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An Experimental Study of Nanofluids Operated Shell and Tube Heat Exchanger with Air Bubble Injection

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ABSTRACT

Shell and Tube heat exchangers are the heat exchangers that are most widely used in industries and for other commercial purposes. There are many techniques that have been utilized to enhance the heat transfer performance of the shell and tube heat exchangers. Air bubble injection is one of the promising and inexpensive techniques that can create turbulence in the fluids resulting in to enhancement of heat transfer characteristics of the shell and tube heat exchangers. In this paper, experimental study of heat transfer characteristics have been done by injecting air bubbles at tube inlet and throughout the tube for 0.1%v/v and 0.2%v/v Al_2O_3 nanoparticle concentration. Results obtained at two different injection points for both concentrations are compared with the case when no air bubble injection is done. The results showed the enhancement in the heat transfer characteristics with air bubble injection and volumetric concentration of nanoparticles. The maximum enhancement was found to be in the case where air bubbles are injected throughout the tube which is followed by the air bubble injection at the tube inlet and without air bubble injection. As the bubbles were injected throughout the tube, approximately 22-33% enhancement was observed. The overall heat transfer coefficient with injecting air bubbles throughout the tube showed an enhancement of about 12-23% and 14-25% for 0.1% and 0.2% of nanofluids.

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NOMENCLATURE

d	Diameter (m)	μ	Viscosity
h	Heat transfer coefficient (W/m^{2}K)	ϕ	Volumetric concentration
m	Mass (kg)	**Subscripts**	
L	Length (m)	avg.	Average
Nu	Nusselt number	bf	Base fluid
Pr	Prandtl number	c	Cold side
Q	Heat Energy (joule)	h	Hot side
Re	Reynolds number	i	Inlet
v	Velocity (m/sec)	LMTD	Logarithmic Mean Temperature Difference
U	Overall heat transfer coefficient (W/m^{2}K)	o	outlet
Greek Symbols		np	nanoparticle
ρ	Density (kg/m^3)		

1. INTRODUCTION

From the recent studies, it has been found that the humans are exploiting limited sources of energy at an alarming rate. This exploitation of energy resources will extinguish them much earlier than expected. This will cause our future generation to starve for these energy resources. To compensate for this growing or rising demand and limited sources of energy extraction, engineers are trying to find out the new or advanced

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techniques to enhance the thermal or heat transfer performance of heat exchangers[1].The world council has estimated that there would be around 50% rise in the energy demand in the coming future years that will be very difficult to achieve if the humans continue to use the energy resources at the present rapid rate[2]. It has been found that heat transfer has critical importance in the world of energy because if there would be more efficiency of heat transfer, then there would be more recovery of heat from the process under consideration. If there would be greater efficiency in recovering the heat, then there would be more energy savings. So, heat exchangers can be widely used to conserve energy by recovering more and more heat through heat transfer process and this conserved energy can be used for different purposes[3].

Shell and tube heat exchanger is one of the most commonly used heat exchangers in industrial applications with the ability to withstand high temperature (from -250°C to 800°C) and high pressure (up to 6000psi) of the working fluid. It is possible to enhance the thermal performance of shell and tube heat exchanger using distinct heat transfer enhancement techniques. One of the techniques that can be used to enhance the heat transfer rate between the fluids used in the shell and tube heat exchanger is air bubble injection technique. It is one of the passive techniques for heat transfer enhancement and very less utilized to enhance the heat transfer rate in heat exchangers. This technique, basically injects air bubble into the flowing fluid creating a turbulence in the flowing stream by reducing the skin friction drag near the wall. When bubble travels through the fluid, it creates a void behind which is to be filled by the liquid surrounding the air bubble, thus creating turbulence in the flowing fluid that ultimately results in the heat transfer enhancement.

Gabillet et al. [4]studied the effect of air bubble injection in turbulent boundary layers and reported an enhancement in turbulent kinetic energy and shear stress. Houshmand and Peles [5] experimentally studied the thermal performance in a micro channel taken into account the air bubble flow rate with water flow rate effect, and 16% enhancement was reported. Celeta et al. [6]studied the heat transfer characteristics of a heated channel by considering the effect of air bubble injection at its inlet and reported an enhancement of about 10 times in the heat transfer. Dizaji and Jafarmadar [7] studied the effect of air bubble injection on the Nusselt number of a double pipe heat exchanger and reported 6-35% enhancement in Nusselt number of a double pipe heat exchanger. Delaure et al. [8]studied the effect of ellipsoid air bubble rise in water on heat flux and found the enhancement in heat flux. Jacob et al. [9]compared the Reynolds stress and shear stress near the wall of single phase flow and two phase flow (air bubble-water mixture) and reported that the two parameters have more value for two phase flow than single phase flow. Nandan and Singh [10, 11] studied the heat transfer characteristics of shell and tube heat exchangers by injecting air bubbles and reported the significant improvement in the performance of heat exchanger. Kern [12] proposed the design procedure of the shell and tube heat exchanger in detailed form. There are many conventional fluids such as ethylene glycol and water that have been utilized as heat transfer fluids in heat exchangers. However,these fluids have very low thermal conductivity impelling researchers to discover new fluids that can give higher heat transfer performance in heat exchangers. To fulfil this need, new heat transfer fluids known as nanofluids were introduced. Nanofluid is a fluid containing solid nano-sized particles of metals and nonmetals whose particle size is less than 100 nm suspended uniformly in the base fluid. The purpose of dispersing the solid nanoparticles in the base fluid was to obtain higher thermal conductivity compared tothe base fluid. The reason for higher thermal conductivity of nanofluid than base fluid is due to high thermal conductivity of solids than liquids. The researchers have realized the great potential of nanofluids to be called the future heat transfer fluids in heat exchanger devices[13]. Xiaohao Wei et al. [14]experimentally studied the thermal conductivity of water based Cu_2O nanofluid synthesized with the help of chemical solution method by considering the reactant molar concentration and nanofluid temperature effect on the thermal conductivity and reported an enhancement in thermal conductivity up to 24% with the use of synthesized nanofluid. The sensitivity and non-linearity were shown by the thermal conductivity towards the nanofluid temperature and reactant molar concentration. The thermal transport properties of nanofluids are the function of nanoparticle concentration and fluid temperature[15-18]. Rohini Priya et al. [19]studied the thermal conductivity of CuO-water nanofluid with 0.016 vol% of CuO in water at 28°C and 55°C, respectively. They reported an enhancement of about 13% and 44% in thermal conductivity at 28°C and at 55°C. L.Syam Sundar et al. [20]experimentally evaluated the thermal conductivity of low volume concentration Al_2O_3 and CuO nanofluids taking water and ethylene glycol mixture (50:50) as a base fluid at different temperatures and volume concentrations and reported that the thermal conductivity of CuO was found to be more than Al_2O_3 under same temperature and volume concentration. Ren et al. [21]studied the effects of micro convection caused due to thermal motion of nanoparticles and interfacial layer formed at liquid-particle interface in order to propose a theoretical model to evaluate the effective thermal conductivity of nanofluids. Fotukian and Nasr Esfahany [22] studied the variation in the heat transfer coefficient and pressure drop on adding small amounts of CuO into water base fluid and reported an enhancement of about 25% in heat transfer coefficient and 20% penalty in pressure drop by adding small amounts of CuO nanoparticles into water as base fluid. Taheri et al. [23, 24]used hydraulic network modelling toevaluate the thermal performance of shell and tube heat exchanger and reported 25-48% enhancement of performance with different parameters. With addition of Al_2O_3 nanoparticles, heat transfer performance of vertical tube of radiator has enhanced up to 31% as compared to base fluid[25]. The objective of the present work is to study the performance of shell and tube heat exchanger with nanofluids and air bubble injection. Air bubble injection significantly improve the heat transfer performance due to turbulence in flowing fluid.

2. NANOFLUIDS PREPARATION

In present study, Al_2O_3 nanoparticles of size 20nm have been used. Nanofluids of 0.1% and 0.2% volume concentrations were prepared with two step method. The required volumetric concentration of nanoparticles is calculated by Equation (1):

$$\phi = \frac{\frac{m_{np}}{\rho_{np}}}{\frac{m_{np}}{\rho_{np}} + \frac{m_{bf}}{\rho_{bf}}} \quad (1)$$

The Al_2O_3 nanoparticles were purchased from Nanoshells, Derrabasi, India. A magnetic stir wasused to completely mix the nanoparticles with the base fluid. In order to remove the agglomerations, the nanofluids were placed in the ultrasonicator for about 2 hours for sonication. There was no need to add the surfactant to stabilize the nanofluids as the nanoparticles completely got mixed with the base fluid.

3. EXPERIMENTAL SETUP & WORKING PROCEDURE

Figures 1 and 2 showthe actual picture schematic diagram of the experimental setup, respectively.

The experimental setup consists of test Section (shell and tube heat exchanger), hot water loop, water loop containing Al_2O_3 nanoparticles (0.1 and 0.2% volumetric concentration) and air injection system. Complete specifications of the test section are given in Table 1 and the components with the accuracy used for the various parameters during the experiment are given in Table 2. Four T-type thermocouples of an accuracy 0.1°C are installed at both the inlet and outlet of the shell and tube along with one the surface of the walls so as to help us to obtain wall temperature.

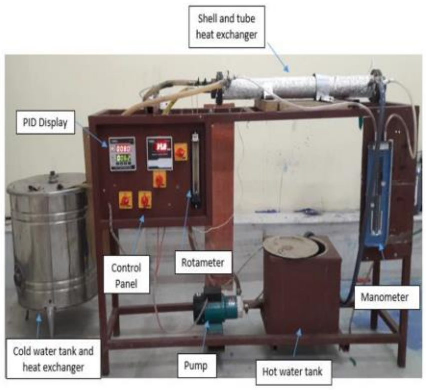

Figure 1. Experimental Set up

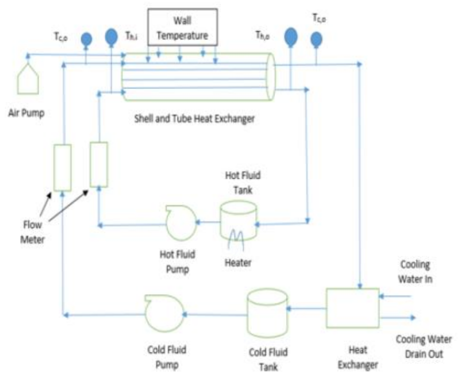

Figure 2. Schematic Diagram of Experimental Set up

TABLE 1. Specifications of test section

Dimensions	Value
Length(mm)	600
Shell diameter(mm)	53
Tube inner diameter(mm)	10
Tube outer diameter(mm)	12.5
No. of Tubes	4

TABLE 2. Accuracy of components

Components	Accuracy
Thermocouples	±0.1°C
Flow meter	±1%
PID	±0.25%

The temperature of hot water is controlled by a PID (Proportional-integral-derivative controller). The PID controls the temperature of the hot water pumped to the shell side. The hot fluid is pumped with a constant mass flow rate of 3.5 lpm and at different temperatures of 30, 40, 50 and 60°C). The nanofluid is circulated at various mass flow rates (0.5, 1, 1.5, 2, 2.5,3 and 3.5 lpm) at a fixed temperature from the tube side. The mass flow rate of the hot water and nanofluid is controlled via two flow meters which are installed on both shell and tube side. The working accuracy of flowmeters is of about 1%. The accuracy and range of instruments is provided in Table 2. For the injection of air bubbles, an aquarium pump, which was able to inject air at the rate of 0.05833 kg/sec was used. For air bubble injection, a small diameter plastic tube with holes the tube was used. The calibration of instruments was the initial step of experimentation. The experimentation was divided into three different cases; a) the nanofluid flows on the tube side without air injection, b) second case in the experimentation was conducted with air bubbles injection at the inlet of the and c) the injection of air bubbles throughout the tube so turbulence can be generated. For the final analysis, average of seven readings at regular time intervals were taken.

4. DATA PROCESSING

Heat transfer characteristics such as heat transfer coefficient, overall heat transfer coefficient and Nusselt number are evaluated in order to analyze the effect of air injection technique applied to the shell and tube heat exchanger.

Reynolds number for the nanofluids is calculated using thefollowing equation:

$$Re = \rho v d/\mu \tag{2}$$

The heat transfer coefficient is evaluated bythe following equation:

$$h_i = 0.23\frac{k_f}{d_i}\mathrm{Re}^{0.8}\,\mathrm{Pr}^{0.33}\left(\frac{11d_i}{L}\right)^{0.7} \tag{3}$$

The following equation is used to calculate the overall heat transfer coefficient:

$$U = \frac{Q_{avg}}{A_O \Delta T_{LMTD}} \tag{4}$$

Equation (5) is used to evaluate logarithm mean temperature difference (T_{LMTD})

$$\Delta T_{LMTD} = \frac{((T_{h,i} - T_{c,i}) - (T_{h,o} - T_{c,o}))}{\ln\{(T_{h,i} - T_{c,i}) - (T_{h,o} - T_{c,o})\}} \tag{5}$$

The Nusselt Number is calculated by the equation given below as Equation (6):

$$Nu = \frac{h \times di}{k} \tag{6}$$

5. RESULTS AND DISCUSSIONS

5.1. Effect on the Heat Transfer Coefficient It has been observed that the heat transfer coefficient increases with increasing Reynolds number. Air bubble injection at different points enhances the heat transfer coefficient as compared to the case without air bubble injection. This is due to the fact that the air bubble rises while flowing along the fluid creates void behind which is to be filled by the surrounding fluid creating turbulence in the flowing fluid, thus causing more heat to be transferred or higherheat transfer coefficient. The air bubble injection throughout the tube causes maximum heat transfer coefficient as compared to the other two cases. Moreover, rising bubbles create more turbulence than the bubbles along the fluid entering the tube which may be the reason for high heat transfer coefficient for air bubble injection throughout the tube than air bubble injection at the tube inlet. From Figures 3 and 4 it has been found that for 0.1% and 0.2% volumetric concentration of water based Al_2O_3nanofluid, the enhancement in the heat transfer coefficient on injecting air bubbles throughout is about 22-33% and 25-35%, respectively, while injecting air bubbles at the tube inlet gave 19-24% and 21-26% enhancement in the heat transfer coefficient as compared to without air bubble injection.

From Figures 5 and 6 it has been observed that at a constant flow rate of hot water and water based Al_2O_3nanofluid, with increase in inlet temperature, the heat transfer coefficient is enhanced.This is due to increase in temperature difference that causes more heat to be carried by the water based Al_2O_3 nanofluid, thus leading to high heat transfer coefficient. The case where air bubbles are injected throughout the tube gave maximum heat transfer coefficient with increase in the hot water temperature which is followed by the other two cases, i.e. with andwithout air bubble injection at the tube inlet. Since the thermal conductivity of nanofluids increase with increase in nanoparticles concentration, heat transfer coefficient for 0.2 % volumetric concentration nanofluid was found to be more than the 0.1 % volumetric concentration of water based Al_2O_3nanofluid in all three cases, i.e., without air bubble injection, air bubble injection at the tube inlet and air bubble injection throughout the tube.

5. 2. Effect On The Overall Heat Transfer Coefficient As shown in Figure 7, the overall heat transfer coefficient increases with increase in Reynolds number as well as Al_2O_3nanoparticle concentration in base fluid. The enhancement in the overall heat transfer coefficient due to injection of air bubbles throughout the tube came out to be 12-23% higher than the case when no air bubbles were injected at the same Reynolds number.

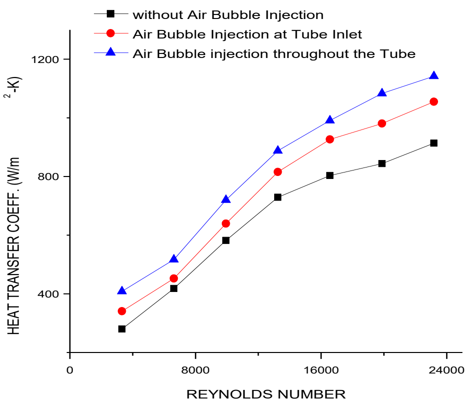

Figure 3. Heat transfer coefficient vs Reynolds number at 0.1% v/v

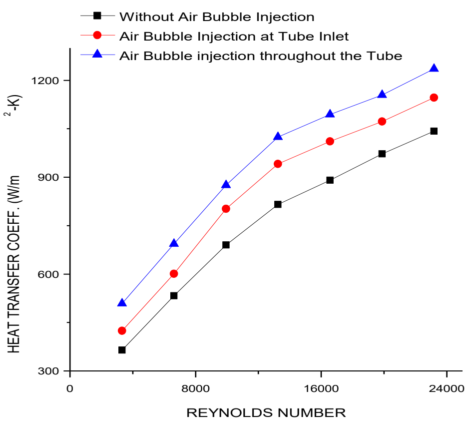

Figure 4. Heat transfer coefficient vs Reynolds number at 0.2% v/v

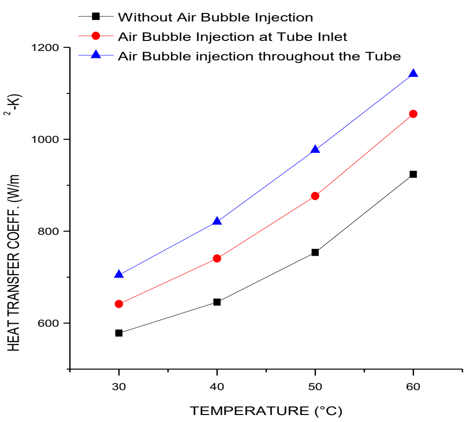

Figure 5. Heat transfer coefficient vs Temperature at 0.1 v/v

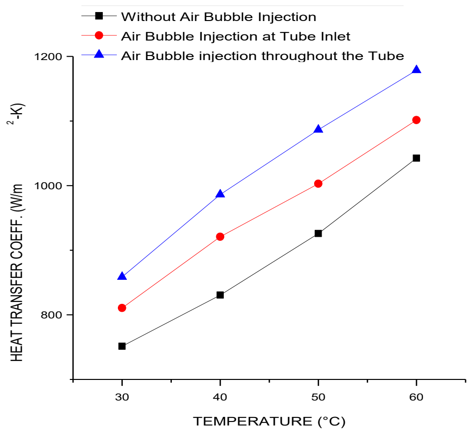

Figure 6. Heat transfer coefficient vs Temperature at 0.2 v/v

Furthermore, this enhancement increased upto 14-25% for the case with nanofluid containing 0.2% volumetric concentration of Alumina. The enhancement is due to the fact that as the bubbles injectedin the fluid, more turbulence is created which caused high heat transfer rate, thus eventually leading in to increase in the overall heat transfer coefficient. Figures 7 and 8 also revealed that the air bubble injection at the tube inlet enhanced the overall heat transfer coefficient by 8-21 and 10-24% with 0.1% and 0.2% volumetric concentration of Al_2O_3nanoparticles,respectively. This may be due to the void created by the air bubbles entering the tube inlet while flowing along the fluid which is to be filled by the surrounding fluid causing more heat to be carried out by the cooling fluid resulting in more overall heat transfer coefficient.

From Figures 9 and 10, it has been inferred that for a constant flow rate of hot water and Al_2O_3nanofluid, increasing the hot water temperature enhanced the overall heat transfer coefficient. The enhancement is due to increase in temperature difference that caused more heat transfer eventually leading to high overall heat transfer coefficient. The case where air bubbles are injected throughout the tube gave maximum overall heat transfer coefficient with increase in the hot water temperature which is followed by the other two cases, i.e.,with and without air bubble injection at the tube inlet. Since the thermal conductivity of nanofluids increase with increase in nanoparticles concentration, overall heat transfer coefficient for 0.2% volumetric concentration of Al_2O_3nanofluid was found to be more than the 0.1 % volumetric concentration of water based Al_2O_3nanofluid in all three cases, i.e., without air bubble injection, air bubble injection at the tube inlet and air bubble injection throughout the tube.

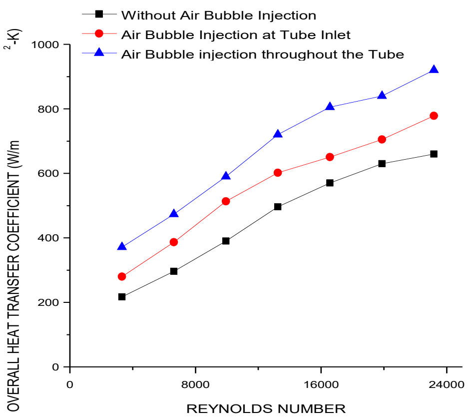

Figure 7. Overall heat transfer coefficient vs Reynolds number at 0.1% v/v

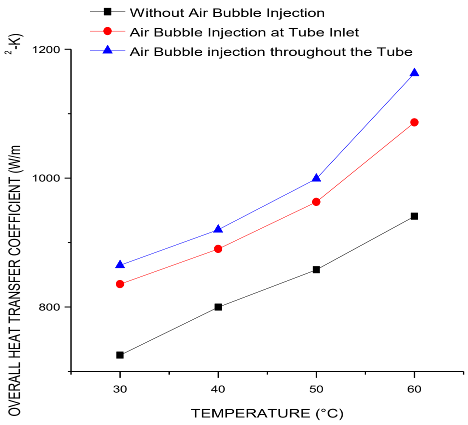

Figure 10. Overall heat transfer coefficient vs Temperature at 0.2% v/v

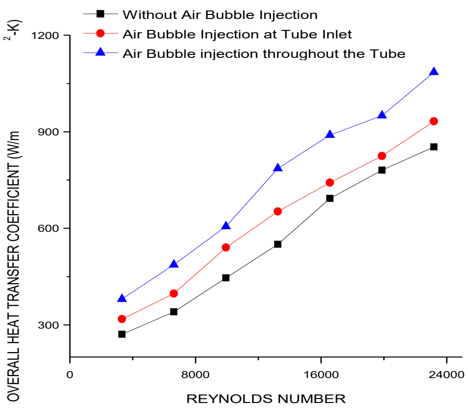

Figure 8. Overall heat transfer coefficient vs Reynolds number at 0.2% v/v

5.3. Effect on the Nusselt Number Nusselt number is found to increase with increase in the Reynolds number and air bubble injection. From Figures 11 and 12, it has been conferred that the injecting air bubbles throughout the tube enhanced the value of Nusselt number by 14-18and 15-20% for the two different concentrations of nanofluids i.e. 0.1% and 0.2% volumetric concentration of Al_2O_3nanoparticles in the base fluid compared withthe case without air bubble injection. The increase of Nusselt number is due to the fact that injection of bubbles increase in the flowing fluid, more turbulence is created in the flowing fluid containing air bubbles leading to more heat transfer coefficient which caused increased Nusselt number. Figures 11 and 12 revealed that the air bubble injection at the tube inlet also increasedthe Nusselt number by 9-14 and 10-15%, respectively with the use of water based nanofluids with 0.1and 0.2%

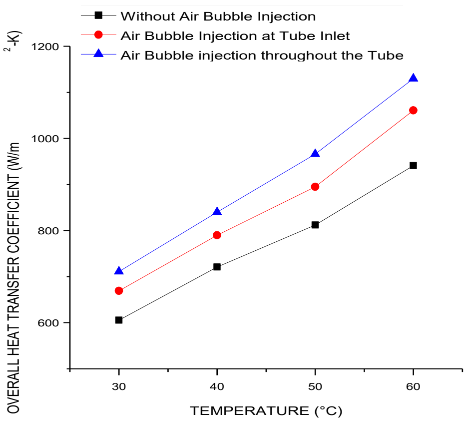

Figure 9. Overall heat transfer coefficient vs Temperature at 0.1% v/v

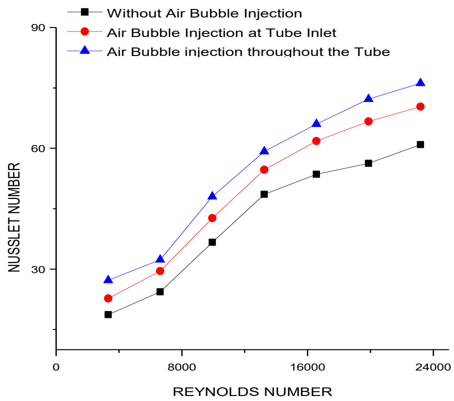

Figure 11. Nusslet number vs Reynolds number at 0.1% v/v

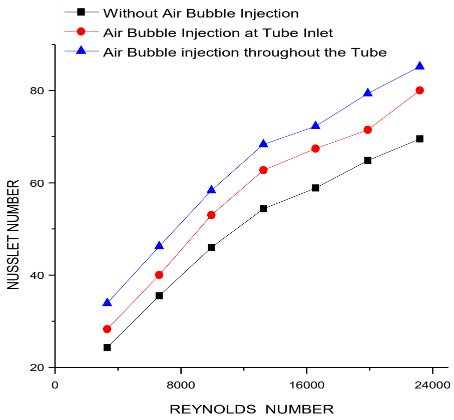

Figure 12. Nusslet number vs Reynolds number at 0.2% v/v

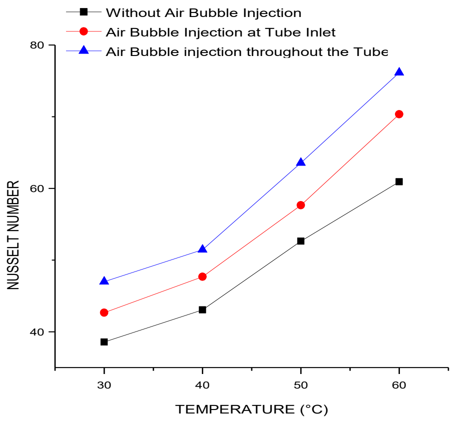

Figure 13. Nusslet number vs Temperature at 0.1% v/v

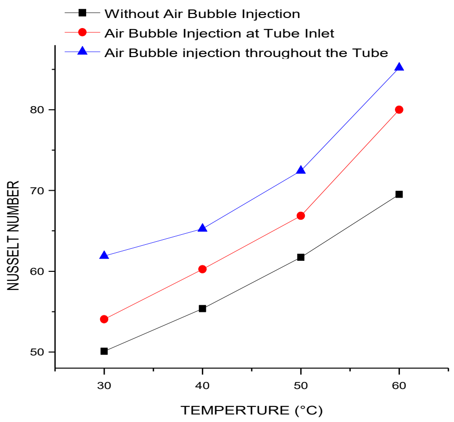

Figure 14. Nusslet number vs Temperature at 0.2% v/v

volumetric concentration of Al_2O_3nanoparticles when compared to the first case when no air bubbles are injected to the flowing fluid. Further increase in Nusselt number happened with increase in fluid inlet temperature as shown in Figures 13 and 14.

6. CONCLUSIONS

Air bubble injection is one of the inexpensive and passive techniques to enhance the thermal performance of a heat exchanger. The air bubble technique enhanced the performance of shell and tube heat exchanger. As the bubbles injected the throughout the tube, approximately 22-33% enhancement was observed followed by the injection of the air bubble at the tube inlet which showed an enhancement of about 19-24% as compared to without injecting any air bubble at a specific Reynolds number and for 0.1% v/v of Al_2O_3 nanoparticles. This enhancement further increased upto an enhancement of about 25-35% with 0.2% v/v concentration of nanofluids

The overall heat transfer coefficient with injecting air bubbles throughout the tube showed an enhancement of about 12-23 and 14-25% for 0.1 and 0.2% of nanofluids which is followed by the injection of the air bubble at the tube inlet which showed an enhancement of about 8-21% as compared to the case without injecting any air bubble at distinct Reynolds number.

The Nusselt number with injecting air bubbles throughout the tube showed an enhancement of about 15-20% which is followed by the injection of the air bubble at the tube inlet which showed an enhancement of about 10-15% as compared to the casewithout injecting any air bubble at a specificReynolds number.

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An Experimental Study of Nanofluids Operated Shell and Tube Heat Exchanger with Air Bubble Injection

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چکیده

مبادله‌کن‌های حرارتی پوسته و لوله‌ای مبادله‌کن‌هایی هستند که به طور گسترده در صنایع و دیگر کاربردهای تجاری استفاده می‌شوند. فنون بسیاری برای افزایش عملکرد انتقال حرارت مبادله‌کن‌های حرارتی پوسته و لوله‌ای وجود دارد. تزریق حباب هوا یکی از فنون امیدوار کننده و ارزان قیمت است که می تواند باعث ایجاد آشفتگی در مایعات شود، که در نتیجه افزایش ویژگی‌های انتقال حرارت مبادله‌کن‌های حرارتی پوسته و لوله‌ای را به دنبال دارد. در این مقاله، بررسی تجربی ویژگی‌های انتقال حرارت در اثر تزریق حباب‌های هوا در ورودی لوله و از طریق لوله برای ۰,۱ و ۰,۲درصدحجمیAl_2O_3 غلظت نانوذرات انجام شده است. نتایج حاصل از دو نقطه تزریق مختلف برای هر دو غلظت در مقایسه با حالت بدون تزریق حباب هوا مقایسه شد. نتایج نشان داد که افزایش ویژگی‌های انتقال حرارت با تزریق حباب هوا و غلظت حجمی نانوذرات صورت می‌گیرد. حداکثر افزایش به ترتیب برای حالت تزریق حباب‌های هوا در داخل لوله ، پس از آن تزریق حباب هوا در ورودی لوله و در آخرین حالت بدون تزریق حباب هواست. همان طور که حباب‌های هوادر سراسر لوله تزریق شد، ضریب انتقال حرارت تقریبا ۲۲ تا۳۳درصدافزایش یافت. ضریب انتقال حرارت کلی با حباب‌های تزریقی در طول لوله نشان می‌دهد که افزایش حدود ۱۲–۲۳٪ و ۱۴–۲۵٪ برای ۰,۱٪ و ۰,۲٪ نانو سیالات است.

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