Investigation of Baffles Based Shell and Tube Heat Exchanger Using Catia and ANSYS Software

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Abstract - A heat exchanger is a device designed to efficiently transfer heat from one medium to another. The media can be separated by a solid wall to prevent mixing or they can be in direct contact. The CFD solution process consists of modeling and matching the basic shell and tube heat exchanger geometry using the ANSYS 18.0 CFD package. The objective of the project is to dimension a shell and tube heat exchanger with helical baffle and to study the flow and the temperature field inside the shell using the ANSYS software tools. Conventional methods used for the design and development of heat exchangers are expensive. CFD provides a quick cost-effective solution for optimization and design of heat exchangers. CFD results are an integral part of the design process and have eliminated the need for prototypes. Due to the development of CFD models, the use of CFD is no longer a specialized activity.

Keywords- Heat Exchanger, Mass Flow Rate, Baffles Spacing, Catia and ANSYS Software.

1 INTRODUCTION

They are widely used in heating, cooling, air conditioning, power plants, chemical plants, petrochemical plants, oil refineries, natural gas processing and sewage treatment. The classic example of a heat exchanger is found in an internal combustion engine in which a circulating fluid known as engine coolant flows through the radiator coils and air flows through the coils, cooling the coolant and heating the incoming air.

There are three main classifications of heat exchangers according to their flow arrangement. In parallel flow heat exchangers, the two fluids enter the exchanger at the same end and travel parallel to each other to the other side. In countercurrent heat exchangers, fluids enter the exchanger from opposite ends. The countercurrent design is the most efficient as it can transfer more heat from the heat medium (transfer) due to the fact that the average temperature difference over any unit length is greater.

Double tube heat exchangers are the simplest heat exchangers used in industries. For one thing, these heat exchangers are inexpensive to both design and maintain, making them a good choice for small industries. But, on the other hand, their low efficiency, in addition to the high space occupied by such exchangers on large scales, has led modern industries to use more efficient heat exchangers, such as shells and tubes or others. But because double tube heat exchangers are simple, they are used to teach basic heat exchanger design to students, and because basic rules for modern and normal heat exchangers are the same, students can understand the techniques design much easier. To start designing a twin tube heat exchanger, the first step is to calculate the heat load on the heat exchanger. It should be noted that for easier design it is better to ignore heat loss in the heat exchanger for the primary design. The heat duty can be defined as the heat gained by the cold fluid which is equal to the heat loss of the hot fluid. Heat is transferred from one fluid to the other through the walls of the tube, either from the tube side to the shell side or vice versa.

Fluids can be liquids or gases on the shell or tube side. To efficiently transfer heat, a large heat transfer area is used, leading to the use of many tubes. This is an efficient way to use energy and avoid wasting thermal energy. BI. Master and others. in 2006 found that more than 30% of heat exchangers are shell and tube type [1]. Shell and tube heat exchangers can be custom designed considering their operability, maintenance, flexibility and safety. This makes it very robust and serves as one of the main reasons why it is widely used in industries [2]. For an efficient heat transfer process, the heat exchanger should have low pressure drop, high shell-side mass flow velocity, high heat transfer coefficient, and no or very low fouling, and so on. Heat transfer also depends on the amount of turbulence created on the hull side. This turbulence can be created using deflectors. Several types of deflectors are listed in the literature. Some of the commonly used ones are segmental, double segmental, triple segmental, donut type, helical type, double helical and flower type. When traditional segmental baffles are used in the shell and tube heat exchanger, a higher pumping power is usually required to compensate for the higher pressure drop under the same heat load. The SG-STHX problems mentioned above were improved or solved by helical baffles [3]. The discontinuous helical tube and shell heat exchanger was initially proposed by Lutcha and Nemcansky [4] and commercially produced by numerical investigation to study the impact of various angles of baffle inclination on fluid flow and shell heat transfer. and continuous helical tube heat exchangers using periodic model. From the computed results, it was observed that the best integrated performance occurs at approximately 45° of helix angle. The performance of the heat exchanger also depends on the pressure drop. Leakage can reduce the pressure drop and therefore the average heat transfer coefficient per compartment.

Gaddis and Gnielinsk [5] proposed a procedure to evaluate the pressure drop and its comparison with experimental data. Based on the flow arrangement, the shell and heat exchangers are classified as parallel (co-current) and counter-current (concurrent). In a counterflow or countercurrent exchanger, the two fluids flow parallel to each other but in opposite directions inside the core (the temperature variation of the two fluids in such an exchanger can be idealized as one-dimensional). As shown later, the counterflow arrangement is thermodynamically superior to any other flow arrangement [6].

It is the most efficient flow arrangement, producing the greatest temperature change in each fluid compared to any other two fluid flow arrangements for a given overall thermal conductance (AU), fluid flow rates (actually capacity rates of fluid heat) and fluid inlet temperatures [7-10]. In addition, use of helical; The baffles proved to be more efficient at transferring heat than the original segmental tube and hull heat exchanger in the same hull structure and at the same mass flow rate.

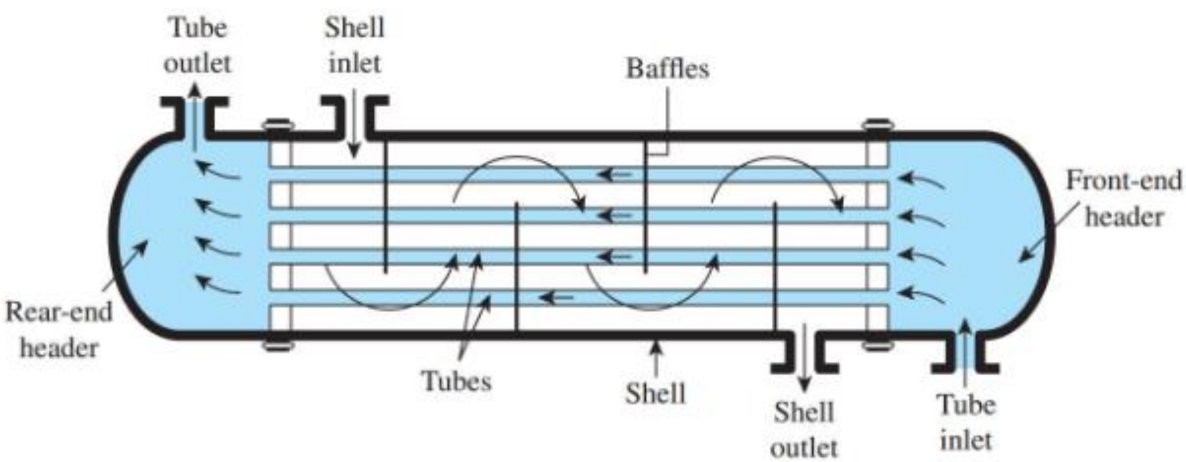

Figure 1. A diagram of shell and tube heat exchangers

2 LITERATURE REVIEW

S.Rajasekaran, et al. (2019). The aim of this article is to develop and test an optimization model for the initial design phase of shell and tube heat exchangers through the application of the Modified Genetic Algorithm (MGA). The Modified Genetic Algorithm is based on the integration of classical genetic algorithm structure and a systematic neighborhood structure. The MGA model can help designers make decisions in the early stages of the design process. With an MGA model, it is possible to obtain an approximately better prediction even when the necessary information is not available in the design process. This model proved that the MGA is able to provide better solutions with higher quality even with inadequate data.

Chen Fang, et al. (2019), steam-vented shell-and-tube heat exchangers show promise because they address the problems of high pressure drop, flow instability, and local drying that are common in conventional two-phase microchannel heat sinks. We present a 3D numerical simulation of the steam venting process in a rectangular microchannel limited on one side by a porous hydrophobic membrane for phase separation. The simulation is based on the fluid volume method (VOF) together with models for interphase mass transfer and capillary force. The simulation shows that the steam ventilation mechanism can effectively mitigate the steam accumulation problem, reduce the pressure drop and suppress local drying in the microchannel. Pressure surge is observed in the steam vent channel. The simulation provides some insight into the design and optimization of steam vented heat exchangers.

Praful Date, et al. (2020), This article proposed the new approach for the improvement of the heat transfer of the plate and fin heat exchanger using an improved fin design facilitating the generation of vortices. The vortex generator can be embedded in the flat fin and also cost-effectively, effecting the unique design and configuration of commonly used heat exchangers. The various design modifications that are implemented and studied numerically and experimentally are discussed in the article.

Akpa, J. G. et al. (2022) , Mathematical models that can be used to predict the transient behavior of heat exchangers in a Heat Exchanger Network (HEN) were developed. This analysis aims to predict thermal transients in heat exchanger networks due to inlet flow temperature fluctuations. This model is used to predict the thermal transient of heat exchanger networks in the crude oil distillation unit of the New Port-Harcourt refinery. The response of heat exchangers across the network to transient input (sinusoidal change in cold stream inlet temperature) was investigated. A finite difference numerical scheme is used to develop a solution algorithm to solve the compensation partial differential model equations. The results reveal the effect of changing inlet temperature on process streams and possible points where temperature control is needed in the heat exchanger networks at the Newport Harcourt refinery.

F. Vera-García, et al. (2022), In this article a simplified model for the study of shell and tube heat exchangers (HXs) is proposed. The model aims to match the HXs when they are functioning as condensers or evaporators. Despite its simplicity, the model proves to be useful for the pre-design and correct selection of shell and tube HXs working in complete and complex refrigeration systems. The heat transfer coefficient and pressure drop correlations are specially selected and treated to implement them in the featured shell and tube HXs. The model is implemented and tested in the modeling of a general refrigeration cycle and the results are compared with data obtained from a specific test bench for analysis of shell and tube HXs.

3 PRINCIPLE

The principal components of an STHE are:

• Shell;

• Shell cover;

• Tubes;

• Channel;

• Tube sheet;

• Bafflesandnozzles.

Other components include tie rods and spacers; Passage divider plates, impact plate, longitudinal baffle, sealing strips, supports and foundation. The Tubular Exchanger Manufacturers Association (TEMA) Standards (1) describe these various components in detail. An STHE is divided into three parts: the front head, the shell and the back head. Changers are described by the letter codes for the three sections for example; a BFL changer has a hood cover, a two pass shell with a longitudinal baffle and a fixed tube sheet rear head.

4 PROCEDURE

Every analysis involves three main steps:

Pre-processor

Solver

post processor

ANSYS Evaluation

5 MODELING COMPOSITES

Composites are a little more difficult to model than an isotropic material such as iron or steel. We need to be especially careful in defining the properties and orientations of the various layers, as each layer can have different orthotropic material properties. In this section, we will focus on the following aspects of building a composite model:

1. Choosing the proper element type
2. Defining the layered configuration

3. Specifying failure criteria
4. Following modelling and post-processing guidelines

6 COMPUTATIONAL FLUID DYNAMICS

Computational Fluid Dynamics is based on the Navier-Stokes equation, which is given in general format as: Computational domain, mesh and boundary conditions The heat exchanger is modeled using three different types of baffles. In these models, only the shell-side fluid domain is modeled and mixed using a tetrahedral grid type. Meshes are generated using the ANSYS Meshing tool. The quality and asymmetry of the elements are checked to keep them within limits. Three grids with a total cell count of ~2.1 million, ~3.7 million, and ~4.3 million are computed. The pressure drop for all three cases is monitored and the difference between ~3.7 million and ~4.3 million is less than 0.5%. Taking into account solution accuracy and computation time, a grid of ~3.7 million was chosen.

The flow in the shell and tube heat exchanger is highly turbulent. Due to the merits of the k-ε turbulence model, it is preferred for modeling turbulence in shell-and-tube heat exchangers. This simulation uses a realizable k-ε turbulence model with a scalable wall function. The scalable wall functions allow for solutions on arbitrarily thin near-wall grids, which is a significant improvement over the standard wall functions. The k-ε realizable model is often used to capture rather coarse mesh contour effects. Solid walls are defined with no-slip moment limit condition. The inlet to the enclosure is defined as a mass flow inlet. Mass flow rates range from 0.0104 kg/s to 0.032 kg/s. The outlet of the enclosure is said to be a pressure outlet with pressure such that the inlet pressure is equal to the pressure drop. All governing equations are solved to second-order precision and the residual bound is set to 10-4. The SIMPLE algorithm was used to solve the pressure-related equations.

Table 1. Geometrical specifications

Sl. No.	Parameters	Specifications
1.	Material	Nickel based Stainless steel
2.	Tube internal diameter	60 mm
3.	Tube external diameter	70 mm
4.	Tube arrangements	Triangular (40 degree angle each other)
5.	Number of tubes	18
6.	Tube effective length	1000 mm

7.	Shell internal diameter	780 mm
8.	Shell internal diameter	790 mm
9.	Baffle number	3

7 SHELL AND TUBE HEAT EXCHANGER

The thermal design of shell and tube heat exchangers (STHEs) is done by sophisticated computer software. However, a good understanding of the basic principles of exchanger design is required to use this software effectively. This article explains the fundamentals of thermal exchanger design, covering topics such as: STHE components; classification of STHEs according to construction and according to service; data needed for thermal design; tube side design; shell-side design, including tube layout, baffle, and shell-side pressure drop; and average temperature difference. The basic equations for tube-side and shell-side heat transfer and pressure drop are well known; here we focus on applying these correlations to optimal heat exchanger design. A follow-up article on advanced topics in shell-and-tube heat exchanger design, such as shell-side and tube-side fluid allocation, use of multiple shells, oversizing, and fouling, is scheduled to appear in the next issue.

A baffle plate heat exchanger is a type of heat exchanger that uses a series of plates or baffles to improve heat transfer between two fluids. It consists of multiple parallel plates arranged in such a way as to create a series of channels for the flow of the two fluids. These plates are designed with alternating patterns of holes or grooves to direct fluid flow and create turbulence, thus maximizing heat transfer efficiency. The baffle plates are positioned to redirect the fluid flow in a zigzag or criss-cross pattern, promoting greater contact and mixing between the hot and cold fluids. This arrangement increases the surface area available for heat transfer and improves the overall heat exchange efficiency.

Hot and cold fluids flow through separate channels, with one fluid passing on one side of the plates and the other fluid passing on the opposite side. As the fluids flow in their respective channels, heat is transferred through the walls of the plate, allowing the hot fluid to transfer its thermal energy to the cold fluid. Baffle plate heat exchangers are commonly used in various industrial applications including heating, ventilation, air conditioning, refrigeration systems and chemical processes. They are particularly effective when there is a significant temperature difference between the two fluids or when efficient heat transfer in a compact design is required.

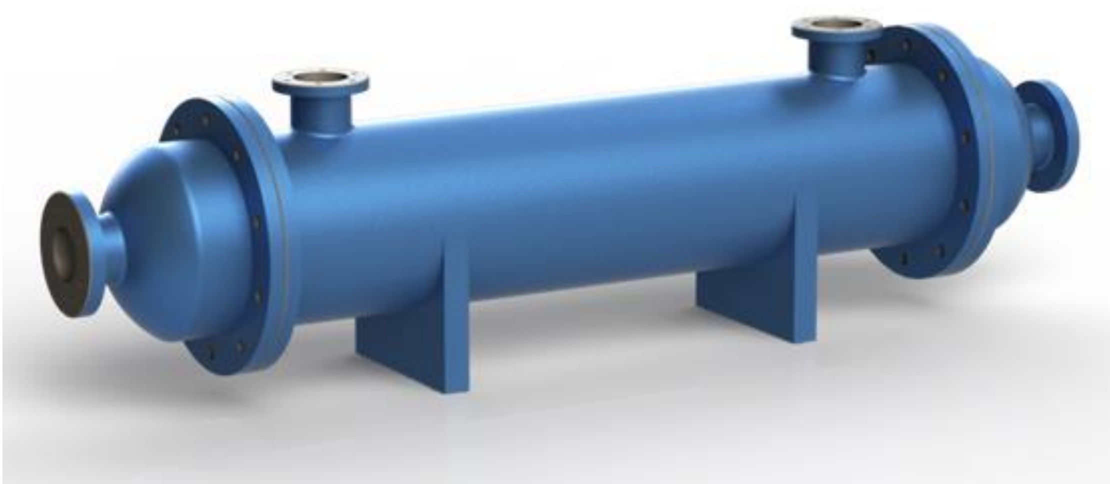

Figure 2. Modeling of shell and tube heat exchanger

A heat exchanger shell refers to the outermost container or shell of a heat exchanger. Heat exchangers are devices used to transfer heat from one fluid to another without the fluids coming into direct contact with each other. They are commonly used in various industries including power generation, chemical processing, HVAC (heating, ventilation and air conditioning) and refrigeration.

The shell of a heat exchanger serves as the primary outer shell that contains the fluid being heated or cooled. It is typically a cylindrical or rectangular vessel made of metal (such as carbon steel, stainless steel or copper) and is designed to withstand the pressure and temperature conditions of the process.

Within the enclosure there are usually one or more tubes or channels through which the heat transfer fluid flows. These tubes are called a tube bundle or tube bank. The enclosure surrounds the tube bundle and contains the fluid being heated or cooled, called the process fluid. The process fluid flows on the outside of the tubes, while the heat transfer fluid flows inside the tubes.

The enclosure is equipped with inlet and outlet connections for both the process fluid and the heat transfer fluid. The heat transfer fluid, often referred to as the thermal medium or working fluid, is circulated through the tubes, absorbing or releasing heat as it comes into contact with the process fluid through the tube walls.

The design and construction of the enclosure depends on many factors such as the operating conditions (temperature and pressure), the properties of the fluids involved, the desired heat transfer efficiency and the overall system requirements. Different types of heat exchanger enclosures include:

Fixed tube sheet: The tube ends are welded or mechanically attached to a tube sheet at each end of the shell, creating a fixed configuration.

Floating Head: One end of the tube bundle is connected to a floating head that can move within the enclosure, allowing for thermal expansion and contraction of the tubes. This design facilitates tube maintenance and cleaning.

U-Tube: The tube bundle consists of U-shaped tubes that are bent into a U-shape, with both ends of the tubes attached to a common tube sheet. This design is suitable for applications where differential thermal expansion between the shell and tube bundle needs to be accommodated.

Shell and Tube: This is the most common type of heat exchanger, consisting of a cylindrical shell and a bundle of straight tubes. The process fluid flows on the outside of the tubes, while the heat transfer fluid flows inside the tubes.

Selection of heat exchanger shell type depends on specific application requirements, such as the nature of the fluids, pressure and temperature differentials, maintenance considerations, and space limitations.

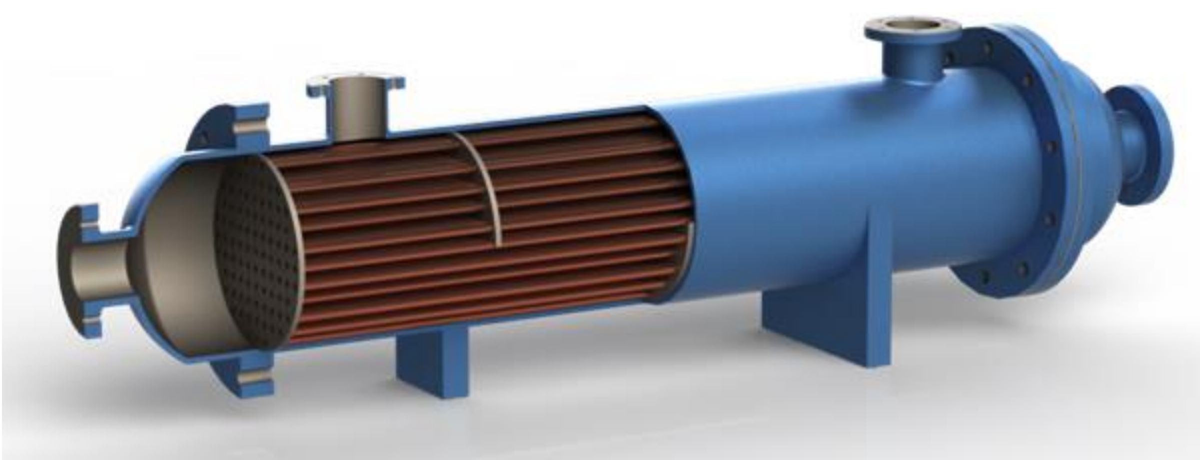

Figure 3. Cross-sectional view of a heat exchanger

A cross-sectional view of a heat exchanger is a representation that shows the internal structure and components of the heat exchanger in cross-section. It provides a cross-sectional view of the heat exchanger, allowing you to view its inner workings.

A heat exchanger is a device used to efficiently transfer heat between two fluids without allowing them to mix. It typically consists of two main fluid paths separated by a barrier or solid plate. The section view helps us understand the arrangement and flow of these paths.

In a sectional view of a heat exchanger you would typically see the following components:

Shell: The outer shell or shell of the heat exchanger, which surrounds the internal components and contains the fluid.

Tubes: These are hollow tubes that carry one of the fluids. They are usually arranged in a bundle or array within the enclosure. The sectional view allows you to see the layout and configuration of the tubes.

Tube Sheet: A tube sheet is a thick metal plate or sheet that supports the tubes and provides a seal between the casing and the tube-side fluid. It is often visible in the section view, indicating the position of the tubes.

Baffles: Baffles are plates or structures placed inside the enclosure to direct fluid flow and enhance heat transfer. They can be seen in the section view, helping to visualize their placement and effect on fluid flow.

Headers: The headers are the distribution chambers at the entrance and exit of the tubes. They distribute the fluid evenly between the tubes or collect it as it leaves the tubes. The section view can show the headers and their pipe connections.

Fins or Plates: In some heat exchangers, fins or plates are attached to the outer surface of the tubes to increase the heat transfer area. These may be visible in the section view, depending on the type of heat exchanger.

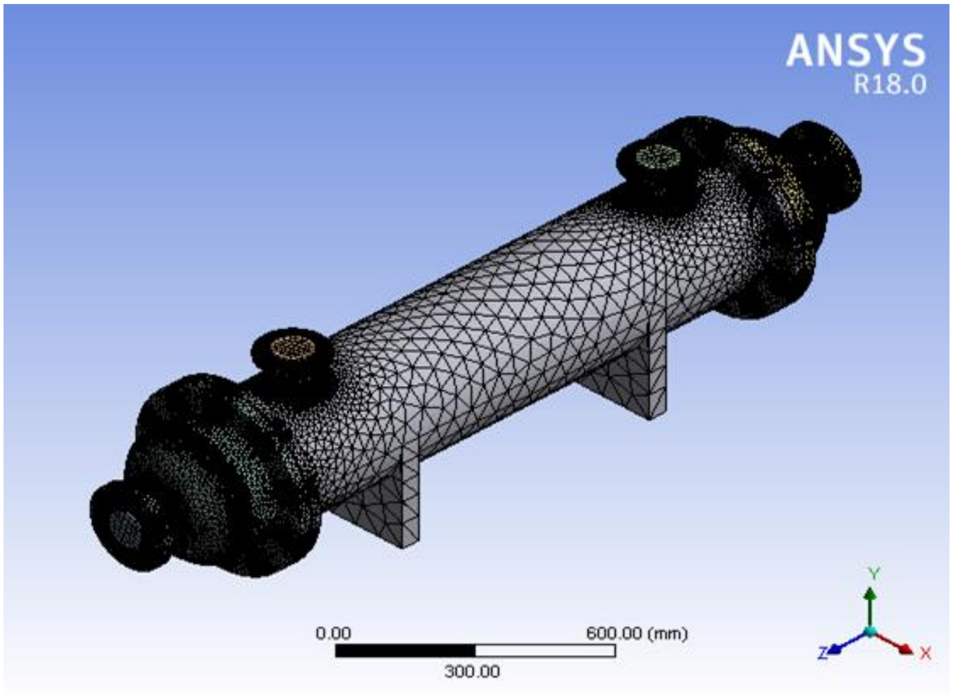

Figure 4. Meshing view of a heat exchanger

Meshing is a process commonly used in computer simulations and computer-aided engineering (CAE) to discretize a continuous domain into a collection of smaller, interconnected elements called "meshes" or "finite elements". In the context of computational analysis, the continuous domain typically represents a physical object or system, such as a solid structure, volume of fluid, or electromagnetic field. The goal of meshing is to approximate the continuous domain with a discrete representation that can be easily manipulated by numerical algorithms. The meshing process involves dividing the domain into smaller sub-regions, such as 2D triangles or quadrilaterals or 3D tetrahedrons or hexahedra, depending on the dimensionality of the problem.

These sub-regions are then connected at specific points called nodes or vertices, forming a network of interconnected elements. Mesh quality plays a crucial role in the accuracy and efficiency of the simulation or analysis. A well-designed mesh should capture the domain's important features and characteristics, minimizing errors and distortions.

Mesh generation techniques and algorithms take into account factors such as domain geometry, desired resolution, type of analysis being performed, and computational constraints to generate an appropriate mesh. Once the meshing process is complete, numerical methods can be applied to solve the problem's governing equations within each element, producing approximate solutions. The results obtained from mesh-based simulation can provide information about various physical phenomena, aiding in design optimization, performance evaluation and decision-making processes in engineering and scientific disciplines.

The section view provides valuable insight into the internal structure of the heat exchanger, allowing engineers and technicians to analyze design, performance and potential issues. Helps understand fluid flow patterns, heat transfer mechanisms and overall heat exchanger efficiency

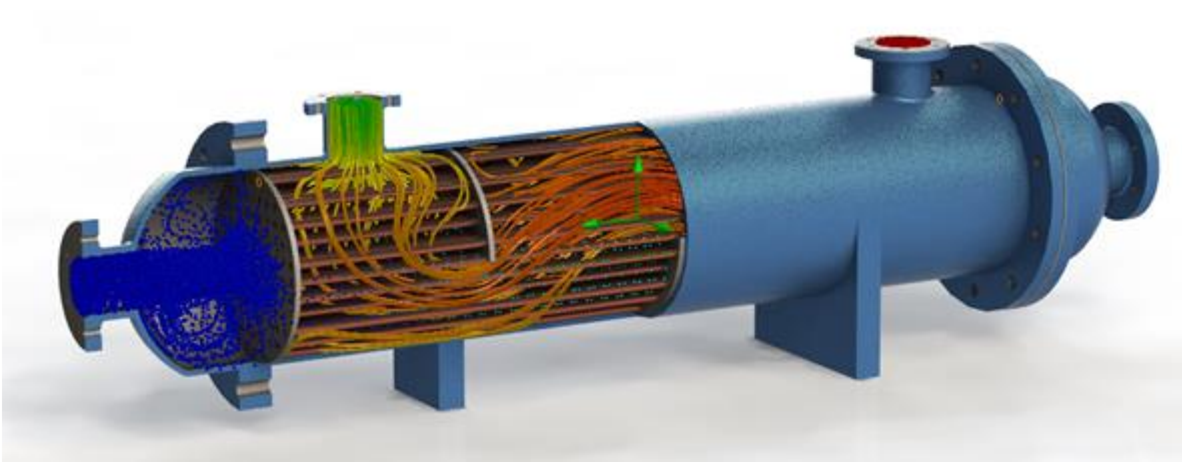

Figure 5. Fluid flow patterns of a heat exchanger

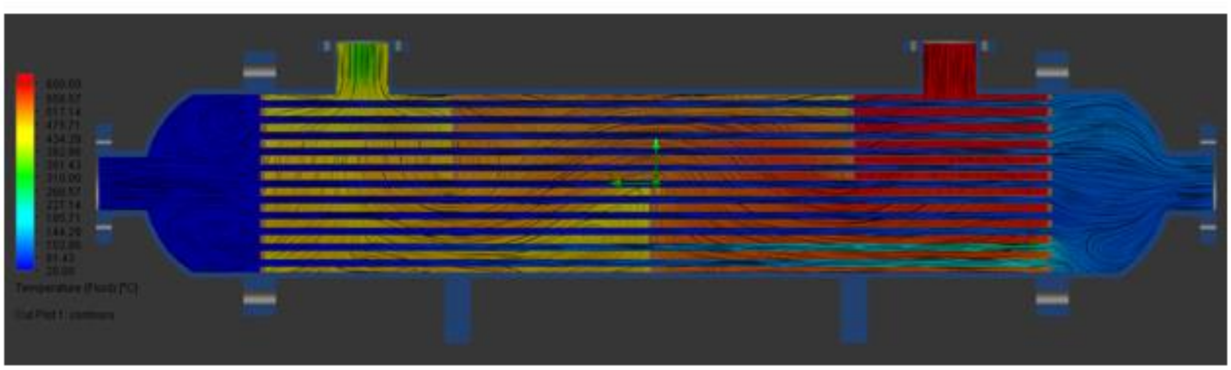

Figure 6. Temperature distribution in a heat exchanger

The temperature distribution in a heat exchanger depends on many factors such as design, operating conditions and fluid properties. However, I provide a general understanding of how the temperature typically varies in a typical countercurrent heat exchanger. In a countercurrent heat exchanger, two fluids flow in opposite directions, with one fluid entering at one end of the exchanger and the other fluid entering at the opposite end. As fluids pass through the exchanger, heat is transferred from the hotter fluid to the cooler fluid.

At the inlet of the heat exchanger, the hot fluid has a higher temperature, while the cold fluid has a lower temperature. As fluids flow through the exchanger, the temperature of the hot fluid decreases while the temperature of the cold fluid increases. Ideally, in a perfectly designed heat exchanger with perfect heat transfer, the fluids would reach a point where their temperatures equalize. However, in practice, there is often a temperature difference between the two fluids, even at the end of the exchanger, due to various factors such as fluid flow rates, heat transfer limitations, and thermal resistances. The temperature distribution can be represented graphically as a temperature profile along the length of the heat exchanger. Initially, the temperature profile shows a sharp temperature difference between the hot and cold fluids, but as they pass through the exchanger, the temperature difference decreases and the profile becomes flatter.

The exact temperature distribution profile depends on factors such as the overall heat transfer coefficient, flow rates, inlet temperatures, fluid properties and the specific design of the heat exchanger (e.g. tube and shell, heat exchanger boards, etc.). In addition, the temperature distribution can be affected by the presence of scale, scaling or other factors that can decrease the efficiency of heat transfer over time.

It is worth noting that there are several mathematical models and numerical methods available to simulate and calculate temperature distributions in heat exchangers based on specific operating conditions and design parameters. These models take into account factors such as fluid properties, heat transfer coefficients, and geometry to provide more accurate predictions of temperature distribution.

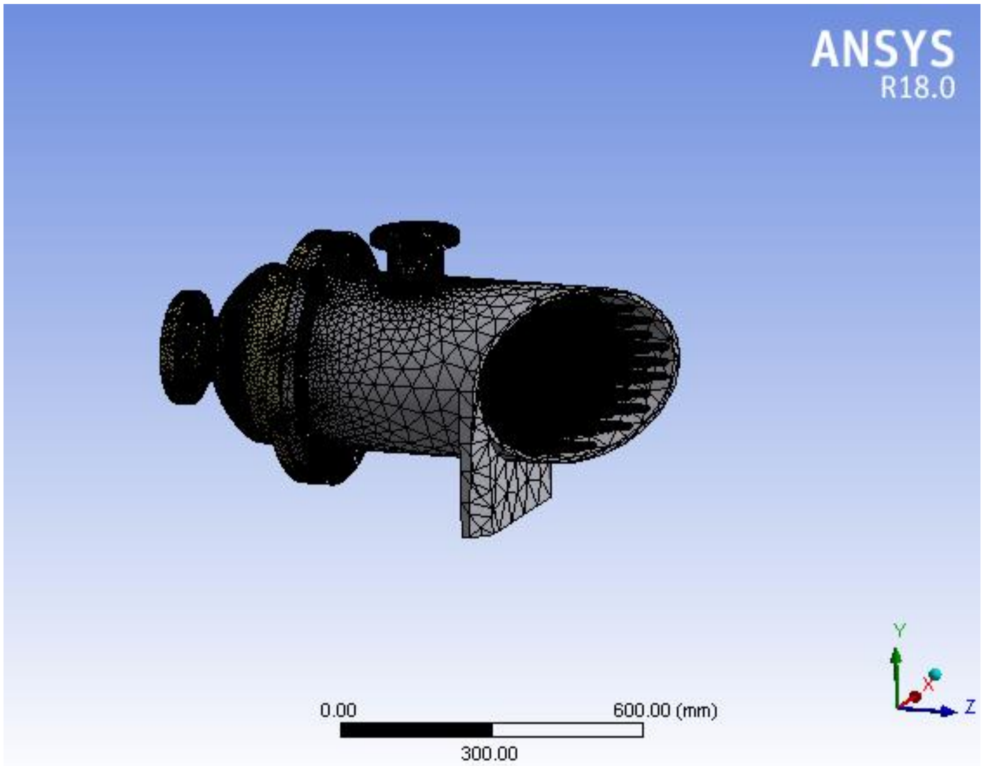

Figure 7. Exact temperature distribution profile of a heat exchanger

8 CONCLUSIONS

It is accessible to process engineers, plant operators and managers. CFD is still a developing art in erosion/corrosion prediction due to the lack of adequate mathematical models to represent the physical process.

From the obtained results, it was found that the triple baffle heat exchanger is better than four baffles types of heat exchangers. It has also been found that the well-defined triple baffle heat exchanger is having more heat flux and thermal distribution. This will further improve the performance of the heat exchangers.

REFERENCES

1. Anas El Maakoul, Numerical comparison of shell side performance for shell and tube heat exchangers with trefoil-hole, helical and segmental baffles, Applied Thermal Engineering (2017).
2. Eduardo M. Queiroz, "Design optimization of shell-and-tube heat exchangers", Applied Thermal Engineering 28 (2018) 1798–1805.

3. B.B. Gulyani, Estimating number of shells in shell and tube heat exchangers: a new approach based on temperature cross, Trans. ASME J. Heat Transfer 122 (3) (2016) 566–571.
4. B.I. Master, K.S. Chunangad, A.J. Boxma, D. Kral, P. Stehlík, Most frequently used heat exchangers from pioneering research to worldwide applications, Heat Transfer Eng. 27 (6) (2016) 4– 11.
5. E.S. Gaddis, V. Gnielinski, Pressure drop on the shell side of shell-and-tube heat exchangers with segmental baffles, Chem. Eng. Process. 36 (2) (2007) 149–159.
6. J. Lutcha, J. Nemcansky, Performance improvement of tubular heat exchangers by helical baffles, Chem. Eng. Res. Des. 68 (3) (2017) 263– 270.
7. K.J. Bell, Heat exchanger design for the process industries, transactions of the ASME, Trans. ASME J. Heat Transfer 126 (6) (2014) 877–885.
8. M. M. El-Fawal, A. A. Fahmy and B. M. Taher, “Modelling of Economical Design of Shell and tube heat exchanger Using Specified Pressure Drop”, Journal of American Science.
9. M.Serna and A.Jimenez, “A compact formulation of the Bell Delaware method for Heat Exchanger design and optimization”, Chemical Engineering Research and Design, 83(A5): 539–550.
10. Q.W. Wang, G.D. Chen, J. Xu, Y.P. Ji, Second-law thermodynamic comparison and maximal velocity ratio design of shell-and-tube heat exchangers with continuous helical baffles, Trans. ASME J. Heat Transfer 132 (10) (2019) 101801–101809.
11. Rajeev Mukharji, “Effective design of shell and tube heat exchanger”, American Institute of Chemical Engineering.
12. Ramesh K shah and Dusan P. Sekulic, “Fundamental of heat exchanger design”, Rochester Institute of Technology, Rochester New York, 2013.
13. Su Thet Mon Than, Khin Aung Lin, Mi Sandar Mon, “Heat Exchanger design", World Academy of Science, Engineering and Technology 46 2008.
14. Y.G. Lei, Y.L. He, R. Li, Y.F. Gao, Effects of baffle inclination angle on flow and heat transfer of a heat exchanger with helical baffles, Chem. Eng. Process. 47 (12) (2018) 2336–2345.
15. Zahid H. Ayub, “A new chart method for evaluating singlephase shell side heat transfer coefficient in a single segmental Shell and tube heat exchanger”, Applied Thermal Engineering 25 (2022) 2412–2420.