Studies of Shell-and-Tube Heat Exchanger with Helical Baffles

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Abstract **Conventional segmental baffles used in shell-and-tube heat exchanger have drawbacks such as high pressure drop, dead zones, flow induced vibrations and bypass flows. These limitations of segmental baffles may be eradicated using helical baffles. In helical baffle, the shell side flow reaches to near plug flow and guides the shell side fluid smoothly. In this paper, experimental and numerical work done using different helical baffles are studied. The comprehensive performance of helical baffle shell-and-tube heat exchanger is superior than the segmental baffle shell-and-tube heat exchanger. Despite of initial high cost and manufacturing constraints, the use of helical baffle may reduce the operating and maintenance cost, save energy and gives good service life.**

Keywords — Continuous helical baffle, discontinuous helical baffle, heat transfer co-efficient, inclination angle, pressure drop, shell-and-tube heat exchanger

I. INTRODUCTION

A heat exchanger is a device which transfer the thermal energy between two or more fluids, or between the solid surface and a fluid [1]. Heat transfer occur in heat exchanger in three modes: conduction, convection and radiation. The heat exchangers are classified based on geometrical conditions (e.g. Plate heat exchanger, double pipe heat exchanger, shell-and-tube type heat exchangers etc.), based on transfer processes (e.g. Direct contact and indirect contact), based on heat transfer mechanism (e.g. Single phase and two phase) and based on flow arrangements (e.g. Parallel flow, counter flow and cross flow) [2]. Among these types of heat exchangers, shell-and-tube heat exchanger (STHX) is widely accepted due to relatively large ratios of heat transfer area to volume, ease of cleaning, reliable design methods and suitable for high pressure applications [3]-[4]. STHX finds its application in number of fields such as chemical process, petroleum refinery, refrigeration, air conditioning, power generation, condensation and evaporation [5]. It has been reported that among the different type of heat exchangers used, 55-70% are STHX [6].

In the STHX, baffle is used to support the tubes and prevent the sagging effect in long tubes and divert the flow towards the tubes to increase the heat transfer co-efficient. In past, various types of baffles were reported namely single segmental, double segmental, triple segmental, disk-doughnut type, helical, double helical and flower type [7]. Among them, segmental baffles were used traditionally. There are many problems reported with the use of conventional segmental baffles (SB) in STHX [8]-[10], e.g., (1) since the SB comes perpendicular to flow directions, a high pressure drop occurs. There are sudden contraction and expansion in flow due to baffle geometry. This leads to the high pressure drop and high pumping power requirement;

(2) a large cross flow strikes on the tube bundles, induces the vibrations and reduce the service life of the exchanger;

(3) flow stagnation region called dead zones generated at the joint of shell walls and baffles which considerably reduced the heat transfer rates;

(4) the mass of shell side fluid flowing on the tube bundle reduces due to bypass flows and leak flow between the shell walls and baffles and between heat exchange tubes and baffles.

J Lutcha and Nemcansky firstly proposed the helical baffle (HB) and showed the effect of different helical baffles on the flow field [12]. Using HB, dead zones and pressure drops considerably reduced as compared to SB [7]. The flow pattern in case of HB-STHX is smooth and moving in screw shape [13]. Due to this flow pattern, there is reduction in flow induced vibration, shell side fouling and increased the heat transfer rate to pressure drop ratio [11].

In this paper, studies of using different types of HB and the factors affecting the performance of STHX are discussed.

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II. Factors Affecting the Performance of STHX

The performance of STHX is affected by many parameters such as type of fluid, mass flow rate of fluids, turbulence, pressure drop (Δp), heat transfer co-efficient (h), fouling, and type of baffle. The high value of h leads to the higher heat transfer, while the higher Δp leads to the higher pumping power requirement.

The fluid properties like viscosity, density, thermal conductivity, specific heat and baffle geometry affect the h and Δp. By increasing the mass flowrate, the heat transfer increases at an expense of increase in Δp. As the turbulence intensity increases the flow resistance increases, which leads to the enhancement in heat transfer [14]. Fouling reduces the performance of STHX by increasing the conduction resistance as well as increases the Δp [15].

The flow pattern of shell side fluid depends upon the type of baffle. A good baffle shape diverts the flow towards the tube bundle, create turbulence and hence increase the heat transfer at a low Δp. A properly designed continuous HB leads to reduction in fouling [17]. Several researchers have done the numerical and experimental investigation for evaluating the performance of STHX by varying the baffle shape. The different shape of baffles studied in STHX are single segmental baffle, double segmental baffle, triple segmental baffle, disc and doughnut baffle, flower type baffle, tre-foil hole baffle, orifice baffle, helical baffles [7]. Among the different type of baffle studied over a decade, a HB proves to be the better option over the traditional SB and gives higher performance than others.

III. Helical Baffle Shell-and-Tube Heat Exchanger(HB-STHX)

There are two type of HB: continuous helical baffle (CHB) and discontinuous helical baffle (DHB) studied over the period to evaluate the performance of STHX.

A. Performance Evaluation of Continuous Helical Baffle STHX (CHB-STHX)

CHB is fabricated by linking the end to end of several continuous helical baffle cycles. One continuous helical cycle is manufactured by stretching the plate by one pitch of screw in axial direction and rotating it by 2π angle along the circumferential direction. However, the manufacturing of CHB is difficult than DHB [18].

Peng et al. [17] conducted the experimental study of HB-STHX with 2 configurations, one with middle-in-middle-out continuous helical baffle (CM) and one with side-in-side-out continuous helical baffle (CS) and compared with SB-STHX. The performance of CS configuration found better than CM and SB-STHX, since in CS configuration the fluid can be effectively forced in helical passage and there is no direct impingement of fluid on shell wall as in CM. Shinde et al. [16] carried out numerical analysis of CHB-STHX with helix angles α =10°, 19°, 21°, 25°, 30°, 38°, 50° and experimental analysis with α =25° by varying the mass flow rates. They concluded that as the helix angle increases, the h and Δp decreases. The initial and installation cost of HB-STHX is higher than the SB-STHX, however they concluded that the maintenance and operating cost of HB-STHX is 20-40% lesser than SB-STHX. Also, energy saving of 15-20% may be achieved using HB-STHX.

Lei et al. [11] studied the effect of baffle inclination angle on flow and heat transfer of HB-STHX with α=15°, 20°, 30°, 40°, 45°, 50° using numerical simulation. They observed near-plug flow on shell side using the CHB. The ratio of h/Δp with all value of α in HB-STHX is higher than that of the SB-STHX, while the α = 45° is optimum. Maakoul et al. [19] numerically compared the performance of STHX with tre-foil hole baffle, CHB and SB. They found that the velocity distribution in case of HB-STHX is more uniform and homogeneous as compared to the SB and tre-foil hole baffles. The ratio of h/Δp in case of HB-STHX is 39% and 192% higher than SB-STHX and tre-foil hole baffle respectively. Ahmed et al. [20] conducted 3-dimensional numerical simulation to compare SB-STHX and CHB-STHX by varying the mass flow rate. The fluid flow pattern of CHB-STHX found rotational while of SB-STHX was in zig-zag manner inducing the dead zones. The ratio of h/Δp of HB-STHX found 72-127% higher as compared to the SB-STHX.

B. Performance Evaluation of Discontinuous Helical Baffle STHX (DHB-STHX)

DHB are formed using oval-shaped plates which are placed at an angle to the axis of heat exchanger. The ends of the plates may be joined to each other which forms the continuous helical baffle at periphery.

Zhang et al. [21] conducted an experimental comparison of overlapped HB-STHX and SB-STHX with α=15° in HB-STHX and cut ratio=25% for SB. The h/Δp of HB-STHX found 51.8%-76.4% higher than SB-STHX. Gao et al. [23] experimentally studied elliptical sector shaped discontinuous HB-STHX with α = 8°, 12°, 20°, 30°, 40°. Based on the ratio of $j/f^{1/3}$ (j = heat transfer factor & f = friction factor), the 40° helix angle gives the best comprehensive performance at same volume flow rate. They suggested that in existing STHX, if retrofitting of HB is required than one must give priority to smaller helix angle from second-law thermodynamic analysis.

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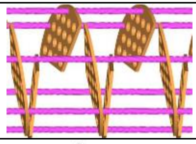
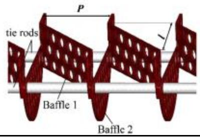
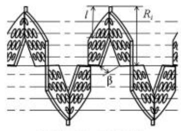
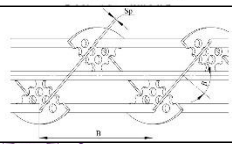
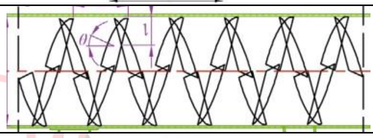
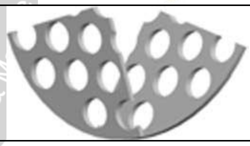
Table I Different helical baffles configurations

Authors/ type	Type of baffle	Numerical / Experimental	Geometry
Maakoul at al. (2016)	Continuous HB-STHX	Numerical	
Zheng at al. (2017)	Trisection HB	Numerical	
Chen et al. (2017)	Unilateral ladder type HB	Numerical	
Wang et al. (2018)	Fold HB	Numerical	
Zhang et al. (2013)	Ovelapped HB	Experimental	
Gao et al. (2015)	Elliptical sector shaped HB	Experimental	
Wang et al. (2015)	Quadrant circumferential overlap HB	Numerical	
Wenjing et al. (2014)	Sextant HB	Numerical	

Wenjing et al. [22] numerically investigated 3 HB shapes (trisection, quadrant and sextant sector) using 3 helix inclination angles (10°, 25° and 40°). The sextant HB gave the better performance in terms of fluid flow due to reduction in leakage through triangle area and close to ideal spiral flow observed. The flow in trisection and quadrant HB observed to be scattered and disordered manner. Zheng et al. [24] numerically analyzed the performance of STHX using 3 trisection HB with α =10°, 15°, 20° and one axial overlap sector baffle with α=20° and one ellipse shape baffle with α=15° and compared with SB-STHX. The performance of trisection HB-STHX with α=20° was best comparatively. Chen et al. [25] performed numerical simulations to compare the unilateral ladder type HB with SB. Using unilateral ladder type baffle, spiral plug flow induced which is accompanied by secondary flow. This type of flow pattern enhances the heat transfer efficiency and decreases the Δp. The comprehensive index $h\ \Delta p^{-1/3}$ of HB-STHX was almost 16% higher than the SB-STHX. Wang et al. [26] proposed ladder-type fold baffle for pre-heating of coal water slurry (CWS) which is non-Newtonian fluid. They concluded that the Nusselt number (Nu) and friction coefficient (f) increases with increase in helical angle. Based on $Nu \cdot f^{1/3}$, the HB with helix inclination angle 18° was giving the best performance among the helical angles investigated.

C. Continuous Helical Baffle STHX(CHB-STHX) vs Discontinuous Helical Baffle STHX(DHB-STHX)

Zhang et al. [8] numerically compared the CHB-STHX with α=40° and middle overlapped DHB-STHX with α=30°, 40° and 50°. The DHB-STHX with α=40° gave the best performance based on the ratio of h/Δp. The performance of DHB-STHX was superior as compared to the CHB-STHX at same baffle inclination angle. Dong et al. [24] numerically simulated 4 different HB-STHX configurations, which were trisection circumferential overlap baffle with α=20° (20°TCO), a quadrant circumferential overlap baffle with α=18° (18° QCO), a quadrant end-to-end baffle with α=18° (18°QEE), and a CHB with α=18.4° (18.4°CH). The comprehensive index j/f was used to compare the performance of STHX. The 20°TCO gave the best performance within the mass flow rate studied.

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IV. Conclusion

The shortcomings of conventional segmental baffle may be overcome using helical baffle. The present study gives the over view of performance evaluation of shell-and-tube heat exchangers with different helical baffle. With the use of helical baffle, the performance of shell-and-tube heat exchanger increased as compared to segmental baffle which depends on many parameters. The helix inclination angle is an important parameter influencing the performance of helical baffle shell-and-tube heat exchanger. The optimum range of helix inclination angle is 20-45°. The discontinuous helical baffle is easy to manufacture and gives superior performance than continuous helical baffle. Despite of high initial cost, the use of helical baffle reduces the operating and maintenance cost (20-40%), save the energy (15-20%) and increase the service life. In future work, the helical baffle may be curved to reduce the pressure drop which further increases the performance of shell-and-tube heat exchanger.

References

[1] Ramesh K. Shah and Dusan P. Sekulic, Fundamentals of Heat Exchanger Design, 2003 John Wiley & Sons, Inc

[2] Sadik Kakac, Hongtan Liu, Anchasa Pramuanjaroenkij, Heat Exchangers – Selection, Rating and Thermal Design, CRC Press, Taylor & Francis Group

[3]B. Khalifeh Soltan, M. Saffar-Avval, E. Damangir, "Minimizing capital and operating costs of shell and tube condensers using optimum baffle spacing," Applied Thermal Engineering 24 (2004) 2801–2810

[4]Resat Selbas,Onder Kızılkan, Marcus Reppichb, "A new design approach for shell-and-tube heat exchangers using genetic algorithms from economic point of view," Chemical Engineering and Processing 45 (2006) 268–275

[5]Farhad Nemati Taher, Sirous Zeyninejad Movassag, Kazem Razmi, Reza Tasouji Azar, "Baffle space impact on the performance of helical baffle shell and tube heat exchangers," Applied Thermal Engineering 44 (2012) 143-149

[6] Qiuwang Wang, Qiuyang Chen, Dongjie Zhang, Min Zeng, Yining Wu, Qiang Gao, U.S. Patent 8,540,011 B2, Sept. 24,2013

[7] Pranita Bichkar, Ojas Dandgaval, Pranita Dalvi, Rhushabh Godase and Tapobrata Dey, "Study of shell and tube heat exchanger with effect of types of baffles," Procedia Manufacturing Vol. 20 (2018) 195-200

[8]Jian-Fei Zhang, Ya-Ling He, Wen-Quan Tao, "3D numerical simulation on shell-and-tube heat exchangers with middle-overlapped helical baffles and continuous baffles – Part I: Numerical model and results of whole heat exchanger with middle-overlapped helical baffle," International Journal of Heat and Mass Transfer 52 (2009) 5371–5380

[9]Yonghua You, Aiwu Fan, Xuejiang Lai, Suyi Huang, Wei Liu, "Experimental and numerical investigations of shell-side thermo-hydraulic performances for shell-and-tube heat exchanger with trefoil-hole baffle," Applied Thermal Engineering 50 (2013) 950-956

[10] Jian Wen, Huizhu Yang, Simin Wang, Shifeng Xu, Yulan Xue, Hanfei Tuo, "Numerical investigation on baffle configuration improvement of the heat exchanger with helical baffle," Energy Conversion and Management 89 (2015) 438–448

[11] Yong-Gang Lei, Ya-Ling He, Rui Li, Ya-Fu Gao, "Effects of baffle inclination angle on flow and heat transfer of a heat exchanger with helical baffles," Chemical Engineering and Processing, 47 (2008) 2336-2345

[12] J. Lutcha, J. Nemcansky, "Performance improvement of tubular heat exchangers by helical baffles," Trans. Inst. Chem. Eng. 68 (1990) 263–270

[13] Leonardo Delgado Ruiz, Carlos Acevedo Penaloza, Guillermo Valencia Ochoa, "Effect of the mass flow rate on the heat transfer phenomena in a shell and tube heat exchanger," International Journal of Applied Engineering Research Vol. 13 Number 14(2018) 11387-11391

[14] Yonghua You, Aiwu Fan, Xuejiang Lai, Suyi Huang, Wei Liu, "Experimental and numerical investigations of shell-side thermo-hydraulic performances for shell-and-tube heat exchanger with trefoil-hole baffle," Applied Thermal Engineering 50 (2013) 950-956

[15] Srbislav B. Genic, Branislav M. Jac´imovic, Marko S. Jaric, Nikola J. Budimir, "Analysis of fouling factor in district heating heat exchangers with parallel helical tube coils," International Journal of Heat and Mass Transfer 57 (2013) 9–15

[16] Sunil Shinde, Umesh Chavan, "Numerical and experimental analysis on shell side thermo-hydraulic performance of shell and tube heat exchanger with continuous helical FRP baffles," Thermal Science and Engineering Progress, 5 (2018) 158-171

[17] B. Peng, Q. W. Wang, C. Zhang, G. N. Xie, L. Q. Luo, Q. Y. Chen, M. Zeng, "An experimental study of shell and tube heat exchangers with continuous helical baffles," Journal of Heat Transfer (ASME) Vol. 129 (2007) 1425-1431

[18] Cong Dong, Ya-Ping Chen a, Jia-Feng Wu, "Flow and heat transfer performances of helical baffle heat exchangers with different baffle configuration," Applied Thermal Engineering 80 (2015) 328-338

[19] Anas El Maakoula, Azzedine Laknizia, Said Saadeddine, Mustapha El Metoui, Abdelkabir Zaite, Mohamed Meziane, Abdelatif Ben Abdellaha, "Numerical comparison of shell-side performance for shell and tube heat exchangers with trefoil-hole, helical and segmental baffles," Accepted Manuscript

[20] Asif Ahmed, Imam Ul. Ferdous, Sumon Saha, "Comparison of performance of shell-and-tube heat exchangers with conventional segmental baffles and continuous helical baffle," AIP Conference Proceeding, 7th BSME International Conference on Thermal Engineering(2017)

[21] Jian-Fei Zhang, Shao-Long Guo, Zhong-Zhen Li, Jin-Ping Wang, Ya-Ling He, Wen-Quan Tao, "Experimental performance comparison of shell-and-tube oil coolers with overlapped helical baffles and segmental baffle," Applied Thermal Engineering 58 (2013) 336-343

[22] DU Wenjing, WANG Hongfu, CHENG Lin, "Effects of Shape and Quantity of Helical Baffle on the Shell-side Heat Transfer and Flow Performance of Heat Exchangers," Chinese Journal of Chemical Engineering, 22(3) 243-251 (2014)

[23] Bin Gao, Qincheng Bi, Zesen Nie, Jiangbo Wu, "Experimental study of effects of baffle helix angle on shell-side performance of shell-and-tube heat exchangers with discontinuous helical baffle," Experimental Thermal and Fluid Science 68 (2015) 48–57

[24] Cong Dong, Xin-Fa Zhou, Rui Dong, You-Qu Zheng, Ya-Ping Chen, Gui-Lin Hu, You-Sheng Xu, Zhi-Guo Zhang, Wen-Wen Guo, "An analysis of performance on trisection helical baffles heat exchangers with diverse inclination angles and baffle structures," Chemical Engineering Research and Design (2017) Accepted Manuscript

[25] Shifan Yang, Yaping Chen, Jiafeng Wu, Huaduo Gu, "Performance simulation on unilateral ladder type helical baffle heat exchanger in half cylindrical space," Energy Conversion and Management 150 (2017) 134–147

[26] Simin Wang, Juan Xiao, Shupei Ye, Chen Song, Jian Wen, "Numerical investigation on pre-heating of coal water slurry in shell and tube heat exchangers with fold helical baffles," International Journal of Heat and Mass Transfer 126 (2018) 1347-1355

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