Heat Exchanger Project
ME4250 - Section 02
Computer Aided Engineering
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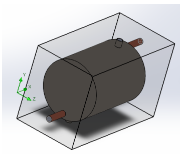
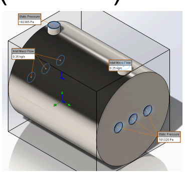
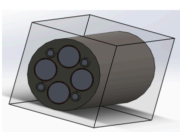
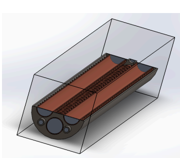
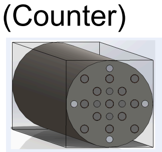
Introduction

A heat exchanger is a device that transfers heat from one substance to another. The earliest uses of heat exchangers consists of heating of rocks and placing them within huts or small tents to warm the interior without fear of burning it down. Through many decades of evolution, heat exchangers have been improved upon over and over. The study of heat exchangers led to having to understand two things, the different flows of fluids and configuration of its design. There are four basic flow configurations that are used which consists of counter, parallel, crossflow and hybrids such as cross counterflow and multipass flow. The design configurations consists of recuperative and regenerative heat exchangers. In a regenerative heat exchanger, the flow path is heated when hot fluid passes through it and then the heat is released to the cold fluid. It is broken down to two types, static and dynamic. In recuperative heat exchangers, it is split into three categories, indirect, direct and specials heat exchangers. Indirect heat exchangers consists of tubular and plate design. Direct heat exchangers consists of cooling towers, direct contact condensers, steam injectors and direct heating. Lastly, special heat exchangers are scraped surface, wet surface air coolers.

Problem Statement

A design of a shell and tube heat exchanger using water as the cooling fluid to reduce the temperature of hot oil (olive oil) flowing through a tube. The design should have a target effectiveness of 25%.

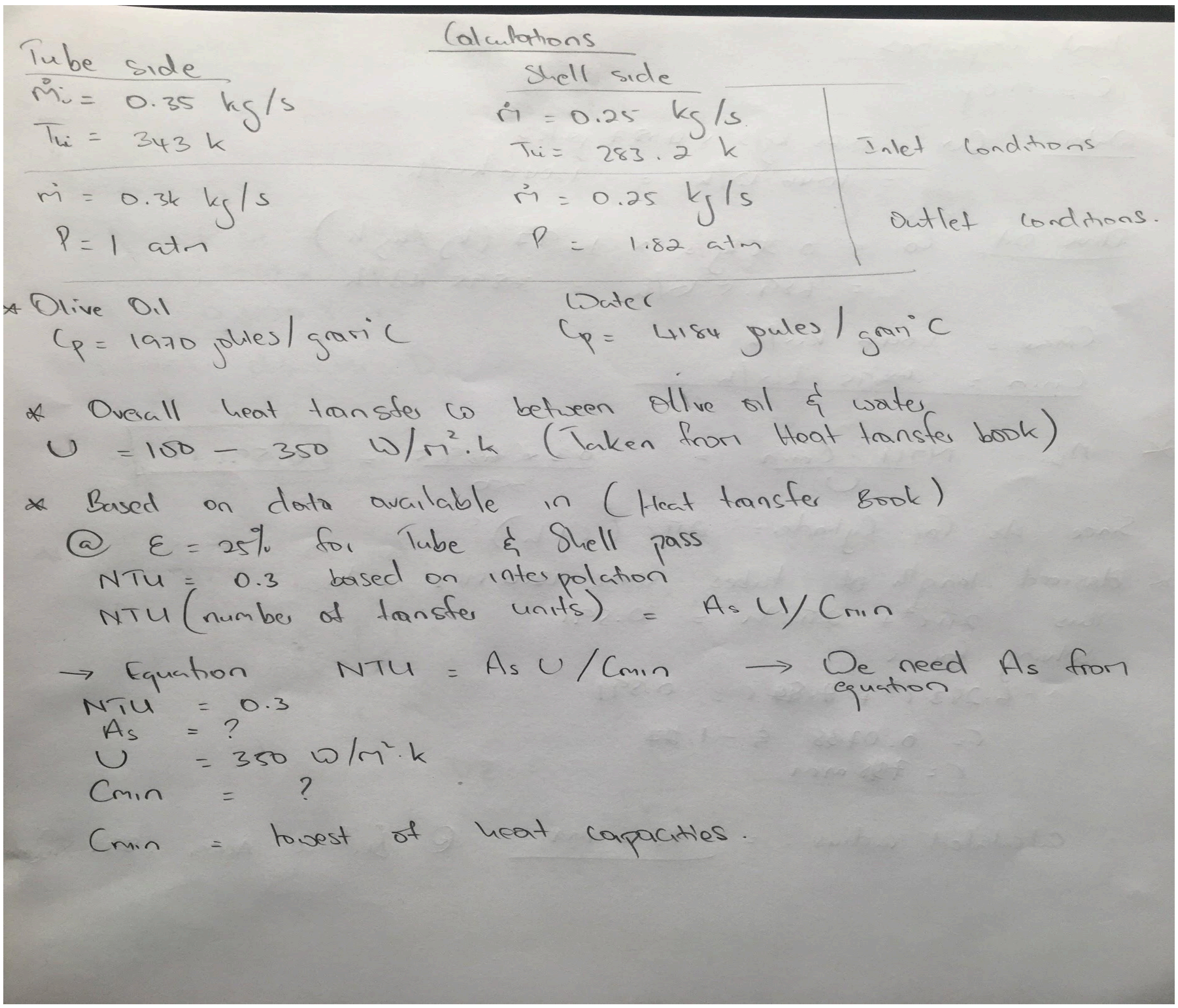
Model Summary

Design Concepts	Fluid Characteristic	Material Assignment	Boundary Conditions	Length (mm)	Diameters (mm)
1 Tube 1 Shell (Parallel) 	V_{co}=.52m/s V_{ho}=.79 T_{ho}= 340.4	Tube- Copper Shell- Cast Iron Sheet	T_{hi}=343 T_{ci} = 283.2 $\dot{m}_{ci}$=.25 kg/s $\dot{m}_{hi}$=.35 kg/s P_{ho}= 1 atm P_{co}= 1.8atm	1200	D_{oi}= 73.8 D_{oo}= 73.8 D_{wi}= 20 D_{wo}= 20
3 Tube 1 Shell (Counter) 	V_{co}= .34 V_{ho}= .08 T_{ho}= 336.7	Tube- Copper Shell- Stainless Steel	T_{hi}=343 T_{ci} = 283.2 $\dot{m}_{ci}$=.25 kg/s $\dot{m}_{hi}$=.35 kg/s P_{ho}= 1 atm P_{co}= 1.8atm	1100	D_{oi}= 36.9 D_{oo}= 36.9 D_{wi}= 20 D_{wo}= 20
4 Tube 1 Shell (Counter) 	V_{co}= .0002 V_{ho}= 1.2 T_{ho}= 334.4	Tube- Copper Shell- Cast Iron Sheet	T_{hi}=343 T_{ci} = 283.2 $\dot{m}_{ci}$=.25 kg/s $\dot{m}_{hi}$=.35 kg/s P_{ho}= 1 atm P_{co}= 1.8atm	1100	D_{oi}= 34 D_{oo}= 34 D_{wi}= 5 D_{wo}= 10
4 Tube 1 Shell- Finned (Counter) 	V_{co}= .0002 V_{ho}= .9 T_{ho}= 332.3	Tube- Copper Shell- Cast Iron Sheet	T_{hi}=343 T_{ci} = 283.2 $\dot{m}_{ci}$=.25 kg/s $\dot{m}_{hi}$=.35 kg/s P_{ho}= 1 atm P_{co}= 1.8atm	1150	D_{oi}= 34 D_{oo}= 34 D_{wi}= 5 D_{wo}= 10
13 Tube 1 Shell (Counter) 	V_{co}= .348 V_{ho}= .19 T_{ho}= 329.6	Tube- Copper Shell- Stainless Steel	T_{hi}=343 T_{ci} = 283.2 $\dot{m}_{ci}$=.25 kg/s $\dot{m}_{hi}$=.35 kg/s P_{ho}= 1 atm P_{co}= 1.8atm	1200	D_{oi}= 10 D_{oo}= 10 D_{wi}= 8 D_{wo}= 8

Calculations

Assumptions

- Steady Flow (no change in conditions w.r.t time)
- Outer Surface of heat exchanger is perfectly insulated
- Mass flow rate of both fluid is constant
- Fluid Properties are constant
- Heat transfer Coefficient is constant and uniform
- Changes in the Kinetic and Potential Energy of fluid stream is minimal



Calculations

Tube side	Shell side	
$\dot{m}_i$ = 0.35 kg/s T_i = 343 k	$\dot{m}$ = 0.25 kg/s T_i = 283.2 k	Inlet Conditions
$\dot{m}$ = 0.3k kg/s P = 1 atm	$\dot{m}$ = 0.25 kg/s P = 1.82 atm	Outlet conditions.

* Olive Oil
C_p = 1970 joules/gram C

Water
C_p = 4184 joules/gram C

* Overall heat transfer co between olive oil & water
U = 100 – 350 W/m².k (Taken from Heat transfer book)

* Based on data available in (Heat transfer Book)
@ ε = 25% for Tube & Shell pass
NTU = 0.3 based on interpolation
NTU (number of transfer units) = As U / Cmin

→ Equation NTU = As U / Cmin → We need As from equation
NTU = 0.3
As = ?
U = 350 W/m².k
Cmin = ?
Cmin = lowest of heat capacities.

heat Capacities

$C = \dot{m} c_p$

Water $C_w = 0.25$ kg/s × 4.187 joules
$= 1046$ W/k $= 1.046$ kW/k

Olive Oil $C_o = 0.35$ kg/s × 1.97 (kJ/kg k)
$= 689.5$ W/k $= .6895$ kW/k

$C_{max} = 1.046$ kW/k
$C_{min} = .6895$ kW/k

** $A_s = \frac{NTU \cdot C_{min}}{U} = \frac{0.3 \times 689.5}{350} = \boxed{0.591\ m^2}$

Since A_s for Cylinder $= 2\pi r(r+h)$

* desired length of tubes were 1200 MM = h

Thus $2\pi r^2 + 2\pi r h = 0.591$

Solving for r

$6.283 r^2 + 7.54 r = 0.591$

$r = 0.0738$ & -1.27

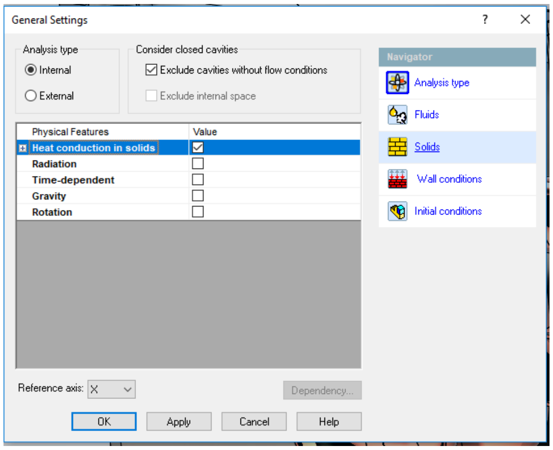
$r = 73.8$ mm

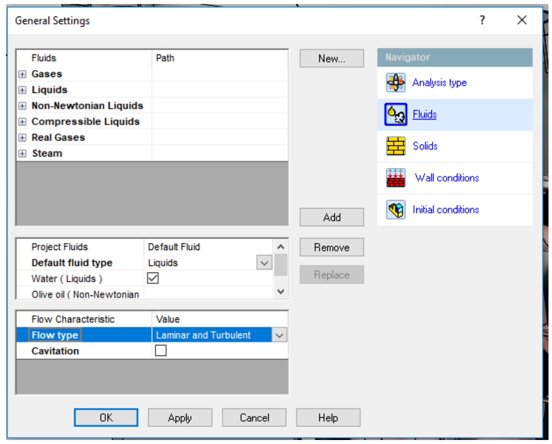
Calculated radius = 73.8 m @ Surface Area .591 x10³mm

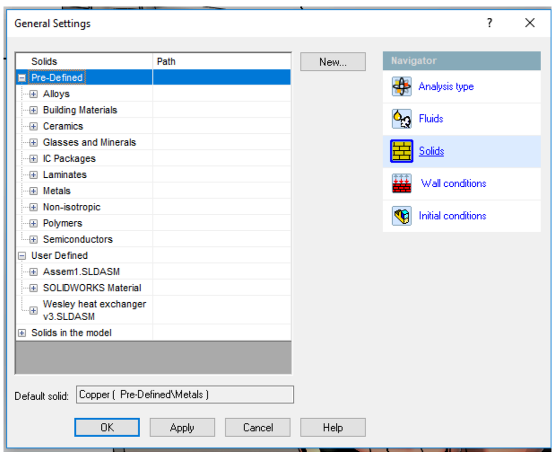
Results

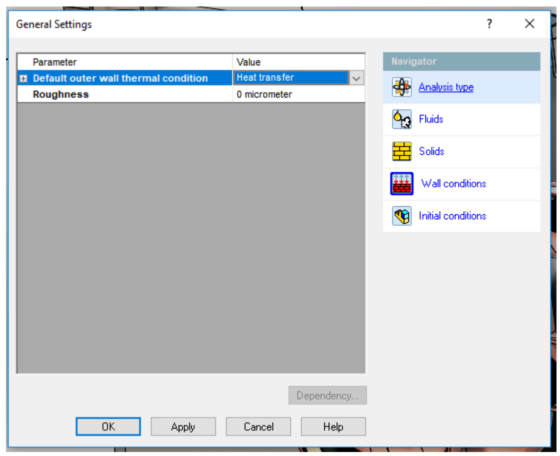
3 Tube 1 Shell

-General settings

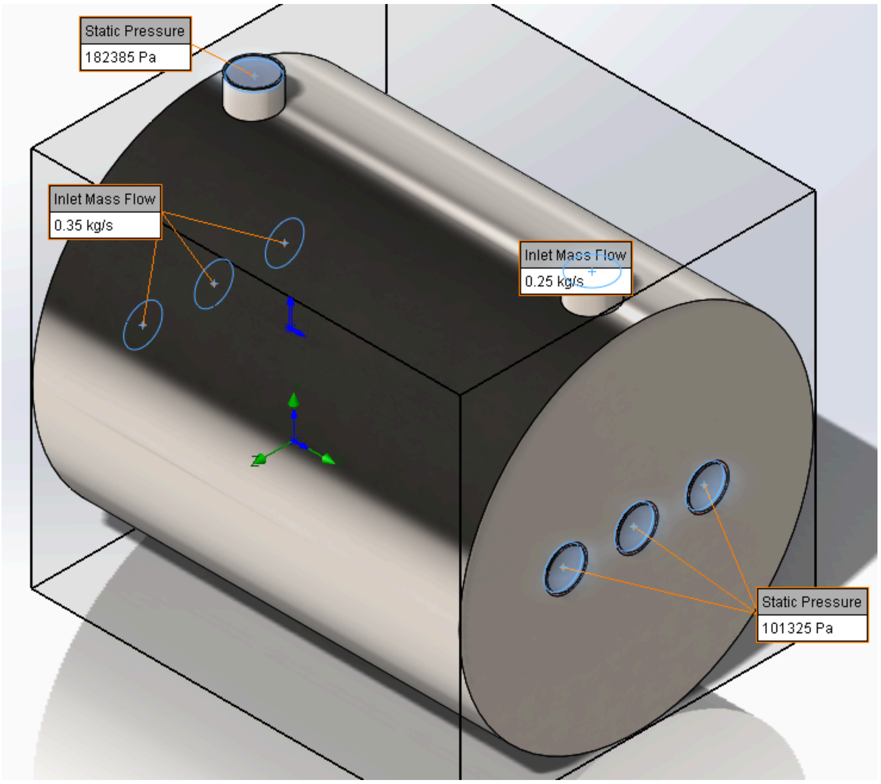








Boundary Conditions

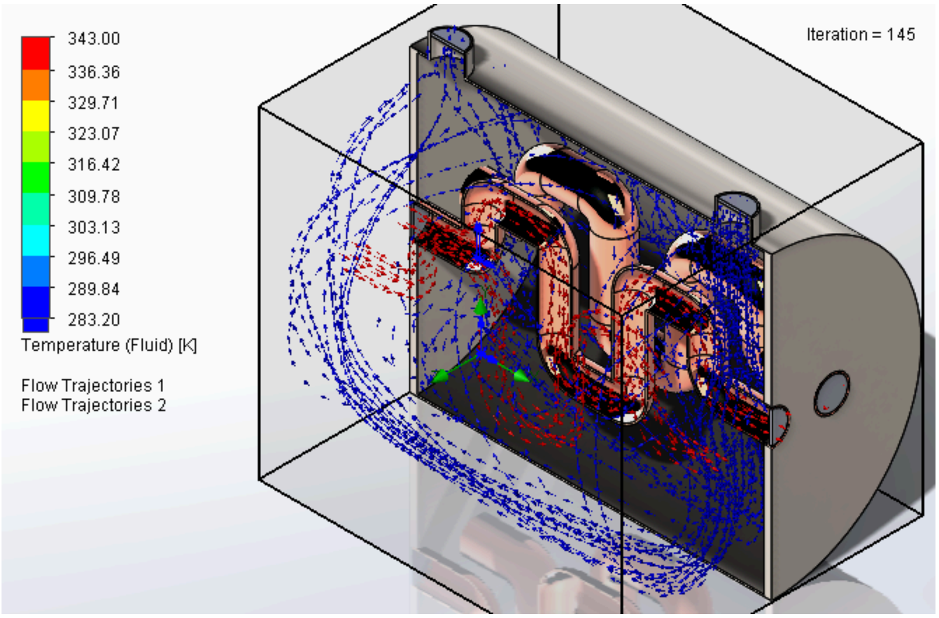


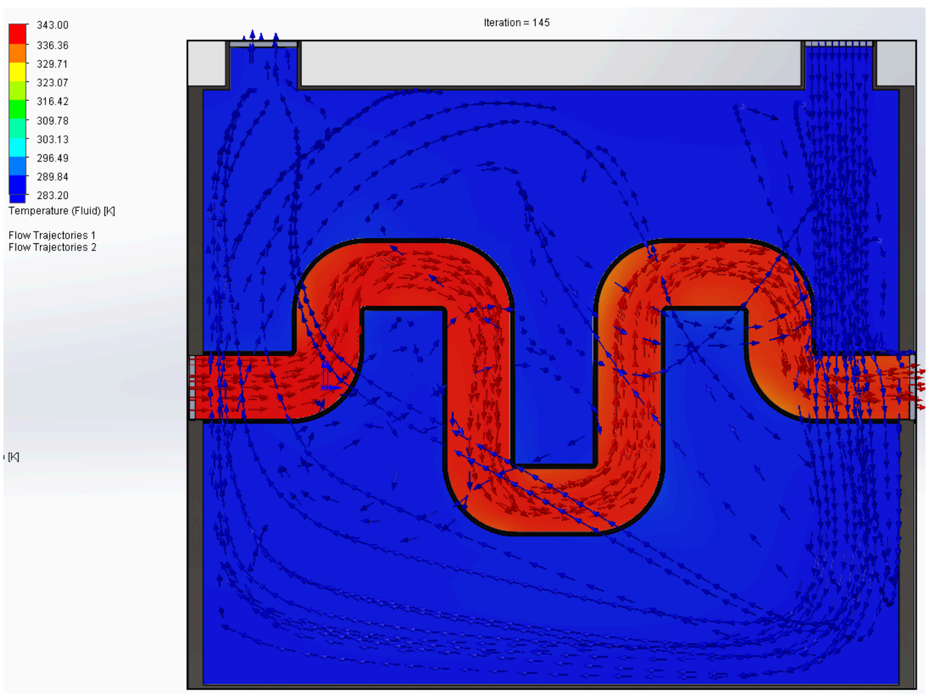
Surface Goals

List of Goals

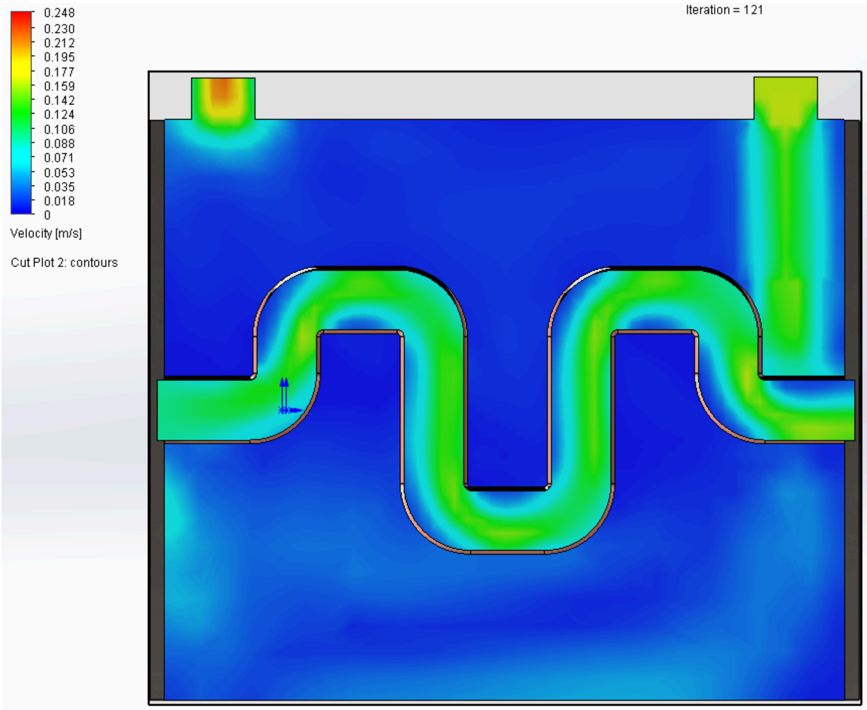
Name	Current Value	Progress	Criterion	Averaged Value
SG Av Temperature (Fluid) 1	340.803 K	Achieved (IT = 83)	1.71917 K	340.747 K
SG Av Temperature (Fluid) 2	283.913 K	04%	0.0140474 K	283.75 K
SG Av Velocity 1	0.1612 m/s	Achieved (IT = 67)	0.0489878 m/s	0.161146 m/s
SG Av Velocity 2	0.0922046 m/s	Achieved (IT = 67)	0.00182788 m/s	0.0922056 m/s

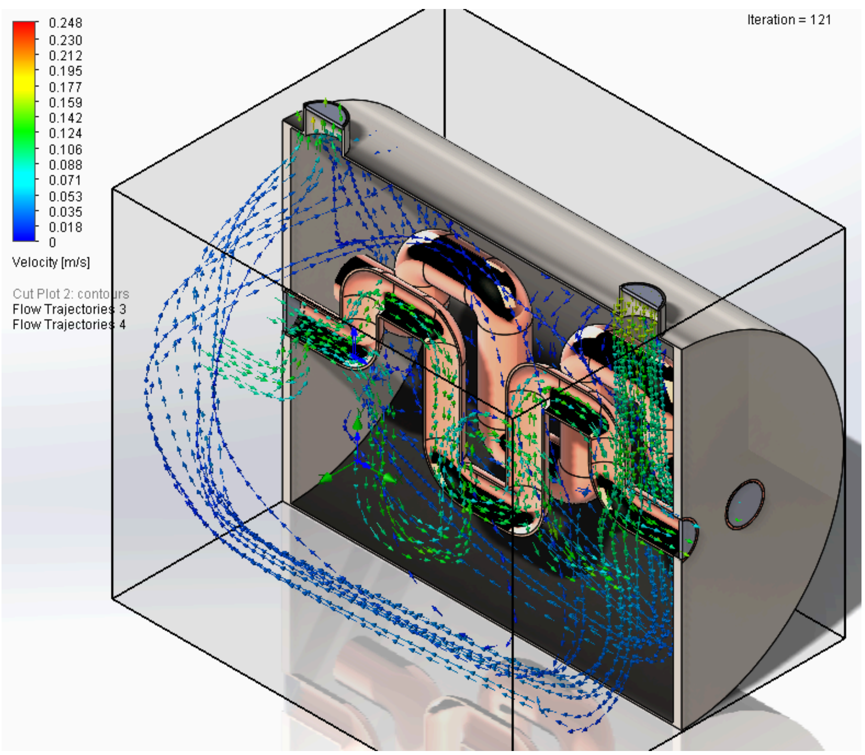
Temperature Plots





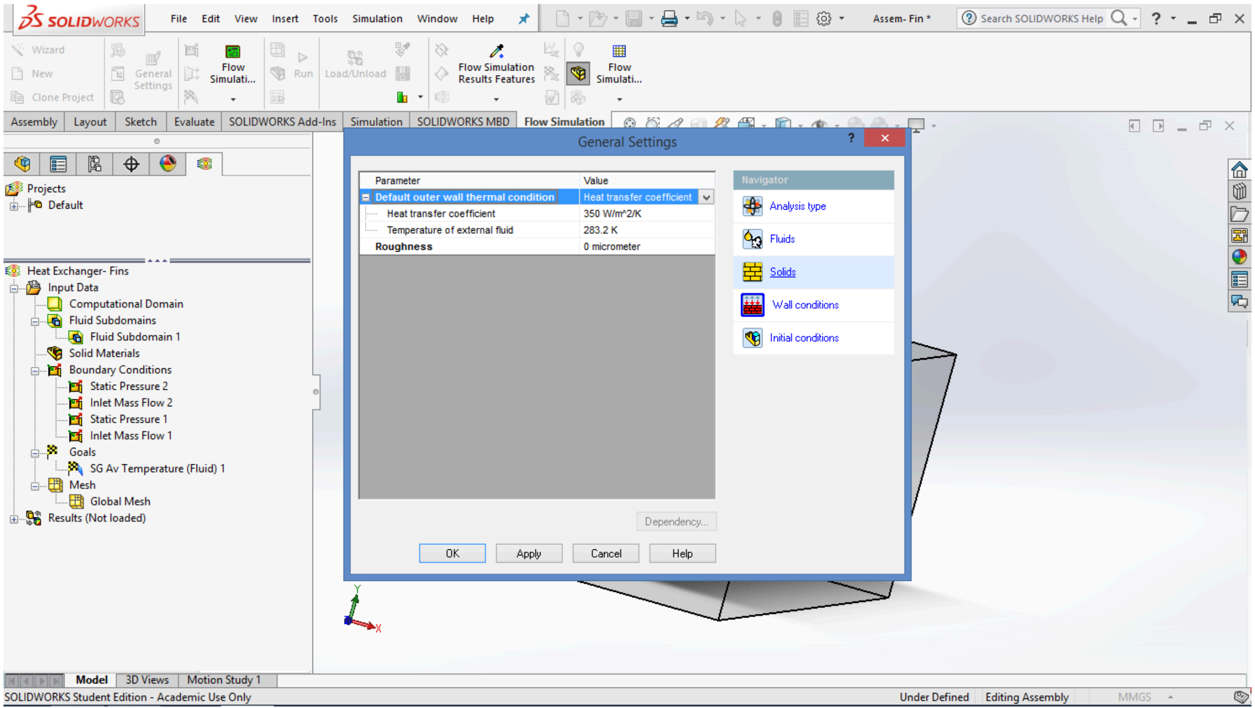
Velocity Plot





4 Tube 1 Shell (Fin)

General settings



Boundary conditions

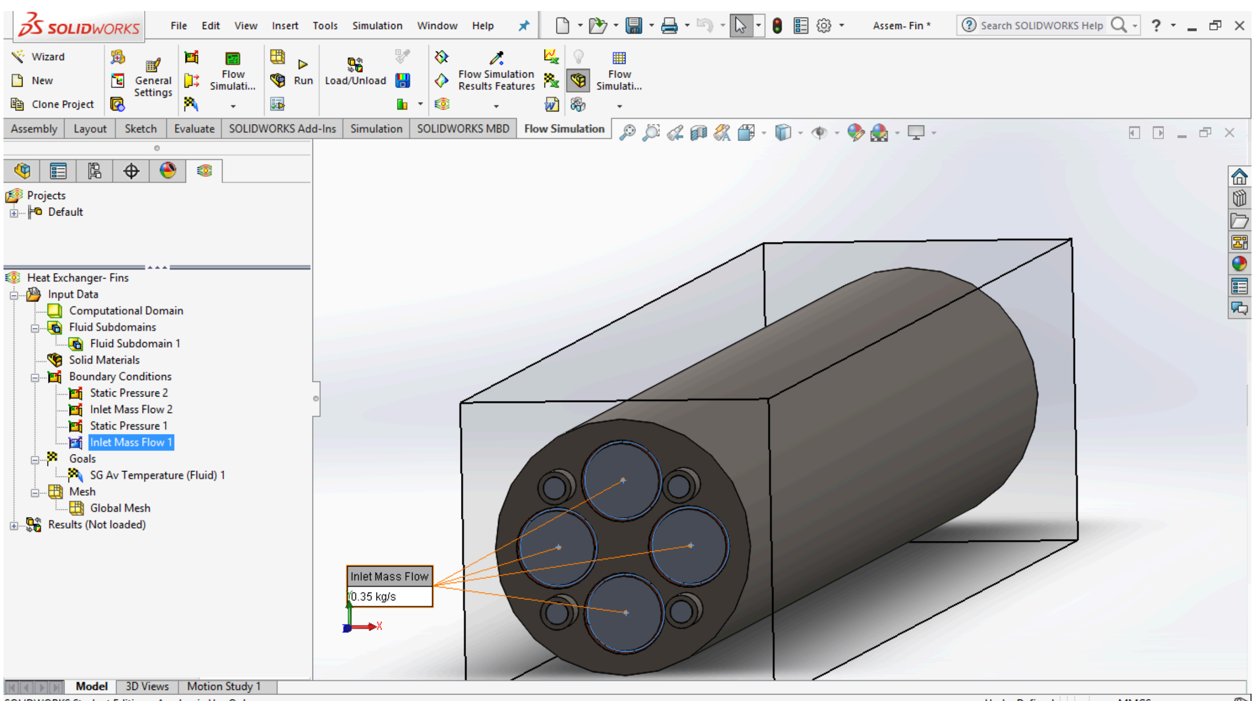


Figure. Inlet Mass Flow of Olive oil

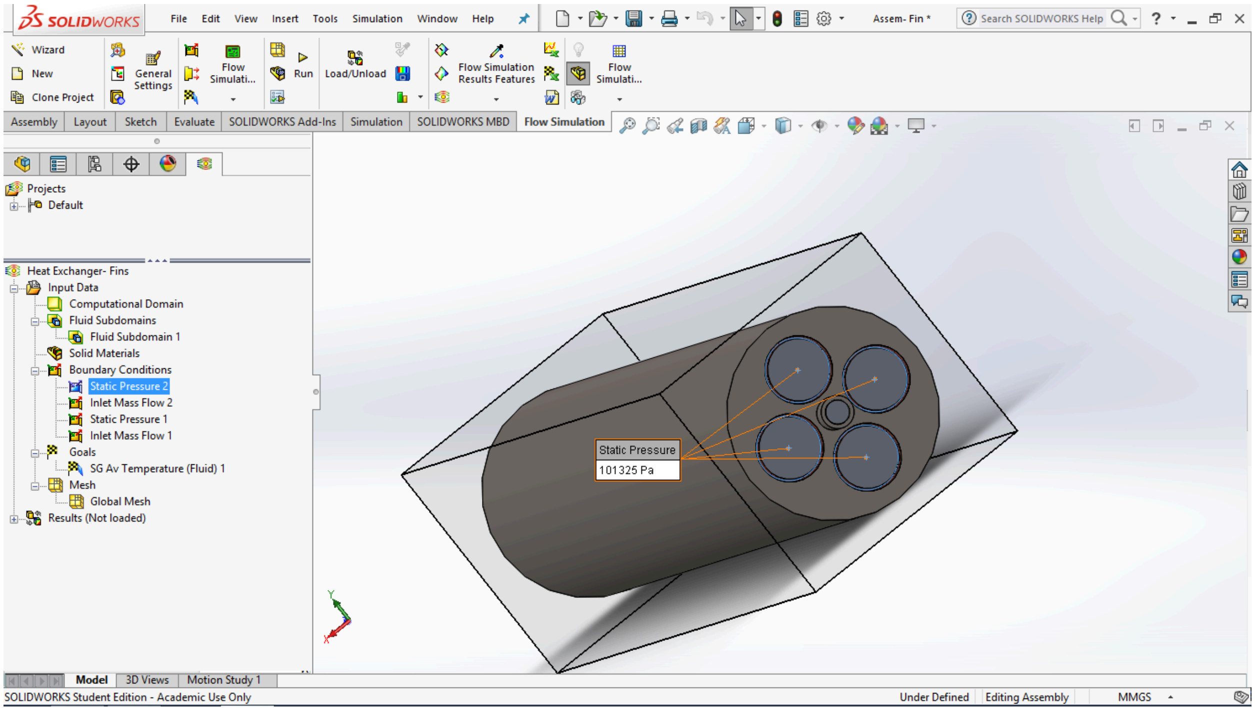


Figure.. Outlet boundary conditions Olive oil

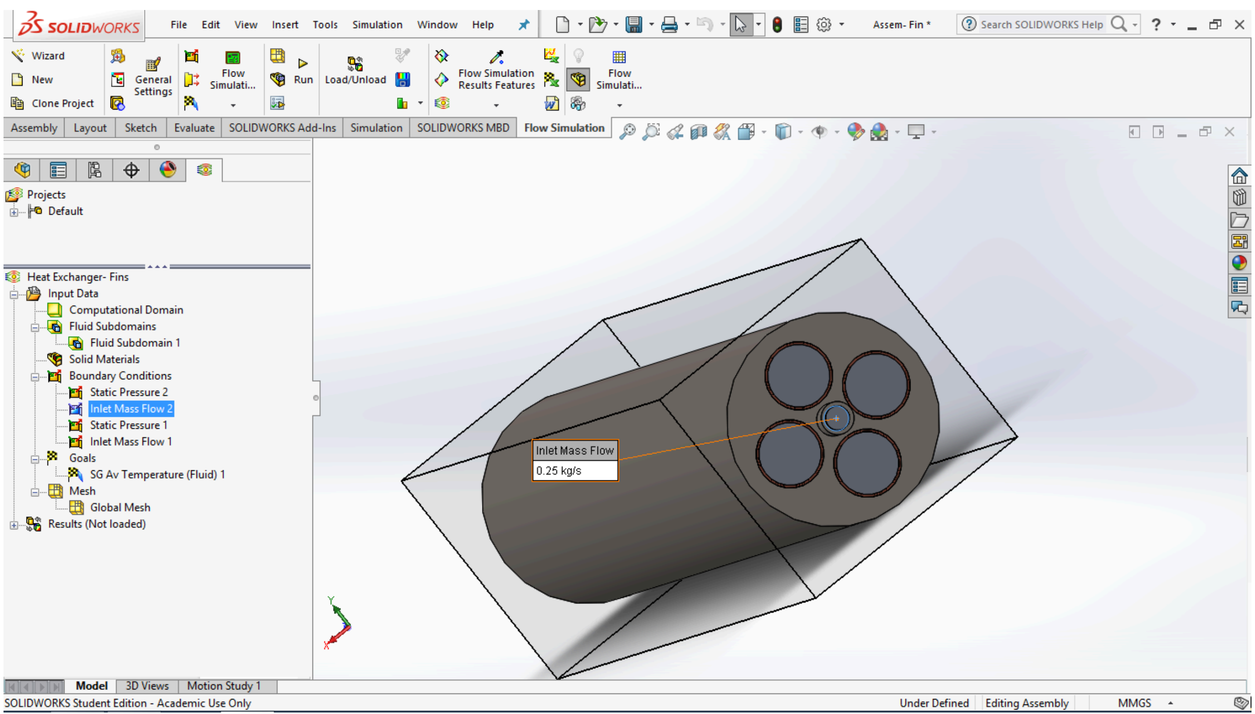


Figure.. Inlet mass flow of water

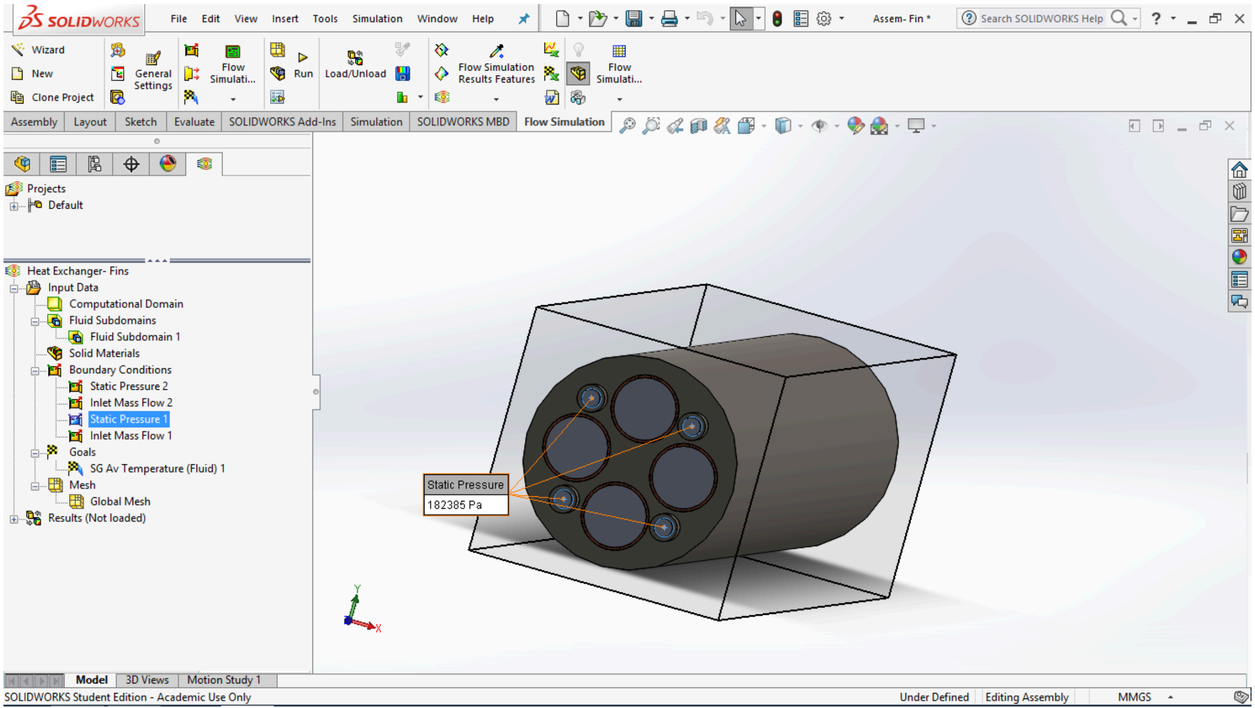
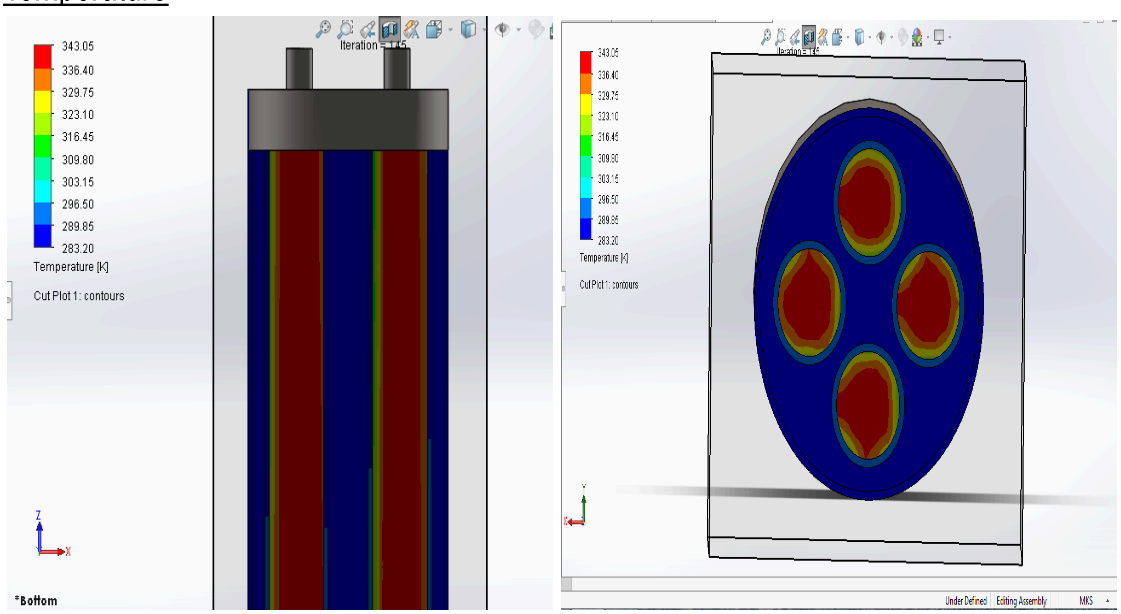


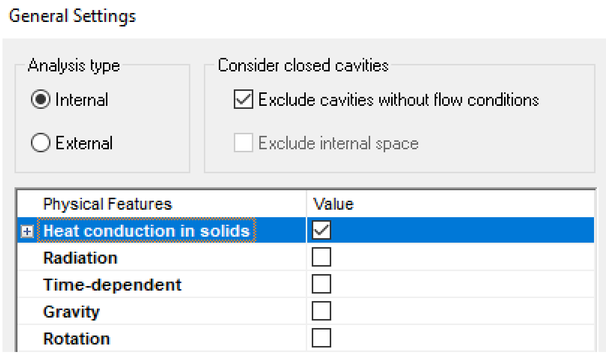
Figure .. Outlet boundary condition

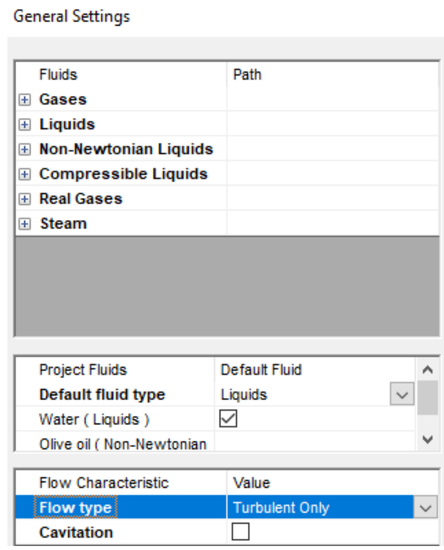
<u>Temperature</u>

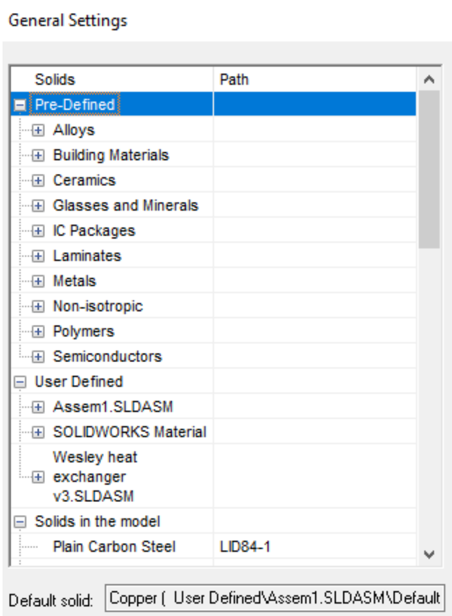


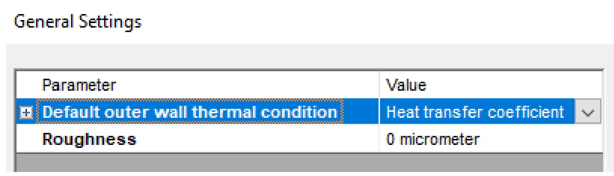
Final Design

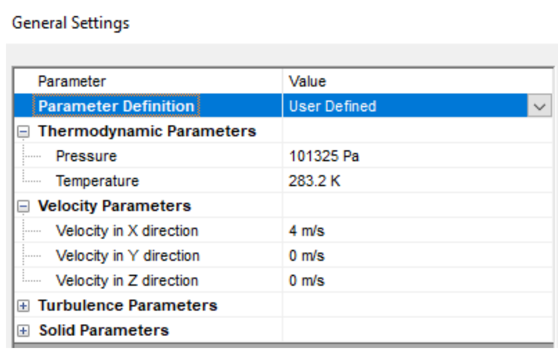
General settings











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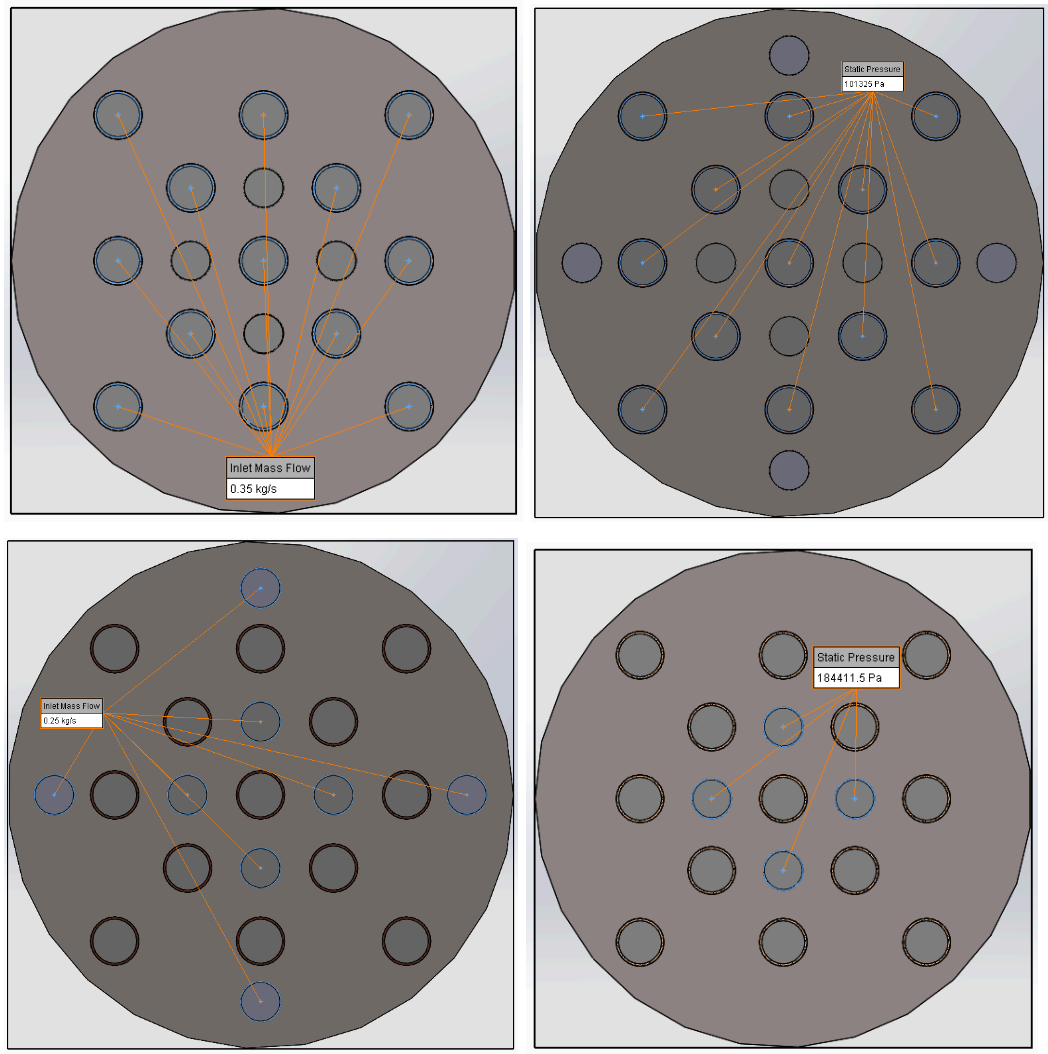
Boundary conditions

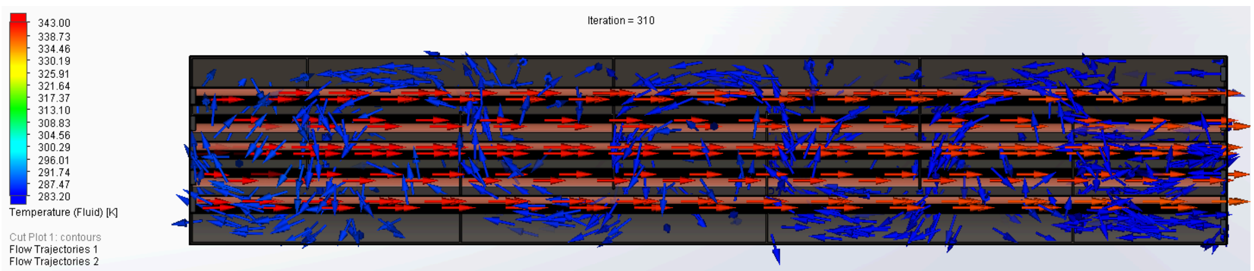


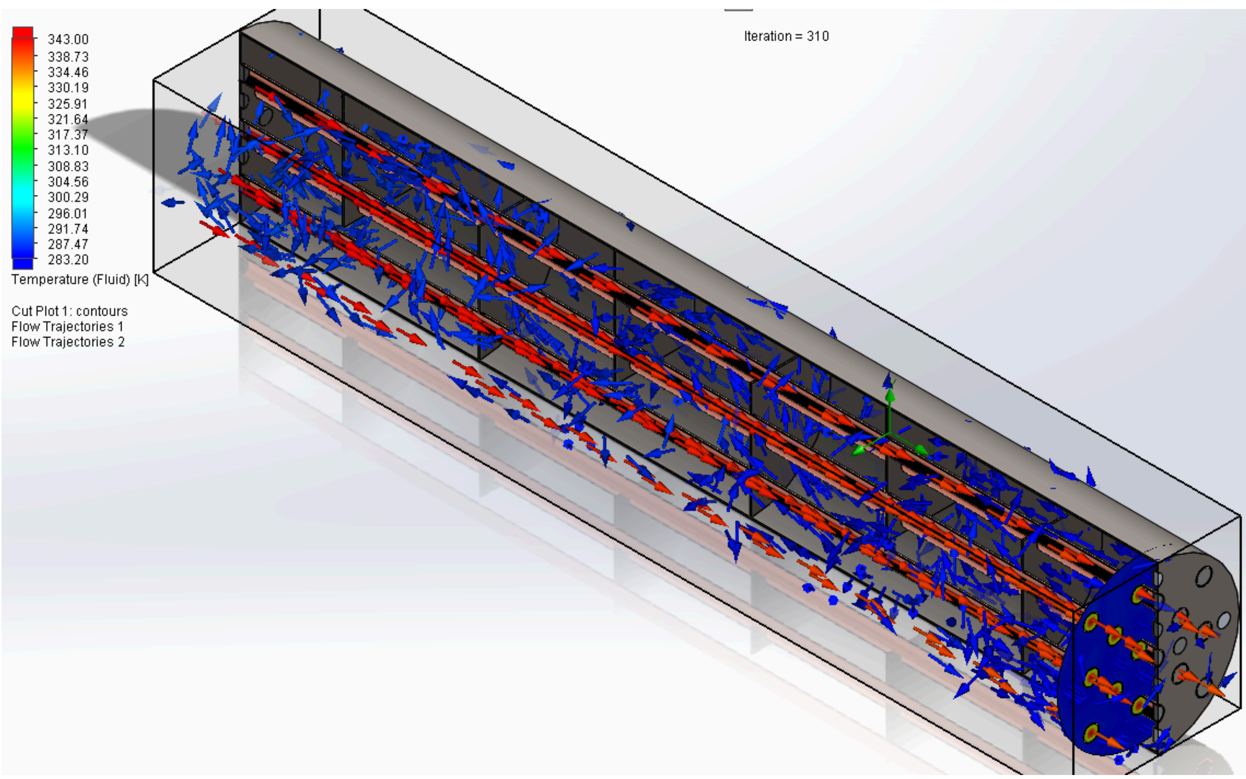
Surface Goals

List of Goals

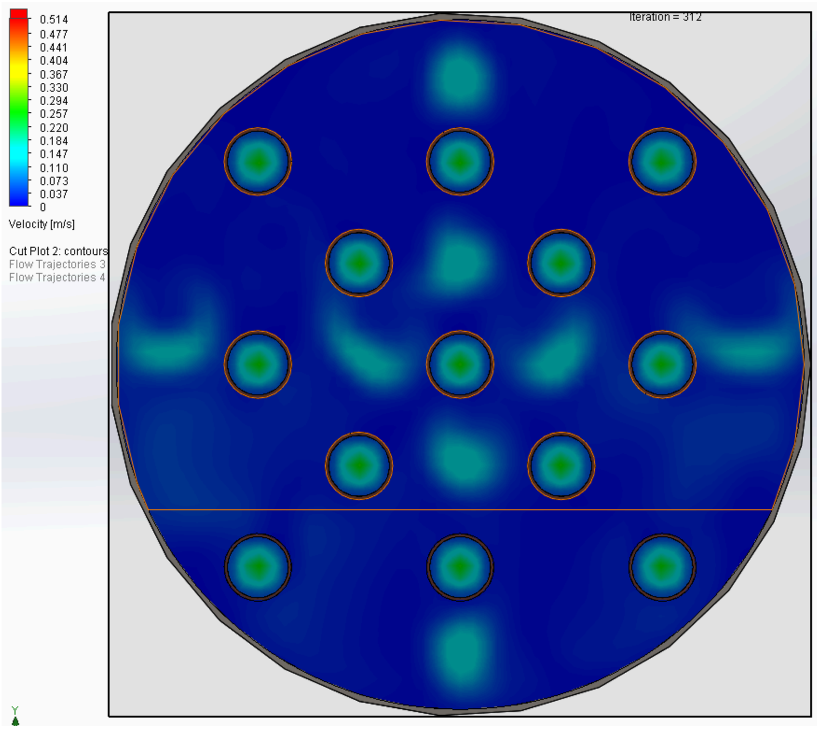
Name	Current Value	Progress	Criterion	Averaged Value
Oil Outlet Temp	329.662 K	Achieved (IT = 191)	0.402801 K	329.602 K
Oil Velocity	0.118607 m/s	Achieved (IT = 253)	1.11136e-005 m/	0.118609 m/s
Water Outlet Temp	287.162 K	11%	0.100888 K	286.813 K
Water Velocity	0.347673 m/s	Achieved (IT = 241)	0.000388807 m/:	0.347478 m/s

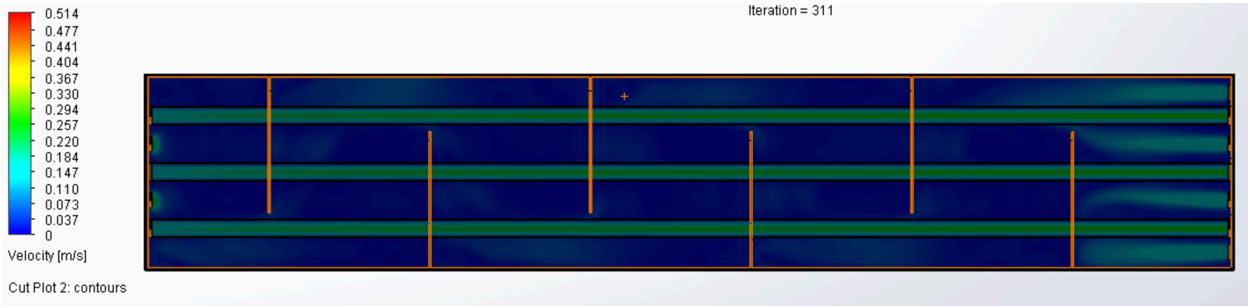
<u>Flow Trajectory Plot</u>



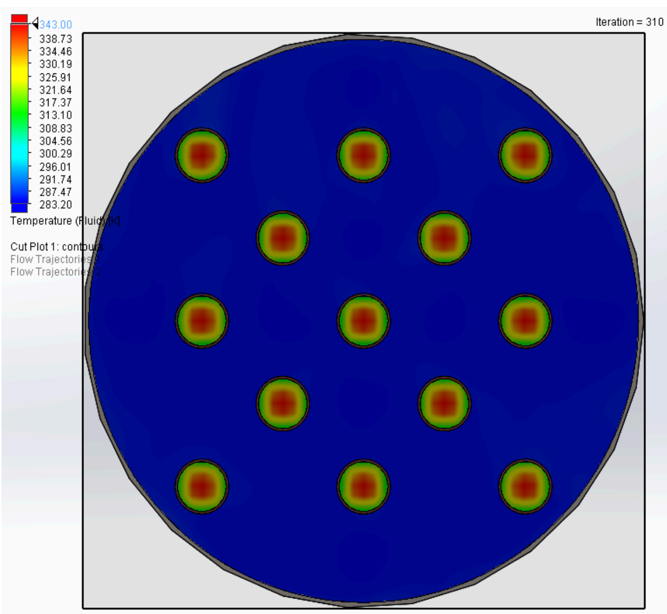


Velocity Plot





Temperature Plot



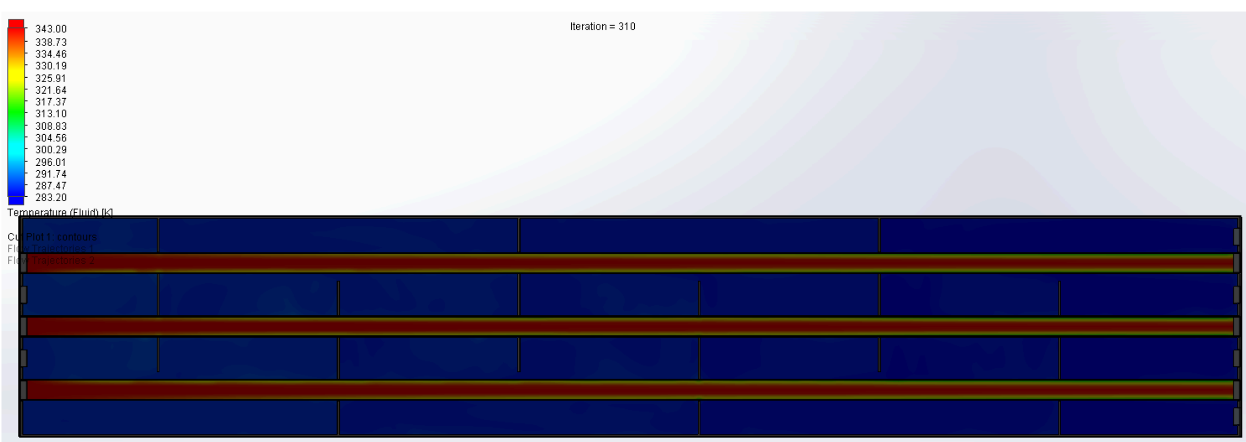


Table. 1 Showing various design of heat exchanger and results

Type of Flow	Output Velocity (V_{co}) m/s	Output Velocity (V_{ho}) m/s	Exit Temperature (T_{h0}) K	Efficiency (ε)%
Parallel				
1 Tube 1 Shell	.52	.79	340.4	4.4
Counter				
3 Tubes 1 Shell (Curved Pipe)	.34	.08	336.7	10.5
4 Tube 1 Shell	.0002	1.2	334.4	14.4
4 Tube 1 shell-Finned	.0002	.9	332.3	18
13 Tube 1 Shell	.3478	.19	329.6	22.3

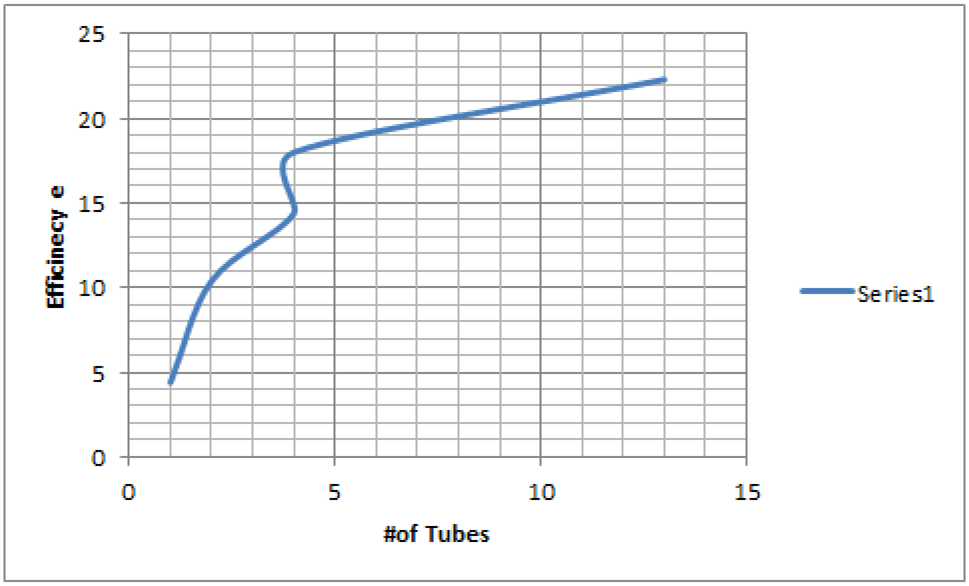


Fig.1 Graph of Efficiency vs #Tubes

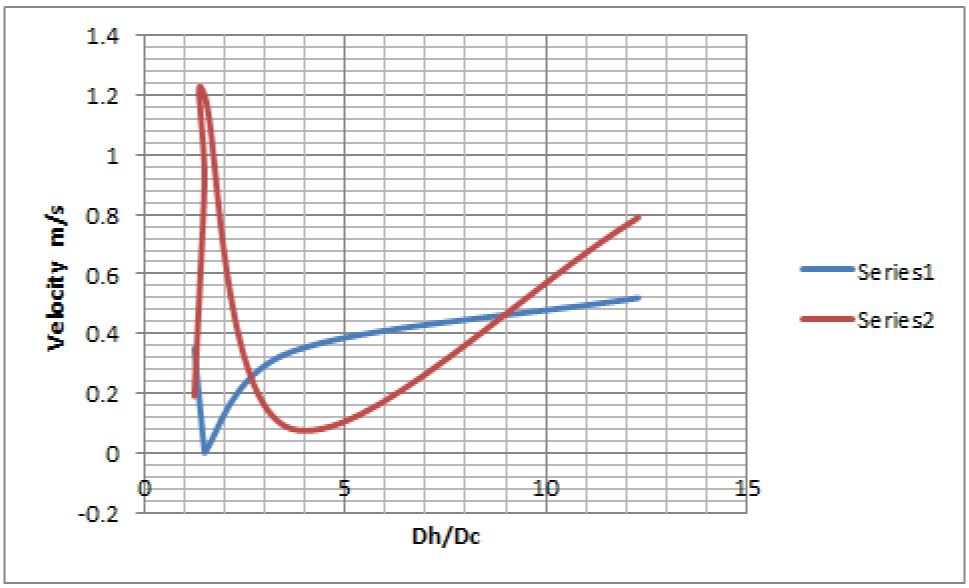


Fig.2 Graph Velocity vs Dh/Dc ratio

Discussion

Based on the values given and the criteria that needs to be met for the Heat Exchanger, various designs and concepts were studied and incorporated with the use of calculations. The Universal heat transfer coefficient was taken from a table of values for various fluids and was found to be 350 W/m2K. The NTU method was preferred and and the desired effectiveness yielded a NTU of .3 based on interpolation, this value was then used to calculate surface area of the tube. The surface area was calculated to be .591m2 , the desired radius of the tube was also calculated to be 123mm with a length of 1200mm.

1 tube 1 shell design used as testing and had a copper tube with Cast Iron Sheet Shell The flow was parallel and this design incorporated a tube that was curved and had a length of 1000mm this design however yielded a efficiency of 4.4% with output velocities of the water and olive oil at .52m/s and .79 m/s respectively. It should be noted these results were experimental and diameters were too big, these resulted in slower exit velocities with very low efficiency. The second design had a 3 tube (curved) made of copper and 1 shell made of Stainless steel and yielded an efficiency 10.5% with velocities 0.34m/s and 0.08m/s for water and olive oil respectively. This design was a lot better than first design as the contact area of water and tubes were increased thus resulting in better cooling process. However the exit velocity of oil was a bit lower, this can be attributed to the curve in tubes that affect the kinetic energy of fluid thus affecting the velocity. The third design had 4 tube made of copper and a 1 shell made of Sheet Cast Iron. This design yielded an efficiency of 14.4 % with velocities of .0002m/s and 1.2m/s for water and oil respectively. The increase in length, reduction in diameter and increase in frequency of the tubes resulted in increased contact with water, a longer time to cool down and decreased cross sectional area, the outlet velocity of the oil was 1.2 m/s as a result of straight tubes that did not damper energy of fluid. This design was edited and the concepts of Fins was applied , the finned alternate yielded a efficiency of 18% with velocities of 0.0002m/s and .9m/s for water and olive oil, the fin increased surface area and also acted as a sort of baffle which

increased turbulence of the water which in turn aided heat transfer. A final design was reproduced and it yielded a efficiency of 22.3% with velocities of .35 m/s and .19 m/s for water and olive oil respectively. It can also be stated that graph of Exit Velocities vs Diameters it can be seen based on simulation that as ratio of diameter of hot tube vs cold tubes increases so does exit velocities.

Based on graph of number of Tubes vs Efficiency it can be seen that increasing the frequency of tubes increases efficiency , this was a result of decreased diameters to allow for increased number of tubes.

Conclusion

1 tube 1 shell design yielded an efficiency of 4.4% with output velocities of the water and olive oil at .52m/s and .79 m/s respectively. The second design had a 3 tube (curved) made of copper and 1 shell made of Stainless steel and yielded an efficiency 10.5% with velocities 0.34m/s and 0.08m/s for water and olive oil respectively. The third design had 4 tube made of copper and a 1 shell made of Sheet Cast Iron. This design yielded an efficiency of 14.4 % with velocities of .0002m/s and 1.2m/s for water and oil respectively. This design was edited and the concepts of Fins was applied , the finned alternate yielded a efficiency of 18% with velocities of 0.0002m/s and .9m/s for water and olive oil. A final design was reproduced and it yielded a efficiency of 22.3% with velocities of .35m/s and .19 m/s for water and olive oil respectively

Based on results obtained from simulations and results it can be deduced that various factors can be manipulated to arrive at desired criteria for an heat exchanger. It can be stated that an increase in the frequency of tubes, adding baffles and fins, reducing the diameter of tubes increasing surface area and area of contact with cooling agent along with making water more turbulent are various ways to increase the efficiency of an Heat exchanger and also ways of making more effective to reach desired goals. It can also be said that increasing the mesh density also helps to refine the results obtained. The final design had an efficiency of 22% with mesh density at 5.

Bibliography

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