Research Journal of Engineering Technology and Medical Sciences (ISSN: 2582-6212), Volume 06, Issue 03, September -2023
Available at www.rjetm.in/

An Overview of Single Phase Flow Heat Transfer Enhancement Methods

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Abstract: In contemporary society, the process of thermal energy exchange between a flowing fluid and its confining channel is ubiquitous. Several methods have been developed to increase the contact area between the fluid and the inner wall and/or disrupt the flow to improve circulation or induce turbulence in order to improve the fluid-to-wall or wall-to-fluid heat transfer. Heat exchanger size can be decreased without sacrificing performance by deploying channels with features that can improve heat transfer. Because it can reduce the amount of expensive working fluids needed and potentially allay safety concerns related to system fluid volume, equipment size reduction is essential. A thorough analysis of single-phase heat transfer enhancement methods is provided here.

Keywords: Heat transfer enhancement, air injection, shell and tube heat exchanger.

I. Introduction

A shell and tube heat exchanger (STHE) is a system component used to accept or reject heat that transfers heat between two or more fluids. The majority of mechanical and chemical systems employ STHEs. Some of the most common uses are in fluid coolers, boilers, condensers, radiators, preheaters, heating and air conditioning systems, and ventilation. An essential part of producing energy efficiently is HEs. HEs affect a system's overall effectiveness and size. Heat exchanger (HE) shapes must reach a consensus between HE effectiveness and pressure drop (P) in order to achieve the desired tradeoff between system efficiency and size [1]–[3]. In each energy conversion system, the There will be a different trade-off between system size and efficiency. The classification of hydrocarbons (HEs) is determined by various factors such as the type of service, structure, fluid mass, surface compactness, flow arrangement, mass of fluids, and transfer mechanisms. Based on their construction, HEs can be classified as either regenerative, extended surface, tubular, or plate exchangers. Triple pipe, spiral tube, and STHEs are the three categories of tubular HEs, which are composed of circular tubes[4]–[6].

Heat exchangers

Without the fluids coming into direct contact with one another, heat can be transferred from one to another using a heat exchanger. HEs are widely utilized in power generation, industrial, commercial, and residential settings for a wide range of applications, such as food and beverage production, chemical processing, power generation, and refrigeration and air conditioning systems.

Classification of Heat Exchangers

Heat exchangers can be categorized according to their design, mode of operation, or use in a number of ways. Numerous factors, such as the necessary heat transfer rate, the kinds of fluids involved, and the available space and resources, will determine the type of HE used in a given application. Based on how they are constructed, HEs can be divided into a number of categories, such as [7]–[10].

- **Heat exchangers with shells and tubes**
The most prevalent kind of HE is this one. It is made up of a cylindrical shell that contains a collection of tubes. While the other fluid circulates around the tubes' exterior in the shell, one fluid passes through the tubes.

- **Heat exchangers on plates**
A stack of plates is what makes up a plate heat exchanger. The fluids pass through channels in the plates. Usually, the plates are curved to maximize the surface area that can be used to transfer heat.

- **Heat exchangers that spiral**
Two long, coiled metal strips make up a spiral heat exchanger; one of the strips is wound around the other to form two distinct channels for the fluids to pass through.

- **Thermostatic tube heat exchangers**
Fins are affixed to the outer surface of the tubes in finned tube heat exchangers, increasing the surface area that can be used for heat transfer.

- **Heat exchangers with plate fins**

The layers of flat plates and corrugated fins alternate in plate-fin heat exchangers. The fins and plates create channels that the fluids pass through.

- **Regenerative heat exchangers**

In regenerative heat exchangers, heat is absorbed and released by a solid material matrix while fluids pass through it. Metal, ceramic, or other materials can be used to create the matrix. HE has numerous systematic effects. By transferring heat from waste streams to entering streams, the HEs can increase the energy efficiency of systems and lower operating costs and energy consumption.

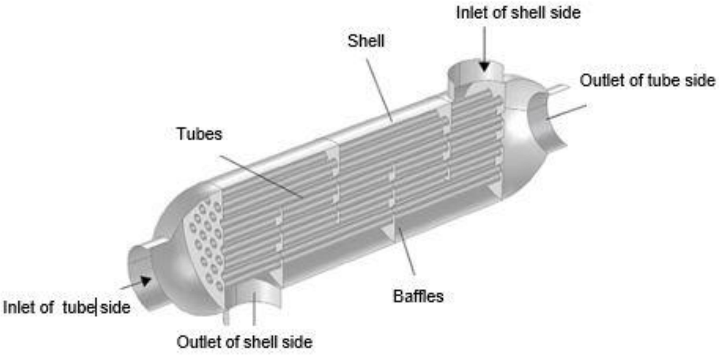

Fig. 1 The structure of the STHE

Limiting STHE requirements

Several limiting requirements must be considered when designing a STHE to ensure efficient and safe operation. Overall, a successful STHE design must take into account limiting requirements such as pressure, temperature, flow rate, fouling, and material limitations. Some of these requirements can be summarized in the following points [6]:

- The STHE must be designed to withstand the maximum pressure to which it will be subjected during operation. This includes both the internal pressure of the fluid being heated or cooled and any external pressure from the surroundings.
- The materials used in the HE must be able to withstand the highest temperature of the fluid being heated or cooled. This is especially important in high-temperature applications, where failing to account for temperature limits can lead to equipment failure and safety hazards.
- To ensure efficient heat transfer, the fluid flow rate through the HE must be within a certain range. Heat transfer will be slow if the flow rate is too low.

II. Heat transfer enhancement method’s overall view

Throughout the last decade, heat transfer enhancement has been developed and widely used in HE applications. The goal of augmentative heat transfer (h) is to accommodate high heat fluxes. To date, attempts have been made to reduce the size and cost of the HE, as well as its energy consumption. The most important variable in reducing the size and cost of the HE, which typically leads to lower capital costs, is lowering the temperature driving force, which boosts second law efficiency and lowers entropy generation. The use of various strategies to increase q via obligatory force convection is a huge effort[11]–[14]. Meanwhile, this method has been discovered to reduce the size of the HE device while also conserving energy. The following points [15]–[18] summarize the significance of using various methods of heat transfer enhancement in STHE:

- Reducing the size of the equipment.
- Increasing heat transfer.
- Lowering the pumping power.
- Minimizing the cost of energy and materials.
- Improving system and process efficiency.
- Creating the ideal HE size.
- Transferring the necessary quantity of heat efficiently.

There are three methods for increasing q within STHEs that reflect the responsibility of all HEs (passive, active, and combined passive and active). The passive approach employs geometrical or surface adjustments that do not require external power, such as treated surfaces, twisted tapes, abrasive surfaces, expanded surfaces, or the use of different inserts. In Fig. 2, examples of such inserts include enhancement devices, wire coils, twisted tape, coiled tubes, swirl flow generation, surface tension devices, and gas and liquid additives. Magnetic field reciprocating plungers, fluid suction for flow disruption, surface or flow vibration, and the use of electromagnetic fields are all examples of active approaches that use external power. The third option is the compound approach, which combines active and passive procedures.

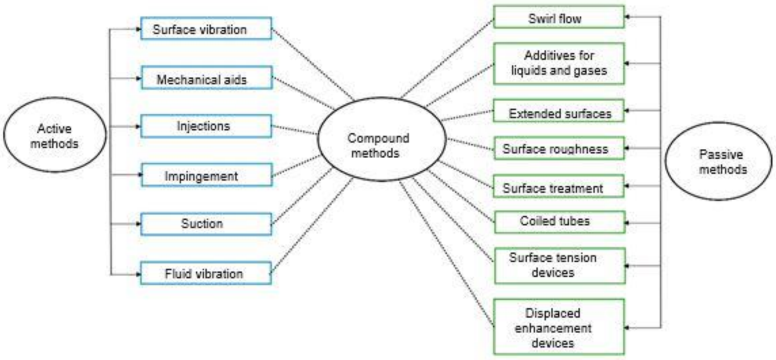

Fig. 2 Types of heat transfer enhancement for active, passive, and compound methods

II. LITERATURE REVIEW

Eiamsa-ard et al. [19] investigated the effects of twisted tapes on the heat transfer of HE (oblique and straight delta winglet, O-DWT, and S-DWT). The O-DWT also has a higher Nu and f than the S-DWT. Across the range studied, the performance factor in tubes fitted with the O-DWT and S-DWT was determined to be roughly 0.92-1.24 and 0.88-1.21, respectively. When it comes to heat transfer improvement, the DWT outperforms ordinary twisted tape. It means that a DWT-equipped HE was more condensed than a traditional twisted tape-equipped HE. Again, any of the TT can effectively replace the DWT.

Wang et al. [20] used a novel baffle type in the STHE, with experiments performed on both the novel baffle and the SB. The operational performances of the two HEs were also compared. According to the findings, the improved model's overall performance was 20-30% higher than the SB in HE under similar conditions. The results of the tests revealed that, because the Re number in the tube and shell sides was the same, the Nu for flower baffles was roughly half that of SBs, and the P of the former was roughly one-third that of the latter. When building HEs to save energy, heat transfer improvement and flow friction growth would be taken into account.

Bhatta and colleagues [21] investigated how CFD could be used in various types of HEs, including fluid flow, P, heat transfer, and existing turbulence models for HEs. They discovered that the k-turbulence model was the most commonly used for HE simulation, and they proposed a method for comparing the research's experimental and numerical findings.

You et al. [22] performed a shell-side thermal and hydraulic analysis of a STHE with trefoil hole baffles. According to the test results, the q on the shell side was effectively increased; however, the flow resistance increased dramatically. Furthermore, as Re increases, both heat transfer performance and P improve. As a result, the q has significantly improved, and the flow resistance has increased significantly. The trefoil-hole baffle may cause a high-speed flush against the downflow tube wall, intense recirculating flow, and a high level of turbulence intensity, according to a numerical simulation of the unit channel. As a result, the temperature boundary thickness near the wall was greatly reduced, and the q improved significantly, resulting in an increase in flow resistance.

Gowthaman and Sathish [23] investigated two distinct baffles in a STHE quantitatively. HEs who meet specific criteria have a strong hand and a low P. When compared to an SB for a new installation, helical baffles reduce shell side P, pumping cost, mass, fouling, and other factors. In comparison to an SB, the increased cross-flow area results in less mass flux across the shell, resulting in a larger P. Because of the reduced bypass impact and less shell side fouling, the helical baffle was significantly larger than the SB. The friction factor and heat transfer enhancement of different STHEs with discontinuous helical baffles were investigated by

Gao et al. [24] The findings revealed that the HE with Lower helix angles have higher shell-side P and h than higher helix angles. The irreversibility of a HE was calculated using entropy production and entrance dissipation theories in second-law thermodynamic comparisons. According to an experimental study, the STHE with lower helix angle baffles produces less irreversibility in the heat exchange procedure in the same heat transfer area and under the same operating conditions. Furthermore, HEs with helical baffles were more efficient under certain shell-side Re conditions.

Wen et al. [25] investigated the THP and revised the ladders pattern fold baffle construction to eliminate the triangle leakage regions in the original STHE. The results showed that in the improved HE, axial short circuit flow was eliminated, and the fluid velocity and temperature distribution inside the shell were more uniform.

Yehia et al. [26] simulated fluid flow fields through HEs over a wide temperature, Res, and geometry range. The tube side Nu and tube side f increased as the MFR increased, while the thermal enhancement factor decreased marginally. The tube side Nu and f increase as the diameter of the inserted vane swirlers decreases as the blade angle decreases, but the tube side thermal enhancement decreases. The factor decreases. When compared to the plain tube scenario, the resulting Nu, f, and thermal enhancement factor were 2.3, 19.02, and 0.86, respectively. Increased swirl vanes improve heat transmission and the thermal enhancement factor, resulting in a more effective HE with less heat transfer area and volume, and thus lower costs.

Wang et al. [27] investigated the effect of rod baffle on thermal performance and P in a double-shell side rod baffle HE (DS-RBHX) using CFD. According to the results, the DS-RBHX has a higher q and P than the SS-RBHX by 34.5-42.7% and 41.6-40.6%, respectively. The efficiency estimation criterion, which was the ratio of the increase in q to the cost of power consumption, was used to evaluate overall performance in this study.

Gomaa et al. [4] looked into the triple concentric tube HE with inserted THP parameters for ribs. We used both experimental and numerical methods. Correlations for Nu, f, and efficacy were also calculated using dimensionless design parameters. At various flow configurations, the Nu and efficacy of the triple tube HE with ribs were greater than those of the triple tube HE without ribs. Without ribs, by 21.48% and 16.74%, respectively. When the flow pattern was countercurrent, the Nu and HE efficacy were higher.

Lei and Jing [9] compared two types of reformed STHEs with louver baffles to STHEs with traditional SBs in order to reduce pumping power and increase overall shell performance. The STHE-LV1 and STHE-LV2 h per P were found to be approximately 94.6-118.2% and 73.3-89.7% higher than the STHE-SG, respectively. Louvre The flow pattern produced by baffles on the shell side of HEs is gentler than that produced by SBs on the shell side of HEs. Because the new STHEs have fewer dead areas and recirculation zones than HEs with SBs, heat transfer efficiency has improved. On the shell side of the two new STHEs, abrupt changes in flow direction were avoided, resulting in a smaller P.

Labbadlia et al. [20] investigated four possible tube arrangement types. The results showed that the tube characteristics had a significant impact on the flow pattern. A 60° design was found to have a 21% more homogeneous flow distribution than a 90° configuration. In comparison to the other designs, the 45° layout provides superior pressure distribution.

Mellal et al. [21] investigated 3D numerical simulations of turbulent water flow and heat transfer in the shell of a STHE. Baffle spacings of 106.6, 80, and 64 mm were investigated, as well as six orientation orientations of 45, 60, 90, 120, 150, and 180°. The simulation was carried out with the COMSOL package and the finite element procedure with Re ranging from 3000 to 10,000. Many numerical outcomes were compared to experimental data and kept close together. When compared to STHE without baffles, the findings demonstrated the importance of the investigated parameters in improving shell-side thermal performance, with the 180° baffle arrangement at 64 mm baffle spacing being the best that ensures mixing flow, yielding a thermal performance criteria of 3.55.

Dizaji et al. [22] used corrugated shell and orrugated tube. The researchers investigated various concave and convex corrugated tube configurations. Corrugations, according to the data, cause an increase in NTU as well as an increase in exergy loss. When both the tube and the shell were corrugated, the exergy loss and NTU increased by about 17-81 and 34-60%, respectively. Exergy loss was greatest in the HE with the concave corrugated shell and convex corrugated tube.

IV. DISCUSSION AND FINDINGS

According to the findings, twisted tape has a greater impact on thermal performance than baffles. Even though heat transfer was increased when nanoparticles with twisted tape inserts were used, thermal performance was reduced. While using nanoparticles in seawater improves heat transmission, it also increases friction significantly. Marzouk et al. [23] used a straightforward technique to inject air into the tube sides where wired nails-circular rod inserts (WNCR) were present. The effects of inserts alone, inserts in combination with air injection, and air injection alone on thermal parameters (such as NTU, and U) and hydraulic performance (P) were examined and analyzed. Exergy efficiency and thermal-hydraulic parameters were also discussed and investigated. The findings revealed that inserts were more noticeable than air injection across all performance criteria. Insert B (the second variety) has a greater impact than insert A (the first variety). The percentage improvements in performance parameters for inserts A and B were 31-131%, 43-177%, 33-143%, 44-184%, 2-19%, and 1-23%, respectively. The ranges for air injection alone with insert A were 2-19% and 1-23%, respectively. Air injection had no effect on HE performance measures such as NTU, p, and thermohydraulic parameters (less than 5%). Pourahmad et al. [24] introduced ABI into the working water using a twin twisted tape turbula- tor. When used in tandem, the effects of these two techniques on the P and Nu were observed. The results showed that increasing the cold water flow rate, ABI flow rate, and Re, as well as decreasing the turbulator ratio, improved the Nu. The results also showed that when the two methods were used simultaneously instead of a simple tube HE, a turbulator-equipped HE (without ABI), and a HE with ABI (without a turbulator), the Nu could be increased by 98-114%, 3-14%, and 20-39%, respectively. According to Hussein et al. [25], the total performance of STHE was achieved when a fin was presented in a soft tube. Furthermore, using a vortex generator, a well-known passive approach, significantly accelerates heat transfer and lowers P. Furthermore, it appears that additional heat transfer techniques, such as vortex The use of generators, structural tube design, interior and exterior HE structures and dimensions, and additive nanofluids improved the overall performance of the HE.Basit Shafiq et al. [26] investigated numerically how combining two passive approaches improved the thermal performance of shell and helical coil tube HEs. In addition to MWCNT/water nanofluids, coiled tubes were used. The results showed that as the coil Reynolds number and nanofluid volume concentration increased, so did the Nusselt number of the fluid flowing through the coil. The thermal performance factor, which serves as an index for HE performance, was also considered. Tavakoli and Soufivand [27] investigated the THP and entropy formation of a hybrid nanofluid in a STHE with two different cross-sectional baffles numerically. According to the numerical data, Baffle 1 is preferable. Data on pressure drop, total entropy production, and performance evaluation criteria (PEC) were discovered. In terms of heat transfer rate and average Nu number values, Baffle 2 is superior. When the baffle type was changed from the second to the first, the maximum change in PEC was 5.13% at Re = 45,000 and = 0%. When = 0% for the first type of baffles, the overall entropy generation increased by 73.68% to its maximum.

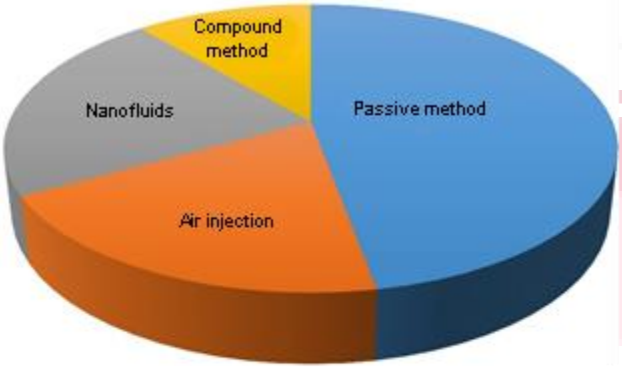

Fig. 3 The percentages of studies of various heat transfer enhancement methods

V.CONCLUSION

STHE heat transfer technologies are currently a hot topic in the energy sector. This type of heat exchanger (HE) is commonly used in industrial and technical applications. The HEs influence the overall efficiency and size of a system. Although there are research papers on heat transfer enhancement methods in STHEs, there is a lack of a comprehensive review that covers all available methods. The paper's work justification is its ability to provide a comprehensive, up-to-date, and systematic review of the various heat transfer enhancement methods (Active, Passive, and Compounds) available in STHEs. The findings of the paper have practical implications for industries, researchers, and engineers, making it a must-read in the field of heat transfer. The document compares and evaluates various heat transfer enhancement methods, assisting in the selection of the most effective method for a specific application. This comparison is significant because it provides a thorough understanding of the benefits and drawbacks of each method. • In order to help academics better understand the most recent developments in the STHE field, this review, which is a follow-up to many papers by previous authors, summarizes the findings of previous studies. This in-depth analysis may help associated experts improve their work. The authors also mention a few issues and ideas that they believe require further investigation in the future.

- There have been 47.8% of studies on the passive approach and the air injection method, increasing heat transfer using nanofluids, and compound methods, respectively, with percentages of previous studies near 20.2, 22.3, and 9.7%.
- The current review introduces experimental and numerical studies primarily related to U and exergy efficiency in STHE. In the In the case of the passive method, adding baffles provides the best heat transfer enhancement, with trefoil hole baffles achieving 450% for U ratio when compared to smooth tubes. Many different tapes are used for heat augmentation, with twisted tape having the best U ratio value of 325%. The U ratios of swirl vane, corrugated tube, and wire coil insert are 130, 161, and 264%, respectively.

•The active enhancement technique for heat transfer enhancement was used in STHEs, and the authors believe that this approach should be given special attention. The injection of air bubbles raises the U ratio, with the maximum value being 452% when compared to only water flow. It has been demonstrated that nanofluid causes growth.

• For the compound method, using blade-shaped turbulators with Fe3O4 results in the highest U ratio (175.9%) when compared to traditional fluid. The combination of air injection and passive heat augmentation techniques, which was shown to be a significant solution to several issues, should be the focus of future research.

• The cost of the nanoparticle type, the negative effects on flow pressure drop, and the environmental toxicity implications of the nanoparticles. With the use of materials coating to improve heat transfer, geometrical designs for surfaces in STHE will be required in the future.

• Heat transfer method theoretical analysis in relevant empirical formulations is required. Also, Because there aren't many relevant numerical simulations, more care is needed.

REFRENCES

[1] Babu BV, Munawar SA. Differential evolution strategies for optimal design of shell-and-tube heat exchangers. Chem Eng Sci.2007;62(14):3720–39. https://doi.org/10.1016/j.ces.2007.03.039.

[2] Zheng W, Jiang Y, Wang Y. The sloshing effects on distribu- tion characteristics of gas–liquid mixture in spiral-wound heat exchanger. J Therm Anal Calorim. 2020;141(1):599–612. https://doi.org/10.1007/s10973-020-09423-2

[3] d classi- fications. In: Zohuri B, editor. Retracted book: compact heat exchangers: selection, application, design and evaluation. Cham: Springer International Publishing; 2017. p. 19–56.

[4] Targui N, Kahalerras H. Analysis of fluid flow and heat transfer in a double pipe heat exchanger with porous structures. Energy Convers Manag. 2008;49(11):3217–29. https://doi.org/10.1016/j.enconman.2008.02.010.

[5] Genić SB, Jaćimović BM, Mandić D, Petrović D. Experimental determination of fouling factor on plate heat exchangers in dis- trict heating system. Energy Build. 2012;50:204–11. https://doi.org/10.1016/j.enbuild.2012.03.039.

[6] Vengateson U. Design of multiple shell and tube heat exchangersin series: E shell and F shell. Chem Eng Res Des. 2010;88(5– 6):725–36. https://doi.org/10.1016/j.cherd.2009.10.005.

[7] Masoud Hosseini S, Safaei MR, Estellé P, Hadi JS. Heat transfer of water-based carbon nanotube nanofluids in the shell and tube cooling heat exchangers of the gasoline prod- uct of the residue fluid catalytic cracking unit. J Therm Anal Calorim. 2019;140(1):351–62. https:// doi. org/ 10. 1007/ s10973-019-08813-5.

[8] Serth RW, Lestina TG. Design of shell-and-tube heat exchangers. In: Serth RW, Lestina TG, editors. Process heat transfer. Boston: Academic Press; 2014. p. 151–97.

[9] Eiamsa-ard S, Wongcharee K, Eiamsa-ard P, Thianpong C. Heat transfer enhancement in a tube using delta-winglet twisted tape inserts. Appl Therm Eng. 2010;30(4):310–8. https://doi.org/10. 1016/j.applthermaleng.2009.09.006.

[10] Wang Y, Liu Z, Huang S, Liu W, Li W. Experimental investiga- tion of shell-and-tube heat exchanger with a new type of baffles. Int J Heat Mass Transf. 2011;47(7):833–9. https://doi.org/10. 1007/s00231-010-0590-x.

[11] Aslam Bhutta MM, Hayat N, Bashir MH, Khan AR, Ahmad KN, Khan S. CFD applications in various heat exchangers design: a review. Appl Therm Eng. 2012;32:1–12. https://doi.org/10. 1016/j.applthermaleng.2011.09.001.

[12] You Y, Fan A, Lai X, Huang S, Liu W. Experimental and numeri- cal investigations of shell-side thermo-hydraulic performances for shell-and-tube heat exchanger with trefoil-hole baffles. Appl Therm Eng. 2013;50(1):950–6. https://doi.org/10.1016/j.applt hermaleng.2012.08.034.

[13] Gowthaman PS, Sathish S. Analysis of segmental and helical baffle in shell and tube heat exchanger. Int J Curr Eng Technol. 2014;2:625–8. https://doi.org/10.14741/ijcet/spl.2.2014.119.

[14] Gao B, Bi Q, Nie Z, Wu J. Experimental study of effects of baf- fle helix angle on shell-side performance of shell-and-tube heat exchangers with discontinuous helical baffles. Exp Therm Fluid Sci. 2015;68:48–57. https://doi.org/10.1016/j.expthermflusci. 2015.04.011.

[15] Wen J, Yang H, Wang S, Xue Y, Tong X. Experimental investiga- tion on performance comparison for shell-and-tube heat exchangers with different baffles. Int J Heat Mass Transf. 2015;84:990–7. https://doi.org/10.1016/j.ijheatmasstransfer.2014.12.071.

[16] Yehia MG, Attia AAA, Abdelatif OE, Khalil EE. Heat transfer and friction characteristics of shell and tube heat exchanger with multi inserted swirl vanes. Appl Therm Eng. 2016;102:1481–91. https://doi.org/10.1016/j.applthermaleng. 2016.03.095.

[17] Wang X, Zheng N, Liu P, Liu Z, Liu W. Numerical investigation of shell side performance of a double shell side rod baffle heat exchanger. Int J Heat Mass Transf. 2017;108:2029–39. https:// doi.org/10.1016/j.ijheatmasstransfer.2017.01.055.

[18] Gomaa A, Halim MA, Elsaid AM. Enhancement of cooling characteristics and optimization of a triple concentric-tube heat exchanger with inserted ribs. Int J Therm Sci. 2017;120:106–20. https://doi.org/10.1016/j.ijthermalsci.2017.06.002.

[19] Lei Y, Li Y, Jing S, Song C, Lyu Y, Wang F. Design and perfor- mance analysis of the novel shell-and-tube heat exchangers with louver baffles. Appl Therm Eng. 2017;125:870–9. https://doi.org/ 10.1016/j.applthermaleng.2017.07.081.

[20] Labbadlia O, Laribi B, Chetti B, Hendrick P. Numerical study of the influence of tube arrangement on the flow distribution in the header of shell and tube heat exchangers. Appl Therm Eng. 2017;126:315–21. https://doi.org/10.1016/j.applthermaleng. 2017.07.184.

[21] Mellal M, Benzeguir R, Sahel D, Ameur H. Hydro-thermal shell- side performance evaluation of a shell and tube heat exchanger under different baffle arrangement and orientation. Int J Therm Sci. 2017;121:138–49. https://doi.org/10.1016/j.ijthermalsci. 2017.07.011.

[22] Sadighi Dizaji H, Jafarmadar S, Asaadi S. Experimental exergy analysis for shell and tube heat exchanger made of corrugated shell and corrugated tube. Exp Therm Fluid Sci. 2017;81:475– 81. https://doi.org/10.1016/j.expthermflusci.2016.09.007.

[23] Marzouk SA, Abou Al-Sood MM, El-Fakharany MK, El-Said EMS. Thermo-hydraulic study in a shell and tube heat exchangerusing rod inserts consisting of wire-nails with air injection: experimental study. Int J Therm Sci. 2021;161:106742. https:// doi.org/10.1016/j.ijthermalsci.2020.106742.

[24] Pourahmad S, Pesteei SM, Ravaeei H, Khorasani S. Experimentalstudy of heat transfer and pressure drop analysis of the air/watertwo-phase flow in a double tube heat exchanger equipped with dual twisted tape turbulator: simultaneous usage of active and passive

methods. J Energy Storage. 2021;44:103408. https://doi.org/10.1016/j.est.2021.103408.

[25] Azeez Mohammed Hussein H, Zulkifli R, Faizal Bin Wan Mahmood WM, Ajeel RK. Structure parameters and designs and their impact on performance of different heat exchangers: a review. Renew Sustain Energy Rev. 2022;154:111842. https://doi.org/10.1016/j.rser.2021.111842.

[26] Basit Shafiq M, Allauddin U, Qaisrani MA, Rehman T-U, Ahmed N, Usman Mushtaq M, et al. Thermal performance enhancement of shell and helical coil heat exchanger using MWCNTs/water nanofluid. J Therm Anal Calorim. 2022;147(21):12111–26. https://doi.org/10.1007/s10973-022-11405-5.

[27] Tavakoli M, Soufivand MR. Performance evaluation criteria and entropy generation of hybrid nanofluid in a shell-and-tube heat exchanger with two different types of cross-sectional baffles. Eng Anal Bound Elem. 2023;150:272–84. https://doi.org/10.1016/j.enganabound.2023.01.024.