Asian Journal of Applied Science and Technology (AJAST)
Volume 8, Issue 4, Pages 80-88, Oct-Dec 2024

Numerical Analysis of Thermal Hydraulic Performance of Heat Exchanger Tube with Inserts

Rishab Baloni[1], Ratan Sanjay[2*] & Rohit Kumar[3]

[1-3]*Mechanical Engineering Department, GRD Institute of Management & Technology, Dehradun, 248001, India.*
Corresponding Author (Ratan Sanjay) Email: ratansanjay24@gmail.com[*]

DOI: https://doi.org/10.38177/ajast.2024.8408

Article Received: 09 September 2024 *Article Accepted: 19 November 2024* *Article Published: 28 November 2024*

ABSTRACT

A heat exchanger is a device which is used to transfer heat between two or more fluids at different temperatures. To increase the rate of heat, transfer between two fluids, passive techniques are used, which changes the fluid flow behaviour inside the heat exchanger tube by using inserts. For the present study an Anchor shaped geometry is attached to a ball is used as inserts. This inserts embedded heat exchanger tube is numerically investigated at a wide range of Reynolds number (Re) i.e. 4000-22000. The geometrical parameters of the inserts are pitch (P = 70, 90, 110, and 130 mm), length of Anchor shape (l_p = 7 mm, 6 mm, and 5 mm), diameter of ball (d = 10 mm, 12 mm, and 14 mm). The complete heat exchanger model and its parameters are analyzed and shown as results (Nusselt number and contours of fluid) of design model with all variations in its parameters is determined by Ansys workbench (Computational fluid dynamics). These variations are pretended to enhance the thermal performance, and observed 329.53% increment of heat transfer as compared to smooth tube, and found maximum thermal performance of 2.160 at Re = 22000, d = 12 mm, l_p = 6 mm) and p = 90 mm.

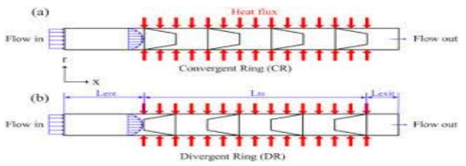
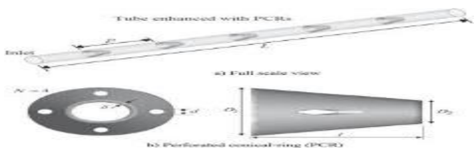
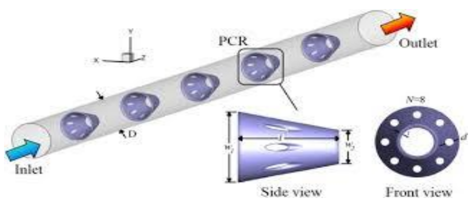
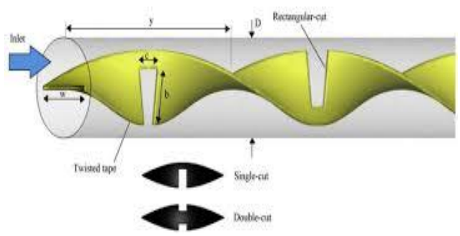
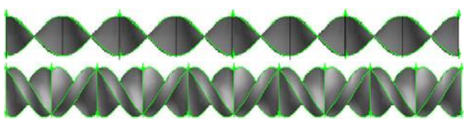
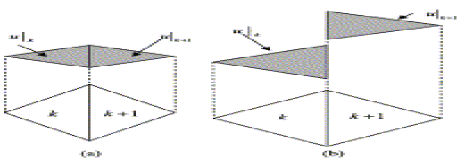
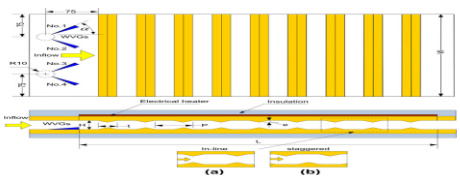
Keywords: THP; Nusselt number; Friction factor; Reynolds number; Anchor shaped inserts; Heat exchanger tube; Smooth tube; CFD; Pitch space.

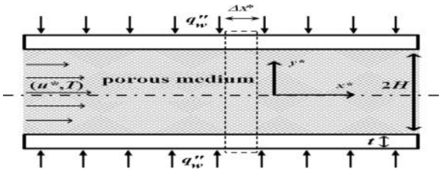
1. Introduction

Transferring heat has become an important part of thermal engineering as well as a main part of heat exchanger systems. It is capable of being broken down into modifications to thermal phases, such as radiation, thermal convection, and thermal conduction. The goal of this paper is to improve the thermal performance and heat flow capacity of model designs in both heating and cooling areas by using distribution flowing zones. The heat transfer rate of design model is expressed as heat exchanger system and the system increases the life of working model in which the system is attached. So the heat exchanger of thermal system is described in this paper. According to the study analyzing the relevant literature, many investigators executed tests involving heat exchanger tubes using a variety about put in geometry other variables, which has led to a wide range for outcomes because of the ways in which these components impact the outcomes. Sheikholeslami and Ganji [1], In the present investigation, a double pipe heat exchanger having perforated tabulators is utilized, & the researchers see an improvement of loss of pressure [2] with a reduction within Nu as a result of a decrease in the gradient of temperature. Although there's a clear correlation between the surface area ratio & thermal efficiency, the proportion decreases as both Rea and PR increase. Sheikholeslami et al. [3], According to the findings of the study, which employed passive methods [4] in conjunction using swirling flow equipment, the incorporation of these equipment significantly improves convection heat transmission. This happens by causing the boundary layer concerning the inner surface of the tube to be disrupted as a result of frequent geometrical alterations. Sheikholeslami et al. [5], Based on the findings of an investigation conducted on nanofluid within a passageway, it was discovered found the Nusselt number [6] improves as you raise the nano element volumetric percentage, Rayleigh number, or Reynolds number, but it decreases alongside increasing Hartmann number. Sheikholeslami et al. [7], By the utilization of a double pipe water to air heat exchanger equipped with discontinuous helical turbulators, he made the observation that the friction factor [8] and Nusselt number decrease as the total surface area ratio & pitching proportion also increase.

One the other hand, thermal efficiency involves an indicator that decreases when the pitch to height ratio increases, whereas it increases when the surface area to volume ratio increases.

Table 1. Literature reviews

Authors	**Geometry**	**Results**
Mohammed et al. [9]	 Conical HET	The results show the increment of Nusselt number and Friction factors at Reynolds number with the decrease of nanoparticle diameter.
Nakhchi et al. [10]	 Perforated conical roughness	The maximum thermal efficiency is observed 1.241 at Re = 4000, d/D = 0.1, D_2/D_1 = 0.6 and N = 10. The heat transfer rate reduces with N = 4 to 10.
Nakhchi et al. [11]	 Perforated conical ring	The maximum hydraulic performance of 1.10 is observed at ϕ = 1.5%, N = 10, Re = 5000. The heat transfer rate improved 278.2% than smooth tube at PCR N = 4.
Nakhchi et al. [12]	 Twisted tape with rectangular cut.	The results show that both of heat transfer [13] and pressure drop are dependent on the cut ratio. The thermal performance value for the case of single-cut twisted tape with b/w = 0.75 and c/w = 0.5 = is about 1.2–1.64.
Jaisankar et al. [14]	 Helical and Left-Right twisted tapes	The results show helical and Left–Right twisted tape system of same twist ratio 3, maximum thermal performance is obtained for Left–Right twisted tape collector with increase in solar intensity.
Syed et al. [15]	 Finned double-pipe heat exchanger with variable fin-tip thickness	Heat exchanger in reducing the cost, weight and frictional loss, in improving the heat transfer rate and making the exchanger energy-efficient.
Promvonge et al. [16]	 Triangular ribbed channel with longitudinal vortex generator	The experimental results show a significant effect of the presence of the rib turbulator and the WVGs on the heat transfer rate and friction loss over the smooth wall channel.

Dehghan et al. [17]	 Microchannels enhanced by porous materials	The present analysis suggests the implementation of porous inserts within flow passages especially when 0.001 < Kn < 0.1 (the slip-flow regime).

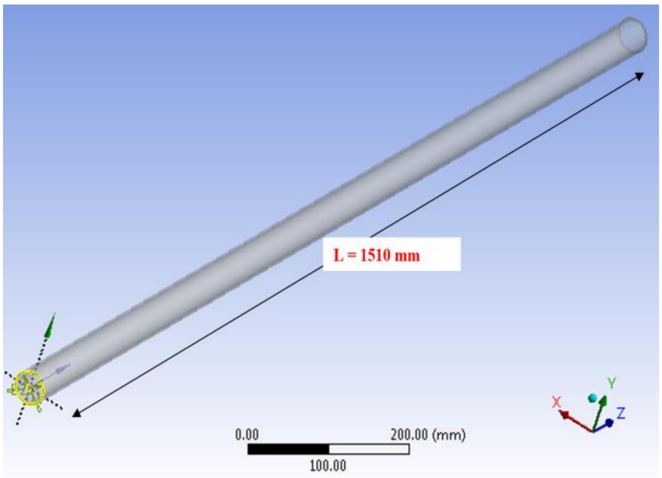
1.1. Objectives of Present Study

(1) To design a heat exchanger tube with or without inserts using Ansys as designing. (2) Simulation of the Design model. (3) To validate the designed model of heat exchanger tube with standard correlations of smooth tube. (4) To study the altered fluid flow behaviour inside the heat exchanger tube as a result of Anchor shaped inserts. (5) To Study of THP, Nusselt Number, Friction Factor.

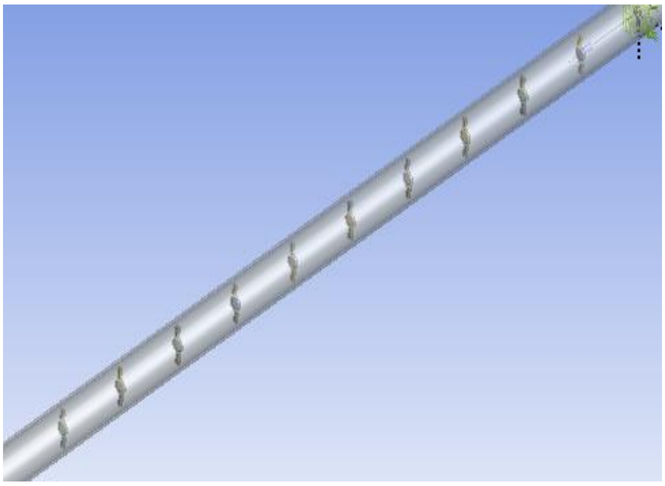
2. Numerical Methodology

2.1. Introduction

The construction regarding a heat exchanger tube that has round Anchor shaped additions gets addressed throughout this part. The tube's shape continues to be investigated during mathematical achievement, thermal efficiency, and modelling utilizing computational fluid dynamics (CFD) technology. This is done with a number of different modifications through length, diameter, & arc of the round Anchor – Shaped roughness. The pitch shape around imperfection is used inside the operational approach, and the fluid flow q is equal to 1000 watts per square meter along the tube.



(a)



(b)

Figure 1. Design of the model

2.2. The Modeling of the Heat Exchanger Tube and the Inserts Using Geometry

The computer program Ansys Fluent 14.0 was used to construct the geometric modelling for the linear heat exchanger tube using a variety during circular Anchor shaped inserts. a and b of Figure 1, as well as the graphical representation of contains a single tube with Anchor shaped inserts which have constant double arc in different length, diameters and constant thickness t_p = 2.6 mm which are complete designed in Anchor shaped as shown in

Figure 1 (a and b). The Smooth's length of the tube is L = 1510 mm, the inner diameter D_{in} = 36 mm and the Outer Diameter D_{out} = 40 mm. We have designed that it has number of variations in the ring diameters (d = 9.8, 11.8, and 13.8 mm) and length of Anchor leg (l_p = 4.9, 5.9, and 6.9 mm) with constant arc and all shapes are attached together to make a perfect design of smooth tube which is finally known as round Anchor shaped HET.

3. Results and Discussion

3.1. Introduction

In this chapter, all results are examined with the help of perfect and valuable design of heat exchanger tube in Ansys software. The observed results are important for indicating and presenting best performance of Anchor shaped model and its design. Various analyses have been performed by adjusting the corresponding pitch time to hydraulic ratio (p/Dh) at values of 1.88, 2.44, 3, and 3.55, depending on the pipe size. The graphs below illustrate the relationship between nu, fr, and these adjustments.

3.2. Relation of the smooth tube with Dittus-Boelter equation

Figure 2 displays the relationship between the Nusselt number (Nu) of smooth surfaces with the Dittus-Boelter equation for a heat exchanger, as well as its relationship with the Dittus-Boelter equation. The Dittus-Boelter correlation provides the basic information required to analyse the enhancement of heat transfer in redesigned solitary tubing.

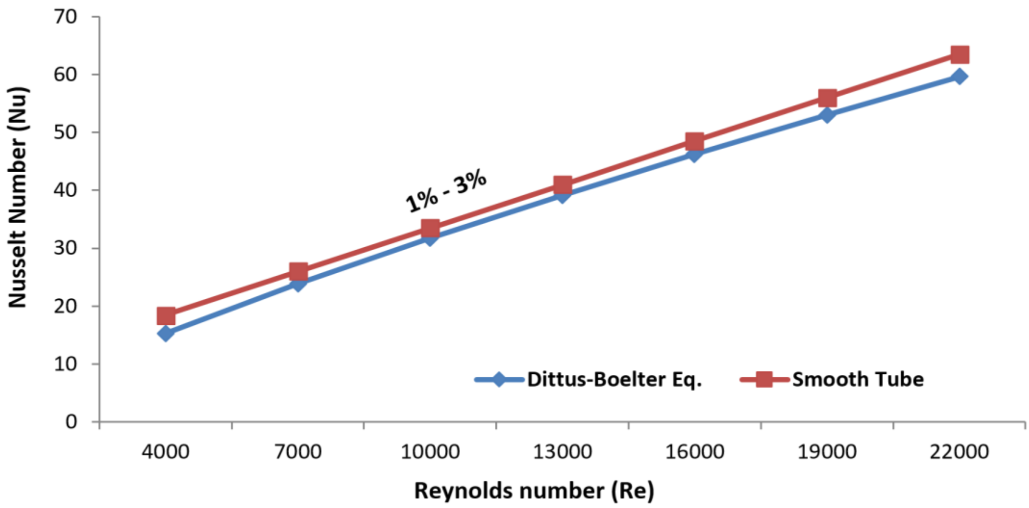


Figure 2. The relationship between the Nusselt number (Nu) and rising flow velocity

3.3. Velocity Effects of Fluid around Anchor Shaped Roughness in HET

Figures 3, 4, and 5 present useful values for velocity distribution around roughness of heat exchanger w.r.to the Re = 4000 – 22000. The highest flow found in the graph in red colour at Re = 22000 when pitch space (P) is taken 88 mm between roughness and d = 9.8 mm. If pitch shape is maximum or less between inserts, then results of velocity contour can tell us a comparison of velocity between smooth and inserted roughness HET. So pitch space is necessary parameters of HET. As can be seen in the graph, the greater velocity that has increased in the heat exchanger tube is 12.34 meters per second. This velocity is obtained when diameter and length of Anchor shaped respectively applied to the roughened tube.

Asian Journal of Applied Science and Technology (AJAST)
Volume 8, Issue 4, Pages 80-88, Oct-Dec 2024

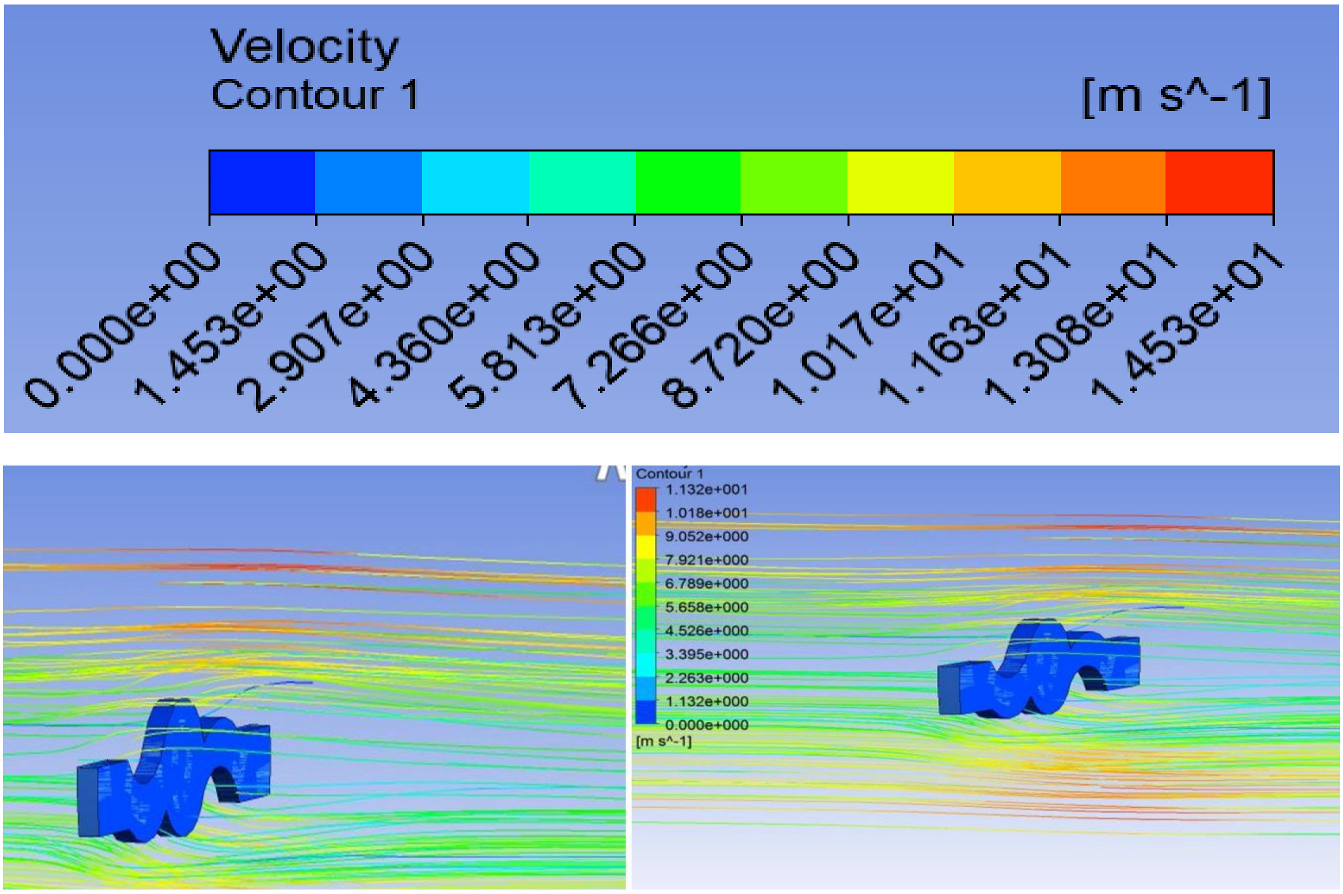


Figure 3. Variations in Velocity of fluid after striking on combined roughness at roundness diameter d = 9

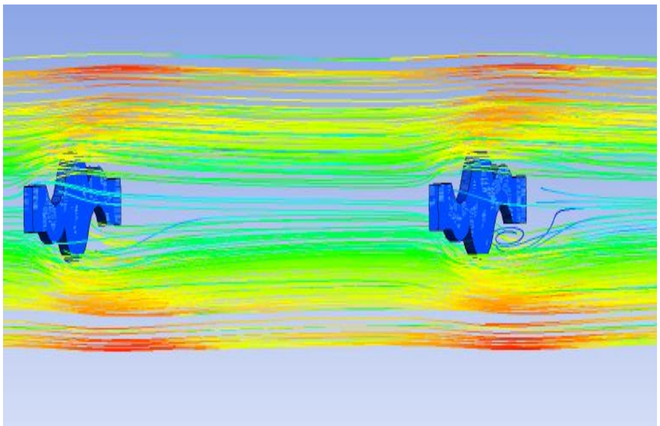


Figure 4. Variations of velocity of fluid in HET at d = 11.8 mm and l_p = 5.8

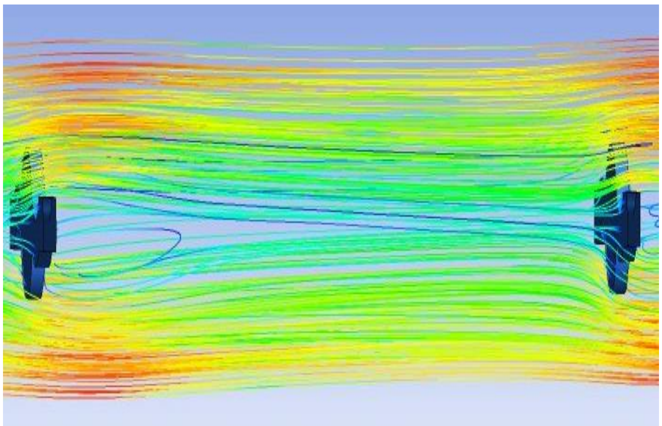


Figure 5. Velocity contour at d = 13.8 mm, l_p = 4.8 mm

4. Effects of Pitch Shape and Roughness on Heat Transfer Rate Characteristics

The turbulent and lamination fluid flow in tubes can be determined by the Re, which are devoid of dimensions' variables. It is demonstrated by the design concept that the speed of heat transfer rises increasing the Re, with it achieving its highest point at Re = 22000. Because pitch area is responsible for maintaining a turbulent environment in tubes, Nu quantities are dependent upon pitch space. The speed of transfer of heat improves having the pitch space, and the highest Nu is attained at P = 88 mm when two rough anchors with an overall length of 5.8 mm with a diameter of 11.8 mm are fixed to the surface as shown in Figure 6.

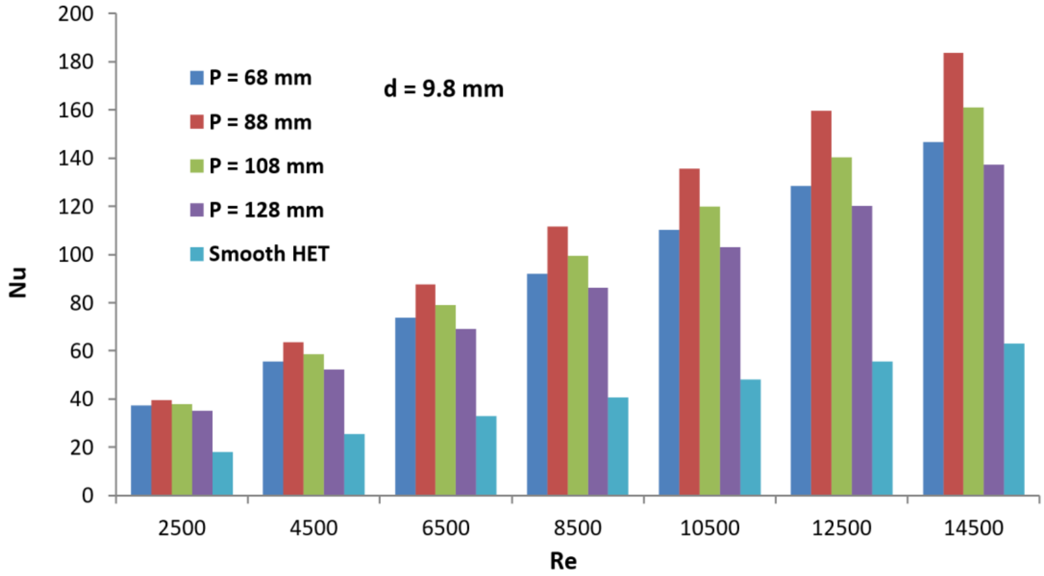


Figure 6. Variations in heat transfer rate at d = 9.8 mm, l_p = 7 mm

In figure 7, Nusselt number is increased with increasing in Reynolds numbers Re = 4000, 7000, 10000, 13000, 16000, 19000, and 22000 with variations in the inserted roughness. Friction factors are obstacles between fluid particles and are influenced by pitch spacing on adjacent Anchor-shaped surfaces. As pressure drop increases, the coefficient of friction grows, aiming to reduce friction impact while increasing heat transfer. Frictional forces can cause issues like energy loss, wear, hot shortness, and residual stress in tube as shown in Figure 8. A comparison between the frictional coefficients for Anchor-shaped imperfection tubes on Re ranging from 4000 to 22000 is presented as shown in Figure 9. A comparison was made between the results and the plain tube Fr = 0.0065, which revealed an increase of 3, 3.50, 3.37, and 2.65 times in relation against smooth tubes at d = 11.8 mm.

4.1. Thermo-Hydraulic Performance

The thermally hydrodynamic efficiency (THP) under heat exchange device tubes having round anchor-shaped imperfection becomes the topic of discussion in this section.

Figure 10 explains the thermal hydraulic performance of the heat exchanger tube with for Reynolds number. The higher thermal performance is obtained η = 2.8 when inserts is used at Re = 22000, P/D_h = 2.44.

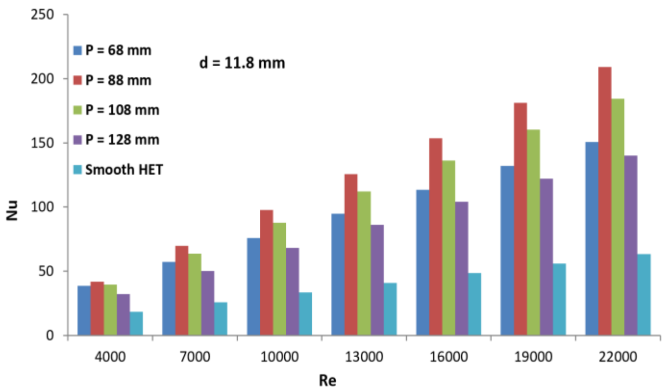


Figure 7. At d = 11.8 mm and lp = 5.8 mm, there are fluctuations in Nusselt number and Reynolds number

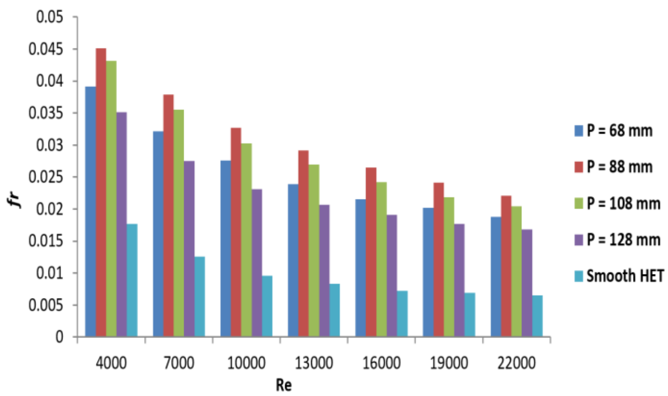


Figure 8. variations of Reynolds number at d = 9.8 mm, l_p = 6.8 mm

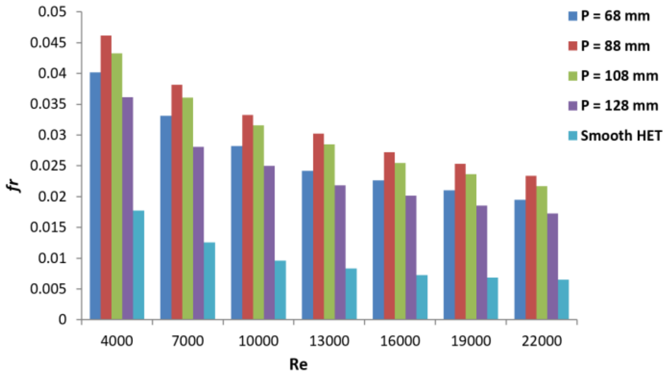


Figure 9. Variations of Friction factors w.r.to Reynolds number at d = 11.8 mm, l_p = 6 mm

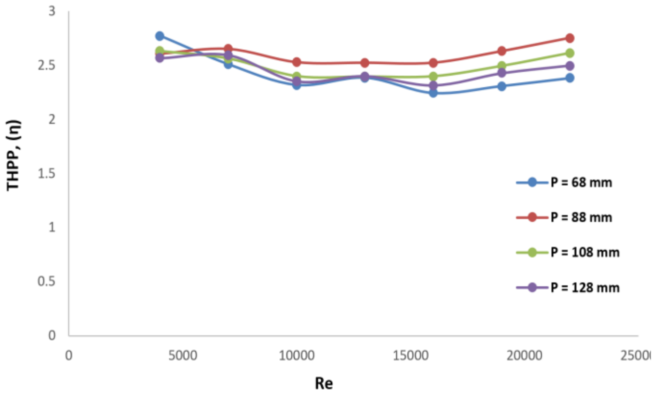


Figure 10. Maximum thermal hydraulic (η_{max}) of HET with inserted Anchor shaped inserts

5. Conclusions

The purpose of this study was to analyze numerically the fluctuations in (Re) and (P) that occur between roughness (P) values of 4000, 7000, 10000, 13000, 16000, 19000, and 22000.

In the following manner, the primary conclusions can be explained:

(1) From all results, it is concluded that heat transfer rate increased with increase in Reynolds number as opposed to friction factors.

(2) Nusselt numbers is increased 1.9 - 3.3 times of smooth tube with decreasing in friction factor from 2.3 to 3.6 of smooth tube at Re = 22000. The lowest friction factor was obtained at P = 128 mm, d = 13.8 mm l_p = 6.8 mm. Highest hydraulic thermal performance was obtained η = 2.8 at Re = 22000, P = 88 mm, P/D_h = 2.44, D_h = 0.036m, d = 11.8 mm, l_p = 5.8 mm and round Anchor shaped roughness.

6. Future Scope

(1) Variations of Pitch space between inserts roughness can improved heat transfer rate.

(2) Thermal performance of HET can by changing in the parameters of Anchor-shaped inserts.

(3) Friction factors can be decrease by using of variations in ball shaped roughness.

(4) The perforated Anchor-shaped roughness can have improved the rate of energy transfer without loss of energy of working model.

Declarations

Source of Funding

This study did not receive any grant from funding agencies in the public, commercial, or not–for–profit sectors.

Competing Interests Statement

The authors declare no competing financial, professional, or personal interests.

Consent for publication

The authors declare that they consented to the publication of this study.

Authors' contributions

All the authors took part in literature review, analysis, and manuscript writing equally.

References

[1] Sheikholeslami, M., & Ganji, D.D. (2016). Heat transfer improvement in a double pipe heat exchanger by means of perforated turbulators. Energy Conversion and Management, 127: 112–123. https://doi.org/10.1016/j.enconman.2016.08.090.

[2] Singh, H., Singh, H., & Kishore, C. (2022). CFD numerical investigation of Heat transfer characteristics of Y-shaped solar air heater. Materials Today: Proceedings, 52: 2003–2013. https://doi.org/10.1016/j.matpr.2021.12.007.

[3] 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.

[4] Singh, H., Kishore, C., Kumar, K.N., Patil, P.P., & Avikal, S. (2021). Numerical analysis of thermal-hydraulic performance of fully developed turbulent flow in heat exchanger tube with Half Moon inserts. Materials Today: Proceedings, 46: 11182–11189. https://doi.org/10.1016/j.matpr.2021.02.385.

[5] Sheikholeslami, M., & Ganji, D.D. (2014). Ferrohydrodynamic and magnetohydrodynamic effects on ferrofluid flow and convective heat transfer. Energy, 75: 400–410. https://doi.org/10.1016/j.energy.2014.07.089.

[6] Singh, H., Chavadaki, S., Kishore, C., Kumar, K.N., & Avikal, S. (2021). Numerical analysis of roughened solar air heater with arc and fan shape roughness to understand heat transfer and fluid flow characteristics. Materials Today: Proceedings, 46: 10662–10667. https://doi.org/10.1016/j.matpr.2021.01.399.

[7] Sheikholeslami, M., Gorji-Bandpy, M., & Ganji, D.D. (2016). Effect of discontinuous helical turbulators on heat transfer characteristics of double pipe water to air heat exchanger. Energy Conversion and Management, 118: 75–87. https://doi.org/10.1016/j.enconman.2016.03.080.

[8] Singh, H., Singh, H., Bahuguna, R., & Kishore, C. (2022). CFD analysis of heat transfer characteristics of rectangular solar air heater with kite shaped roughness. Materials Today: Proceedings, 52: 2014–2025. https://doi.org/10.1016/j.matpr.2021.12.008.

[9] Mohammed, H.A., Abuobeida, I.A.A., Vuthaluru, H.B., & Liu, S. (2019). Two-phase forced convection of nanofluids flow in circular tubes using convergent and divergent conical rings inserts. International Communications in Heat and Mass Transfer, 101: 10–20. https://doi.org/10.1016/j.icheatmasstransfer.2018.12.010.

[10] Nakhchi, M.E., & Esfahani, J.A. (2019). Numerical investigation of different geometrical parameters of perforated conical rings on flow structure and heat transfer in heat exchangers. Applied Thermal Engineering, 156: 494–505. https://doi.org/10.1016/j.applthermaleng.2019.04.067.

[11] Nakhchi, M.E., & Esfahani, J.A. (2019). Numerical investigation of turbulent Cu-water nanofluid in heat exchanger tube equipped with perforated conical rings. Advanced Powder Technology, 30(7): 1338–1347. https://doi.org/10.1016/j.apt.2019.04.009.

[12] Nakhchi, M.E., & Esfahani, J.A. (2019). Numerical investigation of rectangular-cut twisted tape insert on performance improvement of heat exchangers. International Journal of Thermal Sciences, 138: 75–83. https://doi.org/10.1016/j.ijthermalsci.2018.12.039.

[13] Singh, H., Singh, D.P., Bahuguna, R., & Kishore, C. (2022). CFD simulation of thermal hydraulic performance of rectangular solar air heater with combination of boot rib roughness. Materials Today: Proceedings, 65: 3860–3865. https://doi.org/10.1016/j.matpr.2022.07.071.

[14] Jaisankar, S., Radhakrishnan, T.K., & Sheeba, K.N. (2011). Experimental studies on heat transfer and thermal performance characteristics of thermosyphon solar water heating system with helical and left–right twisted tapes. Energy Conversion and Management, 52(5): 2048–2055. https://doi.org/10.1016/j.enconman.2010.11.024.

[15] Syed, K.S., Ishaq, M., Iqbal, Z., & Hassan, A. (2015). Numerical study of an innovative design of a finned double-pipe heat exchanger with variable fin-tip thickness. Energy Conversion and Management, 98: 69–80. https://doi.org/10.1016/j.enconman.2015.03.038.

[16] Promvonge, P., Chompookham, T., Kwankaomeng, S., & Thianpong, C. (2010). Enhanced heat transfer in a triangular ribbed channel with longitudinal vortex generators. Energy Conversion and Management, 51(6): 1242–1249. https://doi.org/10.1016/j.enconman.2009.12.035.

[17] Dehghan, M., Valipour, M.S., & Saedodin, S. (2016). Microchannels enhanced by porous materials: heat transfer enhancement or pressure drop increment. Energy Conversion and Management, 110: 22–32. https://doi.org/10.1016/j.enconman.2015.11.052.