BNUT

Iranica Journal of Energy & Environment
Journal Homepage: www.ijee.net
IJEE an official peer review journal of Babol Noshirvani University of Technology, ISSN:2079-2115

Air Injection's Effect on a Vertical Tube with Helical Corrugation: An Empirical Investigation

A. Bagheri[1], S. Karimian Aliabadi[2]*, F. Ommi[2], K. Ghaemi Osgouie[1]

[1] *Aerospace Engineering Department, Kish International Campus, University of Tehran, Kish, Iran*
[2] *Aerospace Engineering, University of Tarbiat Modares, Tehran, Iran*

P A P E R I N F O

Paper history:
Received 12 September 2023
Accepted in revised form 30 January 2024

Keywords:
Air injection
Cost-benefit ratio
Helicoidal corrugations
Nu number
Pressure drop

A B S T R A C T

Herein, a non-boiling two-phase flow containing air and water through a downward flow in a vertical tube with helical corrugations has been investigated. In this simulation, various flow rates for air and water are considered, and three corrugation pitches 1, 1.5, and 2 cm are included. It can be seen in the results that the pressure drop values decrease with an increase in volume fraction. It should be noted that the reduction of pressure drop values with the reduction of volume fraction (VF) is based on the reduction of the water flow rate, which is visible. By comparing the pressure drop values for each corrugation pitch, it can be seen that as the pitch decreases, the pressure drop values increase significantly. The results for Nusselt number show that Nusselt number decreased with an increase in the volume fraction. By reducing the water flow rate, the intensity of the main flow is reduced the intensity of turbulence is also reduced and the heat transfer coefficient is reduced. Ultimately, the cost-benefit ratio has been utilized to show real results for each studied case.

***doi**: 10.5829/ijee.2024.15.04.02*

INTRODUCTION

Heat exchangers are one of the widely used equipment in industrial units, especially power generation industries. The ever-increasing price of fuel and energy carriers and the need to use efficient methods to increase productivity have forced researchers to use new methods to increase productivity in the equipment. In recent years, special attention has been paid to the use of bubble injection to increase the amount of heat transfer in heat exchangers. The use of sub-millimeter bubble injection on the shell side, regardless of the flow pattern, increases the efficiency and heat transfer coefficient; also increases the pressure drop in the shell heat exchangers, horizontal and vertical spiral tubes (1, 2).

On the other hand, the change in the structure of the pipes is also a matter that can help in increasing heat transfer. Among these changes, we can refer to the creation of corrugation on the surface of the pipe. corrugated pipes are used in a wide range of industries, including food industries, energy industries, chemical industries, etc. due to their high efficiency in heat transfer, suitable structure, suitable compression, and flow stability. It should be noted that the two-phase flow in corrugated pipes can have complicated features compared to smooth pipes. Various studies have been conducted in the field of knowing the characteristics of two-phase flow and the flow regime in smooth pipes. Studies in the field of two-phase flow in vertical pipes to check the flow regime have shown that two-phase flow in all pipe forms, including horizontal, vertical, angled and helical, both ascending and descending flows, bubble flow, and slug flow has always been observed (3). For sake of the title's importance, considerable investigators worked on these topics. Cao et al. (4) studied the corrugated tubes in two-tube helical converter. The exergy and energy studies of the system under his investigation showed that the new geometry provided could improve the thermal performance of the converter. Fang et al. (5) also conducted laboratory work related to

*Corresponding Author Email: karimian@modares.ac.ir
(S. Karimian Aliabadi)

Please cite this article as: Bagheri A, Karimian Aliabadi S, OmmiF, Ghaemi Osgouie K. Air Injection's Effect on a Vertical Tube with Helical Corrugation: An Empirical Investigation, Iranica Journal of Energy and Environment, 2024, 15(4):338-46. Doi: 10.5829/ijee.2024.15.04.02

corrugated tubes and investigated heat transfer in them.

Kim and Ghajar (6) carried out experimental research to study the flow patterns and frictional thermal properties of gas/liquid two-phase flow in a horizontal straight pipe. They reported that addition of a gas phase to a liquid flow increases the interaction, which leads to a level of turbulence and mixing, leading to an increase in the heat transfer rate. In another study, they (7) developed an empirical equation to predict the two-phase flow coefficient inside a horizontal tube for heat transfer. Their study aimed to provide a correlation that could predict the heat transfer coefficient over the entire range of flow patterns in a horizontal pipe. They presented new correction factors to correct the previously proposed correlations. Lopez et al. (8) conducted an experimental and numerical study and investigated the characteristics of gas-liquid two-phase flow inside horizontal pipes. The smooth tube was studied by Thaker and Banerjee (9). They proposed new correlations to predict flow characteristics. Alternating flow and gas/liquid two-phase flow characteristics inside a loop were studied by Ibarra et al. (10, 11). Their results showed that slug flow is the most dominant form of two-phase flow that occurs in the mentioned annular direction. Investigations showed that the direction and shape of the pipes have a significant effect on the characteristics of the two-phase flow.

An experimental investigation on the flow layouts and frictional thermal aspects of gas or liquid 2-phase flow in a straight pipe was conducted by Kim and Ghajar (6). The scientists noted that when a gas phase is added to a liquid flow, the action and response are increased. This causes some turbulence and mixing, which raises the rate at which heat is transferred. Kim and Ghajar (7) created an empirical formula in a different study to forecast the 2-phase flow coefficient for heat transfer in a straight pipe. They set out to establish a correlation in order to determine the heat exchange coefficient throughout the whole spectrum of flow patterns in a straight pipe. In addition, fresh correction factors were introduced to rectify the correlations that were previously proposed by Lopez et al. (8) experimental and numerical investigation. They looked at the characteristics of two-phase gas-liquid flow in straight tubes. Tucker and Banerjee (9) investigated the smooth pipe in the interim. In order to anticipate flow properties, they proposed additional correlations. The effects of nanoparticles and variations in tube diameter on spiral shell and tube heat exchanger heat transfer coefficients were studied by Abazari et al. (12). The forced convection heat transfer and cryogenic cooling in single-phase fluid flow systems were the two systems for which MATLAB code was used to conduct the CFD study and create the model of the previously described heat exchanger. Concerning solar collector tubes, Sundari et al. (13) worked; they conducted experimental research on boiling phenomena in these tubes. They investigated how several factors affected the effectiveness of the system. According to Bagheri et al. (14) in another study, boiling as a new subject is appropriate for a variety of industrial and scientific purposes, such as electric refrigeration, batteries, heat treatment in nuclear power plants, refrigeration equipment, rocket equipment, and so on. Three-dimensional analyses were performed on sidewall steam and air at the same temperature. To do this, they first examined the nuclear boiling type of boiling's temperature forecast. The evaporation characteristics of dormant droplets on a hydrophobic surface in non-boiling mode at a constant temperature were investigated in the work of Liu et al. (15). The findings demonstrated that during droplet evaporation on a hydrophobic surface, droplet evaporation duration has a negative connection with surface temperature but a positive relationship with initial surface size and hydrophobicity. According to Luo et al. (16), there is a dearth of knowledge in the literature about the mechanics of heat transfer in non-boiling areas during seismic activity. Their study closed this gap by employing the Lagrangian-Euler approach to statistically investigate the spray-cooling behavior of heat transport under vibration in jointless regions. Vibrating hot surface tester spray heat transfer data were used to verify the computational fluid dynamics (CFD) model.

Based on studied papers, it can be found that using corrugated pipes and non-boiling two-phase flow as tools to improve heat transfer and efficiency has never been investigated and no experimental, numerical, or analytical study has been done. So from this point of view, there are no valid experimental results for the use of those interested. This has been done well in this article so that the obtained results can unravel the work of researchers in this field. In this experimental work, both fields of non-boiling two-phase flow and grooved pipe structure were investigated.

EXPERIMENTAL SETUP

To implement this project, an experimental system will be designed and implemented as described below. Then, the studied cases will be examined using the primary data obtained from the laboratory system. The general system used for the experimental setup is shown in Figure 1. The laboratory system consists of 2 or three main parts. The first part is related to the flow of water. City water after being filled in a chamber is pumped to the tank of a circulator pump. It is used in order to precisely adjust the placement. Then, a bypass is used to measure the flow rate of water from 2 flow-regulating valves, one in the main direction and the other in the direction of the water rotameter for the flow rate.

In the second part, the airflow is provided by a compressor, and after being regulated by 2 air valves, it enters the mixing chamber. The volume flow rate of air is measured by an air rotameter. The third part is related to

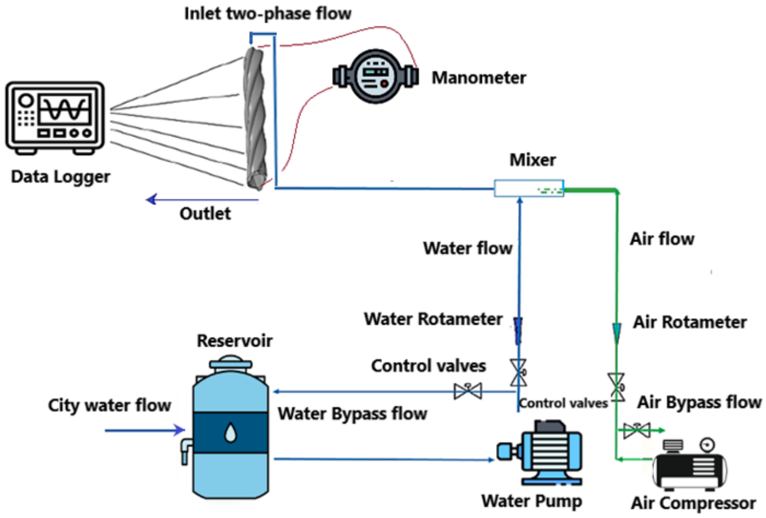


Figure 1. Proposed test section schematic

the testing chamber. The testing chamber consists of a corrugated copper tube that is subjected to constant thermal flux. Heat flux is applied to the tube by wire heaters that are rotated around the tube. To ensure the stability of the thermal flux, a dimmer is used to regulate the applied voltage. In order to check the heat transfer coefficient and the entropic behavior of the 2-phase flow, the temperature of the pipe surface, the temperature of the fluid at the inlet and outlet, and also the ambient temperature are measured by thermal thermocouples. To reduce heat loss, a layer of glass wool is used as insulation. It is worth mentioning that the laboratory data are recorded after the system reaches a thermally stable state.

It should be noted that the airflow will be supplied by a compressor with a power of 1.2 horsepower. The flow rate of the air entering the testing chamber will be measured by a rotameric flow meter (model KHL-08A01M-V). As shown in Figure 1, the 2 streams of water and air are then mixed in a mixing chamber. Figures 2 and 3 show the overview of the mixing chamber. As shown in Figure 2, the end of the tube carrying the airflow is closed, to inject the airflow, 20 holes with a diameter of 0.3 mm will be created in 2 rows of 10 at the end of the tube. These 2 rows will have an angle of 180 degrees. After exiting these holes, the airflow will mix with the water flow and form a non-boiling 2-phase flow of water and air. The air-water mixture flow then passes through a 0.7-meter pipe, which is considered for the thermal balance of the air-water flow (it is assumed that the air-water flow may have a temperature difference at the beginning, this distance is equal to this It is considered that all the heat transfer in the testing chamber is from the heat produced by the thermal element and the heat exchange between the 2 fluids is negligible) into the testing chamber. It is necessary to explain that to check the changes in the forced convection heat transfer coefficient, the inlet and outlet temperature of the water-air mixture and the pipe surface temperature will be measured. The temperature of the mixture will be measured by K-type penetrating sensors (designed for liquid flow), and the surface temperature by K-type surface sensors (designed to measure surface temperature). A Lutron brand 12-channel data logger (Lutron-BTM4208-SD) will also be used to record and display temperatures (temperature sensors are connected to the data logger). To check the amount of pressure drop, a Lutron brand digital pressure drop gauge (Lutron-PM9100) is used. 2 pressure drop detection sensors will be installed at the beginning of the tube and the end of it. Table 1 summarized the characteristics of the measurement instruments.

The present study is designed in such a way that for the upward flow (in this case, the buoyancy force on the bubble and the inertial force of the liquid flow act in the same direction) and the effect of air and water flows (mixing ratio, which has a direct effect on the flow pattern) has, the changes in the flow determine the effect of the inertial force of the flow) and the effect of the changes in the corrugation pitch in the formation of the flow pattern and heat transfer will be investigated. Table 2 briefly shows how to investigate the effect of the mentioned parameters on the thermal behavior and flow pattern of the helical pipe. It is worth mentioning that in this study, air bubbles will be injected into the water flow to form a 2-phase flow. A glass tube will be used to observe the flow in each step in order to check the flow regime. A Canon SX 530 model camera is used to view the stream and record images. To check the thermal behavior, a copper tube, which will be equal to the glass samples in terms of geometrical characteristics, is subjected to a constant thermal flux (the amount of thermal flux will be less than the critical flux required for boiling to ensure the non-boiling current will be placed.

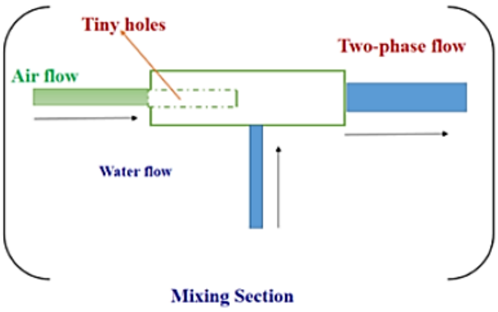
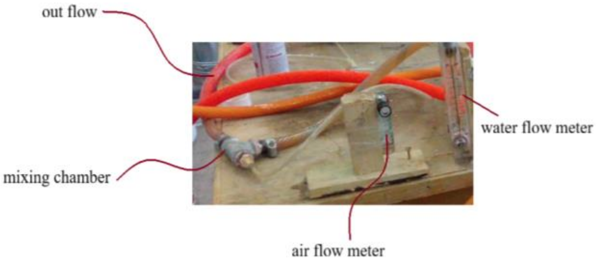
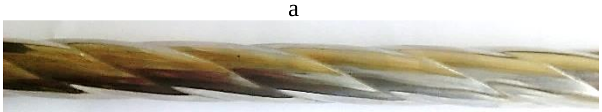


Figure 2. Mixing chamber



a



b

Figure 3. General view of a) utilized experimental setup and b) corrugated tube

Table 1. Characteristics of the measurement instruments

Name	Type	Error
Air rotameter	KHL-08A01M-V	±2 %
Thermal sensor	K-type	±0.1 ºC
Data logger	Lutron-BTM4208-SD	±0.2 %
Pressure drop gauge	Lutron-PM9100	±0.1 %

Table 2. Initial conditions

Helical corrugation pitch (cm)	Water flow rate (Lit/min)	Airflow rate (Lit/min)	Flow orientation	Heat flux (W)
1	2,4,6,8	1,3,5,7	upward	1200
1.5	2,4,6,8	1,3,5,7	upward	1200
2	2,4,6,8	1,3,5,7	upward	1200

Another important issue is the existing uncertainty for the studied parameters. For this purpose, we first mention the uncertainty of the effective parameters:

$\Delta T = 0.000041\ K$

$\Delta P = 0.0001\ bar$

The uncertainty based on the work of Moffat (17) will be as follows:

$$\Delta H = \sqrt{\sum_{i=1}^{N} \left(\frac{\partial H}{\partial X_i}\Delta X_i\right)^2} \quad (1)$$

where $H \approx \frac{P}{T}$

So it will be as:

$$\Delta H = \sqrt{\sum_{i=1}^{N} \left(\frac{\partial H}{\partial X_i}\Delta X_i\right)^2} = \sqrt{\left(\frac{\partial H}{\partial P}\Delta P\right)^2 + \left(\frac{\partial H}{\partial T}\Delta T\right)^2}$$

where:

$$\frac{\partial H}{\partial P} = T$$

$$\frac{\partial H}{\partial T} = P$$

Then for a studied range of T and P, the results for uncertainty will be:

$$\sqrt{(300 * 0.0001)^2 + (1 * 0.000041)^2} = \pm 0.0300$$

$$\sqrt{(310 * 0.0001)^2 + (1.1 * 0.000041)^2} = \pm 0.031$$

$$\sqrt{(295 * 0.0001)^2 + (0.8 * 0.000041)^2} = \pm 0.029$$

Figure 3 represents the utilized experimental setup.

Definitions for used parameters

Two main parameters meaning Nu number and pressure drop are tested in this study. A performance criterion is applied to these parameters to obtain the optimal efficiency points for real usage. Assessing the temperatures of the flow's entrance and exit, and the pipe wall temperature, the heat transfer coefficient is estimated. Using Equation 2, the total thermal energy may be harvested from the fluid flow:

$$q = \dot{m}\, C_P (T_{out} - T_{in}) \quad (2)$$

Having fluid motion leads to a convective form of heat transfer. To obtain the convection heat transfer coefficient, the following equation is used:

$$\bar{h}_{NST} = \frac{q}{A\,(\bar{T}_w - T_b)} \quad (3)$$

Also, Nusselt number (Nu) may be computed by the below equation:

$$Nu = \frac{\bar{h}D}{k_f} \quad (4)$$

where D is the diameter and k_f is the conductive thermal coefficient of the working fluid. The cost-benefit ratio (CBR) is a suitable parameter to check the performance of any heat transfer enhancement method. This parameter is defined as follows:

$$CBR = \frac{\%\left(\frac{\Delta P_i}{\Delta P_0}\right)}{\%\left(\frac{Nu_i}{Nu_0}\right)} \quad (5)$$

RESULTS

Fluid flow features

This section of the paper analyzes the hydraulic performance of the combination of air and water flows inside spiral tubes. Figure 4 shows the changes in pressure loss values according to volume fraction (VF) for pipes with various spiral corrugation pitches. It may be observed that the pressure loss values decrease with an increase in volume fraction. The amount of volume fraction is calculated from Equation 6.

$$VF = \frac{Q_g}{Q_g+Q_l} \tag{6}$$

It is worth noting that the reduction of pressure loss values with the reduction of VF is based on the reduction of the water flow rate, which is visible. It is important to know that reducing the speed of water flow reduces the impact between air bubbles and liquid water packets, as well as the pressure drop. An increase in the speed of the airflow equals an increase in the size of the bubbles and a stronger collision between the bubbles and the water elements. By comparing the pressure drop values for each corrugation pitch, it may be observed that as the corrugation pitch goes down, the pressure drop values go up significantly. This is due to the increased circulation of water in the pipe. As a result, the intensity of vapors increases perpendicular to the main flow of water, which leads to an increase in the intensity of disturbance in the flow, and then the pressure drop increases. It should be noted that the total pressure loss values are presented in Figure 3; the mean values for minimum and maximum pressure drops observed during a 5-minute test period. This period was considered to ensure that the flow has reached its reproducible conditions. It should be mentioned that the pressure drop through combined gas and liquid flows has an oscillating behavior so the results are presented as average values.

Figure 4 represents that through VF increasing the pressure loss encountered with reduction, while the high value of air flow rate causes this parameter to go up. Also, it can be observed that the higher the corrugation pitch, the lower the pressure loss. In Figure 5, the pressure drop ratio is extracted for three corrugation pitches. The ratio of pressure drop is defined as a 2-phase pressure drop (ΔPi) and a single-phase pressure drop (ΔP0). It can be seen that the pressure drop ratio decreases with the increase in volume fraction. More pressure drop ratio occurs in pitch 2 cm.

Heat transfer evaluation

It is necessary to explain that in the process of evaluating thermal behavior, the best parameter is Nusselt number. In fluid dynamics, Nusselt number (Nu) is the ratio of displacement heat transfer to conduction at a boundary in a fluid. This number is a dimensionless number that is closely related to the fluid Reynolds number. Figure 6 shows the behavior of Nusselt number versus volume fraction for different corrugation pitches. The results show that Nusselt number decreased with the increase in volume fraction. Looking at the figures related to Nusselt number, it is easy to see that the curves are drawn for a constant air flow rate. Consequently, an increase in VF is equal to a decrease in the water flow rate. By reducing the water flow rate, the intensity of the main flow is reduced the intensity of turbulence is also reduced and the heat transfer coefficient is reduced. The intensity of the flow turbulence increases with an increase in the airflow speed. It should be noted that when the velocity of the airflow increases, the size of the bubbles also increases (18), resulting in a stronger collision between the air bubbles and the water packets. Also, when the bubbles move inside the tube, they change the boundary layer, which

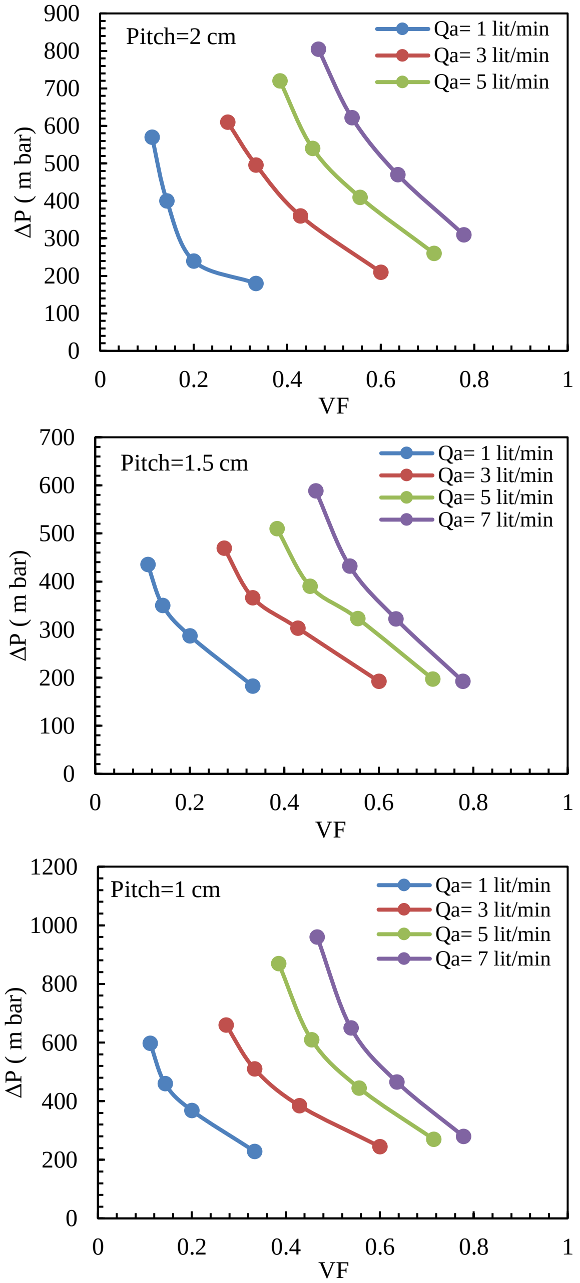


Figure 4. Variation of pressure drop versus volume fraction (VF) for different corrugation pitches

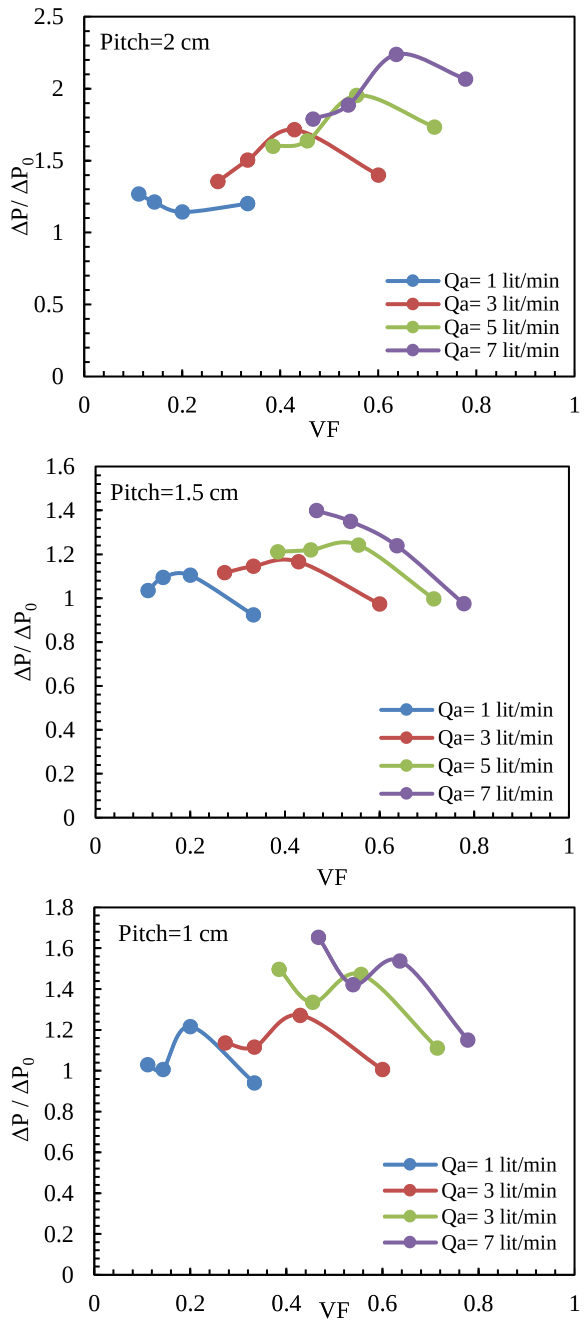


Figure 5. Changing the ratio of pressure drop versus volume fraction

means they interrupt the unified boundary layer in a discrete part and prevent it from strengthening. As the boundary layer remains in the initial conditions, the thickness of the viscous layer decreases. Viscous layers are part of the liquid and since there are very slow movements inside them, displacement has almost no role in heat transfer and is the main conduction mechanism. As a result, by keeping the thickness of the viscous layer small, the thermal resistance of the layer decreases so that the heat transfer increases. The maximum values of Nusselt number correspond to the pipe with the smallest corrugation pitch. Figure 7 shows that the ratio of Nusselt number in the injected air state to that of the base state is almost always greater than one. As a result, the heat transfer rate has increased due to air injection. In fact, with air injection, the effective cross-sectional area for each of the phases is reduced, making them pass faster. On the other hand, the collision of air bubbles with the solid wall of the spiral tube causes the boundary layer to collapse, which increases the heat transfer as mentioned

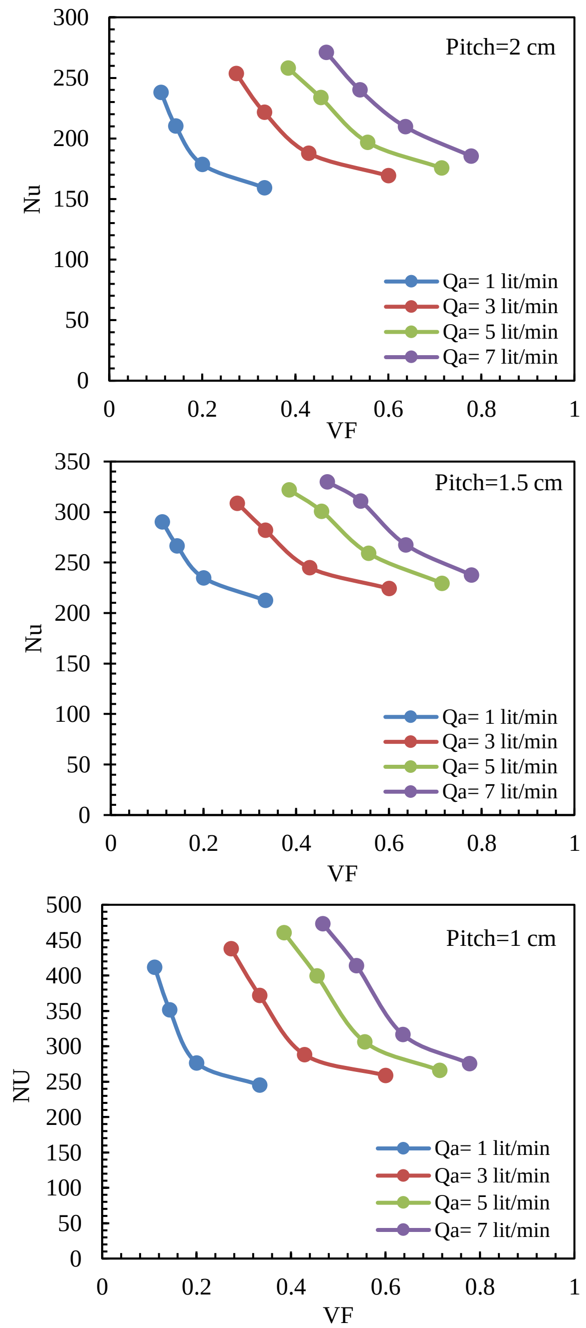


Figure 6. Change of Nusselt number versus volume fraction (VF)

before. Bubbles move in the central area of the tube without any connection with the outer or inner wall of the tube. In these conditions, both sides of the boundary layer are affected by the presence of air bubbles, and the mixing phenomenon increases in both boundary layers (boundary layers created on the inner wall and the outer wall) and heat transfer is improved.

CBR factor assessment

This variable defined in Equation 4, is an operational

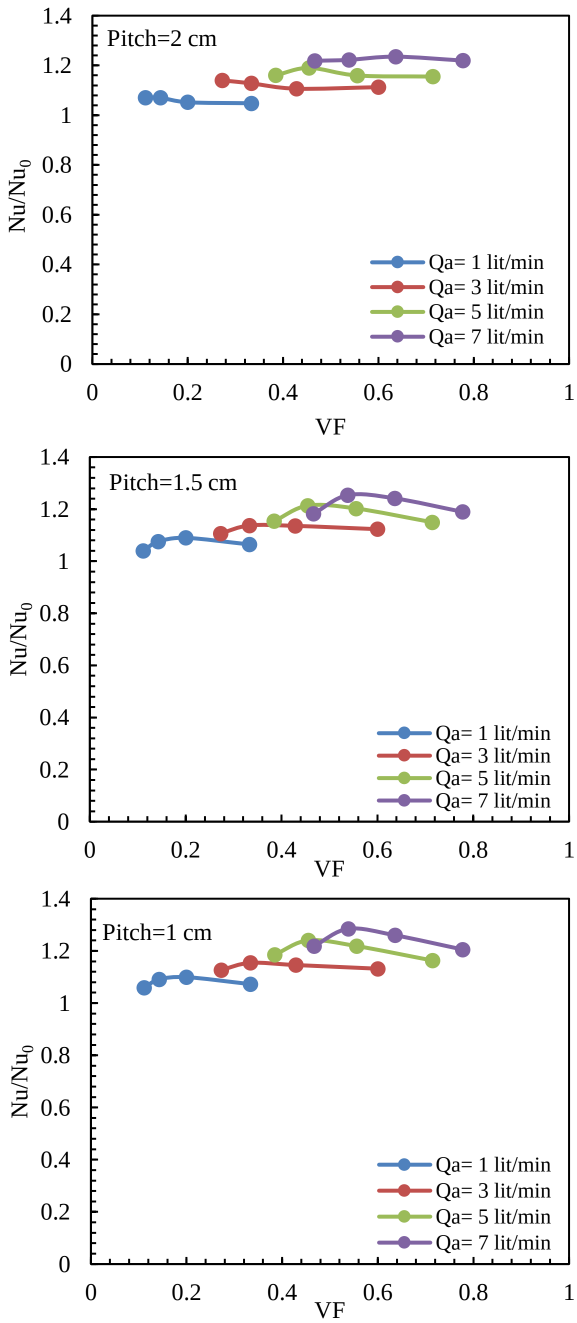


Figure 7. Change of ratio of Nusselt number against volume fraction

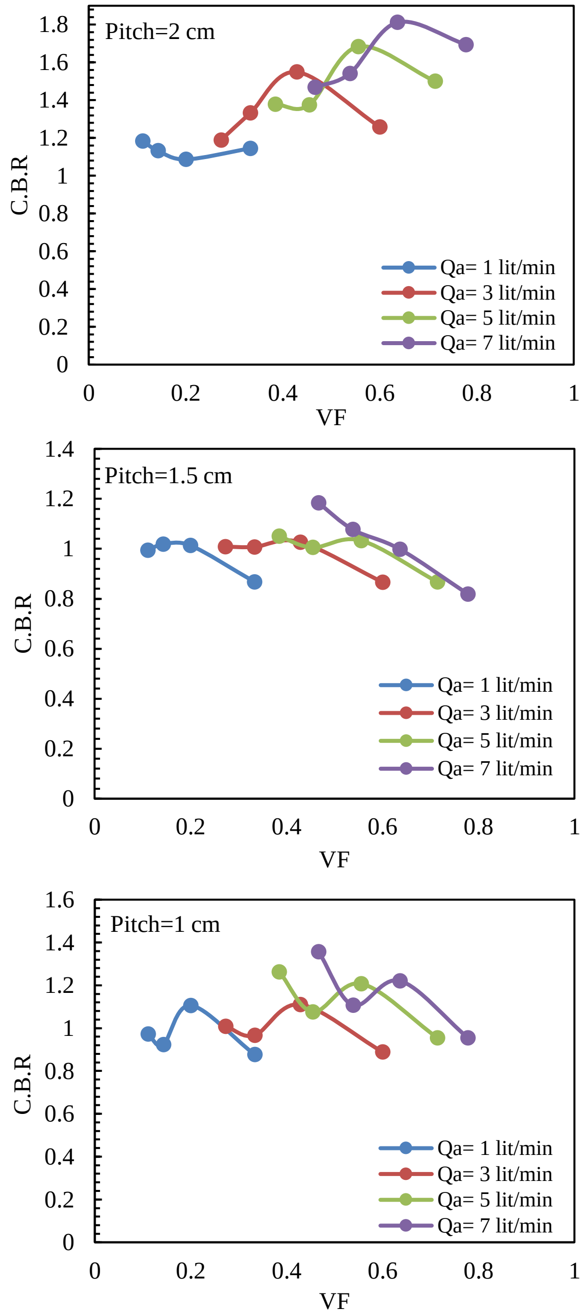


Figure 8. Change of C.B.R factor against volume fraction

was more beneficial than the other corrugation pitch tubes.

parameter and determines whether the considered heat transfer enhancement method is useful or not. Values below one for this criterion indicate that the proposed methodology causes an increase in heat transfer more than an increase in pressure loss. Values greater than one have the opposite meaning. The CBR values manner is shown in Figure 8. The curves are plotted in terms of VF and for different air flow rates as in the previous figures. Pipes with a corrugation pitch equal to 1.5 cm had the best

CBR. factor values (which means the lowest value). This means that air injection in these corrugation pitch tubes

Error analysis

Usually, in engineering sciences, physics, and chemistry, "Observational Error" or "Measurement Error" is considered to mean the difference between the measured value and the actual value. But in statistics, the error is not considered just a mistake in measurement. Changes and errors in the measurement of random phenomena are in their nature. Otherwise, we would not consider such events as coincidences. In laboratory work, error sources can be divided into two main groups:

- Systematic errors: Errors that are not caused by accident and depend on the measurement tools or the measurement process are called systematic errors. In this way, the systematic error lies in the essence of the measurement method or system.
- Random errors: If we repeat the measurement operation several times, the error resulting from this operation is called a random error. Because the conditions and factors affecting the measurement cause inconsistency in recording the correct value for a quantity.

The number of suggested experiments in the CCD plan is 20 for independent input parameters, of which the final 5 experiments are repeated. The purpose of conducting repetitive tests is to prevent human error and to check reproducibility when conducting tests. Based on the data obtained in the 16th to 20th iterations of the tests for the power, the random error is given in Figure 9. It should be noted that the error has been calculated as a percentage of relative error as follows:

$$error\% = \frac{|CBR_{16-20} - CBR_{15}|}{CBR_{15}} \times 100 \tag{7}$$

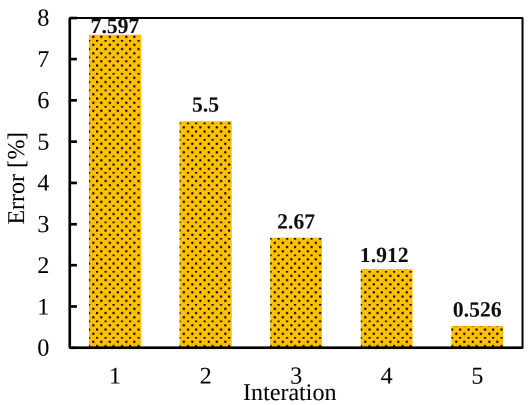


Figure 9. Random error in experiment repetition

CONCLUSION

This research studies the 2-phase non-boiling air and water descending flow in a vertical pipe with a helical corrugation on it. The upcoming study is a laboratory work that studies heat transfer and pressure loss. Four flow rates for air with values of 1, 3, 5, and 7 liters per minute and four flow rates for water with values of 2, 4, 6, and 8 liters per minute are considered, and three corrugation pitches are 1, 1.5, and 2 cm is included in the present study. The main harvests in this work are listed as follows:

- When the volume fraction goes up, the pressure drop comes down. This reduction is more than 70%. It may also be observed that the pressure drop ratio goes down with the increment in volume fraction.
- Nusselt number values have decreased with increasing volume fraction. This reduction is about 31%. While with increasing air flow rate, Nu goes up about 14% on average.
- It should be noted that pipes with a corrugation pitch equal to 1.5 cm had the best CBR factor values (which shows the lowest value). This means that air injection in these corrugation pitch tubes was more beneficial than the others. The best value was 0.86 for VF=0.3 and Qa=1 lit/min

REFERENCES

1. Moosavi A, Abbasalizadeh M, Sadighi Dizaji H. Optimization of heat transfer and pressure drop characteristics via air bubble injection inside a shell and coiled tube heat exchanger. Experimental Thermal and Fluid Science. 2016;78:1–9. Doi: 10.1016/j.expthermflusci.2016.05.011.
2. Khorasani S, Dadvand A. Effect of air bubble injection on the performance of a horizontal helical shell and coiled tube heat exchanger: An experimental study. Applied Thermal Engineering. 2017;111:676–83. Doi: 10.1016/j.applthermaleng.2016.09.101.
3. Godbole P V., Tang CC, Ghajar AJ. Comparison of void fraction correlations for different flow patterns in upward vertical two-phase flow. Heat Transfer Engineering. 2011;32(10):843–60. Doi: 10.1080/01457632.2011.548285.
4. Cao Y, Ayed H, Anqi AE, Tutunchian O, Dizaji HS, Pourhedayat S. Helical tube-in-tube heat exchanger with corrugated inner tube and corrugated outer tube; experimental and numerical study. International Journal of Thermal Sciences. 2021;170. Doi: 10.1016/j.ijthermalsci.2021.107139.
5. Fang Y, Wang Y, Yang H, Lin X. Experimental behavior of concrete-filled thin-walled corrugated steel tubes with large helical angles under monotonic and cyclic axial compression. Thin-Walled Structures. 2022;173. Doi: 10.1016/j.tws.2022.109043.
6. Kim D, Ghajar AJ. Heat transfer measurements and correlations for air-water flow of different flow patterns in a horizontal pipe. Experimental Thermal and Fluid Science. 2002;25(8):659–76. Doi: 10.1016/s0894-1777(01)00120-0.
7. Kim J yong, Ghajar AJ. A general heat transfer correlation for non-boiling gas-liquid flow with different flow patterns in horizontal pipes. International Journal of Multiphase Flow. 2006;32(4):447–65. Doi: 10.1016/j.ijmultiphaseflow.2006.01.002.
8. López J, Pineda H, Bello D, Ratkovich N. Study of liquid-gas two-phase flow in horizontal pipes using high speed filming and computational fluid dynamics. Experimental Thermal and Fluid Science. 2016;76:126–34. Doi: 10.1016/j.expthermflusci.2016.02.013.

9. Thaker J, Banerjee J. On intermittent flow characteristics of gas–liquid two-phase flow. Nuclear Engineering and Design. 2016;310:363–77. Doi: 10.1016/j.nucengdes.2016.10.020.
10. Ibarra R, Nossen J, Tutkun M. Two-phase gas-liquid flow in concentric and fully eccentric annuli. Part I: Flow patterns, holdup, slip ratio and pressure gradient. Chemical Engineering Science. 2019;203:489–500. Doi: 10.1016/j.ces.2019.01.064.
11. Ibarra R, Nossen J, Tutkun M. Two-phase gas-liquid flow in concentric and fully eccentric annuli. Part II: Model development, flow regime transition algorithm and pressure gradient. Chemical Engineering Science. 2019;203:501–10. Doi: 10.1016/j.ces.2019.02.021.
12. Abazari Bahnemiri H, Oloomi SAA, Mirjalily SAA, Zare-Shahabadi A. The Role of Nanoparticles and Different Tube Diameter on Thermal Performance in Shell and Helically Coiled Tube Heat Exchangers with Single Phase and Sub-cooled Boiling Flow. Iranian (Iranica) Journal of Energy and Environment. 2021;12(4):367–77. Doi: 10.5829/ijee.2021.12.04.10.
13. Umayal Sundari A. Performance of Evacuated Tube Collector Solar Dryer with and Without Heat Sources. Iranica Journal of Energy and Environment. 2013;4(4). Doi: 10.5829/idosi.ijee.2013.04.04.04.
14. Bagheri S, Oloomi SAA, Mirjalily SAA, Zare-Shahabadi A. Bubble Dynamics and Nucleate Pool Boiling of Natural Convection. Iranian Journal of Energy and Environment. 2022;13(4):384–97. Doi: 10.5829/ijee.2022.13.04.08.
15. Liu X, Liu L, Yang Y, Liu B, Duan R. Evaporation characteristics of sessile droplets on flat hydrophobic surfaces in non-boiling regime. International Communications in Heat and Mass Transfer. 2023;142. Doi: 10.1016/j.icheatmasstransfer.2023.106614.
16. Luo Z, Liang K, Chen X, Li Z, Wang X, Zhou H, Wang Y. Numerical investigation of the effect of vibration on spray cooling heat transfer in the non-boiling region. Case Studies in Thermal Engineering. 2023;51. Doi: 10.1016/j.csite.2023.103518.
17. Moffat RJ. Contributions to the theory of single-sample uncertainty analysis. Journal of Fluids Engineering, Transactions of the ASME. 1982;104(2):250–8. Doi: 10.1115/1.3241818.
18. Sinaga N, khorasani S, Sooppy Nisar K, Kaood A. Second law efficiency analysis of air injection into inner tube of double tube heat exchanger. Alexandria Engineering Journal. 2021;60(1):1465–76. Doi: 10.1016/j.aej.2020.10.064.

COPYRIGHTS

©2024 The author(s). This is an open access article distributed under the terms of the Creative Commons Attribution (CC BY 4.0), which permits unrestricted use, distribution, and reproduction in any medium, as long as the original authors and source are cited. No permission is required from the authors or the publishers.

Persian Abstract

چکیده

در اینجا، یک جریان دو فاز غیرجوش حاوی هوا و آب از طریق یک جریان رو به پایین در یک لوله عمودی با موج‌های مارپیچ بررسی شده است. در این شبیه‌سازی، دبی‌های مختلف برای هوا و آب در نظر گرفته شده است و سه گام موج دار ۱، ۱/۵ و ۲ سانتی‌متری در نظر گرفته شده است. در نتایج مشاهده می‌شود که مقادیر افت فشار با افزایش کسر حجمی کاهش می‌یابد. لازم به ذکر است که کاهش مقادیر افت فشار با کاهش کسر حجمی (VF) بر اساس کاهش دبی آب است که قابل مشاهده است. با مقایسه مقادیر افت فشار برای هر گام موجدار، می‌توان دریافت که با کاهش گام، مقادیر افت فشار به طور قابل توجهی افزایش می‌یابد. نتایج برای عدد ناسلت نشان می‌دهد که عدد ناسلت با افزایش کسر حجمی کاهش می‌یابد. با کاهش دبی آب، از شدت جریان اصلی کاسته می‌شود، از شدت تلاطم نیز کاسته می‌شود و ضریب انتقال حرارت کاهش می‌یابد. در نهایت، از نسبت هزینه به فایده برای نشان دادن نتایج واقعی برای هر مورد مورد مطالعه استفاده شده است.