Journal of Emerging Technologies and Industrial Applications
Vol. 2 No. 2 (2023) pp. 1-7
e-ISSN: 2948-507X

Journal homepage: https://jetia.mbot.org.my/index.php/jetia/index

Numerical Study on Convective Heat Transfer from Elliptical Tubes in Crossflow

Zahin Zikry Mohamad[1], Suzairin Md Seri*[1]

[1]Faculty of Mechanical and Manufacturing Engineering
Universiti Tun Hussein Onn Malaysia, Batu Pahat, 86400, MALAYSIA

Email: suzairin@uthm.edu.my

Abstract: This study presents a numerical study using Ansys Fluent software to investigate the convective heat transfer from elliptical tubes in crossflow. The primary objectives of the study were to examine the thermal and flow field characteristics of elliptical tubes in crossflow and establish a correlation between flow geometries and the thermal performance of elliptical tube heat exchangers. The scope of the study encompassed a range of parameters, including blockage ratio from 0.06 to 0.5, Prandtl number of 0.71, and Reynolds numbers between 5000 to 46000. Additionally, three different ellipse geometries were considered with aspect ratio is from 1 to 2.62. By employing numerical simulations, the study aimed to gain insights into the heat transfer characteristics of elliptical tubes under crossflow conditions. The results obtained from the simulations were utilized to establish correlations between the geometric features of the flow and the thermal performance of elliptical tube heat exchangers. The findings from this study contribute to a deeper understanding of convective heat transfer in elliptical tubes and provide valuable information for designing and optimizing heat exchangers utilizing such geometries. The obtained correlations offer practical guidance for enhancing the thermal efficiency of elliptical tube heat exchangers operating in crossflow conditions.

Received 18 June 2023; Accepted 10 August 2023; Available online 18 December 2023

Keywords: Elliptical, Thermal Performances, Flow Characteristic

*Corresponding Author:

Suzairin Md Seri,
Faculty of Mechanical & Manufacturing Engineering
Universiti Tun Hussein Onn Malaysia, Batu Pahat, 86400, MALAYSIA
Email: suzairin@uthm.edu.my

1. Introduction

Heat transfer in flow over a tubes bank is very important in heat exchanger design. Plain and finned tube banks are both common. Tube bundles are a component of shell-and-tube heat exchangers, where the flow is similar to crossflow in some places and longitudinal flow in others. The flow can be single- phase or multi-phase likes boilers and condensers. The tube banks have many applications in industry and there may also be combustion, such as in a furnace heat exchanger. Other examples are steam generation in a boiler and air cooling in the coil of an air conditioner.

The tubes observed in the application are usually cylindrical. A change in tube shape may be able to minimize drag and hence increase system performance. The geometry of the tubes has a considerable impact on the flow and heat characteristics of the heat exchanger. Thus, this relation is investigating on convective heat transfer from elliptical tubes in crossflow using 2-dimensional numerical simulations.

Numerical studies on convective heat transfer from elliptical tubes in crossflow are essential because they may gain insight into the heat transfer properties of this particular shape. The tube's elliptical form may impact flow patterns and heat transfer coefficients, distinguishing it from circular tubes. Researchers can better understand how the tube's shape affects heat transfer by numerically studying heat transfer from elliptical tubes in crossflow. They can potentially use this information to improve the efficiency of heat exchangers and other thermal systems that use elliptical tubes.

Previous research findings is presented based on several papers, journals, and books that are connected to the topic. The purpose of this chapter is to give a literature review that will include information concerning numerical and experimental investigations linked to elliptical tubes and heat characteristics. In order to have a better understanding before beginning this course, it is helpful to have this additional data.

The finding, the methods, the geometry, and the consequences will all be covered in this part. In order to generate ideas for the study and provide assistance with the methodology chapter, all of the data and information from the previous research will be compiled.
Table 1: Previous study in tube banks.

Table 1 - Previous study in tube banks

Author & Date	Title	Methodology	Research About
Kongkaitpaibo onet al., 2010	Experimental investigation of convective heat transfers and pressure loss in a round tube fitted with circular-ring turbulators	Experiment	Experimental investigation of convectiveheat transfers and pressure loss in a round tube fitted with circular-ring turbulators (CRT). The results reveal the CRT with the smallest pitch and diameter ratios offers the highest heat transfer rate in accompany with the largest pressure loss.
Haque et al.,2020	Numerical investigation of convective heat transfer characteristic sof circular and oval tube banks with vortex generators	Computer Fluid Dynamics with3D numerical study.	Examine the effect of vortex generators for turbulent flow through a fin-and-tube HE, using different geometric configurations of wing-lets and tubes. The results is when a higher number of winglets at a high angle ofattack, oval tubes with lower aspect ratioin a high Re flow could be preferred for higher heat transfer enhancement with a minimum rise in pressure drop.
Horvat et al.,2006	Comparison of heat transfer conditions in tube bundle cross-flow for different tubeshapes	Computer Fluid Dynamics with2D numerical study.	The purpose of the analysis was to get a detailed insight of the local heat transfer andfluid flow conditions in a heat exchanger and to establish widely applicable drag coefficient and Stanton number functions for the heat exchanger integral model.
Mehrjou et al.,2015	Experimental study of CuO/water nanofluid turbulent convective heat transfer in square cross-section duct	Experiment	The convective heat transfer for aCuO/water nanofluid through a square cross-section duct in the turbulent flow regime has been investigated. The experimental results show that adding CuO nanoparticles to the base fluid enhanced theheat transfer coefficient, and consequently,the Nusselt number of the fluid, as well as the Peclet number, was increased with increasing nanoparticle concentrations.

2. Methodology

This chapter explains how the study will be conducted and the stages involved in finding the the parameter such as aspect ratio of elliptical tube, the ellipse perimeter and the blockage ratio. The methodology also represents the flow of numerical simulation in Ansys Fluent and validation with the

Published by MBOT Publishing
https://jetia.mbot.org.my/index.php/jetia/index

reference paper. This section is critical to this study since a well-planned approach can help fulfil the study's aims.

Firstly, the geometry is based on Anderson geometry perimeter from his experiment (Anderson, 1997). There are 3 sets of geometry ellipse that have been decided to perform in this simulation with different aspect ratio and blockage ratio but same in perimeter. The formula of ellipse perimeter that have been use is from Ramanujan's Approximation Theorem (Chung, 2015). The aspect ratio of an ellipse is determined by comparing the lengths of its major and minor axes. It is also known as the "axis ratio" or the "ratio of major to minor axes. While, the blockage ratio for this numerical study is from in Anderson paper where the radius is devide by the width of each tube. The perimeter, aspect ratio and blockage ratio are effecting the result of the dimension of the domain. The table below show the list of the geometrical details after calculating all the parameters involved. The Figure 1 shows the example of sketching of ellipse, the domain and the meshing.

Table 2 - Geometry ellipse in detail

Geometry	Blockage Ratio	a (mm)	b (mm)	L (mm)	W (mm)
1	0.2	55.50	31.90	2775	319
	0.3	55.50	31.90	2775	212.6667
	0.5	55.50	31.90	2775	127.6
2	0.2	59.40	26.40	2970	264
	0.3	59.40	26.40	2970	176
	0.5	59.40	26.40	2970	105.6
3	0.2	61.30	23.40	3065	234
	0.3	61.30	23.40	3065	156
	0.5	61.30	23.40	3065	93.6

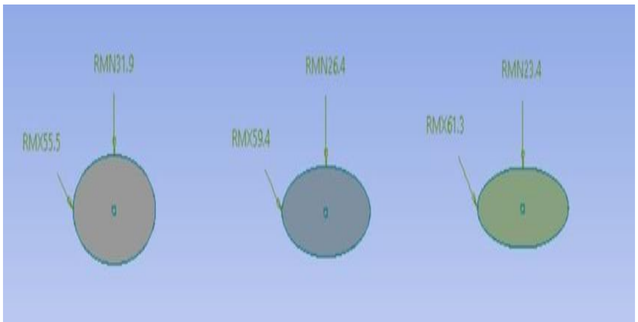

Fig. 1 - Sketching of ellipse with different aspect ratio

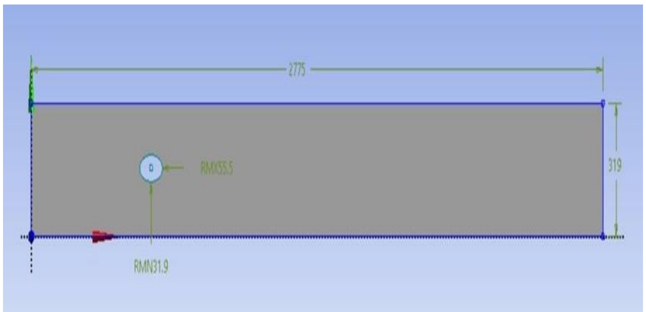

Fig. 2 - Example of domain for geometry 1 with Blockage ratio 0.2

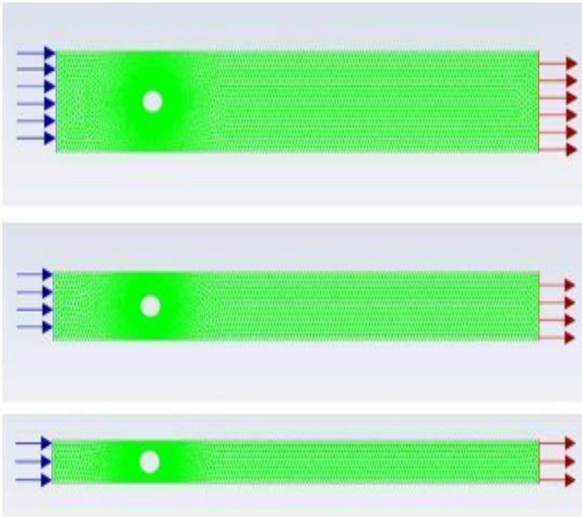

Fig. 3 - Example of meshing for geometry 1 with different blockage ratio

The data collected for validation purposes is compared with the experimental results obtained by Anderson, which have been extensively investigated. In order to conduct the analysis using Ansys Fluent, the identical geometry model employed in Anderson's experiments will be utilized. The boundary conditions, geometry and the graph used in the study are provided below, outlining the specific conditions under which the computational analysis will be performed.

Table 3 - Boundary condition of single tube from Anderson experiment

Parameter	Dimension
Diameter of tube	0.089 mm
Blockage Ratio	0.0585
L	2225 mm
W	1520 mm

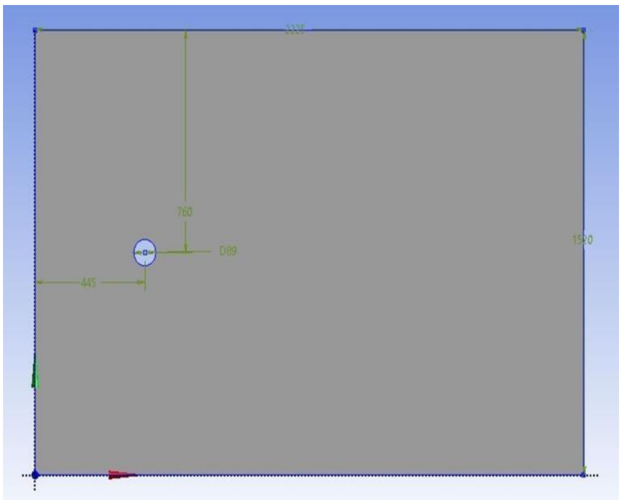

Fig. 4 - Geometry of single tube from Anderson experiment

Published by MBOT Publishing
https://jetia.mbot.org.my/index.php/jetia/index

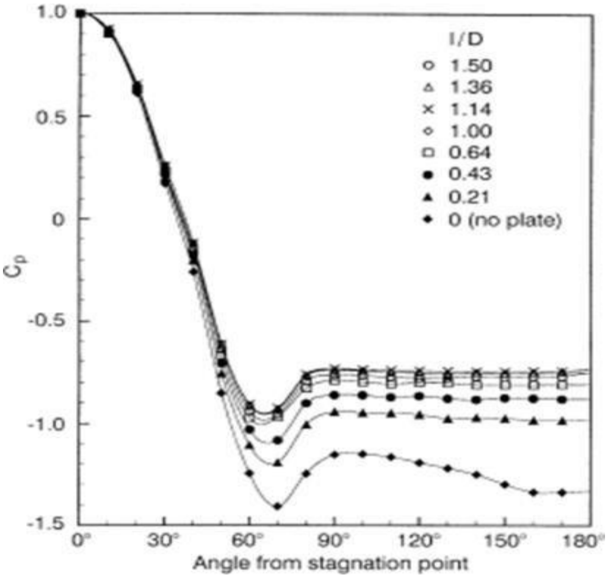

Fig. 5 - Graph Pressure Coefficient, Cp vs Angle from stagnation point (Anderson, 1997)

3. Result and Discussion

The result analysis in this study involves the examination and interpretation of the simulation outputs to understand the complex heat transfer phenomena and derive meaningful conclusions. The goal of result analysis is to assess the performance of elliptical tubes in crossflow, evaluate the effects of geometric parameters, flow conditions, and tube orientation on heat transfer, and provide insights that can be used to optimize the design of heat exchangers, radiators, and other thermal devices.

Numerical Validation

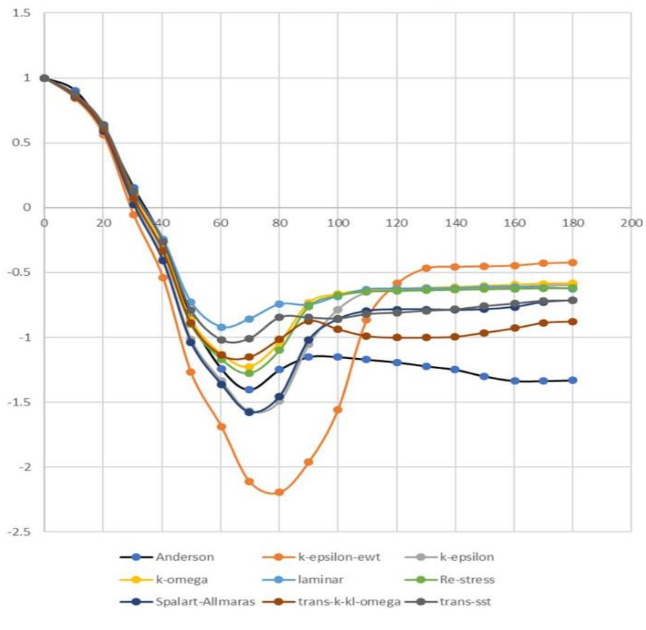

Fig. 6 - Graph of validation with Anderson experiment data

In order to ensure the highest level of accuracy in the validation process, a comprehensive examination and comparison of various viscous models available in Fluent are conducted. After careful investigation, it has been determined that the Transition k-k-kl-omega viscous model in Fluent yields the most favorable outcomes in terms of accuracy and agreement with the experimental data.

Fluid Flow Parameter

The fluid motion or flow characteristics are described by variables or attributes known as fluid flow parameters. These variables offer quantitative data on fluids' characteristics, interactions, and behaviour during flow. Reynolds number and inlet velocity is the main parameter in this section. Table below show the data for all the geometry.

Table 4 - Inlet velocity for all geometry

Reynold Number	10000	20000	46000
Geometry		$U\infty$ (m/s)	
Geometry 1	2.289553	4.579106	10.53194
Geometry 2	2.766543	5.533086	12.7261
Geometry 3	3.121228	6.242456	14.35765

Analysis of Thermal Characteristics

The study and knowledge of how heat is transmitted and distributed within a fluid medium are involved in analyzing thermal properties in the fluid. It focuses on the behaviour of fluids in response to temperature changes and the transfer of heat approaches such as conduction, convection, and radiation.

Average Nusselt Number, Nu

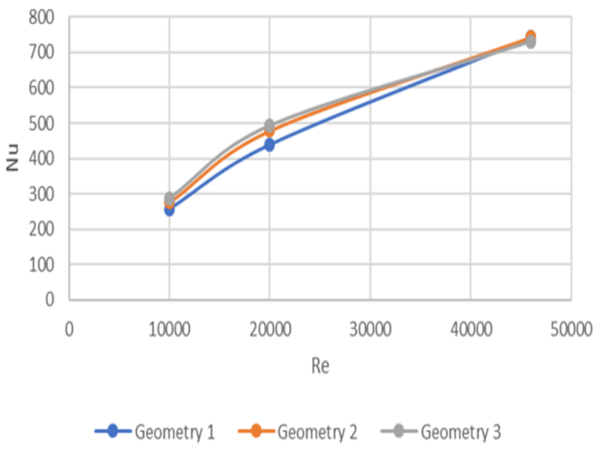

Fig. 7 - Graph of Average Nusselt number at blockage ratio 0.2

The analysis of the Average Nusselt Number at a blockage ratio of 0.2 reveals interesting findings. Among

Published by MBOT Publishing
https://jetia.mbot.org.my/index.php/jetia/index

the different geometries studied, Geometry 2 stands out with the highest Nusselt number value of 743.0. The Nusselt number represents the convective heat transfer efficiency, and this significant value indicates that Geometry 2 exhibits superior heat transfer characteristics compared to the other geometries considered in the study.

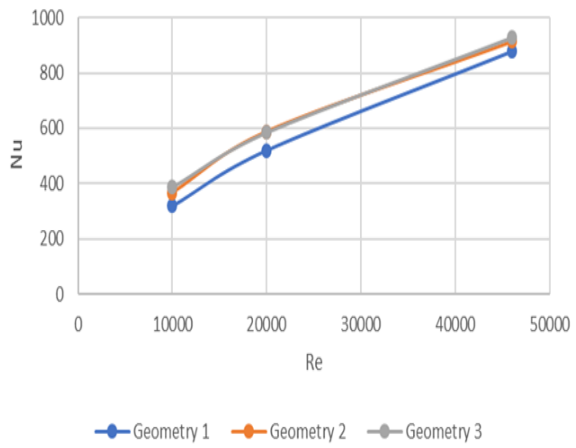

Fig. 8 - Graph of Average Nusselt number at blockage ratio 0.5

The analysis of the Average Nusselt Number at a blockage ratio of 0.5 show that among the examined geometries, Geometry 3 stands out as having the highest Nusselt number value of 926.9858. This finding paves the way for optimizing designs and enhancing thermal performance, particularly for systems operating at a blockage ratio of 0.5.

Average Heat Flux, Q

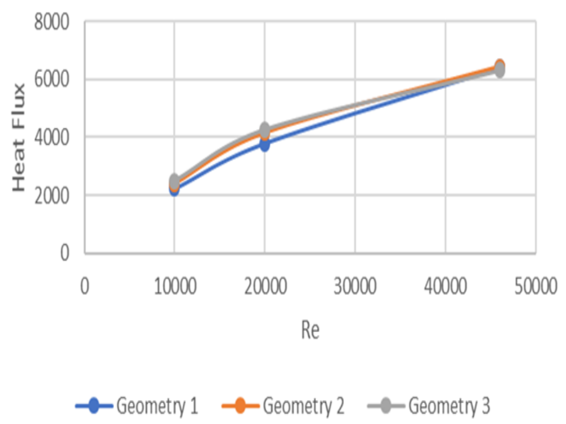

Fig. 9 - Graph of heat flux at blockage ratio 0.2

The analysis of the Average Heat Flux at a blockage ratio of 0.2 provides interesting insights into the heat transfer characteristics of different geometries. Among the geometries studied, Geometry 2 exhibited the highest heat flux value of 6431 W/m2. This finding implies that Geometry 2 experiences the highest rate of heat transfer compared to the other geometries.

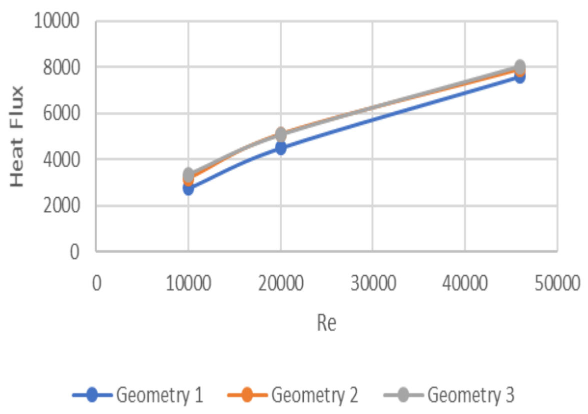

Fig. 10 - Graph of heat flux at blockage ratio 0.5

The examination of the Average Heat Flux at a blockage ratio of 0.5 reveals a noteworthy outcome, as Geometry 3 exhibits the highest heat flux value of 8023 W/m2, indicating its exceptional ability to transfer heat compared to the other geometries considered in the study.

Analysis of Flow Characteristic

The study and understanding of how fluids, such as liquids, behave and move in various settings is referred to as fluid flow characteristics analysis. It entails investigating numerous fluid flow characteristics and factors such as velocity, pressure, temperature, and density. This section will go over the local pressure coefficient in further detail.

Local Pressure Coefficient at Reynold Number 10000

The Local Pressure Coefficient at the stagnation angle of a tube is a dimensionless parameter used to describe the pressure distribution at the point where the fluid flow comes to a halt, known as the stagnation point, on the surface of the tube. This parameter provides valuable information about the pressure behavior in this critical region. Specifically, the analysis presented here focuses on the results obtained at a Reynolds number of 10,000 for Geometry 1.

Published by MBOT Publishing
https://jetia.mbot.org.my/index.php/jetia/index

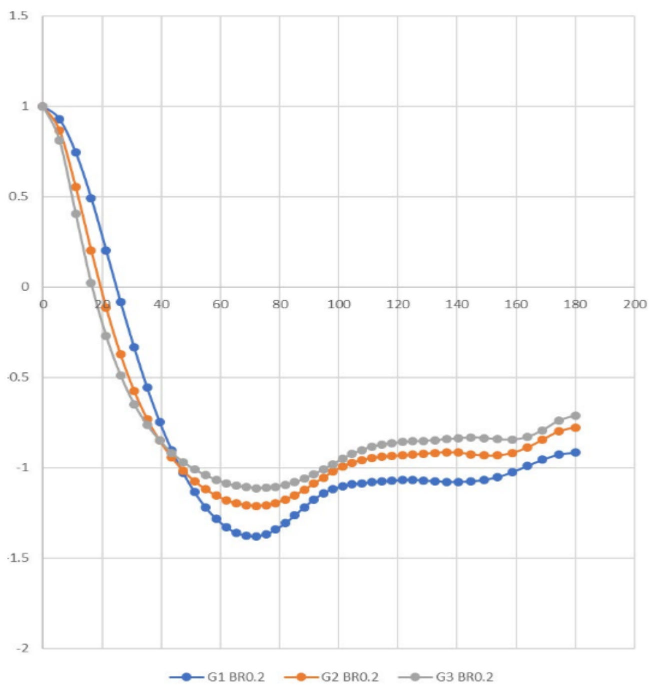

Fig. 11 - Cp vs Angle from stagnation point at Re 10000

Correlation

A correlation is a statistical term that measures the relationship or association between two or more variables. It assists in understanding how changes in one variable affect changes in another.

Pumping Power

Pumping power refers to the amount of power required to pump a fluid through a system or across a specified flow path. It represents the energy needed to overcome the resistance or frictional forces within the system and maintain the desired flow rate. The table and figure below show the requirement of pumping power for all the geometry.

Table 5 - Pumping power for all geometry

Blockage Ratio	**0.2**	**0.3**	**0.5**
Geometry	Pumping Power, W		
G1 Re 10000	0.90	0.60	0.36
G1 Re 20000	6.60	4.40	2.64
G1 Re 46000	74.45	49.71	29.78
G2 Re 10000	1.42	1.67	3.24
G2 Re 20000	10.37	12.27	22.74
G2 Re 46000	129.27	135.10	222.36
G3 Re 10000	2.56	3.02	3.51
G3 Re 20000	19.08	21.73	24.40
G3 Re 46000	224.76	240.40	245.63

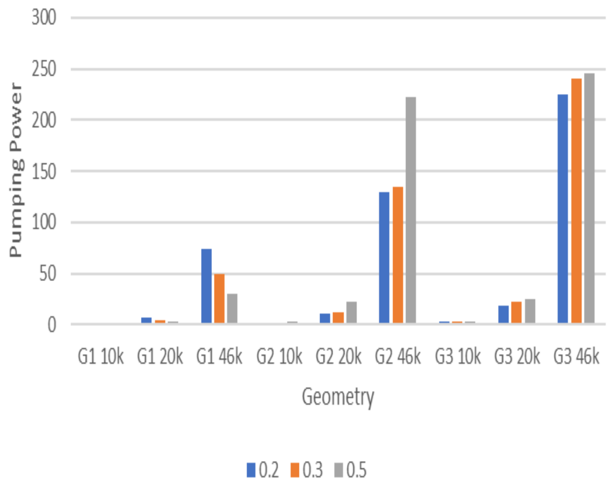

Fig. 12 - Pumping power for all geometry

Efficiency, η

Efficiency refers to the measure of how effectively a system converts the input power into useful output, specifically in relation to the heat transfer process. One way to assess the efficiency is by calculating the ratio of average heat flux to pumping power per unit area.

Table 6 - Efficiency for all the geometry

Geometry	**Blockage Ratio**	**Efficiency, η** Re 10000	Re 20000	Re 46000
Geometry 1	0.2	8.84432074	13.2457198	22.1108019
Geometry 1	0.3	64.8141879	97.0691359	162.03547
Geometry 1	0.5	731.643637	1095.74798	1829.10909
Geometry 2	0.2	20.406126	53.9585761	199.101227
Geometry 2	0.3	148.844582	396.153239	1396.57346
Geometry 2	0.5	1854.82618	4361.28798	13656.9304
Geometry 3	0.2	25.2019984	66.5849664	400.410869
Geometry 3	0.3	187.519856	478.920931	2785.57661
Geometry 3	0.5	2208.66971	5298.88015	28037.2845

A higher efficiency value indicates that a greater proportion of the input power is being effectively utilized to transfer heat, resulting in a more efficient heat transfer process. On the other hand, a lower efficiency value indicates that a notable portion of the input power is either wasted or not optimally utilized, resulting in decreased overall efficiency in transferring heat.

4. Conclusion

In conclusion, the conducted numerical study on convective heat transfer from elliptical tubes in crossflow, the main objectives were successfully achieved, resulting in valuable insights and correlations.

Published by MBOT Publishing
https://jetia.mbot.org.my/index.php/jetia/index

The study aimed to investigate the thermal and flow field characteristics of elliptical tubes in crossflow. By analyzing the numerical data, a comprehensive understanding of how heat is transferred within the elliptical tube configuration when subjected to a crossflow of fluid was gained. The study examined parameters such as average Nusselt number, average heat flux, and local pressure coefficient to characterize the thermal behavior and fluid dynamics in the system.

Furthermore, a correlation was established between the geometric aspects of the flow and the thermal performance of elliptical tube heat exchangers in crossflow. This correlation provides a quantitative relationship between the specific flow geometries of the elliptical tubes and their heat transfer efficiency. It allows for better prediction and optimization of the thermal performance of heat exchangers by considering the geometric design parameters.

Acknowledgement

The authors would like to thank the Research Fund Universiti Tun Hussein Onn Malaysia for supporting this research.

References

[1] Kongkaitpaiboon, V., Nanan, K., & Eiamsa-ard, S. (2010). 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(5), 568–574. https://doi.org/10.1016/j.icheatmasstransfer.2009.12.016

[2] Numerical investigation of convective heat transfer characteristics of circular and oval tube banks with vortex generators. Journal of Mechanical Science and Technology, 34, 457-467.

[3] Horvat, A., Leskovar, M., & Mavko, B. (2006). Comparison of heat transfer conditions in tube bundle cross-flow for different tube shapes. International Journal of Heat and Mass Transfer, 49(5–6), 1027–1038. https://doi.org/10.1016/j.ijheatmasstransfer.2005.09.030

[4] Mehrjou, B., Zeinali Heris, S., & Mohamadifard, K. (2015). Experimental study of CuO/water nanofluid turbulent convective heat transfer in square cross-section duct. Experimental Heat Transfer, 28(3), 282–297. https://doi.org/10.1080/08916152.2013.871606

[5] Huminic, G., & Huminic, A. (2019). The influence of hybrid nanofluids on the performances of elliptical tube: Recent research and numerical study. International Journal of Heat and Mass Transfer, 129, 132-143.

[6] Anderson, E. A. (1997). Effects of a splitter plate on the near wake of a circular cylinder in 2 and 3-dimensional flow configurations. Experiments in Fluids 23.2, 161-174.

[7] Chung, D. D. (2015). Maxillary arch perimeter prediction using Ramanujan's equation for the ellipse. American journal of orthodontics and dentofacial orthopedics, 235-241.