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A Review on Helical Baffles for Shell and Tube Heat Exchangers

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ABSTRACT

The shell and tube heat exchangers are widely used in chemical industries, power plants and refrigeration and air conditioning units. Segmental baffle shell and tube heat exchangers are most widely used one. However, it has the drawbacks of stagnating the flow, higher pressure drop, more vibrations and fouling factors. The helical baffle shell and tube heat exchangers have many advantages like eliminating stagnant flow, vibrations, fouling as well as reducing shell side pressure drops. So, this research paper discuss about the different types of helical baffles are used in shell and tube heat exchangers to reduce the pressure drop, damage from vibration and fluid flow stagnation. Among these types of baffles continuous helical baffle with 40 degree helical baffle provide the optimum for shell and tube heat exchanger.

Keywords:—*Heat Exchanger, Baffles, Pressure Drop, Fluid Flow and Heat Transfer.*

I. INTRODUCTION

Shell and tube heat exchangers are playing a significant role in many engineering fields and process industries. Because, of their manufacturing technology, reliability and versatility. The baffles are the main component for a helical baffle heat exchanger to decide its shell side pressure and heat transfer performance. Many researchers have made intensive researches towards continuous improvements on shell and tube heat exchangers .

For many years, shell and tube heat exchangers have been the most widely used equipment in the industrial fields including oil refining/petrol refinery, electric power plant, steam power generation and chemical industries etc. Because, of their versatility, reliability and easy manufacturing technology. Baffles are one of the most important parts and primary importance of shell and tube heat exchangers, they force the fluid of shell side to flow across the tubes to ensure high heat transfer rates and also provide support for tube bundle. There are different types of baffle arrangement used in shell and tube heat exchangers. The secondary flow and high velocity are the main mechanism of heat transfer enhancement, which can reduce the boundary layer thickness and augment the heat transfer coefficient.

The most commonly used/adopted baffles are called as segmental baffles, cause the shell side fluid to flow in a zigzag manner across the tube bundle. This action improves heat transfer by enhancing turbulence or local mixing on the shell side. However, it also increases the shell side pressure drop and requires a great pumping power and as a result, increases electricity consumption. High range of dead zones, backflows and high risk of vibration failure on the tube bundle are other disadvantages of the segmental baffles.

Another type of baffle arrangement, which introduced and developed by Lutcha and Nemcansky, is called helical baffles. This type of baffle arrangement also known as Helix changer, minimizes the principle shortcomings in design of the convectional segmental baffles and the flow patterns produced by helical baffles are also much close to plug flow condition, which causes to reduction in shell side pressure drop and improves heat transfer performance. Helical baffles consist of two major types; those are continuous helical baffles and non - continuous helical baffles. Those research works are listed here.

II. Literature Review

Andre L.H Costa et al (2008) studied the design optimization of shell and tube heat exchangers by geometrical features and velocity conditions which must be complied in order to reach a more realistic solution for optimization design. They are done thermal surface of the equipment for minimum excess area and maximum pressure drops. They found that the tube side velocity must be between 1 m/sec to 2.5 m/sec and the shell side fluid velocity must be between 0.3 m/sec to 1 m/sec.

Dogan Eryener (2006) thermodynamic analysis is used to determine the optimum baffle spacing. To optimizing of baffle spacing for a shell and tube heat exchanger. He studied with optimum ratio of baffle spacing to shell diameter and tube length for the case of fixed area with different tube layouts. He found that the triangular layout is greater than that of the square tube layout. The optimum baffle spacing ratio becomes smaller, as the tube pitch ratio is increased to reduce the shell side pressure drop for all the tube layouts, the maximum optimum ratios are reported as tube pitch ratio (PR) =1.25, minimum ratios are PR=1.35 and the number of baffles will be smaller in the case of PR=1.25. The optimum ratios decreases as the outer diameter of the tubes increases for the optimum ratio of baffle spacing to shell diameter and tube outer diameter for the case of fixed area with different tube layouts. The optimum ratios decreases as the number of tubes increases when the variation between the optimum ratio of baffle spacing to shell diameter and number of tubes for the case of fixed heat transfer with different tube layouts.

Jian Fei Zhang et al (2009) experimentally studied four different helical baffles (20º, 30º, 40º and 50º) with segmental baffles. They found that the shell side pressure drop of the four shell and tube heat exchanger with helical baffle (STHXs HB) is lower than that of the shell and tube heat exchanger with segmental baffle (STHXSB) under the same flow rate. The three heat exchangers with the same inner shell diameter, the shell side tube bundle zone pressure drop of the shell and tube heat exchanger with helical baffle (STHXs HB) with 20º and 30º helix angles are 45--65% and 55-75% lower than that of the shell and tube heat exchanger with segmental baffle (STHXSB). The shell side pressure drop of heat exchanger with 50º helix angle is lower than that of 40º helix angle. The overall pressure drop decreases with the increase of helix angle, the heat exchangers of 20º and 30º helix angles have much lower overall pressure drop than that of the shell and tube heat exchanger with segmental baffle (STHXSB). The friction factor reduces with the increasing of helical angles from 20º to 30º and friction factor increases from the 40º to 50º. They found that lowest friction factor at 40º helix angle. Under the same oil flow rate, the shell side heat transfer coefficients of the s hell and tube heat exchanger with helical baffle (STHXs HB) are much lower than that of the shell and tube heat exchanger with segmental baffle (STHXSB). The heat transfer coefficients of shell and tube heat exchanger with helical baffle (STHXs HB) with 20º and 30º helix angles are 30-35% and 35-40% lower than that of shell and tube heat exchanger with segmental baffle (STHXSB). Among all the four shell and tube heat exchanger with helical baffle (STHXs HB) the heat transfer coefficient of helical baffle with 40º helical angles is the highest. The heat transfer coefficients per unit pressure drop of the shell and tube heat exchanger with helical baffle (STHXs HB) with 20º and 30º helix angle increases by 30-65% and 120-162% over the shell and tube heat exchanger with segmental baffle (STHXSB). The heat transfer coefficient per unit pumping power of the STHXs HB with 20º and 30º helix angle increases by 30-60% and 110-160% over the shell and tube heat exchanger with segmental baffle (STHXSB).

Jian Feng Yang et al (2015) experimentally studied a combined single shell pass shell and tube heat exchanger with two layer continuous helical baffles (CSSP-STHX). The combined two layer continuous helical baffles can reduce the pressure drop and mitigate fouling and increase compactness and prolong the service life of the STHXs. The material of tube is steel and the material of baffles is stainless steel 304 (0Cr18Ni9). They found that the pres sure drop of the CSSP-STHX is about 25% and the pressure drop of CH-STHX is 14% on average lower than that of the SG-STHX. CSSP-STHX has lower pressure drop than CH-STHX by about 13%. The Nusselt number of CH-STHX and CSSP-STHX are around 43.6% and 47.5% lower than the SG-STHX. The CSSP-STHX has the best comprehensive performance among the three heat exchangers . The comprehensive performance h/Δpm of the CSSP -STHX is 39.7% and 6.1% higher than that of SG-STHX and the CH-STHX.

Jian Fei Zhang et al (2009) studied 3D simulation model with middle overlapped helical baffles using GAMBIT 2.3 and FLUENT 6.3 software. They found that the Nusselt number of the fifth cycle differs from that of the second cycle by less than 2.0% and the difference between the fourth cycle and the fifth cycle is even less than 0.5%. The difference between the 2nd cycle and the fifth cycles are both less than 2% for pressure drop and heat transfer.

Jian Fei Zhang (2009) studied 3D simulated model heat exchanger with middle overlapped helical baffles for three different helix angles (30º, 40º and 50º) in GAMBIT 2.3 and FLUENT 6.3. They found that the pressure drop decreases with the increasing of helix angle and the heat transfer coefficient increases with the decreasing of helix angle. 40º is the optimum helix angle which the comprehensive performance is the best. The pressure drop of model with continuous baffle is 31%-46% higher than that of model with the non-continuous baffles and the pressure gradient of the continuous baffle is about 35%-42% lower than the non-continuous baffles. So, the heat transfer coefficient of the periodic model with continuous baffles is lower than the periodic model with non-continuous baffles.

Jian Wen et al (2015) proposed a ladder type fold baffle to block the triangular leakage zones in original he at exchangers with helical baffles. They found that the shell side heat transfer coefficient of the improved heat exchanger increased by 22.3% to 32.6%, while the overall heat transfer coefficient increased by 18.1% to 22.5% with an average value of 21.4% compared with the shell and tube heat exchanger with helical baffles. Heat transfer coefficient increased by 21.36 kW to 33.65 kW. The overall shell side pressure drop and the tube bundle pressure drop of the ladder type fold baffle heat exchanger is 19.3% to 31% and 68.1% to 86.9% and the overall shell side pressure drop increased by 0.911 kPa to 9.084 kPa.

Jian Wen et al (2015) studied ladder type fold baffle to block the triangular leakage zones in original heat exchangers with helical baffles. They found that the shell side heat transfer coefficient and the shell side pres sure drop increases with the increasing of inlet flow rate or decreasing of folding ratio. At the same inlet flow rate, the shell side heat transfer coefficient increased by 7.3% to 8.4% and pressure drop increased by 14% to 15.7% as the folding ratio decreases from 0.7 to 0.3. The comprehensive performance value increases with the decreasing of the folding ratio and the highest value of comprehensive performance index is equal to 0.3. They studied with three different relative heights of 50%, 60% and 70% at a fixed folding ratio of 0.3. The comprehensive performance of the heat exchanger with the relative baffle height of 60% is the best for excellent heat transfer performance among all the relative heights. They studied four folding angles (30º, 33º, 37º, 41º and 45º) to study its effect on the performance of the heat exchanger with the folding ratio of 0.3 with the baffle height of 60%. They found that the 37º folding angle is given the best comprehensive performance. The fluid flow and heat transfer of three heat exchangers with different baffles were compared. The comparison is based on the optimum ladder type baffle, the sector shape baffle and the segmental baffle. They found that the improved (ladder type folded baffle) s hell and tube heat exchanger with helical baffle performs the best among all the three types of heat exchangers and its heat transfer coefficient is 24-31.1% and 82.8 -86.1% higher than s hell and tube heat exchanger with segmental baffle, i.e. 42.4 kW to 127.9 kW heat exchanged, shell side pres sure drop is 7.5-65.9 kPa. The comprehensive performance of the ladder type folded baffle increased by 46.7% to 54.4% when compared with shell and tube heat exchanger of segment al baffle, and 28.4% to 30.7% when compare with shell and tube heat exchanger with helical baffle.

Li H and Kottke.V (1999) studied the shell side local heat transfer coefficients at each tube in two representative baffle compartments of a shell and tube heat exchanger with disc and doughnut baffles. They found that the same inlet volumetric flow rate for the same Reynolds number. The heat transfer for disc and doughnut baffles is 78% of the single segmental baffles and the pressure drop for disc and doughnut baffles is 55% of the single segmental baffles. The effectiveness of the heat exchanger with disc and doughnut baffles is higher than the single segmental baffles.

Li Lin et al (2016) proposed a novel trisection helical baffled vertical condenser (feed water heater) with liquid dams and gaps for facilitating condensate drainage. They numerically studied the flow and condensation heat transfer characters of two vertical condensers with variable angled trisection helical baffles of both single thread and dual threads and a variable spanned segmental baffled one. The two helical baffled schemes both have three sections with baffle incline angles of 35°, 25° and 15°, and the segmental baffled scheme has also three sections of different spanned baffles, forming decreasing cross section area. Each helical baffle scheme has dual thread helical baffles at first and second sections of incline angles of 35° and 25° while its 15° incline angled third section remains single thread. The average values of heat transfer coefficient of the single thread and the dual thread variable angle trisection helical baffled schemes are 10,634 $W/m_2.K$, 11,790 $W/m^2.K$, which are 22.4% and 35.7% higher than that of the variable spanned segmental baffled one with average heat transfer coefficient of 8688 $W/m^2.K$.

Luhong Zhang et al (2013) experimentally studied comparison of shell side thermodynamic and hydraulics performance of three helical baffles heat exchangers of helical angle of 7°, 13°, 25° and one segmental baffles heat exchanger. They found that the shell side heat transfer coefficient for segmental baffles scheme is the smallest among the four heat exchangers and the shell side heat transfer coefficient increases with the increase of helical angle (β). They suggested that helical baffles heat exchanger with small helical angle is the best choice and the segmental baffles heat exchanger is the worst, if the shell side heat transfer coefficient is considered to choose the heat exchanger. The shell side heat transfer coefficient increases with the Reynolds number for all the heat exchanger schemes. The shell side pressure drop for the helical baffles heat exchanger decreases with the increase of helical baffle angle (β). The shell side pressure drop for segmental baffles heat exchanger is almost equal to the shell side pressure drop for helical baffles heat exchanger with helical angle (β) equals to 13°, and much smaller than the helical baffles heat exchanger with helical angle (β) equal to 7°. The performance index for the helical baffles heat exchanger with 7° is the smallest among the helical baffles scheme and the performance index increases with the increase in helical angles. The performance index for segmental baffles is in between the performance index of helical angles 7° and 13°.

Mahdi Saeedan and Mehdi Bahiraei (2015) numerically studied the flow characteristics and heat transfer in shell and tube heat exchanger with helical baffles. In their study they focus on the effect of geometrical parameters like helix angle and baffle pitch on the convective heat transfer and pressure drop. The numerical simulation was performed at different helix angles i.e. 30°, 32°, 34°, 38°, 40°, 42°, 44°, 46°, 50° and overlapping percentages from 65% to no overlapping. The convective heat transfer coefficient is higher for smaller helix angles. By changing the helix angle from 50° to 30° of pitch 250 mm, they observed 9% increment in the convective heat transfer coefficient. By increasing the helix angle, the slope of variations in pressure drop decreases at helix angle of 50°, from 315 Pa/

m to 225 Pa/m by increasing the baffle pitch from 251 mm to 630 mm. The pressure drop per unit length for helix angle of 30º is more than twice as much as that at helix angle of 50º. From their studies when heat transfer is regarded to be more important than pressure drop, application of helical baffles with high overlapping and low helix angle is appropriate, while in case which similar relative importance is assigned to heat transfer and pressure drop, using helical baffles with low overlapping and low helix angle is suggested.

Parikshit Bet al (2015) studied the pressure drop predictions on the shell side of a shell and tube heat exchanger (STHX) are investigated using the concept of Finite Element Method (FEM). The model has been success fully tested for shell and tube heat exchangers with baffle cut in the range of 25% to 30%. They found that for a minimum baffle cut of 15.5% the predictions are good.

Qiuwang Wang et al (2009) numerically invented a combined multiple shell and tube heat exchanger (CMSP - STHX) with continuous helical baffles in outer shell pass to improve the heat transfer performance. The combined multiple shell and tube heat exchanger (CMSP-STHX) has two shell passes, the inner shell pass and the outer shell pass which are separated by a sleeve tube. The inner shell pass is constructed by segmental baffles and the outer shell pass is constructed by complete continuous helical baffles. The partial pressure drop of inner s hell pass (13,840 Pa) is higher than that of the outer shell pas s (8600 Pa), the overall pressure drop of the combined multiple shell and tube heat exchanger (CMSP-STHX) (22,440 Pa) is slightly lower than that of a segmental baffle shell and tube heat exchanger (SG-STHX) (24,440 Pa). They found that the overall pressure drop of the combined multiple shell and tube heat exchanger (CMSP-STHX) is 13% lower than that of the segmental baffle shell and tube heat exchanger (SG-STHX) under the same mass flow rate and the same overall heat trans ferrate. The average heat transfer rate in the combined multiple shell and tube heat exchanger (CMSP-STHX) is 5.6% higher than that of the segment baffle shell and tube heat exchanger (SG-STHX). The mass flow rate in the combined multiple s hell and tube heat exchanger (CMSP-STHX) is 6.6% higher than that in the segmental baffle shell and tube heat exchanger (SG-STHX) under the same overall pressure drop.

Ramakanth R.N.S.V and Lakshmi Reddy P (2015) experimentally investigated on helical baffle heat exchanger using the Kern method with different shell side flow rates. They used in counter flow design of heat exchangers with a baffle cut of 25%. They studied thermal analysis of a continuous helical baffled heat exchanger us ing Kern method and modified for different flow rates at fixed helical angle of 5º, 10º, 15º, 20º. And also using copper oxide nanoparticle with two different volume concentrations of 0.05% and 0.1%. They found that the helical baffle heat exchanger has far better than overall transfer coefficient than the segmental baffles heat exchanger. The shell side pressure drop was decreased with the increasing of helix angle more than 20_0. The copper oxide nanofluid using two different volume concentrations 0.05% and 0.1% provided better heat transfer coefficient, overall heat transfer coefficient and reduced the pressure drop.

Xiaoming Xiao et al (2013) numerically studied for helical baffles heat exchanger with different Prandtl number (5 to 15,000) fluids and comparison with helical baffles heat exchangers with different helical tilt angle from 10º to 50º (10º, 15º, 20º, 25º, 30º, 35º, 40º, 45º, 50º). They noticed that total heat transfer coefficient for helix angle 35º is bigger than that the helix angle for 20º, 25º and 30º under the same length of heat exchanger, for the length 1000mm of heat exchanger, the total heat transfer coefficient for helix angle of 10º increased to 66.7% than the helix angle of 50º, and helix angle 35º is 5.5%, 8.2%, 3.9% bigger than that of helix angle 20º, 25º and 30º. The heat transfer area value for helix angle of 10º is 25% smaller than the value for helix angle 40º. The heat exchanger length increases 40% to 80% and decreased 30% when helix angle changes from 40º to 50º, and 25º to 10º The required heat transfer area increases 35% and 30% and decreases 45% when helix angle from 40º to 50º, 25º and 10º. They found that the heat exchanger with water as fluid in the shell side achieved the best heat transfer performance when helix angle is 40º and shell side fluid with larger Prandtl number with small helical angle scheme is the optimal s election.

Ya Ping Chen et al (2013) numerically studied a circumferential overlap trisection helical baffle shell and tube heat exchangers . They compared the numerical results with experimental results of heat transfer coefficient and pressure drop. They found the maximum errors in the s hell side heat trans fer coefficient and pressure drop are 14.2% and 17.6%. They suggested that the circumferential overlaptri section helical baffle heat exchanger is suitable for us e with equilateral triangle tube layouts .

Ya Ping Chen et al (2015) experiment conducted on both oil-water and water-water heat transfer in heat exchangers with equilateral triangle tube layout of 16 tubes included five helical baffle schemes with helix angles of 12º, 16º, 20º, 24º, 28º and a segmental baffled heat exchanger for comparison. They found that the small angled helical scheme gave better performance that the shell side heat transfer coefficient and comprehensive index of the 12º helical schemes are around 50% higher than those of the segmental baffle heat exchanger with approximate pres sure drop in both the cases of oil-water and water-water tests .

Yong Gang Lei et al (2008) experimentally and numerically studied hydrodynamics and heat transfer characteristics of a heat exchanger with single helical baffles. They compared of the three heat exchangers with single segmental baffles, single layer helical baffles and two layer helical baffles. They used 25% of cut segmental baffles and the quadrant ellipse shaped helical baffles with 20° helix angle. In their study they found that the Nusselt numbers are higher than the results from Bell-Delaware Method and that is approximately 10%. The heat transfer coefficient of the heat exchanger with single helical baffle is 75% of the value of the heat exchanger with s ingle segmental baffles. The pressure drop of the heat exchanger with s ingle helical baffles is 45 to 55% of the heat exchanger with single segmental baffles. They observed that the ratio of heat transfer coefficient to the same pressure drop for the heat exchanger with single helical baffles is 35 to 65% enhanced. They concluded that the pumping cost for a heat exchanger with single helical baffles is much les s than that of the heat exchanger with single segmental baffles at a given heat.

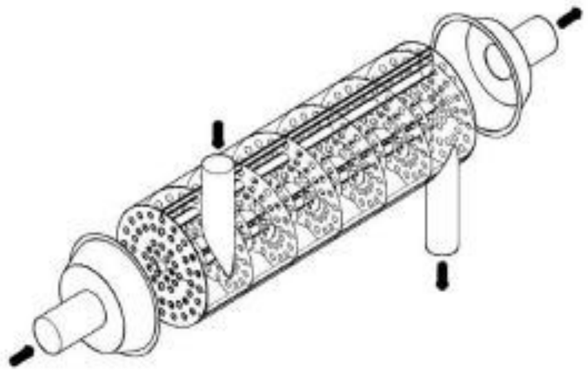

Figure 1: Shell Side helical baffle structure of CSSP-STHX

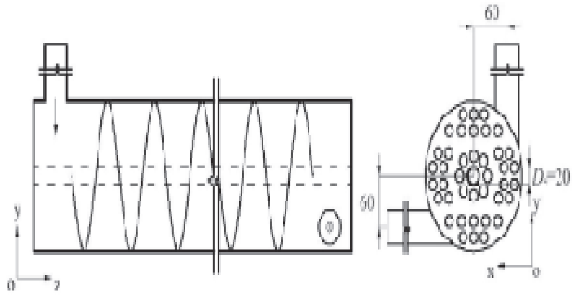

Figure 2: SG STHX

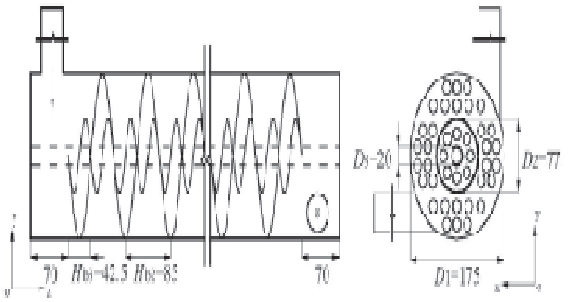

Figure 3: CH STHX

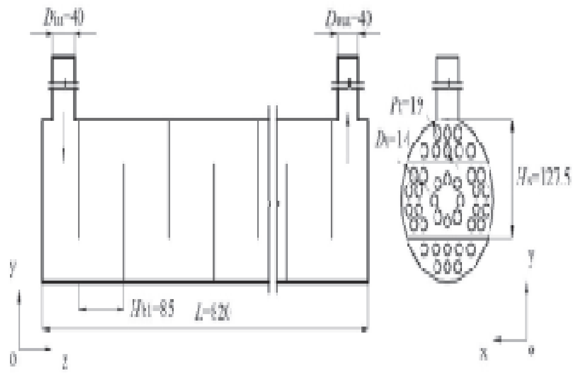

Figure 4: CSSP STHX

III. CONCLUSIONS

Pressure drop is the greater important in design of shell and tube heat exchangers because pumping power costs are highly depended on pressure drop. Therefore, lower pressure drop leads to lower operating costs. Shell and tube heat exchangers with continuous helical baffles proved better for increase in heat transfer coefficient when compared to the conventional segmental baffles based on the same shell side pres sure drop. In shell and tube heat exchangers the flow gets increased by introducing the baffles. The baffles create turbulence and increase the pressure drop on the shell side. The pres sure drop decreases with the increasing of helix angle and the heat transfer coefficient increases with the decreasing of the helix angle, the heat transfer increases with the decreasing the helical angle. The heat transfer coefficient of shell and tube heat exchangers with helical baffle was higher than that of the shell and tube heat exchanger with segmental baffle and the helix angle of 40° was the best among all helix angles.

Continuous helical baffle increased the heat transfer coefficient. But manufacturing of helical baffles are difficult for the shell and tube heat exchangers with larger in size. The shell side heat transfer coefficient and the overall heat transfer coefficient both increases with the increase of shell side flux. Both the heat transfer coefficient and pres sure drop are the critical parameters of heat exchanger performance. The thermal performance factor (TEF) gives the relative performance of a heat enhancing device where heat transfer coefficient and pressure drop are involved.

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