IIETA International Information and Engineering Technology Association
Advancing the World of Information and Engineering

Mathematical Modelling of Engineering Problems
Vol. 11, No. 6, June, 2024, pp. 1593-1600
Journal homepage: http://iieta.org/journals/mmep

Heat Transfer Improvement Using Three Types Novel Turbulators Inserts with Two Pitch Ratios in Double Pipe Heat Exchanger

Hisham A. Hoshi[1], Waleed Yousif Shehab[1], Ayad K. Khlief[1], Farhan Lafta Rashid[2*], Awesar A. Hussain[3,4]

[1] Electromechanical Engineering Department, University of Technology, Baghdad 10011, Iraq
[2] Petroleum Engineering Department, College of Engineering, University of Kerbala, Karbala 56001, Iraq
[3] Department of Mechanical Engineering, Faculty of Engineering and Informatics, University of Bradford, Bradford BD7 1DP, UK
[4] Department of Engineering and Construction, Faculty of Engineering and Construction, Bradford College, Bradford BD7 1QX, UK

Corresponding Author Email: farhan.lefta@uokerbala.edu.iq

https://doi.org/10.18280/mmep.110620

Received: 22 August 2023
Revised: 30 October 2023
Accepted: 15 November 2023
Available online: 22 June 2024

Keywords:
heat exchanger, heat transfer enhancement, thermal performance, friction factor

ABSTRACT

The present work experimentally investigates the effect of novel turbulators on improving heat exchanger (HE) performance. Tests are conducted by insertion of three types of turbulators, 3PS, 4PS, and 5PS, including two pitch ratio PR (5-3.76). The results showed that the enhancement in heat transfer (HT) when using 5PS was more than the remaining two types. The greatest worth was at the lowest pitch ratio. The outcomes of experiments showed that the enhancement in the Nusselt number for each type of 5PS, 4PS and 3PS for small pitch ratio was 194%, 177% and 164% more than that of the plain tube, correspondingly. Also, the thermal performance factor, friction factor, and Nusselt number are all increased as the pitch ratio decreases. As a result, the small pitch ratio delivers a more considerable rate of HT and lower loss in friction. In addition, the results showed that the factor of thermal performance was more significant compared to unity for each type studied, and the maximum value of thermal performance factor acquired at η=1.54 is accomplished for the 5PS turbulators. The Correlations between the friction factor and Nusselt number were evolved for the range of Reynolds number (Re) of 12385 to 24766. The most relevant results of the evaluated study were presented to aid researchers in understanding the advances in HT enhancement in double pipe HE using novel turbulators inserts.

1. INTRODUCTION

The HT surface improvement technology is one of the most common procedures developed for HEs to reduce size and cost and increase the efficiency of heat transfer; that is extensively employed in the industrial domains, power generation, refrigeration, air conditioning, chemical industries and others [1-5]. HT can be improved through multiple techniques and is mainly categorized as active, passive, and combined. The passive technique is one of the essential techniques because it does not require external power, which proved to improve HT when adopted in HEs [6, 7]. Two methods in the passive technique lead to improved HT. The first is a modification of the pipe wall so that it allows for the concentration of the heat and transfers it efficiently, such as a corrugated tube [8-11], grooved tube [12, 13], or ribbed tube [14, 15]. The second method is to insert the tubes, which improve the core flow and turn it into a swirling flow, then result in a higher HT coefficient such as using a twisted tape [16], wire coil [17], conical-ring [18] or other types of tubes. Kumar et al. [19] studied the influence of using a twisted tape insert for a double tube HE, which enhanced the result of the Nusselt number to about 38.75. Sharifi et al. [20] studied numerically the consequence of using a wire coil inserted throughout the pipe on HT features. The findings indicates that the wire coil enhances Nusselt number to 1.77 times. Sheikholeslami et al. [21] founded the double pipe HE HT characteristics and turbulent flow using perforated conical rings were studied experimentally and numerically. Different parameters were examined on HT enhancement and loss in pressure, such as the effect of conical angle, Pitch ratio and open area ratio. The findings show that raising the ratio of open area and pitch and augmenting the conical angle improves thermal performance. Tu et al. [22] forced convection and turbulent flow with inserted pipes in a circular tube were investigated numerically. Different nodes installation of pipe inserted with Re range of 2892-28915 were considered. The outcomes demonstrated a noteworthy improvement in the thermal performance using pipes inserted, and the results proved that raising the spacer length caused a diminution in the HTr rate while increasing the flow resistance. Muthusamy et al. [23] investigated experimentally the effluence of conical cut-out turbulence inserted in a circular tube with an internal fin was. The trials were executed for three pitch ratios: coverage mode and diverge mode. The result was found that the diverge mode gives 315% HT rate, 2.4 thermal performance factor and 3.2 times friction factor of the plain tube. Fan et al. [24] investigated numerically the forced convection of turbulent flow by inserting louvred strip inserts in a round tube and pitch ratio and slant angle. The result showed that the reinforcement in the Nusselt number was about four times greater than the plain tube. The larger angle of slant and the minor pitch were also found to improve the HT rate but enhanced resistance of flow significantly. Liu et al. [25] examined and investigated numerically the HT performance qualities in circular tubes equipped with bidirectional conical strip inserts. The impact of different specifications, like the turbulators count, pitch ratio, and central angle, are also studied. The results with bidirectional conical strip inserts showed an improvement in the Nusselt number by a factor of 2.35–9.85 more than that of the plain tube, while the friction factor is improved by 2.37-21.18 times compared to the plain tube. Abolarin et al. [26] studied experimentally the HT characteristics and drop in pressure in a circular tube by inserting a u-cut twisted tape with and without the ring. The study focused on the depth ratio of cuts and the ring pitch ratio. The outcomes reveal that enhancing the depth ratio and reducing the pitch ring percentage will significantly increase HT.

To the best of the authors' knowledge, there is a lot of researches that deal with the use of turbulence methods to improve the HT in double-pipe HEs, but these researches still need innovative forms of turbulence method to achieve the improvement in HT in this type of HE. In light of this, the aims of this paper are to look over the characteristic of heat transfer in a double pipe heat exchanger of air to water using three novel types of turbulators, 3PS, 4PS, 5PS with two pitch ratios PR (5-3.76) for a range of Reynolds number between 12385 and 24766. The induction of turbulators in this multipart device is likely to produce higher strength of vortex at the external area and faster mixing of fluid between the near-wall and central-core regimes, consequently in an upgrading of HT rate in the outer region and a more significant rise in the ducts thermal performance. The results of the current work may advise future investigation since they will assist researchers comprehend the numerous developments made in the HT enhancement in double pipe HE, which still require further advancement.

2. SETUPAND PROCEDURE FOR EXPERMIMENTATION

The photographic and schematic representation of an experimental configuration for the current study are shown in Figure 1 and Figure 2, respectively.

2.1 Experimental setup

The test setup consists mainly of air-to-water concentric tube heat exchangers, with the following parts.

2.1.1 Test section

The test section length is 1350 mm with a 60 mm surface diameter; the wall thickness was taken to be 1.5 mm, which is made of cast iron, a 50 mm internal tube (1 mm wall thickness), which is fabricated using copper, it has a bigger thermal conductivity. The test section's outer surface was isolated with a 25 mm thick rubber foam to decrease the environmental loss in heat.

2.1.2 Working fluid

(1) Air

Hot air was passed through the inner pipe, which was heated with an electrical heater and supplied to the test section via a blower with a power of 0.75 kW.

(2) Water

The cold fluid was water which was pumped through the annulus via a pump with a power of 0.75 kW (0.5 hp).

2.1.3 Air flowmeter

The airflow rate is measured using an orifice meter to get a Re in the span of 12385 to 24766, representing the desired Re.

2.1.4 Water flowmeter

The rates of water flow were adjusted using a control valve and measured with a digital rotameter.

2.1.5 Thermocouples

The wall temperatures of the outside surface of the inner tube are determined by fixing four k-type thermocouples. To measure the temperatures of the air entering and leaving the inner tube, two thermocouples are connected at the entrance and exit sections of the tube. Two digital thermometers were put in to predict temperatures of inlet and outlet water.

2.1.6 Pressure measurement

To calculate the drop of pressure throughout the test section, taps of pressure are placed upstream and downstream, connected with a flexible tube to a digital micro-manometer.

2.2 Experimental procedures

During experimentation, the inlet hot air temperature was set to 70°C, and the inlet cold water temperature was set to 25°C while the rate of mass flow was kept at 0.0167 kg/s. The following procedures had been done during the experimentation:

- All instruments are calibrated before being used in the experimental setup.
- Different geometric turbulator inserts were made of Aluminum with dimension, as shown in Figure 3, with two-pitch ratios were used to study its outcomes on heat transfer characteristics.
- After the system reaches a stable state, the readings are recorded and used in the heat transfer calculations.

Figure 1. Photograph of the experimental setup

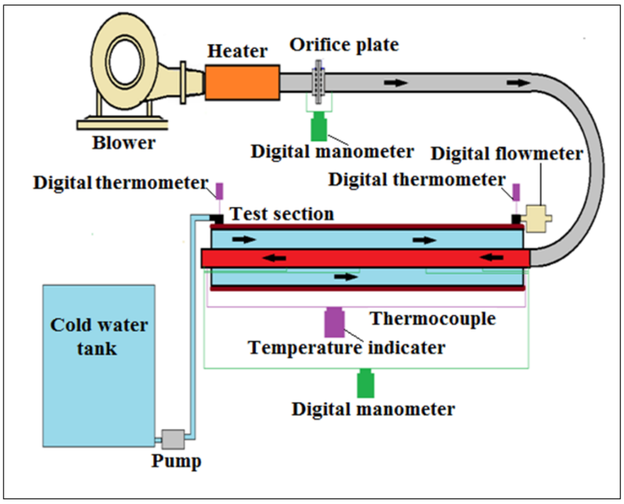

Figure 2. Graphical presentation of the setup

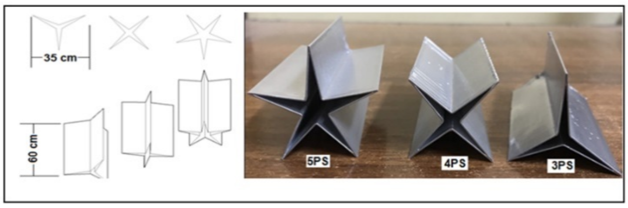

Figure 3. Different geometric novel turbulators

3. REDUCTION OF DATA

The cold fluid Heat absorbed rate, Q_c is provided by:

$$Q_c = m_c.Cp_c.\left(T_{c,o} - T_{c,i}\right) \tag{1}$$

The hot fluid heat transfer rate, Q_h is given by:

$$Q_h = m_h Cp_h\left(T_{h,i} - T_{h,o}\right) \tag{2}$$

The heat transfer average is defined as follows:

$$Q_{avg} = \frac{Q_h + Q_c}{2} \tag{3}$$

The overall thermal coefficient is defined as follows:

$$Q_{avg} = UA_i \Delta T_{LMTD} \tag{4}$$

where,

$$\Delta T_{LMTD} = \left(\left(T_{h,i} - T_{c,o}\right) - \left(T_{h,o} - T_{c,i}\right)\right) \Big/ ln\left(\left(T_{h,i} - T_{c,o}\right) \Big/ \left(T_{h,o} - T_{c,i}\right)\right) \tag{5}$$

The pipe wall thermal resistance is neglected. The overall thermal coefficient is determined on the inner side as follows:

$$\frac{1}{U_i A_i} = \frac{1}{h_i A_i} + \frac{1}{h_o A_o} \tag{6}$$

The HT coefficient of the annulus side is calculated using the average heat transfer rate as follows:

$$Q_{avg} = h_o A_o\left(T_{S.ave} - T_{w.ave}\right) \tag{7}$$

where, A_o is the inner pipe area of the outer surface, $T_{S.ave}$ is the mean pipe outer wall temperature, $T_{w.ave}$ is the mean temperature of the water.

The average inner pipe Nusselt number is obtained as follows:

$$Nu = \frac{h_i d_i}{k_{air}} \tag{8}$$

The value of friction factor is provided by:

$$f = \frac{\Delta P}{\left[\frac{4L}{d_1}\right]\left[\frac{\rho u^2}{2}\right]} \tag{9}$$

The factor of thermal performance (η) is specified by [10, 11]:

$$\eta = \frac{\frac{Nu}{Nu_p}}{\left(\frac{f}{f_p}\right)^{\frac{1}{3}}} \tag{10}$$

where, f_p and Nu_p are friction factor and Nusselt number without turbulator, respectively.

Uncertainty

In the present study, Kline and Mc Clintock procedure [27] is used to calculate the uncertainty for all variables as follows, and the results are listed in Table 1.

$$W_R = \left[\left(\frac{\partial R}{\partial x_1}.W_1\right)^2 + \left(\frac{\partial R}{\partial x_2}.W_2\right)^2 + \cdots \left(\frac{\partial R}{\partial x_n}.W_n\right)^2\right]^{\frac{1}{2}} \tag{11}$$

where, W_R=the uncertainty in results.

R is an independent variable of $x_1, x_2, \ldots, x_n$.

$$R = R(x_1, x_2, \ldots x_n)$$

$W_1, W_2, \ldots, W_n$ is the uncertainty with independent variables.

Table 1. Uncertainties results

No.	Tool	Purpose	Accuracy	Uncertainty
1	K Type thermocouple	Temperature	± 0.1°C	±0.5%
2	digital thermometer	Temperature	± 0.1°C	±2%
3	Inclined Manometer	Pressure	± 1 mm	±6%
4	Anemometer	Velocity	± 0.1 m /s	±4%
5	Digital manometer	Pressure	± 0.5 mm	±5%
8	Nusselt number	--	--	±4%
9	Friction factor	--	--	±6.5%
10	Re	--	--	±6%

4. DISCUSSION OF RESULTS

Figures 4 and 5 show the investigated results from the investigations were compared for the unadorned tube with the

Dittus–Boelter correlations [28] and Gnielinski [29] for Nusselt number are given in Eqs. (12)-(13), Petukhov [30] and White [31] for the friction factor are given in Eqs. (14)-(15), correspondingly. The results appeared to agree very well, and this agreement shows the reliability of the experimental setup.

Dittus-Boelter's equation:

$$Nu = 0.023Re^{0.8}Pr^{0.4} \tag{12}$$

Gnielinski's relation:

$$Nu = \frac{(f/8)(Re - 1000).Pr}{1 + 12.7.(f/8)^{1/2}.(Pr^{2/3} - 1)} \tag{13}$$

Blasius correlation:

$$f = 0.316 \times Re^{-0.25} \tag{14}$$

Petukhov correlation:

$$f = (0.79 \times ln(Re - 1.64))^{-2} \tag{15}$$

The Nu and Nu percentage variations, Nu/Nup with Re for the tube implanted with the novel turbulators, are demonstrated individually in Figures 6(a) and (b). The heat transfer coefficient raised with a slight pitch ratio and rising Re. The improvement in heat transfer for 5PS, 4PS and 3PS was about 194%, 177% and 164% higher than that plain tube, respectively. These improvements in heat transfer are related to increased turbulence. The highest Nusselt number ratio of 1.94 was obtained in the case of 5PS at a slight pitch ratio, which interrupted the development of the fluid flow's boundary layer and raised the intensity of turbulence in the field of flow superior than the rest.

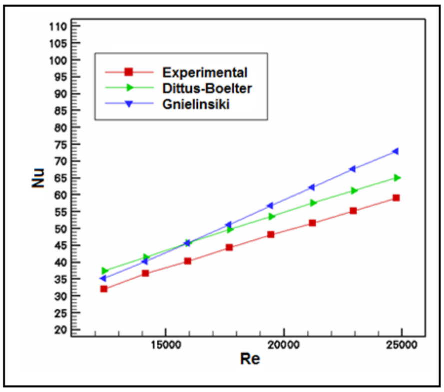

Figure 4. Plain tube with Nu vs. Re validation

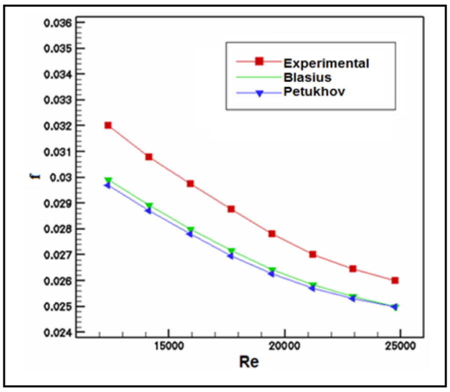

Figure 5. Plain tube f vs. Re

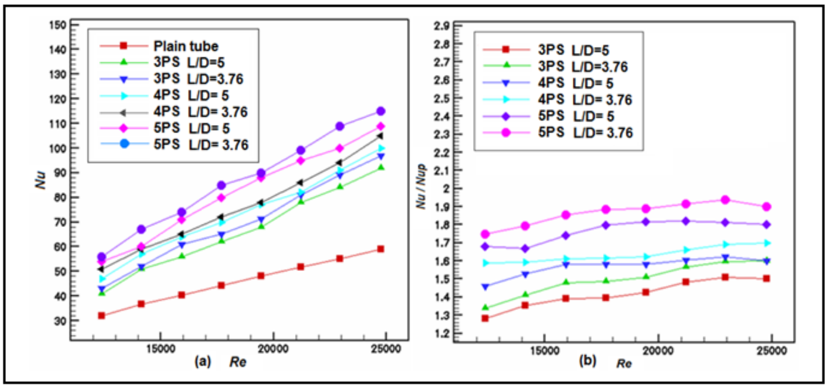

Figure 6. Distinct varieties of (a) Nu and (b) Nu/Nup with respect to Re for different geometric

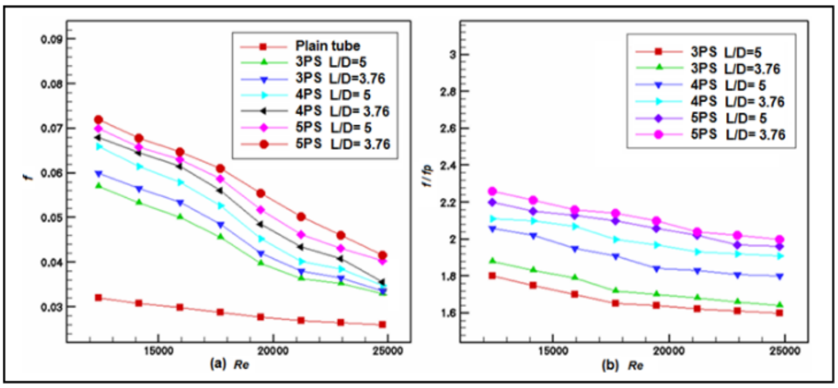

Figure 7. Distinct varieties of (a) f, and (b) f/foVs Re for different geometric

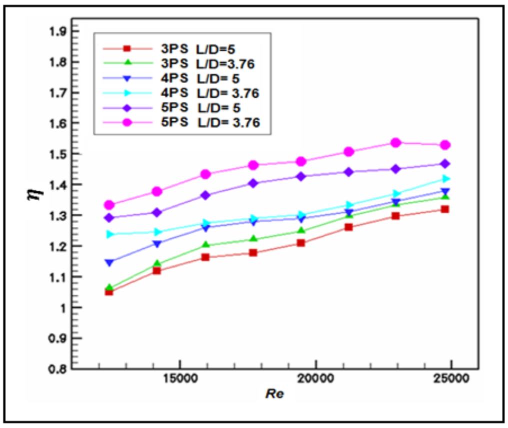

Figure 8. Variations η with Re for different geometric

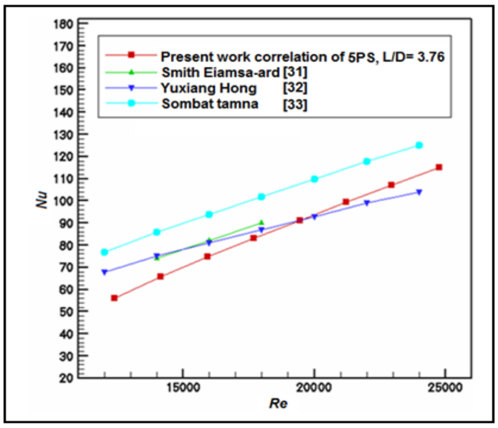

Figure 9. Experimental Nu of ppy geometric inserts is compared with previous work

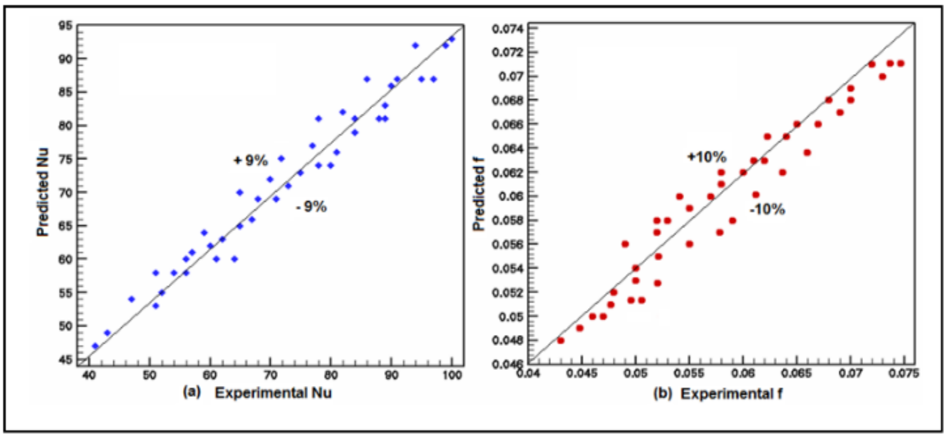

Figure 10. Experimental Comparison (a) Nu and (b) f with correlations predicted data

Figures 7(a) and (b) demonstrate the consequence of using the novel turbulators on friction factor and f/fo against Re. The impact of the novel turbulators causes a significant enhancement in friction factor above the plain tube, and the friction factor is reduced with the rise of Re, as illustrated in the figure. The rise of the swirl intensity and surface area caused by the inserts causes higher friction loss. The f/fo for the implanted tube increases significantly with a slight pitch and decreases with increasing Re values, as shown in Figure 7(b). The 5PS turbulators with L/D 3.76 have a higher f/fo than the other types. This is because 5PS turbulators produce more considerable flow resistance, a more extensive area of surface, and more robust vortex flow, resulting in a significant rise in pressure drop.

Figure 8 illustrates the relationship between thermal improvement factor (η) with Re for different geometric turbulators with different pitch ratios. It can be noted that it tends to increase as Re rises. The performance factor's value exceeds the unity of all cases. At a slight pitch ratio, the enhancement in the case of 5PS turbulators is more significant than the enhancement in other cases. The 5PS turbulators achieve a maximum of about 1.54, which is higher than the 4PS turbulators, around 7.5-7.8%, and higher than the 3PS turbulators, around 12.7-25.6%.

Figure 9 illustrates an evaluation of the Nusselt number obtained in this study with previous studies, which included different clockwise and anti-clockwise warped-tape inserts [32], short-length helical tapes [33], and double V-ribbed warped tapes [34]. When the Reynolds numbers are higher, the heat transfer of the current experiment (5PS) turbulator inserts is lower than that of the double V-ribbed twisted tapes but larger than that of the short-length helical tapes.

Nu and *f* correlations for 5PS are predicted from Eqs. (16) and (17). To predict resistance of flow and HT, as shown in Figures 10(a) and (b). The proposed correlations are consistent with the practical data. Nusselt number and friction factor deviations were between 9% and 10%, respectively. Thus, Nu can be obtained using the following empirical correlation [35-40]:

$$Nu = 0.043\, Re^{0.78} Pr^{0.33} PR^{-0.14} \tag{16}$$

Friction factor can be predicted by the use of the subsequent empirical correlation [41-46]:

$$f = 2.03\, Re^{-0.407} PR^{-0.036} \tag{17}$$

Pr≈0.7 at Re=12385 to 24766, PR (L/D)=3.76-5.

5. CONCLUSIONS

The current study is being carried out to practically examine the HT characteristics and drop in pressure in concentric tube

HEs with three various turbulators. The following conclusions can be expressed:

(1) The friction factor, Nusselt number, and thermal performance factor are all increased as the pitch ratio decreases. As a result, the small pitch ratio delivers a more considerable HT rate and lower loss in friction.

(2) Nu tends to rise with Re, but Nu/Nup shows a slight increase with Re. At the same time, it is noted that the f/fp prefers to drop with increasing the Re for all the used turbulators.

(3) It is observed that the heat transferred in the case of the 5PS insert was greater than that of the 4PS and 3PS inserts. So the improvement in heat transfer for 5PS, 4PS and 3PS was about 194%, 177% and 164% higher than that plain tube, respectively.

(4) The factor of thermal performance is more significant than unity in any situation considered here. The 5PS turbulators achieve the upper most thermal performance factor value at 1.54, which is higher than the 4PS turbulators, around 7.5-7.8%, and higher than the 3PS turbulators, around 12.7-25.6%.

(5) The Nusselt numbers and friction factor for the inner tube of concentric HEs of 5PS turbulators are correlated as a function of the investigated parameters.

(6) Because the performance of 5PS is far superior to that of the plain tube, improvements in energy savings have led to its acceptance in various applications.

REFERENCES

[1] Hasanpour, A., Farhadi, M., Sedighi, K. (2014). A review study on twisted tape inserts on turbulent flow heat exchangers: The overall enhancement ratio criteria. International Communications in Heat and Mass Transfer, 55: 53-62. https://doi.org/10.1016/j.icheatmasstransfer.2014.04.008

[2] Xiong, Q., Aramideh, S., Passalacqua, A., Kong, S.C. (2015). Characterizing effects of the shape of screw conveyors in gas–Solid fluidized beds using advanced numerical models. Journal of Heat Transfer, 137: 061008. https://doi.org/10.1115/1.4029864

[3] Aramideh, S., Xiong, Q., Kong, S.C., Brown, R.C. (2015). Numerical simulation of fast biomass pyrolysis in an auger reactor. Fuel, 156: 234-242. https://doi.org/10.1016/j.fuel.2015.04.038

[4] Xiong, Q., Aramideh, S., Passalacqua, A., Kong, S.C. (2014). BIOTC: An open-source CFD code for simulating fast biomass pyrolysis. Computer Physics Communications, 185: 1739-1746. https://doi.org/10.1016/j.cpc.2014.02.012

[5] Mwesigye, A., Bello-Ochende, T., Meyer, J.P. (2016). Heat transfer and entropy generation in a parabolic trough receiver with wall-detached twisted tape inserts. International Journal of Thermal Sciences, 99: 238-257. https://doi.org/10.1016/j.ijthermalsci.2015.08.015

[6] Sheikholeslami, M., Gorji-Bandpy, M., Ganji, D.D. (2015). Review of heat transfer enhancement methods: Focus on passive methods using swirl flow devices. Renewable and Sustainable Energy Reviews, 49: 444-469. https://doi.org/10.1016/j.rser.2015.04.113

[7] Liu, S., Sakr, M. (2013). A comprehensive review on passive heat transfer enhancements in pipe exchangers. Renewable and Sustainable Energy Reviews, 19: 64-81. https://doi.org/10.1016/j.rser.2012.11.021

[8] Wang, F.Q., Lai, Q.Z., Han, H.Z., Tan, J.Y. (2016). Parabolic trough receiver with a corrugated tube for improving heat transfer and thermal deformation characteristics. Applied Energy, 164: 411-424. https://doi.org/10.1016/j.apenergy.2015.11.084

[9] Jin, Z.J., Chen, F.Q., Gao, Z.X., Gao, X.F., Qian, J.Y. (2017). Effects of pitch and corrugation depth on heat transfer characteristics in six-start spirally corrugated tube. International Journal of Heat and Mass Transfer, 108: 1011-1025. https://doi.org/10.1080/10407782.2018.1459381

[10] Wang, W., Zhang, Y., Li, B., Han, H., Gao, X. (2017). Influence of geometrical parameters on turbulent flow and heat transfer characteristics in outward helically corrugated tubes. Energy Conversion and Management, 136: 294-306. https://doi.org/10.1016/j.enconman.2017.01.029

[11] Kareem, Z.S., Jaafar, M.M., Lazim, T.M., Abdullah, S., Abdulwahid, A.F. (2015). Passive heat transfer enhancement review in corrugation. Experimental Thermal and Fluid Science, 68: 22-38. https://doi.org/10.1016/j.expthermflusci.2015.04.012

[12] Bilen, K., Cetin, M., Gul, H., Balta, T. (2009). The investigation of groove geometry effect on heat transfer for internally grooved tubes. Applied Thermal Engineering, 29(4): 753-761. https://doi.org/10.1016/j.applthermaleng.2008.04.008

[13] Chen, Y.S., Tian, J., Fu, Y., Tang, Z.F., Zhu, H.H., Wang, N.X. (2018). Experimental study of heat transfer enhancement for molten salt with transversely grooved tube heat exchanger in laminar-transition-turbulent regimes. Applied Thermal Engineering, 132: 95-101. https://doi.org/10.1016/j.applthermaleng.2017.12.054

[14] Xu, W, Wang, S., Zhang, Q., Wang, Q, Lu, H, Tan, H. (2016). Experimental and numerical studies of heat transfer and friction factor of terminal liquid phase heat transfer fluid in a ribbed tube. Applied Thermal Engineering, 95: 165-177.

[15] Xu, W., Wang, S., Liu, G., Zhang, Q., Hassan, M., Lu, H. (2017). Experimental and numerical investigation on heat transfer of Therminol heat transfer fluid in an internally four-head ribbed tube. International Journal of Thermal Sciences, 116: 32-44. https://doi.org/10.1016/j.ijthermalsci.2017.01.020

[16] Nakhchi, M.E., Esfahani, J.A. (2018). Cu-water nanofluid flow and heat transfer in a heat exchanger tube equipped with cross-cut twisted tape. Powder Technology, 339: 985-994. https://doi.org/10.1016/j.powtec.2018.08.087

[17] Naphon, P. (2006). Effect of coil-wire insert on heat transfer enhancement and pressure drop of the horizontal concentric tubes. International Communications in Heat and Mass Transfer, 33(6): 753-763. https://doi.org/10.1016/j.icheatmasstransfer.2006.01.020

[18] Guo, J., Yan, Y., Liu, W., Jiang, F., Fan, A. (2013). Effects of upwind area of tube inserts on heat transfer and flow resistance characteristics of turbulent flow. Experimental Thermal and Fluid Science, 48: 147-155. https://doi.org/10.1016/j.expthermflusci.2013.02.017

[19] Kumar, N.R., Bhramara, P., Kirubeil, A., Sundar, L.S., Singh, M.K., Sousa, A.C. (2018). Effect of twisted tape

inserts on heat transfer, friction factor of Fe_3O_4 nanofluids flow in a double pipe U-bend heat exchanger. International Communications in Heat and Mass Transfer, 95: 53-62. https://doi.org/10.1016/j.icheatmasstransfer.2018.03.020
[20] Sharifi, K., Sabeti, M., Rafiei, M., Mohammadi, A.H., Shirazi, L. (2018). Computational fluid dynamics (CFD) technique to study the effects of helical wire inserts on heat transfer and pressure drop in a double pipe heat exchanger. Applied Thermal Engineering, 128: 898-910. https://doi.org/10.1016/j.applthermaleng.2017.08.146
[21] Sheikholeslami, M., Ganji, D.D., Gorji-Bandpy, M. (2016). Experimental and numerical analysis for effects of using the conical ring on turbulent flow and heat transfer in a double pipe air to water heat exchanger. Applied Thermal Engineering, 100: 805-819. https://doi.org/10.1016/j.applthermaleng.2016.02.075
[22] Tu, W., Wang, Y., Tang, Y. (2016). A numerical study on thermal-hydraulic characteristics of turbulent flow through a circular tube fitted with pipe inserts. Applied Thermal Engineering, 101: 413-421. https://doi.org/10.1016/j.applthermaleng.2016.01.106
[23] Muthusamy, C., Vivar, M., Skryabin, I., Srithar, K. (2013). Effect of conical cut-out turbulators with internal fins in a circular tube on heat transfer and friction factor. International Communications in Heat and Mass Transfer, 44: 64-68. https://doi.org/10.1016/j.icheatmasstransfer.2013.03.004
[24] Fan, A.W., Deng, J.J., Nakayama, A, Liu, W. (2012). Parametric study on turbulent heat transfer and flow characteristics in a circular tube fitted with louvred strip inserts. International Journal of Heat and Mass Transfer, 55: 5205-5213. https://doi.org/10.1016/j.ijheatmasstransfer.2012.05.023
[25] Liu, P., Zheng, N., Shan, F., Liu, A., Liu, W. (2018). Heat transfer enhancement for laminar flow in a tube using bidirectional conical strip inserts. International Journal of Heat and Mass Transfer, 127: 1064-1076. https://doi.org/10.1016/j.ijheatmasstransfer.2018.07.128
[26] Abolarin, S.M., Everts, M, Meyer, J.P. (2019). The influence of peripheral u-cut twisted tapes and ring inserts on the heat transfer and pressure drop characteristics in the transitional flow regime. International Journal of Heat and Mass Transfer, 132: 970-984. https://doi.org/10.1016/j.ijheatmasstransfer.2018.12.051
[27] Kline, S.J., McClintock, F.A. (1953). Describing uncertainties in single sample experiments. Mech. Eng., 75: 3-8.
[28] Incropera, F.P., DeWitt, D.P. (2002). Introduction to Heat Transfer. Fourth Ed. John Wiley & Sons, New York, pp. 459-463.
[29] Gnielinski, V. (1976). New equations for heat and mass transfer in turbulent pipe and channel flow. International Chemical Engineering, 16(2): 359-367.
[30] Petukhov, B.S. (1970). Heat transfer and friction in turbulent pipe flow with variable physical properties. In Advances in Heat Transfer, 6: 503-564. https://doi.org/10.1016/S0065-2717(08)70153-9
[31] White, F.M. (2011). Fluid Mechanics. Seventh ed., McGraw-Hill, New York.
[32] Eiamsa-ard, S., Promvonge, P. (2010). Performance assessment in a heat exchanger tube with alternate clockwise and counter-clockwise twisted-tape inserts. International Journal of Heat and Mass Transfer, 53: 1364-1372. https://doi.org/10.1016/j.ijheatmasstransfer.2009.12.023
[33] Hong, Y., Du, J., Wang, S., Huang, S.M., Ye, W.B. (2018). Effect of decaying swirl flow on tubular turbulent heat transfer enhancement by using short length helical tapes. Chemical Engineering Research and Design, 138: 1-12. https://doi.org/10.1016/j.cherd.2018.08.009
[34] Tamna, S., Kaewkohkiat, Y., Skullong, S., Promvonge, P. (2016). Heat transfer enhancement in the tubular heat exchanger with double V-ribbed twisted-tapes. Case Studies in Thermal Engineering, 7: 14-24. https://doi.org/10.1016/j.csite.2016.01.002
[35] Al-Jibory, M.W., Rashid, F.L., Talib, S.M. (2018). Numerical investigation of heat transfer enhancement in ribbed elliptical passage. Journal of Engineering and Applied Sciences, 13(17): 7223-7234.
[36] Aljibory, M.W., Rashid, F.L., Alais, Sh.M. (2018). An Experimental and numerical investigation of heat transfer enhancement using annular ribs in a tube. IOP Conference Series: Materials Science and Engineering, 433(1): 012057. https://doi.org/10.1088/1757-899X/433/1/012057
[37] Rashid, F.L., Al-Jibory, M.W., Talib, Sh.M. (2018). Numerical investigation of heat transfer augmentation in elliptical passage with different rib geometries and aspect ratios. International Journal of Mechanical Engineering and Technology, 9(13): 1390-1409. https://doi.org/10.3923/jeasci.2018.7223.7234
[38] Al-Jibory, M.W., Rashid, F.L., Talib, S.M. (2018). An experimental investigation of heat transfer enhancement in elliptical passage fitted with different rib geometries. International Journal of Mechanical Engineering and Technology, 9(13): 1033-1048.
[39] Hussein, H.Q., Al-Jibory, M.W., Rashid, F.L. (2020). Heat transfer enhancement of gas turbine blades using coated ribs with nanocomposite materials. Journal of Mechanical Engineering Research and Developments, 43(6): 09-22.
[40] Altaie, A., Hasan, M.R., Rashid, F.L. (2015). Numerical Investigation in a circular tube to enhance turbulent heat transfer using opened rings -Triangular cross section. Journal of Babylon University, Engineering Sciences, 3(23): 2015.
[41] AL-Jibory, M.W., Rashid, F.L., Hussein, H.Q. (2020). Review of heat transfer enhancement in air-cooled turbine blades. International Journal of Scientific & Technology Research, 9(4): 3123-3130.
[42] Altaie, A., Hasan, M.R., Rashid, F.L. (2015). Numerical investigation of heat transfer enhancement in a circular tube with rectangular opened rings. Bulletin of Electrical Engineering and Informatics, 4(1): 18-25. https://doi.org/10.11591/eei.v4i1.331
[43] Khalaf, A.F., Rashid, F.L., Basem, A., Abbas, M.H. (2022). Numerical analysis in a lid-driven square cavity with hemispherical obstacle in the bottom. Mathematical Modelling of Engineering Problems, 9(6): 1639-1647. https://doi.org/10.18280/mmep.090625
[44] Rashid, F.L., Hussein, A.K., Malekshah, E.H., Abderrahmane, A., Guedri, K., Younis, O. (2022). Review of heat transfer analysis in different cavity geometries with and without nanofluids. Nanomaterials,

12: 2481. https://doi.org/10.3390/nano12142481
[45] Ahmad, S., Ali, K., Sajid, T., Bashir, U., Rashid, F.L., Kumar, R., Ali, M.R., Hendy, A.S., Darvesh, A. (2023). A novel vortex dynamics for micropolar fluid flow in a lid-driven cavity with magnetic field localization – A computational approach. Ain Shams Engineering Journal, 2023: 102448. https://doi.org/10.1016/j.asej.2023.102448
[46] Ahmad, S., Ali, K., Ayub, A., Bashir, U., Rashid, F.L., Aryanfar, Y., Ali, M.R., Hendy, A.S., Shah, I., Ali, L. (2023). Localized magnetic fields and their effects on heat transfer enhancement and vortices generation in tri-hybrid nanofluids: A novel investigation. Case Studies in Thermal Engineering, 2023: 103408. https://doi.org/10.1016/j.csite.2023.103408

NOMENCLATURE

A	surface area (m^2)
Cp	specific heat (Kj/kg.K)
D	diameter (m)
f	friction facto (--)
h	heat transfer coefficient (W/m^{2}K)
k	thermal conductivity (W/mK)
L	length (m)
$\dot{m}$	mass flow (kg/s)
T	temperature (K)
u	velocity of air (m/s)
Q	heat transfer (J)
P	plain tube (--)
5PS	five-pointed star (--)
4PS	four-pointed star (--)
3PS	three-pointed star (--)
PR	pitch ratio (--)
Re	Reynolds number (--)
Pr	Prandtl number (--)
Nu	Nusselt number (--)

Subscripts

c	cold
h	hot
i	inner
o	outer

Greek symbols

ΔP	pressure drop (Pa)
ρ	density (kg/m^3)