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DESIGN AND THERMAL PERFORMANCE ANALYSIS OF SHELL AND TUBE HEAT EXCHANGER WITH VARIOUS BAFFLES

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Abstract

Shell-and-tube heat exchangers are widely used in chemical, power, and process industries due to their robustness and suitability for high-pressure and high-temperature applications. Among the various design parameters, baffle configuration plays a critical role in enhancing shell-side heat transfer by inducing turbulence, while simultaneously affecting pressure drop. In this study, the thermal and hydraulic performance of a shell-and-tube heat exchanger with different baffle configurations—single baffle, double baffle, and inclined double baffles at 10° and 20°—is numerically investigated. Three-dimensional computational fluid dynamics (CFD) simulations are carried out using ANSYS Fluent to analyze flow behaviour, temperature distribution, pressure drop, and velocity fields on the shell side.

Keywords: Shell-and-tube heat exchanger, CFD, Baffle design, Heat transfer enhancement, Pressure drop

1. Introduction

Heat exchangers are essential thermal devices used to transfer energy between two or more fluids at different temperatures. Among various heat exchanger types, shell-and-tube heat exchangers (STHEs) remain the most widely adopted in industrial applications due to their mechanical strength, design flexibility, ease of maintenance, and ability to operate under high pressure and temperature conditions.

The thermal performance of an STHE is strongly influenced by shell-side flow characteristics. Baffles are installed inside the shell to support tubes, direct shell-side fluid flow across the tube bundle, and enhance turbulence, thereby improving heat transfer. However, improper baffle design can lead to excessive pressure drop, increased pumping power, and flow-induced vibration. Therefore, optimization of baffle geometry and orientation is crucial for achieving high thermal efficiency with acceptable hydraulic performance.

2. Literature Review

Numerous studies have investigated the influence of baffle geometry on shell-side heat transfer and pressure drop in shell-and-tube heat exchangers. Conventional segmental baffles are commonly used due to their simplicity; however, they often cause flow dead zones and high pressure losses. Researchers have explored alternative baffle designs such as helical, inclined, and double baffles to improve shell-side performance.

Previous experimental and numerical studies indicate that inclined and helical baffles promote continuous swirling flow, reduce flow separation, and enhance heat transfer coefficients. However, these designs may increase fabrication complexity. CFD-based investigations have shown that double baffle arrangements can improve turbulence distribution while maintaining structural simplicity. Studies comparing different baffle angles suggest that moderate inclination angles provide an optimal balance between heat transfer enhancement and pressure drop.

3. Heat Exchanger Design Specifications

3.1 Geometry and Design Parameters

The shell-and-tube heat exchanger analyzed in this study is designed based on standard industrial practice. The main geometric and material specifications are summarized below:

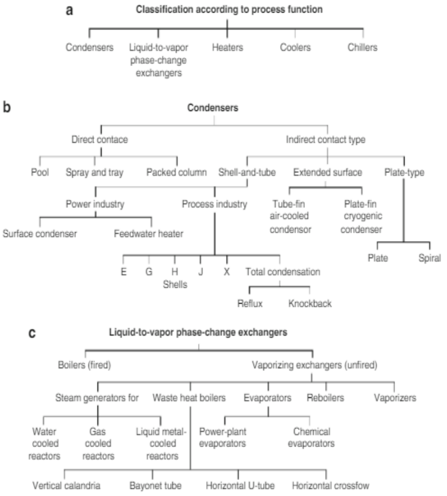
- Shell diameter: 300 mm
- Tube length: 1500 mm
- Tube outer diameter: 15 mm
- Number of tubes: 75
- Tube sheet type: Double
- Material: 316L Stainless Steel (all components)

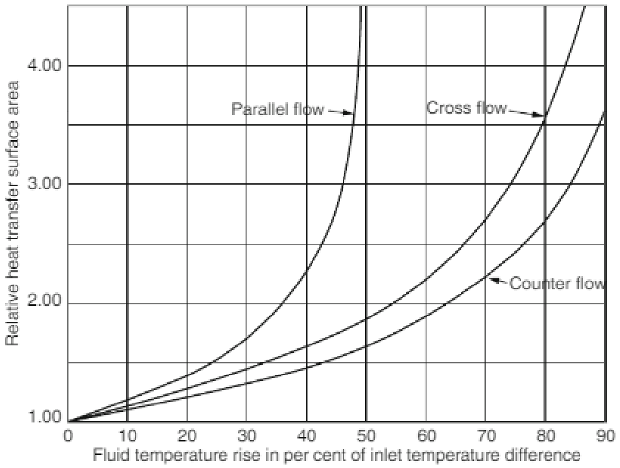
3.2 Baffle Configurations

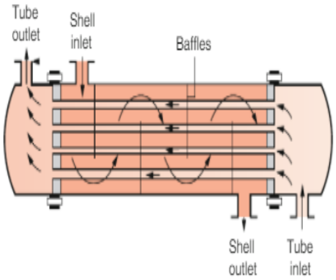
Four different shell-side baffle configurations are considered:

1. Single segmental baffle
2. Double segmental baffle
3. Double baffle with 10° inclination
4. Double baffle with 20° inclination

A heat exchanger is a heat transfer device that exchanges heat between two or more process fluids. Heat exchangers have widespread industrial and domestic applications. Many types of heat exchangers have been developed for use in steam power plants, chemical processing plants, building heat and air conditioning systems, transportation power systems, and refrigeration units.







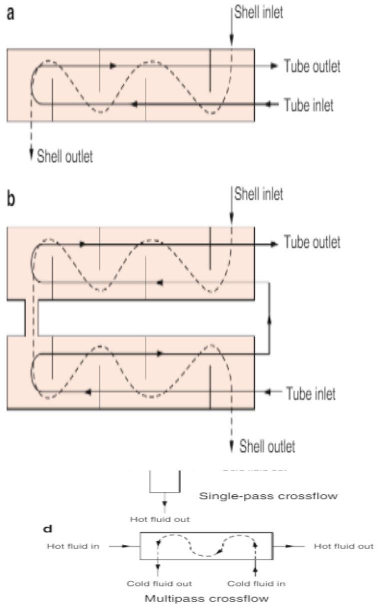


PLATE FIN HEAT EXCHANGER

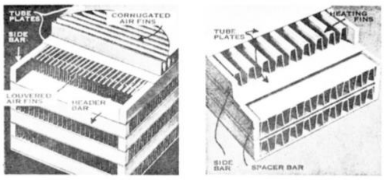
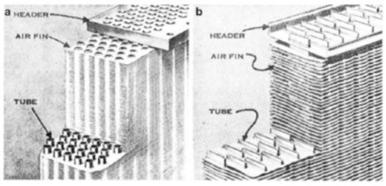
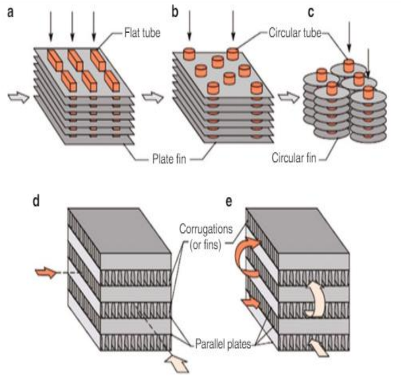
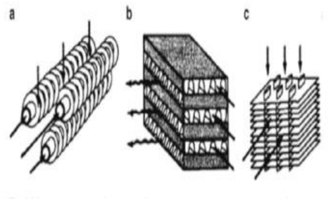


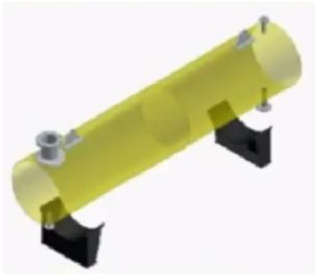
Fig. 2.6 Plate-fin heat exchangers. (Courtesy of Harrison Radiator Division of General Motors Corporation)

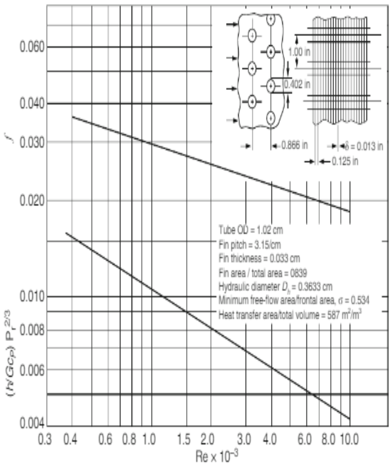


COMPACT HEAT EXCHANGERS AND THEIR CLASSIFICATIONS









LMTD METHOD

The log mean temperature difference (LMTD) is derived in all basic heat transfer texts. It may be written for a parallel flow or counter flow arrangement.

$$\Delta T_m = \frac{\Delta T_2 - \Delta T_1}{\ln \dfrac{\Delta T_2}{\Delta T_1}}$$

Ɛ− NTU Method

The effectiveness / number of transfer units (NTU) method was developed to simplify a number of heat exchanger design problems.

$$\epsilon = \frac{C_{max}(T_{hi} - T_{ho})}{C_{min}(T_{hi} - T_{ci})}$$

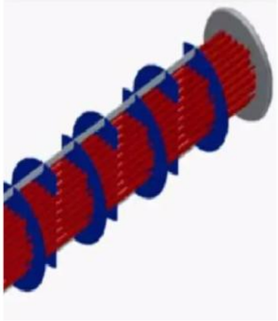
DESIGN CONSIDERATIONS AND ALGORITHM DEVELOPMENT

Shell

Shell is the container for the shell fluid and the tube bundle is placed inside the shell. Shell diameter should be selected in such a way to give a close fit of the tube bundle. The clearance between the tube bundle and inner shell wall depends on the type of exchanger shells are usually fabricated from standard steel pipe with satisfactory corrosion allowance.

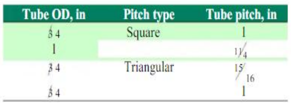
TUBE

Tube OD of ¾ and 1" are very common to design a compact heat exchanger. The most efficient condition for heat transfer is to have the maximum number of tubes in the shell to increase turbulence. The tube thickness should be enough to withstand the internal pressure along with the adequate corrosion allowance. The tube thickness is expressed in terms of BWG (Birmingham Wire Gauge) and true outside diameter (OD).

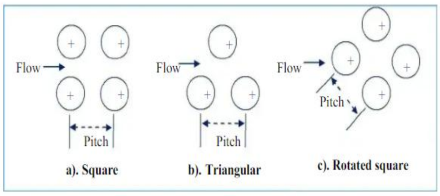


TUBE PASS

The number of passes is chosen to get the required tube side fluid velocity to obtain greater heat transfer co-efficient and also to reduce scale formation. The tube passes vary from 1 to 16. The tube passes of 1, 2 and 4 are common in application.



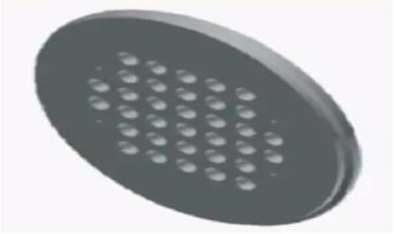
Tube OD, in	Pitch type	Tube pitch, in
¾	Square	1
1		1¼
¾	Triangular	15/16
¾		1



TUBE SHEET

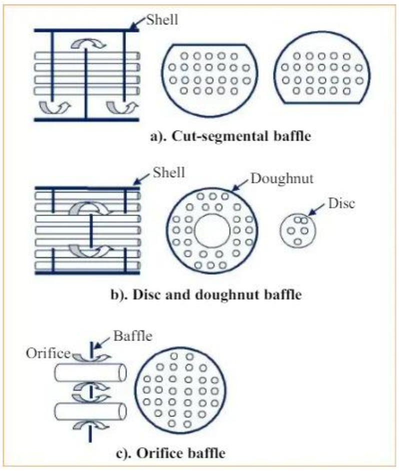
The tubes are fixed with tube sheet that form the barrier between the tube and shell fluids. The tubes can be fixed with the tube sheet using ferrule and a soft metal packing ring. The tubes are attached to tube sheet with two or more grooves in the tube sheet wall by tube

rolling.



BAFFLES

Baffles are used to increase the fluid velocity by diverting the flow across the tube bundle to obtain higher transfer co-efficient. The distance between adjacent baffles is called baffle-spacing



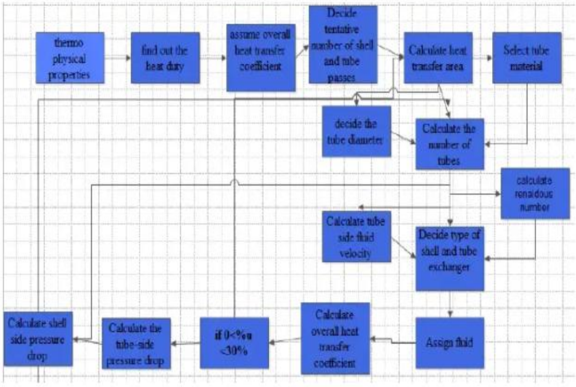


Fig. flow chart of design procedure

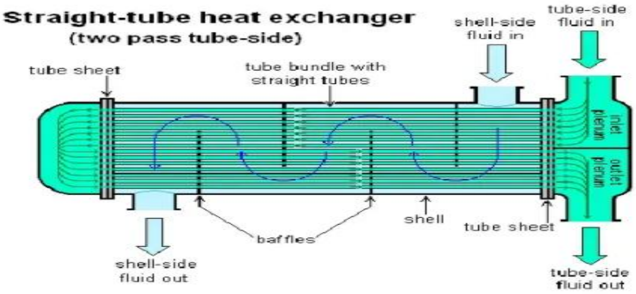


Fig. Two pass shell and tube heat exchanger

MATERIALS:

A material is a substance or mixture of substances that constitutes an object. Materials can be pure or impure, living or non-living matter. Materials can be classified based on their physical and chemical properties, or on their geological origin or biological function.

Structural Steel

Structural steel, one of the other widely used building materials in the construction industry, is also the most studied and best understood. Its behaviour is predictable and is subject to various standards and codes established by agencies such as the American Institute of Steel Construction (AISC) that define its specific shape, cross-section, chemical composition, and mechanical properties.

4. Numerical Methodology

4.1 Computational Model

A three-dimensional model of the shell-and-tube heat exchanger is developed using ANSYS Space Claim. The fluid domain includes the shell-side flow region with tubes modelled as solid walls. The effect of baffles on shell-side flow redirection and turbulence generation is explicitly captured.

4.2 Meshing

An unstructured mesh with local refinement near tube surfaces and baffle regions is generated to accurately resolve boundary layers and flow separation. Mesh independence is ensured by verifying that further refinement does not significantly alter pressure drop and temperature results.

4.3 Governing Equations and Solver

The steady-state, incompressible Reynolds-Averaged Navier–Stokes (RANS) equations are solved along with the energy equation. Turbulence effects are modelled using the SST k–ω turbulence model, which provides reliable predictions for flows with strong separation and adverse pressure gradients. Space claim: Space Claim is a solid modeling CAD (computer-aided design) software that runs on Microsoft Windows and developed by Space Claim Corporation. The company is headquartered in Concord, Massachusetts.

Shell Diameter	300mm
Tube Sheet Type	Double
Material	All Components 316L Stainless Steel
Tube Count	75
Tube Length	1500 mm
Tube Outer Diameter	15mm

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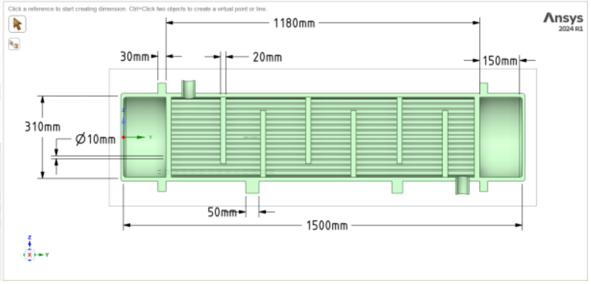
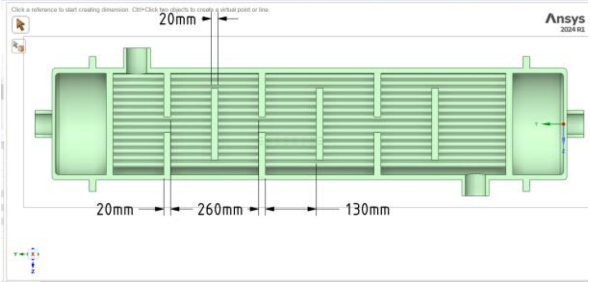
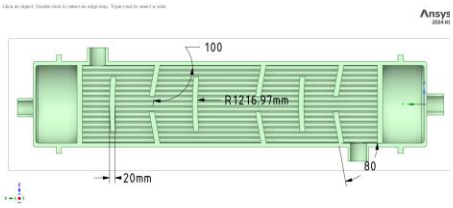
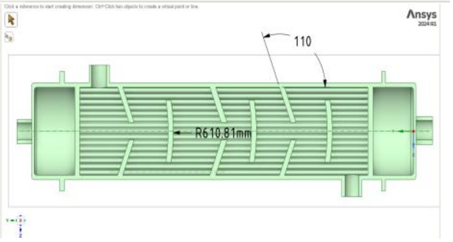


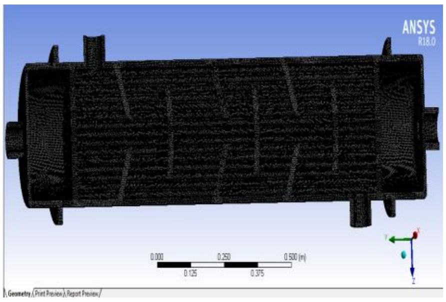


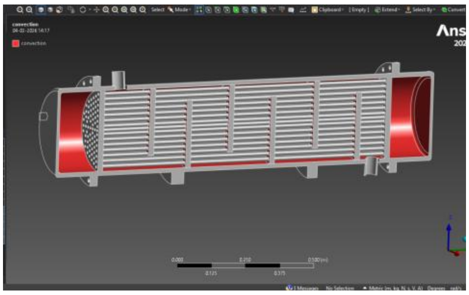


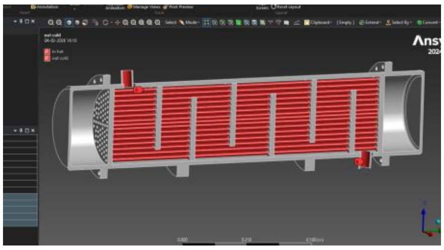


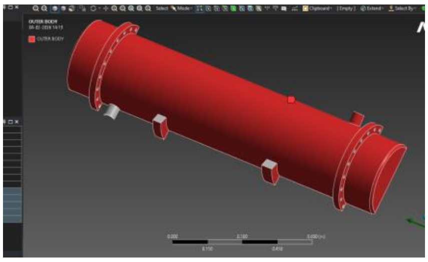
Finite element method:

The finite element method (FEM) is a numerical technique for solving problems which are described by partial differential equations or can be formulated as functional minimization.

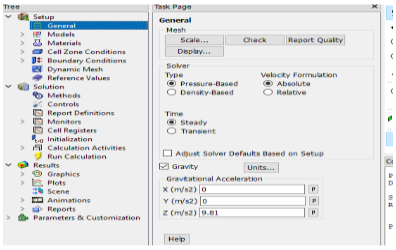




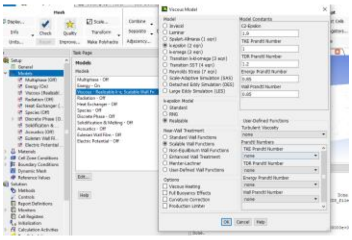




COMPUTATIONALFLUID DYNAMICS: Computational fluid dynamics or CFD is the analysis of systems involving fluid flow, heat transfer and associated phenomena such as chemical reactions by means of computer-based simulation.



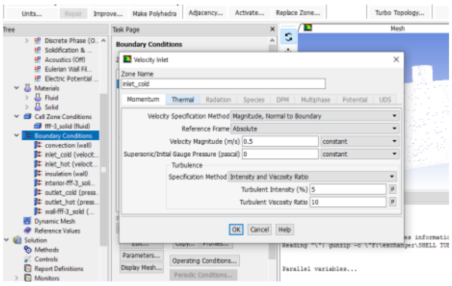
General
Solver Type: ● Pressure-Based ○ Density-Based
Velocity Formulation: ● Absolute ○ Relative
Time: ● Steady ○ Transient
☐ Adjust Solver Defaults Based on Setup
☑ Gravity
Gravitational Acceleration
X (m/s2) 0
Y (m/s2) 0
Z (m/s2) 9.81



Viscous Model
Model: ● k-epsilon (2 eqn)
Model Constants
C2-Epsilon 1.9
TKE Prandtl Number 1
TDR Prandtl Number 1.2
Energy Prandtl Number 0.85
Wall Prandtl Number 0.85

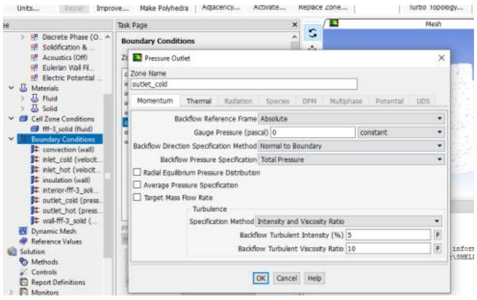
4.4 Boundary Conditions

- Shell-side inlet: Uniform velocity inlet
- Shell-side outlet: Pressure outlet
- Tube walls: Constant wall temperature
- Outer shell: Insulated wall
- INLET



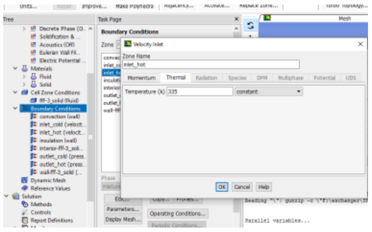
Velocity Inlet
Zone Name: inlet_cold
Velocity Specification Method: Magnitude, Normal to Boundary
Reference Frame: Absolute
Velocity Magnitude (m/s): 0.5 constant
Supersonic/Initial Gauge Pressure (pascal): 0 constant
Turbulence
Specification Method: Intensity and Viscosity Ratio
Turbulent Intensity (%): 5
Turbulent Viscosity Ratio: 10

OUTLET



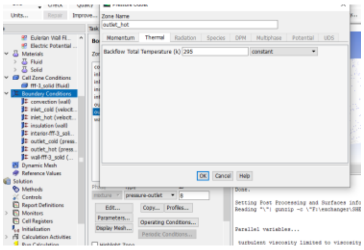
Pressure Outlet
Zone Name: outlet_cold
Backflow Reference Frame: Absolute
Gauge Pressure (pascal): 0 constant
Backflow Direction Specification Method: Normal to Boundary
Backflow Pressure Specification: Total Pressure
☐ Radial Equilibrium Pressure Distribution
☐ Average Pressure Specification
☐ Target Mass Flow Rate
Turbulence
Specification Method: Intensity and Viscosity Ratio
Backflow Turbulent Intensity (%): 5
Backflow Turbulent Viscosity Ratio: 10

HOT



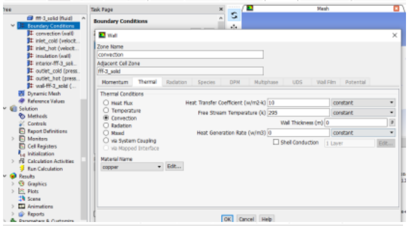
Velocity Inlet
Zone Name: inlet_hot
Thermal
Temperature (k): 335 constant

OUT

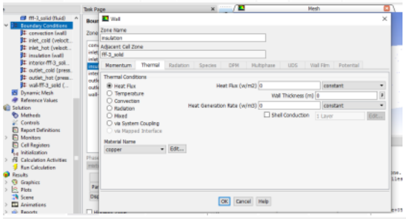


Pressure Outlet
Zone Name: outlet_hot
Thermal
Backflow Total Temperature (k): 295 constant

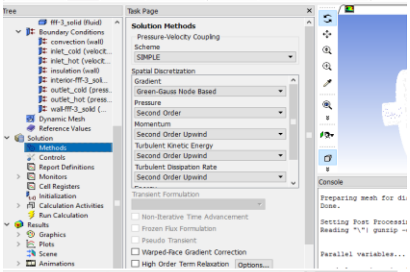
CONVECTION



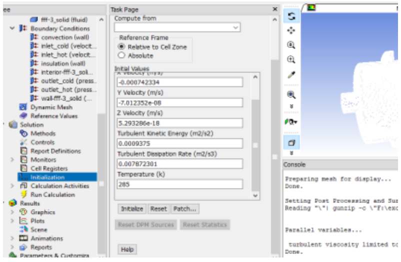
Wall
Zone Name: convection
Adjacent Cell Zone: fff-3_solid
Thermal Conditions: ● Convection
Heat Transfer Coefficient (w/m2-k): 10 constant
Free Stream Temperature (k): 295 constant
Wall Thickness (m): 0
Heat Generation Rate (w/m3): 0 constant
☐ Shell Conduction
Material Name: copper



Wall
Zone Name: insulation
Adjacent Cell Zone: fff-3_solid
Thermal Conditions: ● Heat Flux
Heat Flux (w/m2): 0 constant
Wall Thickness (m): 0
Heat Generation Rate (w/m3): 0 constant
☐ Shell Conduction
Material Name: copper



Solution Methods
Pressure-Velocity Coupling
Scheme: SIMPLE
Spatial Discretization
Gradient: Green-Gauss Node Based
Pressure: Second Order
Momentum: Second Order Upwind
Turbulent Kinetic Energy: Second Order Upwind
Turbulent Dissipation Rate: Second Order Upwind
☐ Warped-Face Gradient Correction
☐ High Order Term Relaxation



Reference Frame: ● Relative to Cell Zone ○ Absolute
Initial Values
X Velocity (m/s): -0.000742334
Y Velocity (m/s): -7.012352e-08
Z Velocity (m/s): 5.293286e-18
Turbulent Kinetic Energy (m2/s2): 0.0009375
Turbulent Dissipation Rate (m2/s3): 0.007872301
Temperature (k): 285

```
Preparing mesh for display...
Done.

Setting Post Processing and Sur
Reading "\"| gunzip -c \"F:\exc

Parallel variables...

 turbulent viscosity limited to
Done.
```

5. Results and Discussion

CFD simulations were performed for four different baffle configurations to evaluate shell-side thermal and hydraulic performance. The key parameters analyzed include pressure drop, velocity distribution, and temperature variation. A comparative assessment is presented to identify the most effective baffle configuration.

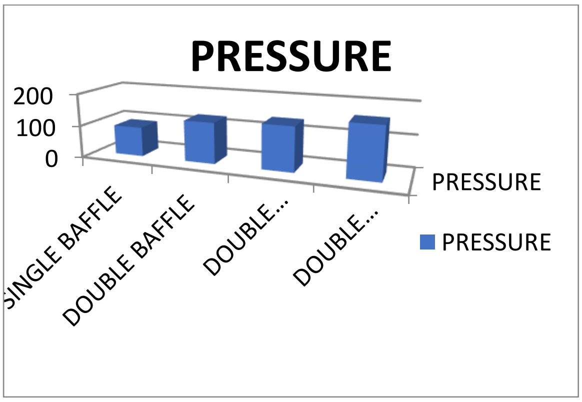
5.1 Pressure Distribution

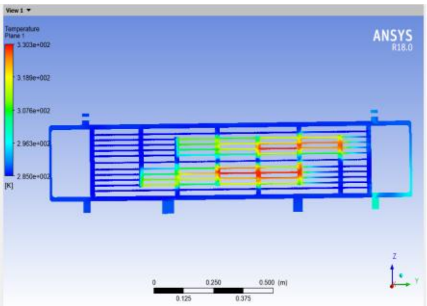
The pressure contours indicate a progressive increase in shell-side pressure drop with the modification of baffle geometry. The introduction of double and inclined baffles enhances flow obstruction and turbulence, resulting in higher pressure losses.

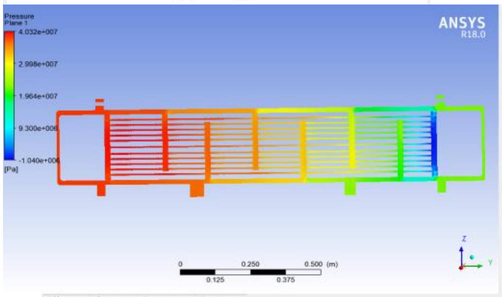
Table 1. Net Shell-Side Pressure Drop

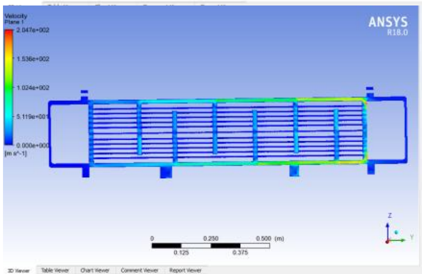
S.NO	BAFFLE	NET PRESSURE (MPa)
1	SINGLE	92
2	DOUBLE	127
3	DOUBLE 10^0	137
4	DOUBLE 20^0	161

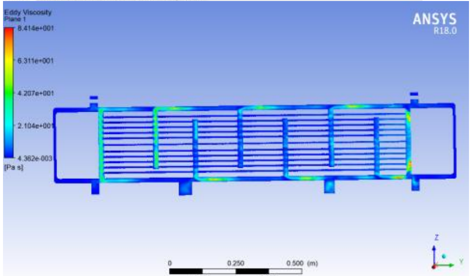
The double baffle with 20° inclination exhibits the highest pressure drop due to increased flow redirection and longer flow paths. Although pressure loss increases, it is accompanied enhanced heat transfer performance.

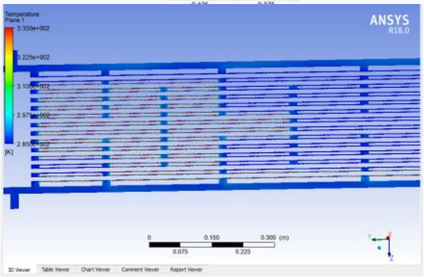


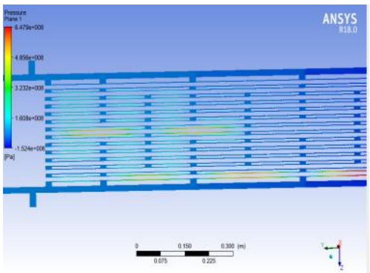

View 1
Temperature
Plane 1
3.303e+002
3.189e+002
3.076e+002
2.963e+002
2.850e+002
[K]
ANSYS
R18.0
0
0.250
0.500 (m)
0.125
0.375

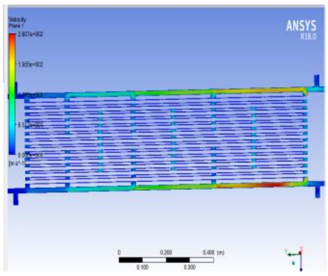

Pressure
Plane 1
4.032e+007
2.998e+007
1.964e+007
9.300e+006
-1.040e+006
[Pa]
ANSYS
R18.0
0
0.250
0.500 (m)
0.125
0.375

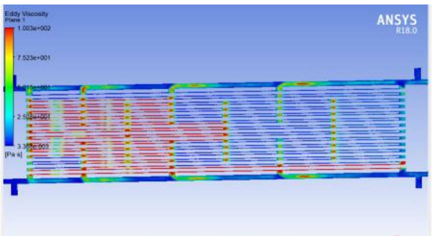

Velocity
Plane 1
2.047e+002
1.536e+002
1.024e+002
5.119e+001
0.000e+000
[m s^-1]
ANSYS
R18.0
0
0.250
0.500 (m)
0.125
0.375

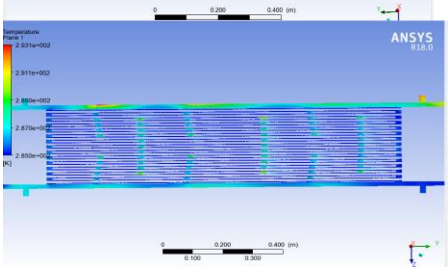

Eddy Viscosity
Plane 1
8.414e+001
6.311e+001
4.207e+001
2.104e+001
4.362e-003
[Pa s]
ANSYS
R18.0
0
0.250
0.500 (m)

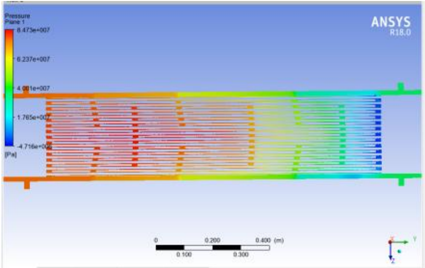

Temperature
Plane 1
3.350e+002
3.225e+002
3.100e+002
2.975e+002
2.850e+002
[K]
ANSYS
R18.0
0
0.150
0.300 (m)
0.075
0.225

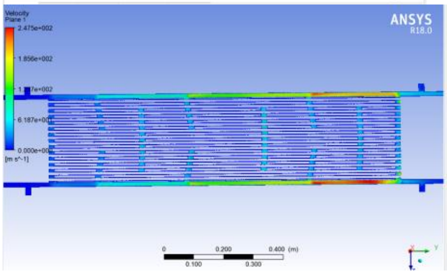

Pressure
Plane 1
6.479e+008
4.856e+008
3.232e+008
1.608e+008
-1.524e+006
[Pa]
ANSYS
R18.0
0
0.150
0.300 (m)
0.075
0.225


Velocity
Plane 1
2.807e+002
1.855e+002
[m s^-1]
ANSYS
R18.0
0
0.200
0.400 (m)
0.100
0.300

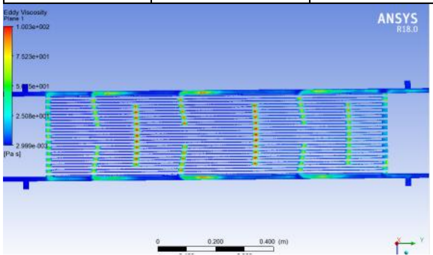

Eddy Viscosity
Plane 1
1.003e+002
7.523e+001
2.508e+001
3.368e-003
[Pa s]
ANSYS
R18.0
0
0.200
0.400 (m)

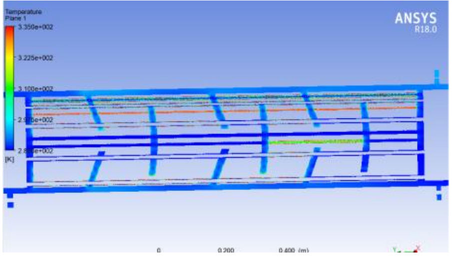

Temperature
Plane 1
2.931e+002
2.911e+002
2.890e+002
2.870e+002
2.850e+002
[K]
ANSYS
R18.0
0
0.200
0.400 (m)
0.100
0.300

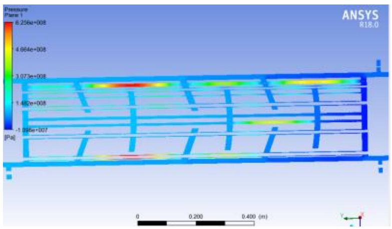

Pressure
Plane 1
8.473e+007
6.237e+007
4.001e+007
1.765e+007
-4.716e+006
[Pa]
ANSYS
R18.0
0
0.200
0.400 (m)
0.100
0.300

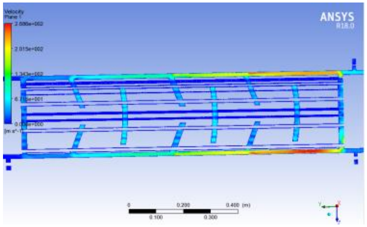

Velocity
Plane 1
2.475e+002
1.856e+002
1.237e+002
6.187e+001
0.000e+000
[m s^-1]
ANSYS
R18.0
0
0.200
0.400 (m)
0.100
0.300

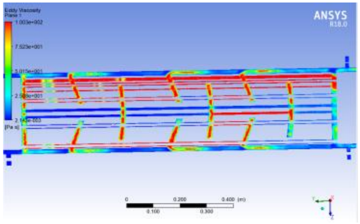
S.NO	BAFFLE	NET VELOCITY (m/s)
1	SINGLE	1.03
2	DOUBLE	1.09
3	DOUBLE 10^0	1.08
4	DOUBLE 20^0	1.15









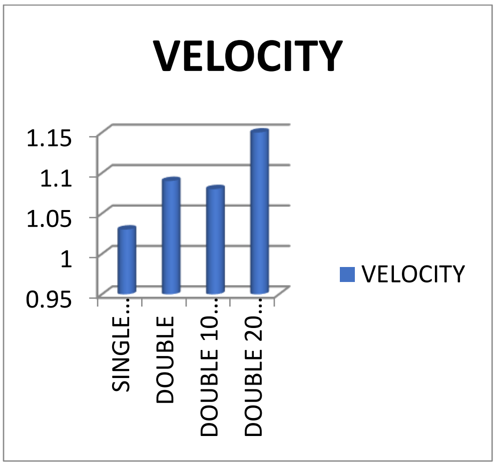


5.2 Velocity Distribution

Velocity contours show that single baffles allow partial bypassing of shell-side fluid, leading to non-uniform flow distribution. In contrast, double and inclined baffles promote stronger cross-flow and higher turbulence intensity.

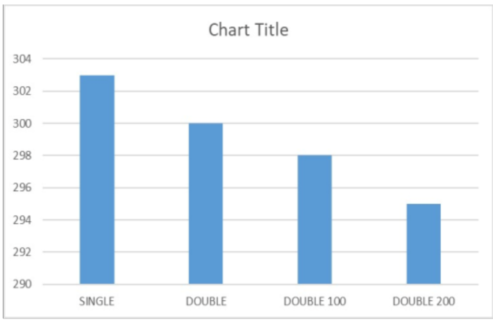
Table 2. Net Shell-Side Velocity

The maximum velocity is observed for the double baffle with 20° inclination, indicating improved fluid mixing and reduced stagnant zones.



5.3 Temperature Distribution

Temperature contours demonstrate improved thermal mixing for inclined baffles. The enhanced turbulence facilitates better heat transfer between shell-side fluid and tube walls.



5.4 Comparative Performance Analysis

Table 3. Net Shell-Side Temperature

S.NO	BAFFLE	NET TEMPERATURE K
1	SINGLE	303
2	DOUBLE	300
3	DOUBLE 10^0	298
4	DOUBLE 20^0	295

From the CFD results, it is evident that modifying baffle geometry significantly affects shell-side flow behaviour. Inclined double baffles increase turbulence intensity and reduce thermal boundary layer thickness, resulting in enhanced heat transfer. Although pressure drop increases with baffle inclination, the improvement in thermal performance justifies the trade-off for industrial applications where heat transfer efficiency is a priority.

6. Conclusion

A numerical investigation of a shell-and-tube heat exchanger with different baffle configurations was carried out using CFD techniques. The study focused on evaluating shell-side thermal and hydraulic performance for single baffle, double baffle, and inclined double baffles at 10° and 20°.

The results show that:

- Baffle configuration has a significant impact on shell-side pressure drop, velocity distribution, and temperature profiles.

- Double and inclined baffles enhance turbulence and improve heat transfer compared to a single baffle arrangement.
- The double baffle with 20° inclination provides the highest heat transfer enhancement due to strong flow mixing, though at the cost of increased pressure drop.
- An optimal balance between thermal performance and hydraulic loss is achieved using inclined double baffles.

References

1. Hessel greaves, J.E., 2002. An approach to fouling allowances in the design of compact heat exchangers. *Applied Thermal Engineering*, 22, pp.755–762.
2. Holman, J.P., 1997. *Heat Transfer*, 8th ed., McGraw-Hill, New York.
3. Zealsing, P., 2004. Heat exchanger design for good process performance. *Chemical Product Finder*.
4. Perry, R.H. and Green, D.W., 1997. *Perry's Chemical Engineers' Handbook*, 7th ed., McGraw-Hill, New York.
5. Rohsenow, W.M., Hartnett, J.P. and Ganic, E.N., 1985. *Handbook of Heat Transfer Applications*, 2nd ed., McGraw-Hill, New York.
6. Kern, D.Q., 2000. *Process Heat Transfer*, Tata McGraw-Hill, New Delhi.
7. McCabe, W.L., Smith, J.C. and Harriott, P., 2005. *Unit Operations of Chemical Engineering*, 7th ed., McGraw-Hill, New York.
8. Babu, B.V., 2004. *Process Plant Simulation*, Oxford University Press.
9. Kothandaraman, C.P. and Subramanyan, S., 2000. *Heat and Mass Transfer Data Book*, Tata McGraw-Hill.