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# Improvisation of Shell Side Heat Transfer Coefficient in Shell and Tube Heat Exchangers using Different Configurations – A Mini Review

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***Abstract*— Heat exchange devices are the most essential components in every process industry. Among them the widely used are shell and tube heat exchangers due to their robust geometry construction, easy maintenance and possible improvements. There is a continuous effort for increasing the film coefficients tube side and shell side so as to improve the overall heat transfer coefficient. The improvement in overall heat transfer coefficient decreases the size of the exchanger resulting in savings in space and cost of the exchanger. The flow on the shell side is usually complex and results in lower values of the shell-side coefficient when compared to that of the tube-side. Efforts to improve shell side coefficient using different types of baffle arrangements and enhanced tubes are discussed here. Flow patterns in the shell side with segmental baffles are discussed. The introduction of sealers to avoid bypass streams improved the overall heat transfer co-efficient of the segmental baffle heat exchanger by 15.6 to 19.7%. For fluids flowing in turbulent conditions the spiral baffle plate heat exchanger showed 38% improvement in heat transfer over the conventional heat exchanger. For same pumping power the heat exchangers with helical baffles will have a higher heat transfer co-efficient compared with conventional segmental baffles. The heat transfer co-efficient can be varied by changing the baffle space and baffle inclination angles. For same mass flow rate, the heat transfer per unit area decreases with the increase of baffle spaces. Within the particular range of Reynolds number for shell side, the optimal helical inclination angle is about 45°, with which the integrated heat transfer and pressure drop performance is the best. Tubes with variety of enhancements such as finned tubes, corrugated tubes etc increased heat transfer.**

***Keywords—shell; tube; segmental; baffle; sealers; spaces; helical; fin; spiral; rod; vane; corrugated; pressure drop; heat transfer co-efficient***

## I. INTRODUCTION

Heat exchange devices are essential components in complex engineering systems related to energy generation, energy transformation and energy conservation in industrial scenes. Among the various types of heat exchangers the commonly used one is shell and tube heat exchanger (STHE). For many years STHE have been used widely in process, power production, chemical and food industries, electronics, environmental engineering, manufacture industry, waste heat recovery, air conditioning and refrigeration and space applications. More than 35 to 40% of heat exchangers are of this kind due to their robust geometry construction, easy maintenance and possible upgrades [1]. The cost of the heat exchanger for optimum performance for the given operation conditions is minimized by improving the shell and tube side film coefficients. For this a variety of changes have been made both on the shell and tube sides.

## II. VARIOUS CONFIGURATIONS

Baffles are the most important shell side components. They not only support the tube bundle but also form a flow passage for shell fluid with the help of the shell. Baffles are of primary importance in improving mixing levels in the shell side and consequently enhancing heat transfer of STHE. There are different kinds of baffle arrangements. Common is segmental baffles. Others are helical, spiral, rod, etc.

### *A. Segmental Baffles*

At first segmental baffles were introduced to improve shell side heat transfer coefficient and then to arrest leakages sealers were introduced. To improve the performance of conventional segmental baffles additional baffle segments such as deflector baffles, disc and donut configuration and others were used. But the main shortcomings of segmental baffles design remained. The flow in the shell side of a STHE with segmental baffles is very complex. The baffle leads to a stream inside the shell, as shown in figure 1 which is partly perpendicular and partly parallel to the tube bank [6]. The streams named $S_L$ and $S_B$ respectively called leakage and bypass streams influence the main stream $S_H$.

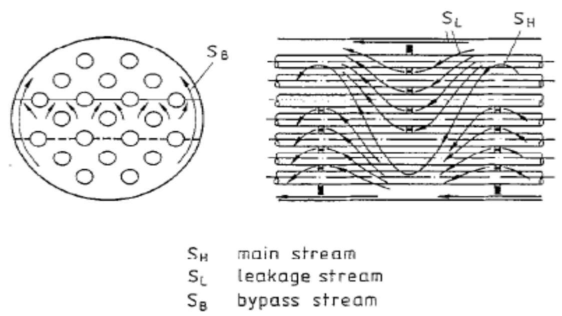



Fig.1 Flow through STHE with segmental baffles [6]

Segmental arrangement of baffles limits maximum thermal effectiveness and encourages dead zones where fouling occurs.

### B. *Helical Baffles*

Helical baffles were proposed to improve the shell side coefficient. Helical baffles are pseudo circular shaped plates that are set up in a way that each one follows the other in a shell by specified angles respect to axis so that the shell side flow passes a helical path. Each baffle occupies one quadrant of the cross section and has a certain inclination with the center line of the exchanger. Four baffles make one set baffle and the fluid returns to its starting situation after crossing the set.

In addition to the effects of baffle spacing the shell side heat transfer coefficient is also affected by baffle inclination angle and fluid flow characteristics.

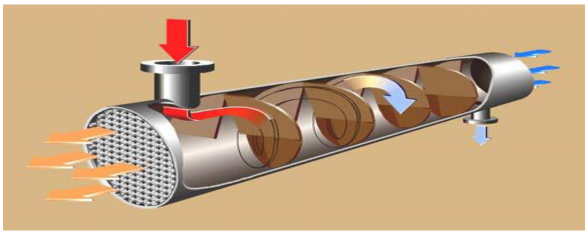


Fig.2.Helical baffle heat exchanger [1]

In comparison with the common shell and tube heat exchanger the main advantages of helical baffle heat exchanger are improvement of shell side heat transfer, less pressure drop for a given mass flow rate, reducing of bypass effects in shell side, decreasing of fouling in shell side and prevention of bundle vibration.

Also different types of external tube surfaces affect the shell side heat transfer coefficient e.g. finned tubes, corrugated tubes etc.

## III. IMPROVISATION USING DIFFERENT BAFFLES

### A. *Segmental baffles shell and tube heat exchanger*

Many publications have appeared which describe methods to calculate the pressure drop in the STHE with baffles [2, 3]. The method of Tinker and Delaware gave the best results compared with other methods [4]. The method of Tinker is relatively complicated. Bell Delaware is the most complete shell and tube heat exchanger design method [5]. The method is based on mechanical shell side details and presents more realistic and accurate results for the shell side film heat transfer coefficient and pressure drop.

Edward S.Gaddis and Volker Gnielinski principally employing Delaware method for calculating shell side pressure drop, introduced few correction factors [6]. The measured shell side pressure drop ($\Delta P_m$) wascompared with the shell side pressure drop calculated ($\Delta P_c$) by the above procedure. However about one third of the experimental points has deviation higher than ± 35%. They also concluded that a well-designed STHE obeying $0.2 \leq (S/D_i) \leq 1.0$ and $0.5 \leq (H/D_i) \leq 0.4$ will have $f_B$ and $f_L$ as low as 0.11 and 0.19 respectively.

There are also few researchers who have studied the effect of leakage on thermal performance of STHE. W.Roetzel and D.Lee have experimentally investigated the leakage flow in STHE with the segmental baffles and found leakage ($S_L$) has great influence on overall heat transfer coefficient [7].All the results demonstrate that the baffle shell leakage is negative for the improvement of heat transfer in shell and tube heat exchangers.

For manufacturing reasons the internal diameter of the shell is always bigger than the external diameter of the tube bundle
for the successful installation. According to the GB 151 National Standards of China there is always a circular gap of around 3 to 7 mm between the shell and the tube bundle for STHE with diameter between 400 mm and 2000 mm. The so called configuration improvement is to install sealers on each baffle in order to block shell gap.

Simin Wang, Jian Wen, and Yanzhong Li improved the configuration of shell and tube heat exchanger through the installation of sealers in the shell side [8]. The installation of the sealers effectively decreased the short circuiting of shell side fluid, thereby increasing shell side heat transfer coefficient by 18.2 to 25.5%. The overall heat transfer coefficient increased by 15.6 to 19.7%. The energy efficiency increased by 12.9 to 14.1%. Pressure losses increased by 44.6 to 44.8%. The increment in pumping power is small when compared to that of heat flux. The sealers are shown in figure 4.

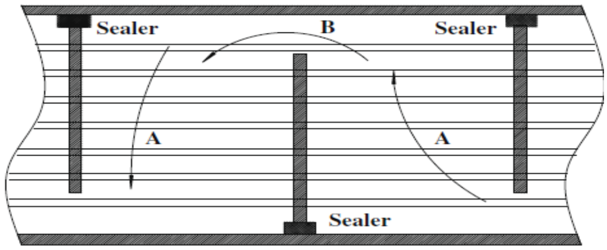



Fig. 3. Schematic flow distribution for baffled shell side flow of improved heat exchanger [8]

Uday C Kapale, and Sathish Chand developed a theoretical model for shell side pressure drop [9]. The model incorporates the effect of the pressure drop in inlet and outlet nozzles along with the losses in the segments created by baffles. For Reynolds numbers between $10^3$and $10^5$the results of the model matched more closely with the experimental results available in the literature than the analytical models developed by other researchers for different configurations of heat exchangers.

Segmental baffles offer large back mixing due to zigzag flow pattern. Fouling occurs in the dead zone on each side of the baffle against the shell. High shell side pressure drop and low heat transfer coefficient result. To overcome all these, various shell side intensification technologieshave been developed to increase the coefficient on the shell side and reduce the pressure drop. One among various technologies is replacement of segmental baffles with spiral and helical ones.

### B. *Spiral baffle plate shell and tube heat exchanger*

Young – Seok Son and Jee-Young Shin improved the conventional shell and tube heat exchanger by introducing spiral baffle plates on the shell side [30]. The set up was numerically simulated in three dimensions using commercial CFD program. The spiral baffle plates changed the flow field on the shell side by introducing rotational flow. The rotational flow eliminated the stagnant portions on the shell side thereby improving the thermal performance. The vortices formed on the shell side also added to improved heat transfer between the shell side and tube side fluids.

A 9% improvement for laminar flow and 38% improvement for turbulent flow were recorded for the spiral baffle plate heat exchanger when compared to the conventional shell and tube heat exchanger with segmental baffles. The shell side pressure drop increased 13 to 14 times due to increased shell side velocity.

*C. Helical baffles shell and tube heat exchanger*

Helical baffles were first proposed by Lutcha J and Nemcansky J in the year 1990. They found that helical baffles caused near plug flow conditions within the shell space and induced rotational flow. The plug flow conditions increased the heat exchanger effectiveness. Rotational flow created vortex which interacted with the boundary layer on the tube surface resulting in increase in film heat transfer coefficient. These effects were achieved with little increase in pressure head[10].

M.R.Jafari Nasr, and A.Shafeghat derived equations for both turbulent and laminar regimes relating pressure drop to heat transfer coefficient and heat transfer area for helical baffled heat exchanger. They developed a straight forward design procedure for helical coil heat exchanger [11].

P.Stehlik *et al.* compared heat transfer and pressure drop correction factors based on Bell-Delaware method for an optimized segmental baffle and a helical baffle heat exchanger. The results showed that properly designed helical baffles offer a significant improvement in heat transfer while providing a reduced exchanger pressure drop. Increase in heat transfer was found beyond baffle angle of 25°and reached a maximum of 1.39 times that for ideal cross flow conditions. The reduction in pressure drop was found to vary from 0.26 to 0.60 depending on helical inclination angle [12].

Sirous Zeyninejad Movassag *et al.* compared the performance of shell and tube heat exchanger by tube bundle replacement with segmental and helical baffles. Helical baffles resulted in better performance compared to segmental baffles. Helical baffles showed lower fouling tendency, pressure drop and higher heat transfer [13].

D.Kral *et al.* discussed the performance of heat exchangers with helical baffles using the results of tests conducted on unit with various baffle geometries [14].

Wang Shuli measured the flow field in shell and tube heat exchangers with helical baffles using laser Doppler anemometry. He found that the optimum helix inclination angle depends on the Reynolds number of the working fluid on the shell side of the heat exchanger [15].

Yong – Gang Lei *et al.* carried out numerical simulation to understand the effect of different baffle inclination angles on fluid flow and heat transfer of heat exchanger with helical baffles [16]. The average Nusselt number of the tube bundle increases with the increase of baffle inclination angle α when $\alpha<30°$ and decreases with increase of baffle inclination angle when $\alpha> 30°$.As shell side Reynolds number increases the pressure drop increases for all inclination angles. For all helical baffle heat exchangers studied, the pressure drops are lower than those of the conventional segmental heat exchangers. The pressure drop increases with the increase of α in all cases considered. The variation is large in the small α region. However the effects of α on pressure drop are small when $\alpha> 40°$. For all the helical baffle heat exchangers studied, the ratios of heat transfer coefficient to pressure drop are higher than those of a conventional segmental heat exchanger. The enhanced performance increases with the increase of baffle inclination angle when $\alpha< 45°$, and decreases when $\alpha > 45°$.

D U Wenjing, Wang Hongfu and Cheng Lin have investigated the role of shape and quantity of the helical baffles in the shell side heat transfer rate and fluid flow performance [17]. Shell side convective heat transfer coefficient increases with the increasing helical angle and the characteristic velocity. The convective heat transfer coefficient of a sextant helical baffle heat exchanger (HBHE) is larger than that of the quadrant and the trisection HBHE, and the corresponding heat transfer rate distribution in its tube surface is also uniform. Shell side pressure drop increases sharply with the augmentation of the characteristic velocity and the reduced helical angle. The pressure drop caused by the trisection helical baffle is the maximum, while that of the sextant helical baffle is the minimum.

Luhong Zhang *et al.* conducted experiments for comparisons of shell side thermodynamic and hydraulics performance among three non-continuous helical baffle heat exchangers and one segmental baffle heat exchanger [18]. Among all the four heat exchangers both the shell side heat transfer rate and the shell side pressure drop peak when the helical angle equals 7° and the shell side heat transfer rate per unit pressure drop at this angle is the smallest.

C.Dong *et al.* performed numerical simulations on flow and heat transfer performances of heat exchangers having six helical baffles of different baffle shapes and assembly configurations, i.e., two trisection baffle schemes, two quadrant baffle schemes, and two continuous helical baffle schemes [19]. They found that the optimum scheme among the six configurations is a circumferential overlap trisection helix baffled heat exchanger with a baffle incline angle of 20° scheme with an anti-shortcut baffle structure, which exhibits the second highest pressure drop, highest overall heat transfer coefficient, shell side heat transfer coefficient and shell side average comprehensive index $h_o/\Delta p_o$.

Farhad Nemati Taher *et al.* used simulation studies and investigated effect of baffle space on the performance of helical baffle shell and tube heat exchanger [20]. The results of the simulation indicate that for the same mass flow rate, the heat transfer per unit area decreases with increase of baffle spaces; however for the same pressure drop, the most extended baffle space obtains higher heat transfer rate. Also the pressure gradient decreased with the increase of baffles space.

B.Khalifeh Soltan *et al.* presented a correlation and summarized a guideline to determine the optimum baffle spacing for segmental baffled shell and tube condensers [21].

Yong-Gang Lei *et al.* studied experimentally as well as numerically the hydrodynamics and heat transfer characteristics of a heat exchanger with single helical baffles [22]. A heat exchanger with two layer helical baffles was designed using computational fluid dynamics method. The comparisons of the performance of the three heat exchangers with single segment baffles, single helical baffles and two layer helical baffles respectively are made. They showed that the heat exchangers with helical baffles have higher heat transfer coefficient to the same pressure drop than that of the heat exchanger with segmental baffles based on numerical results,and the configuration of the two-layer helical baffles has better integrated performance than that of the single-helical baffles.

Jian-Feng Yang *et al.* proposed combined parallel and serial two shell-pass shell-and-tube heat exchangers (CPTSP-STHXs & CSTSP-STHXs) whose outer shell pass are set up continuous helical baffles, to enhance the heat transfer performance [23]. The CPTSP-STHX and CSTSP-STHX are compared with the segmental baffled shell and tube heat exchanger (SG-STHX) by computer simulation. The results of simulation present that, total heat transfer rate Q of the CPTSP-STHX and CSTSP-STHX raise nearly 5.1% and 9.5% respectively, and the heat transfer coefficient of the CPTSP-STHX and CSTSP-STHX enhance nearly 7.6% and 14.8% than that of SG-STHX., while all of them have the same mass flow rate M and the same heat transfer area A and overall pressure drop $\Delta p$. The CSTSP-STHX is the best one among the three.

Jian-Feng Yang *et al.* using numerical simulations studied the effects of sealing strips on shell side flow and heat transfer performance of a heat exchanger with helical baffles [24]. The numerical simulations results showed that the sealing strips are more effective to improve the heat transfer performance of the continuous helical baffles shell and tube heat exchanger than that of the discontinuous helical baffles shell and tube heat exchanger especially in the cases of large mass flow rate.

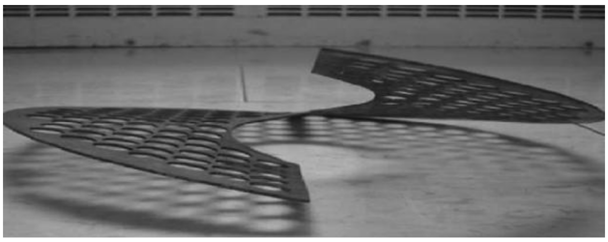
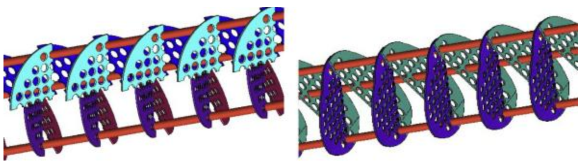


Fig.4. Continuous Helical Baffles [23]

Jian Wen *et al.* using numerical simulations studied on baffle configuration improvement of the heat exchanger with helical baffles [25]. They proposed an improved structure of ladder-type fold baffle to block the triangular leakage zones in original heat exchangers with helical baffles. The shell side heat transfer coefficient increased by 82.8 to 86.1 % when the folding ratio is 0.3, baffle height is 60%, and the folding angle is 37°. The associated pumping power penalty is about 21-549 Watts due to the increased shell side pressure drop. The thermal performance factor increased by 28.4% to 30.7%.



(a) Sector-shaped baffle (b) Ladder-type fold baffle

Fig. 5. Schematic diagram of the tube bundle [25]

Jian-Fei Zhang, et al. conducted experimental tests on five shell and tube heat exchangers. One among them was with segmental baffles and remaining four with helical baffles at helix angles 20°, 30°, 40° and 50° [26]. Heat transfer coefficient per unit pressure drop versus shell side volume flow rate was compared and results showed that heat exchanger with helical baffles have significant performance advantage over the heat exchanger with segmental baffles. Also they found that for the same shell inner diameter the performance of heat exchanger with helical baffles with 30° helix angle is better than that of 20°, and the performance of 40° helix angle is better than that of 50° helix angle. The heat exchanger with helical baffles of 40° angle shows the best performance among the five heat exchangers tested.

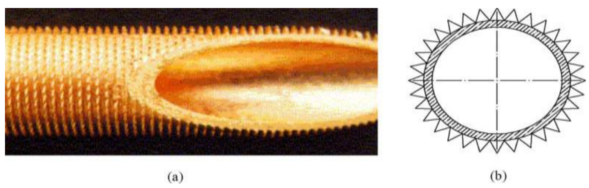
### D. *Rod-vane compound shell and tube heat exchanger*

Liu Wei *et al* developed rod-vane compound heat exchanger and compared flow and heat transfer characteristics of the heat exchanger with that of rod baffle and smooth tube bundle heat exchangers using numerical simulations [32]. The results showed that both rod-vane compound heat exchanger and rod baffle heat exchanger had similar thermal performance which was better than that of smooth tube bundle. Pressure drop point of view the compound heat exchanger was better than the rod baffle type. Both heat exchangers suffered pressure drops greater than that for a smooth tube bundle. By installing vane type spoilers the number of rod baffles and baffle rings decreased resulting in reduced flow resistance. The weight of the heat exchanger decreased reducing the cost of the compound heat exchanger.

## IV. IMPROVISATION USING DIFFERENT ENHANCED TUBES

### A. *Petal shaped finned tubes*

Zhang Zhnegguo, Xu Tao, and Fang Xiaoming studied experimentally a helical baffle heat exchanger with petal shaped finned tubes [27]. Petal shaped finned tubes provided surface area 2.4 times that of a bare tube with the same outer diameter.




(a) Photograph (b) Cross sectional diagram

Fig.6. Petal shaped finned tube [27]

The petal shaped fins resulted in reduced boundary layer disruptions and vortex shedding resulting in reduced pressure drop penalty. The experimental results showed that the shell side heat transfer coefficient based on actual outside surface area of tube bundle and pressure drop increase with increasing volumetric flow rate of shell side fluid.

### B. *Helically corrugated tubes*

S.Rozzi *et al.* studied enhancement of heat transfer by using an experimental set up consisting of shell and tube heat exchangers containing smooth wall tubes and helically corrugated tubes [31]. Effect of corrugation on the wall on heat transfer and pressure loss enhancement for fluid foods was studied using the set-up. Four fluid foods were considered: orange juice, whole milk, apricot puree and apple puree. Rheological studies confirmed the non-Newton behavior of apricot puree and apple puree. Orange juice and whole milk followed Newtonian behavior. For apricot puree during heating process as generalized Reynolds number ($Re'$) increased from 200 to 2800 overall heat transfer increased by 40% and pressure drop increased by four times. During cooling, overall heat transfer increased by 50% over the same range of generalized Reynolds number. Maximum of 78% was observed at $Re' = 2000$. Pressure drop enhancement was similar to that observed during heating. For apple puree with the same experimental set up $Re'$ ranging from 20 to 200 were reached and no enhancement in heat transfer was observed. Pressure drop increased by 11% for cooling and by 20% for heating. For heating of orange juice the set up achieved $Re'$ from 5000 to 19000 that is fully turbulent conditions and only 10% enhancement in overall heat transfer was observed for the range. Pressure drop increased by four times. For cooling the enhancement in heat transfer was 8%. Pressure drop reached a maximum of 6 to 7 times and finally decreased to 5.5 times at higher $Re'$ values. For heating and cooling of whole milk $Re'$ ranged from 5000 to 20,000, heat transfer enhanced by around 10%. Pressure drop increased by around 5 times.

### C. *Micro-finned tubes*

R.Hosseini, A.Hosseini-Ghaffar and M.Soltani conducted experiments on shell and tube heat exchanger with three different types of copper tubes smooth, corrugated and micro-fins [28]. They determined heat transfer coefficient and pressure drop on the shell side using different tubes, maintaining bundles with the same geometry, configuration, number of baffles and length inside the same shell. Corrugated and micro-finned tubes showed degradation of performance at a Reynolds number below 400. At a high Reynolds number the performance of heat exchanger greatly improved for micro-finned tubes.

### D. *Elliptical tubes*

W.Du, H.Wang, X.Yaun, L.Cheng proposed a novel continuous helical baffled heat exchanger with elliptical tubes [29]. Numerical simulation results showed that pressure drop reduced by 72 to 80%. Comprehensive heat transfer performance increased by 32 to 40% when compared to the usual circular tube heat exchanger.

### E. *Rib-shaped finned tubes*

Zhengguo Zhang *et al.* conducted experiments and studied shell side heat transfer coefficient and pressure drop for an integrally helical baffled heat exchanger combined with different enhanced tubes [33]. Rib-shaped fin tubes and low-fin tubes were considered for the study. The shell side Nusselt number of helically baffled heat exchanger with rib shaped fin tubes is 1.9 to 2.3 times as large as that of the helically baffled heat exchanger with low-fin tubes. The enhancement was due to the larger external surface area of the rib-shaped fin tube. The rib-shaped fins repeatedly disrupted the boundary layer and promoted vortex shedding. The geometry of the rib shaped fin tube induced highly three dimensional vorticity and promoted good cross flow mixing of the shell side fluid. The increase in heat transfer was significantly greater than that of the increase in pressure drop for rib-shaped fin tubes.

## V. CONCLUSIONS

The shell side heat transfer coefficient is improved by providing baffles on the shell side and creating cross flow of shell side fluid with respect to the tube bundle. The commonly used baffle is the segmental baffle. The performance of the segmental baffles is improved by stopping the leakages between the shell and the baffles supporting the tube bundle using sealers. The provision of sealers in a segmental baffle shell and tube heat exchanger increased the shell side heat transfer coefficient by 18.2 to 25.5%. For fluids flowing in turbulent conditions the spiral baffle plate heat exchanger showed 38% improvement in heat transfer over the conventional heat exchanger. The ratio of heat transfer coefficient to the pressure drop is more for helical baffle heat exchanger than for segmental baffle exchanger. The performance of helical baffle heat exchanger increases with inclination angle till 45° and starts decreasing after 45°. Among different helical baffle heat exchangers sextant helical baffle heat exchanger is the best with high film heat transfer coefficient and least pressure drop. The configuration of a two layer helical baffle is found to give a better integrated performance than single helical baffle heat exchanger. Simulations results have shown that the ladder-type fold helical baffle improved the thermal performance by 28.4% to 30.7%. Rod-vane compound shell and tube heat exchanger is found to be better than rod baffle heat exchanger and reduces the first cost and the operating cost.

Enhanced shell side film coefficient can also be obtained using petal shaped finned tubes. Micro-finned tubes are found to show better performance at high Reynolds numbers of the shell side fluid. Helical baffle heat exchanger with elliptical tubes is better compared to traditional circular tubes exchanger. Rib-shaped finned tubes provided advantage of high heat transfer rates at the cost of small rise in pressure drop when compared to low-fin tubes. Helically corrugated tubes are found to improve heat transfer for both Newtonian and non-Newtonian fluids.

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