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Impact of Nanoparticles in Water Coolant on Heat Transfer Rate in Parallel and Counter Flow Heat Exchanger

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Abstract: A heat exchanger is a device used to transfer heat between two or more fluids. The fluids can be single or two phases depending on the exchanger type and may be separated by in -direct contact (the two most common kinds of heat exchanger are the shell-and-tube and plate/fin). In this research work double pipe heat exchanger was used to analyze the performance of water coolant for industrial applications. In Heat Exchanger the water coolant temperature increases due to increase in the temperature of oil in the tubes. Therefore, it may decrease the overall efficiency of the equipment resulting from degradation of the lubricant oil. In this regard, it is required some additives to be mixed with water coolant so that to enhance the heat transfer rate of the unit. Due to the excessive heating of the hydraulic oil in the turbine bearings, the material of the bearing found damage and deteriorate. Therefore, the aim of this study was to remove the heat from bearing oil, so that overall efficiency of heating equipment could be increased. In this research work Hydraulic oil was heated at 60^0C and 70^0C as per requirements of the industry. The experiments were conducted at both parallel and counter flow directions. Initially, a baseline experiment was carried out between hot oil and water coolant (without additives or nanoparticles). Besides the heat transfer rate between hot oil and water coolant with the additives (CuO and Al_2O_3) were observed at 1-3% proportion. It was concluded that the heat transfer rate of CuO was increased more than Al_2O_3 and plain water coolant due to more uniform temperature difference maintained between the inlet and outlet of cold and hot fluids due to the higher thermal conductivity of CuO. The maximum heat transfer rate was found to be 36.6 % at 60°C and 38% at 70°C with 3% of CuO additive in water coolant in the counter-flow condition.

Keywords: Heat Exchanger, Nanoparticles, Heat Transfer Rate

1. Introduction

A heat exchanger is a device designed to efficiently transfer or "exchange" heat from one matter to another. Nanofluid is a fluid mixing nanometer-sized particle, called nanoparticles. These fluids are engineered colloidal suspensions of nanoparticles in a base fluid. Nanoparticles which are commonly used in nanofluids are made from numerous materials such as oxide ceramics (Al_2O_3, CuO) [1]. Nanofluids are engineered colloids made of a base fluid and nanoparticles (1-100 nm). It

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has higher thermal conductivity and single-phase heat transfer coefficients than their base fluids [2]. Now a day's coolant (additives to liquid) is used in various engineering applications like in industrial processing applications, automotive, heat ventilation and air conditioned (HVAC) system. Moreover, to enhance the heat transfer performance, solid additives are suspended in the base liquids to change transport properties, flow, and heat transfer features of the liquids [3]. The well-dispersed CuO nanofluid with high volume fractions can be synthesized because it has a higher thermal conductivity than those prepared by the dispersing method [4].The inclusion of nanoparticles has increased considerably the heat transfer at the tube wall for both the laminar and turbulent regimes. Such improvement of heat transfer becomes more pronounced with the increase of the particle concentration [5]. The most common form of a coolant is water, which has vast engineering applications because it has higher heat capacity and heat transfer rate between the two fluids when two fluids flowing in a pipe. Whereas the Prandtl number, Reynolds number and Nusselt number are functions of thermo physical properties of nanofluids, and these numbers strongly influence the convective heat transfer coefficient [6]. The selection of an appropriate heat transfer fluid for heat dissipation is crucial consideration in designing heat exchangers. Heat transfer fluid (HTF) is one of the critical parameters as it affects the size and cost of heat exchanger systems [7]. The Nano fluid can be set up by scattering nanoparticles in ethylene glycol utilizing a sonicator and including surfactant, such nano fluid containing nanoparticles at various strong volume divisions (low to high) [8]. The change in overall heat transfer coefficient and the thermo hydraulic performance characteristics of a single pass multi tube cross flow heat exchanger was observed by [9] in which Al2O3 nanoparticles used in a binary mixture of water and 60: 40% b volume ethylene glycol [9]. In aqueous solution, with and without additives shows the dissimilarity between temperature difference, heat fluxes & heat transfer coefficient by the concentration of surfactant at 400-1200ppm [10]. A. Sivalingam and T. Balusamy [11] presented their review study to enhance the thermal conductivity and temperature differences between hot and cold fluids using various metallic and its oxides like copper, aluminum, copper oxide, aluminum oxide, silicon carbide, silver, iron and carbon nanotubes. These researchers found an enhancement in heat transfer characteristics due to the dispersion of various nanoparticles in the baseline water and showed optimum results compared to the base fluid. While present study focuses on enhancement in heat transfer characteristics due to the dispersing of two highly thermal conductive nanoparticles i.e. copper oxide CuO, aluminum oxide Al2O3 in the baseline water to see the impact of nanoparticles on thermal performance of heat exchanger. This present study has enhanced heat transfer rate by 36.6 - 38% at inlet temperature of 60℃ and 70℃. This enhancement is due to the higher temperature difference is maintained between hot and cold fluids at their inlet and outlet points. While previous studies failed to increase much more heat transfer rate using same type of nanoparticles. A. Sivalingam and T. Balusamy could enhance the heat transfer rate by 20 - 30% using aluminum oxide Al2O3 nanoparticle. Therefore, it is finally concluded and recommended that this present study is more preferable and profitable in various processing industries due to their good heat transfer rate, economical rate and best performances than other fluids.

Nanofluid is containing the nanosized particles exhibits remarkably enhancements in heat transfer rate. The aim of this study is to optimize the nanosized particles under variable particles concentrations. The stabled nanofluid is prepared using standard method for adoption of heat transfer rate. Thus stabled nanofluid is widely used in various engineering fields like biomedical engineering, processing equipment's, textile industry, automobile, refrigeration processes, solar collectors, electronic equipment's and heat exchangers. Furthermore, this paper is highlighted the wide applications and utilizations of nanofluid. Moreover, an addition of 3% of Al2O3 and CuO nanoparticle in the baseline improved the heat transfer rate from 36% to 38%, in counter flow direction. It is seen from results that nanofluids are found more profitable than baseline water at same flow rate. Thus the results suggest that CuO nanofluid at 3% could function very well as working fluid for industrial applications compared to the Al2O3 nanofluid and conventional baseline water.

1.1 Research objectives and Hypotheses of the study

The objective of this study is to enhance thermo-physical properties especially heat transfer rate using copper oxide CuO and aluminum oxide Al2O3 nanofluids. In this study, an experimental work was took place on double pipe heat exchanger using both parallel flow and counter flow directions. In this investigation, the main objective was to enhance the heat transfer rate from hot fluid to cold fluid. Under this investigation, heat was supposed more in case of counter flow directions. In previous investigations, the researchers only could found various thermo physical properties like heat transfer rate, Reynolds number, thermal conductivity, density and viscosity and other related parameters using either parallel flow or counter flow directions at various flow rates under laminar, transition and turbulent flow regimes. Some researchers have experimented on various types of heat exchangers like double pipe, plate type, shell and tube type using various nanofluids containing oxides of metals separately and found higher heat transfer rate between hot fluid and cold fluid. However, in this study, copper oxide and aluminum oxide were dispersed in the baseline water at volume concentration ranging from 1% to 3% and nanofluids. The hot fluid (Hydraulic oil) and cold fluid (CuO and Al2O3-nanofluid) were firstly stabilized under hot plat mechanical stirrer method and then moved towards double pipe heat exchanger selecting both parallel flow and counter flow directions. Under this study experimental investigation, hot oil was heated at 60 °C and 70 °C and than moved towards double pipe heat exchanger for further processes at various flow rates of 1- 2 liter prt minute. In addition to this, at the end of experimental capabilities, various properties like density, viscosity and thermal conductivity of nanofluids were measured through measuring instruments and reults were found that copper oxide CuO exhibited higher enhancement in heat transfer rate than aluminum oxide Al2O3 nanofluids at the same operating temperatures of 60 °C and 70 °C.

1.2 Choosing of specific concentrations and types of nanoparticles in this study

In this study, highly thermal conductive nanoparticles i.e. copper oxide CuO and aluminum oxide Al2O3 were selected due to their higher thermal and physical properties and thus these nanoparticles were dispersed in the baseline water at volume concentration ranging from 1% to 3% according to Ref. [12, 13]. This percentage of nanoparticles was mixed in the baseline water to see the heat transfer characteristics specially heat transfer rate. These nanoparticles i.e. copper oxide CuO and aluminum oxide Al2O3 were also selected due to their smaller sizes and higher stability than other nanoparticles. The thermal properties of copper oxide CuO and aluminum oxide Al2O3 are given in table 1.

Table 1- Thermal properties of copper oxide CuO and aluminum oxide Al2O3

Type of nanoparticle	Particle size in nm	Base fluid	Volume concentration, %	Enhancement in heat transfer rate
Aluminum oxide Al2O3	15	Water	1-3%	36%
Copper oxide CuO	50	Water	1-3%	38%

With the addition of 1-3% volume concentration of copper oxide CuO nanoparticles in baseline water, various thermal properties like density, viscosity, thermal conductive and specific heat were increased compared to the baseline water. This happened is due to the higher Brownian motion and thermal stability inside the heat exchanger pipes. Therefore, these nanoparticles i.e. copper oxide CuO and aluminum oxide Al2O3 were selected for this study due to their good thermal properties and smaller sizes (in nanometers). The stability of nanofluids plays an important role in enhancement of heat transfer rate. This smaller size of nanoparticles enhanced heat transfer rate and stability of nanofluids using hot plate mechanical stirrer method to superb the solution of nanofluid. However, smaller sizes of nanoparticles have greatly impact on Brownian motion and thermal stability. Therefore, high heat has been transferred between hot and cold fluids compared to the previous studies [13, 14].

1.3 Dispersion of nanoparticles in the baseline water to ensure reproducibility

The smaller sizes of aluminium oxide Al2O3 and copper oxide CuO nanoparticles were dispersed in the baseline water having their particle sizes of 15nm and 50mm. The following standard method was used to determine volume concentration of particle. Moreover, nanoparticles are mixed in the baseline water by volume concentration of 1% and 3%. However, dispersion of Al2O3 and CuO nanoparticles in the baseline showed higher stability of nanofluids which increased the heat transfer rate. Although, Al2O3 and CuO nanoparticles in dry powder form have been mixed in baseline water according to the following standard method [15].

$$\phi = \frac{\frac{w_p}{\rho_p}}{\frac{w_p}{\rho_p}+\frac{w_{bf}}{\rho_{bf}}} \tag{1}$$

Wp=weight of nanoparticle (kg)

ρp= density of nanoparticle (kg/m3)

Wbf=Weight of base fluid (kg)

ρbf= density of base fluid (kg/m3)

Highly stabilized nanofluids were feed towards double pipe heat exchanger for further processes and thus stability of nanofluid remained 24 hours. Highly stabilized nanofluid makes more heat transfer rate due to their higher Brownian motion.

1.4 Preparation and Stability of nanofluid

In this research, Al2O3 and CuO nanofluid was prepared using two-step method. In two step method, Al2O3 and CuO particles were dispersed and mixed in the baseline water under hot plate mechanical stirrer method. Under this method, nanofluid was continuously produced and heated by magnetic field produced inside the beaker to produce the well stable solution. This this process took place for 300 minutes than stabilized nanofluid was moved towards test rig for an experimental work The stability of Al2O3 and CuO nanofluid can be assessed through Sedimentation method. This a common technique used to check the stability of nanofluid. In sedimentation method, agglomeration and settling of nanoparticles over time was assessed to indicate stability and instability. After applying stabilization process by hot plate mechanical stirrer, the nanofluid was filled in the storage tank and can be moved towards test rig using water pump [16].

1.5 Selection of Nanoparticle

The selection of nanoparticle size in heat exchangers is a crucial parameter influencing the heat transfer rate and overall performance of the heat exchanger. The selection of nanoparticle based on following factors:

1. Surface Area: Prepared nanofluid is affected due to the surface area of particles (sizes) and shape (cylindrical, circular, trapezoidal, triangular etc.). Nanofluid is much affected due to the smaller and larger surface area. Nanofluid became well stabled due to the smaller surface area of the particles compared to the larger surface area due to the Brownian motion.

2. Availability in the market: These size of nanoparticles (15nm and 50mm) are easily available in the market and is more suitable for increasing various thermal properties of nanofluid".

1.6 Physical and chemical properties of the nanoparticles

Heat transfer rate is a crucial parameter used in various engineering fields especially heat transfer fields. The enhancement in heat transfer depends upon physical and chemical properties of the nanoparticles. The physical and chemical properties of the nanoparticles include their size, shape and surface area. These physical and chemical properties of the nanoparticles impact the heat transfer rate, efficiency and effectiveness of the heat exchanger. Thus the present experimental study investigates the effects of copper oxide CuO and aluminum oxide Al2O3 nanoparticles as well as influence of nanoparticles size and shape. Nanoparticles can be different sizes, structures and shapes. [12] They can be cylindrical, circular, spherical, trapezoidal, triangular etc. the sizes of nanoparticles are ranged from 11nm to 100nm [13]. The nanoparticles consist of various atoms, ions and molecules joined together in a regular or amorphous shape through a various ionic or covalent bonds to specify their location in a space lattice. It was seen that due to larger surface area of nanoparticles, heat transfer rate couldn't function very well. Because of smaller surface area of nanoparticles, more heat transfer has taken place. Therefore, smaller area of nanoparticles could function very well in enhancement of heat transfer rate. While spherical shape of nanoparticles could function very well in enhancement of heat transfer rate and overall efficiency of heat exchangers compared to the other shapes.

2. Methodology

The experimental work was conducted on Laminar /viscous flow heat exchanger research unit (Model of HE) at Mechanical Engineering Laboratory, Quaid-e-Awam University of Engineering, Science and Technology Nawabshah, Sindh, Pakistan as shown in Figure 1.

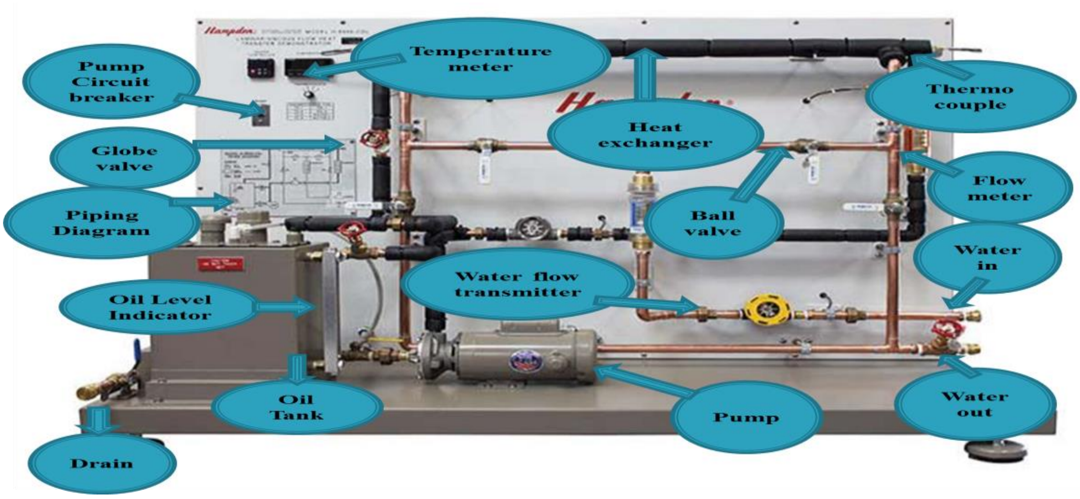

Fig. 1- Laminar /viscous flow heat exchanger research unit

3. Experimental setup

The experiments were conducted in parallel and counter flow directions. In each experiment, seven liters of hydraulic oil (ISO VG 46) as a hot fluid with 60℃ and 70℃ temperature was filled in the test rig. Whereas the water with additives of Al_2O_3 and CuO as well as additives were used as base coolant fluid. The additives were mixed with water in proportion of 1 to 3%. The test rig was operated for 20 minutes as per standard for measuring the heat transfer rate between oil and water coolant. The heat transfer rate was calculated using the energy balance equation (1) and (2).

$$Q_e = \dot{m}_h C_{ph}(T_{h,i} - T_{h,o}) \quad (2)$$

$$Q_a = \dot{m}_c C_{pc}(T_{c,i} - T_{c,o}) \quad (3)$$

where,

$\dot{m}_h$, $\dot{m}_c$: Mass flow rate of hot and cold fluid, respectively

$T_{h,i}$, $T_{h,o}$: Inlet and outlet temperatures of hot fluid

$T_{c,i}$, $T_{c,o}$: Inlet and outlet temperatures of cold fluid

C_{ph}, C_{pc} : Specific heats of cold and hot fluids

4. Results and Discussion

4.1 Heat Transfer Rate at Parallel Flow Condition

The heat transfer rate from hot fluid to coolant (with and without additives/nanoparticles) at parallel-flow as low flow condition was observed at two different temperatures 60°C and 70°C. The experimental data is given in the Table 2.

Table 2- Heat transfer rate at parallel flow direction

S. No.	Hot fluid		Coolant			Heat transfer rate (Btu/hr)
	60°C	70°C	Water	$H_2O + Al_2O_3$	H_2O + CuO	
1	✓		✓			684
2		✓	✓			864.6
3	✓			1%		795
4		✓		1%		964.43
5	✓				1%	865
6		✓			1%	1080.5
7	✓			3%		877
8		✓		3%		1145.5
9	✓				3%	953
10		✓			3%	1161

It was generally observed that the heat transfer rate at 70°C was higher than at 60°C due to higher temperature difference maintained between the fluids as shown in Figure 2. Furthermore, it was also found that additive copper oxide (1 & 3%) added with water coolant showed higher heat transfer rate as compared to the aluminum oxide (1 & 3%). It is due to higher thermal conductivity of copper oxide than aluminum oxide. Moreover, percentile difference of the heat transfer rate using different additives in the water coolant is illustrated in Table 3.

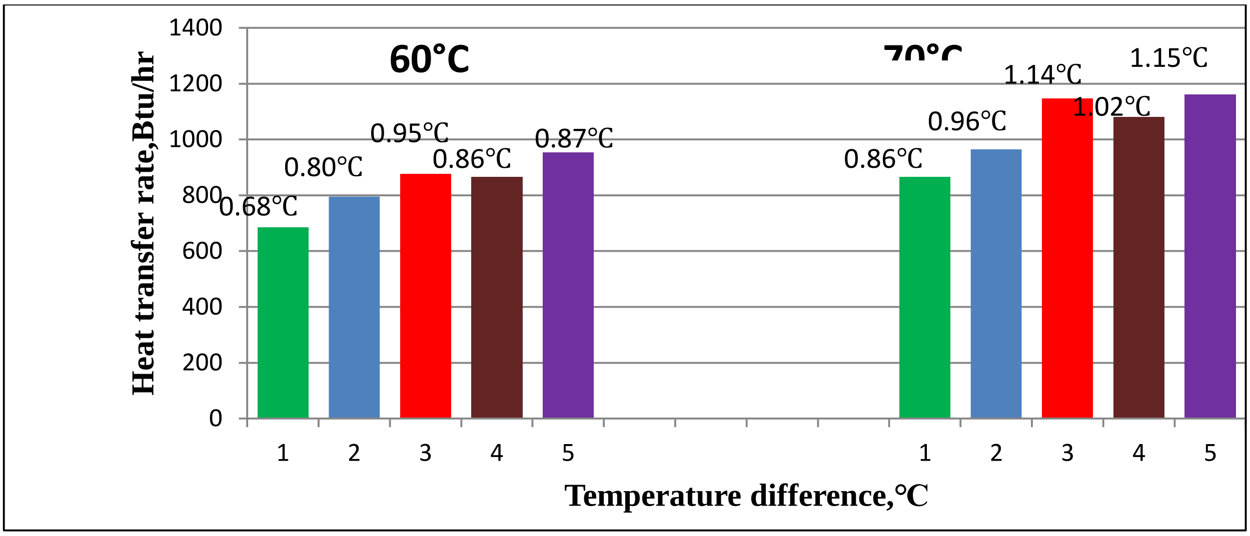

Fig. 2- Temperature difference at Parallel flow condition

Table 3- Percentile difference in Heat transfer rate at parallel flow condition

Types of coolant	Heat transfer rate @ 60°C	Heat transfer rate @ 70°C
Water	684 Btu/hr	864.6 Btu/hr
Water + Al_2O_3 (1%)	14% Increased	10.3% Increased
Water + Al_2O_3 (3%)	22% Increased	24.5% Increased
Water + CuO (1%)	20.90% Increased	20% Increased
Water + CuO (3%)	28.3% Increased	25.4% Increased

Table 3 shows that the heat transfer rate was increased non-uniformly due to the temperature difference maintained between the hot and cold fluids and due to the enhancement of thermal conductivity of the nano- fluid particle.

4.2 Heat Transfer Rate at Counter-Flow Condition

The heat transfer rate from hot fluid to coolant (with and without additives/nanoparticles) at counter flow in low flow condition at two different temperatures 60°C and 70°C. The observed data during experiments are given in Table 3.

Table 4- Heat transfer rate at counter-flow condition

S. No	Hot fluid		Coolant			Heat transfer rate (Btu/hr)
	60°C	70°C	Water	H_2O + Al_2O_3	H_2O +CuO	
1	✓		✓			793
2		✓	✓			915
3	✓			1%		1089
4		✓		1%		1297
5	✓				1%	1117
6		✓			1%	1298.8
7	✓			3%		1152
8		✓		3%		1337
9	✓				3%	1253
10		✓			3%	1462

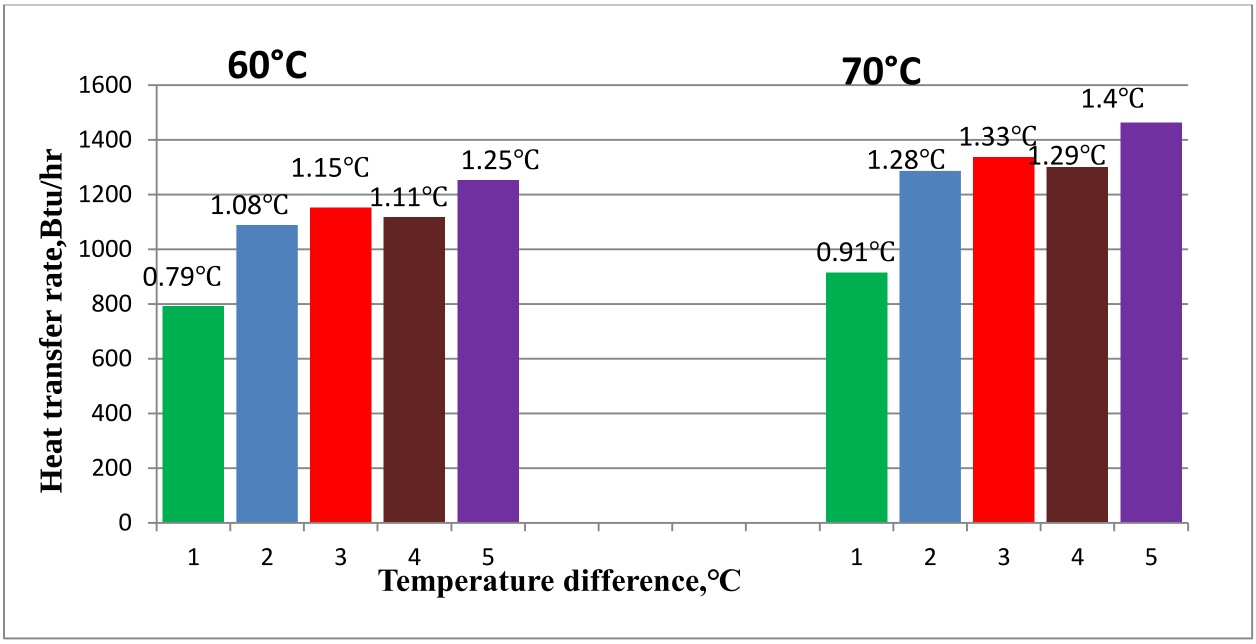

Fig. 3- Heat transfer rate at counter-flow condition

The heat transfer rate was increased uniformly due to the more uniform difference of temperature was maintained between the hot and cold fluids when both fluids passing through the counter flow low flow condition. The temperature difference of 60°C and 70°C during counter flow condition is shown in figure 3. Furthermore, heat transfer rate was also increased due to the enhancement of thermal conductivity of the Nano fluid particle. Moreover, the detail of the heat transfer rate in percentage difference using different additives in the water coolant is given in Table 5.

Table 5- Percentage difference in heat transfer rate using different additives at counter flow condition

Types of coolant	Heat transfer rate @ 60°C	Heat transfer rate @ 70°C
water	793 Increased	915 Btu/hr
Water + Al_2O_3 (1%)	27% Increased	29% Increased
Water + Al_2O_3 (3%)	31.1% Increased	31.5% Increased
Water + CuO (1%)	29.3% Increased	29.5% Increased
Water + CuO (3%)	36.6% Increased	37.4% Increased

Table 5 shows that the suspended of nanoparticles remarkably enhance the heat transfer process and the Nano fluid has larger heat transfer coefficients than that of original base liquid at the same flow rate. Therefore, heat transfer rate feature of a nanofluid was also increased with the increased of the volume concentration of the nanoparticles.

4.3 Effect of volume concentration on heat transfer rate

The heat transfer rate from hot fluid to coolant (with and without additives/nanoparticles) at parallel and counter flow condition using copper oxide CuO and aluminum oxide Al2O3 nanoparticles was observed at two different temperatures 60°C and 70°C. It was generally observed that the heat transfer rate at 70°C was higher than at 60°C due to higher temperature difference maintained between the fluids as shown in Figure 4. Furthermore, it was also found that additive copper oxide

(1 & 3%) added with water coolant showed higher heat transfer rate as compared to the aluminum oxide (1 & 3%). It is due to higher thermal conductivity of copper oxide than aluminum oxide. Moreover, in counter flow direction, the heat transfer rate was increased non-uniformly due to the temperature difference maintained between the hot and cold fluids and due to the enhancement of thermal conductivity of the nano- fluid particle.

The thermal and physical properties especially heat transfer rat was enhanced after the addition of copper oxide CuO and aluminum oxide Al2O3 nanoparticles in the baseline water. It is also found from an experimental work that heat transfer rate of copper oxide CuO and aluminum oxide Al2O3 nanofluid was observed higher compared to the baseline fluid. This is happened due to larger cohesion forces among the particles of copper oxide CuO. This happened is due to the largely temperature difference maintained across the heat exchanger pipe. It is also revealed that an enhancement in heat transfer rate took place at the inlet and outlet points of the heat exchanger pipe due to the higher thermal conductivity of the nanofluid. This enhancement in heat transfer rate exhibits due to the optimum stability and other favorable characteristics. Pumping power consumption and pressure drop across heat exchanger pipe play an important role in heat exchanger devices. Higher the pressure drop and pumping power increased the Brownian motion of nanofluid in the heat exchanger pipe. Higher the density and viscosity of nanofluid in the heat exchanger pipe offers higher obstacles during the movement of nanofluid in the pipe. This may cause higher pumping power consumption, agglomeration of particles and pressure drop during the movement of nanofluid in the heat exchanger pipe. In this study, it also revealed that various factors like heat transfer characteristics length of the pipe, volume flow rate and particles concentration are affecting the performance of the heat exchanger. Based upon this study, heat was supposed to be transferred more in case of counter flow direction compared to the parallel flow direction due to the higher temperature difference across the heat exchanger pipe. During counter flow direction, the movement of nanofluid across heat exchanger pipe was found more due to higher chaotic motion of nanofluids particles. This chaotic motion of nanofluid increased heat transfer rate. Therefore, the volume concentration 3% yields better results and is highly preferred than the other values of nanofluid and baseline water.

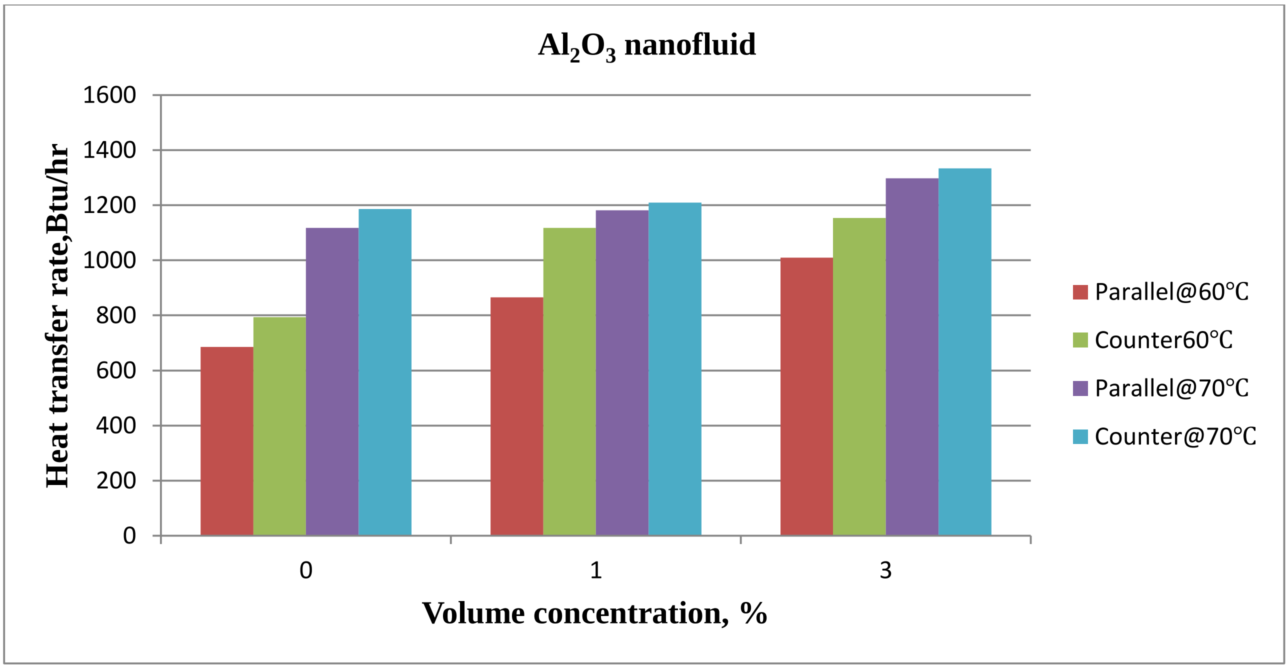

Fig. 4- Effect of heat transfer coeffcient on volume concentration using aluminum oxide Al2O3 nanofluid

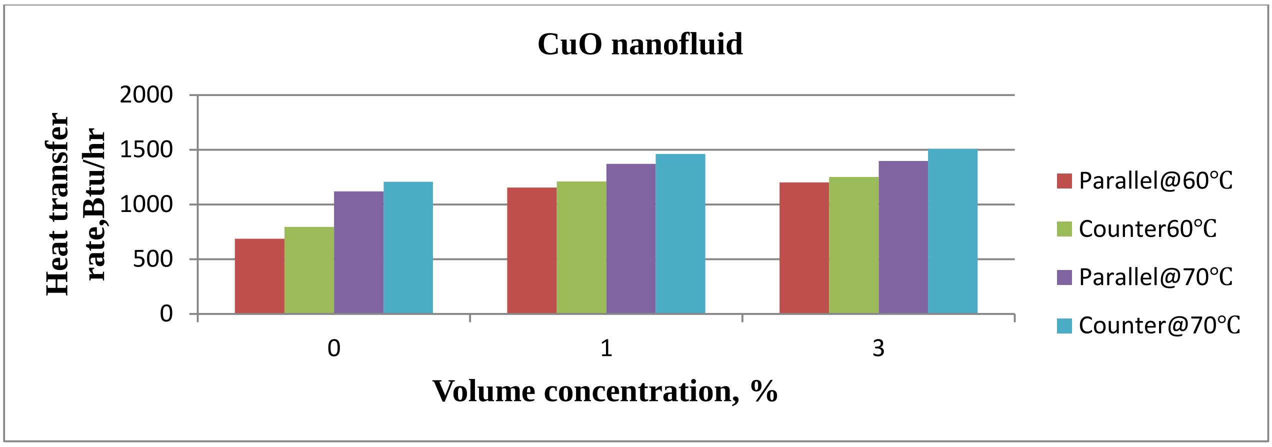

Fig. 5- Effect of heat transfer coeffciient on volume concentration using copper oxide CuO nanofluid

By the dispersion of copper oxide CuO and aluminum oxide Al2O3 nanoparticles in the baseline water, its thermal physical properties at volume concentration ranging from 1% to 3% were increased. The thermal physical properties like density, viscosity, specific heat and heat transfer rat were enhanced after the addition of copper oxide CuO and aluminum oxide Al2O3 nanoparticles in the baseline water. The density and viscosity of nanofluids were measured using calibrated instruments like Pycnometer and viscometer. The density and viscosity of both copper oxide CuO and aluminum oxide Al2O3 nanofluids were found higher compared to the baseline fluid at same operating temperature. It is also seen from an experimental work that density and viscosity of copper oxide CuO nanofluid was observed higher than aluminum oxide Al2O3 nanofluid and baseline fluid. This happened is due to larger cohesion forces among the particles of copper oxide CuO. Therefore, higher cohesion forces among the particles causing more obstacles of particles inside the heat exchanger pipe. Another causing factor is Brownian motion which caused the particles of copper oxide CuO to be move in random motion and non-sequence pattern [17]. Therefore, more temperature difference is maintained across the heat exchanger pipe which may cause to increase heat transfer rate at the inlet and outlet points of the heat exchanger pipe. The heat transfer rate and heat transfer coefficient of nanofluids can be find out using equations (2, 3).

4.4 Statistical analysis

Statistical analysis is the process of collecting raw data and interprets them according to the trends followed by various numerical relations to develop accurate and valuable insights. This Statistical analysis method in this research is also used to quantify the accurate data and results during research process. In this study, statistical analysis was made to measure and enhance the accurate analysis of an existing study. An analysis of experimental capabilities was done using various statistical techniques. But in this work, to expedite the accurate analysis of present study, correlation equations were used to measure the accurate analysis of the experimental capabilities. The following correlation equations were used to analyze the heat transfer enhancement using copper oxide CuO and aluminum oxide Al2O3 nanoparticles. The Acharya et al., 1992, 2001[18] equation is defined as:

$$Nu = 0.1381Re^{0.75}\,Pr^{0.33} \quad (5)$$

$$Nu = 0.298Re^{0.646}Pr^{0.316} \quad (4)$$

Where Nu is Nusselt number, Re is Reynolds number and Pr is Prandlt number

In this study Nusselt number is being used to determine transfer of heat by convection relative to conduction. This dimensionless number is particularly used in heat exchangers, cooling systems and other various heat transfer devices. Nusselt number is a ratio of convective heat transfer coefficient to the conductive heat transfer. The Nusselt number depends upon various factors i.e. convective heat transfer coefficient, characteristics length and thermal conductivity of fluid. An Experimental Nusselt number can be written as.

$$Nu = \frac{h \,.\, D}{K} \tag{6}$$

Where$h$, D, K is convective heat transfer coefficient (W/m2.K), diameter of the pipe (m), thermal conductivity of fluid (W/m. K).

In this experimental study; above correlation equations (1-3) were used to predict an experimental and theoretical Nusselt numbers for both baseline water and nanofluid and at 60-70°C using 1-3% volume concentration. It was found that experimental and theoretical correlations meet their closeness values.

4.5 Empirical Correlation and validiation of experimental results

The validiation of results plays vital important role to determine actual values of the experimetal setups and capabilities. In order to to measure and compare the accurate results of exisiting capabilities, some theoritical corelation models were used to expeditize the accuracy of the exisiting results. Therefore, corelation equations were used to quantify the exisiting results with the theoritical results.

In this study, experimentally investigagtion was done at all cases. Nusselt number also measured to quantify the value of heat transfer rate. Inorder to determine the actual behavior of the nanofluid, a dimensionless number known as Nusselt number is also used. The value s of Nusselt number increased as the values of Reynolds number increased up. Thus it was revelaed that heat transfer coeffcient of nanofluid increased than basline water due to the increasing of its thermal conductivity. Therefore, graph of various emprical correlation for Nusselt number is shown in Figure 6. The development for correlation for Nusselt number is used to minimize the uncertainties in the experimental work. From Figure 6, it is shown that experimental work has more precise and accurate values with the experimental work. It is also observed that Nusslet number for experimental and theroritical work showed the least deviation of ±10%.

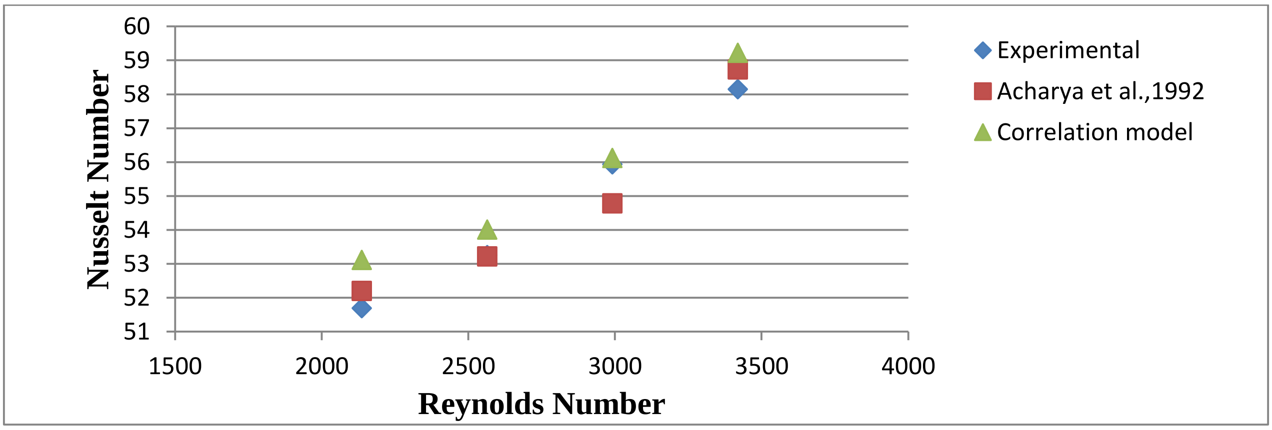

Fig. 6- Effect of Reynolds number on Nusslet number

The calculated values from Figure 6 are used to measure average values of heat transfer coefficient. Heat transfer rate and heat transfer coefficient are mainly depends upon Reynolds number and Nusslet number. Higher the values of Reynolds number and Nusslet number causing more heat transfer rate [12, 14].

4.6 Comparative Study

The comparative study between parallel and counter flow at 60°C and 70°C are given in Figure 7 and 8, respectively. In Figure 7, the result shows that at 60°C in counter flow direction the heat transfer rate is higher than the parallel flow direction due to more uniform temperature difference maintained between hot and cold fluid. In Figure 8, the result shows that at 70°C in counter flow direction the heat transfer rate is higher than the parallel flow direction due to more uniform temperature difference maintained between hot and cold fluid. Furthermore, heat transfer rate was also increased due to the enhancement of thermal conductivity of the Nano fluid particle.

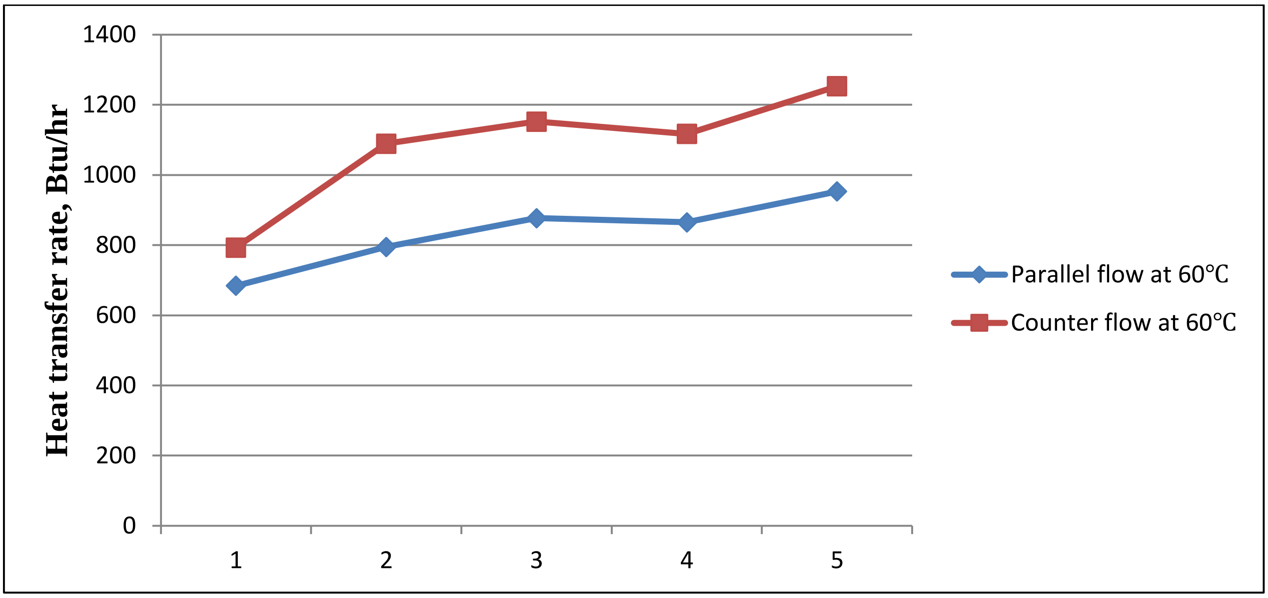

Fig. 7- Comparative results of parallel and counter flow at 60°C

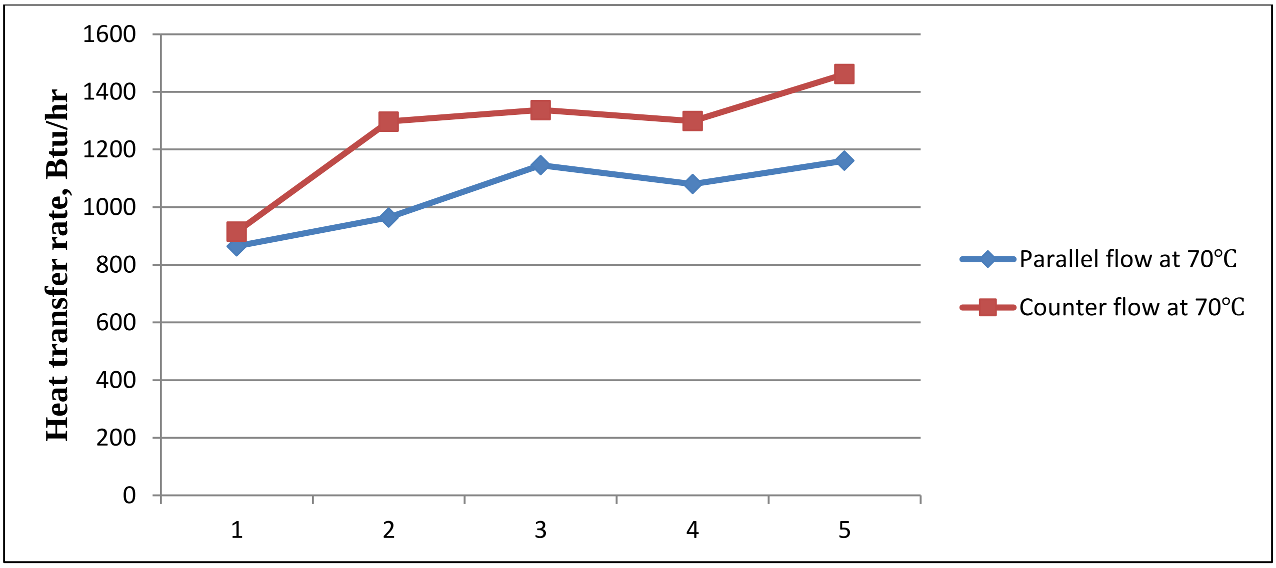

Fig. 8- Comparative results of parallel and counter flow at 70°C

The specific aim of this study is to enhance the heat transfer rate using both baseline water and nanfluid as working fluids at operating temperatures of 60 °C and 70 °C. Basically, dispersion of 1-3% volume concentration of copper oxide CuO and aluminum oxide Al2O3 nanoparticles in the baseline water showed optimum results compared to the base fluid. This enhancement is due to the higher thermal conductivity and temperature difference between hot and cold fluids at their inlet and outlet points of heating equipment. With the addition of 1-3% volume concentration of copper oxide CuO nanoparticles in baseline water showed also good results in heat transfer measurement as well as other thermal properties like density, viscosity, thermal conductive and specific heat were found better in results compared to the baseline water. However, at the same time, smaller pumping power consumption as well as the pressure drop occurred across the heat exchanger pipe. This happened due to the development of various bonding and agglomeration forces near the walls of the heat exchanger pipe which resulted higher obstacles in the heat exchanger pipe. Moreover, in this study an optimum enhancement in heat transfer took place due to the higher stability and other favorable characteristics of copper oxide CuO nanofluid than aluminum oxide Al2O3 nanofluid. With the addition of CuO additive in the water coolant showed maximum enhancement in heat transfer rate and was found to be increased from 36.6 - 38 % at operating inlet temperatures of 60℃ - 70℃ using counter-flow condition.

4.7 Comparative analysis with other studies

A. Sivalingam and T. Balusamy [11] presented their review study to enhance the thermal conductivity and temperature differences between hot and cold fluids using various metallic and its oxides like copper, aluminum, copper oxide, aluminum oxide, silicon carbide, silver, iron and carbon nanotubes. These researchers found an enhancement in heat transfer characteristics due to the dispersion of various nanoparticles in the baseline water and showed optimum results compared to the base fluid. While present study focuses on enhancement in heat transfer characteristics due to the dispersing of two highly thermal conductive nanoparticles i.e. copper oxide CuO, aluminum oxide Al2O3 in the baseline water to see the impact of nanoparticles on thermal performance of heat exchanger. This present study has enhanced heat transfer rate by 36.6 - 38% at inlet temperature of 60℃ and 70℃. This enhancement is due to the higher temperature difference is maintained between hot and cold fluids at their inlet and outlet points. While previous studies failed to increase much more heat transfer rate using same type of nanoparticles. A. Sivalingam and T. Balusamy study could enhance the heat transfer rate by 20 - 30% using aluminum oxide Al2O3 nanoparticle. Therefore, it is finally concluded and recommended that this present study is more preferable and profitable in various processing industries due to their good heat transfer rate, economical rate and best performances than other fluids.

4.8 Safety implications of nanoparticles in cooling systems

Nanofluids have been introduced in many engineering applications due to their higher heat performances in heat exchangers and other cooling systems. This is due to the improved thermo physical properties of nanofluid relative to the base fluid. The addition of nanosized particles exhibits remarkably enhancements in heat transfer rate. This is due to the higher thermal conductivity of nanofluid relative to the base fluid. The improved thermo physical properties of nanofluid increased the thermal performance and energy conversion efficiency which results in reduced energy consumptions in cooling systems and increased safe environment. The nanoparticles have been extensively used due to their good environmental effects in heat exchangers and other cooling systems. Some nanoparticles are toxic and non-toxic but they can be easily manageable and handled through safety devices and precautions. There'll be no any harmful and negative impacts of nanoparticles existing in cooling systems if proper safety precautions shall be applied. The influence of using nanoparticles in cooling systems and heat transfer studies play an important role to address the issues in sensitive applications. Due to safety implications in cooling systems and sensitive applications, a proper planning has been adopted to save any negative impacts and hazardous on heat transfer and other electronic application. Engineered nanoparticles need lot of attention to handle properly. The attention has been carried out during synthesis, preparation and characterization. Good attention has been carried out of toxic nanoparticles to save from biological and environmental impacts on human life.

5. Conclusion

In this study, the heat transfer rate was analyzed between parallel and counter flow directions. The hot fluid was hydraulic fluid at 60℃ and 70℃, whereas the water-based coolant with addition of 1-3% nanoparticles was used. It was concluded that heat transfer rate was increased due to the increasing of nano particle volume concentration i.e. 3% of CuO additive when mixed in the water coolant while passing through counter-flow of laminar flow/viscous flow research unit. It was observed that heat transfer rate of CuO was increased more than that of $Al_2O_3$and water coolant due to more uniform difference of temperature maintained between the inlet and outlet temperature of cold and hot fluid due to the higher thermal conductivity of CuO. The maximum heat transfer rate was found to be 36.6 % at 60℃ and 38% at70℃ when 3% of CuO was mixed with the water coolant while passing through the counter-flow condition. The tests were performed at 60°C and 70°C according to the industrial requirements and weather season.

5.1 Future aspects of studies

In this research study, experimental work was carried out on nanofluids and equipment's performance parameters like heat transfer, density and viscosity. This comparative experimental work has enhanced thermal performance through increasing percentage of additives i.e. between 1-3%. In future aspects, some proportion of hybrid CuO and Al2O3 nanoparticles at volume concentration of 4- 5% shall be added in the baseline water to obtain hybrid nanofluid under different operating conditions, processes and temperatures. The obtained performance shall also be compared with baseline water. In future, nanoparticles like metal particles i.e. Cu and Al shall also be mixed in a water with different particles shape, sizes and structures and same standard method to obtain hybrid nanofluid, Thus obtained results can be compared with the results of base fluid i.e. water. In future, cooling tower shall be used to enhance the more heat transfer between the two fluids efficiently which increases the heat transfer rate and other performance parameters and give the best result as required.

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