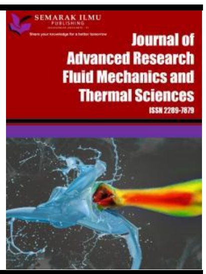
SEMARAK ILMU PUBLISHING

Journal of Advanced Research in Fluid Mechanics and Thermal Sciences

Journal homepage:
https://semarakilmu.com.my/journals/index.php/fluid_mechanics_thermal_sciences/index
ISSN: 2289-7879



Computational Study and Enhancement of Heat Transfer Rate by Using Inserts Introduced in a Heat Exchanger

Sandeep Sadashiv Kore[1,*], Manoj Kumar Chaudhary[2], Adhikrao Sarjerao Patil[3], Vijay Dilip Kolate[2]

[1] Department of Mechanical Engineering, Vishwakarma Institute of Information Technology, Pune 411037, India
[2] Department of Mechanical Engineering, Trinity Academy of Engineering, Pune 411048, India
[3] Department of Mechanical Engineering, Sinhgad Academy of Engineering, Pune 411048, India

ARTICLE INFO

Article history:
Received 20 August 2022
Received in revised form 2 January 2023
Accepted 10 January 2023
Available online 30 January 2023

Keywords:
CFD; inserts; friction factor; heat exchangers; HRT; pressure drop; Reynolds number; Nusselt number

ABSTRACT

The research provides a numerical and computational analysis of improving heat transfer rate in heat exchangers employing obstructing geometries such as Circular Ring, Circular Ring with` clearance, and Hexagonal ring tabulators with different pitch diameter ratios (PDR). All geometries were evaluated with flow obstruction areas of 0.3, 0.4, and 0.5. Flow obstruction area and Reynolds number were the variables that changed during the testing. The pitch diameter ratio employed in the investigation is one. The Reynolds number was changed between 6000 and 21000. For numerical examination, k-- ε technique was used in this study. The use of flow obstruction geometry as a turbulator improves heat transmission derived from the hot surface of the pipe to the air throughout the test region substantially. In this research work, the tested designs, a circular ring separated from the tube wall and a hexagonal ring with the same flow blockage area improve heat transmission. Hexagonal rings incur a lower fluid friction cost than circular rings and circular rings with clearance. The maximal heat transfer enhancement (Nut/Nup) for the diameter ratio of the insert of 0.6.3 is 2.28–3.01.

1. Introduction

Heat exchangers are widely used in many different applications, such as chemical reactors, electronic heat dissipation systems, thermal power plants and cold storage. The performance of heat energy equipment (heaters water and air coolers, condensers, boilers, coils) is primarily determined by the rate of energy exchange and losing pressure through the heat transfer tubes Fluid mixing and vortex generation are primarily responsible for improving heat transmission. It may be expanded by generating various vortices and swirling flow. The vortices and swirl flow reduce viscous sub-layers while enhancing heat transfer area. Various researchers are looking for new heat transfer enhancement techniques [1]. To investigate and improve the thermal performance of a heat exchanger using a heat storage device [2]. To experimental results and numerical data for numerous heats transfer enhancement techniques have been proposed and presented. Among them are

* *Corresponding author.*
E-mail address: sandeep.kore@viit.ac.in

https://doi.org/10.37934/arfmts.103.1.1629

twisted tape [3,4], circular ring turbulator [4-7], conical shaped geometry [8-9], conical rings [10], V-nozzle [11], diamond-shape tabulators [11], The investigation of several inserts with diverse configurations of shape and geometry such as perforated circular ring [12-16], The effects of conical-nozzle form ring inserts on factors related to friction and heat transfer were investigated in a circular tube with convergent and divergent nozzle configurations. The pressure surge is significantly reduced with increasing porosity [17–18]. The system is thought to have a long wavelength and a low Reynolds number, among other things, according to Manjunatha *et al.,* [19]. Utilizing numerical integration, the frictional force and pressure rise have been computed [20]. As the values of variable thermal conductivity rise [21], the temperature rises. Several others include Vaidya, Rajashekhar, Prasad *et al.,* The equations for velocity, temperature, and concentration can be found [22]. Ribs are a well-liked technique for enhancing heat transfer and are used in many heat-exchanging conduits [23]. using heat exchangers with serpentine oval tubes to generate more heat and efficient [24]. It is discovered that as chemical reaction and heat source parameters increase, both the local Nusselt number and the decreased skin friction coefficient rise [25]. The RNG-model is used to numerically solve the governing equations using the finite volume method. A variance of 4.15%, 3.89%, and 7.65% is shown by the simulation results of Nusselt number versus Reynolds number for tubes made of plain, plain twisted tape, and dimple twisted tape when compared to experimental data. At various Reynolds numbers, the dimple twisted tape tube's friction factor is 60 to 70 percent higher than the plain twisted tube's [26]. Highlighted are the creation of non-Newtonian momentum equations, the formulation of conservation equations in sophisticated coordinate systems, and the incorporation of a variety of body forces into momentum equations [27].

The intensification, intensification, or augmentation of heat transfer rate are terms used to describe the method of improving heat transmission. By adding different types of inserts to the flow path, this passive approach increases the rate of heat transmission. The smaller hydraulic diameter of the flow route allows for this to happen. Due to the fluid's spirals' induced centrifugal force, heat transfer is improved by utilising twisted tape inserts. combining dynamic pressure signals and the deep learning technology, a method for identifying the flow regime[28]

As shown by literature research, fluid flow can be successfully obstructed utilising a number of devices, which can increase turbulence intensity. This study work examines numerically and through computational fluid dynamics (CFD) the performance of three different flow obstruction geometries: the hexagonal ring turbulator (HRT), and the circular ring disconnected from the wall. A 30%, 40%, or 50% flow blockage area is maintained for all geometries. Every insert in this study has a ring with the exact same geometry and pitch 1 configuration. A new parameter has been suggested for this investigation. The parameter that has been taken into consideration to assess the performance of inserts with various flow blocking geometries is the percentage of the tube's cross-sectional area that is blocked by the turbulator geometry, or flow blockage area (FBA). For combination turbulators, a lower Reynolds number and the lowest values of coil spring pitch and twist ratio are ideal operating conditions. The development of empirical correlation for Nu, f, and employed experimental data. Inserts with HRT were evaluated among the inserts.

2. Methodology
2.1 Numerical Modelling and Method
2.1.1 Physical geometry

The range of parameters varied during the test is summarised in Table 1. Various configurations of inserts are presented in Table 1. In this study, a total of nine inserts were examined and are listed in Table 2. In this study, the Reynolds number between 6,000 and 21,000 was considered in this research.

Table 1
Range of geometrical parameters

Parameter details	Dimension/range
Pitch diameter ratios (PDR)	2,3 and 4
Flow blockage area(FBA)	30%, 40% and 50%
Reynolds number (Re)	6000- 24000
The inlet temperature of the air	Ambient temperature

Table 2
Inserts configuration

Insert	Configuration
CR30%	Circular ring with FBA 30%
CR40%	Circular ring with FBA 40%
CR50%	Circular ring with FBA 50%
CR30%,1	Circular ring with clearance of 1 mm FBA 30%
CR40%,1	Circular ring with clearance of 1 mm FBA 30%
CR50%,1	Circular ring with clearance of 1 mm FBA 30%
HR30%	Hexagonal ring with FBA 30%
HR40%	Hexagonal ring with FBA 30%
HR50%	Hexagonal ring with FBA 30%

The heat exchanger geometry is created in the ANSYS workbench design module. The fluid domain is separated into three sections, calming section, test section of 1000 mm, and exit section, as presented in Figure 1 and Figure 2. The Table 3 displays all of these meshes Nu and f values.

Fig. 1. A typical insert with HRT

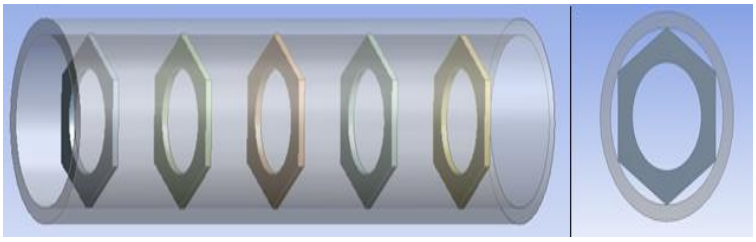


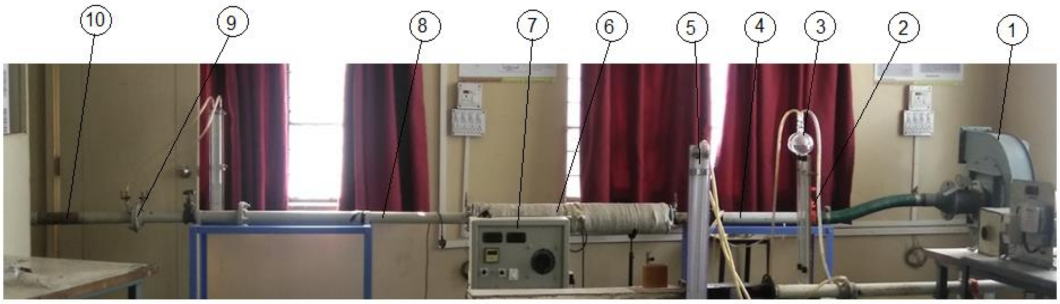
Fig. 2. Test section geometry fitted with Hexagonal Ring (HRT)

Table 3
Grid independence test

No. of elements	Nu	% variation	f	% variation
1482132	75.06457	---	1.2174	---
2012054	76.08066	1.3536	1.2604	3.5321
2413760	76.4295	0.45851	1.257	0.2698
3023156	76.62899	0.261	1.2598	0.2223

3. Experimental Setup

The schematic design of the experimental test apparatus is shown in Figure 3. A 2 HP blower and a heat exchanger tube are part of the open-loop system (test section). In order to monitor the airflow rate, it also has an orifice meter connected to a U-tube manometer that uses water as the manometric fluid. The test section details are shown in Figure 4 and Figure5.



1. Blower 2. Control valve 3. Micromanometer 4. Exit section
5. Manometer 6. Test section 7. Control panel 8. Calming section
9. Orifice meter 10. Entry section

Fig. 3. Experimental setup

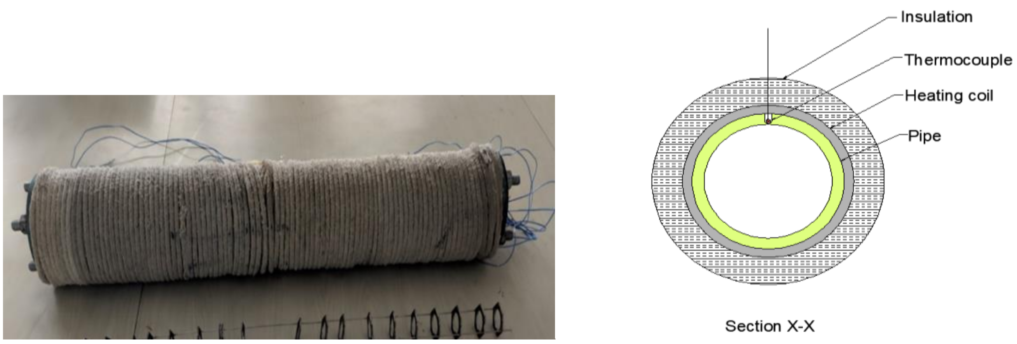


Fig. 4. Test section

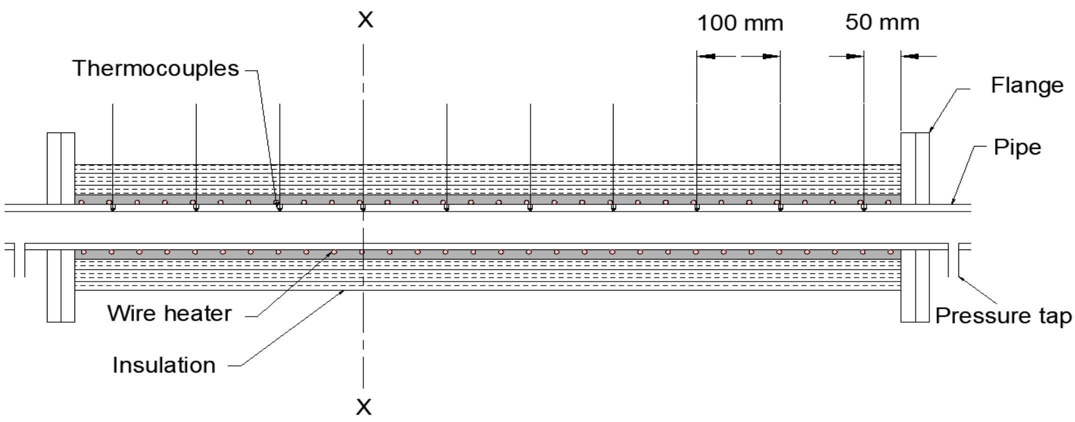


Fig. 5. Test section details

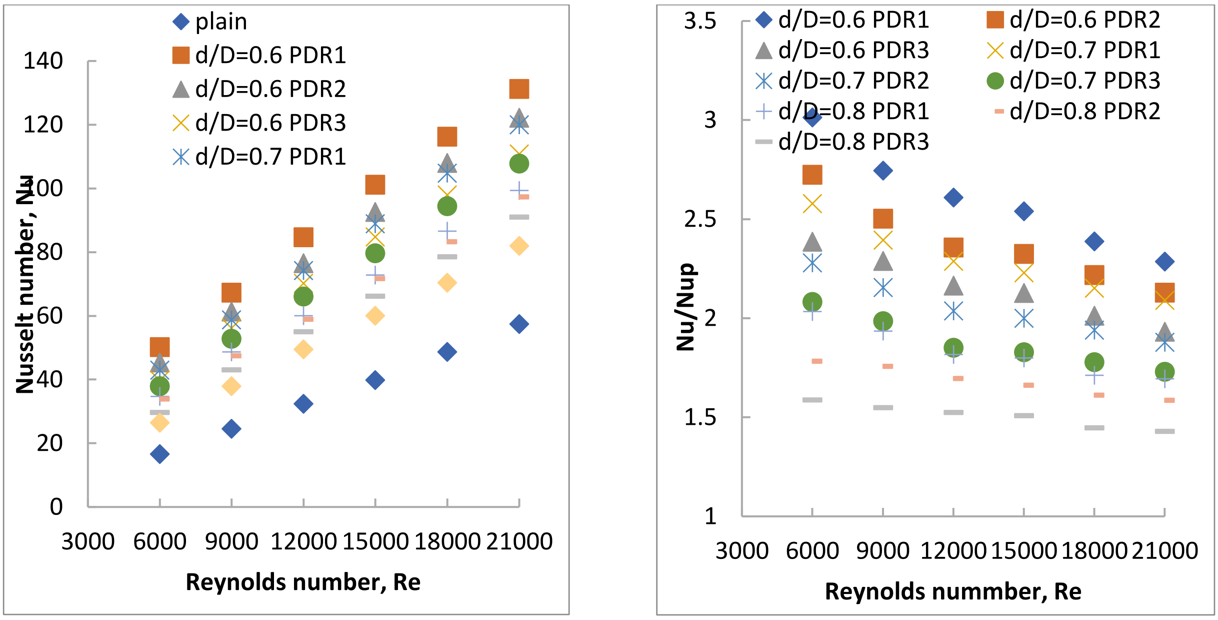
4. Results

In this section, the heat transfers and fluid flow parameters were examined using numerical simulations of fluid flow in a tube equipped with a circular ring and a range of gap sizes.

4.1 Heat Transfer Performance

The results of heat transfer for tubes with HRT fitting at different diameter ratios (0.6, 0.7, and 0.8) and PDR (1, 2 and 3). The variation of Nu with Re for all novel inserts with various pitch ratios is shown in Figure 6 (a)-(b).

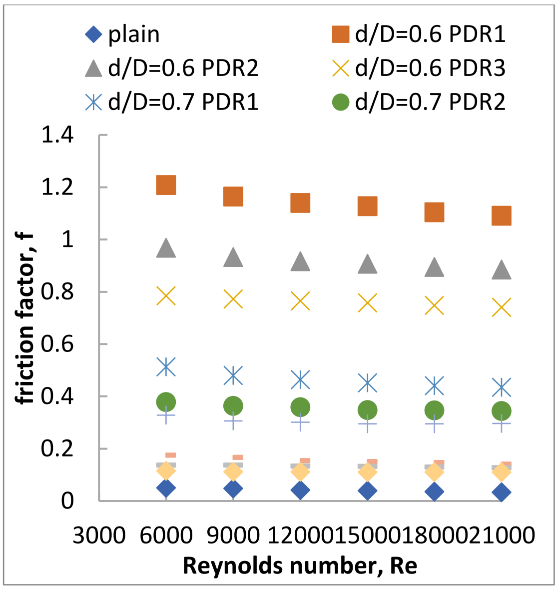
The primary finding is that the test section with HRT inserts has a heat transfer rate that is 47%-201% higher than the smooth tube. The results show that, for a certain range of Reynolds numbers for PDR 1, HRT with diameter ratios of 0.8, 0.7, and 0.6 enhances the heat transfer enhancement rate by roughly 1.69-2.04, 2.08-2.57, and 2.28-3.01 times, respectively. A smaller diameter ratio increases the likelihood of fluid flow obstruction. Nut/Nup is seen to decrease as the Reynolds number increases in Figure 6 (b).



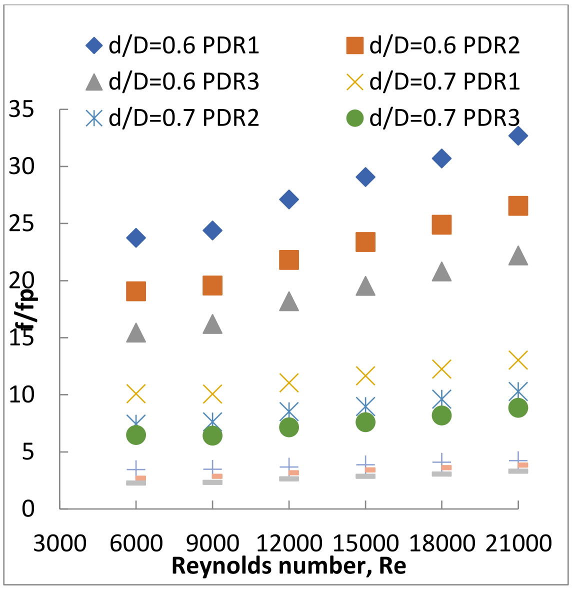
(a) (b)

Fig. 6. Test results (a) Reynolds number versus Nu (b) Reynolds number versus Nut/Nup for HRT Inserts

Figure 7 shows a comparison between the pressure drop across the test section and the pressure drop in a straightforward tube and the improved heat transfer using ring inserts. For all of the test situations, Figure 7(a)-(b) demonstrates that the friction factor somewhat decreases as the Reynolds number rises. The insert's friction factor is between 126% and 230% higher than that of the plain tube, with a diameter ratio of 0.8 and a PDR of 3. This insert has the lowest friction factor. The overall performance factors are presented in Table 4.



(a)



(b)

Fig. 7. Reynolds number versus (a) f and (b) f_t/f_p for HRT

Table 4
Overall performance factor ranges with a different insert

Sr. no.	Insert (FBA, PDR)	Overall performance factor
1	30%,2	1.04-1.26
2	30%,3	1.02-1.22
3	30%,4	1.0-1.21
4	40%,2	0.92-1.18
5	40%,3	0.91-1.15
6	40%,4	0.9-1.13
7	50%,2	0.85-1.07
8	50%3	0.82-1.05
9	50%,4	0.78-1.019

4.2 Empirical Correlations

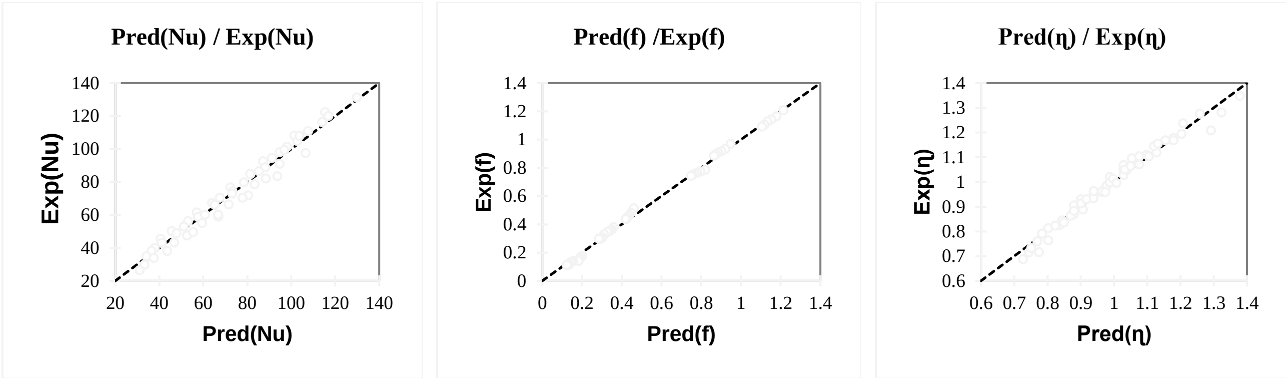
The following empirical correlations were created using the most recent experimental data

$$Nu = 0.023Re^{0.83}(d/D)^{-0.68}PDR^{-0.17} \tag{1}$$

$$f = 0.094Re^{-0.074}(d/D)^{-6.3}PDR^{-0.35} \tag{2}$$

$$\eta = 12.34Re^{-0.23}(d/D)^{1.02}PDR^{-0.06} \tag{3}$$

Figure 8 displays comparisons between expected and experimental results (a)–(c). In terms of thermal performance, HRT is superior to base inserts or inserts with attached rings to the wall.



(a) (b) (c)

Fig. 8. Experimental data compared with predictive data from empirical correlation for (a) Nusselt number (b) friction factor (c) Overall friction factor for HRT

4.3 Numerical Results and Discussion

A computer simulation of fluid flow in a tube with various inserts was used to examine the parameters of heat transmission and fluid flow. The grid distribution inside a circular tube with circular rings is shown in Figure 9. A non-uniform 3-dimensional mesh is employed in this investigation. The grid is smoother around the tube walls and circular ring because to the strong velocity and temperature differences.

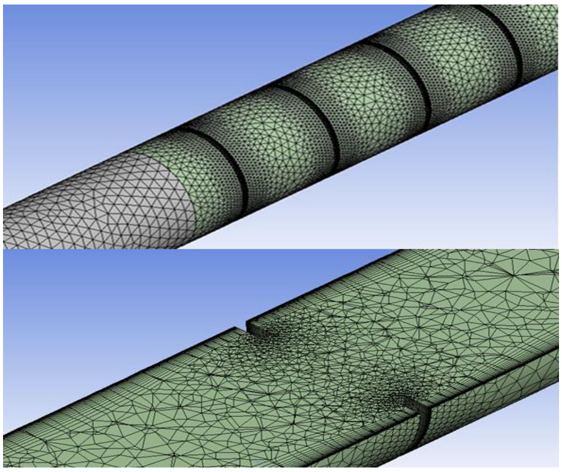


Fig. 9. Mesh structure of the fluid domain

4.4 Velocity Contour

The velocity vectors for the selected pipe models are shown to help understand the domain-specific flow patterns and behaviours. The introduction of a circular ring, as shown in Figure 10(a)-(c), disturbs fluid circulation between the tube wall and core sections. For 50% FBA, the frequency of the primary recirculation vortex is higher. The size of the recirculation vortex grows as FBA increases, as shown in Figure 10(a)-(c).

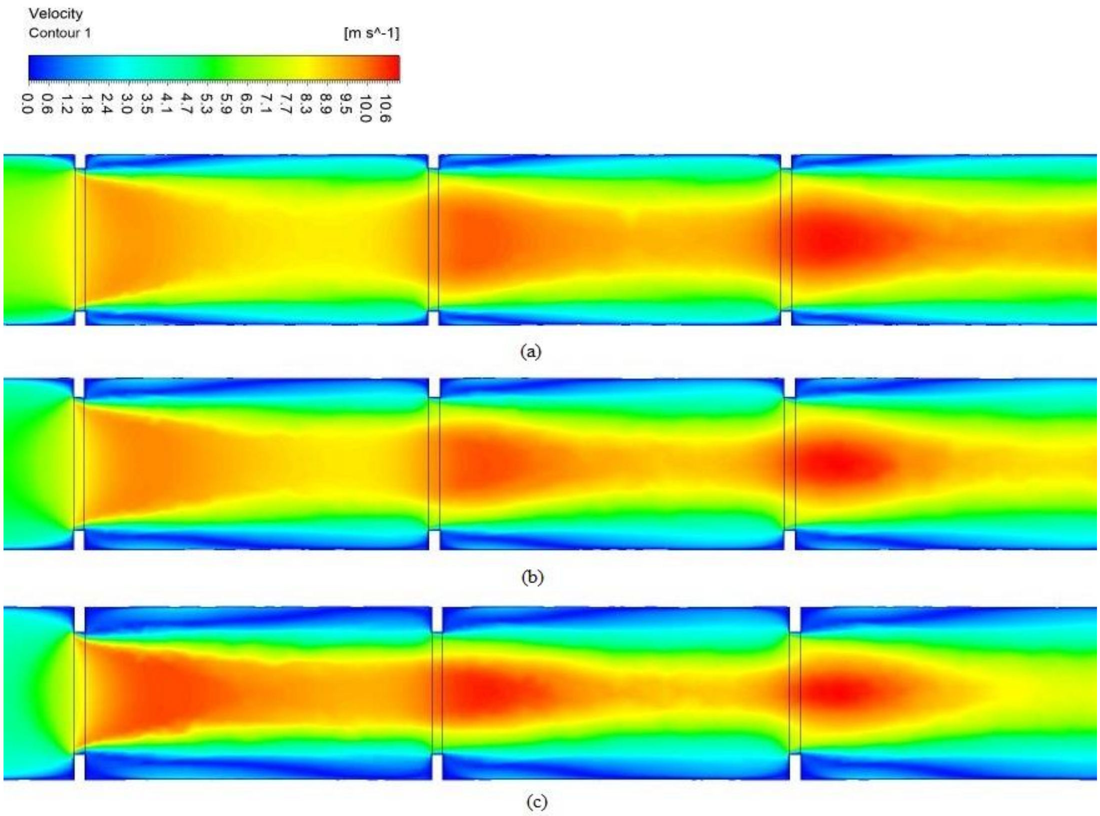


Fig. 10. Velocity contour in tube with (a) 30% rings (b) 40 % ring (c) 50% ring

Figure 11 depicts an axial velocity contour plotted on planes 1, 2, 3, and 4 at axial coordinates 'x' from the ring with x/D values of 0, 0.1, 0.3, and 0.6, respectively. Figure 10 shows the vector contour for different FBA settings. When comparing Figure 11(a)-(c), it is clear that the 50% ring inserts cause significant whirling. Furthermore, as FBA increases, the fluid velocity streamline becomes more curved, indicating that the perturbation in the boundary layer becomes more intense.

Figure 11 and Figure 12 show velocity contours and velocity vector plots for fluid flow within a pipe fitted with a circular ring insert with a circumferential gap. Due to flow separation and reattachment, a standard circular ring with no gap exerts a large shear stress on a tube wall. According to Figure 12, a side-running flow and a core-running flow are produced around the ring, resulting in an intense secondary flow and substantial fluid mixing. The cooling fluid is transported to the tube wall by the moving centre. The velocity contours for tubes with converging and diverging designs are shown in Figure 13.

Journal of Advanced Research in Fluid Mechanics and Thermal Sciences
Volume 103, Issue 1 (2023) 16-29

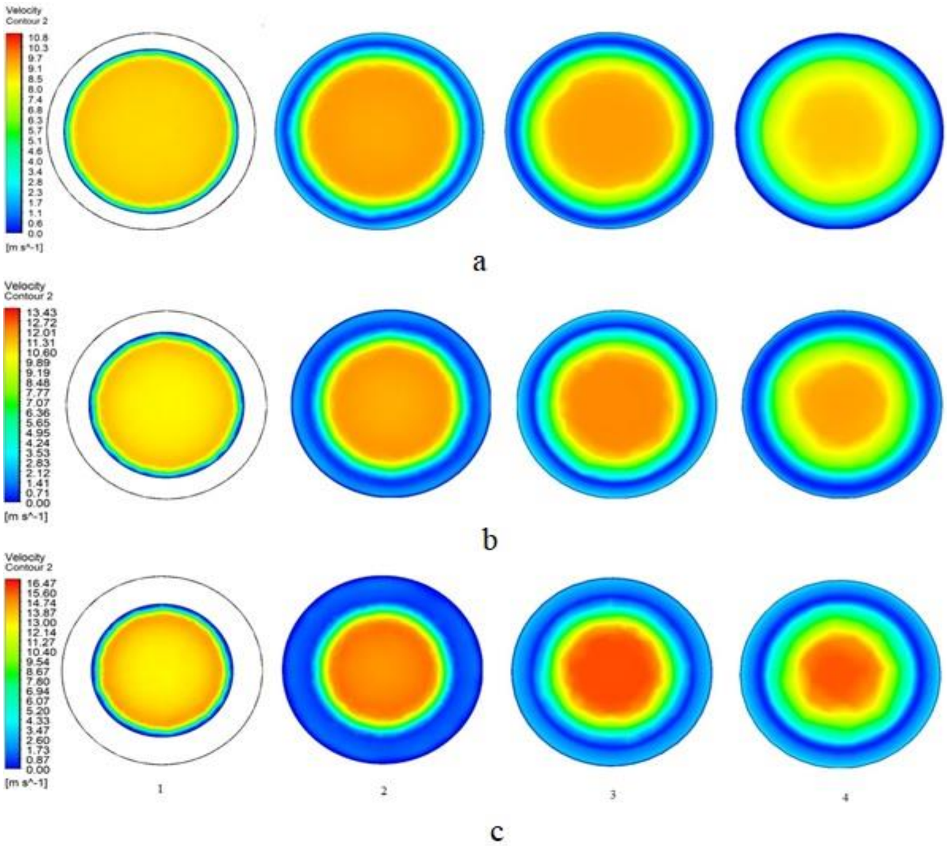


Fig. 11. Velocity contour on a cross-sectional plane 1, Plane 2, plane 3 and plane 4 for (a) 30% ring (b) 40 % ring (c) 50% ring

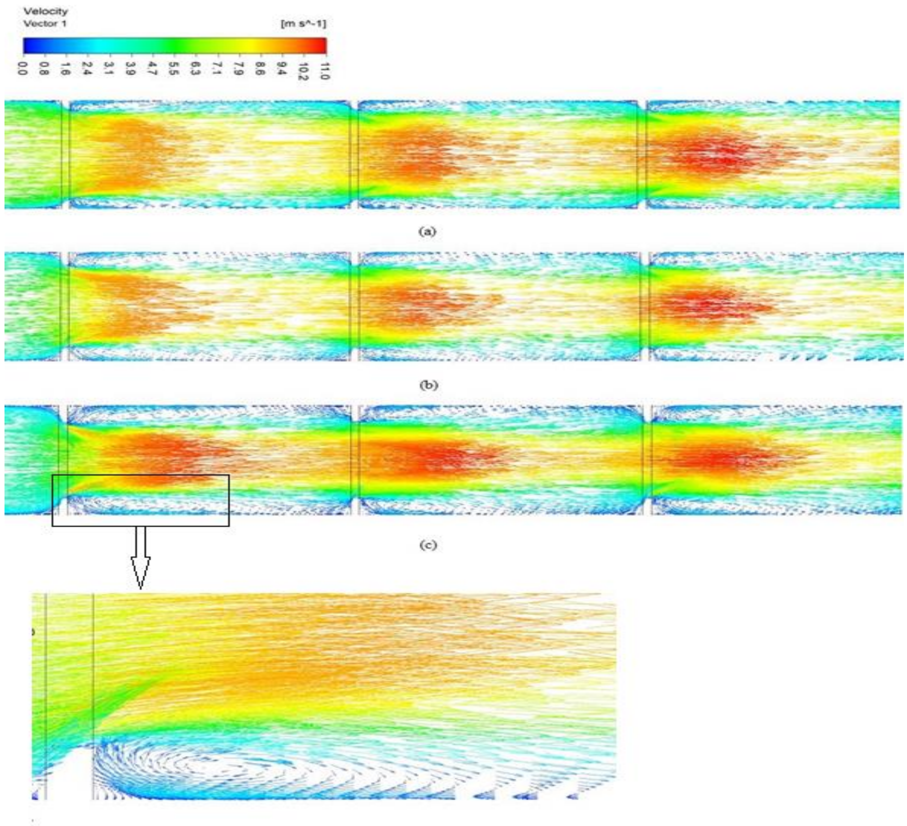


Fig. 12. Velocity vector in tube with (a) 30% rings (b) 40 % ring (c) 50% ring

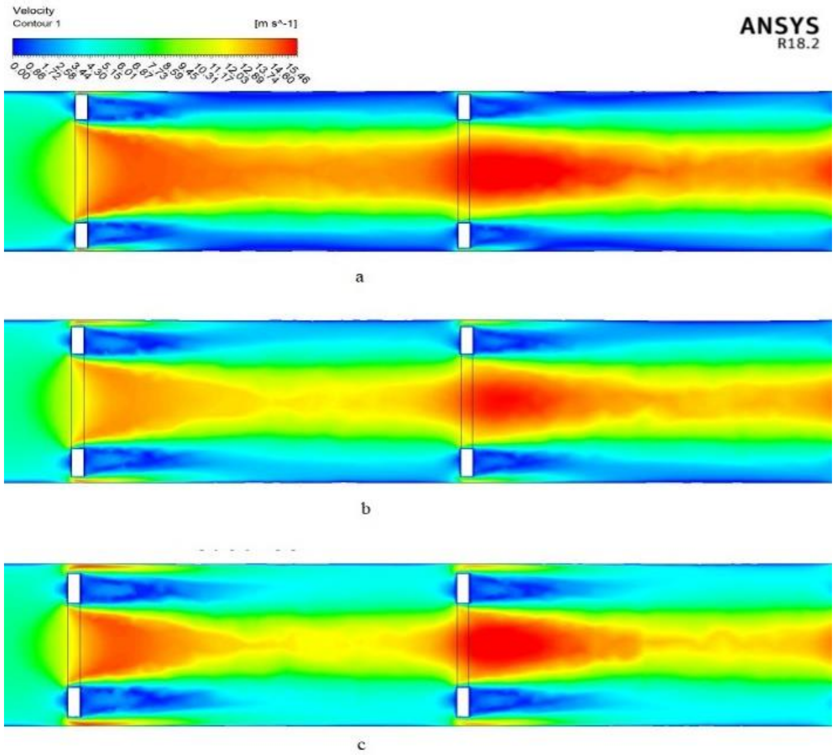


Fig. 13. Velocity contour on a longitudinal plane for insert with (a) 1mm gap (b) 2 mm gap (c) 3mm gap

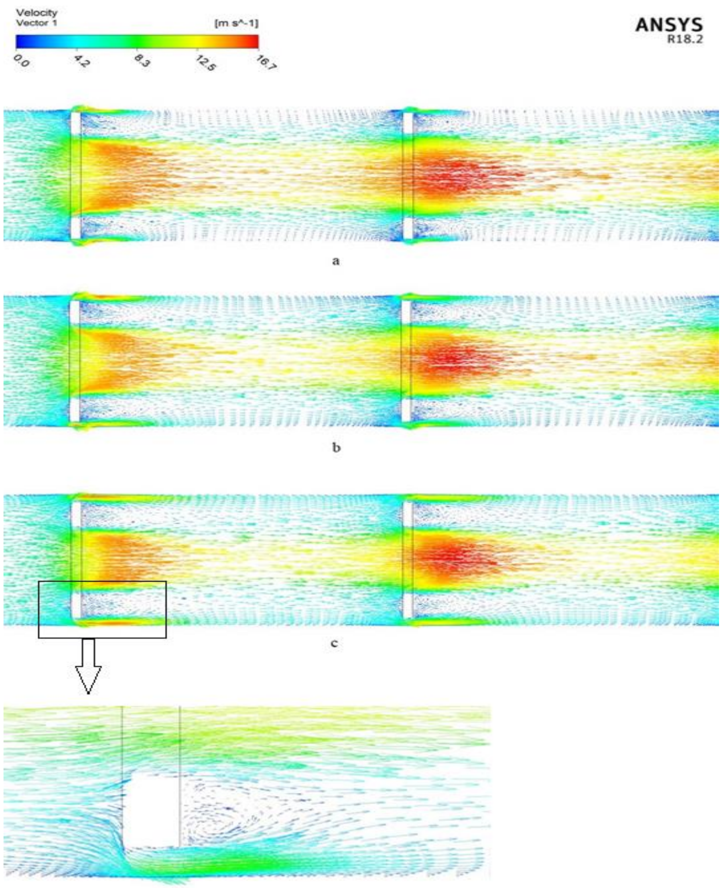


Fig. 14. Velocity vectors on a longitudinal plane for insert with (a) 1mm gap (b) 2 mm gap (c) 3mm gap

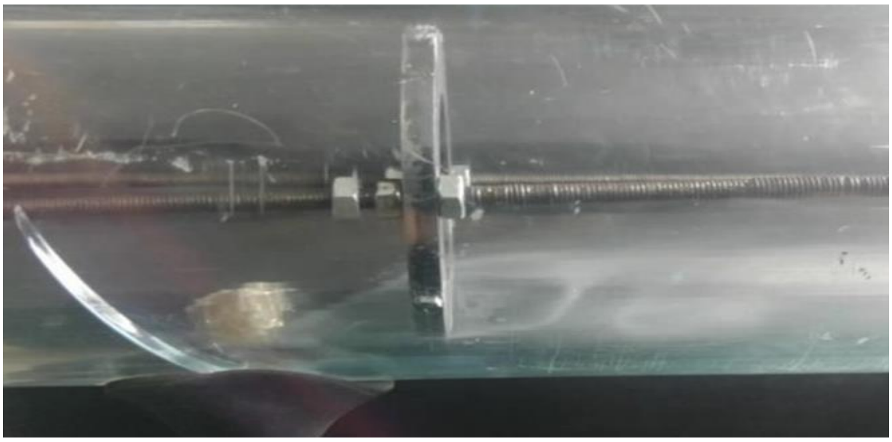


Fig. 15. Photography of flow across the ring with a gap

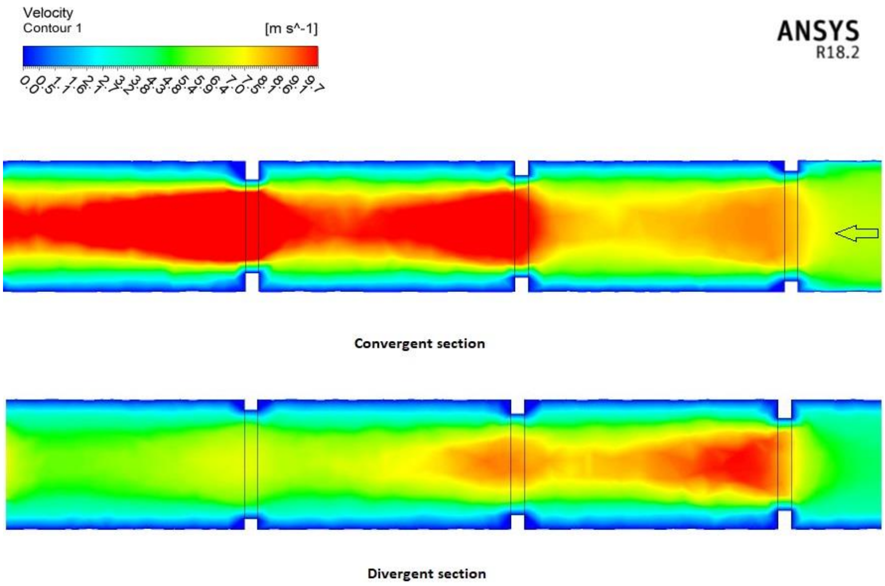


Fig. 16. Velocity contour for convergent and divergent sections

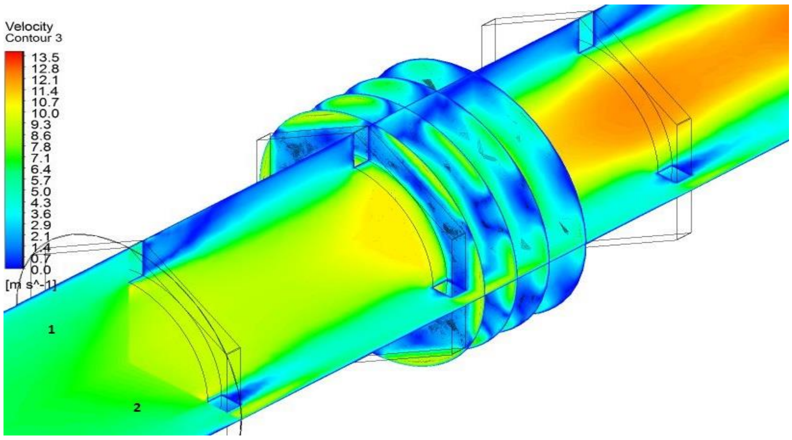


Fig. 17. Velocity contour on various sectional planes for HRT insert

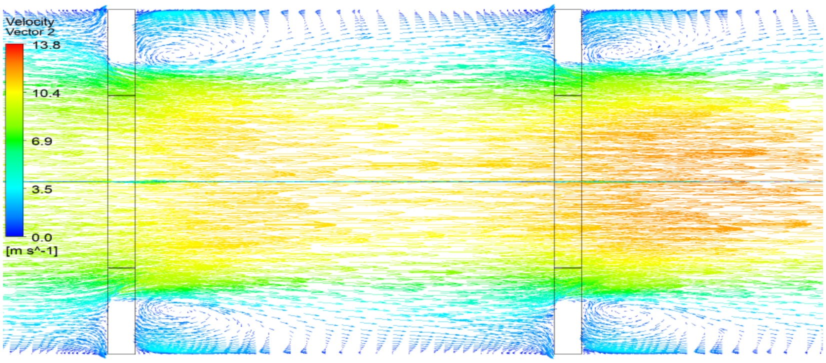


Fig. 18. Velocity vector on longitudinal symmetrical sectional plane 1

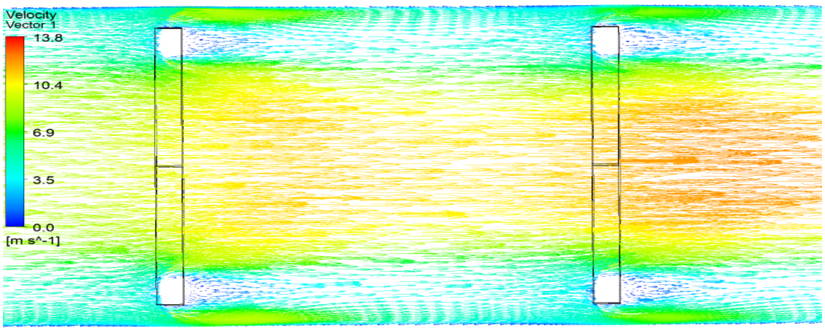


Fig. 19. Velocity vector on longitudinal symmetrical sectional plane 2

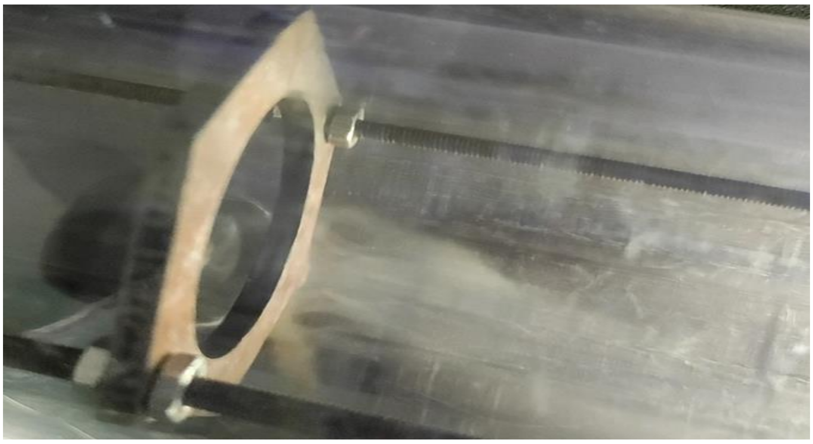


Fig. 20. Photography of flow across the HRT

The velocity contour figures on two longitudinal sectional planes and several transverse sectional planes. In contrast to a circular ring, a fluid-filled area exists between the ring and the wall in a HRT. A circular ring encourages effective flow separation and thins the boundary layer in that area because secondary reverse flow is more common there, as seen in Figure 13-19. As a result, the tube wall experiences a strong shear force. Inflow through the HRT, on the other hand, is less relevant in the area where the ring and the wall are separated. As seen in Figure 20, pair of vortices forms near the wall when the HRT makes contact with the tube wall, enhancing heat transfer locally in the close area. In the present work, a new turbulator, Hexagonal ring turbulator (HRT), was tested experimentally to investigate the thermo-hydraulic performance of a circular heat exchanger tube with air as a working fluid in a turbulent regime.

5. Conclusions

The rate of heat transfers and pressure loss over a flat tube are both significantly increased by flow obstruction within the studied range of all parameters. As FBA and Reynolds number rise, the rate of heat transmission increases. Additionally, pressure drop rises with FBA and somewhat falls with increasing Reynolds number. Heat transmission is improved for a given FBA by a hexagonal ring and a circular ring with clearance (Nut/Nup). The PDR was 1 and the diameter ratio was 0.8 for the insert with the best overall performance factor of 1.04-1.34. Different characteristics, such as perforated, slots, etc., can be used to investigate the impact on heat transport and friction factor. In terms of heat transfer, HRT is superior to base inserts—that is, inserts with rings attached to the wall. Insert with HRT achieves a higher overall performance factor, 1.34, compared to CRT, which only achieves a maximum overall performance factor of 1.26 over the tested range.

Acknowledgement
The authors are grateful to the VIIT, TAE, and SAE Engineering institutes in Pune, Maharashtra, India for their help and lab space. This work was not supported by any research funds.

References

[1] Kumar, Alok, Manoj Kumar, and Sunil Chamoli. "Comparative study for thermal-hydraulic performance of circular tube with inserts." *Alexandria Engineering Journal* 55, no. 1 (2016): 343-349. https://doi.org/10.1016/j.aej.2015.12.013

[2] Agrawal, Piyush, Abhishek Gautam, Anshul Kunwar, Manoj Kumar, and Sunil Chamoli. "Performance assessment of heat transfer and friction characteristics of a packed bed heat storage system embedded with internal grooved cylinders." *Solar Energy* 161 (2018): 148-158. https://doi.org/10.1016/j.solener.2017.12.044

[3] Suri, Amar Raj Singh, Anil Kumar, and Rajesh Maithani. "Experimental determination of enhancement of heat transfer in a multiple square perforated twisted tape inserts heat exchanger tube." *Experimental Heat Transfer* 31, no. 2 (2018): 85-105. https://doi.org/10.1080/08916152.2017.1397814

[4] Kongkaitpaiboon, V., K. Nanan, and Smith Eiamsa-Ard. "Experimental investigation of convective heat transfer and pressure loss in a round tube fitted with circular-ring turbulators." *International Communications in Heat and Mass Transfer* 37, no. 5 (2010): 568-574. https://doi.org/10.1016/j.icheatmasstransfer.2009.12.016

[5] Patil, Adhikrao S., Sandeep S. Kore, and Narayan K. Sane. "Experimental investigation of the effect of flow blockages on heat transfer and fluid friction in a round tube using wall-attached circular rings." *Heat Transfer Research* 50, no. 1 (2019). https://doi.org/10.1615/heattransres.2018025424

[6] Kumar, Alok, Sunil Chamoli, and Manoj Kumar. "Experimental investigation on thermal performance and fluid flow characteristics in heat exchanger tube with solid hollow circular disk inserts." *Applied Thermal Engineering* 100 (2016): 227-236. https://doi.org/10.1016/j.applthermaleng.2016.01.081

[7] Patil, Adhikrao S., and Sandeep S. Kore. "Experimental investigation on thermo-physical characteristics of fluid flow in circular tube enhanced with circular rings with different arrangements." *International Journal of Ambient Energy* 42, no. 12 (2021): 1376-1385. https://doi.org/10.1080/01430750.2019.1608859

[8] Promvonge, Pongjet, and Smith Eiamsa-Ard. "Heat transfer and turbulent flow friction in a circular tube fitted with conical-nozzle turbulators." *International Communications in Heat and Mass Transfer* 34, no. 1 (2007): 72-82. https://doi.org/10.1016/j.icheatmasstransfer.2006.08.003

[9] Promvonge, P. "Heat transfer behaviors in round tube with conical ring inserts." *Energy Conversion and Management* 49, no. 1 (2008): 8-15. https://doi.org/10.1016/j.enconman.2007.06.009

[10] Promvonge, Pongjet, and Smith Eiamsa-Ard. "Heat transfer augmentation in a circular tube using V-nozzle turbulator inserts and snail entry." *Experimental Thermal and Fluid Science* 32, no. 1 (2007): 332-340. https://doi.org/10.1016/j.expthermflusci.2007.04.010

[11] Eiamsa-ard, Smith, and Pongjet Promvonge. "Thermal characterization of turbulent tube flows over diamond-shaped elements in tandem." *International Journal of Thermal Sciences* 49, no. 6 (2010): 1051-1062. https://doi.org/10.1016/j.ijthermalsci.2009.12.003

[12] Chamoli, Sunil, Peng Yu, and Alok Kumar. "Multi-response optimization of geometric and flow parameters in a heat exchanger tube with perforated disk inserts by Taguchi grey relational analysis." *Applied Thermal Engineering* 103 (2016): 1339-1350. https://doi.org/10.1016/j.applthermaleng.2016.04.166

[13] Chamoli, Sunil, Ruixin Lu, Jin Xie, and Peng Yu. "Numerical study on flow structure and heat transfer in a circular tube integrated with novel anchor shaped inserts." *Applied Thermal Engineering* 135 (2018): 304-324. https://doi.org/10.1016/j.applthermaleng.2018.02.052

[14] Bhattacharyya, Suvanjan, Ali Cemal Benim, Himadri Chattopadhyay, and Arnab Banerjee. "Experimental investigation of heat transfer performance of corrugated tube with spring tape inserts." *Experimental Heat Transfer* 32, no. 5 (2019): 411-425. http://dx.doi.org/10.1080/08916152.2018.1531955

[15] Chamoli, Sunil. "Preference selection index approach for optimization of V down perforated baffled roughened rectangular channel." *Energy* 93 (2015): 1418-1425. http://dx.doi.org/10.1016/j.energy.2015.09.125

[16] Chamoli, Sunil. "Hybrid FAHP (fuzzy analytical hierarchy process)-FTOPSIS (fuzzy technique for order preference by similarity of an ideal solution) approach for performance evaluation of the V down perforated baffle roughened rectangular channel." *Energy* 84 (2015): 432-442. http://dx.doi.org/10.1016/j.energy.2015.03.007

[17] Gudekote, Manjunatha, and Rajashekhar Choudhari. "Slip effects on peristaltic transport of Casson fluid in an inclined elastic tube with porous walls." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 43, no. 1 (2018): 67-80.

[18] Gudekote, Manjunatha, Rajashekhar Choudhari, Hanumesh Vaidya, and Kerehalli Vinayaka Prasad. "Peristaltic flow of Herschel-Bulkley fluid in an elastic tube with slip at porous walls." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 52, no. 1 (2018): 63-75.

[19] Gudekote, Manjunatha, Hanumesh Vaidya, Divya Baliga, Rajashekhar Choudhari, Kerehalli Vinayaka Prasad, and Viharika Viharika. "The effects of convective and porous conditions on peristaltic transport of non-Newtonian fluid through a non-uniform channel with wall properties." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 63, no. 1 (2019): 52-71.

[20] Baliga, Divya, Manjunatha Gudekote, Rajashekhar Choudhari, Hanumesh Vaidya, and Kerehalli Vinayaka Prasad. "Influence of velocity and thermal slip on the peristaltic transport of a herschel-bulkley fluid through an inclined porous tube." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 56, no. 2 (2019): 195-210.

[21] Divya, B. B., G. Manjunatha, C. Rajashekhar, Hanumesh Vaidya, and K. V. Prasad. "Analysis of temperature dependent properties of a peristaltic MHD flow in a non-uniform channel: a Casson fluid model." *Ain Shams Engineering Journal* 12, no. 2 (2021): 2181-2191. https://doi.org/10.1016/j.asej.2020.11.010

[22] Vaidya, Hanumesh, C. Rajashekhar, K. V. Prasad, Sami Ullah Khan, Arshad Riaz, and J. U. Viharika. "MHD peristaltic flow of nanofluid in a vertical channel with multiple slip features: an application to chyme movement." *Biomechanics and Modeling in Mechanobiology* 20 (2021): 1047-1067. https://doi.org/10.1007/s10237-021-01430-y

[23] Manoj Kumar Chaudhary, Prashant N Chavan, Ganesh D Sutar, Mr. Omkar B Gaikwad , and Mr. Shubham M Dagade, “Investigation of Turbulent Effect In Forced Convection By Using Various Inserts-A Review.” *International Journal of Management, Technology and Engineering*, Volume 8, Issue IX, (2018); 92-96.

[24] Shrirao, Pankaj N., Manoj K. Chaudhary, and Amol N. Patil. "Performance evaluation of heat transfer characteristics of heat exchanger in longitudinal fluid flow with serpentine tubes of constant pitch." *Materials Today: Proceedings* 72 (2023): 864-869. https://doi.org/10.1016/j.matpr.2022.09.082

[25] Khan, Ansab Azam, Khairy Zaimi, Suliadi Firdaus Sufahani, and Mohammad Ferdows. "MHD flow and heat transfer of double stratified micropolar fluid over a vertical permeable shrinking/stretching sheet with chemical reaction and heat source." *Journal of Advanced Research in Applied Sciences and Engineering Technology* 21, no. 1 (2020): 1-14. https://doi.org/10.37934/araset.21.1.114

[26] Fekadu, Birlie, and H. V. Harish. "Numerical Studies on Thermo-Hydraulic Characteristics of Turbulent Flow in a Tube with a Regularly Spaced Dimple on Twisted Tape." *CFD Letters* 13, no. 8 (2021): 20-31. https://doi.org/10.37934/cfdl.13.8.2031

[27] Tey, Wah Yen, Yutaka Asako, Nor Azwadi Che Sidik, and Rui Zher Goh. "Governing equations in computational fluid dynamics: Derivations and a recent review." *Progress in Energy and Environment* 1 (2017): 1-19.

[28] Khan, Umair, William Pao, Nabihah Sallih, and Farruk Hassan. "Flow Regime Identification in Gas-Liquid Two-Phase Flow in Horizontal Pipe by Deep Learning." *Journal of Advanced Research in Applied Sciences and Engineering Technology* 27, no. 1 (2022): 86-91. https://doi.org/10.37934/araset.27.1.8691