the higher thermal conductivity of Al_2O_3 compared to Fe_2O_3 nanofluid and water. The results suggest that Al_2O_3 nanofluid at 0.175% concentration can perform more effectively as a working fluid than Fe_2O_3 nanofluid and conventional water for industrial applications.

Keywords: Heat Transfer, Heat Exchanger, Nano Fluid, Nano Particle, Convective Heat Transfer Coefficient

Introduction

Different nanoparticles are used now a day for enhancing various thermal properties of nanofluid like heat transfer rate and thermal conductivity. These are directly applied in car radiators and for temperature control in electronic devices. Therefore, heat transfer enhancement is a very important area in thermal engineering. Several techniques have been considered to improve the heat transfer coefficient between the working fluids and the fluid contact surfaces. Heat transfer plays a vital important role in the fields of engineering, science and industries e.g. oil and gas, electrical, food and nuclear, automotive industries, etc. Among various industries like automotive industries is one of the world's most important economic sectors by revenue and has a special impact on the other industries. Growing highly efficient engines for automotive industries is one of the most important goals in automotive industries [1-3].

Nanoparticle is a nanosized solid particle consists of metal and their oxides to be mixed in the baseline water for enhancing the various properties of nanofluid which leads to improve thermal conductivity and better heat transfer characteristics [4].

The effect of size of nanoparticle

The size and dimension of nanoparticles plays vital important role on the physiochemical properties of nanoparticles. Whenever the size changes, the atom and other structure of nanoparticles changes The thermal conductivity of Al_2O_3-nanofluid at various concentrations increases due to the smaller particle size. This is due to larger surface to volume ratio of a small size particle (20nm) which is compared with larger size particle (80nm) [5].

YD Kokate et.al revealed the effects of nanoparticle size on thermal conductivity. As particle size varied of mean diameter 15 nm and 60 nm, their thermal conductivities approximately decreased from 22% to 17% [6].

Applications of nanoparticles

Aluminium oxide (Al_2O_3) nanoparticles have wide applications in the field of industries i.e Biomedical, pharmaceutical, manufacturing and material industries because of their good thermal behaviour, characteristics and durability at high

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operating temperatures. Aluminium oxide (Al_2O_3) nanoparticle is obtained by several methods like sputtering, pyrolysis and laser ablation techniques. Nanoparticles are more stable when dispersed in fluids and tend to improve on the thermal properties of the fluids. Ali N et.al reveals and focuses on various characteristics like stability and performance of nanofluids [7].

Literature Review

Krishna VM et.al reflects that heat can be removed easily from electronic heat transfer equipment using water, Al_2O_3-water, and TiO_2-water nanofluids as working fluids [8]. The researchers investigated the performance parameters like heat transfer and thermal conductivity [9]. Kaggwa A et.al Focused to investigate experimentally the effects of two different nanofluids, Cuo and Al_2O_3-nanofluoid passing through double pipe heat exchanger at different flow rates and volume concentrations [10]. The author showed that by using nanofluids in heat exchanger increase the heat transfer characteristics. Using these nanofluids, the cost and size of heat exchanger saved [11]. In this previous experimentally study, the authors investigated the effects of nano sized particle and showed that Reynolds Number and Nusselt Number were increased using 0.25-0.5% volume concentrations in the turbulent flow regime [12]. In this research, the author focused on future recommendation of nanofluids in the various fields of engineering and gives trends of nanofluid in various heat transfer devices and found various challenging for preparation, obtaining and applications of various nanofluids [13]. In this study, experimentally investigation was done on double pipe, plate type and shell type heat exchanger using Al_2O_3 nanofluid at 0.2, 0.5 and 1% volume concentrations and found that double pipe heat exchanger offers best performance for enhance the heat transfer coefficients than other types of heat exchanger [14]. In this experimental research, overall heat transfer coefficient effects on change in mass flow rate, temperature and weight concentrations and found that 1% Al_2O_3/CuO nanofluid shows best performance than other nanofluid [15]. Mohammad Hosein Barzegar et.al reveals that overall heat transfer coefficient was found experimentally on the double pipe heat exchanger using hybrid nanofluid as coolant. These effects were calculated at different temperature, mass flow rate and concentrations and found good results on this heat exchanger [16]. Amarinder, Sharma et.al experimentally investigated the overall thermal efficiency on single and multipass heat exchangers using aluminium oxide nanofluid and heat transfer enhancement was increased up to 12.64% [17]. Jama and Singh showed that nanofluid is a binary mixture of solid particles and liquid water which enhances the thermal properties of nanofluid specially heat transfer rate and thermal conductivity also [18]. Kafel Azeez et.al revealed and studied numerically about the pressure drop and heat transfer coefficient enhancement for the volume concentration of 1 to 4% using Al_2O_3 nanofluid [19]. Suveg Singh et.al investigated that aluminium and its oxide nanoparticles deposited in the distilled water for superb the thermal behaviour of nanofluid than ordinary fluid and found that thermal conductivity and heat transfer coefficient enhanced more than ordinary distilled water [20]. Reza Aghayari et.al investigated heat transfer rate and overall heat transfer coefficient at volume fraction of 0.001-0.002 and result showed that 8-10% heat transfer rate improved [21]. M. Tajik et.al found that value of thermal conductivity increased up than base fluid and

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investigated thermal performance parameters for cu-nanofluid and al-nanofluid [22]. Ali Habeeb Askar et.al's focused on stability and enhancement 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 [23]. Amin Asadi's aim was to select such a hybrid nanoparticles contain zinc oxide to enhance the heat transfer effectiveness at various concentrations i.e 0.125-1% [24]. Omer A. Alawi et.al showed numerically performance of turbulent flow to estimate the thermal behaviour using various nano sized materials like copper oxide, aluminium oxide, silicon di oxide and zinc oxide [25]. Kunal Koushal Dew and Pankaj Shrivastava calculated various effects by using different nano oxide metals as nanofluid like aluminium oxide, iron oxide and copper oxide and found that copper oxide played a higher role than other nanofluids [26]. Jaafar Albadr et.al showed his keen interested towards various flowing characteristics and heat transfer coefficient using aluminium oxide nanofluid and such investigation was done on double pipe and shell type heat exchangers at different weight concentrations [27]. Mohsen Tahmasebi Sulgani et.al studied on various Nano sized hybrid particles i.e iron oxide and such hybrid particles were filled in the oil for cooling purpose and investigated their hybrid effects at various concentrations [28]. M. Akhtari et.al measured experimental effects of aluminium oxide nanofluid moving in double pipe and shell type heat exchangers under laminar flow conditions and found that the overall performance of shell type heat exchanger is higher than double pipe heat exchanger [29].
Following table 1 shows Thermo-physical properties of aluminium oxide (Al_2O_3) and Iron oxide (Fe_2O_3) nanoparticle.

Table.1: Thermo-physical properties of nanoparticles [30]

Properties	**Aluminum oxide (Al_2O_3)**	**Iron oxide (Fe_2O_3)**
Density (kg/m3)	3900	8800
Thermal Conductivity (W/m.K)	39	7
Specific heat Capacity (J/kgK)	765	104
Appearance	White powder	Reddish brown

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A research study was conducted to analyse the performance of double pipe heat exchanger using baseline water, Al_2O_3 nanofluid and Fe_2O_3 nanofluid at different volume concentrations and flow rates. Such analysis was done using Al_2O_3 nanofluid and Fe_2O_3 nanofluid as a working fluid and moved in test rig for operation and found that the thermal conductivity of these nanoparticles was higher than baseline water. The nanofluid was prepared and stirred by Hot plate Mechanical stirrer for about 2 hours to ensure the proper dispersion before using in test section. In this study ISO VG 64 Hydraulic oil was used as hot fluid to carry out heat from the cold nanofluids.

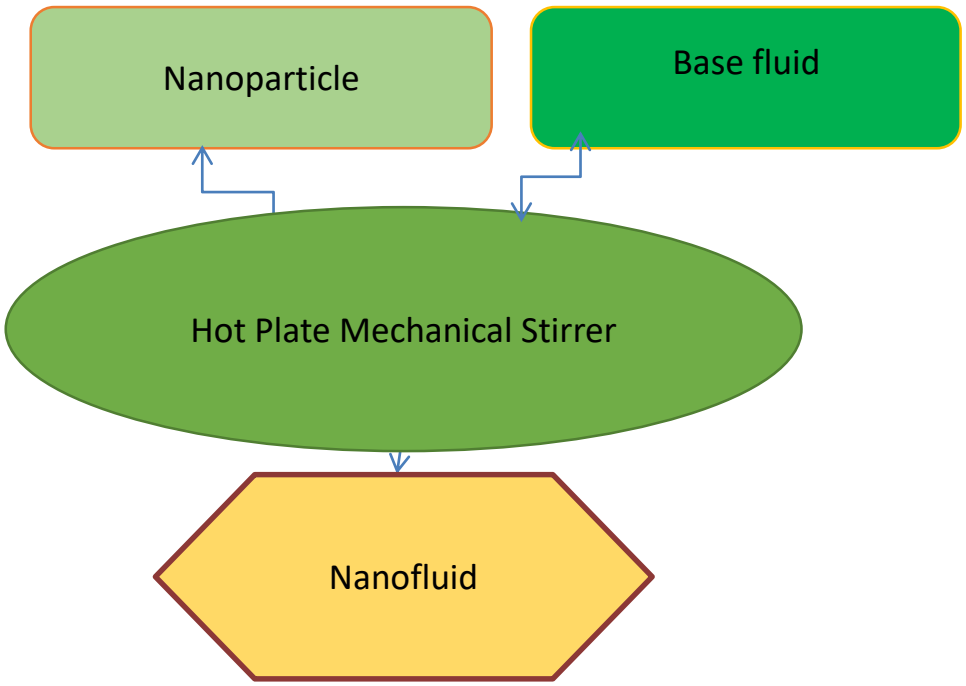
Materials and methods

Nano fluid was produced by suspending aluminium oxide (Al_2O_3) and iron oxide (Fe_2O_3) nanoparticles with particle size 20nm, 30mm in the baseline water in a range of 0.100, 0.125, 0.150, and 0.175% by volume concentration. Moreover, when solid particles with high thermal conductivity were added in the base line water, the overall thermal conductivity and heat transfer rate were improved [31]. These nanoparticles in dry powder form with an average particle size of 20nm, 30mm were mixed in baseline water according to the following standard method:

$$\phi = \left(\frac{wp}{\rho p}\right) / \left(\frac{wp}{\rho p}\right) + \left(\frac{wbf}{\rho bf}\right) \times 100 \quad (1)$$

Where ρp, ρbf = density of nanoparticle and base fluid (kg/m^3), Wbf=weight of base fluid (litters), Wp=weight of nanoparticle (kg).

Nano fluid was prepared through Two-step method using suspending Al_2O_{3-} and Fe_2O_3 nanoparticles in a range of 0.10-0.175% by volume concentration in the baseline water and is shown in figure 1.



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Firstly, nanoparticles with their particular sizes (nm) were purchased in dry powder form and subsequently mixed in base fluid through hot plate mechanical stirrer and thus nanofluid solution formed according to the two step method given in in figure 1.

Stability of nanofluid and Experimental setup

Stabilization process is used to break down the possible agglomeration of the nanoparticles into the baseline water to achieve a superb suspension. Hot plate stirrer method was employed for two hours continuously to mix the nanoparticles smoothly into the base line water. In this way, it is expected to have a long-time stable nanofluid for at least 24 hours. In this study, hot plate agitator was employed for good stability of nanofluid. In this research, Al_2O_3- NF and Fe_2O_3 NF were obtained/formed using two step method. These Nano fluids were checked by keeping NF solution in jars for 24 hrs. [32]. Thermal properties and structures of aluminium oxide Al_2O_3 and iron oxide Fe_2O_3 nanoparticles can be checked using chemical, electro chemical, X-ray diffraction, atomic emission spectroscopy and thermal analysis methods [33]. Figure 2 is the experimental test rig shows the complete operation and the ways through which both fluids move.

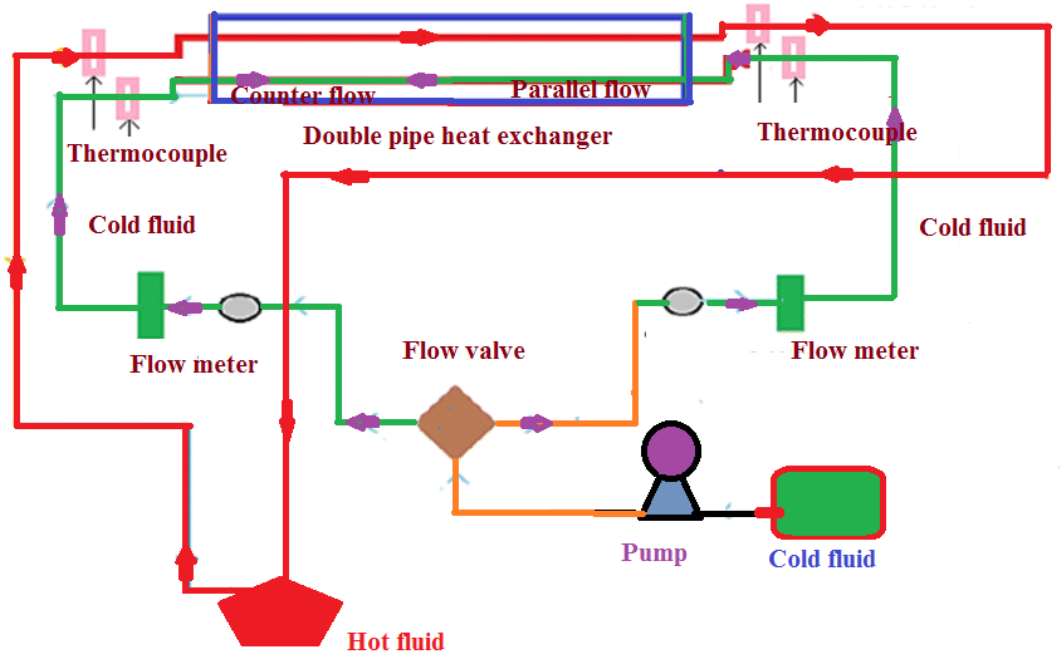

Figure 2 Schematic diagram of test rig

Experimental work was conducted on double pipe heat exchanger and placed in laboratory of heat and mass transfer. The test section comprises two concentric tubes, one contains hot fluid and second cold fluid and both fluids are moving in counter direction. Hot and cold fluids were moved through pumps and controlled through ball

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and gate valves and thus both fluids moved either in parallel direction or counter flow direction is shown is figure 2.

Experimental test rig consists of one oil storage tank with oil pump, one gate vale and one ball valve for controlling the hot and cold fluids. The test section having 0.91m length of pipe made of copper material with inner and outer 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 in the inlet and outlet of the hot and cold fluid pipes for measuring the temperature.

The cold fluid i.e. aluminium oxide-nanofluid or iron oxide- nanofluid and baseline water were moved towards double pipe heat exchanger for further experimental capabilities. Thus, the hot hydraulic oil ISO VG 68 was heated at required operating condition. At the end of experimental capabilities, few oil and nanofluid samples were collected to analyse the efficiency of double pipe heat exchanger. At the same time, some performance parameters like flow rate, wall temperature of test rig, inlet and outlet temperatures of hot and cold fluids were measured separately. The highly calibrated instruments and devices were used to measure viscosity, density and Thermal conductivity of oil and nanofluid.

Data acquisition and calculation

The experimental data were collected after running period of test rig and thus used to calculate various thermo physical properties of nanofluid i.e overall heat transfer coefficient , heat transfer rate , heat flux, Nusselt Number, Reynolds Number at varying volume concentration. Thermal properties are calculated using wall temperature and bulk average temperature. The thermal performance of Nano fluid is analysed through following equations,

Parameter	Symbol	Formula
Heat transfer rate	Qe	$\dot{m}\ Cp(To - Ti)$
Heat flux	q''	$Q/\pi\ DL\ (W/m^2)$
Nusselt number,	Nu	$\frac{hD}{k}$
Heat transfer coefficient	h	$\frac{q}{T_w - T_b}$
Friction factor	f	$0.316/(Re)¼$
Blasius formula	f(th)	$(100.\,Re) - ¼$
Filonenko model	f(th)	$\ln.\,Re.\,0.790 - 1.64$
Reynolds Number	Re	$\frac{\rho VD}{\mu}$
Pumping power ratio	P.P	$\frac{W_{nf}}{W_{bf}} = \left(\frac{\mu_{nf}}{\mu_{bf}}\right)^{0.25}\left(\frac{\rho_{bf}}{\rho_{nf}}\right)^{2}$
Specific heat capacity of nanofluids	Cnf	$\varphi Cp\ + (1 - \varphi)Cf$
Pumping power	P	$V\dot{}\Delta P$

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Results and discussion

Effect of volume concentration on Density and Viscosity of Fe_2O_3 and Al_2O_3-nanofluid

The density and viscosity of Fe_2O_3 and Al_2O_3-nanofluid at various volume concentrations are shown in figure 3 and 4.

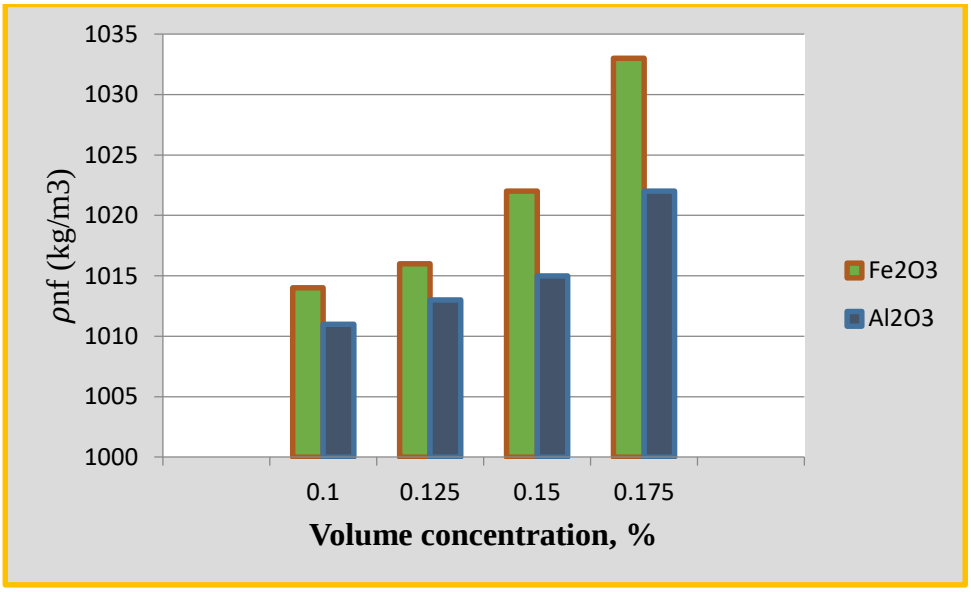

Figure 3 Density of Fe_2O_3 and Al_2O_3-nanofluid at various concentrations

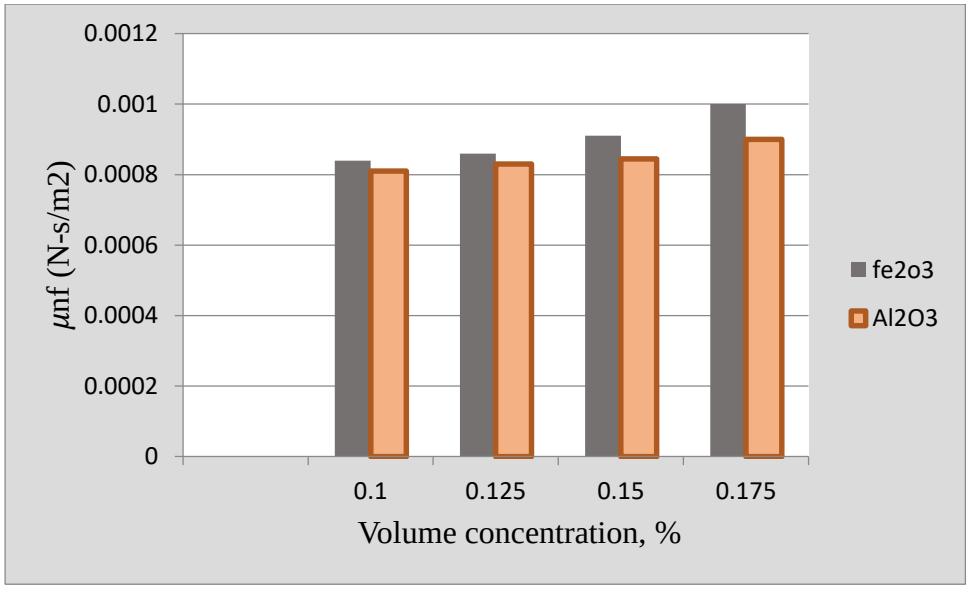

Figure 4 Viscosity of Fe_2O_3 and Al_2O_3-nanofluid at various concentrations

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Density and viscosity of nanofluids plays vital important role in heat transfer fields. More dense fluid imparts more pressure inside tubes but on heating of nanofluid particles expansion take place. Viscosity of nanofluid 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. When Al_2O_3 and Fe_2O_3 nanoparticles were added in the baseline water in the range of 0.10-0.175% , its density and dynamic viscosity increased than baseline water. The enhancement in density and viscosity for Al_2O_3 and Fe_2O_3 nanofluid is measured by 2.2%, 3.32% and 13.92%, 25.5% than baseline water considering at 0.175% volume concentration. The enhancement in density and viscosity for Al_2O_3 and Fe_2O_3 is shown in figure 3, 4.

Effect of Reynolds's Number and Nusselt Number on Heat transfer coefficient

Heat transfer by convection is dramatically affected by the state of the fluid flow. Reynolds number is a measure of the state of flow, in particular, laminar to turbulent. Nusselt number is the ratio of the actual heat flow to what it would be by pure conduction. Convection is more effective than conduction so increasingly agitated fluid temperature and velocity, the heat transfer rate goes up and the Nusselt number increases. It is thus fairly obvious that the Nusselt number is going to be related to the Reynolds number. As shown in given figure 5, good agreement takes place between experimental and predicted values.

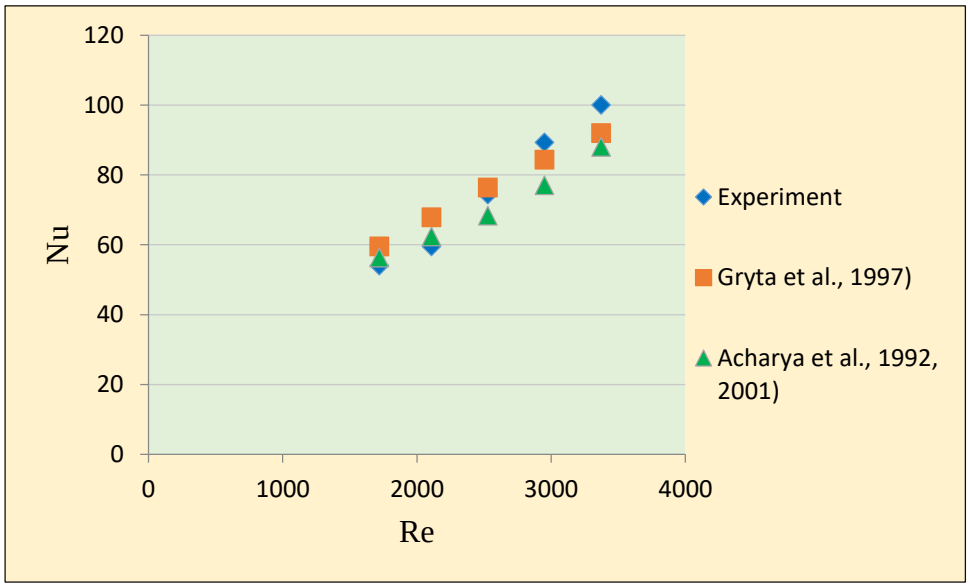

Figure 5. Comparison of experimental and predicted values of Nusselt Number for basefluid and nanofluid

It can be seen from figure 5 that Nusselt number for iron oxide and aluminium oxide under certain values of Reynolds number is higher than basefluid. The validiation of results is a major parameter to check the results using various euations. In this study, experimentally investigagtion of thermo physivcally properties were done at all cases. Nusselt number was found to be increased as Reynolds number increased up

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because of increasing thermal conductivity and heat transfer rates of nanofluid than basline water. The emprical correlation for Nusselt number is shown in figure 5. 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 in volume concentration of Al_2O_3 and Fe_2O_3 Nano particles 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 5 showed the less discripency and highest accuracy of correlation with experomental work. It is thus obviously clear that, correlation gryta et al. (1997) showed the least deviation than corelation of acharya et.al. (1992, 2001).

Following correlations were used for differentiating the errors in Nusselt number.

Sr #	Nusselt number	Correlation
1	Nu	0.298Re^0.646 Pr^0.316
2	Nu	0.1381Re^0.75 Pr^0.33

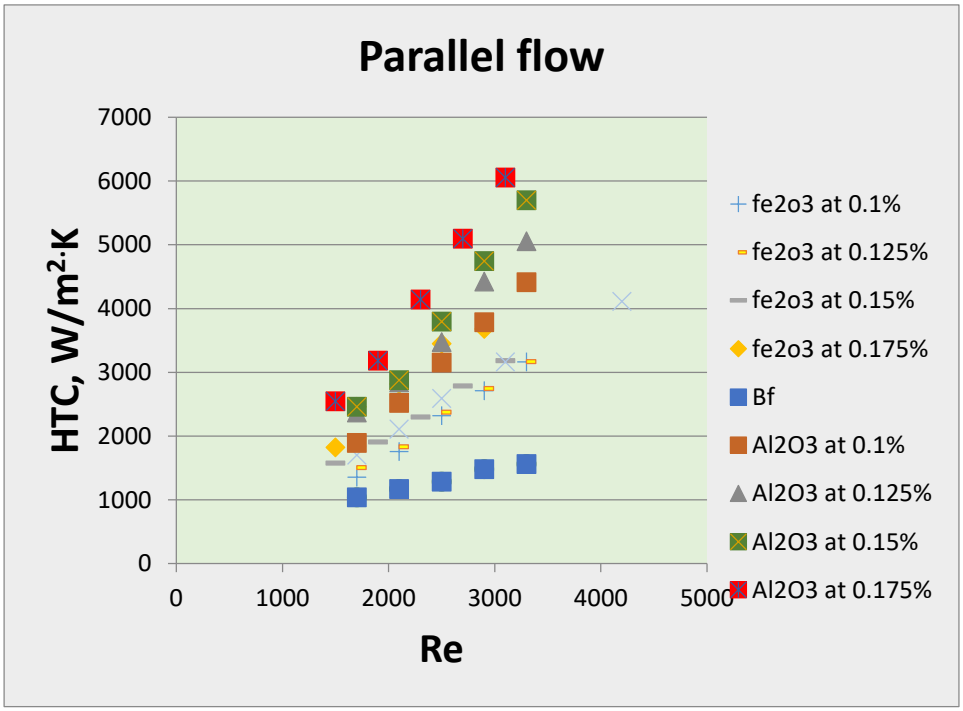

Figure 6. Effect heat transfer coefficient on Reynolds Number in parallel flow

Comparison of convective heat transfer coeffcient for basefluid and nanofluid shows that the convective heat transfer coefficient for nanofluids is higher than basefluid at same Reynolds's Number. Figure 6 and 7 indicates that heat transfer coeffcient for nanofluid is higher due to the higher themal conductivity of nanofluids and thermal boudary layer. This may leads to increase brownian motion of nanofluids particles which resulted from amorphous and chatic motion of nanoparticles in the base fluid.

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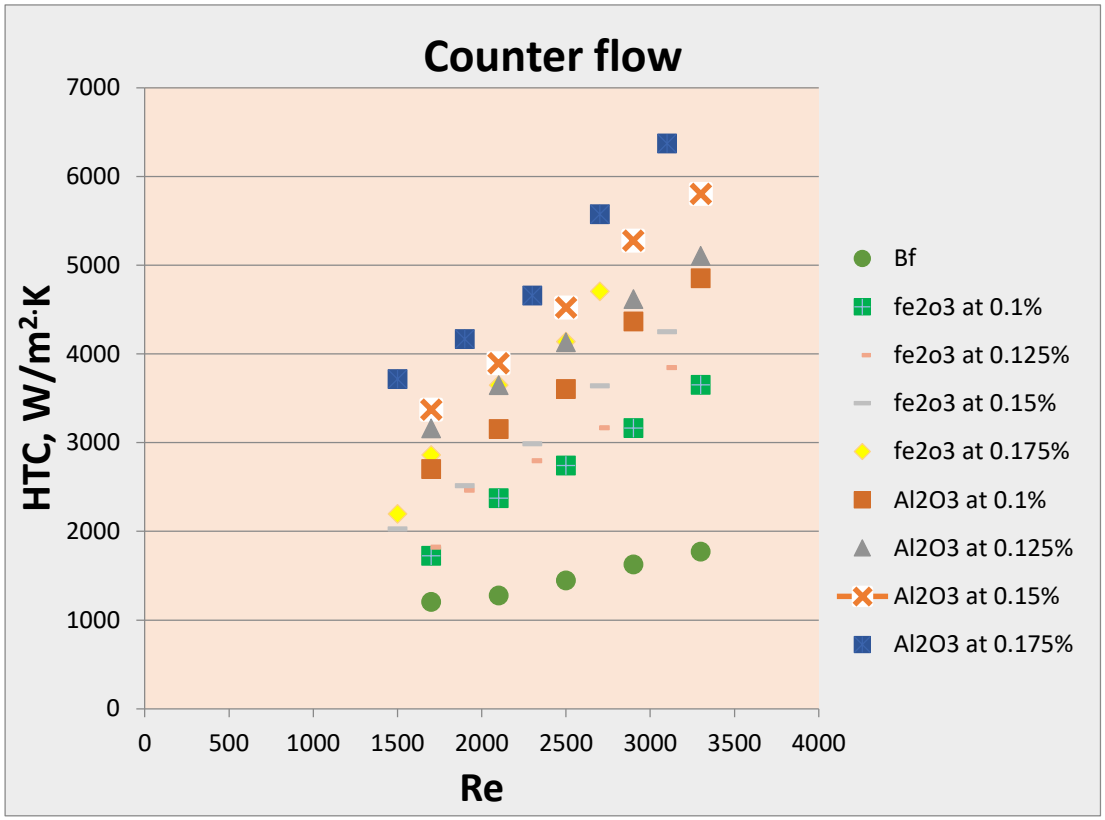

Figure 7. Effect heat transfer coefficient on Reynolds Number in counter flow

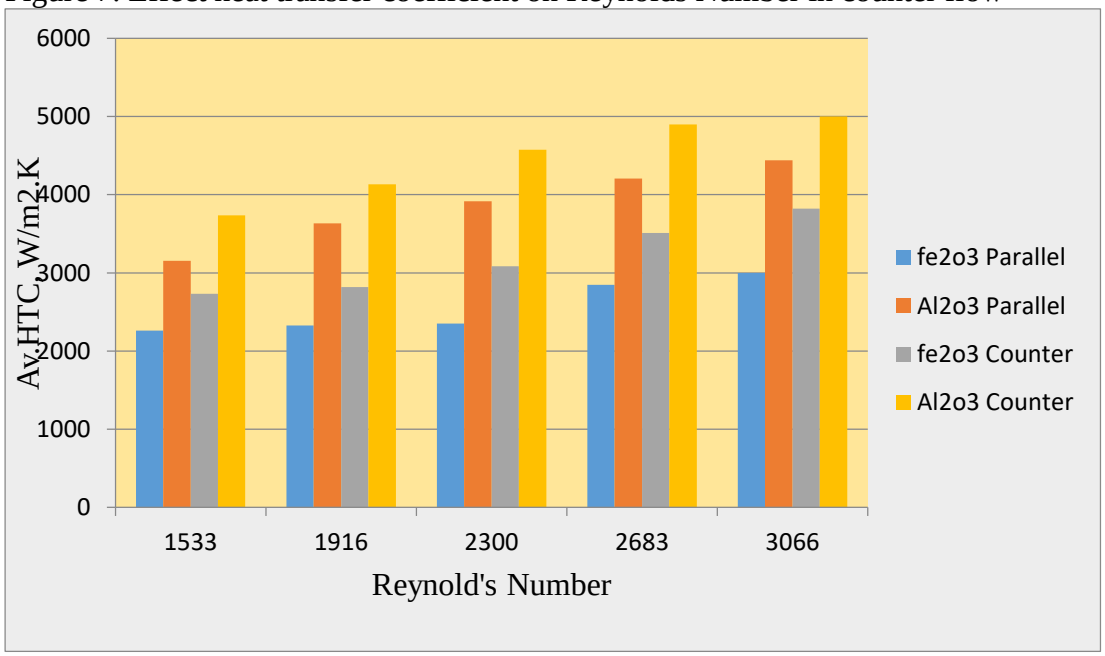

Figure 8. Effect heat transfer coefficient on Reynolds Number in both flows

Convective heat transfer coeffcient of nanofluid maunly depends upon the various factors viz. density, viscosity, thermal conductivity, temperature distribution across

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heat exchanges, velocity, discharge of nanofluid and thickness of boundary layer. From figure 6-8, it indicateds that as values of Reynolds Number increased up from 1330 to 3350, the values of Convective heat transfer coeffcient for both nanodluids incresed up from 6000 W/m^2.K to 6500 W/m^2.K when nanofluids were moved in parallel and counter flow directions. From figure6 and 7, it is clearly shown that Al_2O_3 nanofluid imparts more performance in terms of convective heat transfer coeffcient than Fe_2O_3 nanofluid when moved through counter flow direction. Figure 8 shows the effect of average heat transfer coefficient of nanofluid on Reynolds Number in both flows. It is clearly shown from figure 8 that by increasing Reynolds Number (1533 to 3066) and velocity of fluid, average heat transfer coefficient was increased from 3822-5000 W/m^2.K using Fe_2O_3 and Al_2O_3 nanofluids in both parallel and counter flow directions.

Effect of heat transfer coefficient on volme concentration

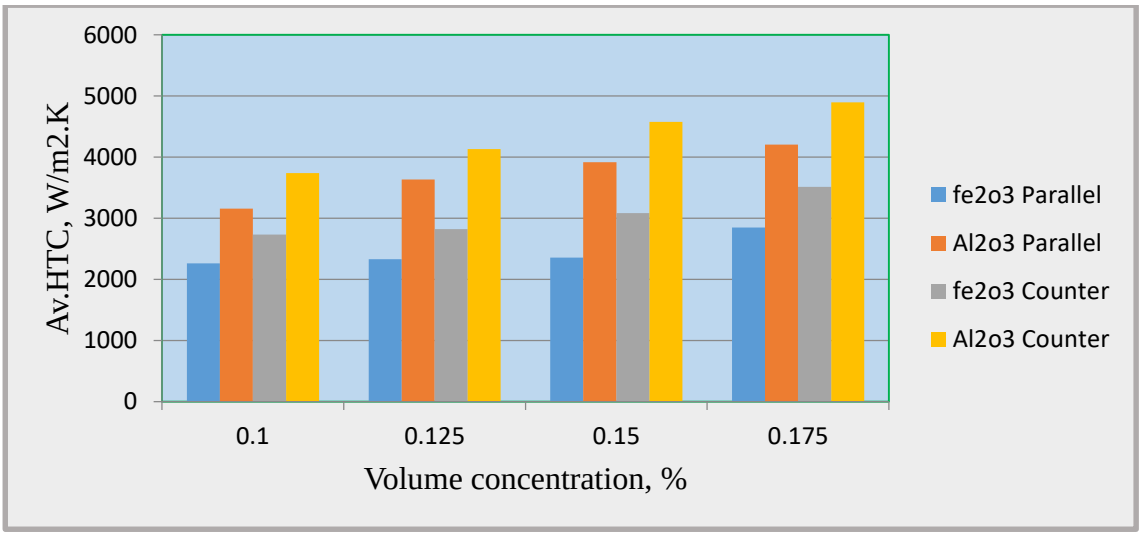

Figure 9. Effect of heat transfer coefficient on volme concentration in parallel and counter flows at various flow rates

The influence of volume concentration in baseline water has major role on heat transfer coefficient. As volume concentration is increased which results in improving thermal properties of nano fluid. The mixing of Al_2O_3 and Fe_2O_3 nanoparticles in baseline water enhanced the heat transfer coefficient due to the increasing thermal conductivity of nanoparticles. It is also shown from figure 9 that average heat transfer coefficients for Al_2O_3 and Fe_2O_3 nanofluds were measured from 4200 to 4950 W/m^2.K and 2850 to 3500 W/m^2.K in both parallel and counter flow direction using 0.175% nanoparticle in the baseline water. Meanwhile, counter flow direction having better performance than parallel flow arrangements for Al_2O_3 NF because in counter flow direction, more difference of temperature maintained between hot and cold fluid. Moreover, It was observed that heat transfer coefficient (HTC) and Nusselt number was increased with increasing volume concentration of both nano particles in the baseline water. The use of nanoparticle in baseline water caused the enhancement of

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various thermal properties of nanofluid.

Conclusion

From experimental work, it is concluded that using Fe_2O_3 and Al_2O_3 nanoparticles at Reynolds number of 1500-3400 showed higher heat transfer rate and its coefficient than baseline water because Al_2O_3 nanofluid has higher thermal conductivity than Fe_2O_3 nanofluid baseline water. Major findings of this research work are summarized as follows:

It is seen that by adding 0.10 to 0.175% volume concentration of Fe_2O_3 and Al_2O_3 nanoparticles in the baseline water produced higher density and viscosity than base fluid. A superb enhancement of 1033 (kg/m3) was achieved at 0.175% volume concentration using Fe_2O_3 nanofluid. Moreover, for iron oxide maximum viscosity enhancement 11.1% was observed at 0.175% volume concentration than aluminium oxide. . Approximately 28% to 37% average heat transfer coefficient was improved in counter flow direction using Iron Oxide and Aluminium Oxide nanofluid in counter flow direction because thermal conductivity of Al_2O_3 is higher than Fe_2O_3 nanofluid and water..

The results suggest that Al_2O_3-nanofluid at 0.175% could function very well as s working fluid than Fe_2O_3 nanofluid and conventional baseline water for industrial requirements.

Nomenclature:

nf	nanofluid	HX	heat exchanger
Al_2O_3	aluminum oxide	BV	ball valve
GV	gate valve	Th1	temperature of hot fluid at inlet
Th2	temperature of hot fluid at outlet		
Tc1	temperature of cold fluid at inlet		
Tc2	temperature of cold fluid at outlet		

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