AMERICAN Journal of Engineering, Mechanics and Architecture
Volume 2, Issue 8, 2024 ISSN (E): 2993-2637

Study on the Temperature Distribution Effect on Heat Exchanger Design by CFD

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Abstract: The heat exchanger (HE) is a device that is used to complete the process of heat transfer between different matters without direct mixing. Therefore, it is of great importance in the transfer of energy and the completion of various energy transition processes. In the processes of HE between different energy systems, many factors influence and play a major and important role in the efficiency of transformation and exchange in forms of energy, such as the length, the material type, the exchange fluid, the surrounding environment, and many other factors. In this work, the effect of the HE temperature of the parallel and counter flow HEs was investigated based on the use of computer simulation programs. There was a significant impact of the exchange factors, especially the length of the HEs in both the parallel and counter-flow HEs, on the quality and efficiency of the HE and the temperature distribution, A steady-state conjugate heat transfer (CHT) model is coupled with computational fluid dynamics (CFD) analysis. In addition, the temperature profile and velocity streamline are also checked to analyze the fluid flow behavior of the radiator.

With large temperature differences, variations in fluid properties due to temperature lead to changes in the surface heat transfer coefficient (SHTC). The combined effects of SHTC and temperature difference determine the heat transfer performance. the heat transfer performance and standard deviation of outlet temperature distribution.

The aim of this paper is to investigate numerically the influence of variable fluid viscosity on thermal characteristics of plate heat exchangers for counter-flow and steady-state conditions. A finite difference method has been used to calculate the temperature distribution and thermal performance of the exchanger. Water is used as the hot liquid being cooled in the side channels, while a number of working fluids whose viscosity variation versus temperature is more severe were used as the cold fluid being heated in the central channel. The temperature distributions of both streams have been plotted along the flow channel for all the above combination of working fluids. It is found that the overall heat transfer coefficient varies linearly with respect to either cold or hot fluid temperature within the temperature ranges applied in the paper. The exchanger effectiveness is not significantly affected when either the temperature dependent viscosity is applied or the nature of cold liquid is changed. paper contains a new method of numerical solution of energy balance equations for the thermal control volumes bounded by two plates.

Keywords: Heat exchangers, Heat transfer, Numerical analysis, Finite difference methods.

Introduction

Heat exchangers are the most widely-used devices for energy transport in the thermal engineering industry covering both most the engineering fields 1,2. Maximizing the thermal efficiency and improving the hydraulic performance of such systems have always been the hot research directions of many scholars. Hence, in recent years, quite a few technologies have been proposed, such as intensifying the thermal physical property of working medium [4], reorganizing the spatial arrangement of heat exchanger units 3, and undermining the thermal resistance of wall boundary layer by incentivizing the roughness 4. By integrating the latter two, a common compound technique is the adoption of concentric tube arrangement filled with porous medium, where fluids flow in counter directions 5.

To be specific, Shirvan et al. 6,7 employed the Response Surface Methodology to perform a sensitivity analysis for evaluating the effects of key effective parameters on the Nusselt number and heat exchanger effectiveness of a DPHE filled with porous media. They discovered different sets of effective parameter values for maximizing the two indicators separately and simultaneously.

Targeting on the development and evaluation of a novel shell-and-tube heat exchanger assembled with porous baffles, Abbasi et al. 8 utilized the CFD simulation to perform a parametric study to figure out the thermos-hydraulic impacts of these baffles. Then, the combination of heat transfer rate and pressure drop was selected by them as the objective functions to perform multi-objective optimization with artificial neural network implemented as the surrogate model.

Shi et al. 9 conducted parametric analysis to investigate the combined effects of the gradients of porosity and pore-size on the performance of flow and heat transfer in tubes filled with gradient porous media. Furthermore, designating Nusselt number vs. friction factor as the objectives, a multi-objective genetic optimization coupled Kriging surrogate model was performed to obtain the design variables corresponding to optimal configurations.

A desirable heat exchanger aims to maintain a proper thermal balance when transferring part of the heat from hot fluid to cold fluid 10. However, current thermal management systems have certain limitations. For instance, the heat exchanger cannot dissipate heat in time when the reaction temperature rises, resulting in a decrease in heat dissipation capacity. Therefore, it is highly anticipated to achieve balanced heat transfer by minimizing pressure drop and maximizing heat dissipation 11.

Peng et al. 12,13 used several traditional one-dimensional models of ideally flow distribution (a uniform flow, a linear flow, a semi parabolic flow), and took a four-stream PFHE which has 36 passages as an example to analyze the impact of non-uniform flow distribution on the heat transfer efficiency of multi-stream plate-fin heat exchanger (MPFHE).

Taking into account the impact of headers, distributors and gross passages, computational fluid dynamics (CFD) techniques are used by Yang et al. 14 to determine the flow distribution in PFHE.

Simulation software is one of the most important engineering tools in investigating information about the work of engineering devices, as this software is based on simulating the virtual reality of working conditions and calculating expectations and the effects resulting from operating these various systems 15,16,17.

As a result of what simulation programs are doing, many industrial and engineering systems have been developed recently, as these programs reflect a clear picture of the work of the different systems and indicate potential faults and ways to address them during engineering design, even in some cases after implementing the design in reality 18,19.

The simulation programs give hope of modifying the realistic designs with the lowest effort, cost, and best possible performance 20,21,22. In this study, the operational and design conditions of the HE are highlighted, such as the flow rate of the matter inside the HEs, the length of the HE, and the effect of these conditions on the efficiency of the HEs.

Studying energy sources alone is considered insufficient to determine the greatest benefit from them 23,24. Here, work is highlighted in the aid of systems that are concerned with utilizing energy, such as turbines of all kinds, boilers of all kinds, coolers, pumps, and other support systems . The HE is considered one of the most important systems that help in the process of completing the various energy cycles, as it is based on completing the transfer of heat from the different parts of the systems without the need for physical mixing 25,26.

2- Heat Exchange Theory

Heat exchangers figure (1) are devices for exchanging energy between two or more fluids. They find applications in various industries like power, process, electronics, refining, cryogenics, chemicals, metals and manufacturing sector. Even though heat exchanger designs have been reported quite extensively, they are generally limited to steady-state performance, single phase fluids, a few of the many possible flow arrangements and only two fluid heat exchangers. The effect of heat loss to the ambient from a parallel flow double pipe heat exchanger is also investigated and the results are compared with those available in the literature. The results are presented both in terms of the temperature distribution along the length of the heat exchanger 27.

Typically, HEs are classified according to the internal arrangement, flow profile, and internal structure. One of the most widespread HEs depends on the flow of fluids inside it, so hot and cold fluids flow in the same direction or in the opposite direction in what is known as the parallel-flow or counter-flow HE, respectively. Figure (1) shows the types of HEs used in this study, where the figure (2) refers to the parallel flow HE, while the Figure 3 refers to the counter flow HE. Applications of exchangers: Heat exchangers have many applications such as heating and cooling in homes as well as in the car, but in industry they are multiple, whether in energy production or chemical and petrochemical industries and petroleum refining and this is within the reach of our topic.

Fluid flow conditions in heat exchangers: There are two conditions of fluid flow direction in heat exchangers:

1. Parallel flow The direction of fluid flow in this case is similar, that is, the two fluids are traveling In the same direction as in Fig (1)
2. The opposite flow The direction of flow of the two fluids is opposite, that is, the two substances go in opposite directions, as in Fig(2). The horizontal axis (x-Axis) in the above two figures represents the length of the exchanger and it is noted in the opposite flow that the temperature difference is approximately constant along the heat exchanger, while in parallel flow, it is noted that the difference is very large in the entry of the exchanger and decreases along its length. Practical applications have shown that opposite flow is more efficient than parallel flow.

The log mean temperature difference approach is considered for the design as the following: $q = \dot{m}\, h(ih,i - ih,o)$

and, $q = \dot{m}\, c(ic,o - ic,i)$

The above equations can be rewritten in term of using the temperate difference as:

$q = \dot{m}\, h.\ Cp.h(Th,i - Th,o)$

and, $q = \dot{m}\, c\ .\ Cp.c(Tc,o - Tc,i)$

Finally, the overall heat transfer expressed

as the Equation 3; $q = U.\ A.\ \Delta T$m 28

The log mean temperature is calculated based on the structure of the HE with an assumption of insulated HE from its surrounding, negligible axial conduction along the tube, constant fluid specific heat, and constant overall heat transfer coefficient. So the log mean temperature can be given as:

$\Delta Tlm = \Delta T2 - \Delta T1 \ln (\Delta T2/\Delta T1) = \Delta T1 - \Delta T2 \ln (\Delta T1/\Delta T2)$

Where,

the parallel-flow exchanger temperature condition is:

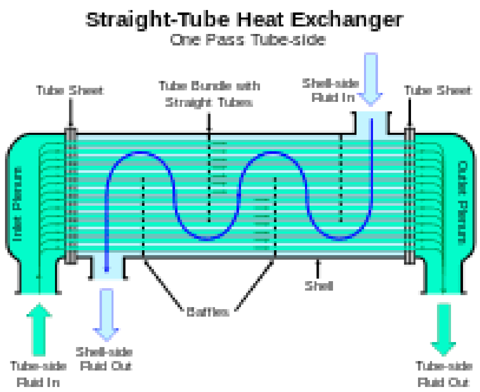
$\Delta T1 = Th,1 - Tc,1 = Th,i - Tc,i$

$\Delta T2 = Th,2 - Tc,2 = Th,o - Tc,o$

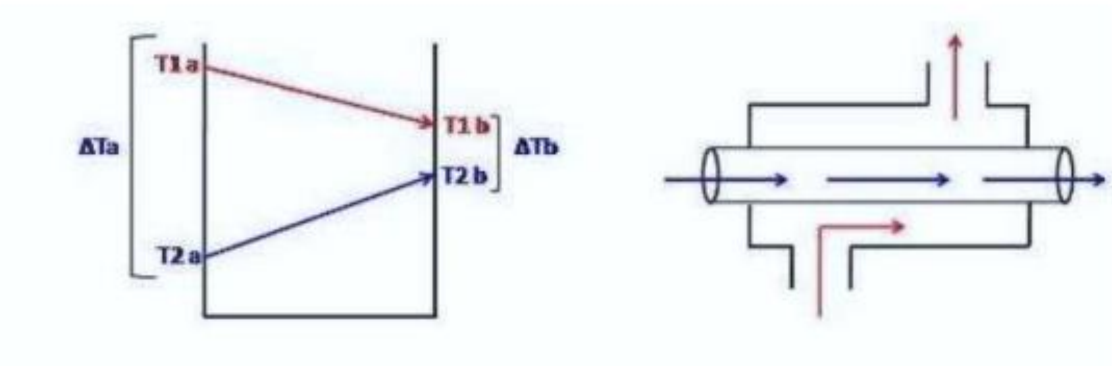
and, the counter-flow exchanger temperature condition is:

$\Delta T1 = Th,1 - Tc,1 = Th,i - Tc,o$

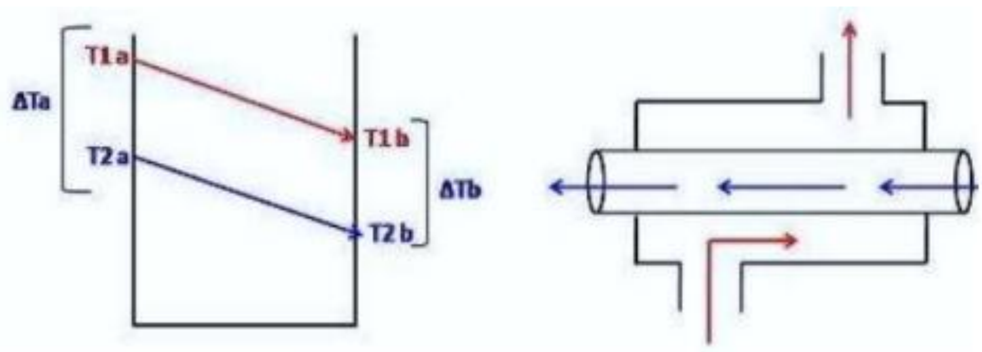
$\Delta T2 = Th,2 - Tc,2 = Th,o - Tc$,i 29



(Figure 1) heat exchanger



(Figure 2) Parallel Flow Status



(Figure 3) Counter flow 30

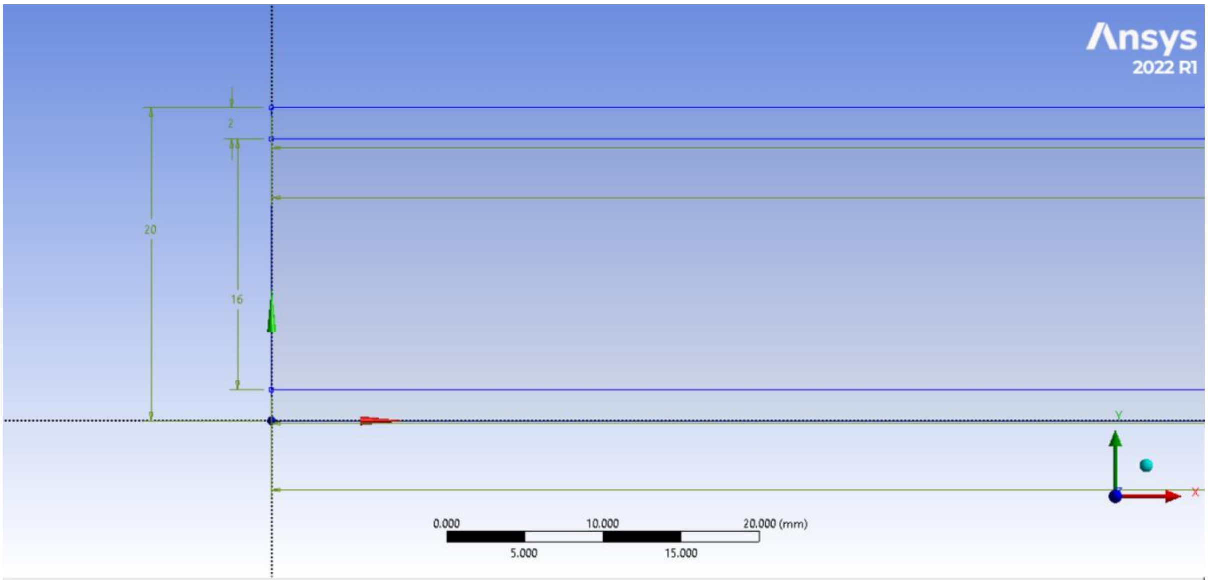
3- Results and Discussion

The approach to achieve the objective of the paper is deriving the governing equations and developing a computer program based on finite differences to solve them. To solve the governing equations, the flow channel is divided into small elements in axial direction. Physical properties are constant for each element, while viscosity changes from one element to another one. The program is run under four different conditions, namely: no axial conduction, axial conduction in the plates and in the flow channels, axial conduction in the plates only, and axial conduction in the flow channels only.

The results of this paper are based on studying the effect of HE length for different types, including parallel and counter HE with a hot substance flow rate equal to 0.25 k and 0.35 kg/s for the cold substance. The effect of the HE length has been studied for several lengths, which are 6, 8, m of the mentioned systems. Where it is found inside the parallel HE with liquid water medium. Figures 4A to 4D and Figures 5A to 5D show the temperature distribution inside the parallel HE with liquid medium between the hot and cold substances as it is clear that the temperature difference gap decreases by increasing the HE length . Figure 7 A to D shows the temperature distribution inside the counter HE. It is clear that the temperature difference gap in the counter HE decreases with increasing the length of the HE.

The results show the effect of the design conditions on the performance of the HEs, as we found that the length of the HE plays a major role in influencing the increase in heat exchange between the materials used in the HE (hot-cold). The heat exchange performance increases in the two types of HEs used, which are the parallel-flow exchanger and the counter-flow exchanger. The reason for the increase in the efficiency of the heat exchanges with increasing length is due to the increase in the surface area of the heat exchange and the increase in the time period to which the heat transfer materials are exposed between them.

The results also show that the counter-flow HE has a higher efficiency than the parallel-flow HE because of the higher temperature difference in the counter-flow HE compared to the parallel-flow exchanger. Many researchers studied the problems with HEs and ways to improve the quality of heat transfer in HEs. Here we found Wang et al. 31 who studied the increase in the heat exchange area, and they found that the efficiency of the HE increased, which is what was supported in this study. Zheng et al. 32 also studied the shape of the HE channels and found that by modifying the HE design internally, the efficiency of the HE is improved. Here we also found that this study supports this idea and develops the scientific content of that hypothesis.



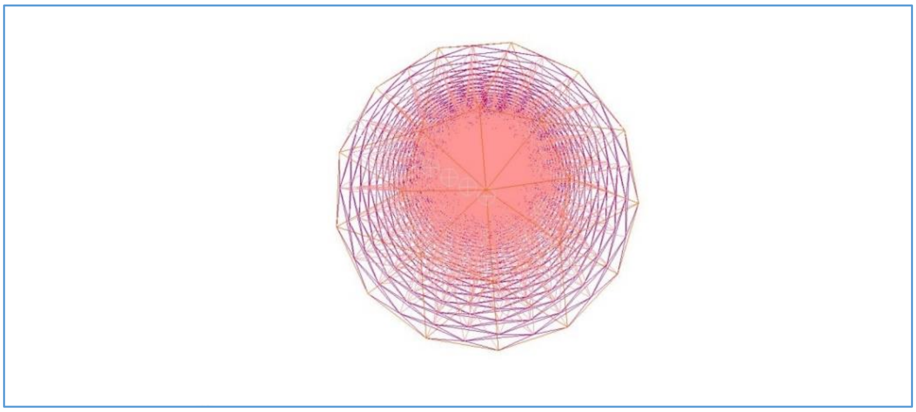


Figure (4) Represent The pipe geometry of computational flow domain.

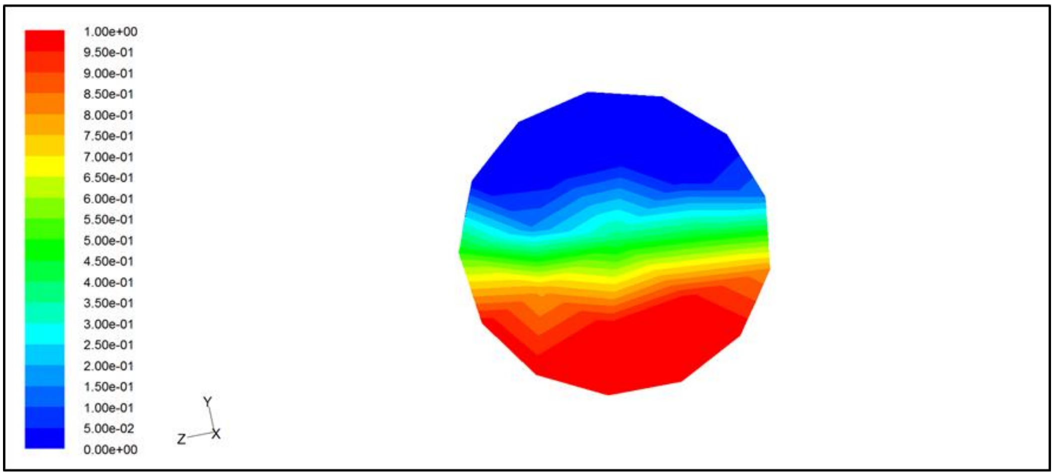


Figure (5) cross section of the flow.

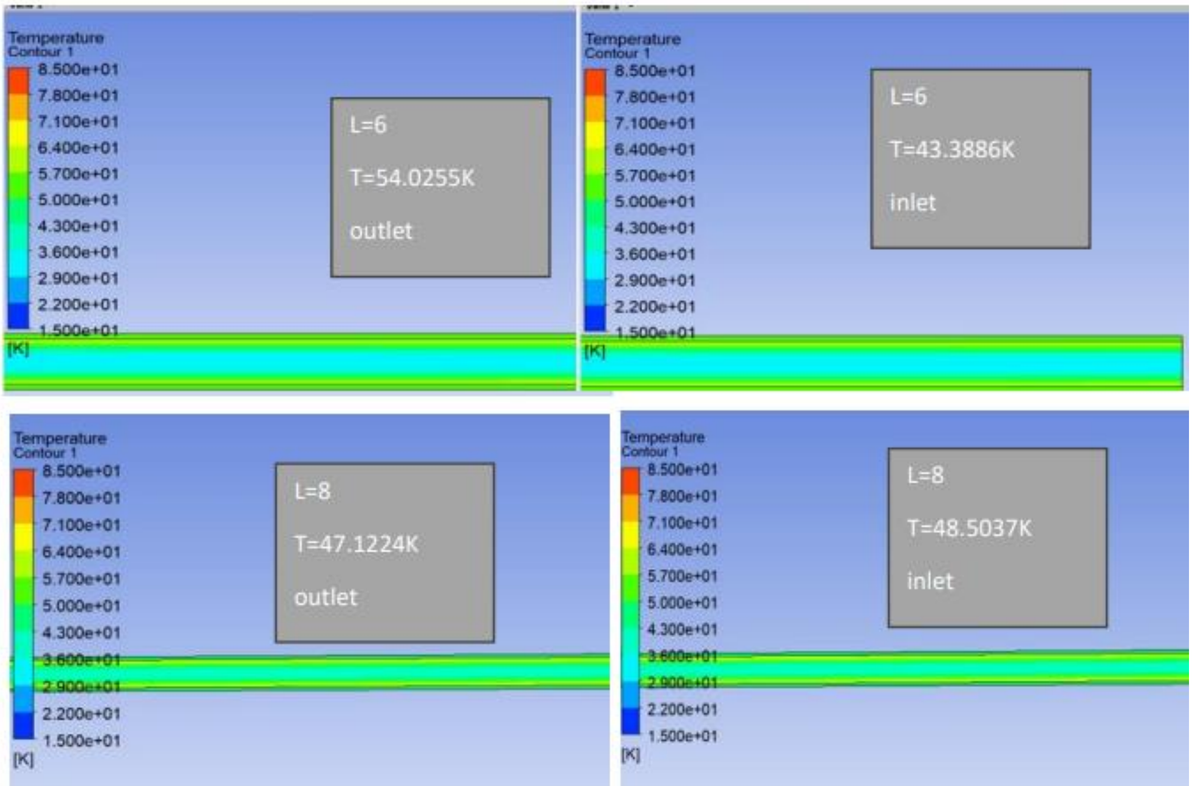


Figure (6) Parallel HE with length "6,8 "m.

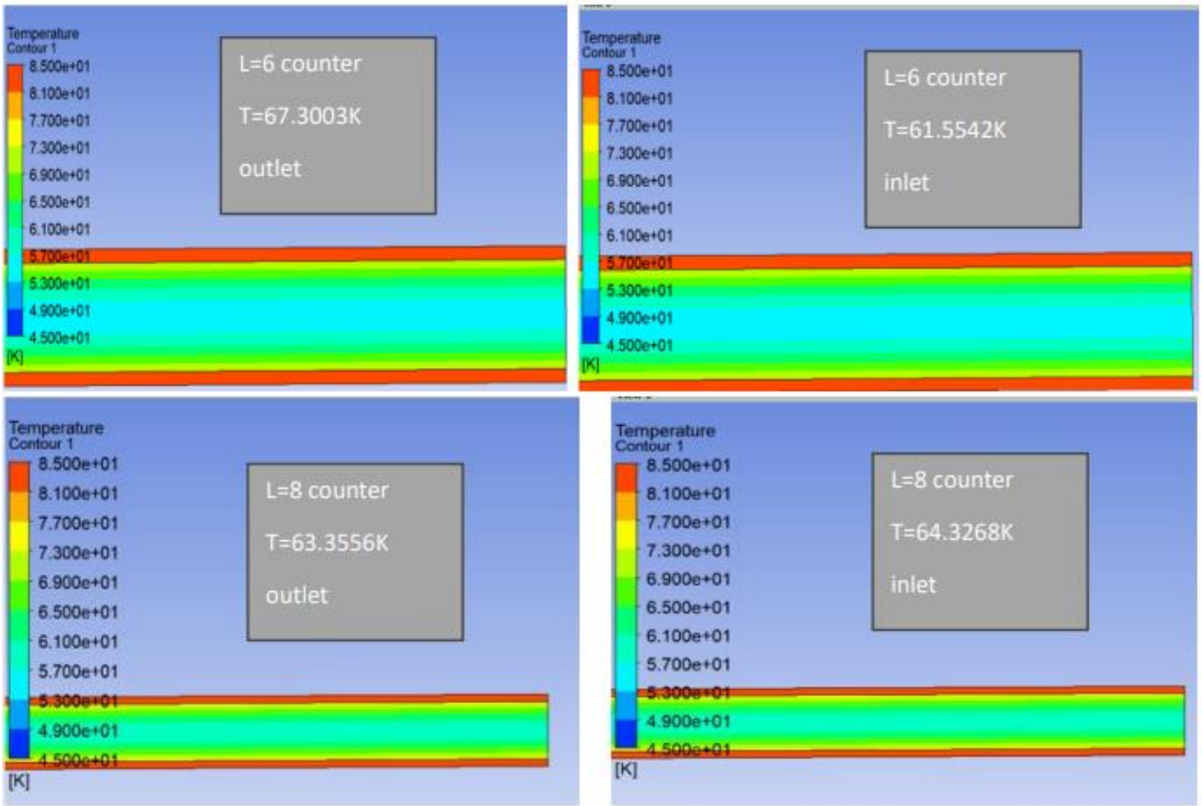


Figure (7) Counter HE temperature distribution at length"6,8.

4- Conclusion

Overall, this study is based on verifying the design conditions of parallel and counter-flow HEs, and in particular, studying the effect of increasing the length of the HEs on the efficiency of heat exchange. As it becomes clear from these results, the heat distribution within the HEs, whether in parallel or counter flow, is more homogeneous. The reason for the increase in the efficiency of HEs by increasing the length is due to the increase in the surface area of heat exchange and the increase in the time period for heat exchange processes inside the HEs. It was also found that by comparing the parallel and counter-flow HEs, the counter-flow HEs have a higher efficiency, and this is due to the reason of the temperature difference between the ends of the HE, which is higher than the temperature difference in the parallel-flow HE. In general, it is found that the change in the design conditions of HEs of different types often has an impact on increasing the efficiency of heat exchange. This is supported by previous research and scientific studies, and here it is recommended that studying the improvement of new design conditions is necessary to increase the efficiency of HEs in the future..-7-

The change of temperature from inlet to outlet was found increasing with decreasing Reynolds number. . Pressure drop increases with increase in Reynolds number .

5- Nomenclature

Symbols	Description	Symbols	Description
U	Overall heat coefficient	ηo	Temperature effectiveness
A	A	Af	Fin surface area
Rw	Conduction resistance	q	Heat transfer
Rw	Conduction resistance	$\dot{m} h$	Mass flowrate, hot side

$\dot{m}c$	Mass flow rate, cold side	ic,o	Fluid enthalpy cold side outlet
$\dot{m}c$	Mass flow rate, cold side	ic,i	Fluid enthalpy cold side inlet
Rf,h	Fouling factor, hot side	ih,o	Fluid enthalpy hot side outlet
ih,i	Fluid enthalpy hot side inlet	Tc,i	Temperature, cold inlet
Cp,h	Specific heat at constant pressure, hot side	Th,i	Temperature, hot inlet
Cp,c	Specific heat at constant pressure, cold side	ηf	Fin efficiency
Th,o	Temperature, hot outlet	ΔTm	Mean temperature difference

Reference

1. J.S. Kwon, S. Son, J.Y. Heo, J.I. Lee, Compact heat exchangers for supercritical CO2 power cycle application, Energ. Convers. Manage. 209 (2020) 112666.
2. S. Pandey, H. Kallath, H.Y. Choi, T. Sibilli, J.K. Min, J. Chetwynd-Chatwin, M. Y. Ha, Numerical study of the effect of flow nonuniformities on the low-pressure side of a cooled cooling air heat exchanger, Appl. Therm. Eng. 217 (2022) 119113
3. M. Faizan, A. Almerbati, Evolutionary design of compact counterflow heat exchanger, J. Energ. Resour.- ASME 145 (2023) 032102.
4. R. Ferhat, A.Z. Dellil, K. Boualem, M.K. Hamidou, Thermal performance of a corrugated wall with artificial roughness, J. Heat Trans-T. ASME 141 (2019) 084501.
5. N.O. Moraga, C.E. Rosas, V.I. Bubnovich, J.R. Tobar, Unsteady fluid mechanics and heat transfer study in a double-tube air-combustor heat exchanger with porous medium, Int. J. Heat Mass Tran. 52 (2009) 3353–3363.
6. K.M. Shirvan, R. Ellahi, S. Mirzakhanlari, M. Mamourian, Enhancement of heat transfer and heat exchanger effectiveness in a double pipe heat exchanger filled with porous media: numerical simulation and sensitivity analysis of turbulent fluid flow, Appl. Therm. Eng. 109 (2016) 761–774.
7. K.M. Shirvan, S. Mirzakhanlari, S.A. Kalogirou, H.F. Oztop, M. Mamourian, Heat transfer and sensitivity analysis in a double pipe heat exchanger filled with porous medium, Int. J. Therm. Sci. 121 (2017) 127–137.
8. H.R. Abbasi, E.S. Sedeh, H. Pourrahmani, M.H. Mohammadi, Shape optimization of segmental porous baffles for enhanced thermo-hydraulic performance of shell-andtube heat exchanger, Appl. Therm. Eng. 180 (2020) 115835.
9. C. Shi, M. Wang, J. Yang, W. Liu, Z. Liu, Performance analysis and multi-objective optimization for tubes partially filled with gradient porous media, Appl. Therm. Eng. 188 (2021) 116530.
10. R.D. Jilte, et al., Battery thermal management system employing phase change material with cell-to-cell air cooling, Appl. Therm. Eng. 161 (2019), 114199.
11. S. Shafiee, M.H. McCay, Different reactor and heat exchanger configurations for metal hydride hydrogen storage systems – a review, Int. J. Hydrog. Energy 41 (22) (2016) 9462–9470.

12. X. Peng, Z. Liu, C. Qiu, J. Tan, Passage arrangement design for multi-stream platefin heat exchanger under multiple operating conditions, Int. J. Heat Mass Transf. 77 (2014) 1055–1062.

13. X. Peng, Z. Liu, C. Qiu, J. Tan, Effect of inlet flow maldistribution on the passage arrangement design of multi-stream plate-fin heat exchanger, Appl. Therm. Eng. 103 (2016) 67–76.

14. H. Yang, J. Wen, X. Gu, Y. Liu, S. Wang, W. Cai, Y. Li, A mathematical model for flow maldistribution study in a parallel plate-fin heat exchanger, Appl. Therm. Eng. 121 (2017) 462–472

15. Zheng, Z., Fletcher, D. F., & Haynes, B. S. (2014). Transient laminar heat transfer simulations in periodic zigzag channels. International Journal of Heat and Mass Transfer, 71, 758–768. doi:10.1016/j.ijheatmasstransfer.2013.12.056.

16. Sharma, H., Monnier, É., Mandil, G., Zwolinski, P., & Colasson, S. (2019). Comparison of environmental assessment methodology in hybrid energy system simulation software. Procedia CIRP, 80, 221-227. doi:10.1016/j.procir.2019.01.007

17. Zou, Y., Xiang, K., Zhan, Q., & Li, Z. (2021). A simulation-based method to predict the life cycle energy performance of residential buildings in different climate zones of China. Building and Environment, 193, 107663. doi:10.1016/j.buildenv.2021.107663.

18. Guo, K., Zhang, N., & Smith, R. (2015). Optimisation of fin selection and thermal design of counter-current plate-fin heat exchangers. Applied Thermal Engineering, 78, 491–499. doi:10.1016/j.applthermaleng.2014.11.071.

19. Figley, J., Sun, X., Mylavarapu, S. K., & Hajek, B. (2013). Numerical study on thermal hydraulic performance of a Printed Circuit Heat Exchanger. Progress in Nuclear Energy, 68, 89–96. doi:10.1016/j.pnucene.2013.05.003.

20. Alsaad, M. A. (2013). Wind energy potential in selected areas in Jordan. Energy Conversion and Management, 65, 704–708. doi:10.1016/j.enconman.2011.12.037

21. Gobakis, K., & Kolokotsa, D. (2017). Coupling building energy simulation software with microclimatic simulation for the evaluation of the impact of urban outdoor conditions on the energy consumption and indoor environmental quality. Energy and Buildings, 157, 101–115. doi:10.1016/j.enbuild.2017.02.020.

22. Alaqel, S., Saleh, N. S., Djajadiwinata, E., Saeed, R., Alswaiyd, A., Al-Ansary, H., El-Leathy, A., Zeitoun, O., Jeter, S., AbdelKhalik, S., Khayyat, A., Danish, S., & Al-Suhaibani, Z. (2021). A novel particle-to-fluid direct-contact counter-flow heat exchanger for CSP power generation applications: Design features and experimental testing. Renewable Energy, 170, 905–926. doi:10.1016/j.renene.2021.02.049.

23. Chen, Y.-S., Tian, J., Zhu, H.-H., Fu, Y., & Wang, N.-X. (2021). Experimental and numerical study on thermal performance of a fluoride salt-to-air heat exchanger. Annals of Nuclear Energy, 108876. doi:10.1016/j.anucene.2021.108876.

24. Zhang, H., Shi, L., Xuan, W., Chen, T., Li, Y., Tian, H., & Shu, G. (2022). Analysis of printed circuit heat exchanger (PCHE) potential in exhaust waste heat recovery. Applied Thermal Engineering, 204, 117863. doi:10.1016/j.applthermaleng.2021.117863.

25. Alrwashdeh, S. S., & Ammari, H. (2019). Life cycle cost analysis of two different refrigeration systems powered by solar energy. Case Studies in Thermal Engineering, 16, 100559. doi:10.1016/j.csite.2019.100559.

26. Alrwashdeh, S. S., Manke, I., Markötter, H., Klages, M., Göbel, M., Haußmann, J., ... & Banhart, J. (2017). In operando quantification of three-dimensional water distribution in

nanoporous carbon-based layers in polymer electrolyte membrane fuel cells. ACS nano, 11(6), 5944-5949. doi:10.1021/acsnano.7b01720

27. Application of numerical methods to study the effect of variable fluid viscosity on the performance of plate heat exchangers M.A. Mehrabian and M. Khoramabadi Department of Mechanical Engineering, Shahid Bahonar University of Kerman, Kerman, Iran.
28. Al-Falahat, A. M., Qadourah, J. A., Alrwashdeh, S. S., khater, R., Qatlama, Z., Alddibs, E., & Noor, M. (2022). Energy performance and economics assessments of a photovoltaic-heat pump system. Results in Engineering, 13, 100324. doi:10.1016/j.rineng.2021.100324.
29. Alrwashdeh, S. S. (2021). Investigation of the energy output from PV panels based on using different orientation systems in Amman-Jordan. Case Studies in Thermal Engineering, 28, 101580. doi:10.1016/j.csite.2021.101580
30. Arab oil and natural gas … the first arab website specialized in the oil and natural gas industry.
31. Wang, Z., & Li, Y. (2016). Layer pattern thermal design and optimization for multistream plate-fin heat exchangers - A review. Renewable and Sustainable Energy Reviews, 53, 500–514. doi:10.1016/j.rser.2015.09.003.
32. Zheng, Z., Fletcher, D. F., & Haynes, B. S. (2014). Transient laminar heat transfer simulations in periodic zigzag channels. International Journal of Heat and Mass Transfer, 71, 758–768. doi:10.1016/j.ijheatmasstransfer.2013.12.056.