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

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Abstract— When evaluating a shell and tube heat exchanger, it is important 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 types of baffles that are used 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 improves 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 various 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 impeded. Double segmental baffles mitigate vibrational damage more effectively than their single-segmental counterparts do. When helical baffles are used, 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 types of baffles.

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

I. INTRODUCTION

Through the utilization of heat exchangers, thermal energy can be transferred between two or more fluids, or between solid particles and a fluid, which are at different temperatures and are in thermal contact with one another. The most fundamental aspect of how a heat exchanger works is that it moves heat around without altering the fluid in any way while doing so. This is the most crucial aspect of how a heat exchanger works. Heat exchangers do not involve any transfer of thermal energy or work to or from the environment in which they are located. The two most important ways that heat can be transferred are called conduction and convection. Classification of heat exchangers can be done according to the processes of heat transfer, the number of fluids involved, the degree of surface compactness, as well as the construction features, flow configurations, and heat transfer mechanisms [1]. Heat exchangers are utilized extensively in a wide variety of engineering applications, including but not limited to chemical engineering processes, the generation of electricity, the refining of petroleum, refrigeration and air conditioning, the food sector, and other applications. Shell and tube heat exchangers have the advantage of being relatively simple to produce and having a wide range of application options for gaseous as well as liquid media across a wide temperature and pressure range [2]. In addition to these benefits, shell and tube heat exchangers are one of the numerous types of heat exchangers that are available.

It is essential for the proper operation of a heat exchanger to have two fluids passing through it that have temperatures that are different from one another. One flows directly through tubes, while the other flows outside the tubes but is still contained within the shell. Each has its own flow path (the shell side). Through the walls of the tube, heat can be transferred from one fluid to another, either from one fluid to another on the tube side or from one fluid to another on the shell side. On either the shell or the tube side of the device, fluids can take the form of either liquids or gases, depending on the application. In order to achieve efficient heat transmission, it is necessary to make use of a large heat transfer surface as well as multiple tubes. Utilizing energy effectively and preventing the waste of thermal energy is an effective strategy for cutting costs and saving money. A heat exchanger is a piece of equipment that is used in the field of heat transfer. Its purpose is to transfer thermal energy (enthalpy) between at least two fluids, between a solid surface and a fluid, or between solid particles and a fluid at different temperatures. Heat exchangers can also be used to transfer enthalpy between solid particles and a fluid. Generally speaking, heat exchangers do not have any heat from the outside and the workers do not collaborate with one another. Common applications for this technology include the heating and cooling of fluid streams, the dissolution and reformation of single- and multi-part fluid streams, and the disappearance and formation of new fluid streams. A variety of applications seek to either recover or discard heat, sterilise, pasteurise, fractionate, or distil a working fluid; concentrate, crystallise, or control the course of action in a working fluid; or all of the above. In some heat exchangers, the fluids that are carrying out the process of heat transfer are brought into direct contact with one another. The transfer of heat from one fluid to another in a heat exchanger typically takes place in one of two ways: either through an isolating wall or into and out of a wall in a temporary manner, rather than in a continuous manner. In many different types of heat exchangers, the fluids are kept separate from one another by a heat transfer surface, and they only combine when it is absolutely necessary to do so. This task calls for the utilisation of recuperators, which are a specific type of exchanger that employs direct transfer. The term "indirect transfer type" refers to heat exchangers that have a discontinuous heat exchange between hot and cold fluids by utilising thermal energy storage and discharge through the exchanger surface or matrix. This type of heat exchanger is known as an indirect transfer type. Leakage of fluid from one fluid stream into another is a common issue with these types of exchangers. This issue is brought on by differences in pressure and matrix rotation, as well as the switching of valves within the exchanger itself. During the process of heating or cooling, the heat exchanger is said to be sensible if it does not cause any phase change in any of the fluids that move through it. There is the potential for inward thermal energy sources to be present in exchangers, such as electric heaters and components for atomic fuel, which could be used to generate heat [3,4].

In some types of exchangers, such as boilers, fired heaters, and fluidized-bed exchangers, combustion and synthetic response can actually take place inside the exchanger itself. Some heat exchangers, such as scratched surface exchangers and stirred tank reactors, contain mechanical forms of equipment that can be used for heat transfer. These mechanical forms of equipment can be found in some heat exchangers. The process of conduction is responsible for the majority of the heat transfer that takes place within the isolating mass of a recuperator. As it may be, in a heat pipe thermal exchanger, the heat pipe serves as an isolating wall while also promoting heat exchange. This is accomplished by the working liquid accumulating, dissipating, and conducting heat within the heat pipe while it is in operation. All things considered, if the liquids are immiscible, the isolating wall may not be necessary, and the interface between the liquids may serve in place of a heat exchanger surface, as in a direct contact thermal exchanger [5-8].

HEAT EXCHANGERS UTILIZATIONS

The utilisation of heat exchangers is a significant issue that calls for an in-depth investigation to be conducted so that all of the relevant aspects can be covered. Typical applications for these materials include the process industry, the mechanical equipment industry, as well as home machines, vehicles, space heating, power production, and chemical processing. Other applications include mechanical equipment manufacturing. Heat exchangers can be utilised for the purpose of heating region systems, which is a function that is becoming more and more widespread in today's society. In order to assist in the condensation or evaporation of the liquid that is contained within the air conditioner and the freezer, heat exchangers are also utilised. In addition, these are utilised as components of milk preparation machines for the purposes of filtration and sanitation. Their application can be found in both domestic and industrial settings. In Table 1, the application of heat exchangers is broken down according to the various business models that are available.

Table 1: Distinct types of businesses make use of heat exchangers

S.No	Organizations Name	Applications
1	Power	Air conditioners and heaters, radiators, oil coolers, cooling circuits, and energy recovery.
2	Polymer	Polypropylene production and polyvinyl chloride production reactor jacket conditioning.
3	Biopharma	Cleaning with steam and water with the intention of using water cooling for the injection ring.
4	Marine	Grease oil cooling, fresh water distillers, pre-heating of diesel fuel, central cooling, and marine cooling systems.
5	Automobile	Painting, priming, rinsing, and pickling
6	Hydrocarbon managing	Methanol preheating, fluid hydrocarbon refrigeration, sustained preheaters, carbon dioxide extraction or expulsion, and ammonia synthesis
7	Food and Beverages	Ovens, cookers, preheating and handling food, milk sanitization, beer cooling and purification, juice and syrup purification, chilling or cooling the product to the necessary temperature

HEAT EXCHANGER CATEGORIZATION

The exchange forms, quantity of liquids, heat exchange components, and other characteristics of heat exchangers can be used to classify them. Shell and tube, printed circuit, and plate and plate fin heat exchangers are examples of common types. The configuration of a shell and tube heat exchanger is typically determined by connections; for example, the Kern methodology and Bell Delaware method are the most frequently used relationships.

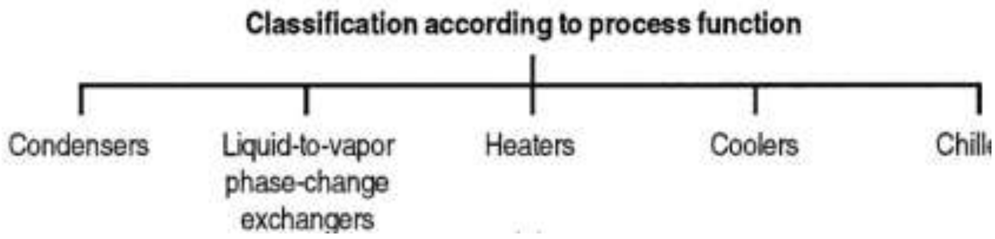

Figure 1: Classification according to process function

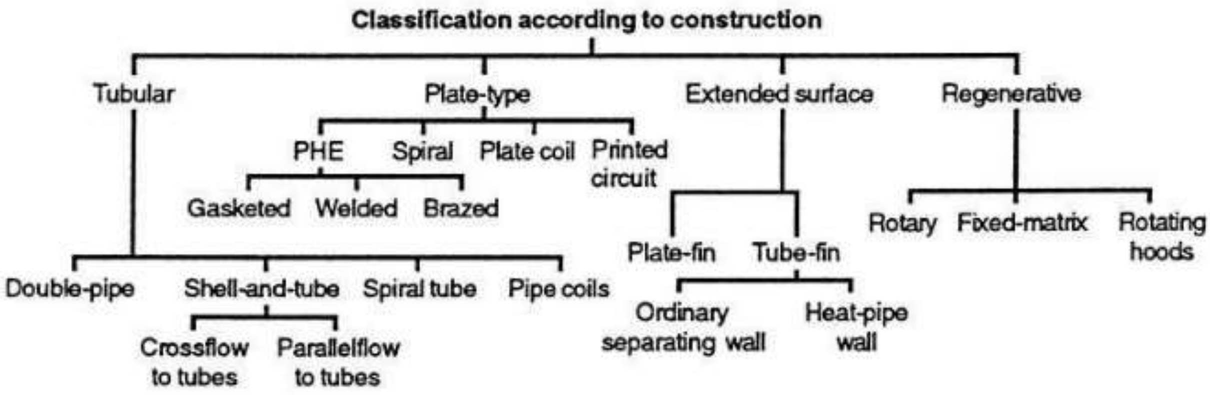

Figure 2: Classification according to type of construction

SHELL AND TUBE HEAT EXCHANGER

This type of heat exchanger is often constructed using a group of circular tubes that are arranged in a cylindrical housing with the axis of the tube running in the same direction as that of the housing. While one fluid travels inside the tubes' interior, the other travels both along and across their length. The most important parts of this heat exchanger are the tubes (or tube bundle), shell, front-end head, rear-end head, baffles, and tubesheets, all of which are described in numerous books on heat transfer. Shell-and-tube heat exchangers can have a variety of different internal constructions, depending on the desired heat transfer and pressure drop performance as well as the methods employed to reduce thermal stresses, to prevent leakages, to provide for ease of cleaning, to contain operating pressures and temperatures, and to Exchangers that use shells and tubes are known as classed and constructed in compliance with the widely used TEMA (Tubular Exchanger Manufacturers Association) standards (TEMA, 77/1999), as well as HE-I81, DIN, and other standards in Europe and worldwide, and ASME (American Society of Mechanical Engineers) boiler and pressure vessel regulations. A notation system has been created by TEMA to indicate the primary categories of shell-and-tube heat exchangers. In this approach, each exchanger is identified by a combination of three letters, with the first letter identifying the kind of front-end head, the second letter indicating the type of shell, and the third letter indicating the type of rear-end head. AES, BEM, and CEM are examples of well-known shell-and-tube exchangers. AEP, CFU, AKT, and AJW were all involved. It should be stressed that there are other particular types of shell-and-tube exchangers that are commercially available and that include front-and-rear-end heads. The TEMA letter designation might not be able to be used to identify these exchangers.

The installation of heat exchanger equipment that is more effective in performance and in reducing or extra energy, cost, and material has become essential in order to cut down on the overall cost and resources that go into transporting this heat energy. The primary objective of this endeavor is to minimize the aggregate cost that is associated with doing so. In this manner, heat transport is transformed into a fundamental technique.

As streams of two liquids with different temperatures are brought into close contact with one another, the fundamental guideline of operation is made more evident; yet, even if they are brought into close proximity, they are still prevented from mixing by a physical limit. At that point, the temperature difference between the two liquids will typically have been adjusted due to the transfer of heat via the tube wall. Fluids can be either liquids or gases, and they can exist on either the shell side or the tube side of the device. The ultimate purpose is to successfully exchange thermal energy, and an enormous heat exchange area should be used by encouraging the use of many tubes. This can be accomplished by provoking the use of numerous tubes. As a result, wasted heat can be put to productive use. This is an efficient way to reduce overall energy use [9-12].

Shell and Tube Heat Exchangers, also known as STHEs, are devices that are utilized for the purpose of exchanging thermal energy and can be found in the food processing industry, power plants, oil refineries, marine applications, and transmission coolers, among other places. In power plants, for instance, they are typically utilized as condensers or boilers, and the steam that is delivered is then used to drive a turbine and generate electricity. Their construction differs from that of conventional heat exchangers in that they consist of an outside shell that is outfitted with baffles and an inward tube bundle that is encased within the STHE headers. This gives them a unique pattern. This form of heat exchanger is able to endure huge pressures as a result of its external shell design, which is in the shape of a cylindrical tube and functions as a pressure vessel.

The baffles, which are controlled walls that are a part of the tube bundle, are responsible for restricting the flow of one liquid all the way through the outer shell, while another liquid is responsible for transferring it through the interior of the tube bundle. These two liquids are exchanging heat with one another through the conductive tube bundle walls, and as they go through the heat exchanger, one of the liquids will become cooler while the other one will become hotter, or vice versa. The headers, which help to pass on the fluid that is streaming inside the tube bundle, could be fastened or welded to the outside shell in order to fulfil their function. The modification of STHE has run into a lack of research to think about the interconnection between turbulent fluid stream structures and heat exchange coming to fruition as a result of effects on the baffles due to the higher cost of the complex trial set up and the fact that there has been a lack of research to think about the interconnection between turbulent fluid stream structures and heat exchange coming to fruition.

Exhibiting geometries that are complex. The segmental baffle shell and tube heat exchanger is the type of STHE that is utilized the most frequently. This type of heat exchanger also includes an outside shell and inner tubes; however, it also incorporates transitional walls known as baffles, which help to fortify the tube bundle and furthermore force the outer shell stream to experience a more drawn out course, as shown in Figure 2.

These baffles could be of an advantageous stature, and their entire length is depicted by a metric that is known as the percent baffle cut. The percentage of baffle cut can be articulated to a rate that is based on the diameter of the outer shell. For example, if you have a half baffle cut, this indicates that the baffles will have a total stature that is equal to half of the separation that runs lengthwise across the shell that contains the tube bundle. In a similar fashion, the distance between each baffle is monitored by a parameter that is known as baffle pitch, and this value can fluctuate all the way through the heat exchangers [13].

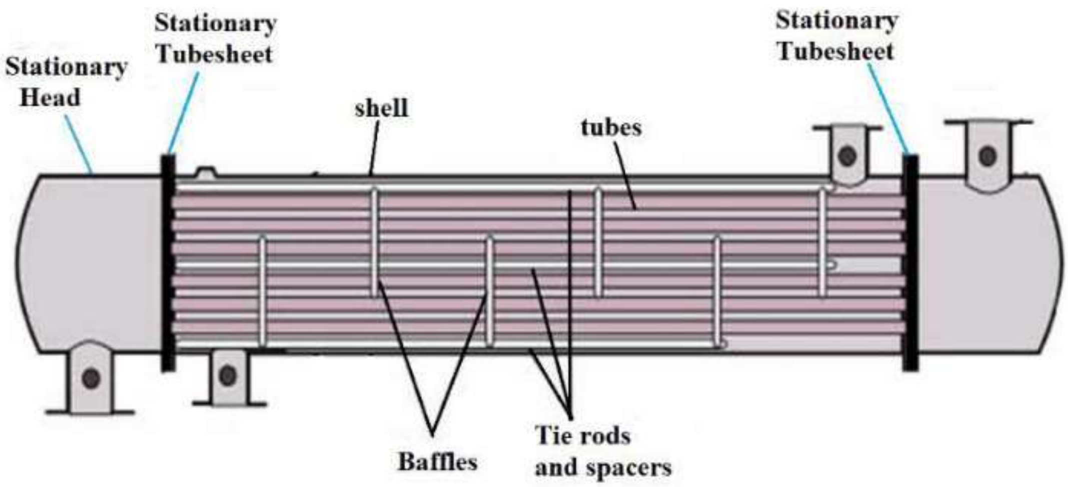

Figure 2: Shell and tube heat exchanger structure and its components

The design of these baffles does not strictly adhere to the concept of late straight walls. A variety of baffle shapes, such as rod baffles, helical baffles, and flower baffles, have been the subject of coordinated considerations. It's possible for the tube bundle that's housed inside the shell of a STHE to comprise a variety of alternative tube layout and action configurations. The parameter termed as tube pitch determines how much space there is between each tube in the tube bundle for the inside-to-focus expulsion to occur. Because increasing the amount of open surface area available for heat transfer allows for a greater number of tubes to be accommodated within the shell, the tube pitch is often a very small partition. As can be seen in figure 3, the stream that is contained within these varieties of shell-and-tube heat exchangers is partitioned into three distinct flow regions: the entrance flow region, the internal flow region, and the window flow zone.

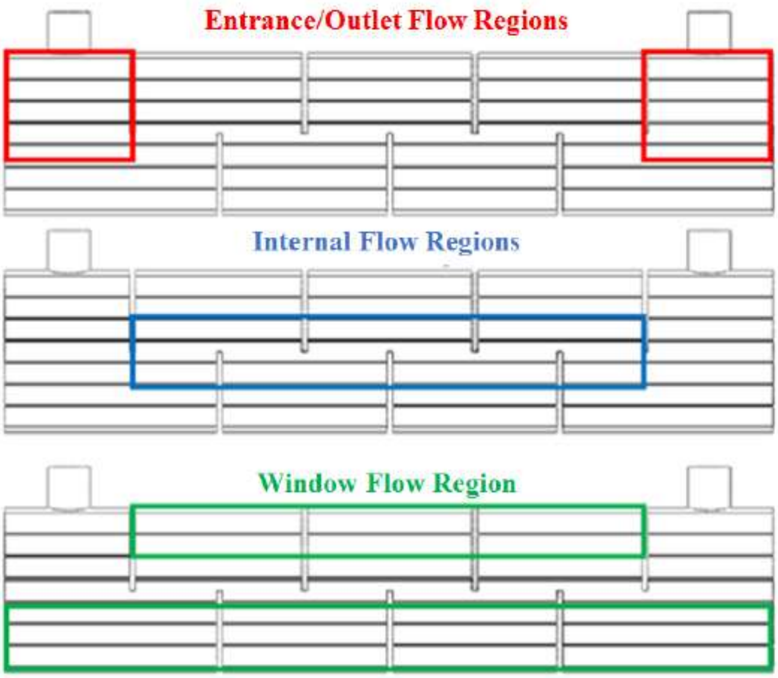

Figure 3: Entrance, internal, and window flow regions

When it reaches the entrance region, the fluid flow that is coming from the shell's approaching side expands and flows in a direction that is perpendicular to the tube bundle. In a similar manner, the flow of fluid in the outlet region moves in a direction that is perpendicular to the tube bundle, but it converges on the output pipe. The fluid travels through the internal zone to reach the region where the flow of fluid is limited by the baffles, which move up and down the length of the chamber.

BAFFLING

Baffles are currently being utilized so that tubes may be supported, an acceptable velocity can be maintained for the liquid on the shell side, and failure of tubes caused by flow-induced vibration can be avoided. They fulfil the function of directing the flow of fluid on the shell side, which results in an increase in the rate of heat transfer [14-16].

There are two different kinds of baffles, and they are as follows:

Plate baffles, Rod baffles

Plate baffles can have a single segment, a double segment, or even a triple segment, as demonstrated in figure 4.

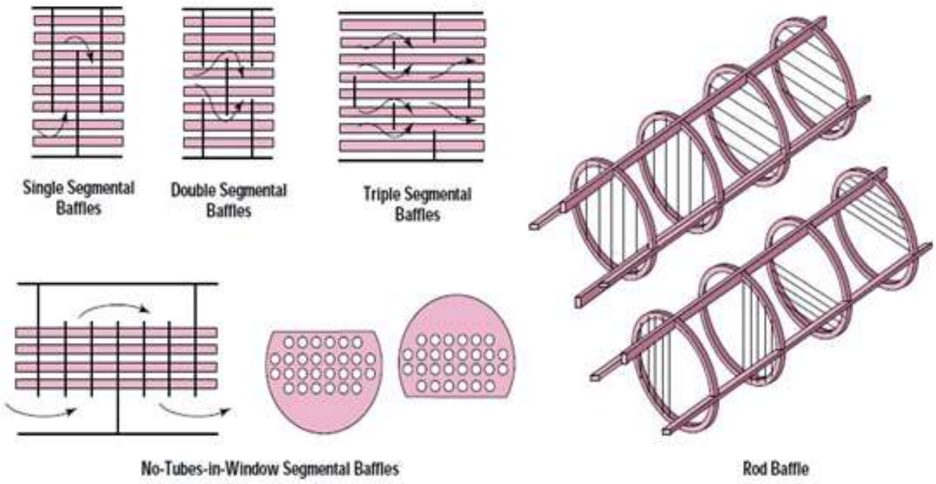

Figure 4: Plate and rod baffles

II. LITERATURE REVIEW

In a timely manner, the relevant research literature is analyzed in order to gain an understanding of the effects of heat transfer and flow characteristics of heat exchangers in general, and shell and tube heat exchangers in particular.

Heat transfer performances (HTPs) of molten salt in the shell side of a shell and tube heat exchanger were tested in the laboratory by Bao-Cun Du et al. (2017) using a specially developed flow arrangement that included U-shaped tubes. This layout was implemented in the laboratory. Experiments are carried out on a shell and tube heat exchanger (STHE) equipped with segmental baffles. Corresponding heat transfer relationships are then fitted and validated by the use of conventional correlation. The findings indicate a higher level of agreement, with only a 2% difference existing between the correlations that were fitted to the data and the data that was tested.

An experimental review of a few shell and tube heat exchangers was published by Jian-Fei Zhang et al. (2009). The heat exchangers included one with segmental baffles and four with helical baffles at helix angles of 20 degrees, 30 degrees, 40 degrees, and 50 degrees, respectively. The results show that the heat transfer coefficient of the heat exchanger with helical baffles is lower than the heat transfer coefficient of the heat exchanger with segmental baffles, while the shell side pressure drop of the former is even much lower than that of the latter. This is based on the similar flow rate on the shell side of both heat exchangers. Any enhancement to the system should be implemented with the end goal of improving the shell side heat exchange based on the same flow rate. This should be kept in mind at all times. Based on the analysis of heat transfer coefficient per unit pressure drop (and pumping power) versus shell side volume flow rate, the following conclusions were drawn from the modelling: (1) the heat exchanger with helical baffles have critical execution advantage over the heat exchanger with segmental baffles; (2) for a similar shell inner diameter, the execution of heat exchanger with helical baffles with 30° helix angle is superior to that of 20°, and the execution of 40° helix angle is greater than Out of the five heat exchangers that were tested, the one with the helical baffles set at a forty-degree angle demonstrates the best execution.

Jie Yang and Wei Liu (2015) came up with the idea for a brand new shell and tube heat exchanger that had updated plate baffles. It is investigated using numerical methods in conjunction with a shell-and-tube heat exchanger that has rod baffles. FLUENT 6.3 and GAMBIT 2.3 are two modelling and computational software packages that are widely used in corporate virtual products. Both the modelling method and the experimental approach are put to the test. Aftereffects of heat transfer, flow performance, and exhausting performance are broken down on the shell side. Plate baffle heat exchangers have a Nusselt number that is approximately 128–139% of the number for rod baffle heat exchangers. In comparison to the rod baffles heat exchanger, the pressure drop for the innovative one is around 139–147% lower. The heat exchanger with the new plate baffles consistently demonstrates significantly greater exhausting performance (115–122%) than the one with the rod baffles. In order to demonstrate the benefits of the innovative shell and tube heat exchanger, the temperature field, the pressure field, and the path lines are investigated.

In this particular piece of research, Hamed Sadighi Dizaji and colleagues (2017) investigated the impact that a shell and tube heat exchanger would have if it were created with a corrugated shell and a corrugated tube rather than a flat shell and a flat tube. A closer look was taken at the distinct behaviors shown by corrugated tubes with concave and convex profiles. In a shell and tube heat exchanger, the energy loss that occurs as a result of simultaneously utilizing corrugated tubes as both the internal tube and the external tube (shell) is not something that has been investigated in recent years. In point of fact, previous tests have revealed focused solely on the warm qualities of corrugated tubes; the effect of these tubes' layering on the energetic properties has not been investigated. Exergonic parameters were thus temporarily centred on a shell and tube heat exchanger made of corrugated shell and corrugated tube in the current work. The aforementioned criteria were evaluated for several different corrugated tube game plans. A one-of-a-kind mechanism that was developed specifically for this purpose was used to transport the corrugated tubes. The findings indicated that grooves were responsible for the increase in both the amount of energy loss and the NTU. In the event that both the tube and the shell become corrugated, the energy loss and the NTU will increase by approximately 17% to 81% and 34% to 60% respectively. The heat exchanger with the most extreme energy tragedy was observed to be one that was built of a convex corrugated tube and a concave corrugated shell.

Experimental research was conducted on two different shell and tube molten salt heat exchangers by Jin Qian et al. (2017). These included a gas-cooled heat exchanger with finned tubes and a molten salt-to-salt heat exchanger with segmental baffles in the shell side. The heat transfer coefficients on the tube side, the shell side, and both sides combined are calculated using a nonlinear regression scheme, and the results are compared with three empirical correlations. In terms of the outcome, the Wu's Equation has demonstrated a higher level of agreement with the experimental data in comparison to both the Gnielinski's and Hausen's Equations.

Ambekar et al. (2016) focused their attention on the ways in which the heat transfer coefficient and pressure drop are affected by the different configurations of baffles found in shell and tube heat exchangers. The heat transfer in a shell and tube heat exchanger was increased by baffles, which also contributed to an extended pressure drop. The layout of a Shell and Tube Heat Exchanger with segmental baffles, helical baffles, and flower baffles is presented, and the results of the various diversions show that the same shell side mass flow rate, heat transfer coefficient, pressure drop, and heat transfer rate can be obtained with the single segmental baffle configuration producing the most phenomenal results.

Anas et al. (2016) documented and evaluated the thermo-hydraulic performance of shell and tube heat exchangers using a variety of baffle configurations. Through the utilization of trefoil hole baffles, the heat transfer has been improved. On the other hand, this adjustment is implemented despite the fact that there would be a significant drop in pressure. In addition, in order to assess the effect of the shell side thermo-hydraulic performance under varying different design parameters, the performance factors with an essentially not too bad exactness are anticipated by numerical model predicts with the assistance of experimental data for segmental baffles. This is done in order to evaluate the effect of the shell side thermo-hydraulic performance.

Experimental and numerical analyses were used by Bala Bhaskara Rao J. and Ramachandra Raju V. (2016) in their investigation of a single shell and multiple pass heat exchangers using a variety of tube geometries, ranging from circular tubes to elliptical tubes. Experimentation is being considered for both the hot fluid in the tube side and the cold fluid in the shell side, using circular tubes with a tube count of 600 and a baffle cut of 25%. The results are presented as rates of heat transfer and reductions in pressure for a range of Reynolds numbers, from 4000 to 20000. The fluent programme is what is used to perform the numerical analysis. For the purpose of doing that study, circular and elliptical tube geometries with 450, 600, and 900 orientations are all considered. Comparisons are made using the outcomes of experimental data and numerical analysis of 25% baffle cut, quarter baffle cut, and mirror quarter baffle cut configurations.

III. METHODOLOGY

As part of the experiment, a traditional shell and tube heat exchanger (STHX) with a segmental baffle was deployed. In this type of heat exchanger, the hot water flows in the tube side, while the cold water flows in the shell side in a configuration known as a counter current. In order to carry out numerical analysis, the geometrical parameters for the experimental setup are carried out. The experimental findings are used to validate the numerical findings. If the error rate is within a tolerable range, the new design configuration of the STHE will include adjustments to the Tube layout, Baffle cut, and number of Baffles. Existing boundary conditions are investigated using these newly developed models [17].

- When designing and optimizing a shell and tube heat exchanger, it is absolutely necessary to have a solid understanding of the relevant technical vocabulary.
- Rating is the process of determining how much heat is transferred and how much pressure is dropped by a heat exchanger.
- Sizing refers to the process of determining the construction type, as well as the physical size, flow arrangement, tube material, and fins.

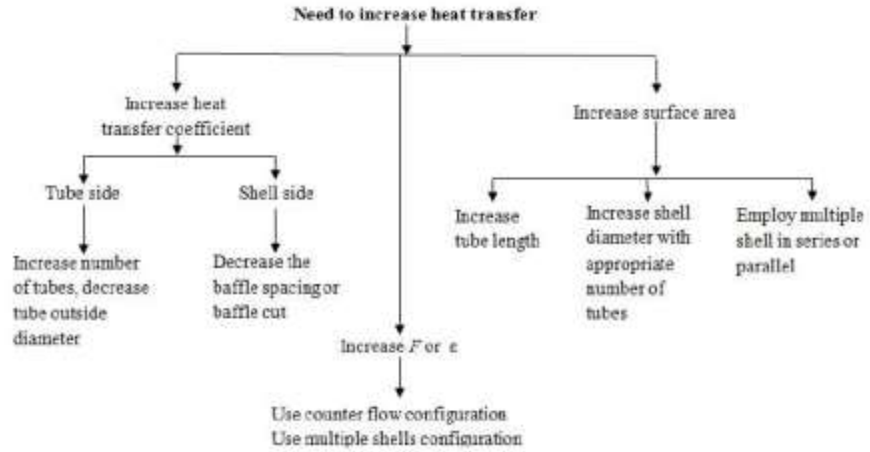

Figure 5: Effects of geometrical variables on heat transfer in STHX

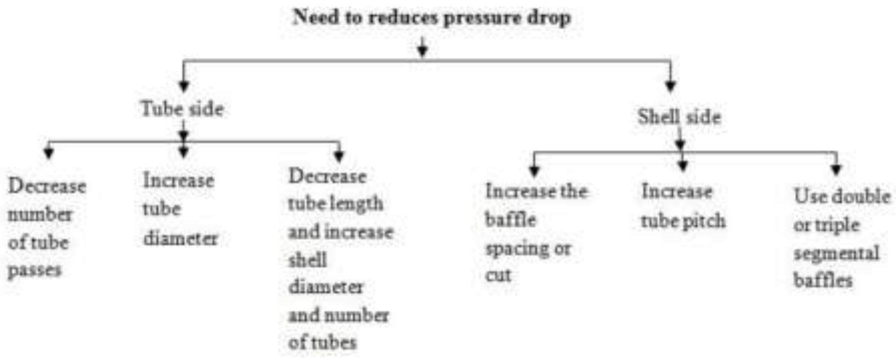

Figure 6: Effects of geometrical variables on pressure drop in STHX

Any shell and tube heat exchanger should strive to maximize heat transmission while simultaneously minimizing pressure drop as its primary goals. As can be seen from the figures 5 and 6, it is necessary to reduce the diameter of the tubes in order to boost the amount of heat that is transferred. On the other side, it has been discovered that increasing the diameter of the tube should be done in order to lower the pressure drop. Because of this, the variables in the process of obtaining the objective functions become contradictory. As a result, we require optimization in order to locate the values that will allow us to concurrently maximize one objective function while simultaneously minimizing the impact of another objective function. The design of a shell and tube heat exchanger involves a number of variables that are subjected into conflicting situations. These variables include the shell diameter, the tube diameter, the tube layout angle, the baffle cut, the tube layout pitch, the length of the tube, the baffle spacing, and the number of tubes.

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. The computational fluid dynamics (CFD) method uses a type of numerical approach known as discretization to advance approximation of the governing equations of fluid mechanics in the fluid region that is of interest [18].

By solving fundamental equations and by limiting the processes of fluid flow, CFD is able to offer information on significant flow features such as pressure loss, flow distribution, and mixing rates. Traditional methods of testing and experimentation are supplemented with CFD analysis, which provides additional insight and increases your confidence in your designs. It consumes fewer time. This leads to products or processes having a better design, a lower risk, and a faster time to market.

The Navier Stokes Equation

The behaviour of a fluid over a period of time is modelled by the Navier-Stokes equation. In this section, we will derive the Navier-Stokes equation in the form that is most frequently seen in works dealing with fluid simulation in computer graphics. The literature on modern fluid simulation found in computer graphics might be intimidating at first, particularly because the techniques given frequently draw on decades' worth of previous study. In a similar manner, general texts on fluid mechanics are frequently very mathematical, whereas texts aimed at fluid simulation are frequently geared toward mechanical engineers and concentrate on particular forms of the Navier-Stokes equation that frequently arise in engineering applications, such as modelling airflow over a wing. To give the reader a reliable mathematical reference on how the fully general Navier-Stokes equation is derived, with annotations along the way to correct common misunderstandings, and to provide the mathematical intuition behind physical quantities such as pressure and viscosity [19], that is the purpose of this section.

Let's take this whole incompressible Navier-Stokes equation and break it down into its component parts, term by term, now that we've derived it. We will see that due to the separability of differential equations, we are able to solve each term independently and apply these operations in serial. Because of this, it is helpful to obtain an intuitive mathematical and physical understanding of each term as well as any additional constraints, such as incompressibility: Remember that equations (3.29 and 3.18) are what make up the incompressible version of the Navier-Stokes equation:

$$\frac{\partial \mathbf{u}}{\partial t} = \mathbf{f} - \frac{1}{\rho}\nabla p + \nu\nabla^2\mathbf{u} - (\mathbf{u}\cdot\nabla)\mathbf{u}$$

$$\nabla\cdot\mathbf{u} = 0 \qquad (1)$$

Advection: $-(\mathbf{u}\cdot\nabla)\mathbf{u}$. This is most likely the most complicated term, as we will see when we discuss methods of solution, and in fact, it is what makes the Navier-Stokes equation a non-linear differential equation due to the fact that it contains two factors of u. In other words, it is what makes the Navier-Stokes equation a non-linear differential equation. The transportation of any amount through a vector field is referred to as advection. For instance, advection occurs when particles move through a vector field, and it's also possible for scalar quantities, like temperature, to be advected through a vector field. In addition to being performed on scalar fields, advection can also be performed on vector fields. To add insult to injury, a vector field is capable of advecting itself. This phenomenon is referred to as self-advection, and it is this phenomenon that the advection term of the Navier-Stokes equation describes in perfect detail. It is difficult to provide further intuition, other than to say that this forms the basis of how to establish a rule to advance from one timestep to the next, as we are modelling future velocity as some function of the current velocity. This is the only thing that comes to mind when attempting to provide further intuition [20].

Diffusion/Viscosity: $\nabla^2\mathbf{u}$, is accountable for modelling the fluid's viscosity in a given environment. Intuitively, one way to think about this form of diffusion is as the application of a smoothing filter in an iterative manner. Generally speaking, velocities that are close to one another will average out to the same value. The viscosity of the substance determines how quickly the velocities will disperse. This helps to explain why viscous fluids settle considerably more quickly after being agitated and exhibit a less "lively" behaviour.

Pressure: $-1/\rho\,\nabla p$ takes into consideration the variations in fluid pressure that cause the observed changes in velocity. Take for example two fluid volumes that are next to one another: if the pressure is extremely high in one fluid volume, but it is low in all of the surrounding fluid volumes, then fluid will seek to migrate out to the low pressure locations (Because of this, it is the cancellation of the divergence field that indicates the path of the maximum pressure increase).

Body Force: **f**, the final concept to consider is the free body force, which is a representation of any external force that is imparted to the fluid. This is typically gravity, but it does not have to be constant. Instead, it might be an arbitrary function over space or time, a parameter of the simulation (such temperature or density), or a forcing function that is employed for aesthetic control.

Continuity/Incompressibility: $(\nabla\cdot\mathbf{u}) = 0$. Despite the fact that this condition is not included in equation 1, it must be satisfied in order to successfully simulate an incompressible fluid. It asserts that there is no deviation in the velocity field in any location on the planet. This ensures that the total amount of fluid that is present at any given time is always equal to the total amount of fluid that is present at any given point in time. The incompressibility condition can be shown to be satisfied by using exactly this equation. When forces are applied inside the fluid, this is what empirically causes a vector field to be "swirly." The reason for this is that when a force is locally applied to a uniform field, it automatically generates divergence. This is what gives a vector field its "swirly" appearance. Since the field must be divergence free everywhere, vortex patterns frequently appear because they are the only way for large velocities to exist while still maintaining a locally divergence free field; each fluid volume in a vortex has an equal amount of fluid coming in as it does going out. This is because the field must be divergence free everywhere.

KERN METHOD

The calculation of shell-side coefficients and pressure drop can be completed quickly using this method, which is also quite straightforward. This method can't be used effectively since it doesn't take into account leakages between the baffle and the shell or the tube and the baffle, and it's only capable of providing a set baffle reduction of 25%. The Kern approach is discussed in the model-1, model-2, and model-3 models. Models 4, 5, and 6 all use the same governing equations and input parameters, hence comparisons between these models are not possible. This strategy was employed as a single objective function by Hadidi at el. [20], Mohanty et al. [21], and Asadi at el. [22]. Models 1 and 2 deal with multi-objective optimization, while Model 3 focuses on single-objective optimization.

THERMAL AND ANALYTICAL MODELLING

The surface area of the heat exchanger can be calculated using [19]

$$A=\frac{q}{U\Delta T_{LM}F} \quad (2)$$

Where q represents the heat amount, U stands for the overall heat transfer coefficient, ΔT_{LM} stands for the logarithmic mean temperature difference, and F stands for the correction factor.

The rate of heat transmission can be calculated using,

$$q=\dot{m}_s c_{ps}(T_{hi}-T_{ho})=\dot{m}_t c_{pt}(T_{co}-T_{ci}) \quad (3)$$

$$U=\frac{1}{\frac{1}{h_o}+R_{o,f}+\frac{d_o}{d_i}\left(R_{i,f}+\frac{1}{h_i}\right)} \quad (4)$$

Where $R_{o,f}$ and $R_{i,f}$ are the fouling resistance figures gathered from the available literature.

$$d_i=0.8d_0 \quad (5)$$

PRESSURE DROP AND OBJECTIVE FUNCTION

Increasing the flow velocity of a heat exchanger with a constant heat capacity will result in an increase in the heat transfer coefficient, as well as an increase in the amount of pressure drop, which will result in additional operating costs.

$$\Delta P_t = \Delta P_{tubelength}+\Delta P_{tubeelbow}=\frac{\rho_t v_t^2}{2}.\left(\frac{L}{d_i}f_t+p\right).N_p \quad (6)$$

Assumed p = 4 from Kern et al. [19] and assumed p = 2.5.

$$\Delta P_s = f_s\left(\frac{\rho_s v_s^2}{2}\right).\left(\frac{L}{B}\right).\left(\frac{d_s}{D_e}\right) \quad (7)$$

Where *fs* is the friction factor.

$$f_s = 2b_0 Re_s^{0.15} \quad (8)$$

$b_0 = 0.72$ [28] $valid for Re_t < 40000.$

$$P=\frac{1}{n}\left(\frac{\dot{m}_t}{\rho_t}\Delta P_t+\frac{\dot{m}_s}{\rho_s}\Delta P_s\right) \quad (9)$$

$$C_{inc} = 8000 + 259.2A_{t,t}^{0.91} \quad (10)$$

Where *Cinc* is the capital investment for exchangers both shell and tubes made out of stainless steel.

$$C_{oc} = Pk_{ell}\tau \quad (11)$$

$$C_{opc} = \sum_{k=1}^{ny} \frac{C_{oc}}{(1+i)^k} \quad (12)$$

$$C_{totc} = C_{inc} + C_{opc} \quad (13)$$

Where *Ctotc* is total cost taken as the objective function, which includes energy cost (*kell*), capital investment (*Cinc*), total discounted operating cost (*Copc*) and annual operating cost (*Coc*).

IV. SIMULATION RESULTS

The piece of software known as Matlab was used to model a shell-and-tube heat exchanger. The following is a list of the geometrical requirements that are utilized in shell and tube heat exchangers:

Table 1: Geometrical Specifications

Parameters	Specifications
Material	Stainless steel
Tube internal diameter	4 mm
Tube external diameter	6 mm
Tube arrangements	Triangular
Number of tubes	7
Tube effective length	184 mm
Shell internal diameter	44 mm
Baffle number	4
Baffle cut	~22%

The pressure drop is an extremely important factor to take into consideration during the design phase of shell and tube heat exchangers. This is due to the fact that it is directly connected to the operational expenses and overall effectiveness of the system. A decrease in pressure drop results in a less significant need for pumping power, which in turn contributes to an improvement in the system's overall efficiency. According to the pressure contours presented above, the downward trend in pressure that can be observed, as well as the conclusion that a higher pressure is required at the inlet in order for the fluid to be able to pass through to the outlet, may be drawn. The pressure drop caused by segmental baffles is significantly higher than that caused by the other two types of baffles, but the pressure drop continues to go lower as the baffle type progresses towards helical baffles, as the graph to the right demonstrates.

It is clear from looking at the pressure contours that the amount of pressure drop that occurs varies in direct proportion to the quantity of mass flow that is being carried. As seen in the graph before it, the following graph displays the variation in shell side pressure drop as a function of mass flow rates ranging from 0.0104 kg/s to 0.032 kg/s. As can be seen in the graph, there is not much of a difference in the amount of pressure that is dropped across any of the three baffles when the mass flow rate is very low. The variation in pressure drop is amplified to a higher degree to the extent that there is a proportional increase in the mass flow rate. As a consequence of this, it is advised that heat exchangers working at greater mass flow rates utilize helical baffles rather than segmental or double segmental baffles. This is because helical baffles are more efficient.

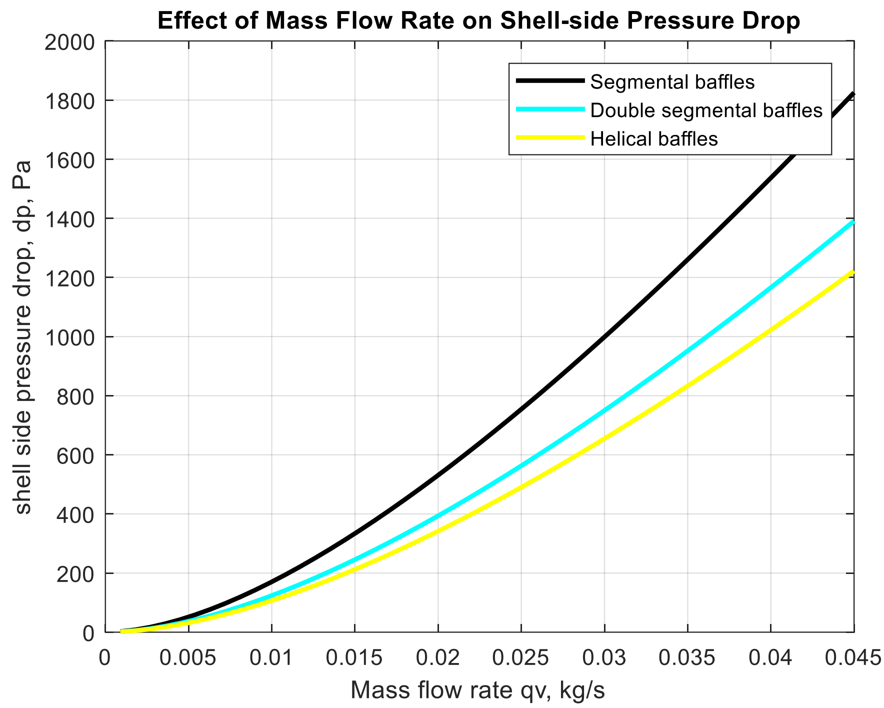

Figure 7: Shell-side Pressure Drop vs mass flow rate

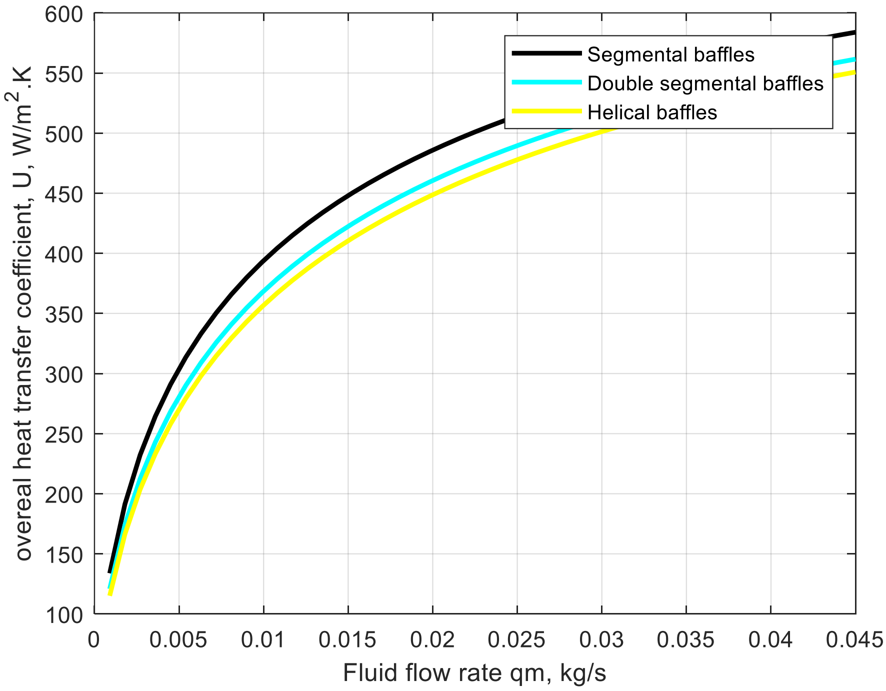

Figure 8: overall heat transfer coefficient fluid flow rate

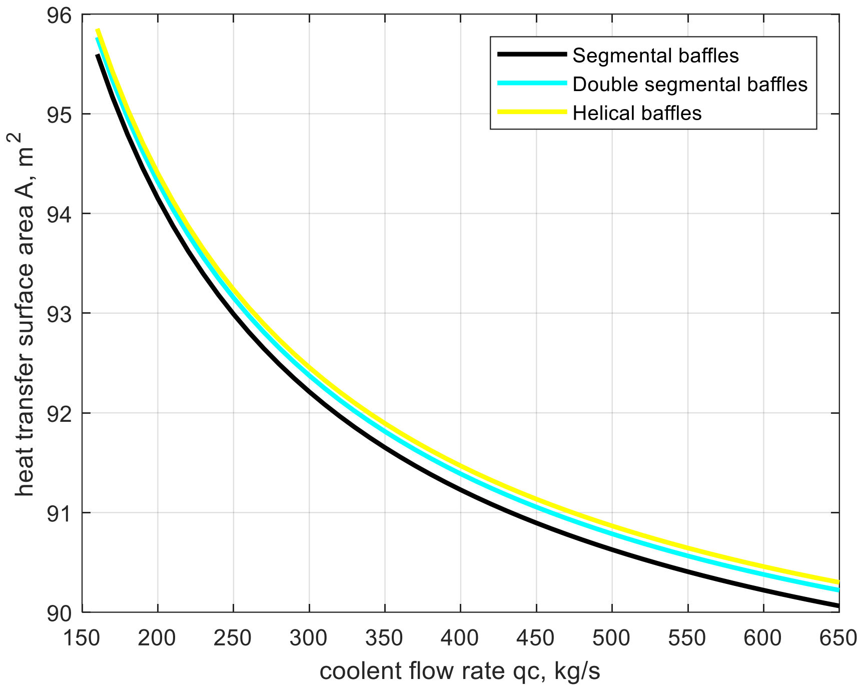

Figure 9: heat transfer surface area vs coolent flow rate

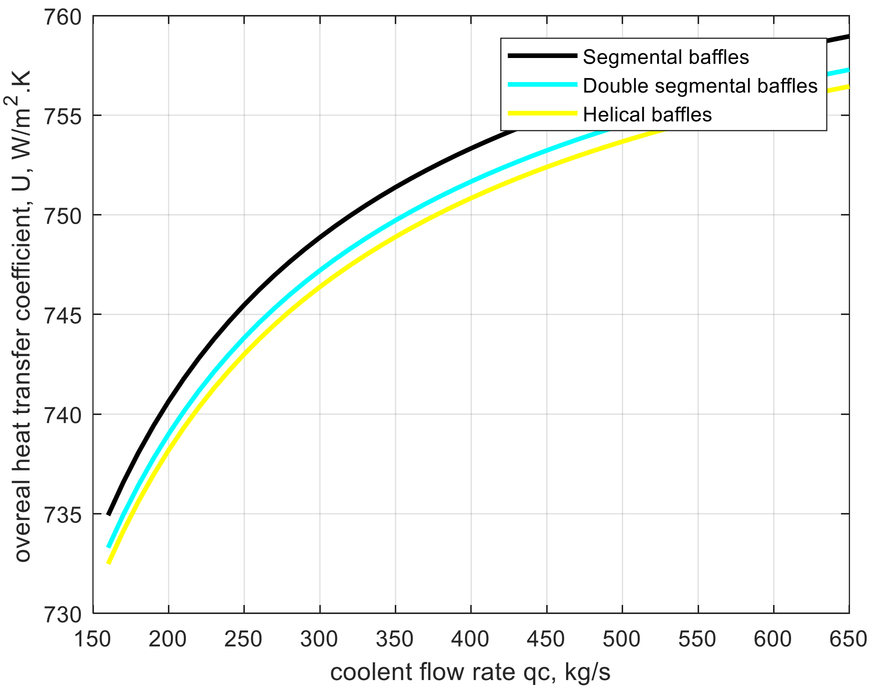

Figure 10: overall heat transfer coefficient vs coolent flow rate

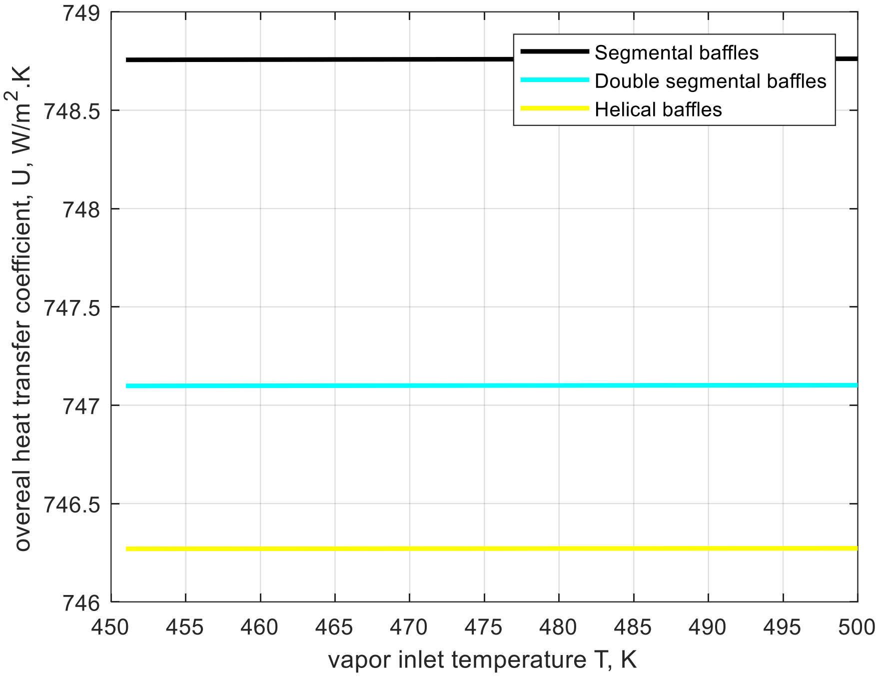

Figure 11: overall heat transfer coefficient vs vapor inlet temperature

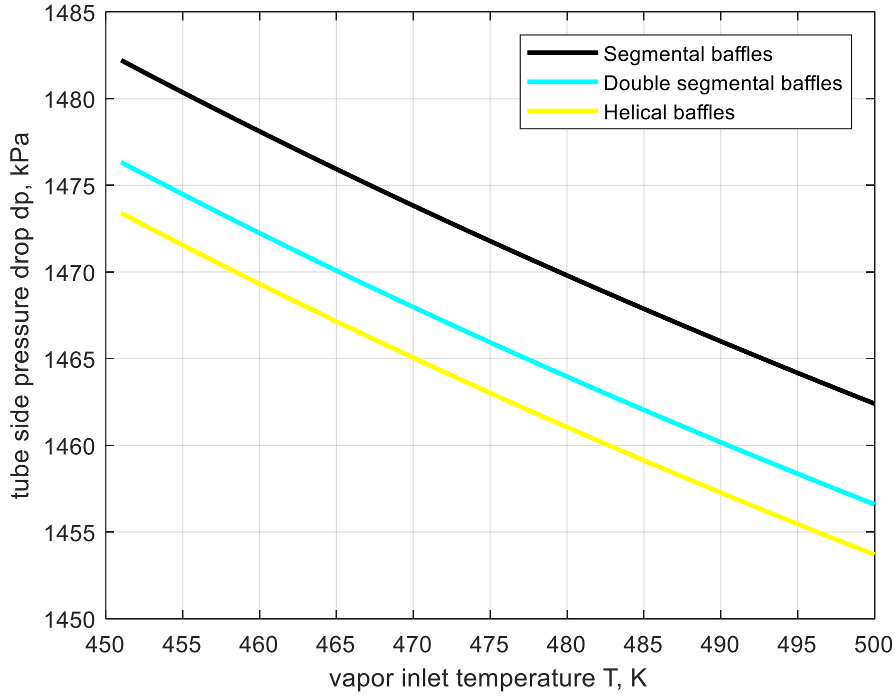

Figure 12: Tube side pressure drop vs vapor inlet temperature

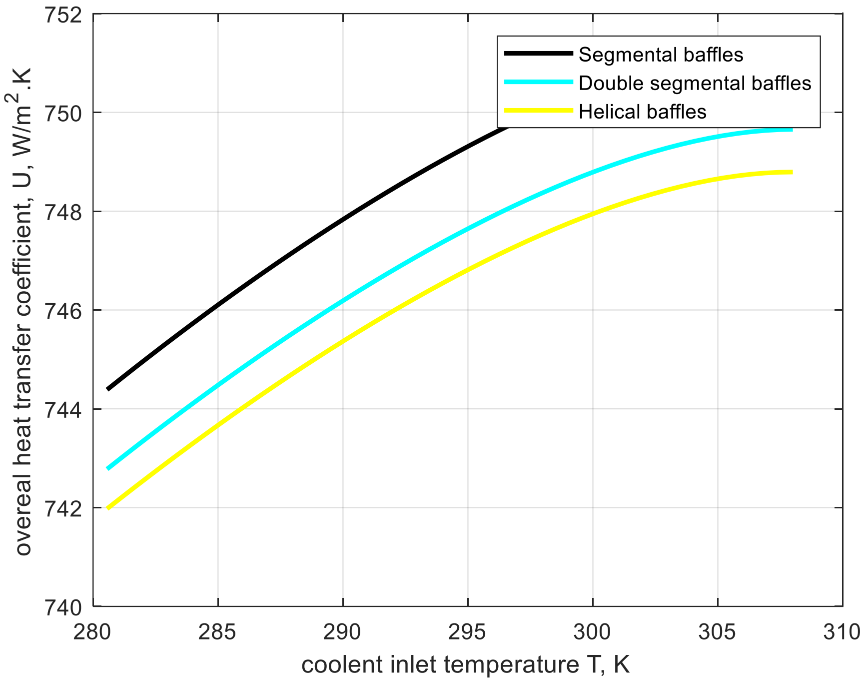

Figure 13: overall heat transfer coefficient vs coolent inlet temperature

V. CONCUSLION

In this work, the fluid performance on the shell side of shell and tube heat exchangers is computed with the help of a numerical model and then compared. In order to demonstrate the role that baffles play in the pressure drop experienced by shell and tube heat exchangers, numerical simulations make use of a variety of baffle designs, including segmental, double segmental, and helical baffles. When the number of baffles is raised past a certain threshold, there is a significant decrease in the pressure that is experienced. It was found that single segmental baffles produce the greatest pressure decrease, while helical baffles produce the least. This was determined by experimenting with different types of baffles while ensuring that the other dimensions remained unchanged.

The formation of dead zones is illustrated by single segmental baffles, which occur when the movement of heat is blocked. To find a solution to this issue, some people have turned to using double segmental baffles. Additionally, it lessens the vibrational damage caused by noise and tremors in comparison to single segmental baffles. However, using helical baffles rather than the other two type's results in a lower pressure drop, which contributes to an overall increase in system efficiency. As a consequence of this, it has become clear that helical baffles are better to the other two types of baffles.

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