ME324 – SHELL & TUBE HEAT EXCHANGER

GROUP 03

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1. INTRODUCTION

The heat exchanger consists of a cylindrical vessel (shell) and a bundle of smaller tubes positioned within the shell. This arrangement facilitates efficient heat transfer between two fluids. Shell and tube heat exchangers find extensive applications in various industries, including oil refineries, chemical processing plants, power generation facilities, HVAC systems, and more. They are particularly suitable for scenarios involving high pressures and temperature differentials. These heat exchangers offer numerous advantages, including versatility, robust construction, and compatibility with a wide range of fluids and operating conditions. The tube bundle is strategically placed within the shell using tube sheets at both ends. These tube sheets provide structural support and ensure effective fluid separation between the shell side and tube side. The fluid flowing through the shell side can adopt various flow patterns, such as parallel flow, counterflow, or crossflow. Baffles are strategically positioned within the shell to optimize heat transfer by directing the fluid flow across the tubes.

1.1 PROBLEM

Compare the effectiveness of parallel flow and counter flow configurations and test the effectiveness of two different baffle types.

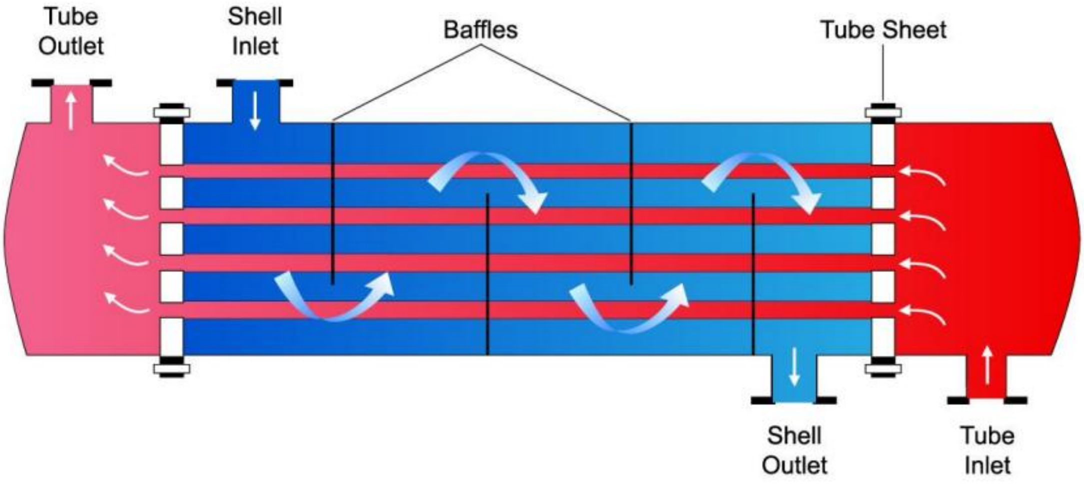

Figure 1.1: Heat Exchanger

1.1.1 Given Data

- Tube side fluid = Air
- Shell side fluid = Water
- Shell inlet Temperature = 22 ^{0}C
- Tube inlet Temperature = 115 ^{0}C
- Inlet Pressure of shell = 3 bar
- Pressure inside tubes = 1 atm
- Shell inlet velocity = 0.5 m/s
- Tube inlet velocity = 1 m/s

1.1.2 Dimensions

- Shell diameter = 750 mm
- Length = 1500 mm
- Tube diameter =- 75 mm
- No. of tubes = 25

1.2 WORK PLAN

SHELL & TUBE HEAT EXCHANGER
TASK 1
FINDING APPROPIATE MATERIALS
E/19/265
FINDING APPROPIATE SHELL AND TUBE THICKNESS
E/19/023
FINALIZING BAFFLE TYPE
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TASK 2
DESIGN OF THE SOLID MODEL
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TASK 3
EXTRACT THE SHELL AND TUBE DOMAINS
E/19/023
TASK 5
FLUENT ANALYSIS - DISK & DOUGHNUT BAFFLE / PARALLEL FLOW
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FLUENT ANALYSIS - DISK & DOUGHNUT BAFFLE / COUNTER FLOW
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FLUENT ANALYSIS - CUT SEGMENT BAFFLE / PARALLEL FLOW
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FLUENT ANALYSIS - CUT SEGMENT BAFFLE / COUNTER FLOW
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TASK 6
CREATING REPORT
E/19/023
CREATING PRESENTATION
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E/19/331
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1.3 MATERIAL SELECTION

1.3.1 Shell Material Options

1. **Carbon Steel**
    - **Properties:** High strength, good weldability, and cost-effective.
    - **Temperature Range:** Up to 425°C.
2. **Stainless Steel (304 or 316)**

- **Properties:** Excellent corrosion resistance, good strength, and high temperature resistance.
- **Temperature Range:** Up to 870°C for 304, up to 925°C for 316.

3. **Inconel (Alloy 600)**

- **Properties:** High strength, oxidation, and corrosion resistance at high temperatures.
- **Temperature Range:** Up to 982°C.

1.3.2 Tube Material Options

1. **Copper**
    - **Properties:** Excellent thermal conductivity, good corrosion resistance.
    - **Temperature Range:** Up to 200°C.
2. **Stainless Steel (316)**

- **Properties:** Excellent corrosion resistance, good thermal conductivity, and high temperature resistance.
- **Temperature Range:** Up to 925°C

❖ Even though we have obtained the different material sets, the ANSYS Student package allows to use common materials only. Therefore, we have to switch to aluminum and copper.

1.4 DETERMINATION OF SHELL AND TUBE THICKNESSES.

Parameters and Assumptions

1. Tube Diameter (D): 75 mm (0.075 m)

2. Operating Temperature (T): 115°C

3. Pressure (P): 1 atm

4. Fluid Velocity (v) 1 m/s

5. Material: Assume stainless steel for the tube

Determination of Allowable Stress for Material

Assume a common stainless steel, such as SS304, at 115°C. The allowable stress can be obtained from ASME material tables. For SS304 at 115°C, stress is approximately 137.9 MPa.

Determination of Corrosion Allowance (C)

A typical corrosion allowance is about 1 mm (0.001 m).

Determination of Tube Thickness Using ASME Formula

The ASME formula for calculating the minimum required thickness for a cylindrical shell under internal pressure is:

$$t = P.\frac{D}{2S + 0.8P} + C$$

Where:

- t is the minimum required thickness.

- P is the internal pressure (0.101325 MPa).

- D is the internal diameter (0.075 m).

- S is the allowable stress (137.9 MPa).

- C is the corrosion allowance (0.001 m).

Plugging in the values:

$$t = 0.101325.\frac{0.075}{2 \times 137.9 + 0.8 \times 0.101325} + 0.001$$

t = 1.03 mm

Thickness of the tube = 1.5 mm

1. Shell Diameter (D): 750 mm (0.75 m)

2. Operating Temperature (T): 22°C

3. Pressure (P): 3 bar (300 kPa or 0.3 MPa)

4. Velocity (V): 0.5 m/s

5. Material: Assume carbon steel for the shell

Determination of Allowable Stress for Material

- Assume a common carbon steel, such as ASTM A516 Grade 70, at 22°C. The allowable stress can be obtained from ASME material tables. For ASTM A516 Grade 70 at 22°C, S is approximately 138 MPa.

Determination of Corrosion Allowance (C)

- A typical corrosion allowance C is about 3 mm (0.003 m).

Determination of Shell Thickness Using ASME Formula

The ASME formula for calculating the minimum required thickness for a cylindrical shell under internal pressure is:

$$t = P.\frac{R}{SE - 0.6P} + C$$

Where:

- R is the internal radius (0.75 m / 2 = 0.375 m).

- E is the weld efficiency (assume 1 for seamless or fully radiographed welds).

$$t = 0.3.\frac{0.375}{138 \times 1 - 0.8 \times 0.3} + 0.003$$

t = 3.81 mm

Thickness of the shell = 4 mm

2. DESIGN

For the analysis we have selected two baffled types.

1. Cut segment type
2. Doughnut and disk type

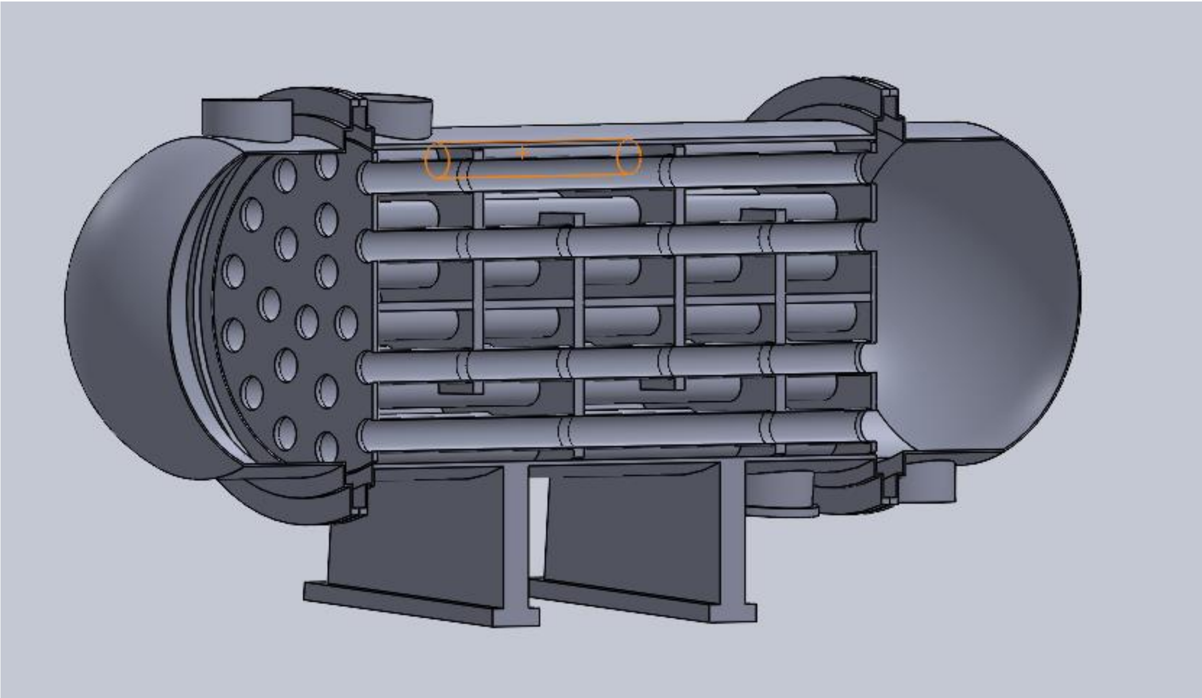

Figure 2.1: Cut Segment Type Baffled Heat Exchanger

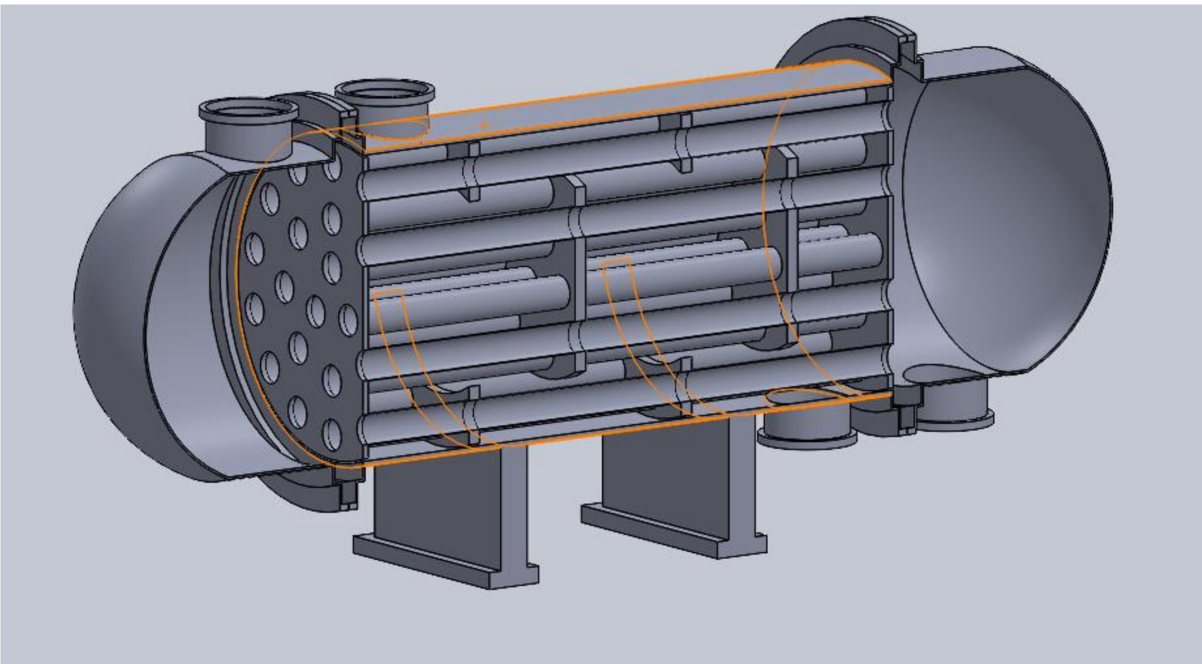

Figure 2.2: Doughnut and Disk type Baffled Heat Exchanger

3. FLUID DOMAIN EXTRACTION

The Heat Exchanger operates with two fluids. Air flows through the tube, while liquid water flows through the shell. Consequently, we must separate the solid and fluid boundaries before analyzing the model in ANSYS Fluent.

The fluid domain extraction can be done using four methods using SolidWorks software package or ANSYS software package.

1. SolidWorks Intersect function
2. ANSYS Design Modeler Fill using cavity/ caps
3. ANSYS Space Claim Volume extraction function

Here we have attempted all the functions, but unfortunately, none of them provided the correct domain due to a design error. All the methods are user-friendly, except for the Design Modeler Fill using cavity option, which requires manual selection of all the wall boundaries of the fluid domain. However, the ANSYS Space Claim software has the capability to identify and rectify errors in models, which is why we opted for the third option for fluid domain extraction.

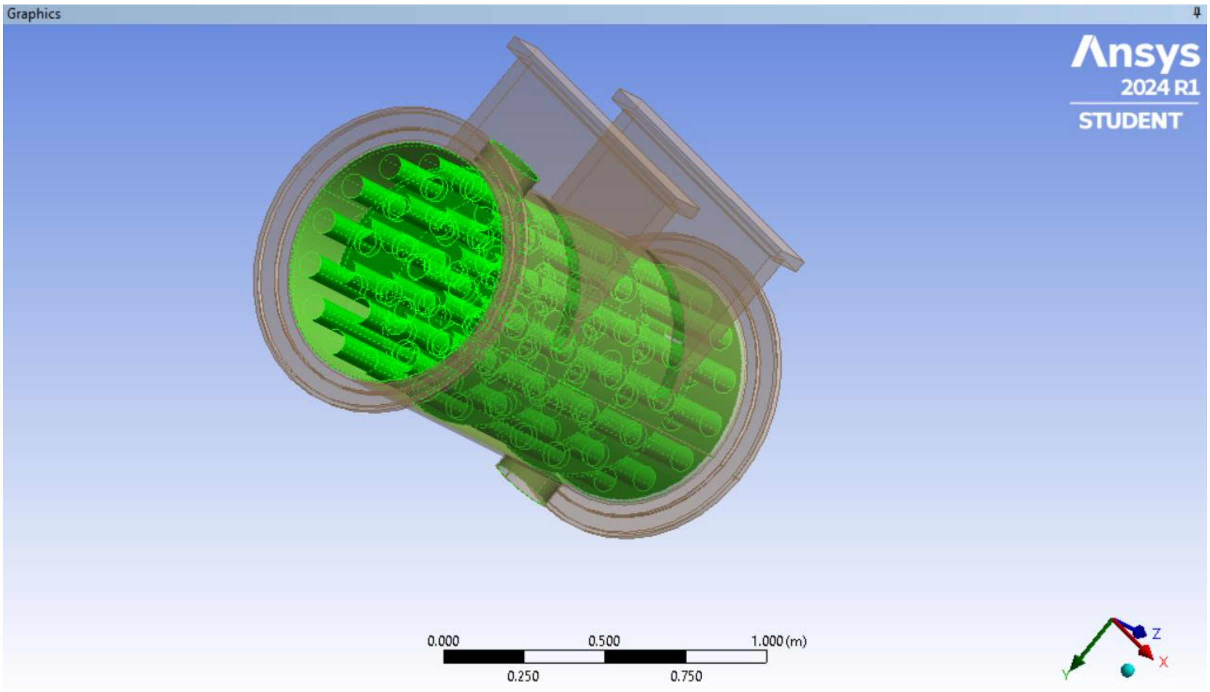

Figure 3.1: Manual Wall Selection in Design Modeler

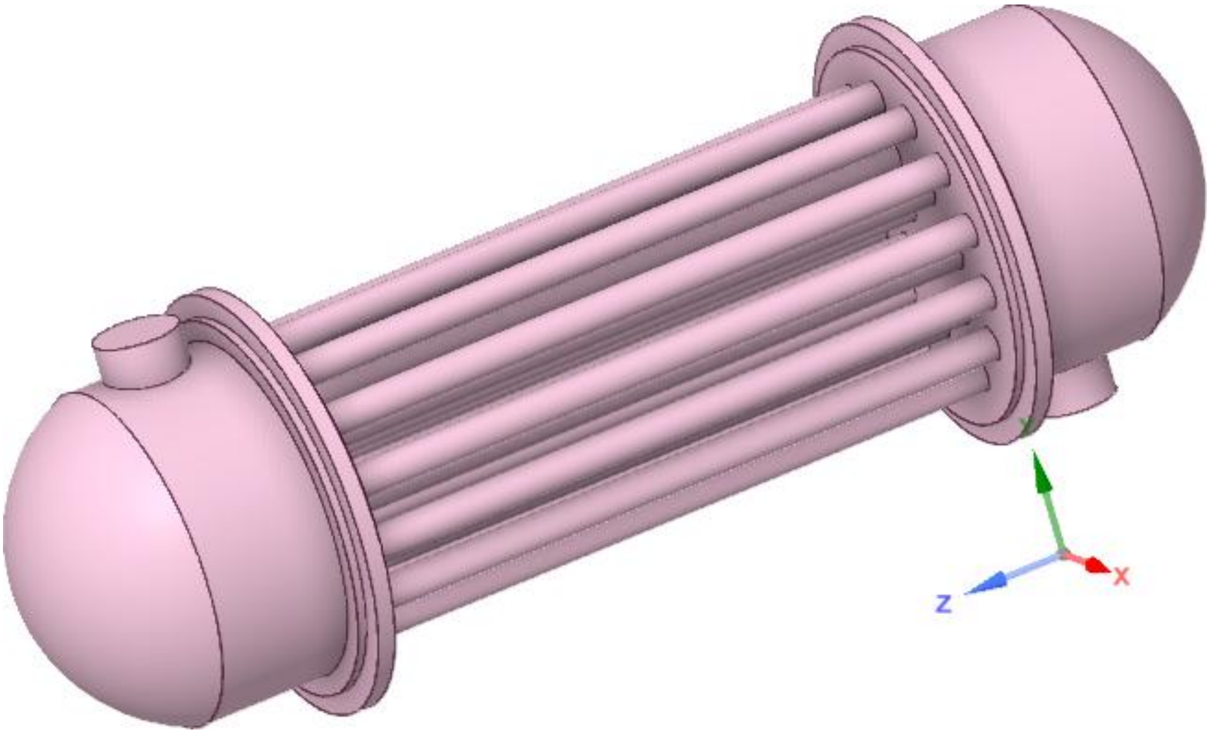

Figure 3.2: Tube Flow Domain

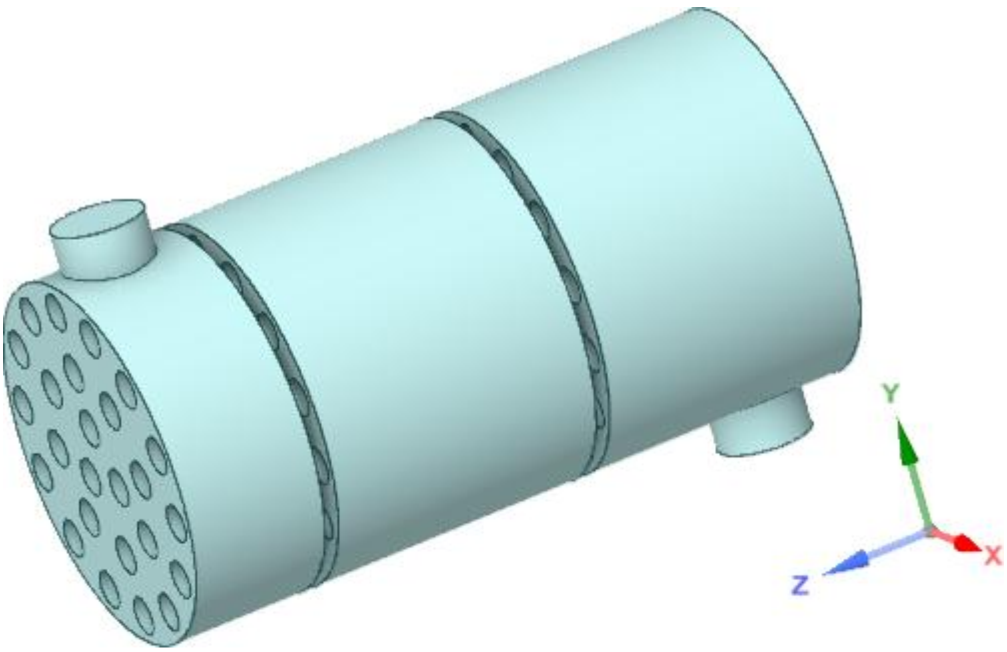

Figure 3.3: Shell Flow Domain

4. MESH

Due to limitations in ANSYS Student Package, the finest mesh that can obtain is less fine than the default mesh. (Maximum element count for ANSYS Fluent is 512000).

Mesh Quality

Element Size	-	2 m
Elements	-	970966
Nodes	-	167786
Aspect Ratio	-	1.15 – 5
Skewness	-	0.9

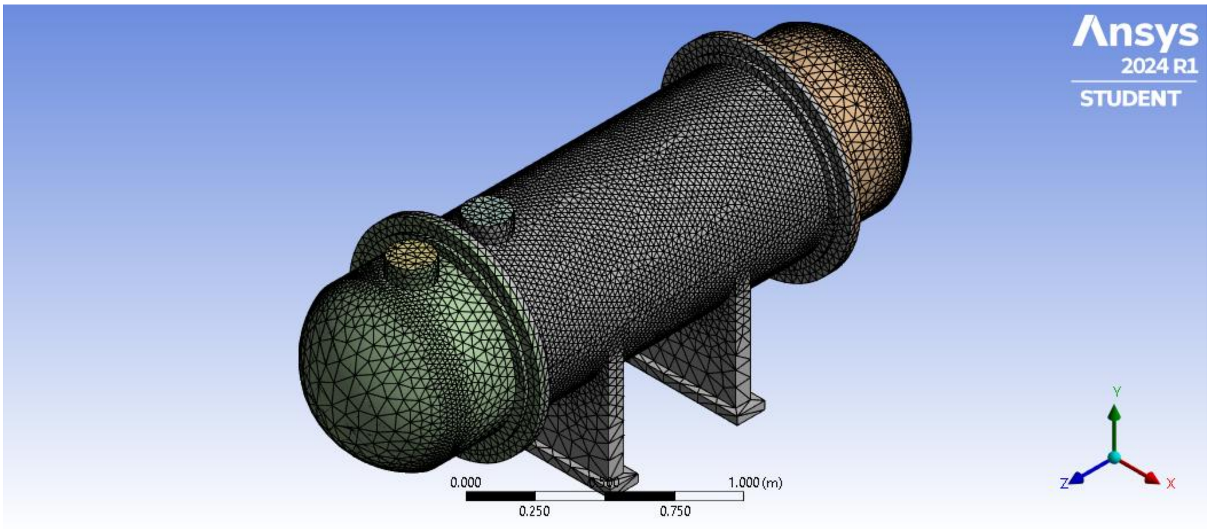

Figure 4.1: Generated Mesh

5. ANSYS FLUENT

5.1 BOUNDARY CONDITIONS

For the analysis we need to set six locations to add the boundary conditions.

1. Shell Inlet – Temperature 295 K, velocity 0.5 m/s, Pressure 3 bar
2. Tube Inlet – Temperature 388 K, velocity 1 m/s, Pressure 1 atm
3. Shell Outlet – Pressure outlet
4. Tube Outlet – Pressure outlet
5. Tube wall – Copper/ solid
6. Shell wall – Aluminum/ solid
7. Gravity – 9.81 m/s^2

6 RESULTS

6.1 DOUGHNUT – DISK BAFFLED/ PARALLEL FLOW HEAT EXCHANGER

Here, the shell flow and the tube flow are in same direction. We consider a mid-plane of the Heat exchanger to visualize the contours of pressure and temperature variations.

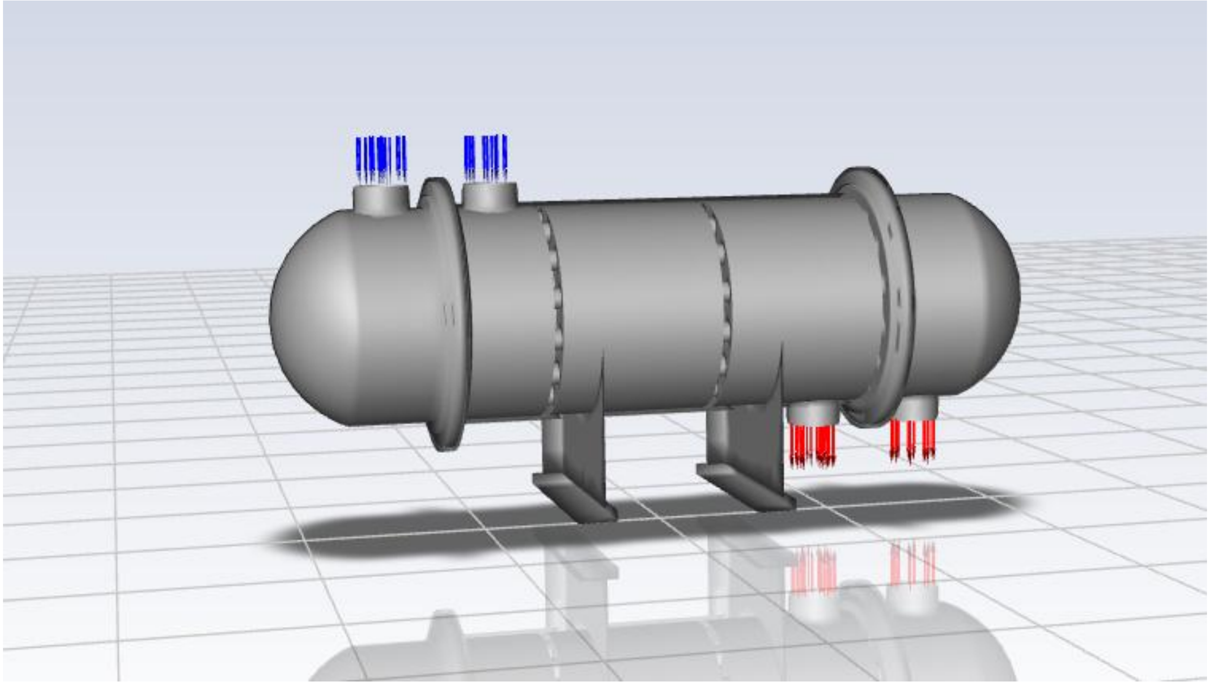

Figure 6.1: Inlet and Outlet of The Heat Exchanger

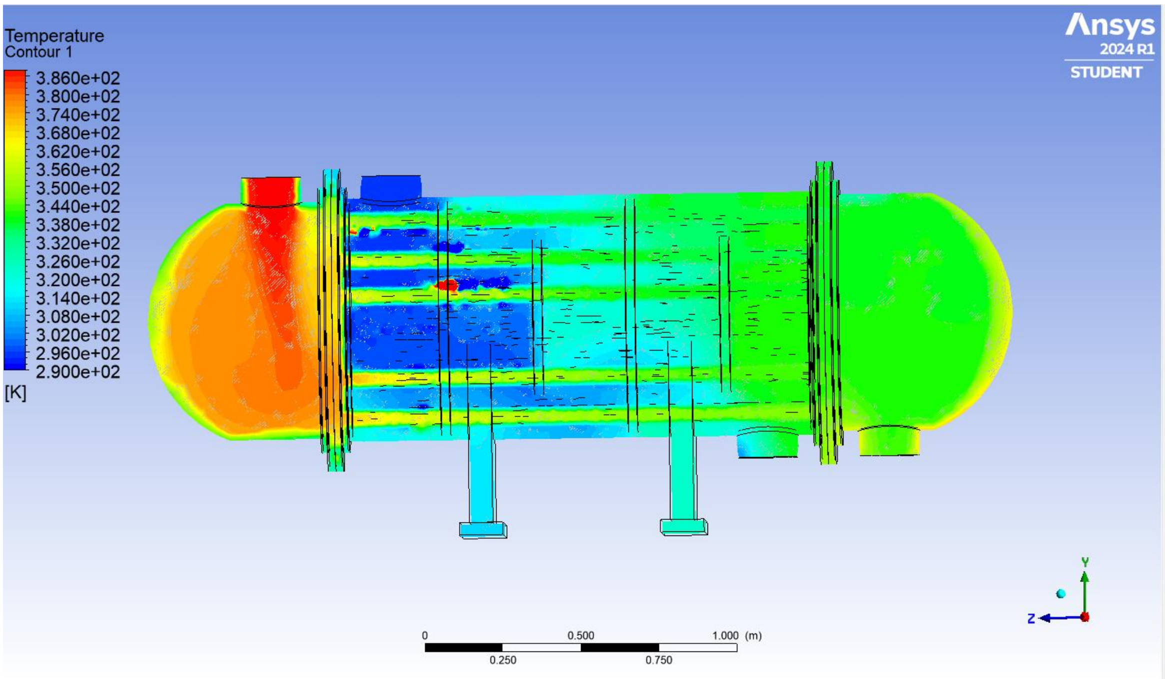

Figure 6.2: Temperature Variation in Heat Exchanger

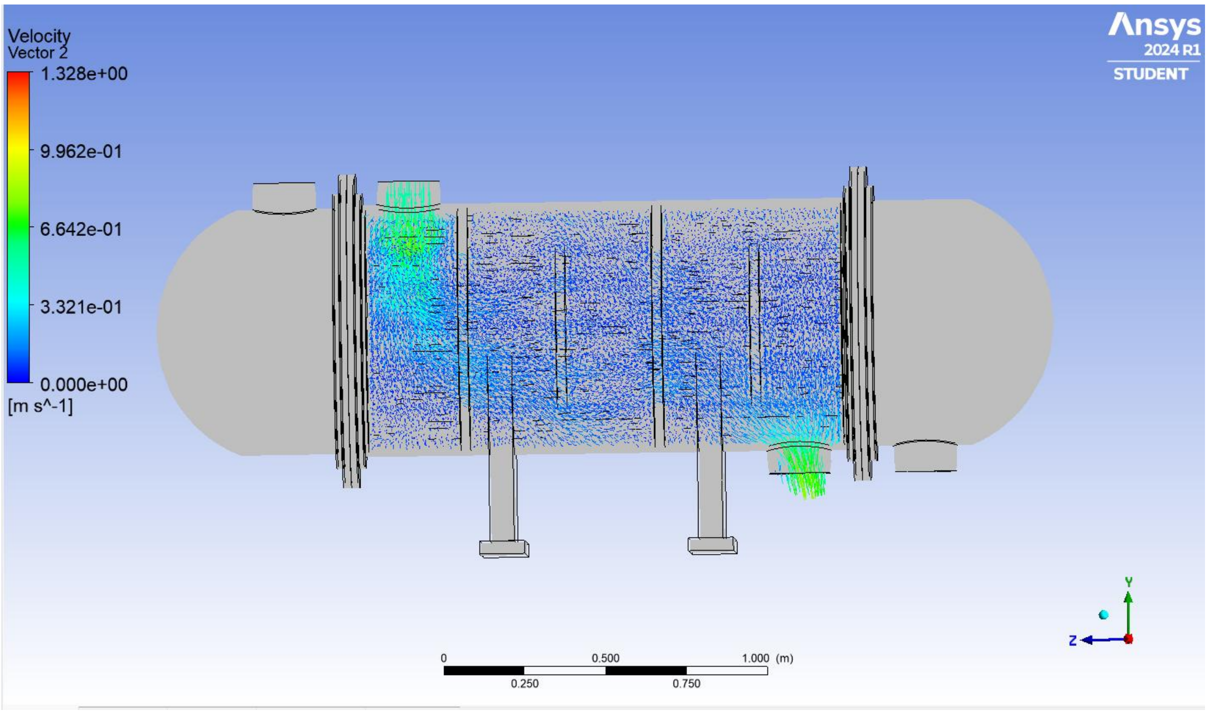

Figure 6.3: Shell Flow Vectors

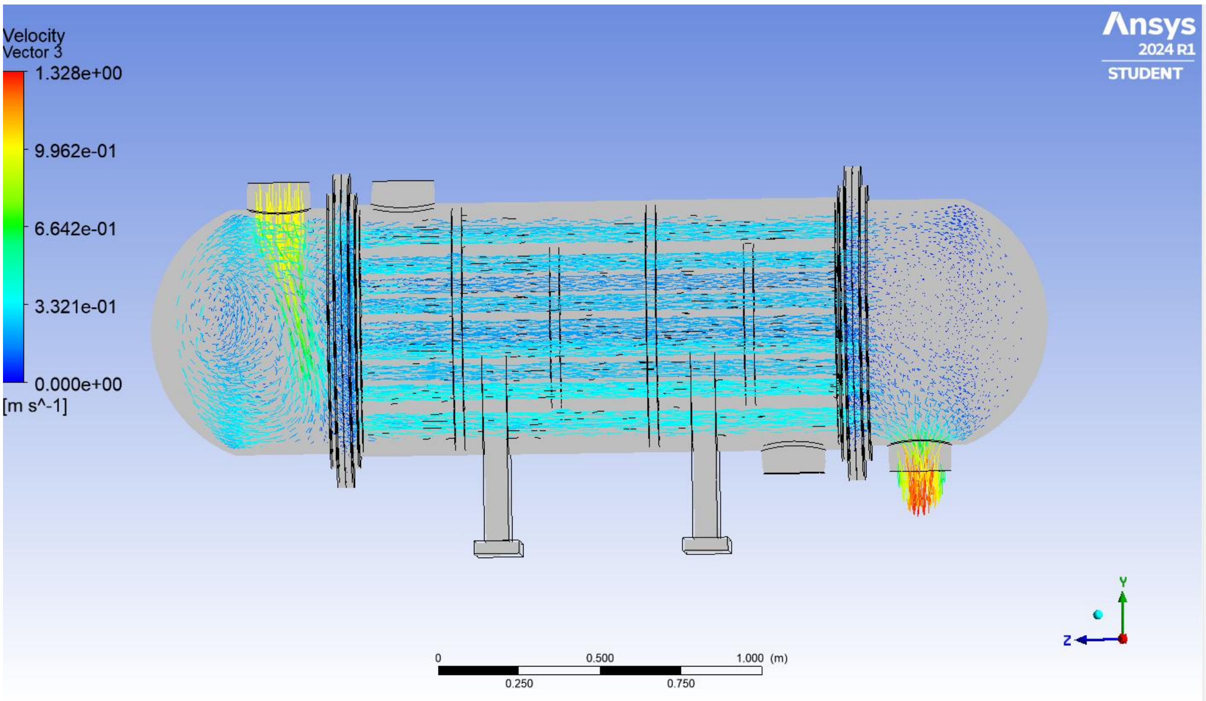

Figure 6.4: Tube Flow Vectors

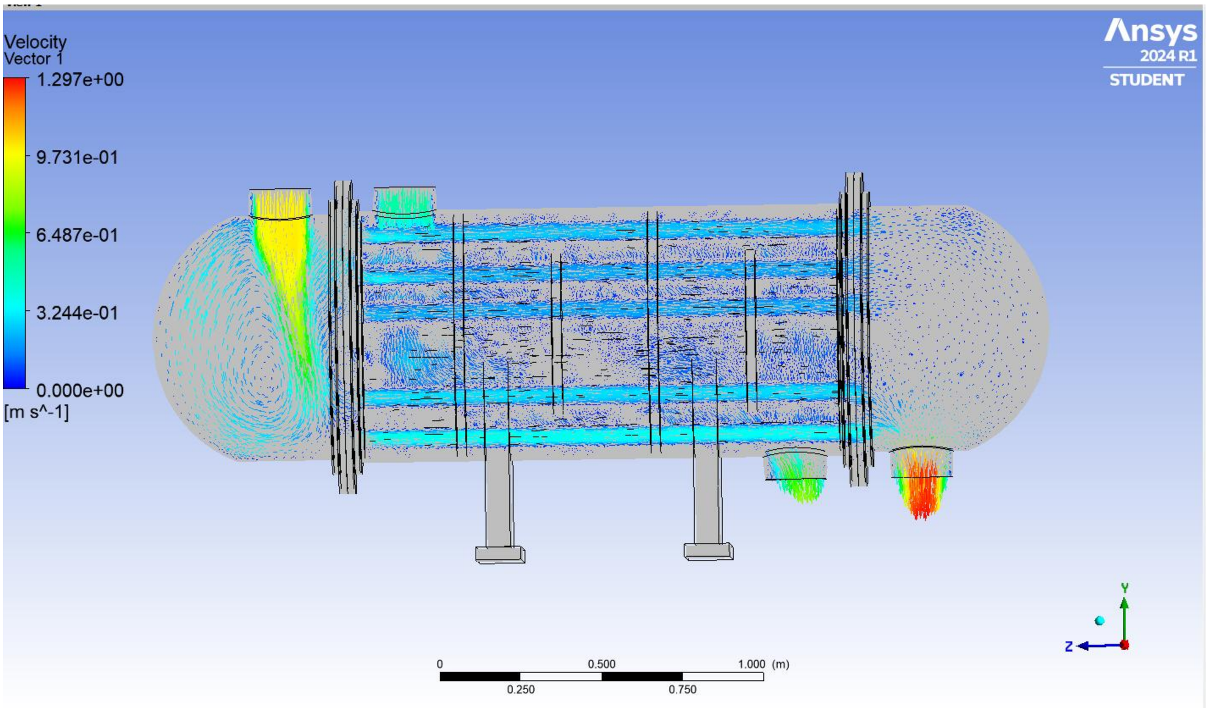

Figure 6.5: Flow Vectors for the Mid-Plane

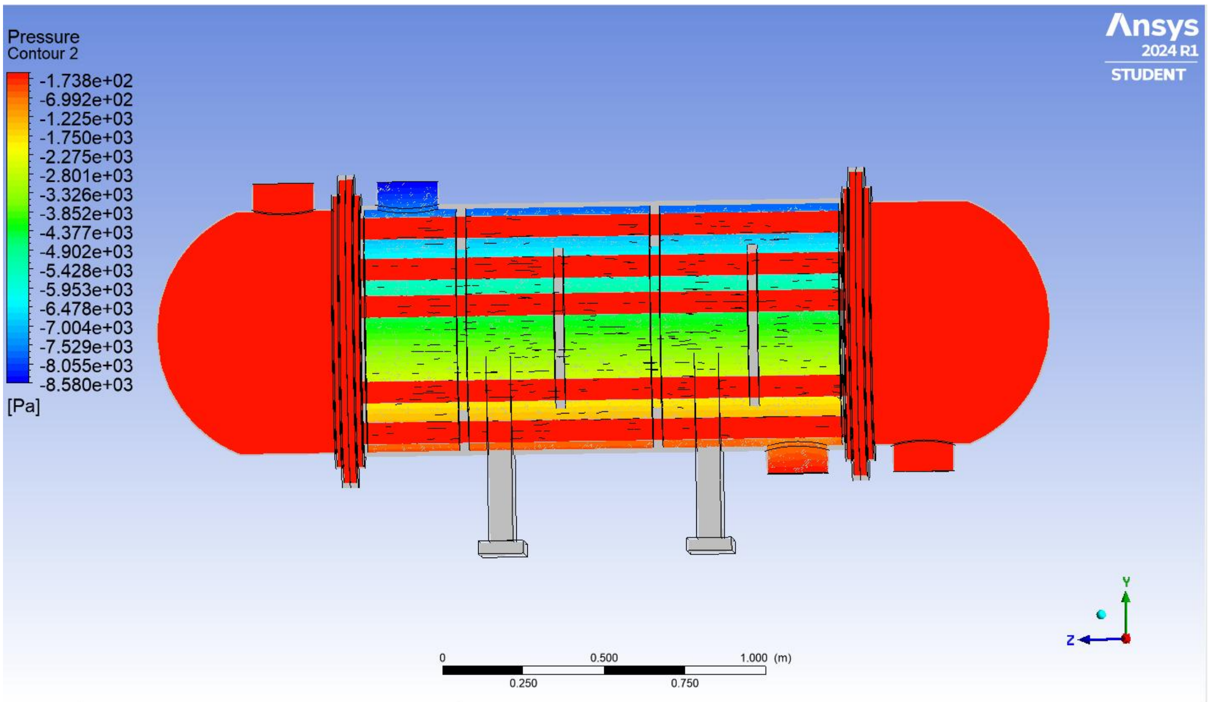

Figure 6.6: Pressure Contour

6.2 DOUGHNUT – DISK BAFFLED/ COUNTER FLOW HEAT EXCHANGER

Here, the shell flow and the tube flow are in opposite directions.

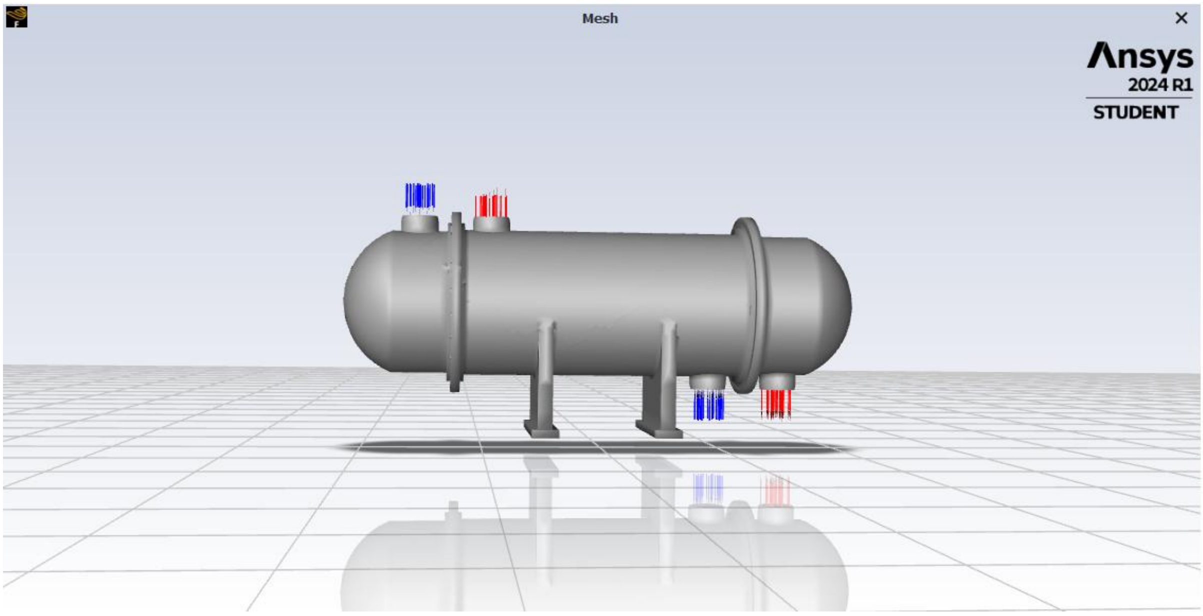

Figure 6.7: Inlet and Outlet of The Heat Exchanger

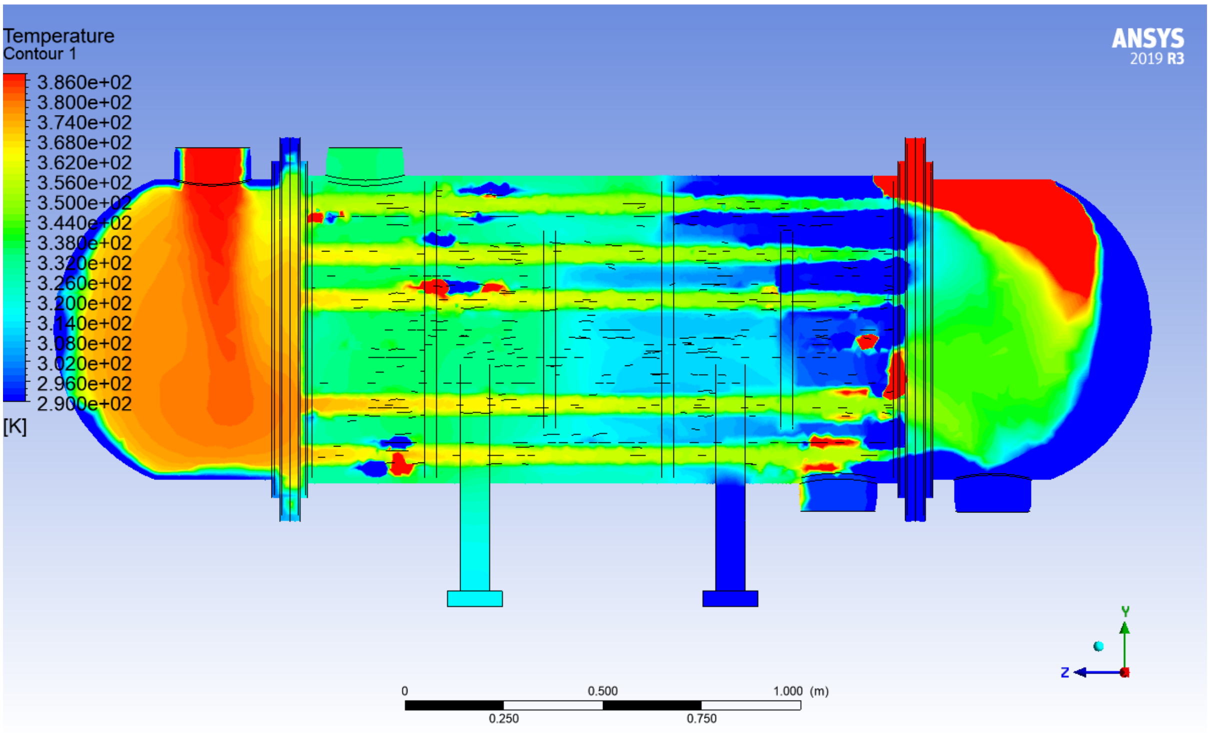

Figure 6.8: Temperature Variation in Heat Exchanger

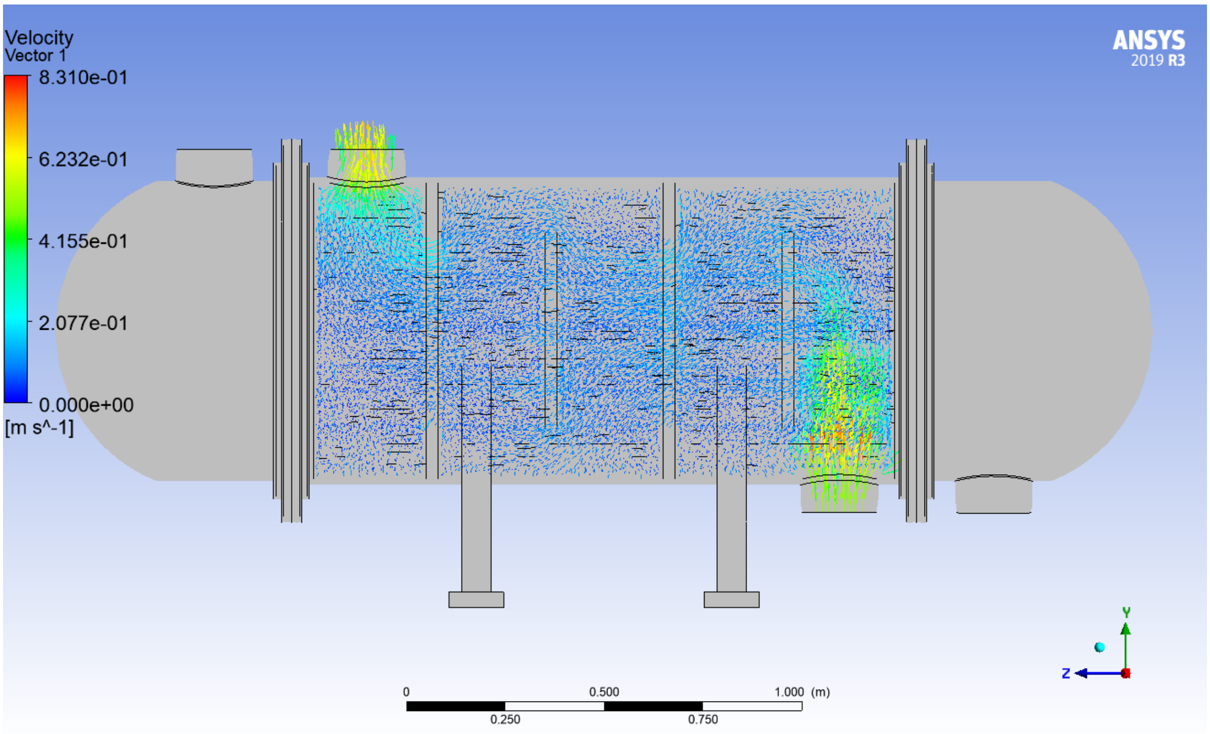

Figure 6.9: Shell Flow Vectors

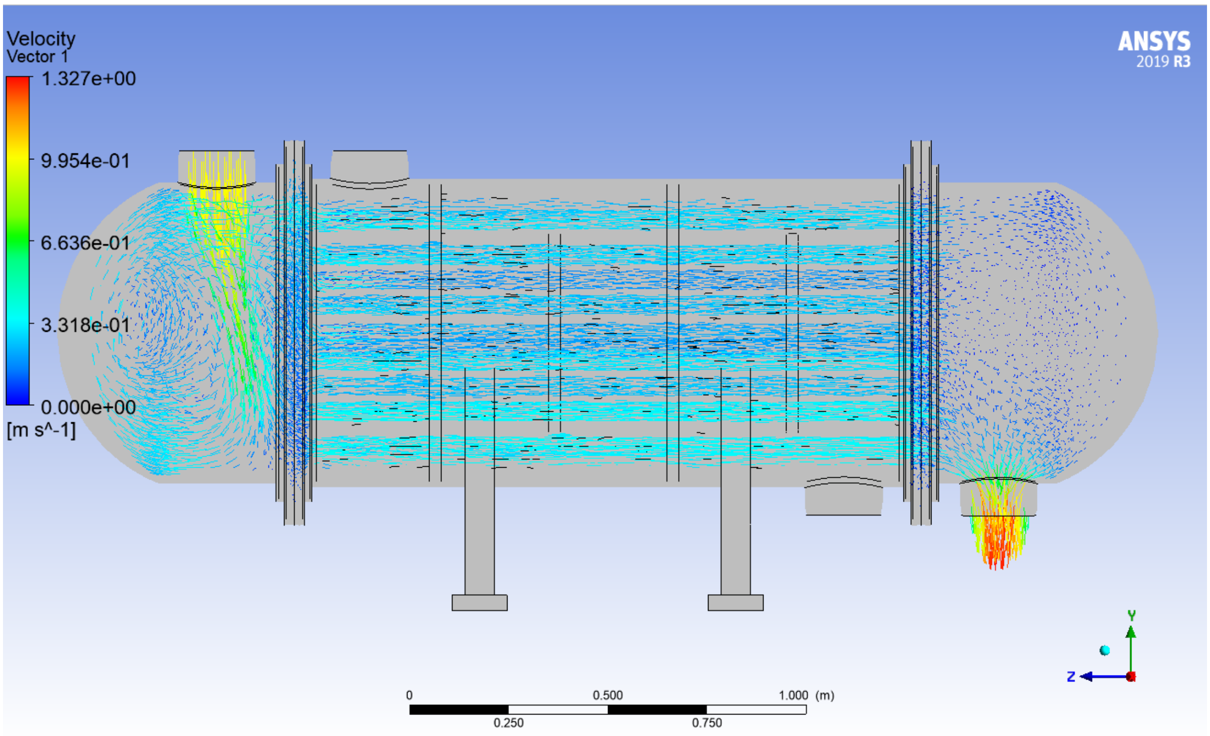

Figure 6.10: Tube Flow Vectors

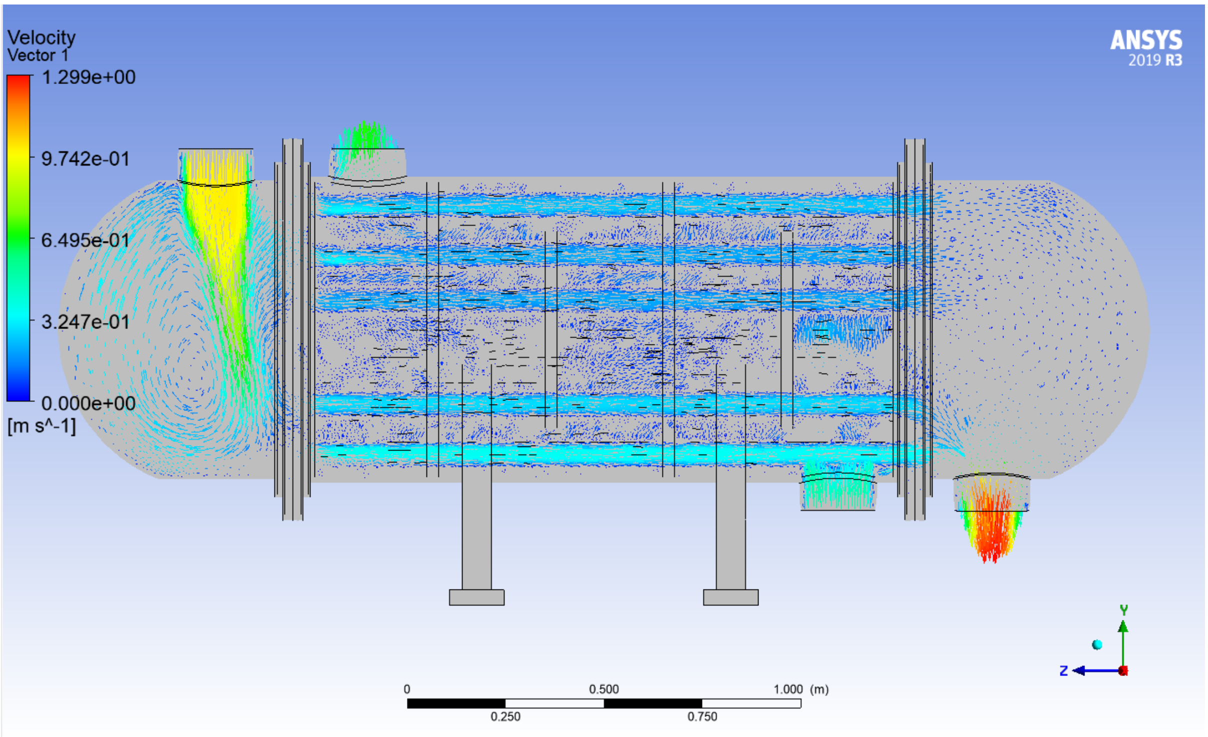

Figure 6.11: Flow Vectors for the Mid-Plane

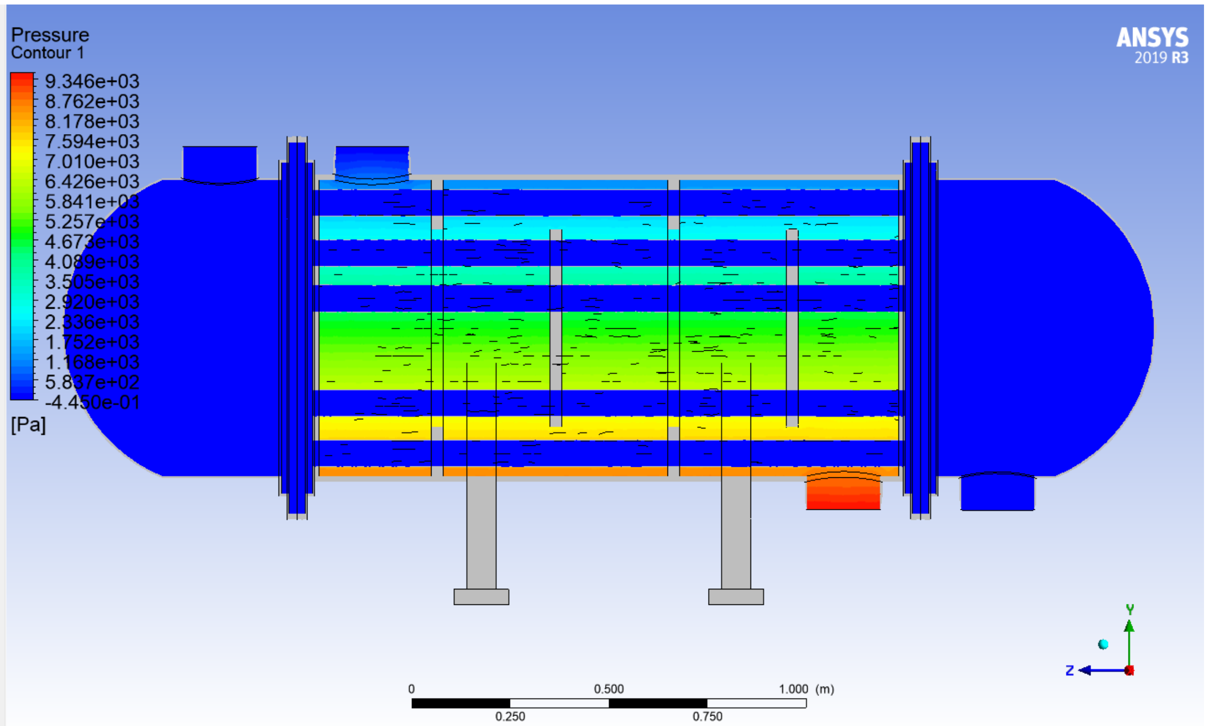

Figure 6.12: Pressure Contour

6.3 CUT SEGMENTT BAFFLED/ COUNTER FLOW HEAT EXCHANGER

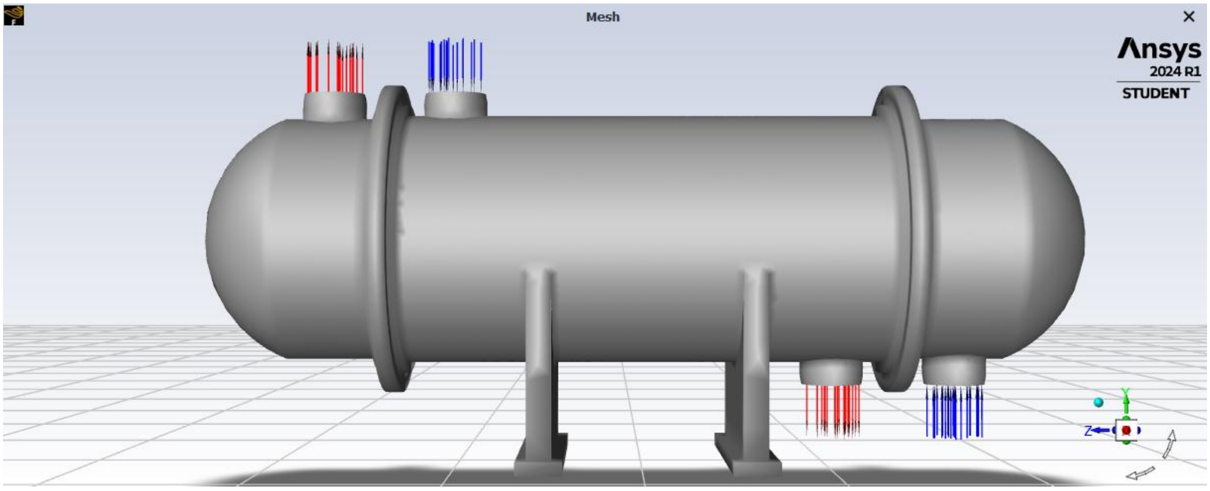

Figure 6.13: Inlet and Outlet of The Heat Exchanger

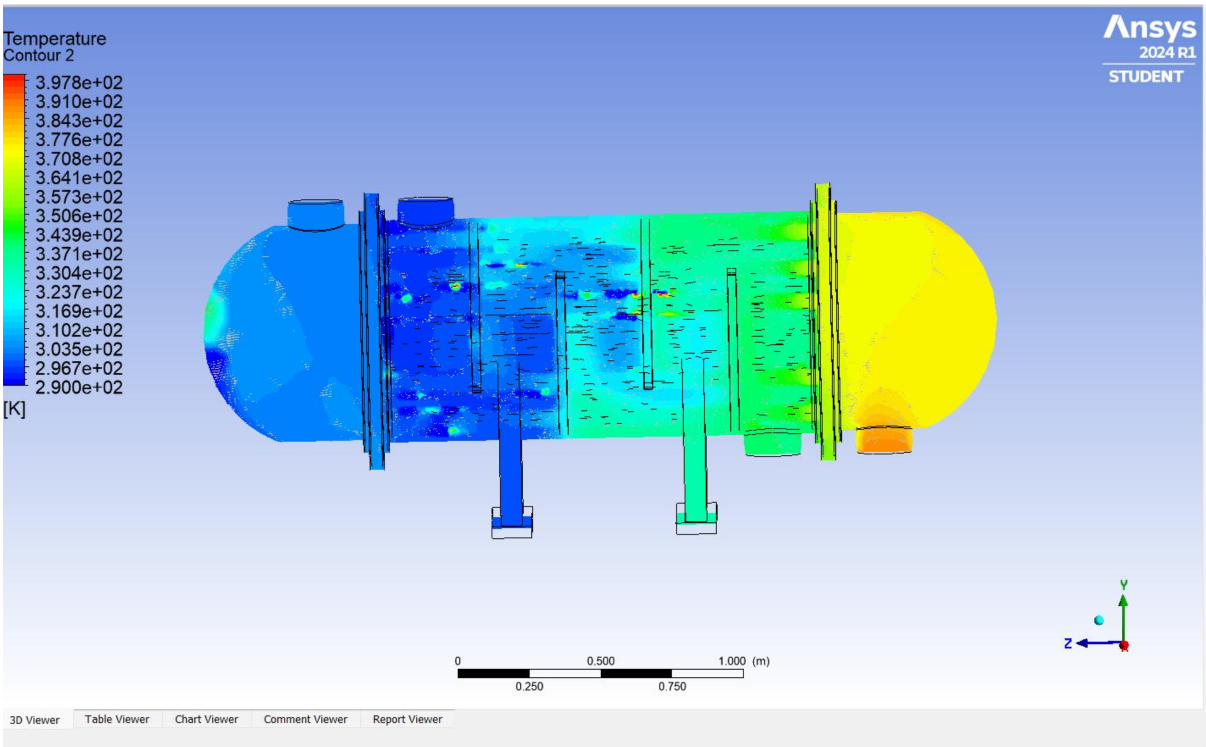

Figure 6.14: Temperature Variation in Heat Exchanger

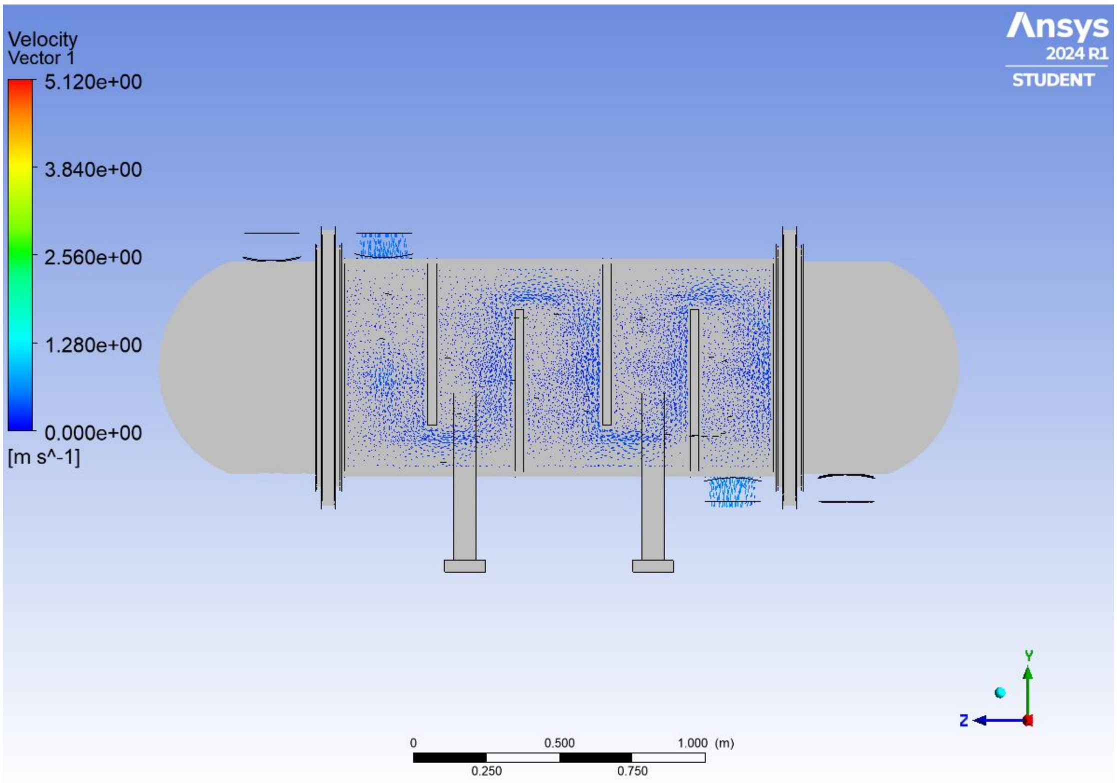

Figure 6.15: Shell Flow Vectors

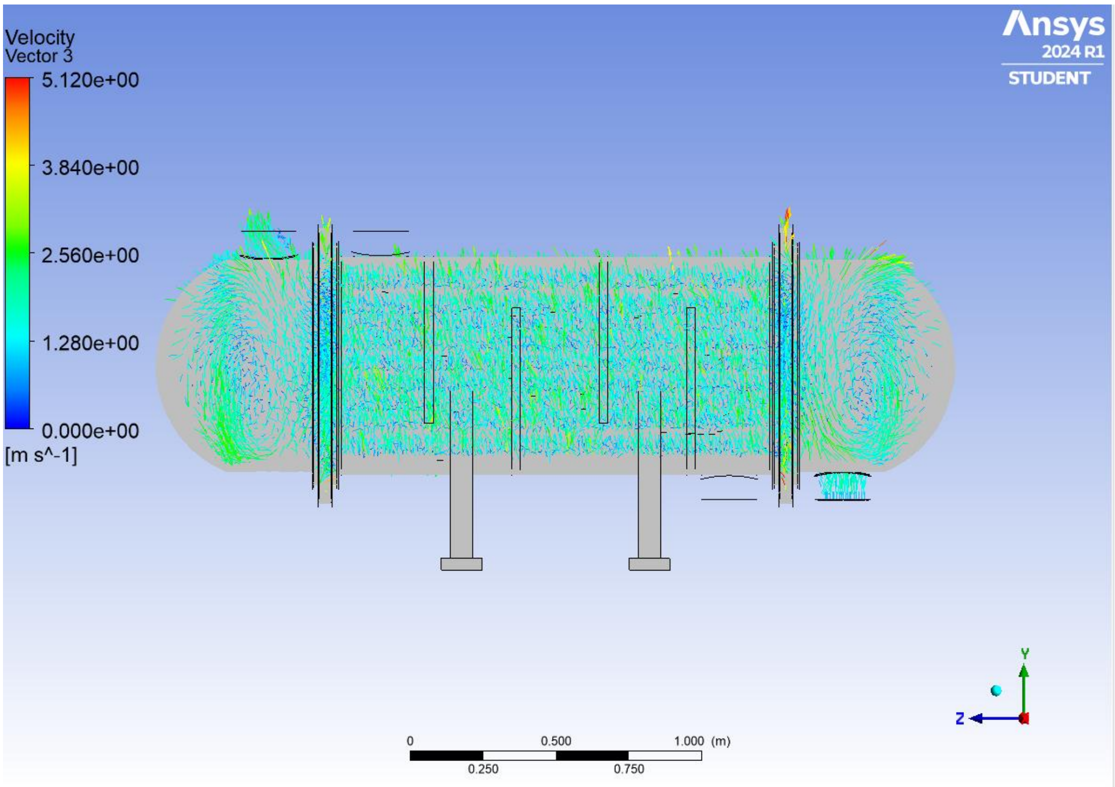

Figure 6.16: Tube Flow Vectors

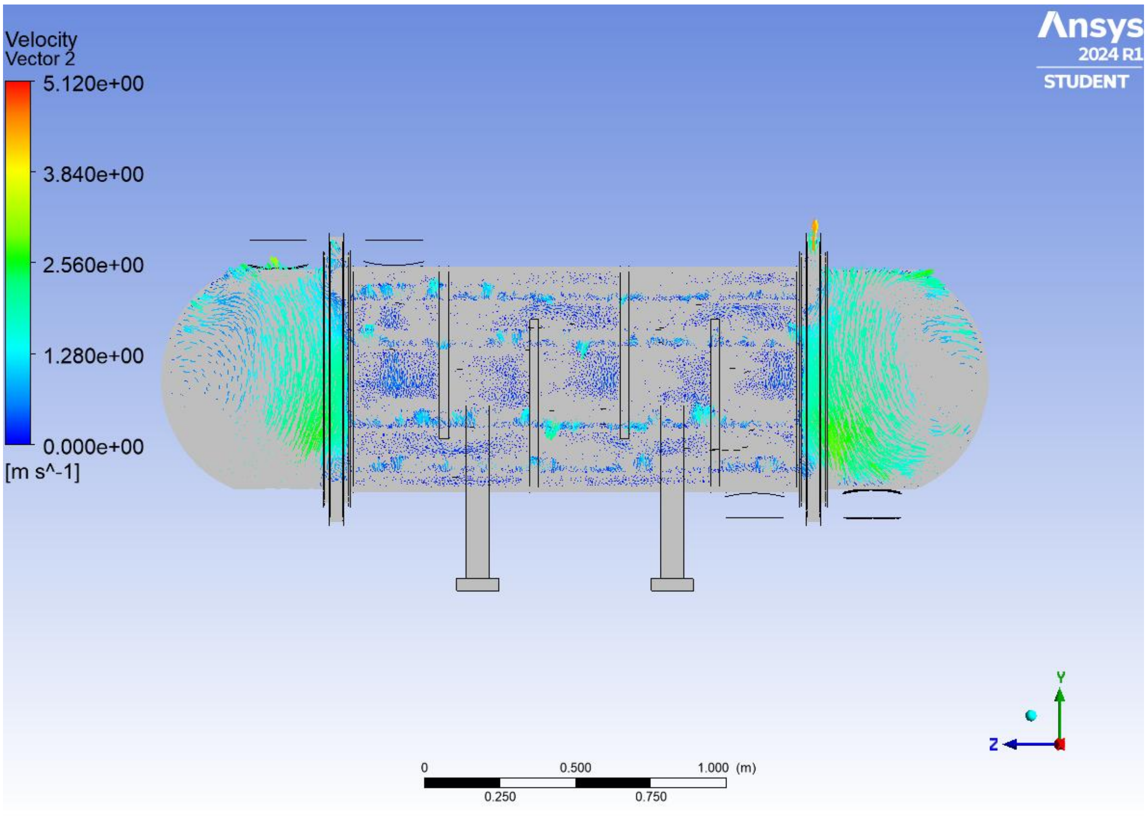

Figure 6.17: Flow Vectors for the Mid-Plane

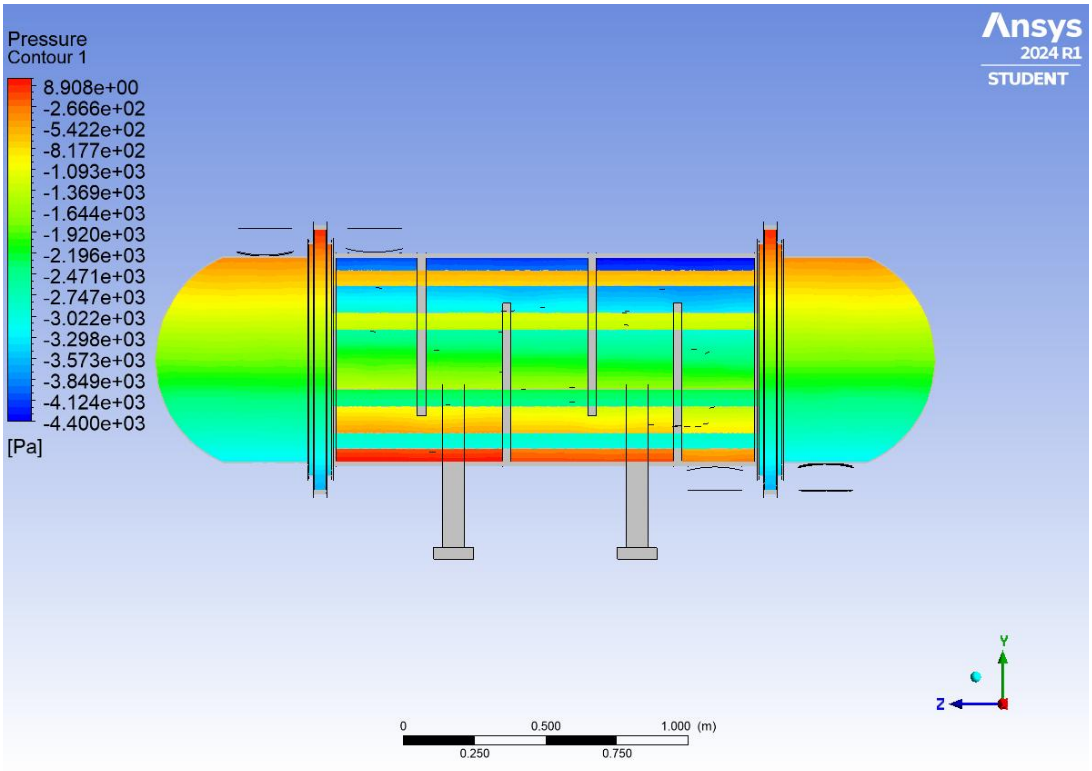

Figure 6.18: Pressure Contour

6.4 CUT SEGMENT BAFFLED/ PARALLEL FLOW HEAT EXCHANGER

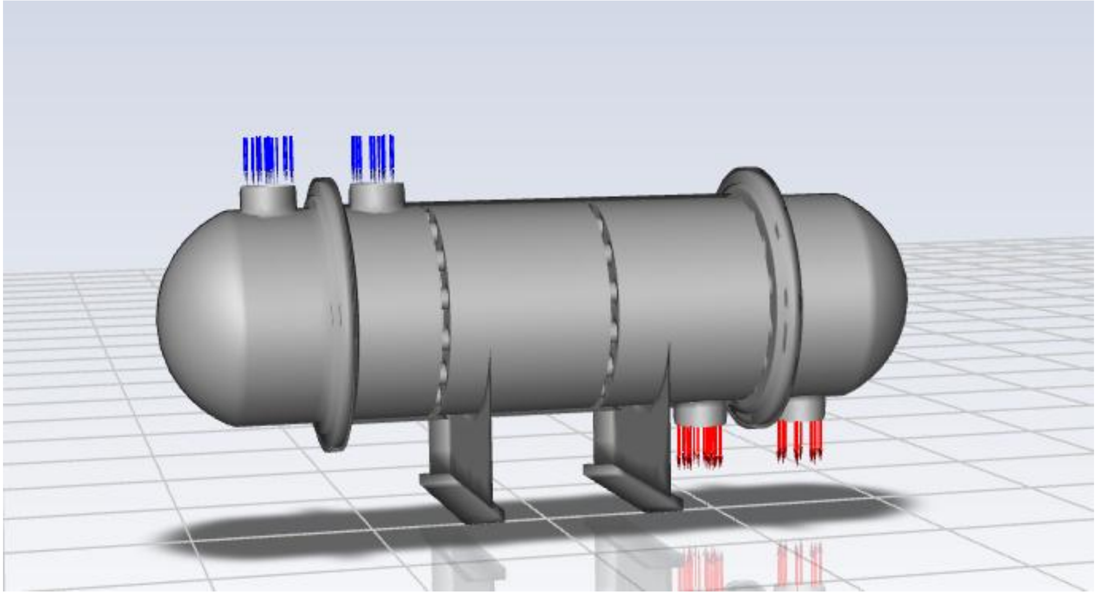

Figure 6.19: Inlet and Outlet of The Heat Exchanger

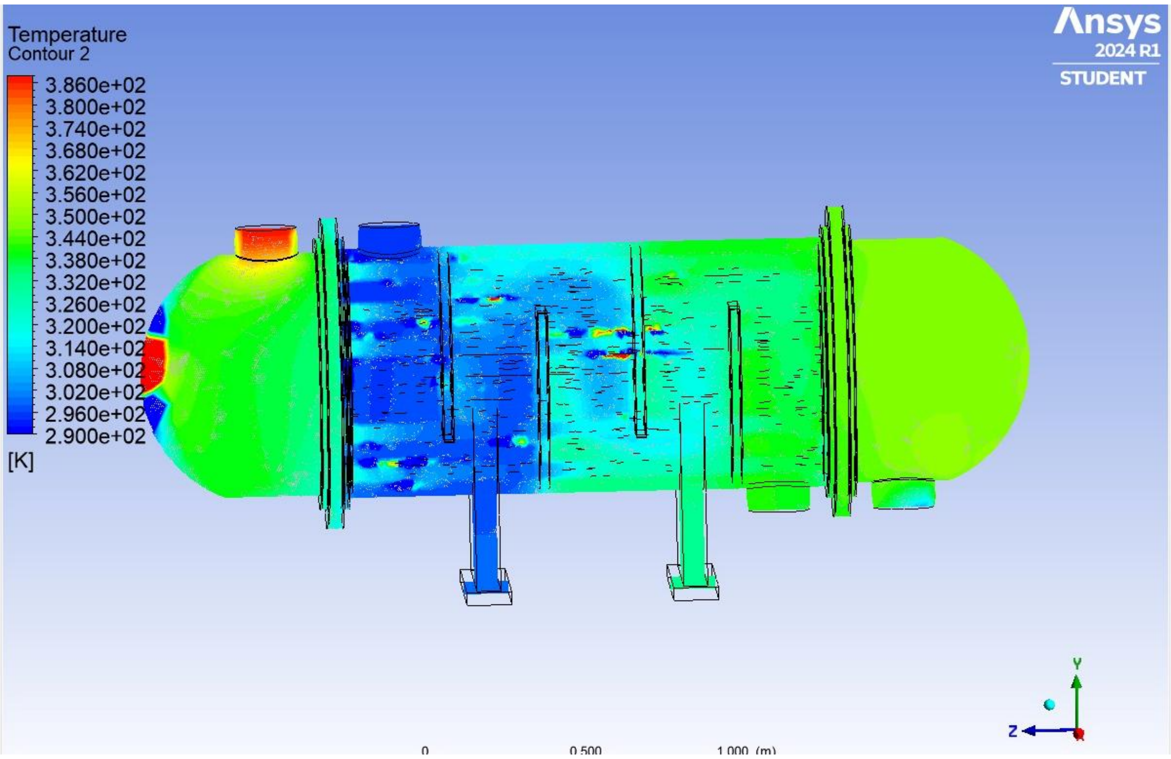

Figure 6.20: Temperature Variation in Heat Exchanger

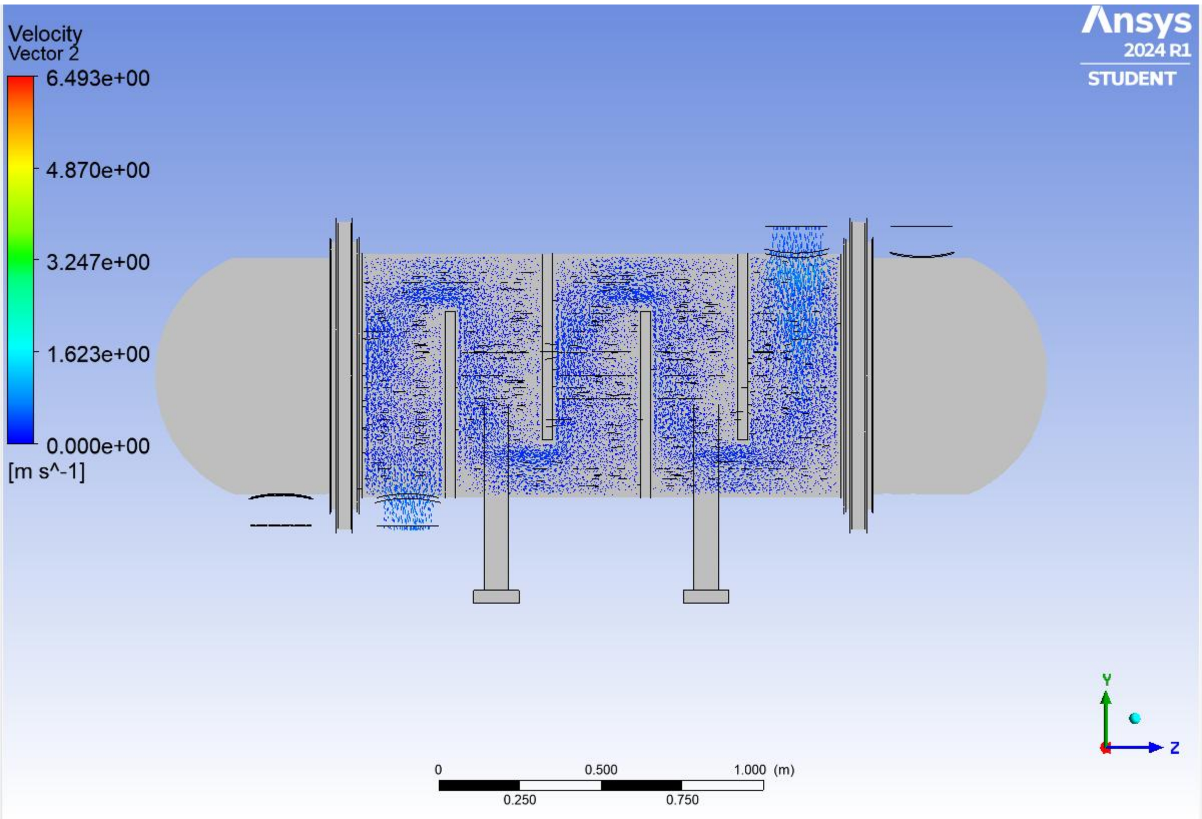

Figure 6.21: Shell Flow Vectors

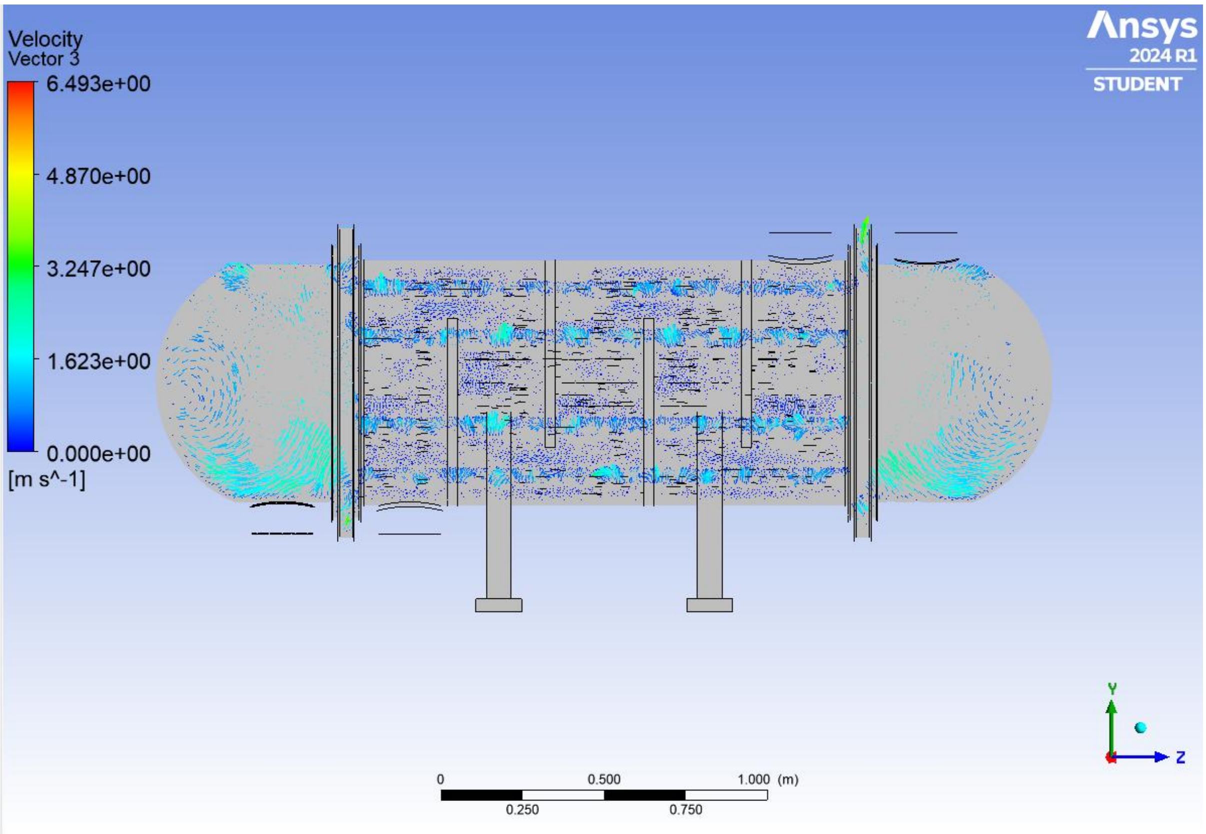

Figure 6.22: Tube Flow Vectors

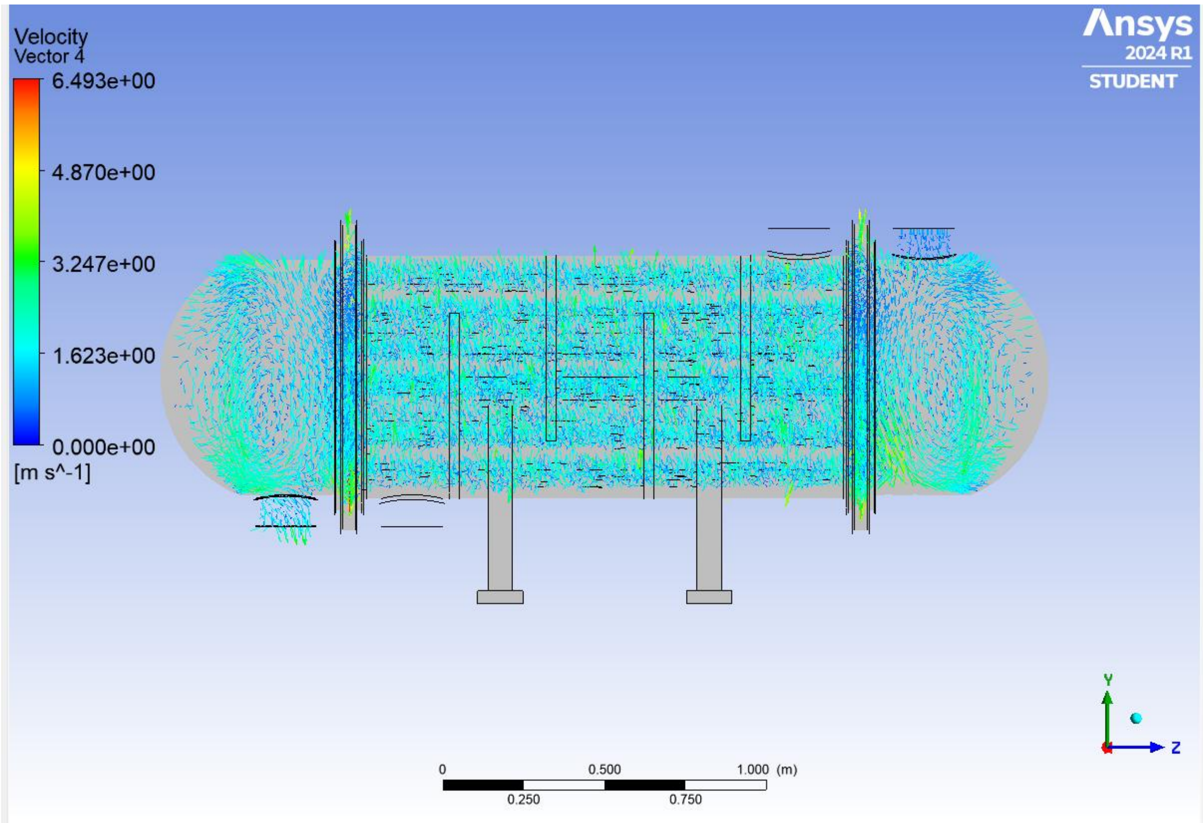

Figure 6.23: Flow Vectors for the Mid-Plane

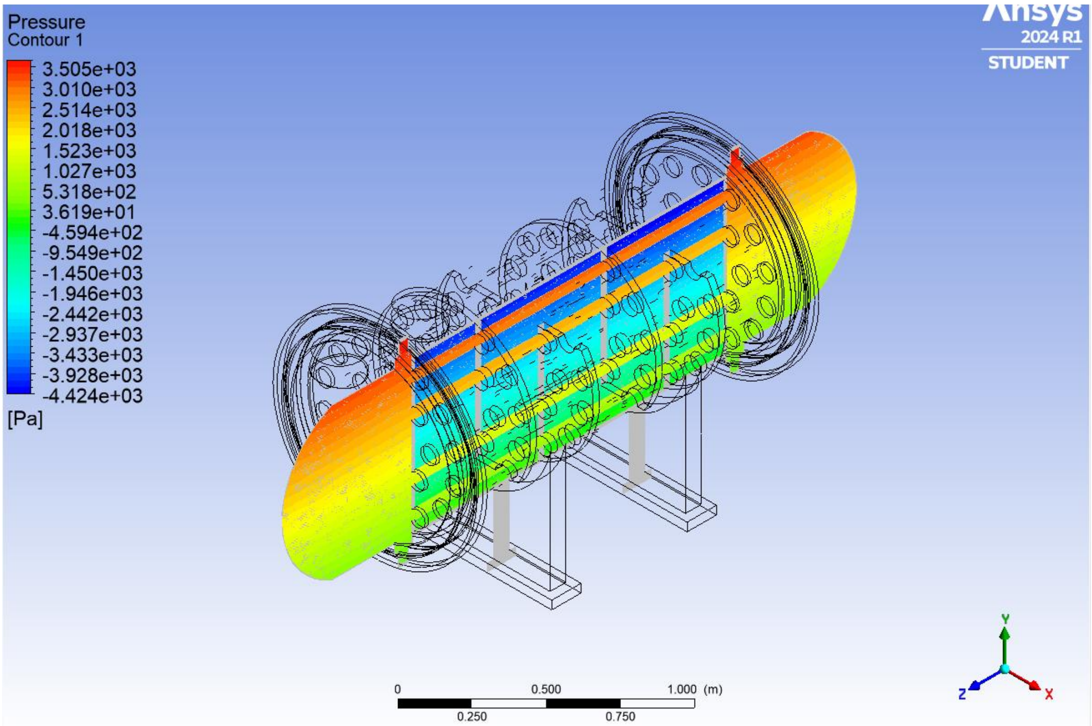

Figure 6.24: Pressure Contour

7. COMPARISON

Table 7.1: The Outlet Temperatures at the Shell Outlet and Tube Outlet for Four Different Flows

Heat Exchanger Type	Flow Type	Temperature /K	
		Shell outlet	Tube Outlet
Doughnut -Disk	Parallel	320	338
Doughnut -Disk	Counter	326	296
Cut Segment	Parallel	344	314
Cut Segment	Counter	337.1	303.5

As illustrated in Table 7.1, the Doughnut and Disk type baffled counter-flow heat transfer system exhibits superior heat transfer capabilities. This system effectively reduces the inlet air temperature by approximately 100 degrees Celsius.

In comparison, the Cut Segment baffle heat exchanger demonstrates greater effectiveness when considering the parallel flow pattern for both baffle types. The cut segment baffle-type heat exchanger exhibits a significant reduction in inlet hot air temperature at the inlet, as depicted in Figure 6.20. This phenomenon can be attributed to the higher water volume flowing near the tube inlet than the Disk and Doughnut baffle types.

In terms of counter-current flow, Doughnut and Disk type baffle heat exchangers exhibit superior performance. This can be attributed to the increased turbulence of water flow through the baffles. However, the marginal difference between the two designs suggests that both are effective for counter-current flows.

It is evident that counter-current flows are significantly more efficient compared to parallel flows in heat exchangers. This can be explained by the temperature differential between the two fluids at the heat exchange surfaces. In counter flow, the cooler fluid enters the system at the warmer secondary fluid inlet, resulting in a higher heat transfer rate. In contrast, parallel flow involves both fluids entering at relatively lower temperatures at their respective inlets.

Therefore, based on the aforementioned findings, the **Doughnut Disk baffle type Counter flow** system is the optimal choice for heat exchangers.

8. DISCUSSION

During the execution of this mini-project, numerous challenges were encountered. Tasks 1 and 2 were completed without any complications.

However, significant time was expended on Task 3, specifically in extracting fluid domains. Initial attempts using Design Modeler consistently yielded the entire Heat Exchanger as the fluid domain. Extensive research and exploration of various web tutorials failed to provide a viable solution. Subsequently, the Intersect function in SolidWorks was employed, but it also proved ineffective.

Eventually, a simplified approach was discovered utilizing the Space Claim feature in Ansys software. Regrettably, this method also encountered difficulties. After dedicating considerable effort and time, it was ascertained that a minute opening, likely resulting from a design flaw, was the root cause of the failures experienced across all methods.

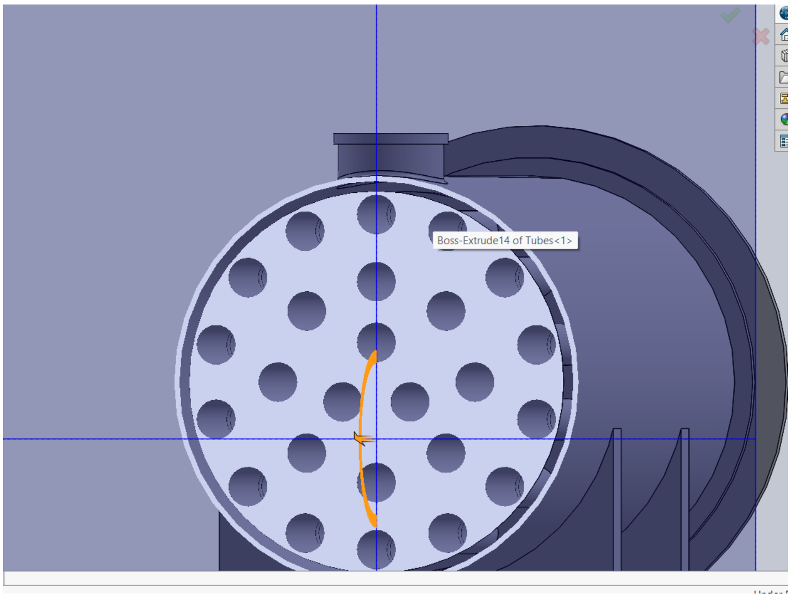

Figure 8.1: Gap Between Baffles and the Shell Walls

As illustrated in Figure 8.1, a minor clearance between the baffle and the shell wall led to inaccuracies in the extraction of the fluid domain.

The mesh generation process was time-consuming in the Ansys Student License. Fortunately, one team member had access to the complete version of Ansys 2019. The default mesh was too fine for the Ansys Fluent Student package, so we increased the element size to reduce the mesh quality. Consequently, we were unable to conduct a proper mesh convergence study. The element size was increased from 0.15 m to 2 m.

In the final stages of the project, we encountered an issue while generating the Midplane and Temperature contours. Initially, everyone obtained a single-colour contour for the temperature gradient, while other parameters were satisfactory. After extensive testing, we discovered that using a user-defined temperature difference allowed us to obtain the correct temperature gradient.

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1. Enerquip (2019) *Heat Exchanger Material Selection based on Common Criteria*, *Enerquip*. Available at: https://www.enerquip.com/heat-exchanger-material-selection/.

2. *Materials and Construction* (no date) *www.shell-tube.com*. Available at: https://www.shell-tube.com/Materials-and-Construction.html#:~:text=Heat%20exchangers%20with%20shell%20diameters.

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