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Experimental Analysis of Heat Transfer Enhancement in Double Tube Heat Exchanger with Air Injection

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Abstract

. Double-tube heat exchangers are frequently utilized due to their low assemble and maintenance cost. In order to extract a large amount of thermal energy at minimum time and cost, an active method of air bubble injection was developed to increase the heat transfer rate through vertical double-tube heat. The current study explores the influence of air bubble injection on the thermal efficiency of vertical double tubes at counter flow. There were two main modes were adopted to conduct the experiments. The first mode was done without air injection (single phase). In the second mode, the air was injected into the heat exchanger's outer tube through a ring tube into the annular side of the heat exchanger. Cold water flow rate was ranged as (3, 3.5, 4, 4.5, 5 LPM) with 17°C temperature, while hot water was kept constant at (3LPM) with inlet temperature 70°C, and air was injected with (0.5, 1, 1.5, 2 LPM). Results found that overall heat transfer was enhanced by (41%), NTU (49%), effectiveness enhanced by (44%) and Nusselt number (45.2%).

Keywords: Double tube heat exchanger; Heat transfer enhancement; Air bubbles injection; Number of heat transfer unit (NTU); Overall heat transfer coefficient (U); Effectiveness (ε).

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1- Introduction

Heat exchangers are important tools utilized in a variety of operations like utilizing, exchanging, and transporting thermal energy in different applications. Double tube heat exchanger was selected as the significant type of heat exchanger that has a variety of uses. Many industrial processes use two-phase flow, which is preferable because it allows for the mixing of gases and liquids to enhance the heat and mass transfer. Several methods are used to enhance heat transfer in heat exchangers such as fins, nano particles [1], metal foam, etc. Due to the rising demand for more energy, some researchers focused on creating effective heat exchangers with less expensive and simple manufacturers such as Ebrahem Tavousi et al. [2], focus on several passive strategies since it is the least expensive compared to active strategies for enhancing friction factor and heat transfer rate.

Recently due to two-phase flow features it is used with the application that exchanges thermal energy to improve heat transfer. The success of this method depends mainly on the injection technique, shape, size, and number of bubbles. In this context, Samira et al. [3] illustrated experimentally the improvement of a vertical double tube heat exchanger by injecting air inside the annular space of the heat exchanger with holes diameters 0.3mm and 0.8mm and number of holes was n=36 and n=6 air was injected with 0.098kg/s and 26°C cold water at(5000>Re <16000 and 25°C), and hot water was (Re=5500 and 40°C), the results finding that n=36 and d=0.3mm was the proficient design of perforations. Hussain Habib et al. [4] experimentally clarify the effect of air bubble injection into a vertical double tube heat exchanger, air bubble was injected through 0.5 mm holes diameter and (2, 4, 6, 8, 10 LPM) air flow rate, cold water was ranged as (1.5, 1.25, 0.75 LPM) and 0.25 LPM), and hot water was kept constant at 1.5 LPM, injected air bubbles led to make turbulence inside flow and temperature difference that is a great factor that heat transfer depends on it, air injection can enhance heat transfer rate by 30 %. Shahid Mahdi Talib et al. [5] presented an experimental study of the effect of injected air bubbles into the horizontal shell and tube heat exchanger, the air was injected inside the shell with 0.06kg/s, and hot water flow rate changes along the experiment as (4, 5.25, 6.5, 7.65, 8.9, 10.1, 11.3, 12.5 LPM) and cold water maintain constant at 4 LPM. Nu number enhanced in the shell with air injection 25.5 %, heat transfer rate enhanced by 4.25 % in shell, 8.42 % in a tube and 13.63 % in shell and tube together.

Abdulrasool et al. [6] clarified experimentally enhanced heat transferred in double tube heat exchanger by turbulator perturbations and injection air bubbles. Reynold's number changed between 5000-17000. Nu number enhanced from 19 % to 26 % and the friction factor was raised from 36 % - 43 %.

In line with previous studies, the current research discusses the possibility of increasing the rate of heat transfer in an adiabatic double tube heat exchanger by

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injecting air bubbles through a PTFE ring tube with (36 holes) placed at the base of the outer tube of the heat exchanger, Bubbles mixed with cold water. Also, the novelty of the present study summed up by that, this research explored how heat exchanger thermal performance is impacted by changing air flow rate amount, annulus side flow rates, and the tube side flow rate which at that point differs from previous studies.

2- Experimental Work

The experimental facility was sketched in Fig. 1, schematic which consists of:

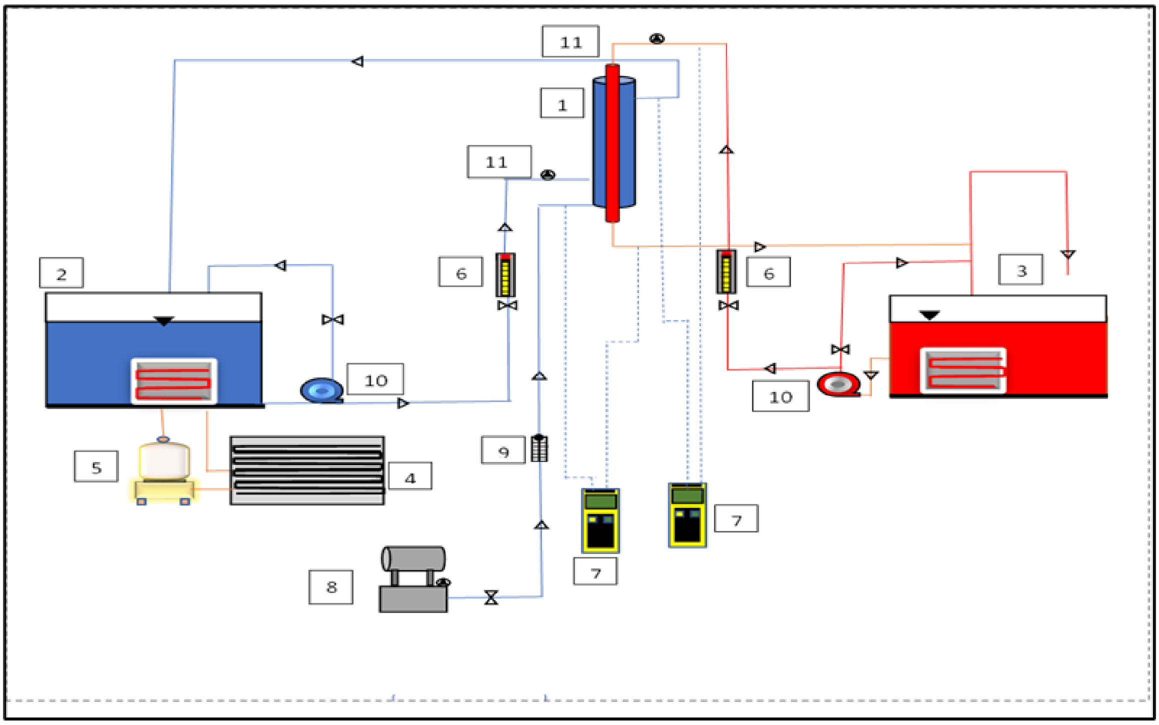

Fig. 1. Experimental Schematic, 1, Double tube heat exchanger; 2, Cold water tank;3, Hot water tank;4, condenser;5, compressor;6, water flow meter;7, Temperature data logger;8, Air compressor;9, Air flow meter;10, water pump;11, inlet pressure gauge;12, outlet pressure gauge

2.1. Test Section

Is made up of two concerned tubes placed at vertical planes, see Fig. 2, thermally isolated by glass wool to prevent heat losses to the environment. All dimensions of the heat exchanger are illustrated in Table 1. The outer tube was made of Perspex while the inner tube was made of copper.

2.2. Cooling Unit

Water is being cooled in a 250 L cold water tank. water would be cooled in a compression refrigeration unit (condenser, expansion valve, evaporator, and compressor) to a temperature close to 17°C and then pumped to the outer tube of the heat exchanger.

2.3. Heating Unit

A cylindrical tank with a capacity of 60 L was used to save hot water, which included an electrical heater for heating water and to control temperature and keep it at 70°C thermostat was used. Hot water is pushed into the central tube with a 3 LPM mass flow rate that is measured by a water flowmeter before being pushed into the heat exchanger and then returned to the hot water tank.

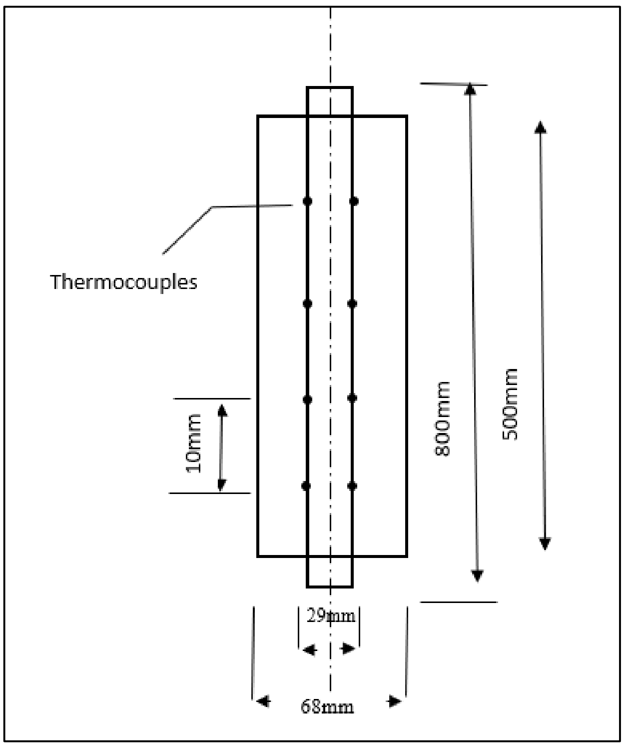

Fig. 2. Schematic of Double Tube Heat Exchanger

Table 1. Dimension of Double Tube Heat Exchanger

Parameter	Shell	Tube
Inside diameter	66	28
Outside diameter	68	29
Material	Perspex	Copper alloy
Length(mm)	500	800

2.4. Air Bubbles Injection Technique

Tiny bubbles were created inside the annulus region, by using a PTFE ring tube placed at the bottom of the heat exchanger with a diameter of 57 mm and with several holes equal to 36 holes distributed at an equal distance on the circumference of the ring, each hole have a diameter 0.3 mm. The air compressor was used to push air with an environment temperature of 25°C into the outer tube mixed with cold water. Specifications of the ring are illustrated in Table 2.

Table 2. Specification of Ring

Test	Diameter of ring (mm)	Holes number	Holes diameter(mm)
Ring	57	36	0.3

3- Test Procedure

Before starting work, it must ensure no leakage occur in the test rig and that all parts are isolated accurately to complete the heat exchange process perfectly. The first step was select the temperature difference by operating cold and hot systems, measured the inlet temperature of hot and cold water by using Four thermocouples K-Type were used to measure inlet and outlet temperatures of cold and hot water, and 16 thermocouples were distributed along the heat exchange surface, each four thermocouples was placed at 100mm from the bottom of the heat exchanger, all thermocouples connected to 12-channel Datta logger Lutron BTM-4208SD. Then these cold and hot water was circulating through pipes used to transport water from the tank to the heat exchanger, and all pipes were isolated by rubber foam insulation. Water circulates by using Two pumps were used to push cold water from the tank to the outer tube of heat exchanger and hot water from the tank to the inner tube of the heat exchanger. The specification of the pumps was the same for two pumps; voltage (220 V), maximum height (30 m), power (370 W), and maximum discharge (30 LPM).

The next step was controlling the flow of water by valves were used and measuring their specific flow rate by Two flowmeters type (ZYIA-LZM) with range 2-18LPM and accuracy $\pm 4\%$ was used to measure the mass flow rate of hot and cold water before entering the heat exchanger tubes, and preparing the air compressor with an air flowrate controller to one air Rotameter type (MATHESON SLPM-U310) with range 0.5-6 LPM was used to measure the volumetric flow rate of air, and then supplying the air to ring and let mixing with cold water done, test condition illustrated in Table 3. Work was done firstly without air, and the heat exchange reached the steady state condition after 15 minutes. Heat exchange occurs and measurement was read from the PC of the data logger, the measurement will intake along heat exchanger. This process will repeat for each cold and air flow rate.

Table 3. Test Condition

Case	Cold water flow rate (LPM)	Hot water flow rate (LPM)	Air flow rate (LPM)
1. Without air injection	3,3.5,4,4.5,5	3	0
2	3,3.5,4,4.5,5	3	0.5
3	3,3.5,4,4.5,5	3	1
4	3,3.5,4,4.5,5	3	1.5
5	3,3.5,4,4.5,5	3	2

4- Data Reduction Equation

4.1. Calculation of overall heat transfer coefficient

For double tube heat exchanger at counter flow, the calculation can be made to determine the heat transfer amount by Holman [7].

$$Q_h = \dot{m}_h C_{ph}(T_{h,in} - T_{h,out}) \quad (1)$$

$$Q_c = \dot{m}_c C_{pc}(T_{c,in} - T_{c,out}) \quad (2)$$

The average of the total heat transfer rate Q_{ave} is calculated as follows:

$$Q_{ave} = \frac{1}{2}(Q_h + Q_c) \quad (3)$$

Where Q_{ave}, Q_h and Q_c represent average, hot, and cold heat transfer rate (Watt), respectively $\dot{m}_c$ are hot and cold mass flow rate (LPM), respectively. C_{ph} and C_{pc} are specific heat capacity for hot and cold water.

$T_{h,out}$ and $T_{c,out}$ = hot and cold-water outlet temperature (°C), $T_{h,in}$ and $T_{c,in}$ = hot and cold-water inlet temperature.

Overall heat transfer unit (U) can be calculated by equation but firstly we need to calculate the logarithmic mean temperature between inlet and outlet for both liquids [8].

$$U = \frac{Q_{ave}}{A\,\Delta T_{LMTD}} \quad (4)$$

Where LMTD is a temperature difference in logarithmic terms, it's computed in the following equation:

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

For counterflow:

$$\Delta T_{in} = T_{hi} - T_{ci} \quad (6)$$

$$\Delta T_{out} = T_{ho} - T_{co} \quad (7)$$

$$\Delta T_{LMTD}=\frac{\Delta T_o-\Delta T_i}{\ln(\frac{\Delta T_o}{\Delta T_i})} \quad (8)$$

The surface area of the tube calculated from the equation:

$$A_s=\pi d_i L \quad (9)$$

4.2. Calculation of the number of thermal units

The number of heat transfer units (NTU) of a double tube heat exchanger can be calculated as follows:

$$NTU=\frac{A\,U}{C_{min}} \quad (10)$$

Where C_{min} is described as follows:

$$C_{min}=\min(\dot{m}_c C_{p,c}, \dot{m}_h C_{p,h}) \quad (11)$$

4.3. Effectiveness

The subscripts on the effectiveness symbols designate the fluid that has the minimum value of $\dot{m}$, for the counter-flow exchanger [9]:
Also, the general equation of the effectiveness can be calculated as follows:

$$\varepsilon=\frac{\text{Actual heat transfer}}{\text{Maximum possible heat transfer}} \quad (12)$$

$$Q_{max}=(\dot{m}C_p)_{min}(T_{hi}-T_{ci}) \quad (13)$$

Effectiveness of heat transfer of cold water can be calculated with:

$$\varepsilon_c=\frac{T_c-T_c}{T_c-T_h} \quad (14)$$

4.4. Reynold number and Nusselt number

The Reynolds number "Re_c" for cold water using the following equation [10]:

$$Re_c=\frac{\rho_c u_c d_{i,c}}{\mu_c} \quad (15)$$

The average Nusselt number of Hot water tubes can be calculated from:

$$Nu=\frac{h\,di}{k} \quad (16)$$

The following equation can be used to obtain friction factor values [11]:

$$f_c=\frac{\Delta P}{(\frac{L}{D})(\frac{\rho_c u^2{}_c}{2})} \quad (17)$$

5- Result and Discussion

The results obtained from experimental designed systems have been provided and analyzed for the study of several parameters such as overall heat transfer coefficient U, number of heat transfer units NTU, effectiveness, pressure drop, friction factor, and Nusselt number. Due to air bubbles stirring up the liquid, which accelerates the removal of heat from the heat transfer surface [12].

Fig. 3 show the variation of overall heat transfer U with different cold water and air flow rates at the constant hot flow rate. Results found that the overall heat transfer coefficient was increased at all conditions of cold-water mass flow rate, maximum enhancement value of U was 41% at (Q_c = 5 LPM) and with air flow rate (Q_a = 1.5 LPM), heat transfer increased as a result of natural vertical mobility of bubbles from the bottom side towards the top side because of buoyancy force this contributed to destroy the thermal boundary layer that formed around the hot water tube which led to increasing heat transfer rate.

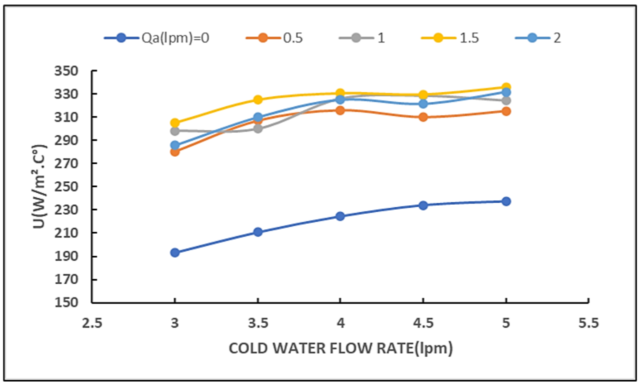

Fig. 3. Variation U with Cold Water Flow Rate

Fig. 4 Shows the variation of(U_{tp}/U_{sp}), with void fraction at different cold flow rates and constant hot flow rate (Q_h=3LPM). Where U_{tp} mean value of overall heat transfer in case of air injection and U_{sp} mean value of overall heat transfer in case without air injection, the figure shows that the ratio of (U_{tp}/U_{sp}) clearly increases as the amount of cold water flow rates, then present maximum value was equal to 1.58 clear at (Q_c=3 LPM), air needed to create the greatest improvement in(U_{tp}/U_{sp})can be represented as 1.5LPM. Due to thermal enhancement brought on by the air bubbles augmentation approach, all ratios of (U_{tp}/U_{sp})are greater than unity.

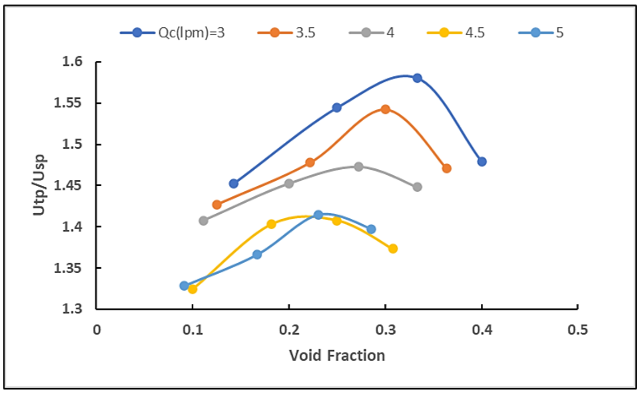

Fig. 4. Variation of $\mathbf{U_{tp}/U_{sp}}$ with Volume Fraction

As seen in Fig. 5 number of heat transfer unit NTU changes with changes in cold water and air flow rates, there are significant increases in NTU, at all studied flowrates the maximum enhancement occurs at (Q_c =5 LPM) and (Q_a= 1.5 LPM), NTU enhanced by 49% compare with the case without air injection.

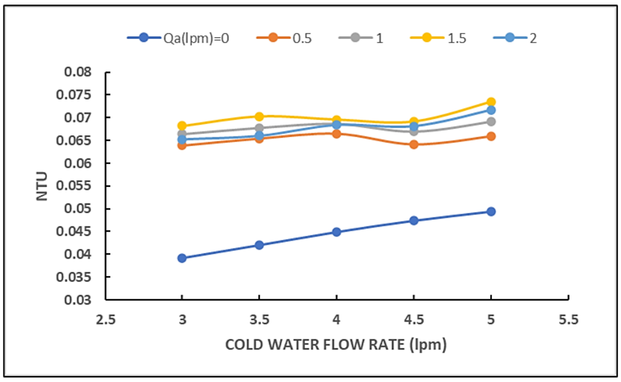

Fig. 5. Variation NTU with Cold Water Flow Rate

Fig. 6 illustrates the effectiveness variation with cold water and airflow rates. The result finds that effectiveness increases with an increase in cold water as a result of an increase in Reynolds number which means an increase in turbulators that causes an increment in heat transfer rate, air bubbles injection can enhance effectiveness by 44%.

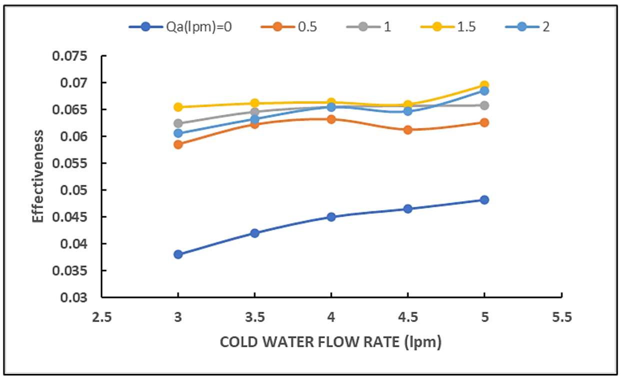

Fig. 6. Variation of Effectiveness with Cold Water Flow Rate

Fig. 7 focused on the effect of air bubble injection on the pressure drop and the effect of changing the inlet of cold-water flow rate, in all values of air bubble injection pressure drop increases, where air plays a good turbulator which increases the pressure drop until reaches maximum value was obtained from inject 2 LPM of air in 5 LPM of cold water and pressure drop was increased with increase cold water flow rate as a result of increasing velocity inside the tube [13].

In this context Fig. 8 show the enhancement Nusselt number by injecting different air flow rates through different cold water flow rate. The results show that the Nusselt number value was increased with an increase in Reynold number and air flow rates, and the maximum enhancement value was 45.2% compared to case without air injection.

Nusselt number value depends on the heat transfer coefficient value [14] that is affected directly by air bubble injection. so, the Nusselt number was increased in the present study due to an increase in heat transfer coefficient.

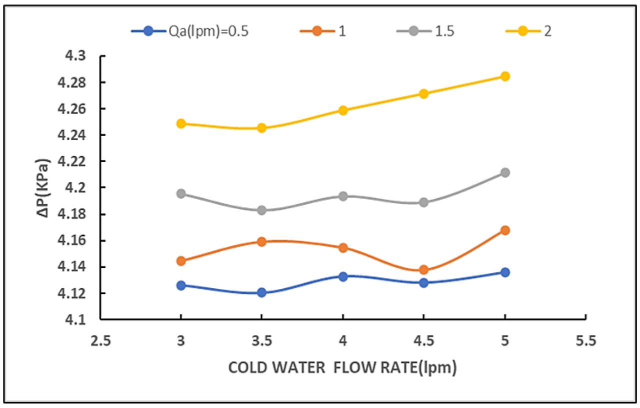

Fig. 7. Variation of Pressure Drop with Cold Water Flow Rate

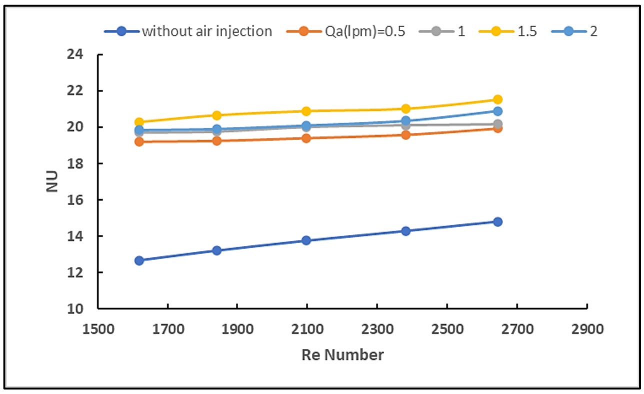

Fig. 8. Variation Nusselt Number with Reynold Number

The enhancement ratio of the Nusselt number in the case of air injection to the Nusselt number in the case without air injection (NU_{tp}/NU_{sp}) variation with Reynold number was clarified in Fig. 9 The enhancement ratio was decreased with the increase in Reynolds number and the enhancement ratio increased with increase air flowrate, maximum enhancement value was 1.60 at (Q_a =1.5 LPM) flow rate of air so, air bubbles injection increases the enhancement ratio of Nusselt number.

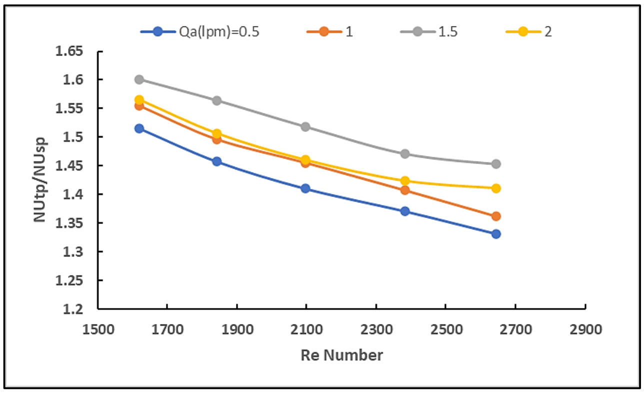

Fig. 9. Variation of $\mathbf{Nu_{tp}/Nu_{sp}}$ with Reynold Number

The friction factor modified in Fig. 10 found that the friction factor was decreased with an increase in cold water flow rate while increased with an increase in air flow rate due to increasing turbulator with air injection which led to an increased friction factor value [10].

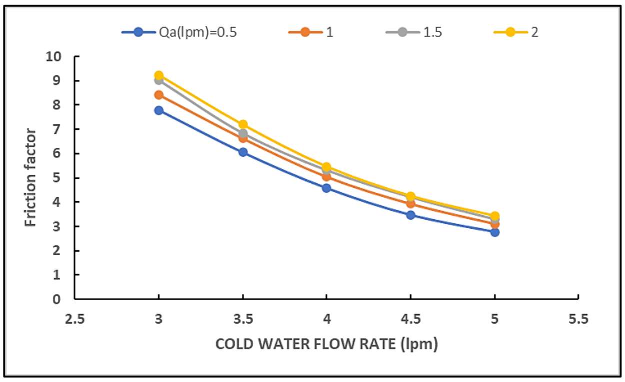

Fig. 10. Variation Friction Factor with Cold Water Flow Rate

Fig. 11 shows the effect of injecting air bubbles through the ring inside the vertical double tube heat exchanger, a comparison between cases without air injection with cases with air injection, which shows that overall heat transfer was increased through case air injection and increased with increased cold water flow rate.

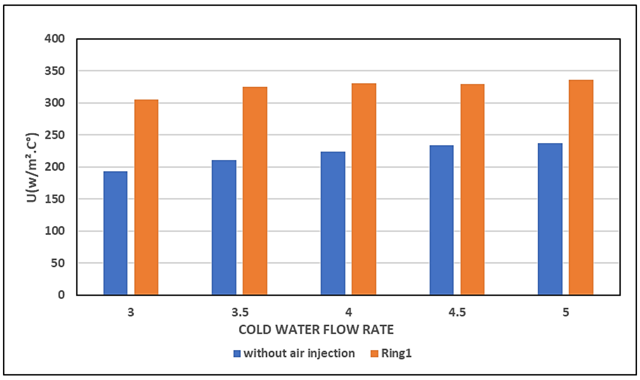

Fig. 11. Comparison between U of Two-Phase Flow with Single-Phase

To verify the experimental finding, the result of the present study was validated with the previous study, as seen in Table 4. The result appeared to agree with the mentioned study.

Table 4. Compares the Results between the Present Study and Other Current Study

Ref	Flow rate LPM	Number of holes	orientation	Shell diameter(cm)	Length (cm)	finding
[3]	Shell=4.6-14.8 Tube=5.5 Air=5	36	vertical	6.2	58.7	Nu=69 Nu_{tp}/Nu_{sp}=1.6 ε=0.16
Present study	Shell=3-5 Tube=3 Air=0.5-2	36	vertical	6.6	50	Nu=22 Nu_{tp}/Nu_{sp}=1.61 ε=0.076

6- Conclusion

The following conclusion can be summarized as follows;

1. Air bubble injection was an effective method for improving the thermal performance of the heat exchanger.
2. Overall heat transfer coefficient increases with an increase in cold water flow rate and air flow rate. Maximum enhancement in U was 41% compared with the case without air injection.
3. Number of heat transfer units enhanced by 49% at (Q_a=1.5 LPM).
4. Air bubble injection makes significant enhancement in effectiveness which is equal to 44%.
5. The maximum value of the Nusselt number was obtained when injecting (Q_a= 1.5 LPM) inside (Q_c= 5LPM). Nusselt number enhanced by 45.2%.
6. The enhancement value of (Nu_{tp}/Nu_{sp}) was increased with an increase in air flow rate, a maximum enhancement ratio of 1.60 was obtained from (Q_a=1.5 LPM) of air, and the enhancement ratio was decreased with an increase in cold water flow rate.
7. Pressure drop was increased with increased air flow rate, and maximum pressure drop value occurred at (Q_a= 2 LPM).
8. Due to the effect of air bubbles injection, the friction factor was increased with an increased air flow rate, and with an increase in cold water flow rate, the maximum friction factor was obtained from inject (Q_a=2LPM) in (Q_c=3LPM).

Nomenclature

A area, m²
C_p constant value
Q heat transfer rate
Nu Nusselt number
NTU number of heat transfer unit
K thermal conductivity (W/m. K)
h heat transfer coefficient (W/m². K)
LMTD logarithmic mean temperature difference, K
f friction factor
L length, m
d diameter, m
U overall heat transfer coefficient
ṁ mass flow rate, (kg/s)
Re Reynold number
T Temperature, K

Greek symbols

μ Dynamic viscosity, kg/m. s
ρ Density, kg/m³
ε Effectiveness

Subscript

i inside
o outside
Ave average
tp two-phase flow
sp single phase
in, c inlet cold water
out, c outlet cold water
in, h inlet hot water
out, h outlet hot water

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التحليل التجريبي لتعزيز نقل الحرارة في مبادل حراري مزدوج الانبوب بحقن الهواء

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١ جامعة بغداد، كلية الهندسة، قسم الهندسة الميكانيكية، بغداد، العراق

الخلاصة

في العديد من المصانع حول العالم، تعتبر المبادلات الحرارية اداة صناعية مهمة جدا، تهدف الدراسة الى تقليل حجم المبادل الحراري من اجل تطوير مبادلات حرارية صغيرة وذات اداء عالي وذلك لان مساحة المبادل مهمه جدا لمعظم المصانع والاعمال اليوم تم استخدام طريقة فعالة وهي حقن الهواء لتحسين انتقال الحرارة في مبادل حراري مزدوج، تراوح معدل تدفق الماء البارد للمبادل الحراري (٣,٣,٥,٤,٤,٥,٥لتر/دقيقة) مع درجة حرارة ١٧درجة مئوية، بينما ضل الماء الساخن ثابتا عند (٣لتر/دقيقة) وعند ٧٠ درجة مئوية، وتم حقن الهواء بكميات (٠,٥,١,١,٥,٢ لتر/دقيقة). اظهرت النتائج ان نقل الحرارة الكلي قد تم تعزيزه بنسبة(٤١%)، الفعالية عززت بنسبة (٤٤%)، عدد وحدات نقل الحرارة NTU (٤٩%)، ورقم نسلت تم تحسينه بنسبة (٤٥,٢%).

الكلمات الدالة: مبادل حراري مزدوج الانبوب، تعزيز نقل الحرارة، حقن فقاعات الهواء، عدد وحدات نقل الحرارة (NTU)، معامل نقل الحرارة الكلي(U)، الفعالية.