Enhanced Shell and Tube Heat Exchanger Optimized Utilizing a diversity of Baffle Arrangements: A Survey

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***Abstract*—** when analyzing a shell and tube heat exchanger, it is vital to take into consideration both the thermal performance and the pressure drop of the device. The direction that fluid is flowing, as well as the sorts of baffles that are employed in various orientations, can have an impact on both the thermal performance and the pressure drop. Improving heat transfer by increasing the complexity of the baffles enhances heat transfer, but at the same time increases pressure loss, which requires more pumping power. This has an impact on the system's overall efficiency. In this thesis, the author presents the results of numerical simulations performed on several types of baffles, including single segmental, double segmental, and helical baffles. This illustration shows how the addition of baffles to a shell-and-tube heat exchanger can reduce the pressure drop. The formation of dead zones is illustrated by single segmental baffles, which occur when the movement of heat is blocked. Double segmental baffles mitigate vibrational damage more effectively than their single-segmental counterparts do. When helical baffles are utilized, dead zones are not allowed to exist, which results in a decrease in pressure drop. When there are fewer "dead zones," the rate of heat transfer is increased. As a result of the smaller pressure drop, less pumping power is required, which contributes to an increase in the overall efficiency of the system. According to the findings, helical baffles perform significantly better than the other two forms of baffles.

***Keywords*—** Shell and tube heat exchanger, baffle, segmental baffle, double segmental baffle, helical baffle, overall performance etc.

I. INTRODUCTION

The fundamental layout of shell and tube heat exchangers was first developed in the early 1900s to meet the requirements of power plants' condensers and feed water heaters, both of which operate at pressures that are relatively high. During the 1920s, the technology used in the production of shells and tubes became quite well developed, mostly as a result of the efforts of a relatively small number of big producers [1]. For the rapidly expanding oil industry, units of up to 500 square metres, or around 750 millimetres in diameter and 6 metres in length, were constructed. In the 1930s, designers derived design principles from the data that emerged from ideal tube banks. These concepts were established. In the literature, the phenomenon of shell side pressure drop is not even discussed until the late 1940s. Before the 1960s, viscous flow was one of the most challenging challenges for shell side flow, and very little was known about it at the time.

Shell and tube heat exchangers are the type of heat exchangers that are used the most frequently owing to the large diversity of configurations and operating situations that they can accommodate as well as their harsh conditions. They find usage in power stations, chemical industries, process industries, and other types of businesses as well. Shell and tube heat exchangers are characterized by their relatively high ratios of heat transfer area to volume and weight, in addition to their simplicity in terms of cleaning requirements. It is possible for the pressure to range anywhere from a vacuum to very high values, and there is a wide range of acceptable pressure drops. Because there are many different types of shell flow and patterns of tube bundles, the design is flexible enough to be altered separately for each fluid. The costs associated with accommodating thermal stresses are relatively low. There is a wide range of sizes available for heat exchangers, from very small to extremely huge (5000 m2). It is possible to achieve the successful separation of fluids. In the field of process manufacturing, heat exchangers are among the most common types of machinery. Heat exchangers come in a wide variety of shapes, sizes, and configurations, and can be purchased for either commercial or residential use.

There are many different varieties of heat exchangers. There are four distinct categories that can be utilized to categories heat exchangers according to their construction. It is possible for these heat exchangers to be of the tube, plate, extended surface, or regenerative type. The shell and tube heat exchanger, the double pipe heat exchanger, the spiral tube, and other similar devices are all examples of tubular heat exchangers. The plates that make up a plate heat exchanger are placed one on top of the other to create the most surface area possible for the transfer of heat. Extended surfaces are any surfaces that are attached to the body in order to provide the largest amount of surface area for the purpose of heat transfer [2-6].

Many other types of businesses make use of shell and tube heat exchangers in addition to tubular heat exchangers. Heat transfer can be accomplished with a shell and tube heat exchanger, which can adapt to and thrive in virtually any industrial process. The shell and tube heat exchanger is well recognized as the "workhorse" of the industrial heat transfer industry in today's day and age. Because of their adaptability and versatility, shell and tube heat exchangers are employed in a diverse array of applications. This is one reason for its widespread use. In addition to these characteristics, shell and tube heat exchangers offer a robust geometric design, and they are simple to clean and maintain. It is also able to provide the maximum possible opportunities for subsequent upgrading in order to accommodate the changing circumstances.

Shell-and-tube heat exchangers are constructed out of round tubes that are stacked atop enormous cylindrical shells. The axis of the tube is aligned in a manner that is parallel to that of the shell tube. While one stream of fluid travels through the interior of the tubes, the second stream travels on the exterior of the tubes, either across or along them. The fluid stream on the shell-side of a baffled shell-and-tube heat exchanger travels between pairs of baffles before moving in a direction that is parallel to the tube [7,8].

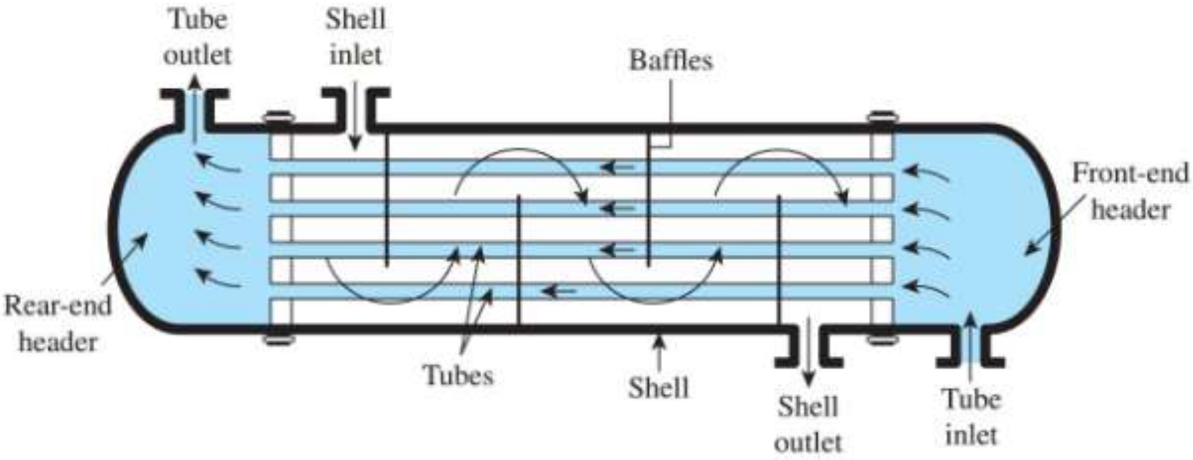

Figure: 1: Schematic diagram of a shell and tube heat exchanger with one shell pass and one tube pass

A shell and tube exchanger, also known as a STHX (see figure 1), is made up of a bundle of tubes that are arranged axially down the length of a hollow shell. It is possible for the tubes to be permanently positioned, or they may be detachable for ease of cleaning and replacement. In addition, a wide variety of alternative head and shell plans are commercially available to be purchased. The Tubular Exchanger Manufacturers Association (TEMA) utilizes a three letter designation to denote the front end, shell, and backside types of tubular heat exchangers.

The transfer of heat from a solid item to a fluid, or between two or more fluids, can be accomplished with the use of a device known as a heat exchanger. Either a complete wall can be placed between the fluids to keep them from mixing, or the fluids can be in direct touch with one another. They find widespread application in the fields of space heating, refrigeration, air conditioning, power stations, chemical plants, petrochemical plants, petroleum refineries, as well as the treatment of sewage and the processing of natural gas [9-12].

There are three primary methods by which heat can be transferred, and these are as follows:

1. **Thermal Conduction**: The process of conduction is practically involved in every single operation that involves the passage of heat. The transport of heat (internal energy) from one portion of a body to another through microscopic collisions of particles and the movement of electrons is known as thermal conduction. The disordered microscopic kinetic energy and potential energy that is transferred as a result of the microscopically interacting objects, which include molecules, atoms, and electrons, is referred to collectively as internal energy. All states of matter, including solids, liquids, gases, and plasmas, are capable of undergoing the process of conduction.

2. **Convection**: The transmission of heat that occurs as a result of the bulk movement of molecules inside fluids, such as gases and liquids, as well as molten rock, is referred to as convection. Convection can occur via advection, diffusion, or all of these processes simultaneously.

3. **Radiation**: The emission or transmission of energy across space or through a material medium in the form of waves or particles is what we mean when we talk about radiation. There are many varieties of heat exchangers used in industrial settings, some of which include plate fin, shell and tube, double pipe, plate and shell, pillow plate, and others. These heat exchangers can be purchased in the market in a variety of configurations to meet the requirements of specific applications. The shell and tube heat exchanger, also known as a STHX, was the type of heat exchanger that saw the most application in industrial settings. Shell and tube heat exchangers are the most common type utilized in industrial settings because, in comparison to other types of heat exchangers, they are simpler to maintain and clean, they are less expensive, and they offer greater flexibility and adaptability.

- Tube side fluid inlet
- Shell side fluid inlet
- Baffles
- Shell head
- Tube side fluid out
- Shell side fluid out
- Tubes
- Shell
- Tube plate

STHX is one of the types of fluids that does not enable the two fluids to be mixed together. In this, one fluid is permitted to travel through the tubes, while another travels through the shell (which holds tubes).

Different types of shell-and-tube heat exchangers can be distinguished by the flow configuration they employ:

Parallel flow: Working media are permitted to move in the same direction towards the outlet in this form of heat exchanger, which keeps the inlets for the hot fluid and the cooler fluid at the same end of the heat exchanger [15].

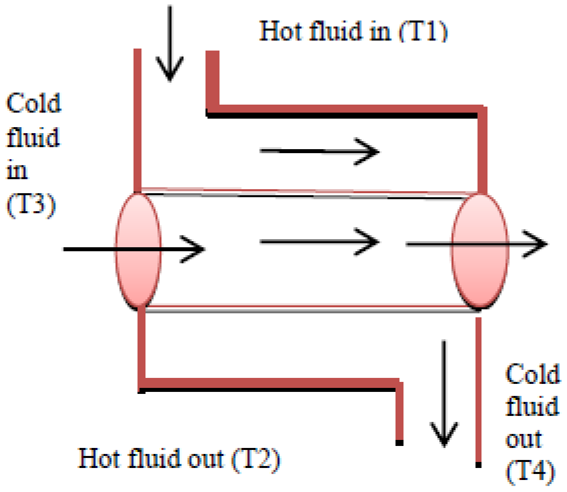

Figure 2: Parallel flow heat exchanger

Counter flow: Both the entry point for one pipe and the exit point for another pipe are located on the same end of the heat exchanger. Therefore, as a result of this setup, fluids will be moving in the opposite direction to one another.

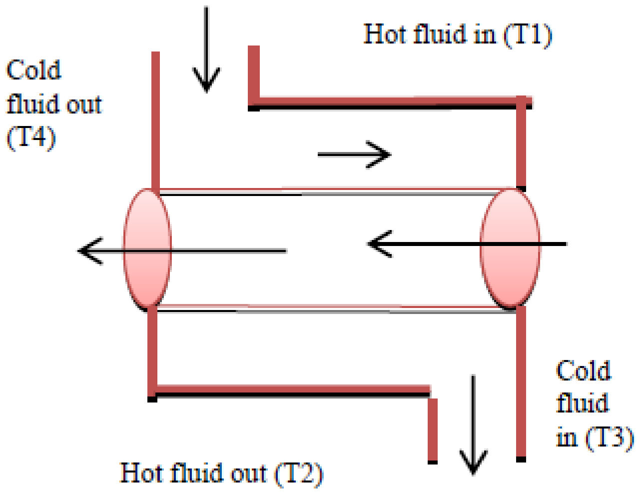

Figure 3: Counter flow heat exchanger

Cross flow: Cross flow is the term used to describe the movement of fluids in directions that are perpendicular to one another.

It is possible to install a STHX with a significant number of pipes. These pipes are stored in such a way that the horizontal axis of the pipe remains parallel to the shell at all times. The strength of the shell is designed to endure both the high pressure and the high temperature. Pumps are utilized in order to direct the flow of the fluids that are to occur. The pipe bundles are used to transport one of the two fluids, while the shell is used to transport the other fluid. It is not permitted for the fluid in the shell to travel along a straightforward route; rather, various configurations are made in order to make the flow more complicated.

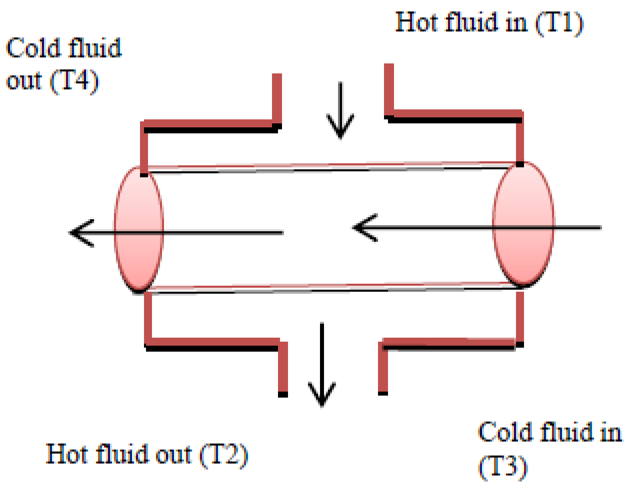

Figure 4: Cross flow heat exchanger

The utilization of baffles allows for the complexity of fluid flow to be successfully regulated. The pipes are held in place by these baffles as well. Baffles come in a variety of forms, and since there is no predetermined quantity of them, we are free to employ them in whatever way that best suits our needs. Within the shell, the baffles also hold the pipes in place. We utilize a wide variety of baffle types:

- Segmental baffles
- Double segmental baffles
- Helical baffles
- De-resonating baffles
- Orifice baffles

Shell and tube heat exchangers have a variety of applications, the most common of which is to facilitate the transmission of heat between two different fluids or media. These are utilized in the manufacturing sector for the purpose of either heating or cooling [16,17]. The primary applications are as follows:

- Space heating
- Refrigeration
- Air conditioning
- Power plants
- Chemical plants
- HVAC
- Air processing

Advantages: The fact that STHX are simple to service is one of their primary advantages, and this is especially true when they are placed with floating baffles. Those baffles that are not soldered to the shell are known as floating baffles.

II. LITERATURE REVIEW

According to SelbasR. et al. [10], genetic algorithms (GA) have the potential to be efficiently employed for the optimal design of a shell and tube heat exchanger through the manipulation of design variables. Based on the findings of the study, he drew the conclusion that combinatorial algorithms, like genetic algorithms, offered a considerable advantage over conventional design approaches when it came to producing optimal designs. The genetic algorithm was substantially faster than other approaches in calculating the global minimal cost, and it offers a higher benefit in terms of generating various answers over other methods that are of the same quality.

Ortega J.M. and colleagues [11] developed a straightforward algorithm for the design and monetary enhancement of multi-phase 1-2 shell and tube heat exchangers that are arranged in series. The design model was designed by using the FTout line technique and inequality constraints, both of which guarantee that attainable and straightforward equations were obtained for the 1-2 shells and tube arrangement.

Ozcelik Y. and colleagues [12] reported that many thousands of alternative shell and tube heat exchangers may be examined by varying the large number of parameters such as tube length, tube outer diameter, pitch size, layout angle, baffle space ratio, and number of tube side passes for which a genetic based algorithm was developed, programmed, and applied to estimate the optimum values of discrete and continuous variables of the MINLP (mixed integer nonlinear programming) test problem. These parameters include the length of In the end, an extension was made to the genetically based algorithm in order to do parametric studies and locate the optimal configuration of heat exchangers. This was accomplished by reducing the total annual capital cost and energy cost as much as possible.

Because of the growing need for heat exchangers in the industrial sector, it became imperative to develop designs for heat exchangers that were more efficient. Keeping this fact in mind, B. Peng and colleagues [8] in 1975 recommended the use of two STHX that were outfitted with helical continuous baffles rather than segmental baffles. Because the "overall pressure drop" was maintained at the same level, the heat transfer coefficients from the shell side for the earlier baffle designs were greater than those for the later designs. When compared to the heat transfer coefficient of the segmental baffles, the continuous helical baffles have a value that is 10% higher. When a connection was created between Nu, Re, and friction factor and Re, the mean square deviation was less than 3.12%. In 1976, B. Huadong Li et al. [5] investigated the pressure drop and heat transfer on the shell side of a shell-and-tube heat exchanger that was installed with segmental baffles fitted at different spacing. This was done with the intention of obtaining the values of various working parameters for a heat exchanger. The values of both parameters were recorded for each row, each tube, and each individual compartment after being measured. At a Reynolds number of 5000, it was discovered that increasing the baffle gap increased the heat transfer coefficient. Additionally, flow velocity reached previously unattained levels. When compared to the values shown by long baffle spacing, the pressure drop values for short baffle spacing were significantly lower.

Experiments and research have been conducted by Bin Gao, Qincheng Bi, and Miao Gui about the influence of baffle overlap proportion on the heat transfer performance and shell side flow of the shell and tube heat exchanger with continues helical baffles. The overlap proportion of 10% was tested with a shell and tube heat exchanger, along with three different helix angles of 20 degrees, 30 degrees, and 40 degrees. Experimentally, comparisons were done with the data of a shell and tube heat exchanger that had the same helix angle but with a different overlap fraction of fifty percent. The findings of the study reveal that the helix angle and the overlap proportion both have a significant impact on the rate at which heat is transferred. At the same Reynolds number or at the same mass flow rate, the overall performance of a shell and tube heat exchanger with a small overlap proportion is superior to that of a shell and tube heat exchanger with a big overlap proportion. According to the theory of entropy dissipation, a shell and tube heat exchanger with a significant baffle overlap fraction has reduced irreversibility.

The discussion of Fettaka et al. [14] on multi-objective optimization of the heat transfer area and pumping force of a shell and tube heat exchanger was proposed to provide the designer with a number of different Pareto front designs that catch the trade-off between the two objectives. MATLAB's rapid and elitist non-dominated sorting genetic algorithm (NSGA-II) was used to achieve the improvement so that it may be made available to users. The algorithm was used to determine the effect of utilising the continuous values of the tube length, diameter, and thickness as opposed to utilising the discrete standard industrial values in order to obtain optimal area and pumping power. This was done in order to get optimal results for both optimal area and optimal pumping power. In addition, it was discovered that discretization of the tube length, width, and thickness had a remarkably insignificant effect on the optimal cost plan.

The researchers Ahmadi P. et al. [15] developed the best possible design for a cross-flow heat exchanger in order to reduce the amount of entropy that was produced. The NTU approach was utilised in order to make an accurate determination of the pressure drop and overall efficiency of the heat exchanger. The application of a fast and elitist non-dominated sorting genetic algorithm, also known as NSGA II, was used in order to simultaneously reduce the number of entropy production units and the total annual cost (the sum of the initial investment as well as the costs of operation and maintenance). It is clear from this that any geometrical adjustments, such as reducing the number of entropy generation units, would result in an increase in the overall annual cost, and that this is also true in the opposite direction.

Hajabdollahi H. and colleagues [16] worked on the thermo-economic optimization of a shell and tube condenser using two new optimization methods, namely genetic and particle swarm (PS) algorithms. Their research was based on the idea that these algorithms are more effective than traditional optimization techniques. In comparison to the PS algorithm, it was discovered that the GA gives better results for the amount of time a computer's CPU is active. In the end, a sensitivity analysis of the design parameters was carried out at the point where they were optimal. The findings shown that an increase in the number of tubes initially results in a decline in the objective function, and that this decline is followed by a significant increase in the objective function. It achieves greater outcomes while also reducing the amount of time the CPU is active.

III. COMPUTATIONAL FLUID DYNAMICS (CFD)

The field of study known as computational fluid dynamics, or CFD for short, is concerned with the prediction of fluid flow, heat transfer, mass transfer, chemical responses, and other related phenomena. This is accomplished by numerically solving mathematical equations that govern the processes in question. In computational fluid dynamics (CFD), approximation of the governing equations of fluid mechanics in the fluid region of interest is achieved through the use of a numerical approach known as discretization.

CFD solvers contain a sophisticated set of algorithms that are used for modelling and simulating the flow of fluids, gases, heat, and electric currents. These algorithms are used to model and simulate the flow of these different types of flows. It is not conceivable to make many technological improvements in the fields of aerospace, vehicle manufacturing, or space exploration. Applications that make use of CFD approach include the design of aerofoils in the field of aeronautics, the simulation of drag in the field of automotive design, jet and thermal flow in the field of engine design, and cooling airflow in the field of electronic device design [16-19].

Visualization of fluid flow, heat and mass transfer, chemical reactions (explosions), and other associated processes is made possible by computational fluid dynamics (CFD). It finds application in virtually all areas of industry, including food processing, water treatment, marine engineering, automobile design, aerodynamics, and the design of gas turbines. Fluid flow problems can be examined much more quickly with the assistance of CFD software than they can be through testing at an earlier stage in the design cycle, for a lower cost, and with a reduced level of risk. The Navier-Stokes equations are a set of partial differential equations that describe the flow of fluid, and they serve as the basis for computational fluid dynamics (CFD). In computational fluid dynamics (CFD), the region of interest is segmented into a significant number of cells or control volumes. The Navier-Stokes partial differential equations can be rewritten in each of these cells as algebraic equations that relate the velocity, temperature, pressure, and other variables such as species concentrations to the values in the neighbouring cells. These equations can be found by clicking on the "Rewrite" button in the top right corner of each of these cells. After that, these equations are solved using numerical methods. The result is a comprehensive image of the flow that is accurate down to the resolution of the grid. As a consequence of this, the set of equations can be solved iteratively, which will lead to the production of a comprehensive description of the flow across the domain. These methods were initially developed at the beginning of the 1970s, and by the beginning of the 1980s, the first commercial CFD software had been developed. Since that time, CFD has made significant advancements, and its geometric flexibility has grown to the point where there are currently only a very small number of geometries that are too complex to be adequately represented. There have been many models built for physical phenomena such as turbulence, multiphase flow, chemical responses, and radiative heat transfer, and the usability of software has significantly increased thanks to the development of strong pre- and post-processors [21-23].

IV. COMPONENTS OF SHELL-AND-TUBE HEAT EXCHANGERS

Shell-and-tube heat exchangers are characterized by their primary consisting of components [18]:

- Tubes
- Tubesheet
- Shell and Shell-Side Nozzles
- Tube-Side Channel and Nozzles
- Baffles
- Tie-rods

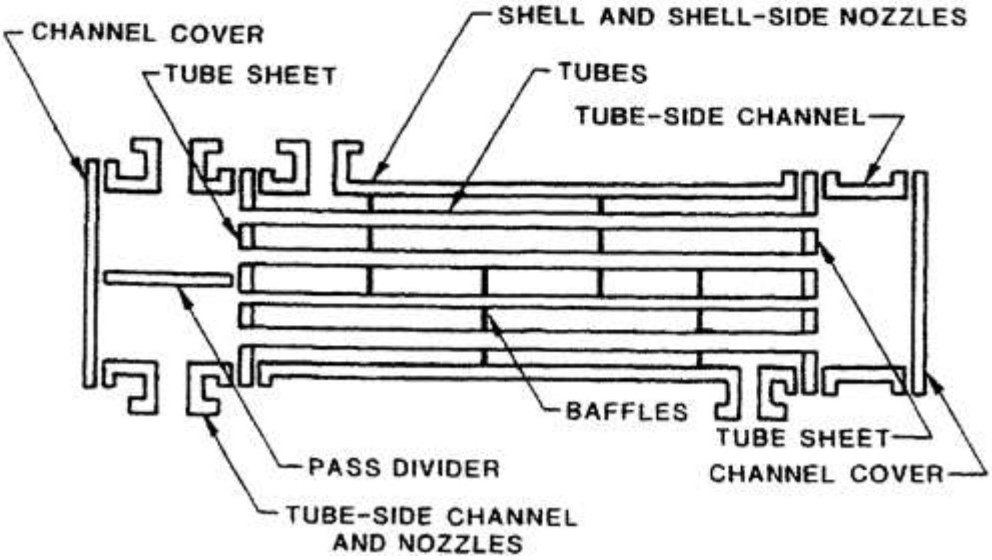

Figure 5: Components of STHX

Tubes

Tubes are the fundamental components of shell and tube heat exchangers. They provide the heat transfer surface between one liquid that is flowing inside the tube and another liquid that is flowing across the outside of the tube. Shell and tube heat exchangers are also referred to as shell and tube heat pumps. The tubes may be continuous or welded, and the materials that compose them are typically copper or steel amalgams. There is a possibility that certain applications will call for the utilization of additional composites made of nickel, titanium, or aluminium. The expulsion cycle is used to deliver consistent tubing, while the folding of a strip into a chamber and the subsequent welding of the crease are used to make welded tubing. Welded tubing is typically more conservative than its seamless counterpart.

The outermost surfaces of the tubes may be uncovered, extended, or enhanced (finned), depending on the design chosen. In situations in which one liquid has a heat transfer coefficient that is significantly lower than that of the other liquid, finned surface tubes are utilized. They provide two to four times as much heat transfer zone outwardly as the exposed tube serves as a comparison, and this larger proportion assists with counterbalancing a lower outside heat transfer coefficient.

The most common widths for tubes are 5/8", 34", and 1". It is possible to use tubes of a smaller size, but doing so will make it more difficult to achieve exact cleaning. Tubes with a greater width are sometimes used in order to either facilitate mechanical cleaning or to achieve a lower pressure drop than would otherwise be possible. Between 12 and 16 BWG is the normal range for the thickness of tube dividers (from 0.109 crawls to 0.065 inches thick). When using a tubing material that is relatively pricey like titanium, it is common practice to employ tubes with dividers that are between 18 and 20 BWG in size.

Tubesheets

The tubes are secured in place by being inserted into openings in the tubesheets. Next, the tubes are either pushed into grooves that have been carved into the openings or they are welded to the tubesheet at the point where the tube protrudes from the surface. This prevents the liquid on the tube side from mixing in with the liquid on the shell side of the container. The tubesheet is typically a single round plate of metal that has been suitably bored and scored to take the tubes (in the desired example, which are square or three-sided), the gaskets, the spacer poles, and the screw circle where it is attached to the shell. In other words, the tubesheet is generally a round plate. The distance between the centres of the tube opening is referred to as the tube pitch, and the tube pitch is typically 1.25 times the exterior dimension of the tubes. Other tube pitches are frequently utilized to lessen the shell side pressing factor decrease and to manage the speed at which the shell side liquid travels across the tube group. Both of these functions are accomplished through the utilization of the tube group. The higher heat transfer and more minimization that a three-sided pitch provides are two primary reasons why it is so commonly used. A square pitch makes it easier for mechanical cleaning to be done on the outside of the tubes. In addition to the U-tube groups, you will also need two tubesheets. A tube-to-tube sheet joint that has been moved from its original position as the result of a mechanical extension of the tube against the tubesheet is typically referred to as a shifted joint. As a result of the prevalence of roller expanders in the process of creating this joint, it is often referred to as a movable joint. Much less frequently, tubes are lengthened by pressure-driven cycles in order to have an effect on a mechanical bond. A similar welding process can be used to attach tubes to the front or inboard face of the tubesheet. Strength welding assumes that the mechanical strength of the joint is mostly provided by the welding system, and that all that needs to be done to remove the cleft that would otherwise be there is for the tubes to be delicately extended against the tubesheet. Seal welding stipulates that the mechanical strength of the joint is mostly supplied by the tube extension, with the tubes being welded to the tubesheet for improved hole insurance. This is done so that the junction can withstand greater loads. The increased unwavering quality, decreased service costs, and decreased frequency of cycle spills are the general arguments in favour of the expenditure of seal-welded joints. When clad tubesheets are used, when tubes with partition thickness of less than 16 BWG (0.065 inch) are utilised, and for some metals that can't be suitably extended to complete a worthwhile mechanical bond, sealwelded joins are essential (titanium and Combination 2205 for example). In situations in which it is desirable to prevent the two liquids from mixing with one another, a tubesheet that is folded in half, like the one shown in Figure 3, may be used. Because the area in between the tubesheets can be accessed by the outside world, it is imperative that any leakage of either type of liquid be discovered right away.

Figure 6: Double Tubesheet

In spite of the fact that it is a mechanical necessity, the tubesheet needs to be able to withstand the destructive assault of the two liquids that are contained within the heat exchanger, and it also needs to be electrochemically viable with the tube and all of the material that is located on the tube side.

Shell and Shell-Side Nozzles

The shell functions as a container for the liquid on the shell's periphery, while the spouts serve as the entry and exit points for the liquid. Rolling a metal plate of appropriate dimensions into a chamber and welding the longitudinal seam is a common method used in the manufacture of the shell, which normally has a cross section in the shape of a roundabout. By trimming the line that represents the optimum width to the appropriate length, one can create little breadth shells. The roundness of the shell has an important role in determining the maximum size of the baffles that may be embedded, and consequently, the effect of shell-to-baffle spillage. The delta spout typically features an impingement plate (Figure 7) that is only installed underneath it. This plate is intended to deflect the approaching liquid fly so that it does not impact the top line of tubes directly and at a high rate of speed. This impact has the ability to generate vibration, as well as disintegration and cavitation. To install the impingement plate while maintaining adequate flow territory between the shell and plate for the flow to release without undue pressing factor misfortune, it may be necessary to eliminate a few tubes from the round trip design. This may be the case if the impingement plate is to be installed.

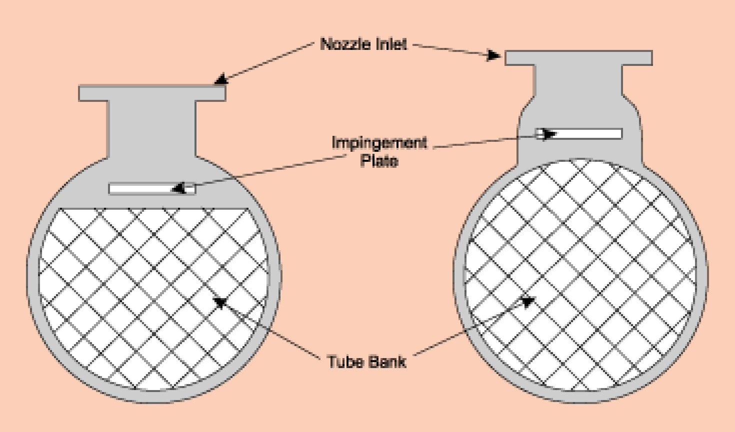

Figure 7: Nozzle Impingement Plate Tube-Side Channel and Nozzles

The sole function of the tube-side channel and spouts is to regulate the flow of liquid into and out of the tubes that make up the heat exchanger. These channels and spouts will typically be created out of a variety of materials because the tubeside liquid is, on average, more damaging (viable with the tubes and tubesheet obviously). It is possible that they are clad rather than made of a strong compound. Channel covers are included in the package with the channel shuts. They are circular plates that are secured to the channel ribs by bolts. They can be removed for tube inspection without causing any disruption to the side funnelling of the tube. Hats with flanged spouts or strung associations are frequently used rather than channels and channel covers in heat exchangers that are on the more compact side. The tube-side funnelling is accomplished by the use of the hats.

V. CONCLUSION

Shell and tube heat exchangers, in all of their varying configurations, are probably the fundamental heat exchanger arrangement that is used the most frequently and is distributed the most widely in process industry applications. This is because shell and tube heat exchangers are extremely efficient. There are a few distinct iterations of the fundamental format, each of which can be implemented to address a particular set of challenges. First and foremost, baffles minimize tube vibration caused by flow-induced whirlpools and keep tubes in the correct position during gatherings and other activities by keeping the tubes in place. Second, they regulate the flow of fluid from the shell side through the tube field and into and out of the tube field, which results in an increase in both the velocity of the flow and the coefficient of heat transfer. To be more specific, the purpose of this work is to investigate how well a baffle with each of the segments performs in several general heat transmission scenarios.

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