"Enhancement of Heat Transfer in Concentric Tube Heat Exchanger by Attaching Vortex Generator on Tube Surface"

OPEN ACCESS

AG-2023-1001

Volume: 3

Issue: 2

Month: April

Year: 2024

ISSN: 2583-7117

Published: 01.04.2024

Citation:

Uttam Patel[1], Piyush Kumar Verma[2], Dr. B. Suresh[3]. "Enhancement of Heat Transfer in Concentric Tube Heat Exchanger by Attaching Vortex Generator on Tube Surface." International Journal of Innovations In Science Engineering And Management, vol. 3, no. 2, 2024, pp. 11–20.

Uttam Patel[1], Piyush Kumar Verma[2], Dr. B. Suresh[3]

[1]Research Scholar, Department of Mechanical Engineering, Corporate Institute Of Science & Technology, Bhopal
[2]Asst Prof., Department of Mechanical Engineering, Corporate Institute Of Science & Technology, Bhopal
[3]Prof. & HOD, Department of Mechanical Engineering, Corporate Institute Of Science & Technology, Bhopal

Abstract
This study focuses on the evaluation of "heat transfer enhancement" (HTE) performance in a "Concentric Tube Heat Exchanger" (CTHE) utilizing a trapezoidal vortex generator. The analysis is conducted using the "Computational Fluid Dynamics" (CFD) software "ANSYS Fluent". The analysis of heat transmission and fluid flow is performed for different configurations of vortex generators. The study also examines the impacts of Vortex Generators (VGs) and simulates the turbulence flow using the "k- model". The study involved the examination of four distinct configurations, in which the VGs were positioned at varying locations and inclination angles relative to the tube axis. The VGs are angled at 30 degrees within the tube in Case 1. The VGs in Case 2 are angled at a right angle to the tube. In Case 3, there are 40 VGs located either inside or outside the tube. Lastly, in Case 4, there are 48 VGs positioned either inside or outside the tube. In order to investigate the impact of VGs on flow and heat transfer enhancement, the outlet temperature of the hot and cold fluids, as well as the temperature of the hot and cold fluids throughout the length of the tube, and each of the adjusted cases' pressure drops for both hot and cold fluids are adjusted to case 1's standard. The results indicate that VGs are efficacious in all scenarios. Nevertheless, the most significant enhancement in temperature gap was seen in instance 3 for the outer tube fluid and case 4 for the inner tube fluid. There exists a negligible difference in temperature between case 3 and case 4 within the inner tube.

Keyword: Heat transfer, computational fluid dynamics, vortex generator, turbulence, etc.

I. INTRODUCTION

Heat exchangers allow for the transmission of heat, either between different fluids or between a fluid and a solid surface in the absence of physical contact. The term "fluid" is broad enough to include not just liquids but also gases and vapours.[1]–[3] This means that the flow arrangement determines the operational mode of heat-exchanging devices, and there are several conceivable modes. Whether it's heating or cooling, a heat exchanger can do it without the fluids coming into direct touch with one another.[4]–[7]

A number of critical features must be carefully considered during the design phase of heat exchangers in order to achieve high performance and efficiency.[8]–[10] Integrating these design factors allows engineers to maximise heat exchanger performance, improve energy efficiency, and guarantee dependable operation in many industrial domains.[11]–[13] Maximizing the transferable heat surface area ought to be one of the fundamental design objectives of any heat exchanger. The efficiency of the "heat exchange" mechanism improves as the surface area increases. Either a small design with several tiny tubes or plates or the incorporation of extended surfaces (fins) may achieve this.[14]–[16]

There is a notable lack of study on optimised geometrical designs and sophisticated surface modifications for heat transfer improvement in twin pipe heat exchangers with a counter-flow arrangement. Extensive research has focused on traditional technologies like turbulators and expanded surfaces, but there has been little on novel ways that may significantly increase heat transfer rates while reducing pressure drop penalties. There needs to be more research on counter-flow heat exchangers since our current knowledge of the additive effects of various improvement methods is inadequate. There has to be further research into how operational factors like fluid flow rates, Reynolds numbers, and temperature differentials affect the efficiency of heat transfer enhancement mechanisms in counter-flow double pipe heat exchangers. In addition, studies devoting attention to the manufacturability, cost-effectiveness, and compatibility issues that arise when adopting improved designs on a large scale are few. By filling in these knowledge gaps, we can design heat transfer solutions that work better and last longer for counter-flow double pipe heat exchangers; this has far-reaching implications for a variety of fields and technologies, from manufacturing to renewable energy.

II. OBJECTIVE

- To study the effect of vortex generator in flow of fluid.
- To study the effect of heat enhancement in double pipe heat exchanger with vortex generator.
- To study the temperature drop of hot fluid by the variation in angle of VGs (vortex generator)
- To study the effect in temperature of cold fluid by adding the VGs in outer tube.
- To study the effect in pressure of cold and hot fluid with presence of VGs in both inner or outer surface of the tube.

III. RESEARCH AND METHODOLOGY

A. Governing equation

The flow undergoes three-dimensional (3D) steady-state testing in the following investigation. Navier-Stokes equations with Reynolds averaged terms (RANS). For a Newtonian fluid that is incompressible, the following are the momentum and continuity equations:

$$\frac{\partial u_i}{\partial x_i} = 0$$

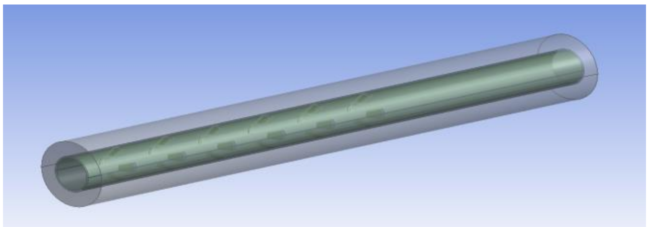
$$u_j \frac{\partial u_i}{\partial x_i} = \frac{\partial p}{\partial x_i} + v \frac{\partial^2 u_i}{\partial x_j \partial x_i} - \frac{\overline{\partial \acute{u}_i \acute{u}_j}}{\partial x_j}$$

"Where the term ((〖∂u〗 _i)´(u_j)´)¯is the Reynolds stress due to the change of velocity."

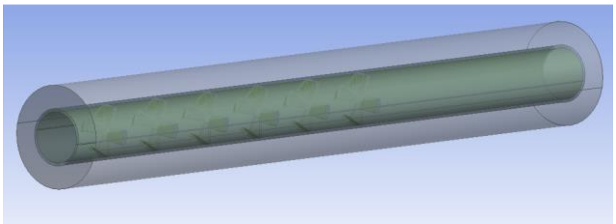
B. Computational domain

A "Concentric Tube Heat Exchanger" (CTHE) with varying configurations of "vortex generators" (VG) attached to the inner wall constitutes the computational domain for the simulations. Aside from its 300 mm length, the tube's dimensions are 20 mm in inner diameter, 40 mm in outer diameter, and 1 mm in wall thickness. In order to improve heat transmission, trapezoidal VGs with dimensions of 6 mm for the base, 3 mm for the tiny base, 8 mm for height, and 1 mm for thickness are used on both the inside and outside of the tube. These VGs are angled at 30° and 90° with respect to the surface, respectively, and are oriented in the opposite direction of the flow. As seen in Figure, a total of 24, 40, and 48 VGs are produced in the inner and outer walls, respectively, by inserting six rows of four diametrically opposing VGs. Thirty millimetres separate each set of vertical grooves.

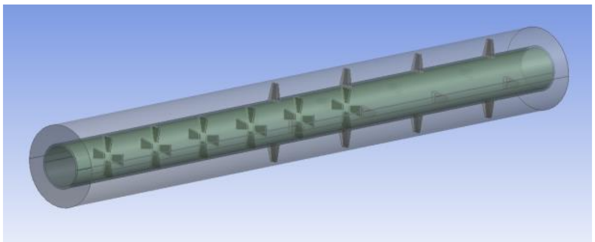
In case 1, VGs here are angled at 30 degrees with respect to the tube's surface, perpendicular to the direction of flow. The graphic shows that there are 24 VGs, and they are only visible on the inner tube surface. In case 2, the VGs are perpendicular to the tube axis. The graphic shows that there are 24 VGs, and they are only visible on the inner tube surface. "In case 3, VGs may be seen on the tube's inside and outside. Each vortex generator, inner and outer, forms a right angle with the surface of the tube. Forty VGs are present in this example, with 24 on the inner side of the tube and 16 on the exterior. Figure depicts the design's application in this instance." In case 4, VGs may be seen on the tube's inside and outside. Each vortex generator, inner and outer, forms a right angle with the surface of the tube. There are a total of 48 VGs in this instance, with 24 on the inside and 24 on the outside of the tube. Figure depicts the design's application in this instance.



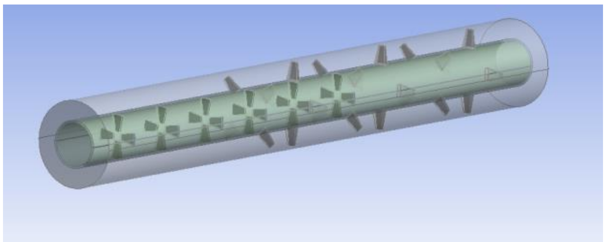
Case 1



Case 2



Case 3



Case 4

Figure 1 Design of double pipe heat exchanger with Vortex Generator at Inner surface and outer surface of the Tube

Table 1 Considered cases

Cases	Description
Case 1 – inner 30°	VGs are present in inner surface of tube with 30°
Case 2 – inner 90°	VGs are present in inner surface of tube with 90°
Case 3 – 4 Row outer	VGs are present in inner and outer surface of tube with 90° and having 4 row in outer surface
Case 3 – 6 Row outer	VGs are present in inner and outer surface of tube with 90° and having 6 row in outer surface

C. *Meshing*

All the simulations are done using a mesh that has polyhedral cells. At the VGs, the tube wall that divides the two fluids, and, in cases when the annular area's outer wall and the inner and outer surfaces of the tube both have VGs, the mesh is fine-tuned. As a result of the mesh formation in the computational domain, table 2 lists the amount of elements and nodes.

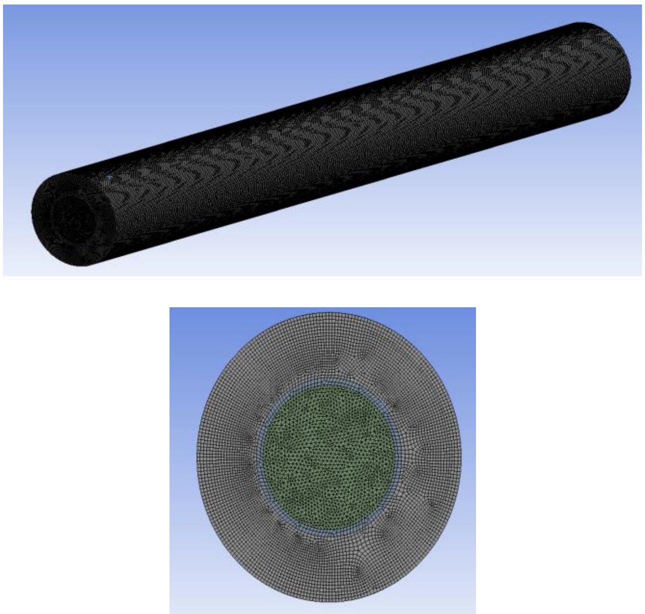


Figure 2 Meshed domain of shell and tube heat exchanger

Table 2 Meshing Details

Cases	Nodes	Element s
Case 1	3911360	5444075
Case 2	537186	824282
Case 3	1905967	8837634
Case 4	376201	1714603

D. Boundary condition

Here, the computational fluid dynamics (CFD) programme ANSYS Fluent was used for the numerical calculations. By jointly determining the momentum and pressure-based continuity equations, the linked algorithm generates the pressure-velocity combination. The spatial discretization of the convective forms is accomplished using a second-order upwind design, resulting in double the accuracy when computing the flow equations. The diffusion terms are second-order accurate and centrally differed. A standard for convergence is set for the flow equation of 10-

6. Nevertheless, the outcome of the energy calculation is given by a 10− 8.

A counter-flow system is in place, with hot water travelling through the tube at a temperature of 30° C (303 K) and cold water flowing through the annulus at a temperature of 20° C (293 K). The shell's outside is brought into an adiabatic state with a boundary condition of zero heat flow. The inlets are configured to have a mass flow rate. Coupled walls are used to tube walls. The graphic displays these boundary conditions. Hot fluid flows through the inner tube, while cold fluid flows through the outer shell; both are water. Use of steel for solid tube construction. In the table, you can see the water and steel properties.

Table 3 Thermo-Physical Properties of Water and Steel

Properties	Unit	Water	Steel
Density	Kg/m3	998.2	8030
Thermal conductivity	W/mK	0.6	16.27
Specific heat	J/kg.K	4182	502.48
Viscosity	Kg/m.s	0.001003	-

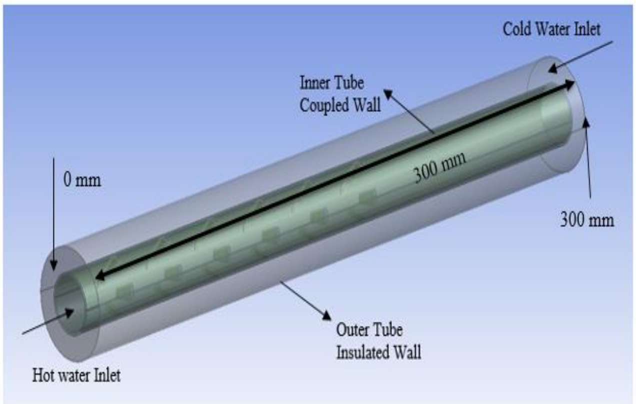


Figure 3 Boundary Condition

E. Validation

"In order to verify the correctness of the CFD findings, validation tests are run to examine the precision and detect any discrepancies in the numerical simulations. In order to verify the current simulation's outcome with (Aridi et al., 2022)[17] the outcome of the simulation, compare the heat transfer ratio in a shell and tube heat exchanger with and without a vortex. The mass flow rate in the inner tube (hot water) is 0.0315 kg/s, whereas in the outer shell (cold water) it is 0.1258 kg/s. Hot water is 30 degrees and cold water is 20 degrees at the starting stage of the simulation. Figure 4 shows the verified results."

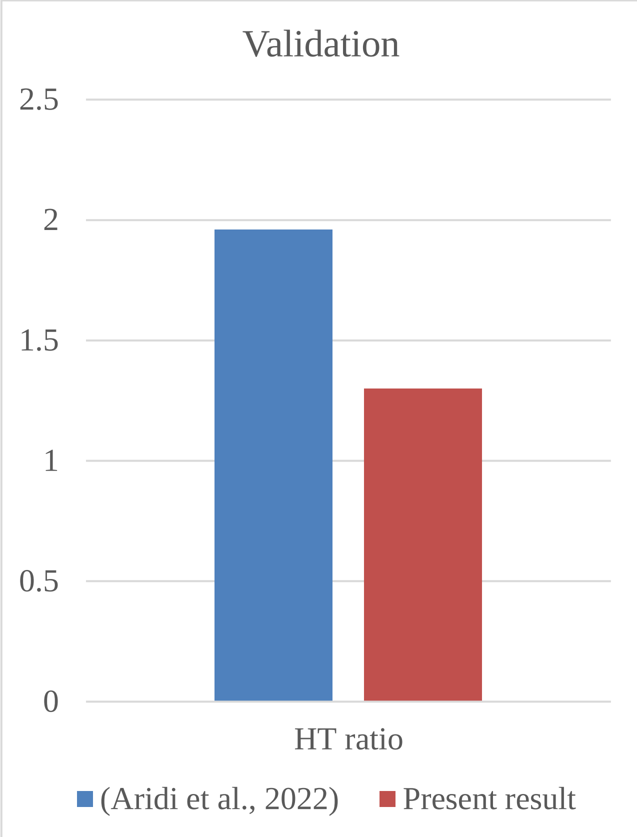
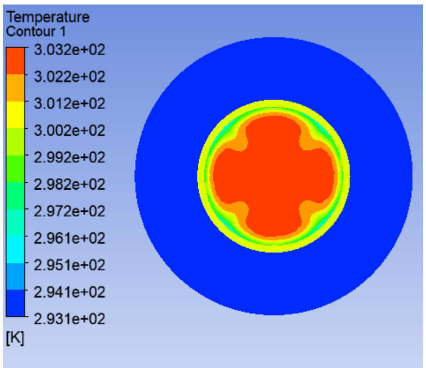


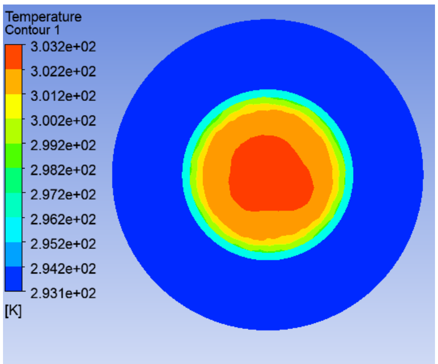
Figure 4 Validation

IV. RESULT AND DISCUSSION

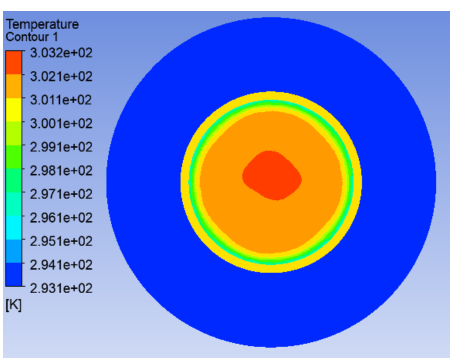
A. Temperature contour

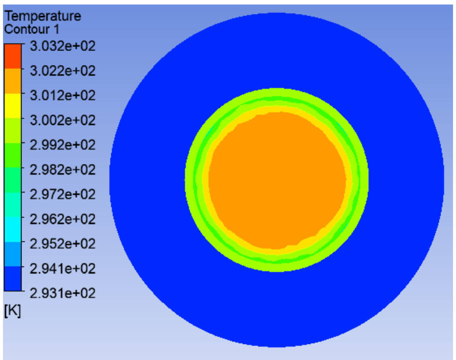
"Vortex generators (VGs) positioned within the concentric tube heat exchanger's (CTHE) inner surface have a substantial impact on the temperature distribution throughout the tube's length. These VGs act as barriers that change the dynamics of the flow, which improves heat transfer from the heated water in the inner tube to the cold water in the outside tube or shell. Due to heat exchange with the cold water in the outer tube, the hot water cools as it passes through the inner tube. As a first step, the temperature distribution is most impacted close to the tube wall and the VGs. But when the flow channel passes through successive rows of VGs, the temperature distribution changes noticeably, and not just in the area around the tube wall and VGs.





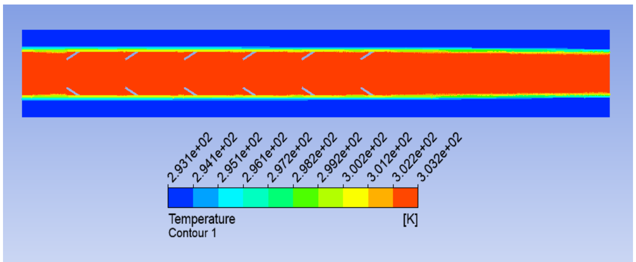
At hot water outlet Case 1 At hot water outlet Case 2



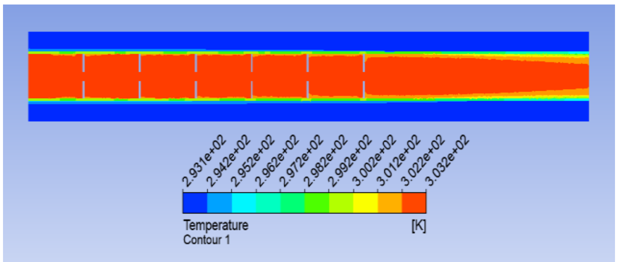


At hot water outlet Case 1 At hot water outlet Case 2

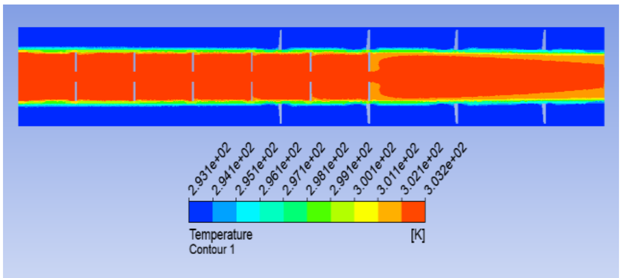
Figure 4 Temperature Contour at both end



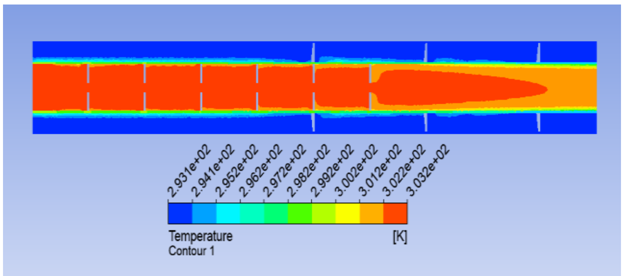
Case 1



Case 2



Case 3



Case 4

Figure 5 Temperature Contour at Mid plane

Overall, the presence of VGs within the "concentric tube heat exchanger" significantly improves its heat transfer by enhancing the convective heat transfer process between the hot fluid flowing in the inner tube and the cold fluid circulating in the outer tube of the shell. This leads to a more uniform temperature distribution along the length of the tube, with the cooling effect on the hot water becoming increasingly evident as it progresses through the exchanger. Figure 7 illustrate that outlet temperature of the hot water is slightly decreases and there is a major difference in case 3 and case 4 from the case 1. Case 3 and case 4 very minor difference in outlet temperature. Figure 7 illustrate that the outlet temperature of cold water in case 3 is maximum and in case 2 and case3 having similar temperature. In cases 4 and 3, the greatest temperature difference between the hot and cold water is shown in Figure 8. In case of temperature difference in hot water case 3 and case 4 having a minor difference.

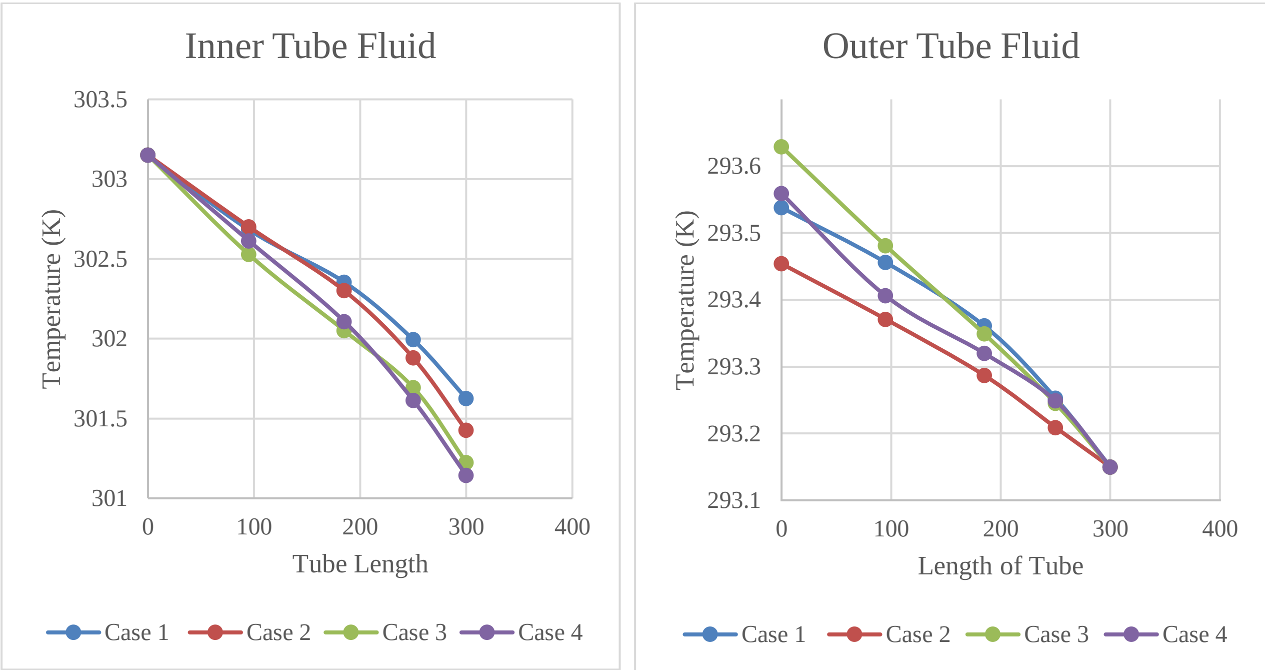


Figure 6 Temperature of inner tube and outer tube fluid along the length

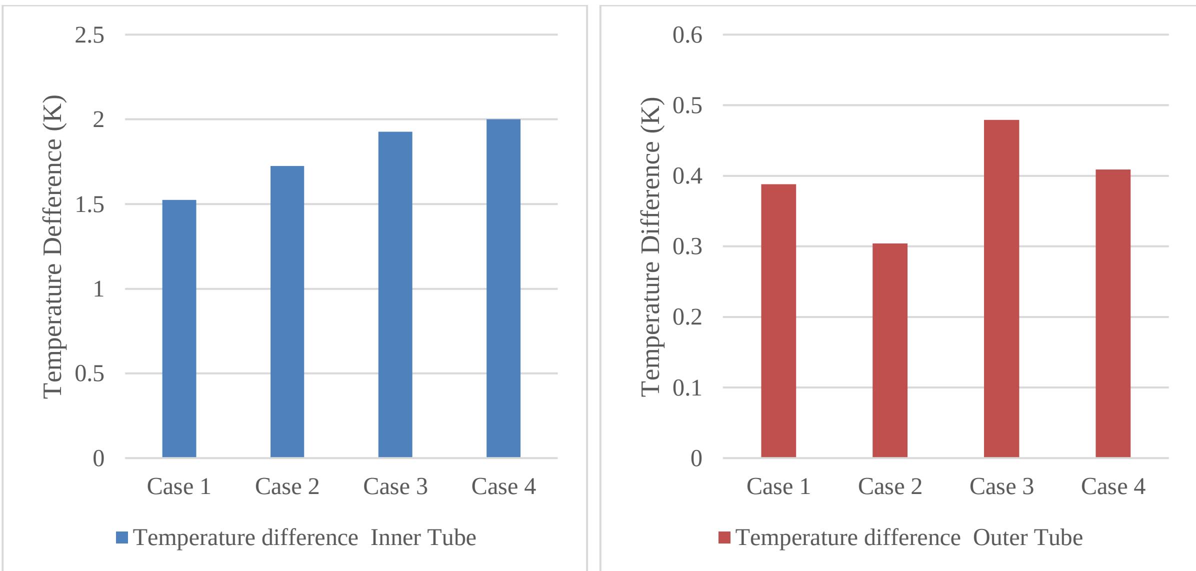
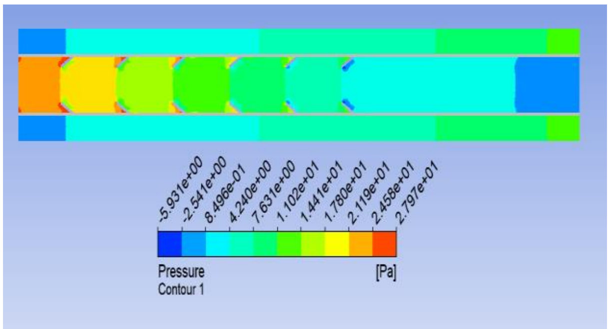


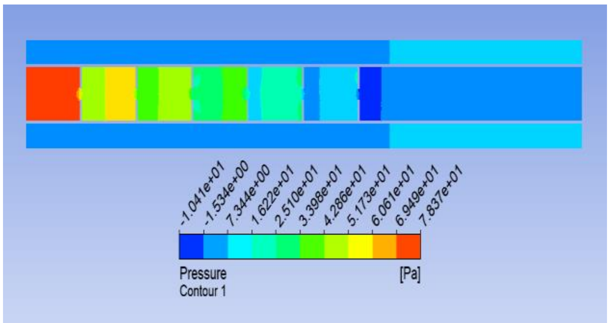
Figure 7 Temperature Difference of hot water and cold water

B. Pressure contour

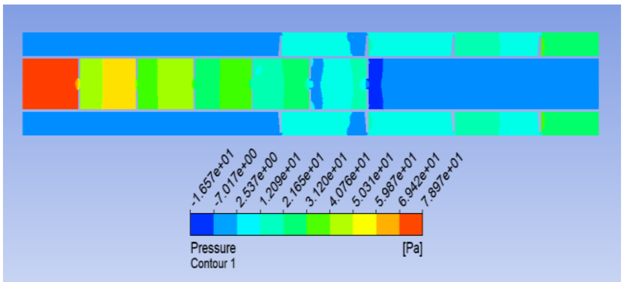
In the concentric tube heat exchanger (CTHE), the pressure distribution along the length of the tube is influenced by several factors, including the flow of the hot water through the inner tube and the cold water circulating through the outer tube or shell. Furthermore, the pressure characteristics inside the exchanger may be changed by incorporating vortex generators (VGs) onto the inner surface of the tube. At the inlet of the inner tube, where the hot fluid enters, the pressure are high. As the hot water flows along the length of the tube, it undergoes a cooling process due to the heat exchange with the colder water in the outer tube. This decrease in temperature is accompanied by a corresponding decrease in pressure, following the principles of fluid dynamics. The pressure gradually decreases as the hot water progresses along the tube, reaching its lowest point at the outlet where it exits the tube. At this point, the pressure approaches zero, reflecting the open-ended nature of the tube.



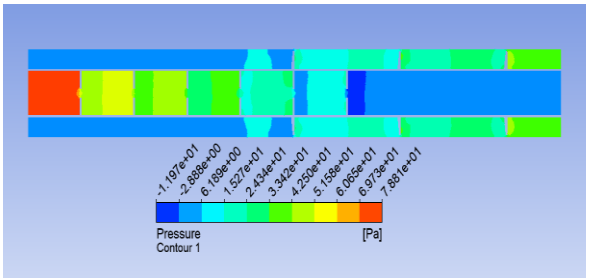
Case 1



Case 2



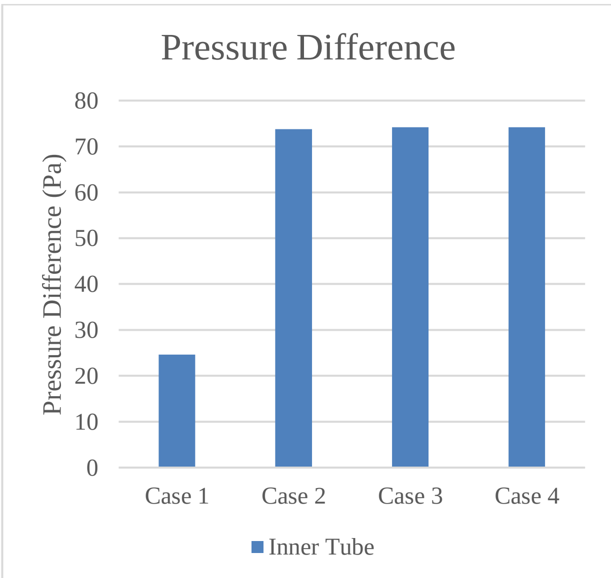
Case 3



Case 4

Figure 8 Pressure Contour at the mid plate

In summary, the pressure distribution in a "concentric tube heat exchanger" is influenced by the flow of the hot and cold water through the inner tube and outer shell, respectively, as well as by the presence of vortex generators that modify the flow dynamics. Despite localized variations due to the VGs, the overall pressure trend follows a predictable pattern, with pressure decreasing along the length of both the inner tube and outer shell, ultimately approaching zero at their respective outlets. The overall pressure difference at the inner tube and outer tube (Shell) are mention in the graph, which is show in below Figure 14. Pressure difference at the inner tube is same in case 2, 3, and 4. But in the outer tube pressure difference is increases in case 2, 3, and maximum at case 4.



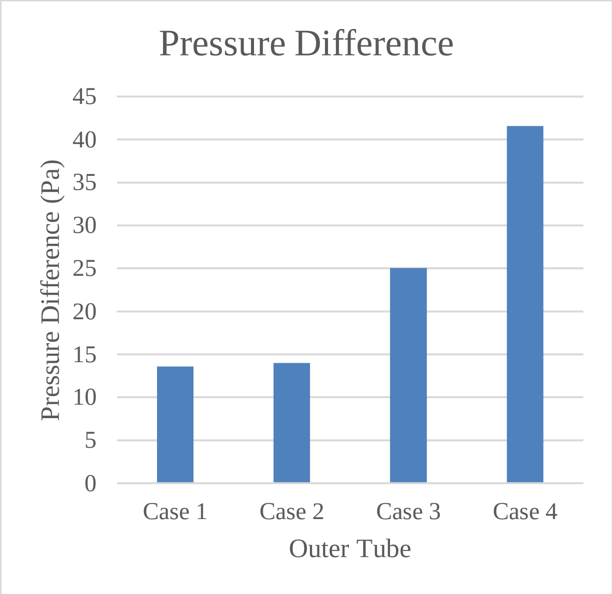
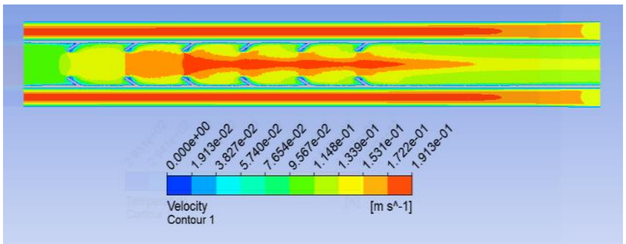


Figure 10 Pressure Difference in Inner Tube and Outer Tube

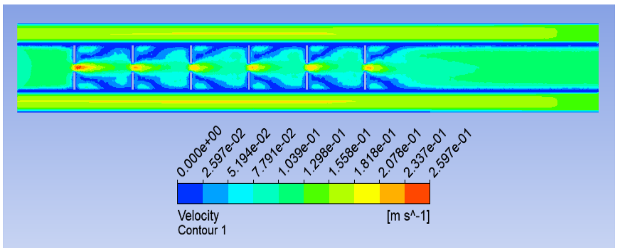
C. Velocity contour

Efficient heat transfer in a concentric shell and tube heat exchanger is dependent on the dynamics of fluid flow in the inner tube, which carries the hot water, and the outer tube or shell, which contains the cold water. Within the inner tube, as the hot water encounters vortex generators (VGs) or obstacles strategically placed along its inner surface, the flow transitions into turbulence. In contrast, within the outer tube or shell, the cold water enters at the inlet with relatively low velocity. As it progresses along the length of the shell, the velocity of the cold water increases. The velocity increase in the cold water within the outer tube is a consequence of the pressure drop along its length, ultimately leading to higher flow velocities at the outlet.

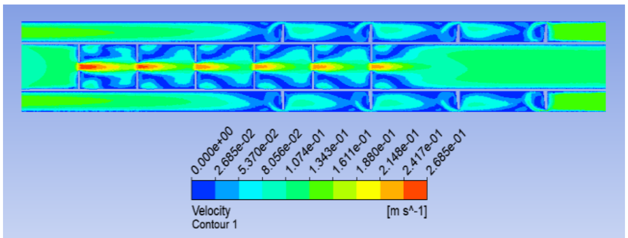
Overall, in the concentric shell and tube heat exchanger, the interaction between the hot water flowing within the inner tube and the cold water circulating in the outer tube is influenced by various factors, including the presence of vortex generators in the inner tube and the pressure gradient along the length of the outer tube. These dynamics play a crucial role in optimizing heat transfer efficiency within the exchanger, ensuring effective cooling of the hot fluid and heating of the cold fluid.



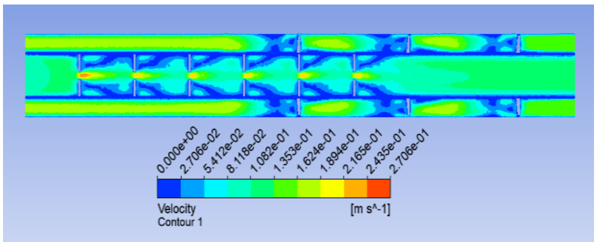
Velocity Contour at mid plane of Case 1



Velocity Contour at mid plane of Case 2



Velocity Contour at mid plane of Case 3



Velocity Contour at mid plane of Case 1

Figure 9 Velocity contour and streamline

V. CONCLUSION

This research used computational methods to examine the effect of "vortex generators" on heat transmission in a Concentric Tube Heat Exchanger. In order to investigate the geographical effect of VGs on heat transfer augmentation, the simulation research was conducted on four separate instances of VGs in various places. Therefore, geometry, in this instance the placement of the VGs, has impacted heat transmission in every instance. The VGs in this investigation were found on both the inside and outside of the inner tube. The output temperature, temperature differential, and pressure at the inner and outer tubes demonstrate that VGs improve heat transmission in all instances. Both the annular and the parts-tube flows exhibited turbulence, with the former exhibiting greater heat transfer efficiency because to the increased turbulence in the hotter zone. The following points were determined with more specificity:

- Case 1 has low-pressure difference in both “hot and cold-water flow”, which is 24.62 and 13.57 Pa respectively.
- Case 4 has low-pressure difference in both “hot and cold-water flow”, which is 74.18 and 41.58 Pa respectively.
- In the outlet of the inner tube, temperature is maximum in case 1, which is 301.626 K.
- Case four, having minimum outlet temperature in inner tube, which is 301.144 K.
- Temperature difference at inner tube is minimum at case 1, which is 1.52 K. Maximum at case 4, which is 2 K.
- In case 3 and case 4 changes in temperature difference is very minor.
- Temperature difference at outer tube is minimum at case 1, which is 0.39 K. Maximum at case 3, which is 0.479 K.
- In the whole study, find that case 3 is effective for heat transfer.

The future scope for enhancing heat transfer in double pipe heat exchangers with counter-flow arrangement is promising, with several avenues for exploration and innovation. Advanced computational modeling techniques, such as computational fluid dynamics (CFD) coupled with optimization algorithms, offer great potential for designing optimized geometries and surface modifications to maximize heat transfer efficiency while minimizing pressure drop. Furthermore, the integration of emerging materials with superior thermal conductivity and surface characteristics, such as nanomaterials and advanced alloys, potentially useful for increasing the efficiency of heat exchangers with two pipes operating in opposite directions,. Moreover, the application of additive manufacturing techniques opens up possibilities for the fabrication of complex geometries and customized heat transfer surfaces, facilitating the implementation of tailored enhancement strategies. Working together To further improve heat transfer in counter-flow double pipe heat exchangers and realize their full potential in various industrial and environmental contexts, it will be necessary to conduct multidisciplinary research involving specialists in areas like control engineering, fluid dynamics, and materials science.

References

[1] S. K. Singh, M. Mishra, and P. K. Jha, “Nonuniformities in compact heat exchangers - Scope for better energy utilization: A review,” *Renew. Sustain. Energy Rev.*, vol. 40, pp. 583–596, 2014, doi: 10.1016/j.rser.2014.07.207.

[2] M. R. Saffarian, F. Fazelpour, and M. Sham, “Numerical study of shell and tube heat exchanger with different cross-section tubes and combined tubes,” *Int. J. Energy Environ. Eng.*, vol. 10, no. 1, pp. 33–46, 2019, doi: 10.1007/s40095-019-0297-9.

[3] O. E. Turgut, M. S. Turgut, and M. T. Coban, “Design and economic investigation of shell and tube heat exchangers using Improved Intelligent Tuned Harmony Search algorithm,” *Ain Shams Eng. J.*, vol. 5, no. 4, pp. 1215–1231, 2014, doi: 10.1016/j.asej.2014.05.007.

[4] F. Liang *et al.*, “Experimental investigation on improving the energy separation efficiency of vortex tube by optimizing the structure of vortex generator,” *Appl. Therm. Eng.*, vol. 195, no. June, p. 117222, 2021, doi: 10.1016/j.applthermaleng.2021.117222.

[5] G. E. Miller, “Biomedical Transport Processes,” *Introd. to Biomed. Eng.*, pp. 937–993, 2011, doi: 10.1016/B978-0-12-374979-6.00014-9.

[6] H. Xiao, Z. Dong, R. Long, K. Yang, and F. Yuan, “A study on the mechanism of convective heat transfer enhancement based on heat convection velocity analysis,” *Energies*, vol. 12, no. 21, 2019, doi: 10.3390/en12214175.

[7] H. Karkaba, T. Dbouk, C. Habchi, S. Russeil, T. Lemenand, and D. Bougeard, “Multi objective optimization of vortex generators for heat transfer enhancement using large design space exploration,” *Chem. Eng. Process. - Process Intensif.*, vol. 154, p. 107982, 2020, doi: 10.1016/j.cep.2020.107982.

[8] M. Awais and A. A. Bhuiyan, “Enhancement of thermal and hydraulic performance of compact finned-tube heat exchanger using vortex generators (VGs): A parametric study,” *Int. J. Therm. Sci.*, vol. 140, no. January, pp. 154–166, 2019, doi: 10.1016/j.ijthermalsci.2019.02.041.

[9] H. Han, S. Wang, L. Sun, Y. Li, and S. Wang, “Numerical study of thermal and flow characteristics

for a fin-and-tube heat exchanger with arc winglet type vortex generators," *Int. J. Refrig.*, vol. 98, pp. 61–69, 2019, doi: 10.1016/j.ijrefrig.2018.10.021.

[10] S. A. Marzouk, M. M. Abou Al-Sood, E. M. S. El-Said, M. M. Younes, and M. K. El-Fakharany, *A comprehensive review of methods of heat transfer enhancement in shell and tube heat exchangers*, vol. 148, no. 15. Springer International Publishing, 2023. doi: 10.1007/s10973-023-12265-3.

[11] R. Zarei, K. Razzaghi, and F. Shahraki, "Experimental characterization of heat transfer enhancement in a circular tube fitted with Koflo Blade™ inline mixer," *Chem. Eng. Process. - Process Intensif.*, vol. 166, no. March, p. 108508, 2021, doi: 10.1016/j.cep.2021.108508.

[12] P. Promvonge and S. Skullong, "Thermo-hydraulic performance in heat exchanger tube with V-shaped winglet vortex generator," *Appl. Therm. Eng.*, vol. 164, no. April 2019, p. 114424, 2020, doi: 10.1016/j.applthermaleng.2019.114424.

[13] H. Budiarto and F. Umam, "Prototype of Heat Exchanger U-Tube Model Shell and Tube Counter Flow," no. January 2018, 2018, doi: 10.2991/icst-18.2018.188.

[14] M. Farnam, M. Khoshvaght-Aliabadi, and M. J. Asadollahzadeh, "Heat transfer intensification of agitated U-tube heat exchanger using twisted-tube and twisted-tape as passive techniques," *Chem. Eng. Process. - Process Intensif.*, vol. 133, pp. 137–147, 2018, doi: 10.1016/j.cep.2018.10.002.

[15] S. P. Louis, S. Ushak, Y. Milian, M. Nemś, and A. Nemś, "Application of Nanofluids in Improving the Performance of Double-Pipe Heat Exchangers—A Critical Review," *Materials (Basel).*, vol. 15, no. 19, pp. 1–23, 2022, doi: 10.3390/ma15196879.

[16] Syaiful, M. P. Hendraswari, M. S. K. T. Tony, and M. F. Soetanto, "Heat transfer enhancement inside rectangular channel by means of vortex generated by perforated concave rectangular winglets," *Fluids*, vol. 6, no. 1, 2021, doi: 10.3390/fluids6010043.

[17] R. Aridi, S. Ali, T. Lemenand, J. Faraj, and M. Khaled, "CFD analysis on the spatial effect of vortex generators in concentric tube heat exchangers – A comparative study," *Int. J. Thermofluids*, vol. 16, no. October, p. 100247, 2022, doi: 10.1016/j.ijft.2022.100247.