RESEARCHERID
THOMSON REUTERS

[ICAME-2018] ISSN 2348 – 8034
Impact Factor- 5.070

GLOBAL JOURNAL OF ENGINEERING SCIENCE AND RESEARCHES

INVESTIGATION ON PERFORMANCE OF SHELL AND TUBE HEAT EXCHANGER WITH ASSORTED BAFFLE PARAMETERS

K. Srinivasulu
Assistant Professor, CMR College of Engineering & Technology, Telangana, India

ABSTRACT

Shell and Tube heat exchangers (STHXs) are extensively used in the ever growing process industry requirements. With the advancement in the technology used in the STHXs we have seen a tremendous use of the helical baffles to improve the heat transfer performance. From varying angles to sizes and shapes of the helical baffles our priority is mainly to compare and study the performance improvements from segmental baffles to helical baffles. In this presentation an experimental setup has been made for both Shell and Tube heat exchangers with segmental baffles (STHXsSB) and Shell and Tube Heat exchangers with Helical Baffles (STHXsHB). The helical baffles used here are discontinuous-helical baffles. The widely used Bell-Delaware method is used to validate the experimental data. The accuracy of the present method is validated in this presentation. From all the results achieved with this setup it is observed that the performance of the heat exchangers with helical baffles is in every way better than the original segmental baffles heat exchangers. We have seen a 10.37% decrease with the pressure drop and a 7.74% increase in the Logarithmic Mean Temperature Difference between the Segmental baffle and Helical baffle the advantage being with the helical baffle. From this a statement can be made that helical baffles can be considered for all existing Heat Exchangers.

I. INTRODUCTION

Thermal energy loss in the process industry is a significant issue due to the high temperatures and multiple heat intensive processes involved. High-grade thermal energy is typically recovered within processes. However, lower grade heat is often rejected to the environment. The benefits of capturing and utilizing low grade thermal energy are highly dependent on the qualities and properties of the heat in the waste streams. The temperature of the low grade heat stream is the most important parameter, as the effective use of the residual heat or the efficiency of energy recovery from the low grade heat sources will mainly depend on the temperature difference between the source and a suitable sink. Shell-and-tube heat exchangers (STHXs) are widely used in many industrial areas, and more than 35–40% of heat exchangers are of this type due to their robust geometry construction, easy maintenance, and possible upgrades. Besides supporting the tube bundles, the baffles in shell-and-tube heat exchangers form flow passage for the shell-side fluid in conjunction with the shell. The most-commonly used baffle is the segmental baffle, which forces the shell-side fluid going through in a zigzag manner, hence, improves the heat transfer with a large pressure drop penalty. This type of heat exchanger has been well-developed [2–4] and probably is still the most-commonly used type of the shell and- tube heat exchangers.A number of improved structures were proposed for the purposes of higher heat transfer coefficient, low possibility of tube vibration, and reduced fouling factor with a mild increase in pumping power [7–9].However, the principal shortcomings of the conventional segmental baffle still remain in the improved structures of the abovementioned studies. A new type of baffle, called the helical baffle, provides further improvement.

Lutcha et al [12] they first developed this type of baffle. They investigated the flow field patterns produced by such helical baffle geometry with different helix angles. They found that these flow patterns were very close to the plug flow condition, which was expected to reduce shell-side pressure drop and to improve heat transfer performance.

Stehlik et al. [13] compared heat transfer and pressure drop correction factors for a heat exchanger with an optimized segmental baffle based on the Bell–Delaware method [2–4] with those for a heat exchanger with helical baffles.

Kral et al. [14]. discussed the performance of heat exchangers with helical baffles based on test results of various baffles geometries. One of the most

important geometric factors of the STHXHB is the helix angle. Recently a comprehensive comparison between the test data of shell-side heat transfer coefficient versus shell-side pressure drop was provided for five helical baffles and one segmental baffle measured for oil-water heat exchanger [15]. It is found that based on the heat transfer per unit shell-side fluid pumping power or unit shell side fluid pressured drop, the case of 40 deg helix angle behaves the best.

Sullivan et al. Conducted the market survey in all of Europe and came to conclusion that 42% of the market share consists of the shell and tube type heat exchanger. Using simple components, the exchanger can be constructed in a variety of geometries to operate up to and beyond pressures of 400 bar and temperatures of 800℃. Rugged safe construction, availability in a wide range of materials, mechanical reliability in service, availability of standards for specification and design, and long collective operating experience and familiarity with the design are some of the reasons for its wide use in industry.

Gentry et al. The RODbaffle exchanger was developed by Phillips Petroleum Company in 1970 primarily to overcome the problem of flow-induced tube vibration [12]. In this exchanger, baffles are constructed from an array of support rods. The support rods are welded at each end to a circumferential baffle ring. Since a single RODbaffle supports a given tube only on one side, a set of four RODbaffles, is required to support the tube from all four sides. RODbaffles are therefore used in sets of four and are connected to each other with longitudinal side bars, making a cage assembly. In addition to overcoming the problem of tube vibration, the RODbaffle design lowers the pressure drop and fouling, at the same time improving the thermal effectiveness. A number of applications of RODbaffle exchangers, and their mechanical design features, are discussed by Gentry [12].

Butterworth et al. introduced and did a lot of research with the Twisted-Tube Exchanger. The tubes used in the twisted-tube exchanger are formed by a single-step process, producing tubes with an oval cross section and a superimposed twist [13]. This illustrates how the tubes touch and support each other along the length. Although the twisted tubes touch each other, there are sufficient gaps between them for the shell-side flow. Shell-side flow also experiences a swirling motion similar to the tube-side flow. This results in increased turbulence for the tube-side as well as shell-side flow. Generally, twisted-tube designs give 40% higher heat transfer coef. cients than the conventional single segmental baffle shell-and-tube exchanger for the same pressure drop. These exchangers are commercially available from Allards of Sweden and Brown Fintube Company of the United States. The exchangers can also be designed by combining twisted and plain tubes in the same tube bundle to meet specified heat transfer and pressure drop requirements. A recent article [14] provides results of some tests performed at Brown Fintube Company on the heat transfer and pressure drop characteristics of twisted-tube exchangers.

II. PROBLEM STATEMENT

The main objective of this project is manufacturing of two shell and tube heat exchangers one with helical baffles and the other with conventional segmental baffles. Experiment is conducted with both the cold fluid and hot fluid using water. The experimental results are validated with various analytical methods. The comparison is made between helical baffles and segmental baffles to validate which type of baffles are suitable for better performance.

III. MODELING THE TUBE LAYOUT FOR SHELL AND TUBE HEAT EXCHANGER

For this purpose we have used the design software SOLIDWORKS 2014 for designing the Tube Layout

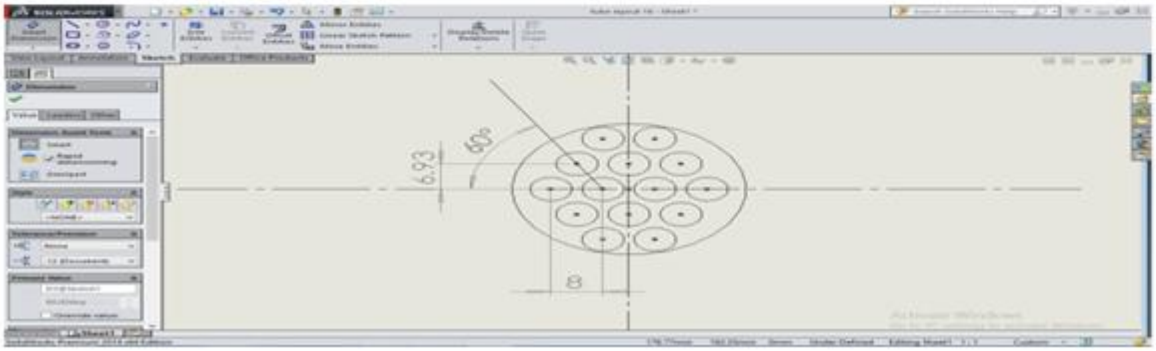

Fig.1. Tube Layout for Shell and Tube Heat Exchanger

IV. PHYSICAL CONSTRUCTION OF THE TUBES

The same layout designed in Solid works is printed on a paper in a 1:1 scale and the same template is used to drill the holes into sheet.A Polycarbonate Sheet is used for the cutting and drilling of the layout. The template of the layout is pasted on the sheet and stuck and then drilling is done into the sheet. The Tubes used for the shell and tube heat exchanger is Stainless steel tubes.

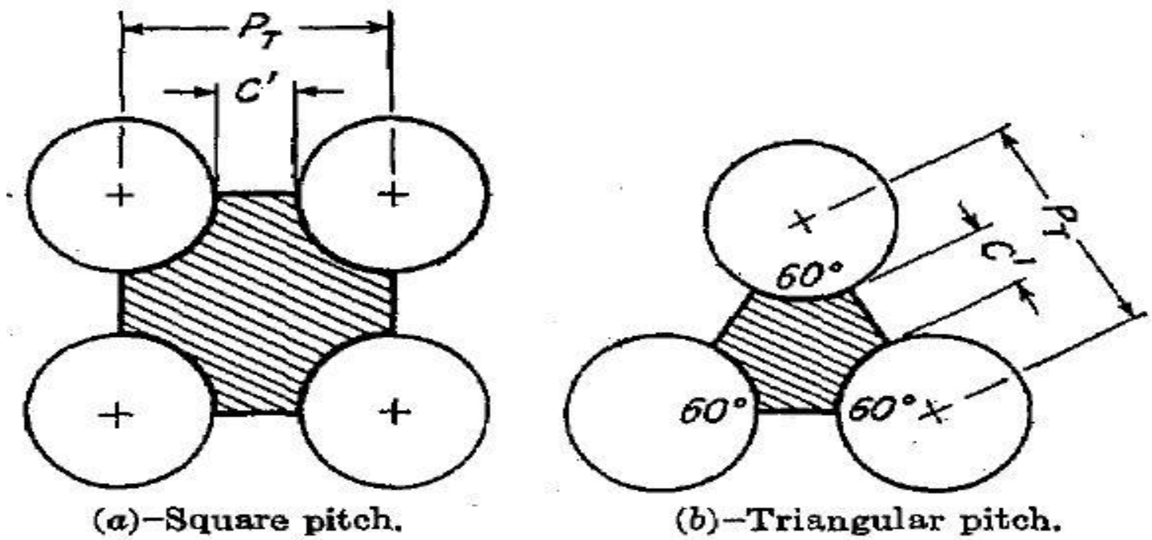

Fig.2 Schematic of the Tube Layout

Fig. 3 Polycarbonate sheet and stainless steel Tubes

V. DESIGN OF THE HELICAL BAFFLE

The Helical Baffles are considered at approximately 60 deg. and the initial angle of 45 deg. The pitch of one revolution is 125 mm.The helical baffle was made using the same software Solidworks in 3D modelling. A plane was created in the 3D modelling module and and the plane was placed at 60 degrees to vertical place and 45 degrees to side plane. The same thing can be seen in the helical baffles which are not continuous. In a shell-and-tube heat exchanger, a more important function of the baffles, besides supporting the tube bundles, is to change the flow direction of fluid in the shell-sides so as to enhance heat transfer rate.

This is only the first quadrant of the whole 360 degree revolution. The same principle involved in the next of the three quadrants is also done and the shape of the quadrant is the same. Now the front face of the baffle is copied and templates were made and the same templates fixed on teen sheets as the same polycarbonate sheets were difficult to drill the shapes of the holes.

VI. EXPERIMENTAL SET UP

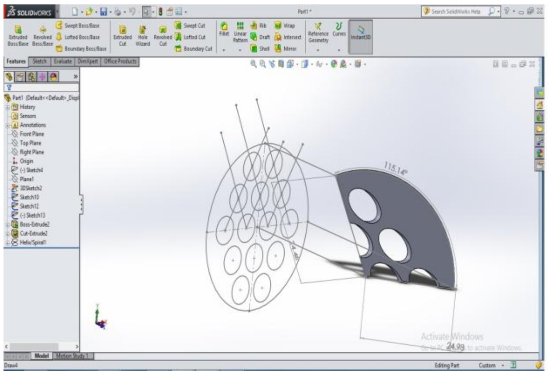

Fig.4 Design of Helical Baffle

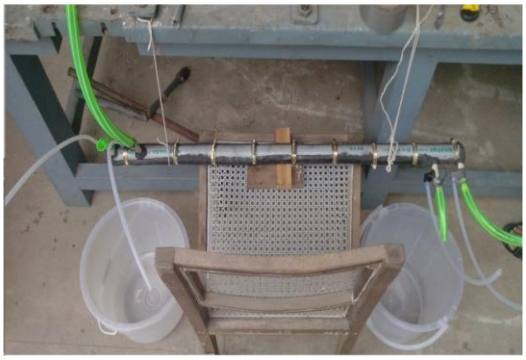

Fig. 5 Experimental Set up

VII. RESULTS AND DISCUSSIONS

The values which we need to calculate the performance of the heat exchangers are shown in the table below and they were calculated using alcohol thermometer at the inlets and outlets . Both the fluids used for this experiment is water.

Values for Shell and Tube Heat Exchanger with Segmental Baffles (STHXsSB) Conditions for Hot Fluid

Table 1- Experimental values segmental baffles Shell side

Parameter	**Units**	**Value**
T_1 , Hot Fluid inlet	(℃)	74
T_2 , Hot Fluid outlet	(℃)	45
W, Flow rate	kg/hr	133.31
c , specific heat	J/kgK	4182.87
S , Specific gravity	-	1
μ, Dynamic viscosity	Pa.s	4.749×10^{-4}
k, Thermal Conductivity	W/mK	0.6507
R_d, Reynolds Number	-	4854.771
ΔP, Pressure Difference	Pa	2598.76

Table2- Experimental values of segmental baffles tube side *(Condition for Cold Fluid)*

Parameter	**Units**	**Value**
t_1 , Hot Fluid inlet	(℃)	29
t_2 , Hot Fluid outlet	(℃)	37
W, Flow rate	kg/hr	160.7
c , specific heat	J/kgK	4178
S , Specific gravity	-	1
μ, Dynamic viscosity	Pa.s	7.7656×10^{-4}
k, Thermal Conductivity	W/mK	0.6174
R_d , Reynolds Number	-	14024.64
ΔP , Pressure Difference	Pa	588.4

Table 3 Velocity of Shell and Tube side Segmental Baffle

Parameter	**Shell**	**Tube**
Flow rate in, m^3/kg	3.703×10^{-5}	4.464×10^{-5}
Area of Flow, m^2	5.618×10^{-4}	2.1237×10^{-5}
Diameter of the Flow, m	0.036	0.0052
Average Temperature, T_{avg} in ℃	59.5	33
Kinematic Viscosity at T_{avg}	0.482×10^{-6}	0.779×10^{-6}
Velocity , m/s	0.065	2.101

Table 4 Values for Shell and Tube Heat Exchanger with Helical Baffles (STHXsHB) (Conditions for Hot Fluid)

Parameter	Units	Value
T_1 , Hot Fluid inlet	(°C)	74
T_2 , Hot Fluid outlet	(°C)	50
W, Flow rate	kg/hr	133.31
c , specific heat	J/kgK	4182.375
S , Specific gravity	-	1
μ , Dynamic viscosity	Pa.s	4.934×10^{-4}
k, Thermal Conductivity	W/Mk	0.6483
R_d , Reynolds Number	-	4854.771
ΔP , Pressure Difference	Pa	2329.08

Table 5- Experimental values for Helical baffles Tube Side *(Condition for Cold Fluid)*

Parameter	Units	Value
t_1 , Hot Fluid inlet	(°C)	29
t_2 , Hot Fluid outlet	(°C)	40
W, Flow rate	kg/hr	160.7
c , specific heat	J/kgK	4178
S , Specific gravity	-	1
μ, Dynamic Viscosity	Pa.s	7.678×10^{-4}
k, Thermal Conductivity	W/Mk	0.6181
R_d, Reynolds Number	-	14024.64
ΔP, Pressure Difference	Pa	588.4

Table 6 - Velocity calculations for helical baffles

Parameter	Shell	Tube
Flow rate in, m^3/kg	3.703×10^{-5}	4.464×10^{-5}
Area of Flow, m^2	5.618×10^{-4}	2.1237×10^{-5}
Diameter of the Flow, m	0.036	0.0052
Average Temperature, T_{avg} in °C	59.5	33
Kinematic Viscosity at T_{avg}	0.482×10^{-6}	0.779×10^{-6}
Velocity , m/s	0.065	2.101

The following Formulae are used for the calculation of inner and outside heat transfer coefficients.

ISSN 2348 – 8034
Impact Factor- 5.070

$$LMTD = \frac{\Delta T_A - \Delta T_B}{\ln\left(\frac{\Delta T_A}{\Delta T_B}\right)}$$
……………………………………………………………………………………………….(1)

$h\_o = j\_H\ k/D\ 〖(c\mu/k)〗\ ^{\wedge}(1/3)\ \phi\_s$
…………………………………………………………………………………….(2)

$\phi\_s\ = (\mu/\mu\_w\ )^{\wedge}0.14 = 0.71$
…………………………………………………………………………………………….(3)

$$h_o = j_H \frac{k}{D} \left(\frac{c\mu}{k}\right)^{1/3} \phi_s$$
………..(4)

$$h_o = 19 \times \frac{0.6507}{0.036} \times \left(\frac{4182.87 \times 7.7656 \times 10^{-4}}{0.6507}\right)^{1/3} 0.71$$
…………………………………………………………………………….(5)

Table 7 Temperature differences for segmental Baffle (shell side)

Hot Fluid	Cold Fluid	Diff
74	37	37
45	29	16
29	8	21

Table 8 Temp Table for segmental baffle (Tube side)Helical Baffle

Hot Fluid	Cold Fluid	Diff
74	37	37
45	29	16
29	8	21

Now from Stehlik et al we have a formulation of the empirical formulas and we used these empirical formulas for the analytical measurements of heat transfer coefficient. The calculations are just as follows.

$$Nu_s = 0.62 \times (0.3+\sqrt{Nu_{lam}^2 + Nu_{turb}^2}\ ) \times Y_2 \times Y_3 \times Y_4 \times Y_7 \times Y_8 \times Y_9 \times Y_{10}$$

$$Nu_{lam} = 0.664\ Re^{0.5}\ \ Pr^{0.33} = 67.79$$

$$Nu_{turb} = \frac{0.037\ Re^{0.7}\ Pr}{1+2.433\ Re^{-0.1}\ (Pr^{0.67}-1)} = 20.179$$

Table 9 - Temperature Difference for Helical Baffles

Hot Fluid	Cold Fluid	Diff
74	40	34
50	29	21
24	11	13

VIII. CONCLUSIONS

From studying various journals we have found that the new Design of Helical Baffles as opposed to the conventional Helical baffles has a better advantage in heat transfer and pressure drop. Hence both the type of heat exchangers were made. The helical Baffles was first designed in Solidworks with a 50 to 60 deg angle and templates were made with 1:1 ratio. Same sizes of Shell and tube were used for both helical and Segmental Baffles. For Hot fluid we used water at 74℃ and cold water at room temperature. Stainless steel tubes with ID 5.2 mm were used for tube and arranged in 60 deg triangular pitch layout. After the heat exchangers were assembled together experiments were conducted and from the experiments we conducted we see that the pressure drop was improved by 10.37%.The heat transfer coefficient for helical baffles improved by 22.95%.The Logarithmic Mean temperature Difference (LMTD) was improved by 7.74%. From all this we make a strong conclusion that the helical baffles is a considerable upgrade to the existing heat exchangers and implementing helical baffles is suggested.

REFERENCES

1. *Master, B. I., Chunangad, K. S., and Pushpanathan, V., 2003, "Fouling MitigationUsing Helixchanger Heat Exchangers," Proceedings of the ECI Conferenceon Heat Exchanger Fouling and Cleaning: Fundamentals and Applications,Santa Fe, NM, May 18–22, pp. 317–322.*
2. *Bell, K. J., 1981, "Delaware Method for Shell Side Design," Heat ExchangersThermal Hydraulic Fundamentals and Design, S. Kakac, A. E. Bergles, and F.Mayinger, eds., Taylor & Francis, Washington, DC.*
3. *Bell, K. J., 1986, "Delaware Method of Shell Side Design," Heat ExchangerSourcebook, J. W. Pallen, ed., Hemisphere, Washington, DC.*
4. *Bell, K. J., 1988, "Delaware Method of Shell-Side Design," Heat TransferEquipment Design, R. K. Shah, E. C. Sunnarao, and R. A. Mashelkar, eds.,Taylor & Francis, New York.*
5. *Bell, K. J., 2004, "Heat Exchanger Design for the Process Industries," ASME J. Heat Transfer, **126**_6_, pp. 877–885.*
6. *Schlünder, E. U., ed., 1983, Heat Exchanger Design Handbook, Vol. 3, Hemisphere,Washington, DC.*
7. *Mukherjee, R., 1992, "Use Double-Segmental Baffles in the Shell-and-Tube Heat Exchangers," Chem. Eng. Prog., **88**, pp. 47–52.*
8. *Saffar-Avval, M., and Damangir, E., 1995, "A General Correlation for DeterminingOptimum Baffle Spacing for All Types of Shell and Tube Exchangers,"Int. J. Heat Mass Transfer, **38**_13_, pp. 2501–2506.*
9. *Li, H. D., and Kottke, V., 1998, "Effect of Baffle Spacing on Pressure Dropand Local Heat Transfer in Shell-and-Tube Heat Exchangers for StaggeredTube Arrangement," Int. J. Heat Mass Transfer, **41**_10_, pp. 1303–1311.*
10. *Stehlík, P., and Wadekar, V. V., 2002, "Different Strategies to Improve Industrial Heat Exchange," Heat Transfer Eng., **23**_6_, pp. 36–48.*
11. *Khalifeh Soltan, B., Saffar-Avval, M., and Damangir, E., 2004, "Minimizationof Capital and Operating Costs of Shell and Tube Condensers Using Optimum Baffle Spacing," Appl. Therm. Eng., **24**_17–18_, pp. 2801–2810.*
12. *Lutcha, J., and Nemcansky, J., 1990, "Performance Improvement of TubularHeat Exchangers by Helical Baffles," Trans. Inst. Chem. Eng., Part A, **68**, pp.263–270.*
13. *Stehlik, P., Nemcansky, J., and Kral, D., 1994, "Comparison of CorrectionFactors for Shell-and-Tube Heat Exchangers With Segmental or Helical Baffles," Heat Transfer Eng., **15**_1_, pp. 55–65.*

ISSN 2348 – 8034
Impact Factor- 5.070

14. *Kral, D., Stelik, P., Van Der Ploeg, H. J., and Masster, B. I., 1996, "HelicalBaffles in Shell-and-Tube Heat Exchangers, Part One: Experimental Verification," Heat Transfer Eng.,* ***17****_1_, pp. 93–101.*
15. *Zhang, J. F., Li, B., Huang, W. J., Lei, Y. G., He, Y.-L., and Tao, W. Q., 2009,"Experimental Performance Comparison of Shell Side Heat Transfer for Shelland-Tube Heat Exchangers With Middle-Overlapped Helical Baffles and Segmental Baffles," Chem. Eng. Sci.,* ***64****, pp. 1643–1653.*
16. *Shuli, W., 2002, "Hydrodynamic Studies on Heat Exchangers With HelicalBaffles," Heat Transfer Eng.,* ***23****_3_, pp. 43–49.*
17. *Zhnegguo, Z., Tao, X., and Xiaoming, F., 2004, "Experimental Study on HeatTransfer Enhancement of a Helically Baffled Heat Exchanger Combined WithThree-Dimensional Finned Tubes," Appl. Therm. Eng.,* ***24****_14–15_, pp. 2293–2300.*
18. *Peng, B., Wang, Q. W., Zhang, C., Xie, G. N., Luo, L. Q., Chen, Q. Y., andZeng, M., 2007, "An Experimental Study of Shell-and-Tube Heat ExchangersWith Continuous Helical Baffles," ASME J. Heat Transfer,* ***129****, pp. 1425–1431.*
19. *Lei, Y. G., He, Y. L., Chu, P., and Li, R., 2008, "Design and Optimization of Heat Exchangers With Helical Baffles," Chem. Eng. Sci.,* ***63****, pp. 4386–4395.*
20. *Patankar, S. V., and Spalding, D. B., 1974, "A Calculation Procedure for theTransient and Steady State Behavior of Shell-and-Tube Heat Exchanger," HeatExchanger Design and Theory Source Book, N. F. Afgan and E. U. Schlunder, eds., McGraw-Hill, New York.*
21. *Butterworth, D., 1978, "A Model for Heat Transfer During Three-DimensionalFlow in Tube Bundles," Sixth International Heat Transfer Conference, Toronto, Canada, Paper No. HX-6.*