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# Thermal performance evaluation of Shell and U-tube heat exchanger fitted with helical baffles

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## Abstract

Shell and U-tube heat exchangers [UTHX] have been commonly used in Industries over the year. The main objective in any design of heat exchanger is the estimation of the minimum heat transfer area required for a given heat duty (q), as it governs the overall cost of heat exchanger. The proposed Shell and U-tube heat exchanger [UTHX] is a counter flow type heat exchanger having U–shaped tube and comprises of helical baffles. Three dimensional CFD simulations have been performed on ANSYS CFX to compare the thermo-hydraulic performance in terms of parameters like heat transfer rate, overall heat transfer coefficient, effectiveness, pressure drop, for shell and U- tube type heat exchanger without helical baffles and with helical baffles. For this analysis, water is opted as the working fluid for tube side and shell side. Hot water is flowing through the tube side whereas cold water is circulated through the shell. The analysis revealed that the heat exchanger with U- tube and helical baffles has improved heat transfer characteristics with moderate penalty of pressure drop.

**Key Words:** Shell and U-tube heat exchanger, Heat transfer rate, Helical baffle, Effectiveness.

## 1. INTRODUCTION

A heat exchanger is a heat transfer device that is used for transfer thermal energy between two or more fluids, between a solid surface and a fluid, or between solid particulates and a fluid available, at different temperatures. In most of heat exchanger available, the fluids separated by a heat transfer surface, and in which they ideally do not mix. As the name implies, the tubes of a Shell and U-tube heat exchanger [UTHX] are bent in U shape. Evidently, there is only one tube sheet is available in a U-tube heat exchanger. However, the bending of tubes represents an additional cost. Further, the minimum U-bend diameter is usually three times the tube outside diameter so that the central pass-partition lane is considerably large in a U-tube heat exchanger [UTHX] than in one having straight tubes. Consequently, for a given number of tubes, a U-tube heat exchanger will have a larger shell diameter compared with straight tube. The additional cost of the bending of U-tubes and large shell diameter more or less offset the saving in cost due to the elimination of one tube-sheet. Thus the cost of a U-tube heat exchanger is comparable to that of a fixed tube-sheet exchanger.

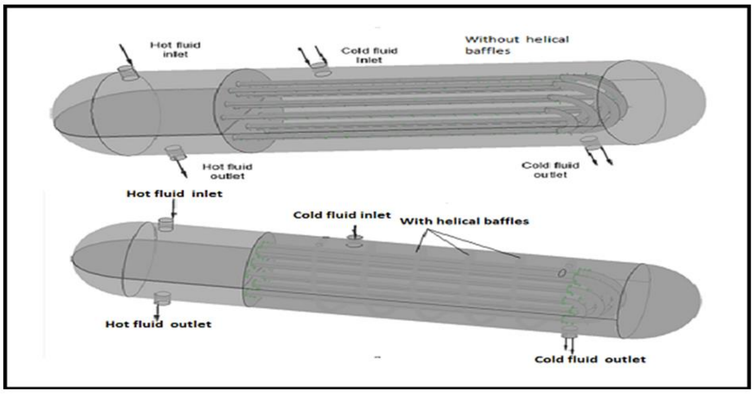


**Figure 1:** U-Tube Heat Exchanger [UTHX] with and without helical baffles

Although many heat exchangers are used in industries, yet the shell-and-tube heat exchanger (STHX) has comparatively simple manufacture and multi-purpose applications in a large temperature and pressure range, so still they extensively used in industries [1]. STHX consist of different types of conventional baffles to change the direction of the flow and to support different tubes. Usually segmental baffles are used because of its improved heat transfer qualities as it boosts the turbulence on the shell side of the exchanger. Despite having a great advantage, the STHXs containing segmental baffles have few major drawbacks too [2,3]: (1) The flow separates at the edge of the baffles due to successive contractions and expansions, so the pressure drop is very high across the shell; (2) The flow in the "dead zone" is stagnant, therefore competency to heat transfer becomes low; (3) STHX operating time is affected due to the strong induced vibrations and hence decreases; (4) Large sides of the shell results in fouling resistance. Several baffles have been designed to prevail the above-mentioned negatives in STHX performance among which helical baffles (having 40o optimal angle) perfectly replaces segmental baffles hence maximizing the performance [4]. STHXs with helical baffles comprise of inclined angles (vertical to the axis) ranging between 10o - 40o which gives the perfect pattern required for the fluid to flow by aiding the tube bundles in turn increasing its performance. Use of helical baffles propose many benefits [5, 6]

## 2. Geometric configuration

A conventional UTHX with helical baffles, havinghot water flowing in the tube side and cold water flowing in the shell side in a counter flow arrangement is shown below. The shell has an external diameter of 200 mm, a thickness of 2.5 mm and a length of 1000 mm and nine tubes with an external diameter of 19mm are installed inside the shell. More details are given in Table-1.

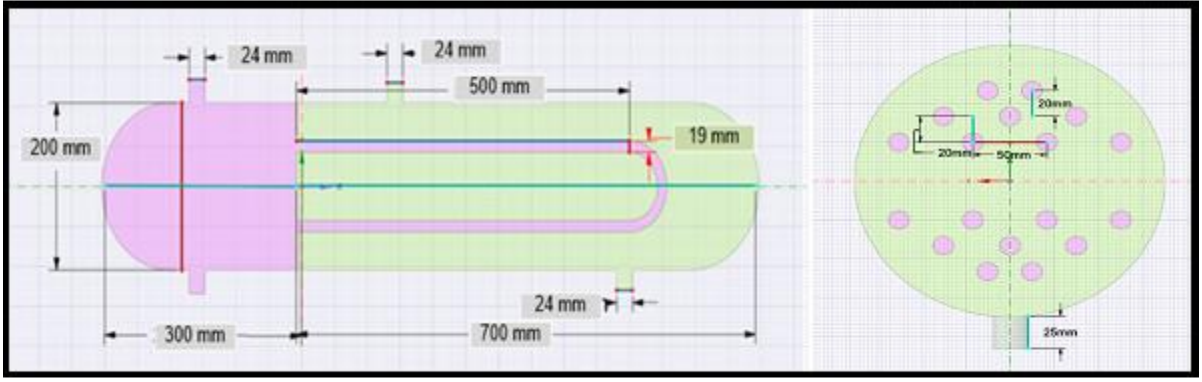


**Figure 2:** Geometrical Configuration and Test Condition

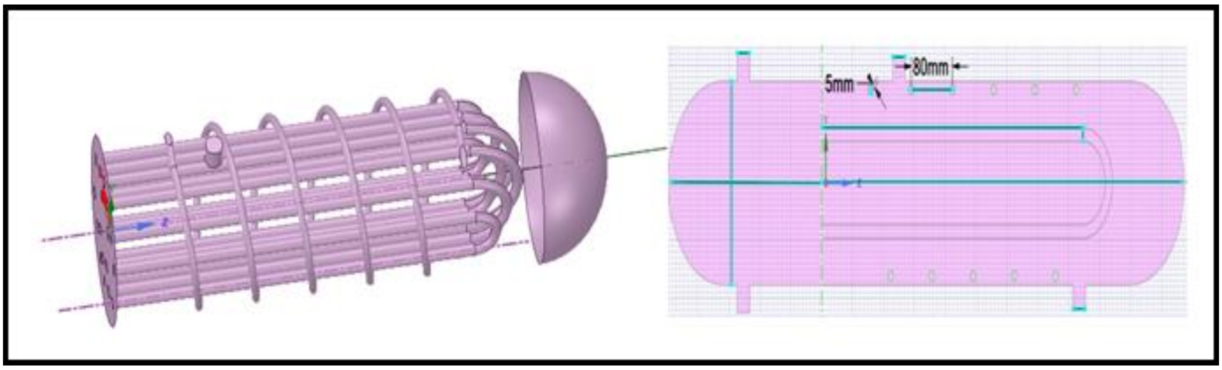


**Figure 3:** Arrangements of helical baffles

**Table 1:** Specifications of Shell and tube Heat Exchanger

| **Component** | **Parameter** | **Value** |
|---|---|---|
| Shell | Shell Material | MS |
| | Shell Length | 1000 mm |
| | Shell OD | 200 mm |
| | | |
| Tube | Tube Material | Copper |
| | Tube OD | 19 mm |
| | Tube Length | 1200 mm |
| | Thickness of the Tube | 2 mm |
| | | |
| Baffle | Baffle Material | MS |
| | Baffle Space | 80 mm |
| | Baffle Thickness | 5 mm |
| | | |
| Tube Sheet | Tube Sheet Material | MS |
| | No. of Tube Sheet | 1 |

## 3. Boundary conditions and Governing equations

Different boundary conditions are to be set for UTHX to work perfectly. The momentum boundary condition of no slip and no penetration is selected for solid walls. The thermal boundary condition of Adiabatic is selected for the shell wall inlet and outlet nozzle walls, while the thermal boundary condition of coupling heat transfer (two interfaces with coupled wall) is selected for the walls of tubes, baffles, and tube bundle. The inlets for the shell and tube sides are set as boundary conditions of mass-inlet, the outlets are set as pressure-outlet. Zero pressure is presumed for outlets and inlet pressure is equal to the pressure drop on both shell and tube sides. The temperature for shell inlet and tubes inlet is 303K and 337K respectively. The fluid flow and heat transfer calculation are done by the commercial software ANSYS CFX in the computational domains. Friction factor, conduction and radiation effects are neglected in the present analysis . Averagetemperature values are taken for calculation of fluid properties . SST k-ω turbulence model is used in the present study because it can give superior performance

In the proposed UTHX shell-side fouling resistance is ignored in the energy equation. Water is believed as a Newtonian and incompressible fluid. The seepage between tube and baffle and between baffle and shell is insignificant. This work includes ANSYS CFX software to construct a hydrodynamic model based on the unstructured-grid finite volume method and on the numerical solution of equations of continuity, momentum and energy.

Equation of continuity:

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}+\frac{\partial w}{\partial z}=0 \qquad (1)$$

Momentum conservation equations:

$$\rho\left(\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}+w\frac{\partial u}{\partial z}\right)=-\frac{\partial p}{\partial x}+\mu\nabla^2 u \qquad (2)$$

$$\rho\left(\frac{\partial v}{\partial t}+u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}+w\frac{\partial v}{\partial z}\right)=-\frac{\partial p}{\partial y}+\mu\nabla^2 v \qquad (3)$$

$$\rho\left(\frac{\partial w}{\partial t}+u\frac{\partial w}{\partial x}+v\frac{\partial w}{\partial y}+w\frac{\partial w}{\partial z}\right)=-\frac{\partial p}{\partial z}+\mu\nabla^2 w \qquad (4)$$

Where, $\nabla^2=\frac{\partial^2}{\partial_x^2}+\frac{\partial^2}{\partial_y^2}+\frac{\partial^2}{\partial_z^2}$

Energy conservation equation:

$$\frac{\partial T}{\partial t}+u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}+w\frac{\partial T}{\partial z}=a_{f\nabla^2}T \qquad (5)$$

## 4. Data Reduction

Thermal analysis of U-tube heat exchanger involves rating and sizing of heat exchanger. Rating problem deals with determination of rate of heat transfer, heat transfer coefficient, outlet temperature. Sizing problem involves selection of tube material, flow arrangement, determining physical size of heat exchanger to meet specified heat transfer. The equations used for the data reduction are as follows,

The overall thermal coefficient of the shell and tube heat exchanger is calculated by equation (6).

$$U=\frac{q}{A\Delta T_{LMTD}} \qquad (6)$$

Heat transfer rate is calculated by equation

$$q=\dot{m}_h c_p\left(T_{h,i}-T_{h,o}\right) \qquad (7)$$

Where $\dot{m}_h$stands the hot fluid mass flow rate, and Moreover $T_{h,i}$ *and* $T_{h,o}$ stand for the temperatures in the inlet and outlet of the hot fluid, respectively. “A” denotes the heat transfer area of the shell and tube heat exchanger

$$A=N_t\pi d_0 L \qquad (8)$$

Where ,$d_0$ = Tube outside diameter, L = Length of tube ,$N_t$ = No of tubes

$\Delta T_{LMTD}$ states the logarithmic mean temperature difference that can be evaluated as below:

$$\Delta T_{LMTD}=\frac{\Delta T_2-\Delta T_1}{In\left(\frac{\Delta T_2}{\Delta T_1}\right)}\text{(for counter flow arrangement)} \qquad (9)$$

In the above equation, $\Delta T_1=T_{h,i}-T_{c,o}$ and $\Delta T_2=T_{h,o}-T_{c,i}$ .

$T_{h,i}$ *and* $T_{h,o}$ stand for the temperatures in the inlet and outlet of the hot fluid, respectively. In addition, $T_{c,i}$denotes the temperature at the cold fluid inlet, and $T_{c,o}$ announces the exit temperature of the cold fluid.

Effectiveness is calculated via Eq. (10)

$$\varepsilon=\frac{T_{h,i}-T_{h,o}}{T_{h,i}-T_{c,i}} \qquad (10)$$

**Table 2:** Thermo-physical property parameters of water[7]

| **Item** | **Value (273 K < T < 373 K)** |
|---|---|
| Cp, J/kg.K | 10632.6–55.924 × T+0.15968 × T2 -0.00014983 × T3 |
| μ, kg/m.s | 0.11165–0.00095 × T+2.7424 × 10− 6 × T2 -2.6089 × 10− 9 × T3 |
| ρ, kg/m3 | 753.3 + 1.879 × T-0.00357 × T2 |
| λ,/m.K | − 2.58673 + 0.02399 × T-5.91953 × 10− 5 × T2 +4.92088*10− 8 × T3 |

## 5. Mesh generation

The mesh generation is process in which a domain is discretized into a number of small cells. The convergence and stability of a numerical solution is solely dependent on mesh quality. In order to generate a quality mesh, ANSYS MESH module is used. An unstructured mesh containing tetrahedral has been selected for meshing. A photograph meshing of heat exchanger is presented in Figure 4. The details of selected parameters for the present numerical study are provided in Table 3.

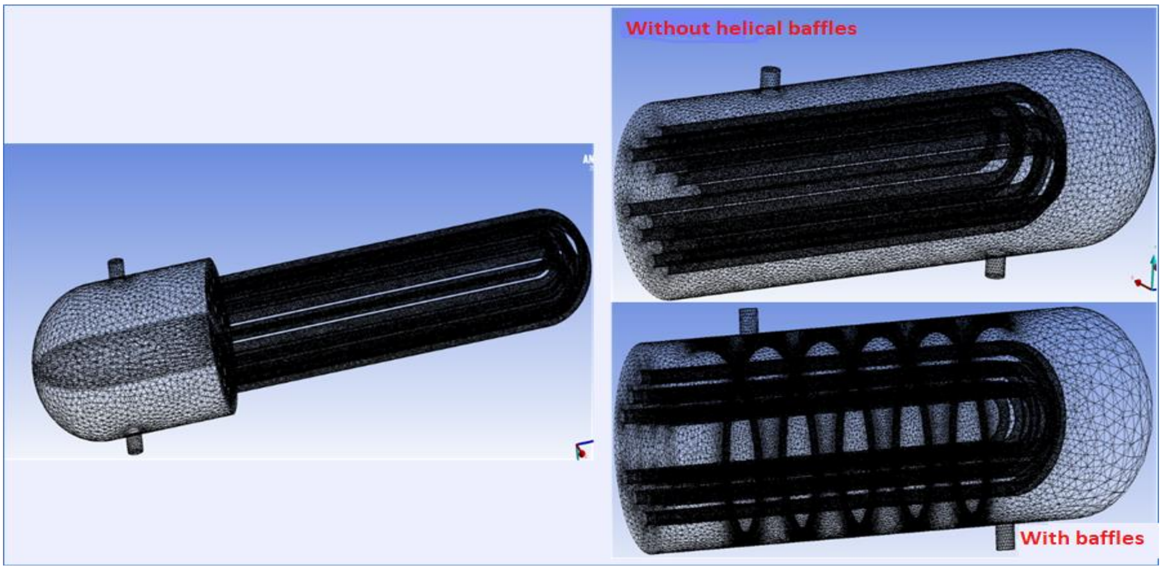


**Figure 4:** A photograph meshing of heat exchanger

**Table 3:** Details of selected parameters for the present numerical study

| **Description** | **Value** |
|---|---|
| Number of elements | 4565729 |
| Number of nodes | 869603 |
| Hot inlet temperature | 337 K |
| Cold inlet temperature | 303 K |
| Hot and Cold outlet condition | 0 Pa |
| Ambient reference temperature | 20ºC |
| Turbulence model | SST k-ω |
| Number of iterations | 1000 |

## 6. Result and analysis

In this work, the effect of incorporating helical baffles has been studied. The findings are presented in the form of effects of varying mass flow rate on the shell side while keeping mass flow rate on the tube side constant. Further the study includes variation of stream line patterns, the velocity contour, temperatures contour and pressure drop in shell side due to presence of helical baffles[8].

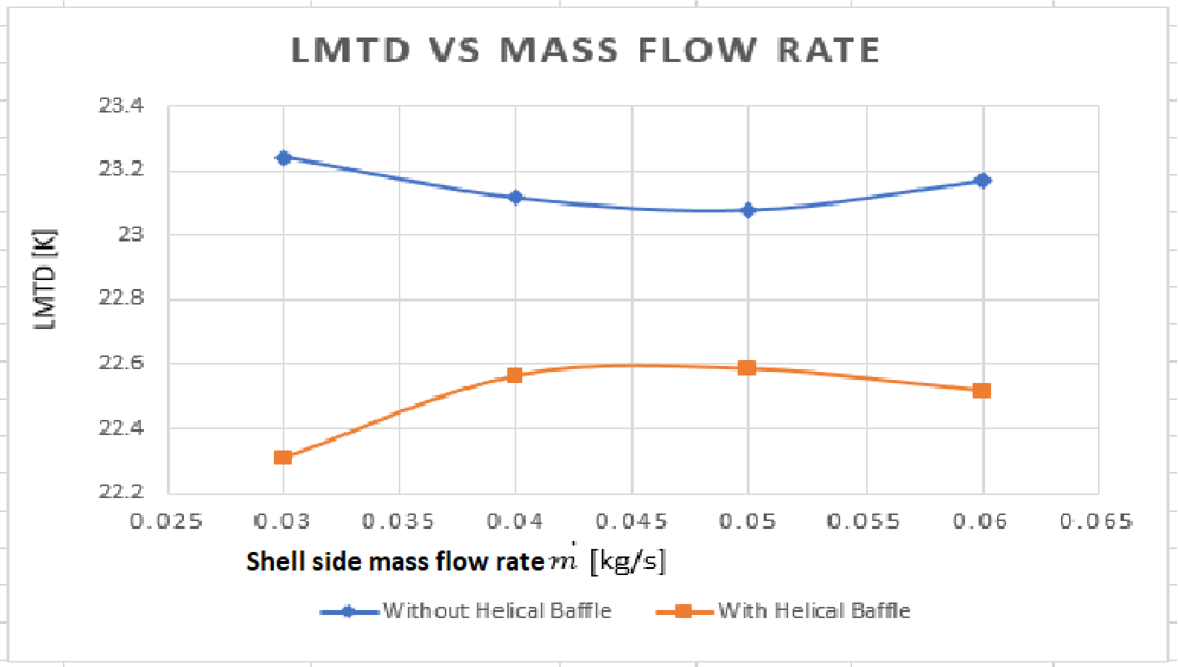


**Figure 5:** Variation of LMTD against shell side mass flow rate

The Figure 5, shows the variation of LMTD against shell side mass flow rate while keeping the tube side mass flow rate 0.04kg/s. It is observed that LMTD value for shell and tube type with baffles demonstrated lower LMTD value indicating that heat Transfer between hot and cold fluid is augmented compared to the shell and tube type without baffle. The reason for heat Transfer improvement is the disturbance caused by the secondary flow induced by the helical baffles, besides the fluid flow path has also significantly increased due to the helical path provided by the baffles[9].

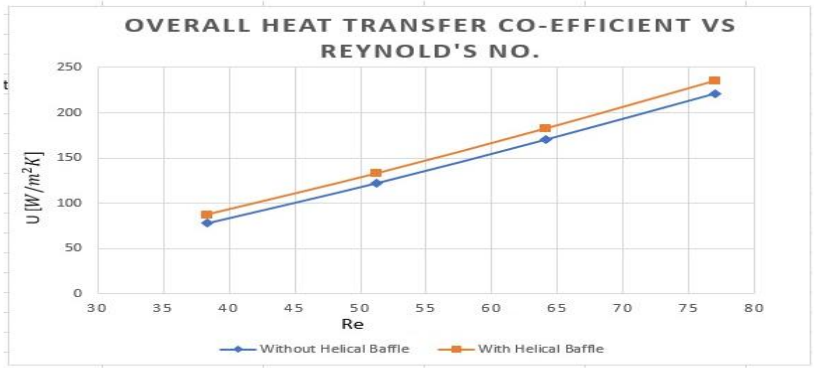


**Figure 6:** Overall heat transfer co-efficient vs. Reynold's number

This graph shows comparative difference result of Overall Heat transfer coefficient vs. Reynolds number of U-tube heat exchanger (UTHX) with and without helical baffles. Overall heat transfer coefficient [10-11]is also dependent on convective heat transfer coefficient so increase in Reynolds number results into higher heat transfer rate.

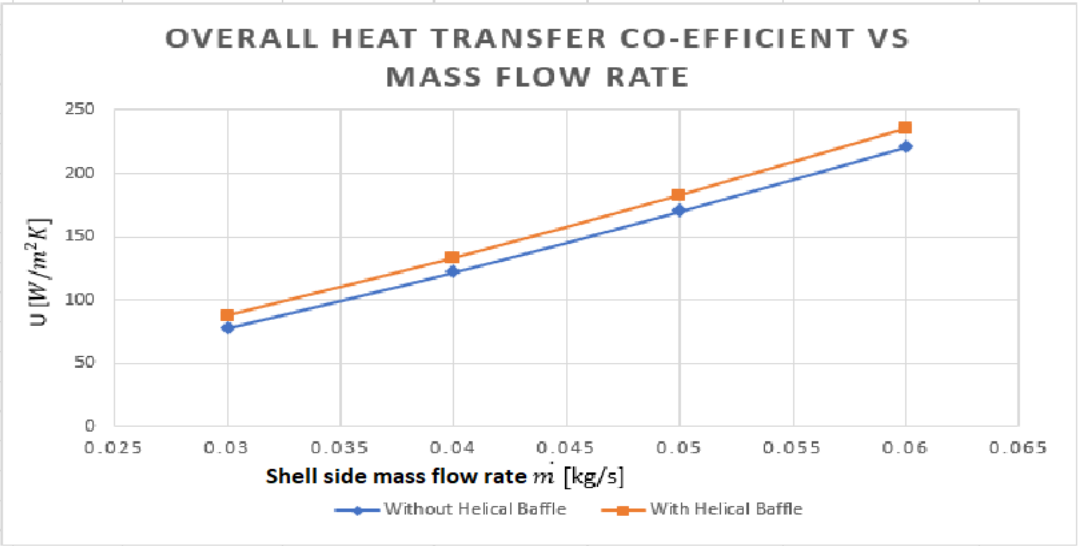


**Figure 7:** Overall heat transfer co-efficient vs. massflow rate

This graph shows comparative difference result of Overall Heat transfer coefficient vs. Shell side mass flow rate of U-tube heat exchanger (UTHX) with and without helical baffles [12]. Overall heat transfer coefficient value increases more in U-tube heat exchanger (UTHX) with helical baffles as shell side mass flow rate increases .

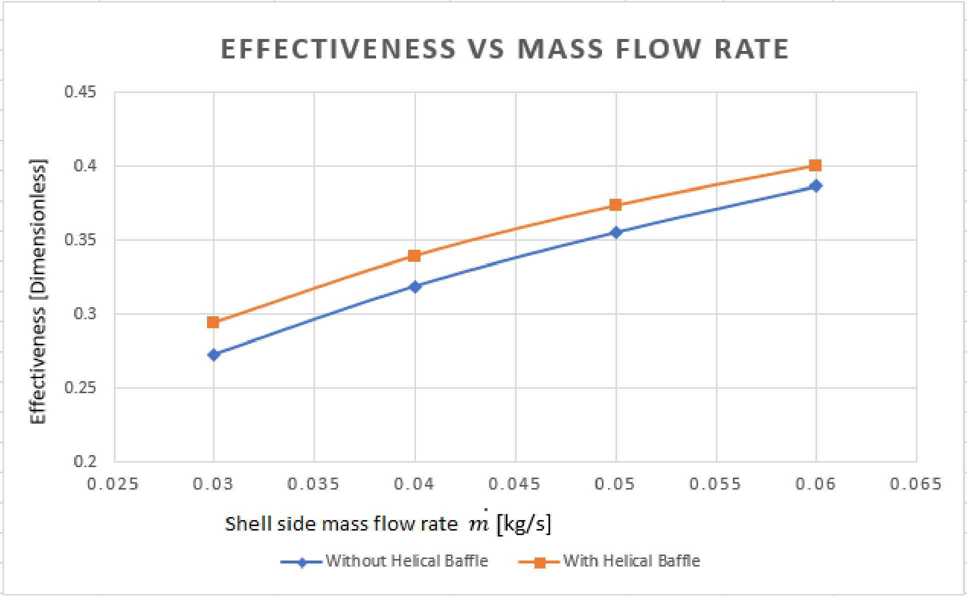


**Figure 8:** Effectiveness vs. massflow rate

The above graph shows comparative result of effectiveness of U-tube heat exchanger (UTHX) with and without helical baffles. Graph clearly shows that effectiveness of helical baffles fitted tube heat exchanger is higher than plain tube[13].

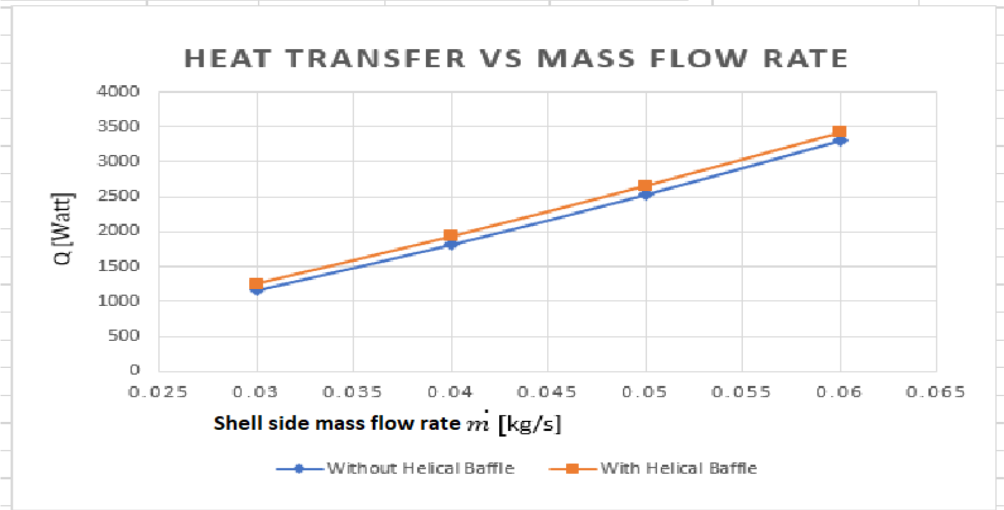
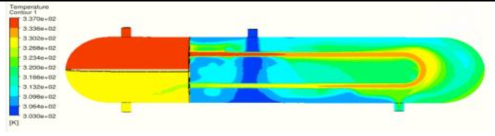
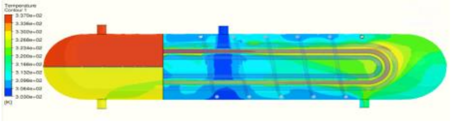
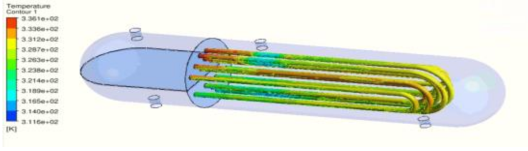
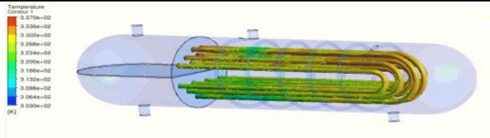
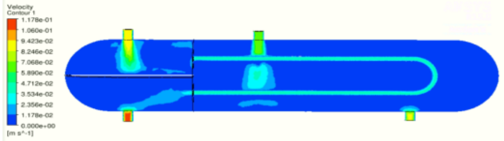
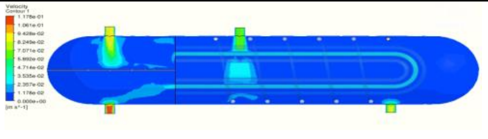
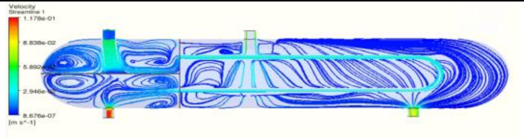
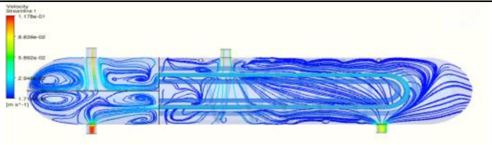


**Figure 9:** Heat transfer vs. massflow rate

The above figure shows the variation of Heat transfer against shell side mass flow rate while keeping the tube side mass flow rate 0.04kg/s. It is observed that Heat Transfer value for shell and tube type with baffles demonstrated higher value compared to the shell and tube type without baffle [14]. The reason for heat transfer improvement is the disturbance caused by the secondary flow induced by the helical baffles[15], besides the fluid flow path has also significantly increased due to the helical path provided by the baffles .

The table 4, shows the Variation of Velocity contour, Stream line patterns, Temperature contour, and Pressure drop between Shell and U tube heat Exchanger with and without helical baffles with varying mass flow rate in Shell side .The figure depicts the pressure drop study in the shell side fluid [16] .It is observed that compared to the plain shell and u tube heat Exchanger, higher pressure drop is encountered in case of shell and u tube heat exchanger with baffles[17-18]. The potential cause of this pressure drop is the turbulence induced as the secondary flow induced by the baffles superimposed with the core flow .Further the presence of baffles reduces the free flow passage which in turn increases the flow velocity locally

**Table 4:** Variation of Velocity contour, Stream line patterns, Temperature contour, and Pressure drop in STHX with & without helical baffles

| **HX Conditions** | **Without helical baffles** | **With helical baffles** |
|---|---|---|
| Shell side mass flow rate : 0.03kg/s<br>Tube side mass flow rate : 0.04kg/s |  |  |
| |  |  |
| |  |  |
| |  |  |

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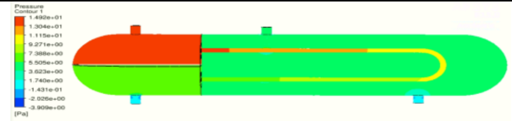
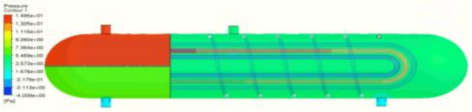
|  |  |  |
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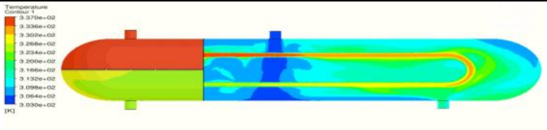
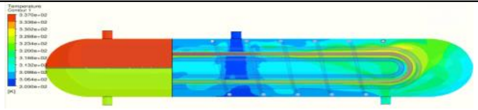
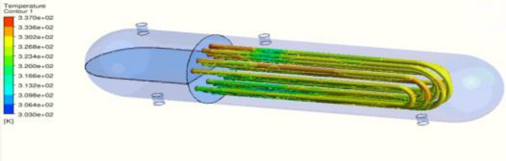
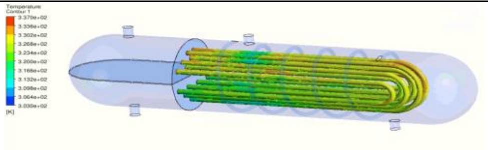
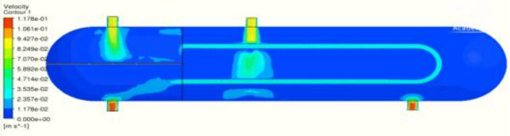
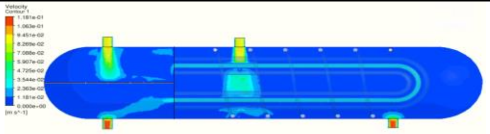
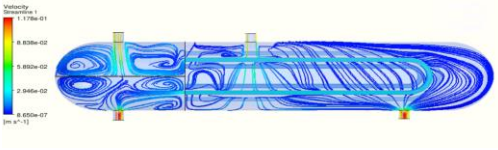
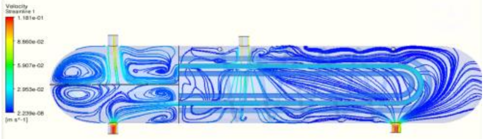
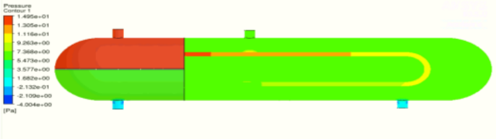
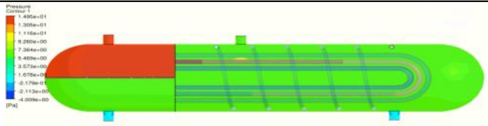
| Shell side mass flow : 0.04kg/s<br>Tube side mass flow rate : 0.04kg/s |  |  |
|  |  |  |
|  |  |  |
|  |  |  |
|  |  |  |
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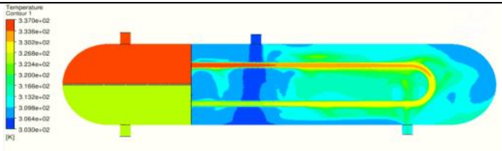
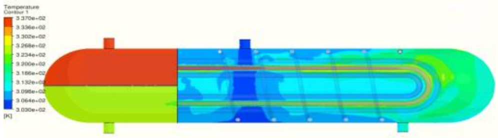
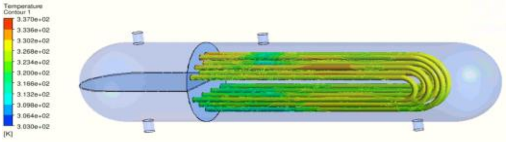
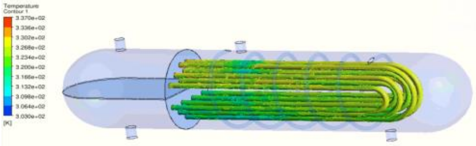
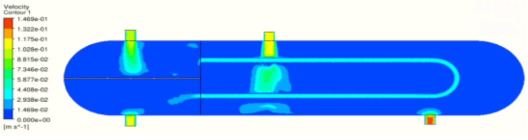
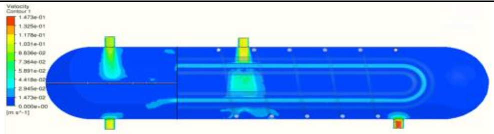
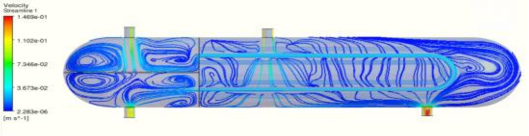
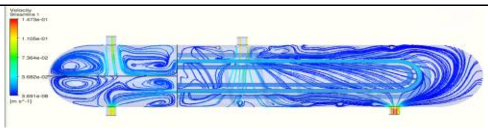
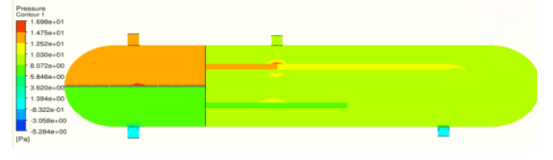
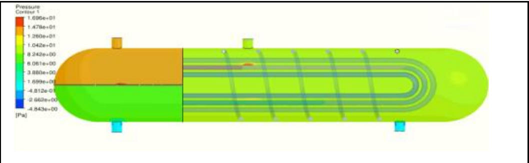
| Shell side mass flow : 0.05kg/s<br>Tube side mass flow rate : 0.04kg/s |  |  |
|  |  |  |
|  |  |  |
|  |  |  |

|  |  |  |
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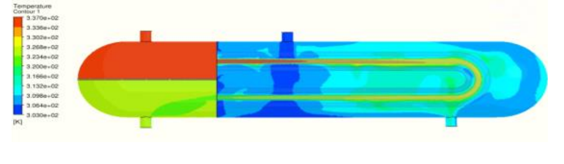
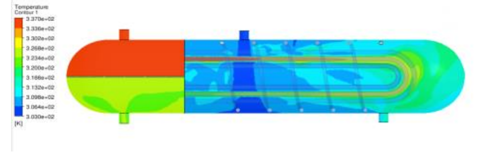
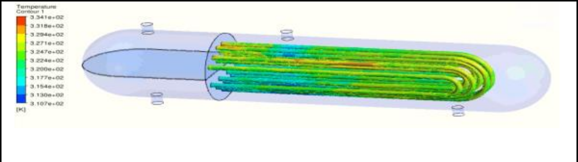
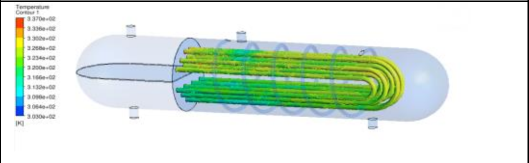
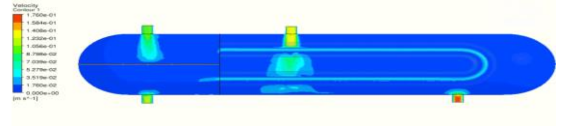
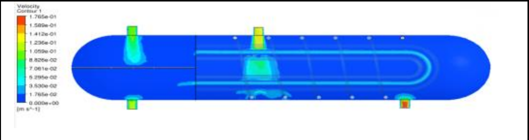
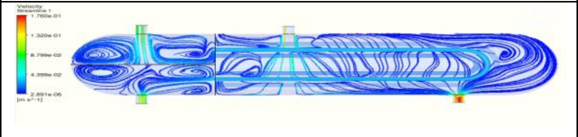
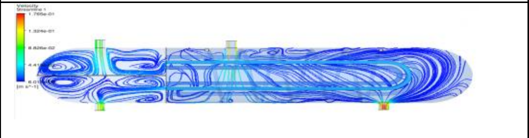
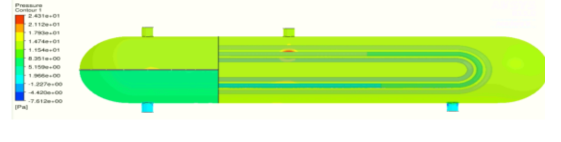
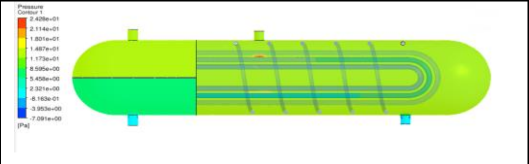
| Shell side mass flow : 0.06kg/s<br>Tube side mass flow rate : 0.04kg/s |  |  |
|  |  |  |
|  |  |  |
|  |  |  |
|  |  |  |

## 7. Conclusion

In this work CFD Analysis has been carried out to evaluate the effect of introducing helical baffles in most widely used shell and u tube type heat Exchanger in the various industry .

The study reveals that

(i) shell and u tube heat exchanger with helical baffle demonstrated improved thermal performances compared to the shell-and u tube heat Exchanger without baffle .

(ii) The variation of overall heat Transfer Co-efficient with shell side mass flow rate indicated improvement upto 12% for the mass flow rate range from 0.03 to 0.06 kg/s. However,the pressure drop comparatively increased in the range above 0.04 kg/s shell side mass flow rate .

(iii) Corresponding to the mass flow rate 0.03kg/s, the improvement in overall heat Transfer Co-efficient is maximum over the mass flow rate test range , hence it is recommended from this study over the range of test parameter to operate the heat exchanger for the mass flow rate 0.03 kg/s for optimum performance.

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