Improved Shell and Tube Heat Exchanger (STHX) Customized using a variety of Baffle Arrangements: A Review

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Abstract— Thermal performance and pressure drop are important aspects to consider when evaluating a shell and tube heat exchanger. Thermal performance and pressure drop are both affected by the direction of fluid flow and the types of baffles used in different orientations. Increasing the intricacy of baffles improves heat transfer while simultaneously increasing pressure loss, which necessitates more pumping power. This affects the efficiency of the system. The numerical simulations on diverse baffles, such as single segmental, double segmental, and helical baffles, are presented in this thesis. The effect of baffles on pressure drop in a shell and tube heat exchanger is seen here. Single segmental baffles demonstrate the establishment of dead zones when heat transport is impeded. When compared to single segmental baffles, double segmental baffles reduce vibrational damage. Because dead zones are eliminated when helical baffles are used, pressure drop is reduced. Heat transfer is improved when there are fewer dead zones. Smaller pumping power is required as a result of the lower pressure drop, which improves overall system efficiency. The results reveal that helical baffles are superior to the other two types of baffles.

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

I. INTRODUCTION

The basic design of shell and tube exchangers was introduced in the early 1900's to fill the needs of power plants such as condensers and feed water heaters operating under relatively high pressures. During the 1920's shell and tube manufacturing technology became fairly well developed, mainly because of the efforts of relatively few major manufacturers [1]. Units up to 500 m2 i.e., approximately 750 mm diameter and 6 m length, were manufactured for the rapidly growing oil industry. In the 1930's the designers established design principles from the data emerging from ideal tube banks. Shell side pressure drop is not even mentioned until late 1940's in the literature. Viscous flow was one of the most difficult problems for shell side flow and was poorly understood until the 1960's.

Shell and tube exchangers are the most generally utilized sort of heat exchangers due to their extensive variety of configuration and working conditions and rugged conditions. They are used in the power stations, chemical industries, process industries etc. Shell and tube exchangers provide relatively large ratios of heat transfer area to volume and weight and they can be easily cleaned. Pressure can vary from vacuum to very high values and permissible pressure drop can vary within a wide range. The design can be adjusted independently for each fluid because of a variety of shell flow types and tube bundle arrangements. Thermal stresses can be accommodated rather inexpensively. The sizes of heat exchanger vary from very small to extremely large values (5000 m2). Positive separation of fluids can be obtained. Heat exchangers are ubiquitous pieces of equipment in the process industry. There are different types and designs of heat exchangers are available both commercially and domestically.

Heat exchangers can be of many types. The classification of heat exchangers in terms of construction can be of four different types. These heat exchangers can be tubular, plate type, extended surface, regenerative type. Examples of tubular heat exchanger are shell and tube heat exchangers, double pipe heat exchangers and spiral tubes etc. Plate heat exchangers consist of various plates stacked together giving maximum surface area for heat transfer. Extended surfaces are the surfaces which are attached to the body so as to give maximum surface for heat transfer [2-6].

Tubular heat exchangers are used in many industries especially Shell and tube heat exchanger. Shell and tube heat exchanger can adopt and thrive in almost every industrial process heat transfer. Today, Shell and tube heat exchanger is regarded as a 'workhorse' of industrial heat transfer. The reason being used as wide range of shell and tube heat exchanger is because of its versatility and flexibility. Apart from these qualities, shell and tube heat exchanger provides robust geometry construction, and are easy to clean for maintenance. It can also provide maximum possibilities of further up gradation in order to suite the new situations.

Shell-and-tube heat exchangers are made of round tubes arranged on large cylindrical shells with the tube axis parallel to that of the shell tube. One stream of fluid flows through the tubes while the other stream flows on the shell-side, across or along the tubes. In baffled shell-and-tube heat exchanger, the shell-side fluid stream flows across pairs of baffles and then flows parallel to the tube [7,8].

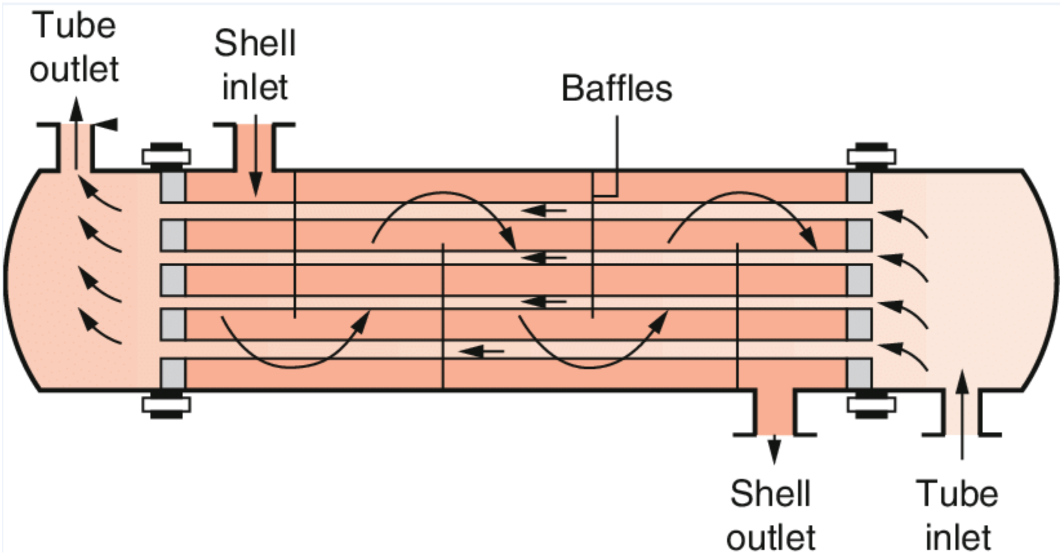

Figure: 1: Schematic diagram of a shell and tube heat exchanger with one shell pass and one tube pass

A shell and tube exchanger (STHX) (figure 1) comprises of a bundle of tubes placed axially along the length hollow shell. The tubes might be for all time situated or removable for simplicity of cleaning and substitution. Furthermore, various diverse head and shell plans are monetarily accessible. The Tubular Exchanger Manufacturers Association (TEMA) utilizes a three letter code to indicate the front end, shell, and backside sorts.

A heat exchanger is a device used to transfer heat between a solid object and a fluid, or between two or more fluids. The fluids may be separated by a solid wall to prevent mixing or they may be in direct contact. They are widely used in space heating, refrigeration, air conditioning, power stations, chemical plants, petrochemical plants, petroleum refineries, and natural gas processing and sewage treatment [9-12].

There are three basic modes of heat transfer which include:

1. **Thermal Conduction**: Conduction is virtually involved in all operations in which heat transfer is taking place. Thermal conduction is the transfer of heat (internal energy) by microscopic collisions of particles and movement of electrons within a body. The microscopically colliding objects, that include molecules, atoms, and electrons, transfer disorganized microscopic kinetic and potential energy, jointly known as internal energy. Conduction takes place in all phases of matter, such as solids, liquids, gases and plasmas.

2. **Convection**: Convection is the heat transfer due to bulk movement of molecules within fluids such as gases and liquids including molten rock. Convection takes place through advection, diffusion or both.

3. **Radiation**: Radiation is the emission or transmission of energy in the form of waves or particles through space or through a material medium. There are different types of heat exchanger available in market as per their application such as such as plate fin, shell and tube, double pipe, plate and shell, pillow plate, etc. are a few types of heat exchangers used on an industrial scale. Among which shell and tube heat exchanger (STHX) were used in industries mostly. Shell and tube heat exchangers mostly used in industries because of they can easily cleaned up, lower cost, more flexible adaptability compared with other heat exchanger.

- 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 among the type which doesn't allow the mixing of the two fluids. In this one fluid is allowed to pass through tubes and another fluid passes through the shell (which holds tubes).

Types of shell and tube heat exchangers based on flow configuration:

Parallel flow: In this type the inlets for the hot fluid and cooler fluid are kept at the same end of the heat exchanger and the working Medias are allowed to move in the same direction towards the outlet [15].

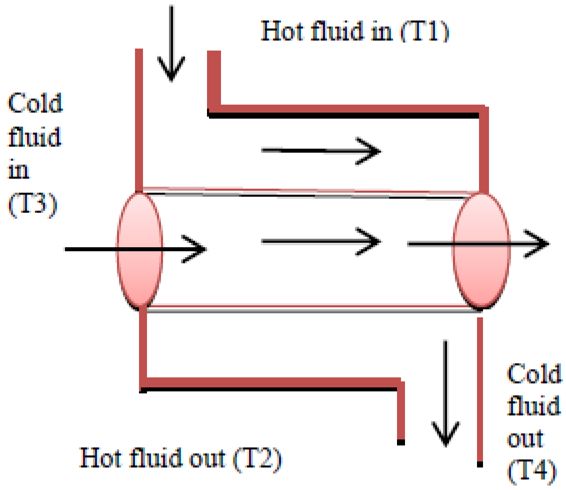

Figure 2: Parallel flow heat exchanger

Counter flow: On the same end of the heat exchanger inlet of one pipe and outlet of another pipe is made. Hence by this configuration fluids will be travelling in vice versa direction to each other.

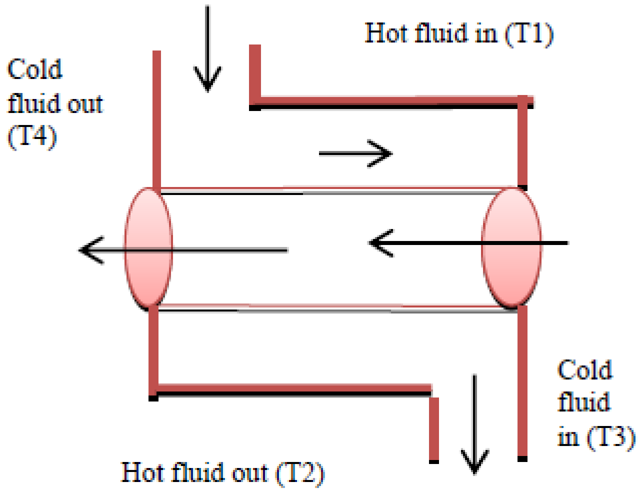

Figure 3: Counter flow heat exchanger

Cross flow: If fluids are made to move perpendicular to each other this is called cross flow.

A STHX can be installed with large number of pipes. These pipes are kept in order that the horizontal axis of pipe is parallel to the shell. Shell is made strong enough to withstand high pressure and high temperature. The fluids to be flown are directed by use of pumps. One of the two fluids is passed through pipe bundles and the other fluid is allowed to pass through shell. The fluid in shell is not allowed to follow a simple path instead some arrangements are done to make the flow complex.

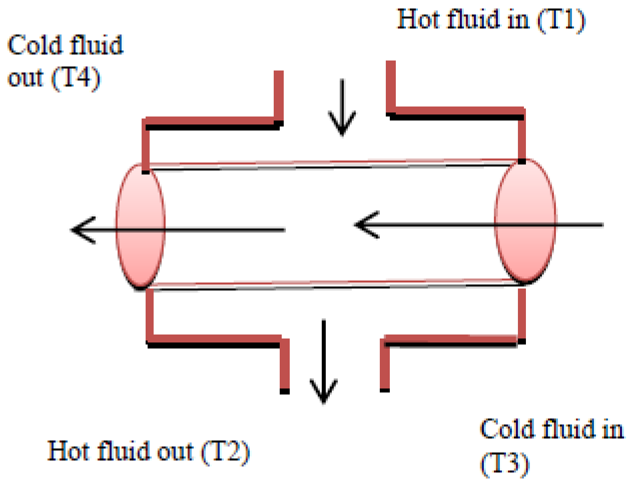

Figure 4: Cross flow heat exchanger

The complexity in fluid flow is managed by the use of baffles. These baffles also hold the pipes. Baffles are of different types and no fixed number of baffles is available, so we can use baffles as per we require. The baffles also hold pipes inside shell. We use different kinds of baffles:

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

Applications of shell and tube heat exchanger:

These are highly used to make heat transfer possible between two fluids or mediums. These are used in industrial sectors for heating or cooling purpose [16,17]. The main applications are:

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

Advantages: The main advantage of STHX is that they are easy to service mainly when installed with floating baffles. Floating baffles are the baffles that are not welded to shell.

II. Literature Review

SelbasR. et al. [10] suggested that genetic algorithms (GA) can be effectively applied for the optimal design of shell and tube heat exchanger by varying the design variables. From the study he inferred that the combinatorial algorithms such as genetic algorithms gave significant improvement in the optimal designs compared to the conventional designs. Genetic algorithm was significantly fast in determining global minimum cost and has greater advantage in obtaining multiple solutions over different methods of same quality.

Ortega J.M. et al. [11] carried out simple algorithm for the design and economic improvement of multi-phase 1-2 shell and tube heat exchanger in series. The design model planned utilizing the F_{Tout} line strategy and inequality constraints that guarantee attainable and straight forward expressions were obtained for of 1-2 shells and tube arrangement.

Ozcelik Y. et al. [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, 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 problems. Finally, the genetic based algorithm was extended to make parametric studies and to find optimum configuration of heat exchangers by minimizing the sum of the annual capital cost and energy cost.

As the need of heat exchangers became more for industrial sector, it was necessary to design more efficient heat exchanger. Keeping this in mind in 1975 **B. Peng et al**[8] proposed two STHX with helical continuous baffles installed in them rather than segmental baffles. As the "overall pressure drop" was kept same the heat transfer coefficients from shell side for former baffles was higher than the later ones. The heat transfer coefficient for the continuous helical baffles is 10% more than the segmental baffles. The mean square deviation was less than 3.12% when correlation between Nu, Re and friction factor and Re was developed. For obtaining the values of various working parameters for a heat exchanger in 1976 **B.**

Huadong li et al.[5] investigated the pressure drop and heat transfer on shell side of shell-and-tube heat exchanger installed with segmental baffles fitted at different spacing. Measurement of both parameters was doe per row, per tube and each compartment. It was achieved that at Re 5000 the increase in baffle space enhanced heat transfer coefficient. Flow velocity also reached higher values. Short baffle spacing showed less values of pressure drop compared to that of long baffle spacing.

Bin Gao, Qincheng Bi & Miao Gui, have done experiments and study on effect of baffle overlap proportion on heat transfer performance and shell side flow of the shell and tube heat exchanger with continues helical baffles. Overlap proportion of 10% with shell and tube heat exchanger and different helix angle of 20o, 30o, and 40o were tested. Experimental comparisons were made with data of shell and tube heat exchanger with same helix angle but at different overlap proportion of 50%. Researcher gave result which indicates that both helix angle and overlap proportion have great effect on heat transfer. The overall performance of shell and tube heat exchanger with small overlap proportion is better than large overlap proportion at same Reynolds number or at equal mass flow rate. But shell and tube heat exchanger with large baffle overlap proportion has less irreversibility according to theory of entransy dissipation.

Fettaka et al. [14] discussed on multi-objective optimization of the heat transfer area and pumping force of a shell and tube heat exchanger was introduced to furnish the designer with various Pareto front arrangements which catch the trade-off between the two objectives. The enhancement was performed utilizing the quick and elitist non-dominated sorting genetic algorithm (NSGA-II) accessible in MATLAB. The algorithm was utilized to decide the effect of utilizing the continuous values of the tube length, diameter and thickness as opposed to utilizing discrete standard industrial values to get optimal area and pumping power. Moreover, it was found that discretization of the tube length, width and thickness had an exceptionally minor impact on the ideal cost plan.

Ahmadi P. et al. [15] formulated an optimal design for cross flow heat exchanger in order to minimize and entropy generation. An NTU method was applied for estimation of the heat exchanger pressure drop, as well as effectiveness. Fast and elitist non dominated sorting genetic algorithm (i.e., NSGA II) was applied to minimize the entropy generation units and the total annual cost (sum of initial investment and operating and maintenance costs) simultaneously. It reveals that any geometrical changes, which decrease the number of entropy generation units, lead to an increase in the total annual cost and vice versa.

Hajabdollahi H. et al. [16] worked on thermo-economic optimization of a shell and tube condenser, based on two new optimization methods, namely genetic and particle swarm (PS) algorithms. It was found that GA provides better results for computer CPU running time, compared to PS algorithm. Finally, a sensitivity analysis of design parameters at the optimal point was conducted. Results showed that an increase in the tube number leads to decrease in the objective function first then it leads to a considerable increment in objective function. It has better results as well as less CPU running time.

III. COMPUTATIONAL FLUID DYNAMICS (CFD)

Computational Fluid Dynamics (CFD) is the science of forecasting fluid flow, heat transfer, mass transfer, chemical responses, and related phenomena by solving mathematical equations, which govern these processes by using a numerical process. CFD applies numerical techniques called discretization to progress approximation of the governing equations of fluid mechanics in the fluid region of interest.

CFD solvers contain a complex set of algorithms which are used for modeling and simulating the flow of fluids, gases, and heat and electric currents. It is impossible to have many technological advances in aeronautics, automobiles, and space. CFD methodology is used in applications such as aerofoil design in aeronautics, drag simulation in automobile design, jet and thermal flow in engine design and cooling airflow in an electronic product [16-19].

CFD allows visualizing fluid flow, heat and mass transfer, and chemical responses (explosions) and related phenomena. It is used in almost all industrial sectors: food processing, water treatment, marine engineering, automotive, aerodynamics and gas turbine design. With the assistance of CFD software, fluid flow problems are analyzed faster than by testing at an earlier stage in the design cycle, for less money, and with lower risk. The foundation of CFD is built on Navier-Stokes equations, the set of partial differential equations that fluid flow. With CFD, the area of interest is subdivided into a large number of cells or control volumes. In each of these cells, the Navier-Stokes partial differential equations can be rewritten as algebraic equations that relate the velocity, temperature, pressure, and other variables such as species concentrations, to the values in the neighboring cells. These equations are then solved numerically. It yields a complete picture of the flow down to the resolution of the grid. As a result, the set of equations can then be solved iteratively, yielding a complete depiction of the flow throughout the domain These techniques were started in the early 1970s, and the first commercial CFD software came to existence in early 1980s. Since then, CFD has come a long way, and geometric flexibility has increased to the point where there are now a very few geometries too complex to be represented accurately. Many models have been developed for physical phenomena such as turbulence, multiphase flow, chemical responses and radiative heat transfer, and the usability of software has increased greatly with powerful pre- and post-processors [21-23].

IV. COMPONENTS OF SHELL-AND-TUBE HEAT EXCHANGERS

The principal components of shell-and-tube heat exchangers are [18]:

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

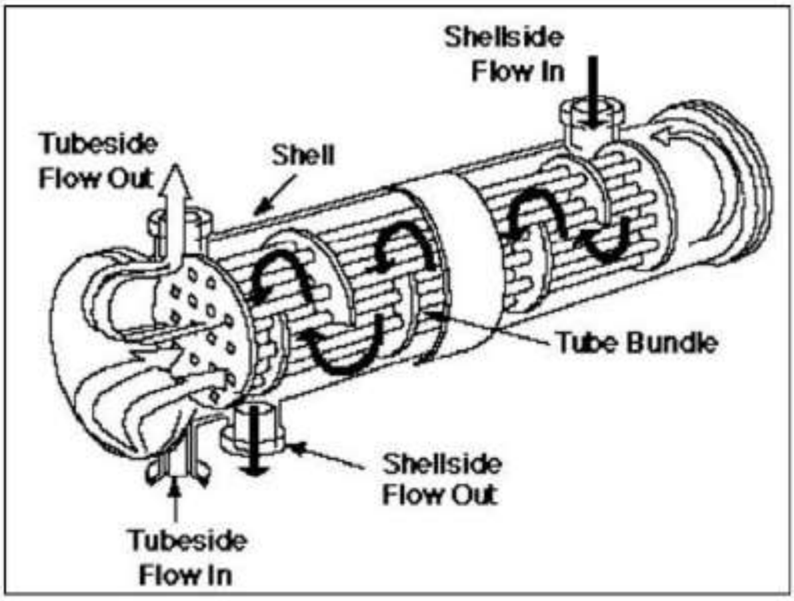

Figure 5: Components of STHX

Tubes

Tubes are the fundamental parts of shell and tube heat exchangers, giving the heat move surface between one liquid flowing inside the tube and the other liquid flowing across the outside of the tube. The tubes might be consistent or welded and most usually made of copper or steel amalgams. Other composites of nickel, titanium, or aluminum may likewise be needed for explicit applications. Consistent tubing is delivered in an expulsion cycle; welded tubing is created by folding a strip into a chamber and welding the crease. Welded tubing is normally more conservative.
The tubes might be either exposed or with expanded or improved (finned) surfaces outwardly. Finned surface tubes are utilized when one liquid has a generously lower heat move coefficient than the other liquid. They give two to four fold the amount of heat move zone outwardly as the comparing exposed tube, and this are proportion assists with counterbalancing a lower outside heat move coefficient.
Ordinary tube breadths are 5/8", ¾" and 1". Tubes of more modest measurement can be utilized however they are more hard to clean precisely. Tubes of bigger width are some of the time utilized either to encourage mechanical cleaning or to accomplish lower pressure drop. The typical tube divider thickness goes from 12 to 16 BWG (from 0.109 crawls to 0.065 inches thick). Tubes with more slender dividers (18 to 20 BWG) are utilized when the tubing material is moderately costly like titanium.

Tubesheets

The The tubes are held set up by being embedded into openings in the tubesheets and afterward either ventured into grooves cut into the openings or welded to the tubesheet where the tube juts from the surface. This forestalls the liquid on the shell side from blending in with the liquid on the tube side. The tubesheet is generally a solitary round plate of metal that has been appropriately bored and scored to take the tubes (in wanted example - square or three-sided), the gaskets, the spacer poles, and the screw circle where it is attached to the shell. The distance between the focuses of the tube opening is known as the tube pitch; regularly the tube pitch is 1.25 occasions the external measurement of the tubes. Other tube pitches are much of the time used to diminish the shell side pressing factor drop and to control the speed of the shell side liquid as it flows across the tube group. Three-sided pitch is frequently applied as a result of higher heat move and minimization it gives. Square pitch encourages mechanical cleaning of the outside of the tubes. Two tubesheets are needed aside from U-tube groups. A moved joint is the normal term for a tube-to-tube sheet joint coming about because of a mechanical extension of the tube against the tubesheet. This joint is regularly accomplished utilizing roller expanders; subsequently the term moved joint. Less oftentimes, tubes are extended by pressure driven cycles to influence a mechanical bond. Tubes can likewise be welded to the front or inboard face of the tubesheet. Strength welding assigns that the mechanical strength of the joint is given fundamentally by the welding system and the tubes are just delicately extended against the tubesheet to take out the cleft that would some way or another exist. Seal welding assign that the mechanical strength of the joint is furnished principally by the tube extension with the tubes welded to the tubesheet for better hole insurance. The expense of seal-welded joints is generally advocated by expanded unwavering quality, decreased support costs, and less cycle spills. Sealwelded joints are required when clad tubesheets are utilized, when tubes with divider thickness under 16 BWG (0.065

inch) are utilized, and for certain metals that can't be sufficiently extended to accomplish a worthy mechanical bond (titanium and Combination 2205 for example). Where blending between the two liquids should be evaded, a twofold tubesheet, for example, is appeared in Figure 3 might be given. The space between tubesheets is available to the environment so any spillage of either liquid ought to be immediately identified.

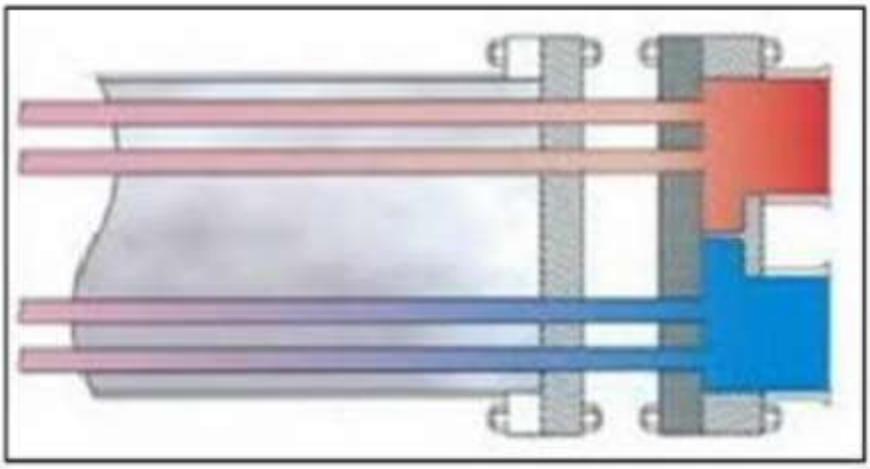

Figure 6: Double Tubesheet

The tubesheet, notwithstanding its mechanical necessities, should withstand destructive assault by the two liquids in heat exchanger and should be electrochemically viable with the tube and all tube-side material.

Shell and Shell-Side Nozzles

The shell is basically the holder for the shell-side liquid, and the spouts are the gulf and leave ports. The shell typically has a roundabout cross segment and is regularly made by rolling a metal plate of suitable measurements into a chamber and welding the longitudinal joint. Little breadth shells can be made by cutting the line of the ideal width to the right length. The roundness of the shell is significant in fixing the greatest measurement of the baffles that can be embedded, and hence the impact of shell-to-baffle spillage. The delta spout regularly has an impingement plate (Figure 7) set only underneath to redirect the approaching liquid fly from affecting straightforwardly at high speed on top line of tubes. Such effect can cause disintegration, cavitation or potentially vibration. To put the impingement plate in and still leave sufficient flow territory between the shell and plate for the flow to release without unreasonable pressing factor misfortune, it very well might be important to discard a few tubes from the round trip design.

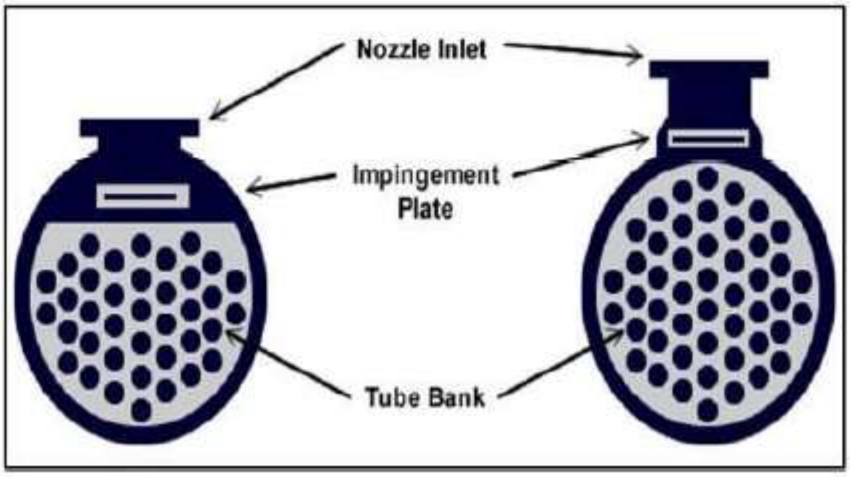

Figure 7: Nozzle Impingement Plate Tube-Side Channel and Nozzles

Tube-side channel and spouts just control the flow of the tube-side liquid into and out of the tubes of the exchanger. Since the tubeside liquid is by and large more destructive, these channels and spouts will regularly be made out of combination materials (viable with the tubes and tubesheet obviously). They might be clad rather than strong compound. The channel closes are furnished with channel covers. They are round plates that bolt to the channel ribs and can be taken out for tube assessment without upsetting the tube side funneling. In more modest heat exchangers, hats with flanged spouts or strung associations for the tube-side funneling are frequently utilized rather than channels and channel covers.

V. Conclusion

It is likely that the shell and tube heat exchangers, in all of its various configurations, are the most widely used and widely distributed fundamental heat exchanger arrangement in process industry applications. There are several variations of the fundamental layout that can be used to deal with a wide range of issues. Firstly, baffles keep the tubes in their proper position during gathering and activity, and they prevent tube vibration caused by flow-induced whirlpools. Secondly, they control the shell-side flow to and from the tube field across the tube field, thereby increasing both the speed of the flow and the heat transfer coefficient. Specifically, the goal of this work is to investigate how well a baffle with each of the segments performs in general heat transfer scenarios.

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