Experimental Analysis on Shell and Tube Heat Exchanger Using ANSYS

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Abstract - *Enhancing the heat transfer rate is an important factor in a heat exchanger. In Shell and tube heat exchanger, there is continuously requirement on improving the performance and effectiveness. The effect of various parameters like mass flow rate, inlet temperature on the overall heat transfer rate is studied. Based on the results obtained from the model developed parameters are optimized for better performance. In order to achieve this, many parameter is to be changed like flow of fluid, tube diameter, number of tubes, baffle arrangement, different types of baffles shapes and baffle spacing. This experiment is performed on the shell and tube heat exchanger for parallel fluid flow and the readings are taken. With this reading Overall Heat Transfer Coefficient for different flow rate is calculated by LMTD and NTU method and their results are compared. Also the model is prepared on Solidworks Software and CFD is performed on ANSYS R16.1 for one of the reading for parallel and counter flow and maximum value of wall heat transfer coefficient on hot and cold domain is obtained. Also number of baffles are added and all the results are compared to validate the design.*

Key Words: Shell and Tube Heat Exchanger, Segmental Baffles, Overall Heat Transfer Coefficient, CFD

1. INTRODUCTION

Heat exchanger may be defined as "it is an equipment which transfers the energy from hot fluid to a cold fluid having maximum rate and less investment and running cost. The rate of heat transfer depends on the thermal conductivity of dividing wall and convective heat transfer coefficient between the fluids and wall. Heat transfer rate also changes according to the boundary conditions like insulated wall condition or adiabatic condition. Heat transfer in a heat exchanger usually involves convection in each fluid and conduction through the wall separating the two fluids. Heat exchangers are classified based on various features such as transfer process, fluids flow direction, number of fluids, surface compactness, heat transfer mechanism, construction etc.

1.1 Shell and Tube Heat Exchanger

Shell and tube heat exchanger is built of round tubes mounted in a cylindrical shell with the tube axis parallel to that of the shell. In shell and tube, one fluid flow inside the tube, the other flow across and along the tubes. The major components of the shell and tube heat exchanger are baffles and tube sheets, shell, front end head, rear end head, tube bundle.

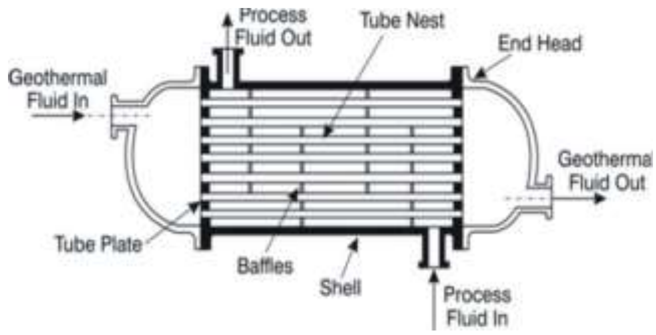

Fig 1: Shell and Tube Heat Exchanger

1.2 Types of Fluid Flow

1) Parallel Flow:

As the name suggests, the flow of the hot and the cold fluid is taking place in the same direction in this case. The temperature difference between the hot and cold fluid keeps on decreasing from one end to the other.

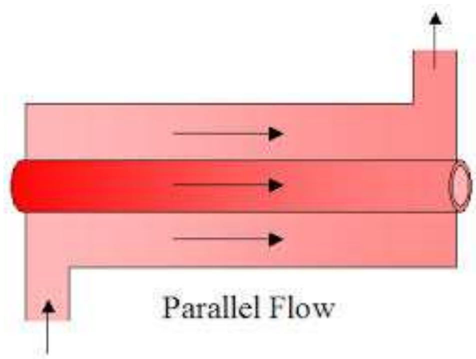

Fig 2: Parallel Flow

2) Counter Flow:

In this setup, the hot fluid enters from one end of the exchanger and the cold from the opposite end. This results in nearly constant temperature difference between the hot and the cold fluid. This is a significant aspect and makes counter flow heat exchangers preferable over parallel flow heat exchangers.

International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 07 Issue: 03 | Mar 2020 www.irjet.net p-ISSN: 2395-0072

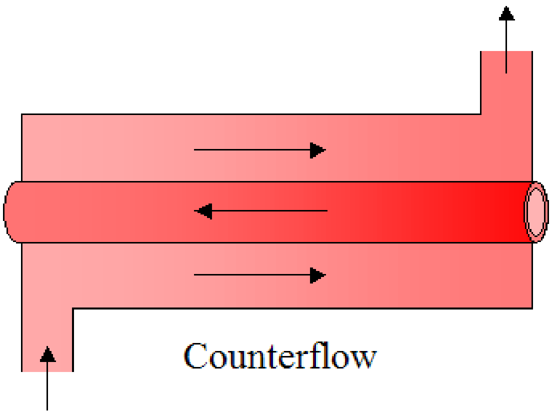

Fig 3: Counter Flow

2. Experimental Setup:

Fig 4: Experimental Setup of Shell and Tube Heat Exchanger

The apparatus consists of:

1. Shell:

   Inner diameter: - 145mm

   Thickness: - 5mm

   Material: - Mild Steel

2. Tubes:

   Outer diameter: 8mm

   Inner diameter: 5.5mm

   Material: Copper

   No. of Tubes: 20

   Length: 550mm

3. Reading and Calculation

Experiment is performed for parallel flow for different flow rates.

Table 1: Reading

SR. NO.	Hot Water			Cold Water		
	Flow Rate (lps)	Inlet Temp. (°C)	Outlet Temp. (°C)	Flow Rate (lps)	Inlet Temp. (°C)	Outlet Temp. (°C)
1	0.028	54	47	0.022	32	35
2	0.021	49	44	0.0227	32	34
3	0.035	44	42	0.166	31	35

3.1. Log Mean Temperature Difference method:

The heat transfer rate may be obtained from the overall energy balance for hot side

$Q_h = m_h C_{ph} (T_{h1} - T_{h2})$

$$T_{c2} = \frac{Q_h}{m_c C_{pc}} + T_{c1}$$

$\Delta T_1 = T_{h1} - T_{c2}$ $\Delta T_2 = T_{h2} - T_{c1}$

Log mean Temperature Difference can be calculated by using following formula:-

$$\Delta T_m = \frac{\Delta T1 - \Delta T2}{\ln \frac{\Delta T1}{\Delta T2}}$$

The overall heat transfer coefficient can be calculated by using following formula:-

$Q = U_0 A \Delta T_m$

3.2. NTU Method:

The heat capacity rates are calculated by following formula

$C_h = m_h C_h$

$C_c = m_c C_c$

If $m_h C_h < m_c C_c$: $C = \frac{m_h C_h}{m_c C_c}$

$Q_{max} = C_{min} (T_{h1} - T_{c1})$

Actual heat transfer rate is calculated by:

$Q_{act} = m_h c_h (T_{h1} - T_{h2})$

Heat transfer effectiveness can be calculated by:

$$\varepsilon = \frac{Qact}{Qmax}$$

The overall heat transfer coefficient can be calculated by:

$$\varepsilon = \frac{1-\exp[-NTU(1-C)]}{1-C\exp[-NTU(1-C)]}$$

$$NTU = \frac{UA}{Cmin}$$

$$U = \frac{NTU \times Cmin}{A}$$

3.3. Overall Heat Transfer Coefficient by LMTD Method:

Table 2: Result of LMTD method

SR. NO	Mass Flow Rate (kg/s)	Overall Heat Transfer Coefficient [W/m²K]
1	0.028	261.49
2	0.021	175.132
3	0.035	158.926

3.4. Overall Heat Transfer Coefficient by NTU Method:

Table 3: Result of NTU method

SR. NO.	Mass Flow Rate (kg/s)	Overall Heat Transfer Coefficient [W/m²K]
1	0.028	305.889
2	0.021	551.628
3	0.035	130.13

The Comparison of the overall heat transfer coefficient is shown by graph

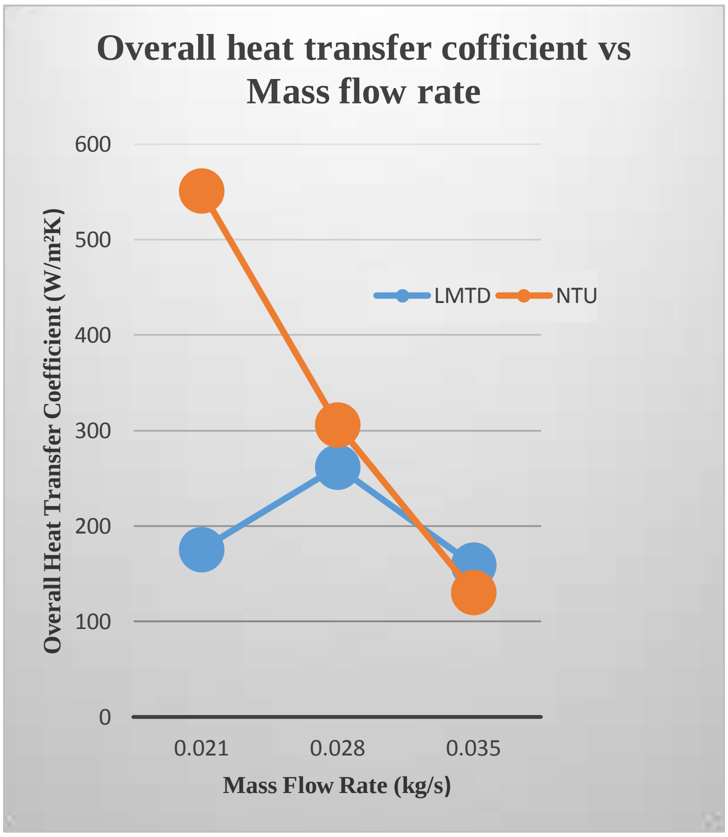

Chart 1: Overall heat transfer coefficient v/s Mass Flow Rate

3.5. Computational Fluid Dynamics

(1) Design of Model:

Using the actual dimensions of the experimental setup a geometric model is created using Solidworks Software.

Now two more models were created adding 2 and 4 baffles in the existing model as a modification.

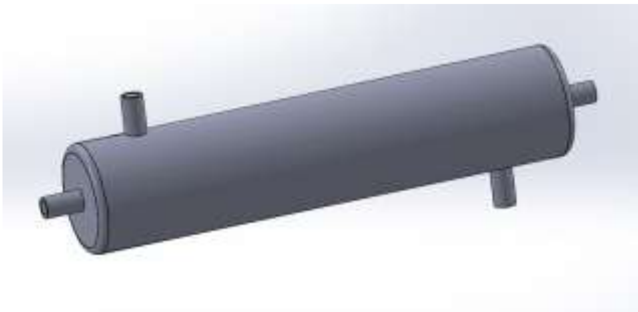

Fig 5: 3-Dimensional Model

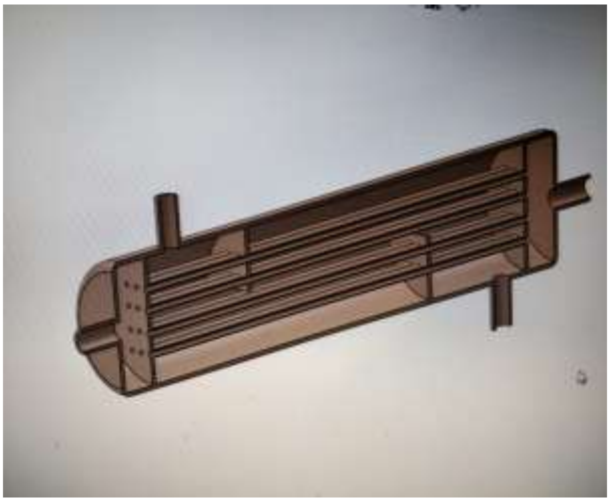

Fig 6: Heat Exchanger with 2 baffles

Fig 7: Heat Exchanger with 4 baffles

(2) Meshing:

The meshing part is done in the Meshing software package of ANSYS. The mesh was generated with a high smoothing and fine sizing. The meshing for 2 baffles and 4 baffles model in also shown in the figure below:

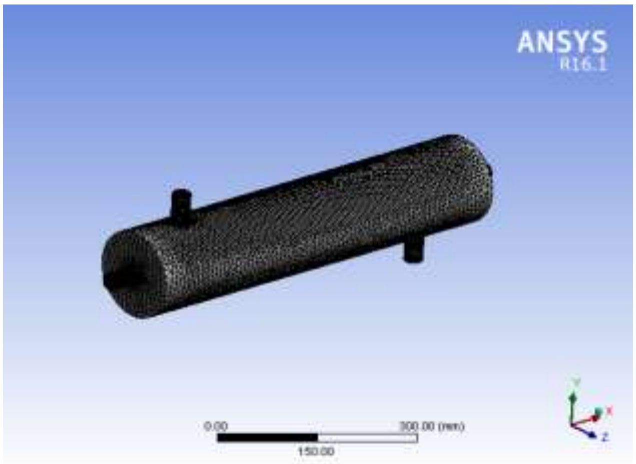

Fig 8: 3-D Model Mesh

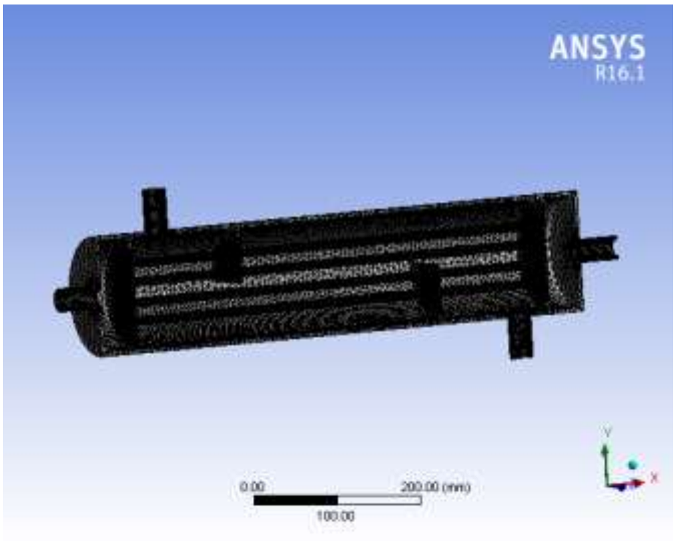

Fig 9: Mesh of Heat Exchanger with 2 Baffles

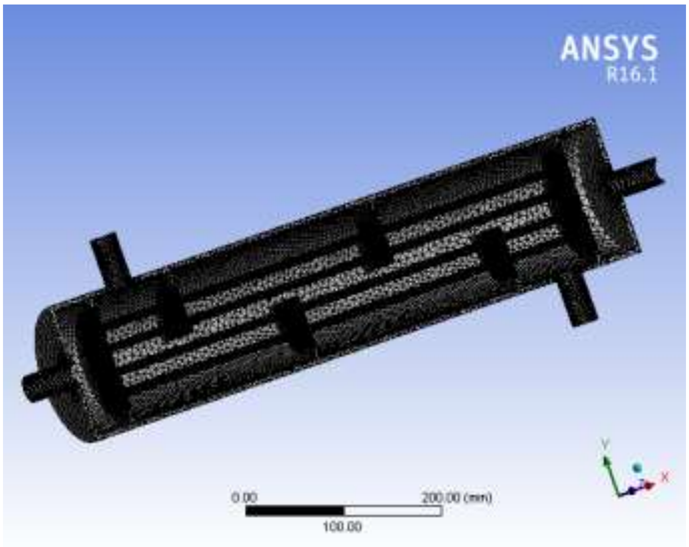

Fig 10: Mesh of Heat Exchanger with 4 Baffles

3.6. Results of CFD:

Maximum Value of Wall Heat Transfer Coefficient on hot and cold domain is calculated in ANSYS for parallel and counter flow with and without baffles for constant flow rate of 0.028kg/s of hot fluid and 0.022kg/s of cold fluid.

3.6.1. Parallel flow without baffles:

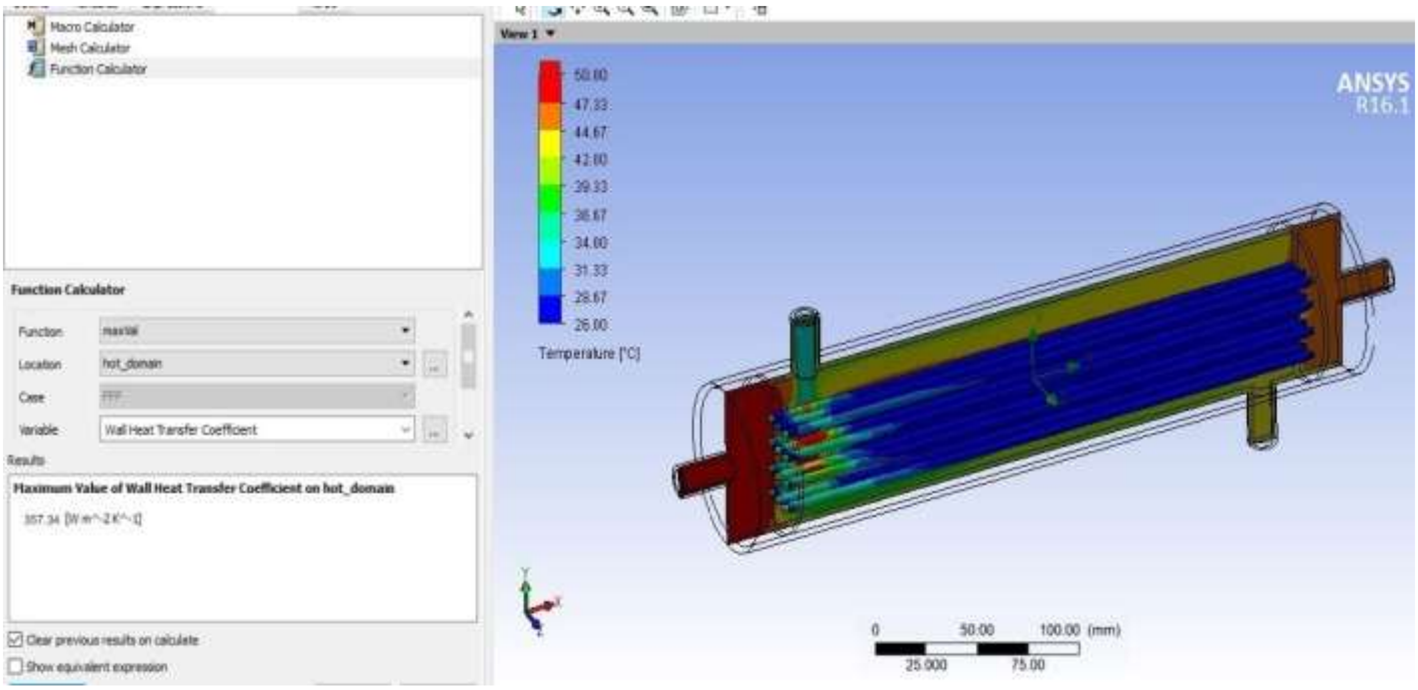

Fig 11: Maximum Value of Wall Heat Transfer Coefficient on Hot domain

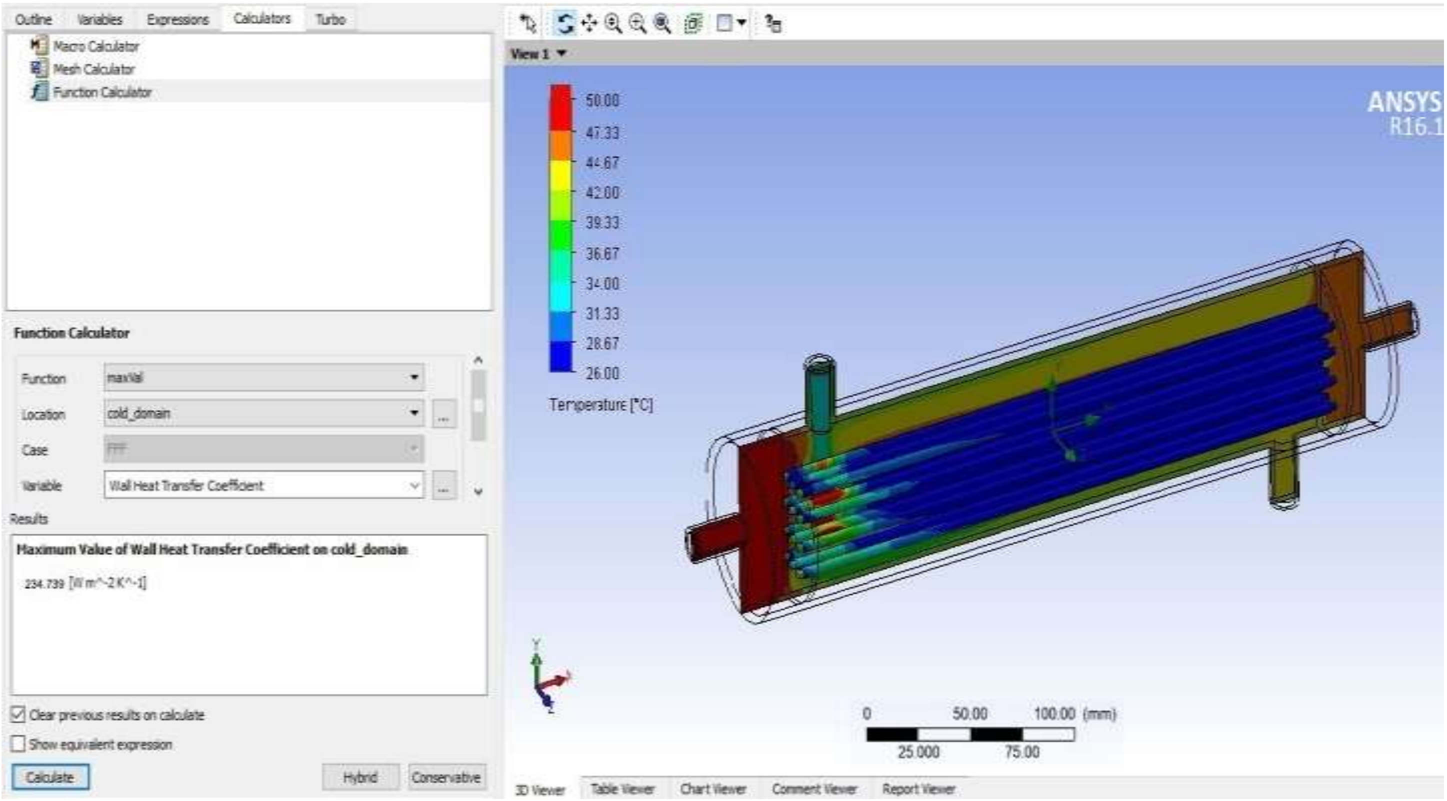

Fig 12: Maximum Value of Wall Heat Transfer Coefficient on Cold domain

3.6.2. Counter flow without baffles:

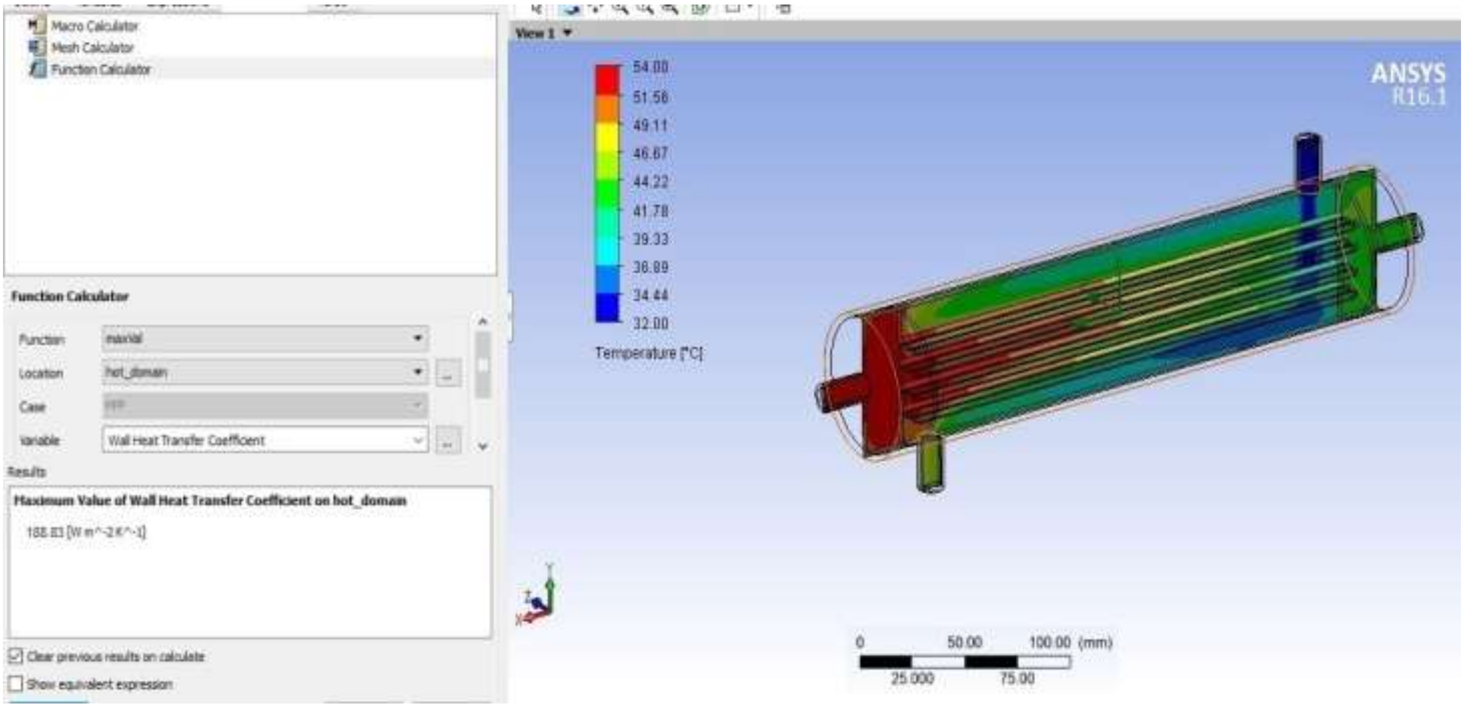

Fig 13: : Maximum Value of Wall Heat Transfer Coefficient on Hot domain

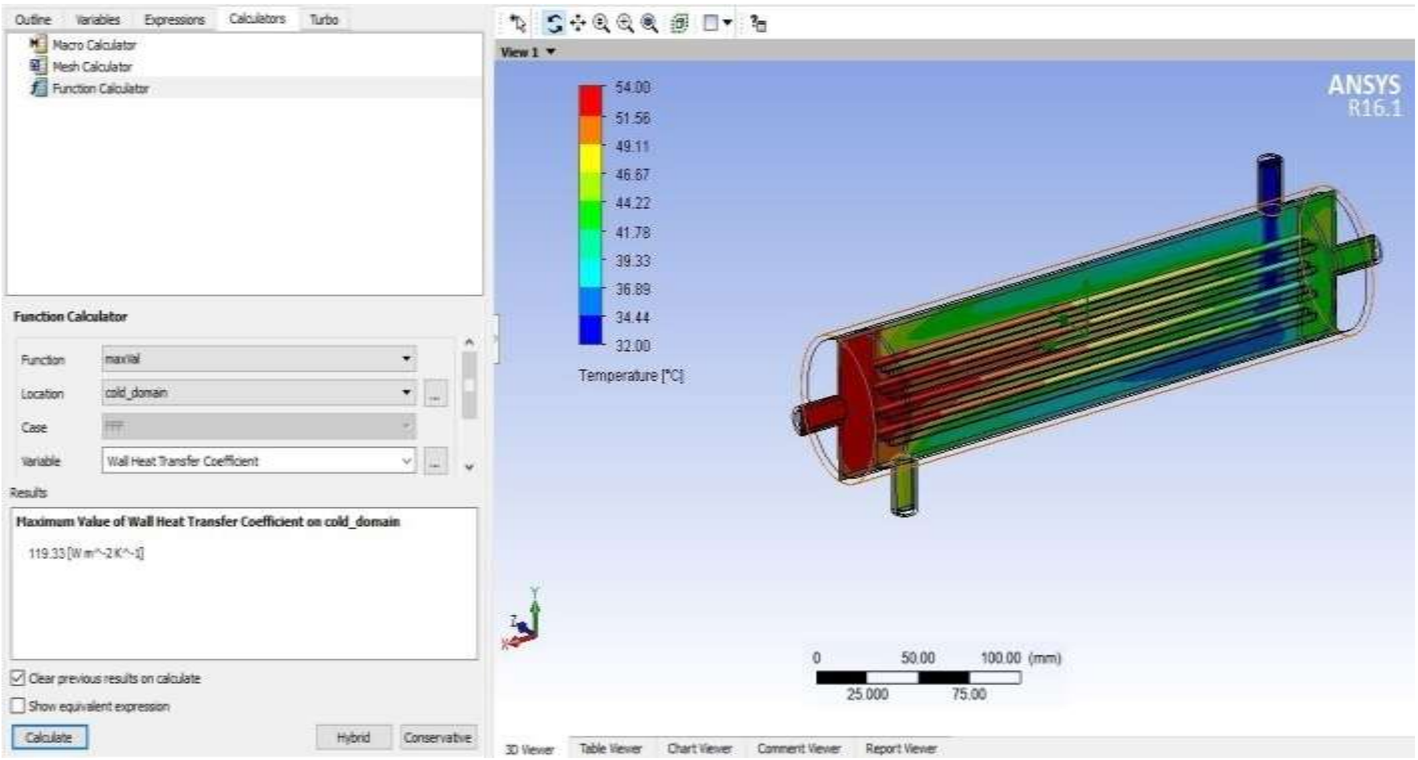

Fig 14: : Maximum Value of Wall Heat Transfer Coefficient on Cold domain

3.6.3. Parallel Flow with 2 Baffles:

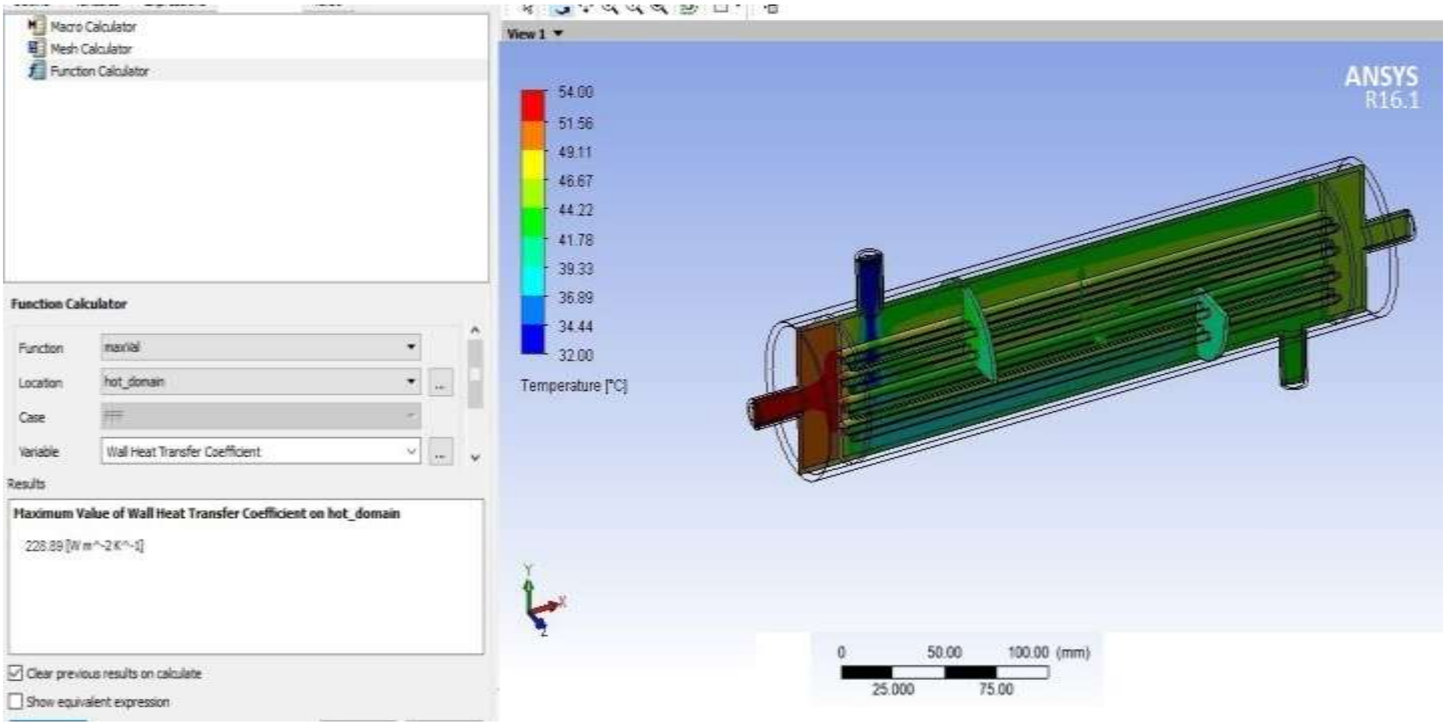

Fig 15: : Maximum Value of Wall Heat Transfer Coefficient on Hot domain

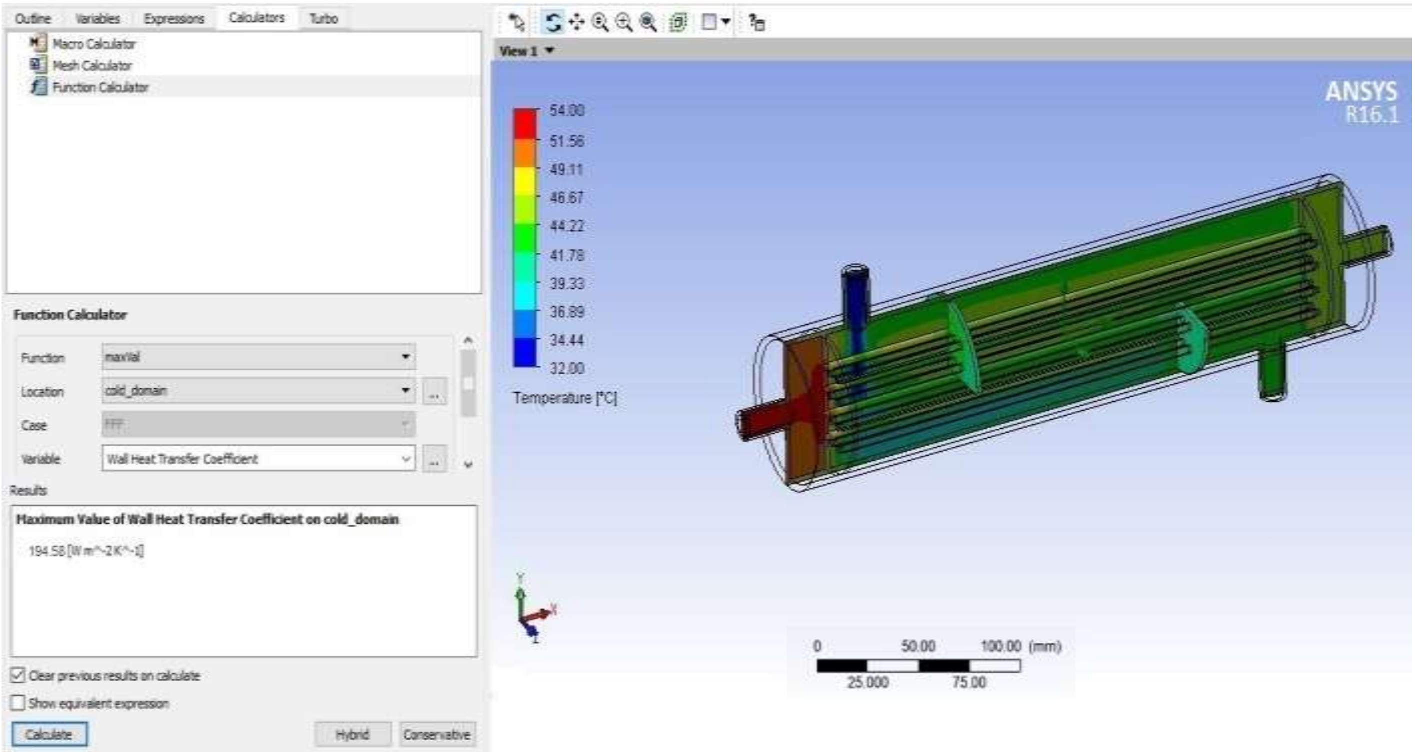

Fig 16: : Maximum Value of Wall Heat Transfer Coefficient on Cold domain

3.6.4. Counter Flow with 2 baffles:

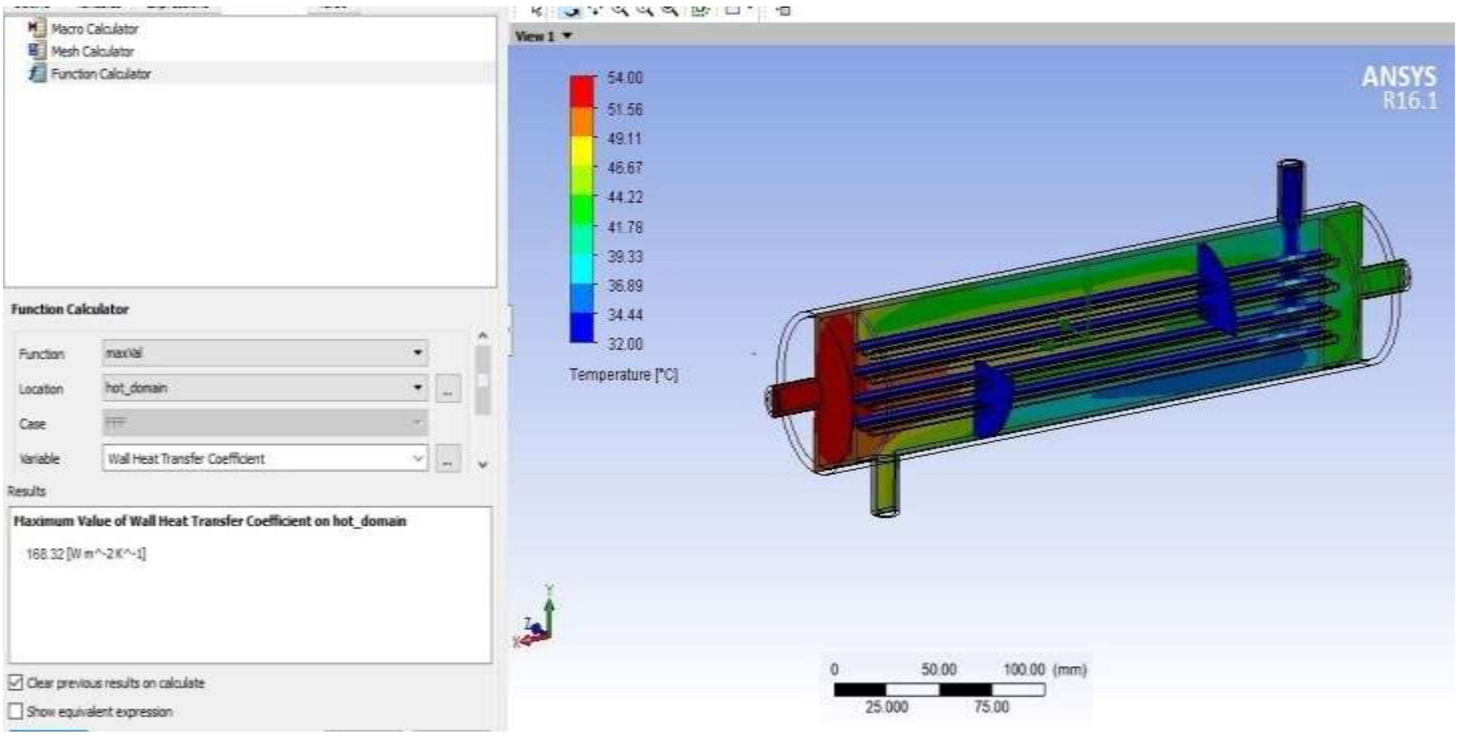

Fig 17: : Maximum Value of Wall Heat Transfer Coefficient on Hot domain

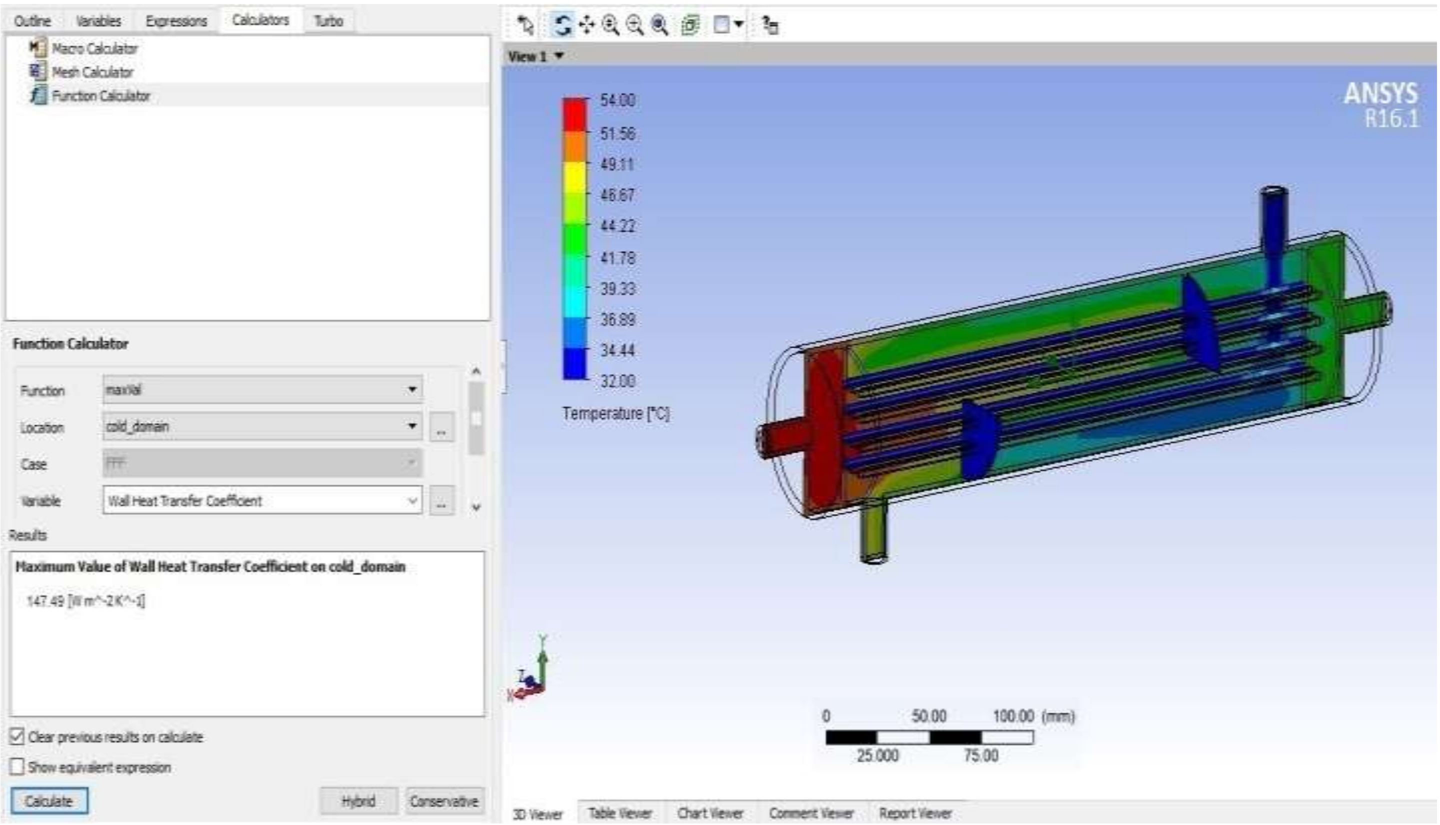

Fig 18: : Maximum Value of Wall Heat Transfer Coefficient on Cold domain

3.6.5. Parallel flow with 4 baffles:

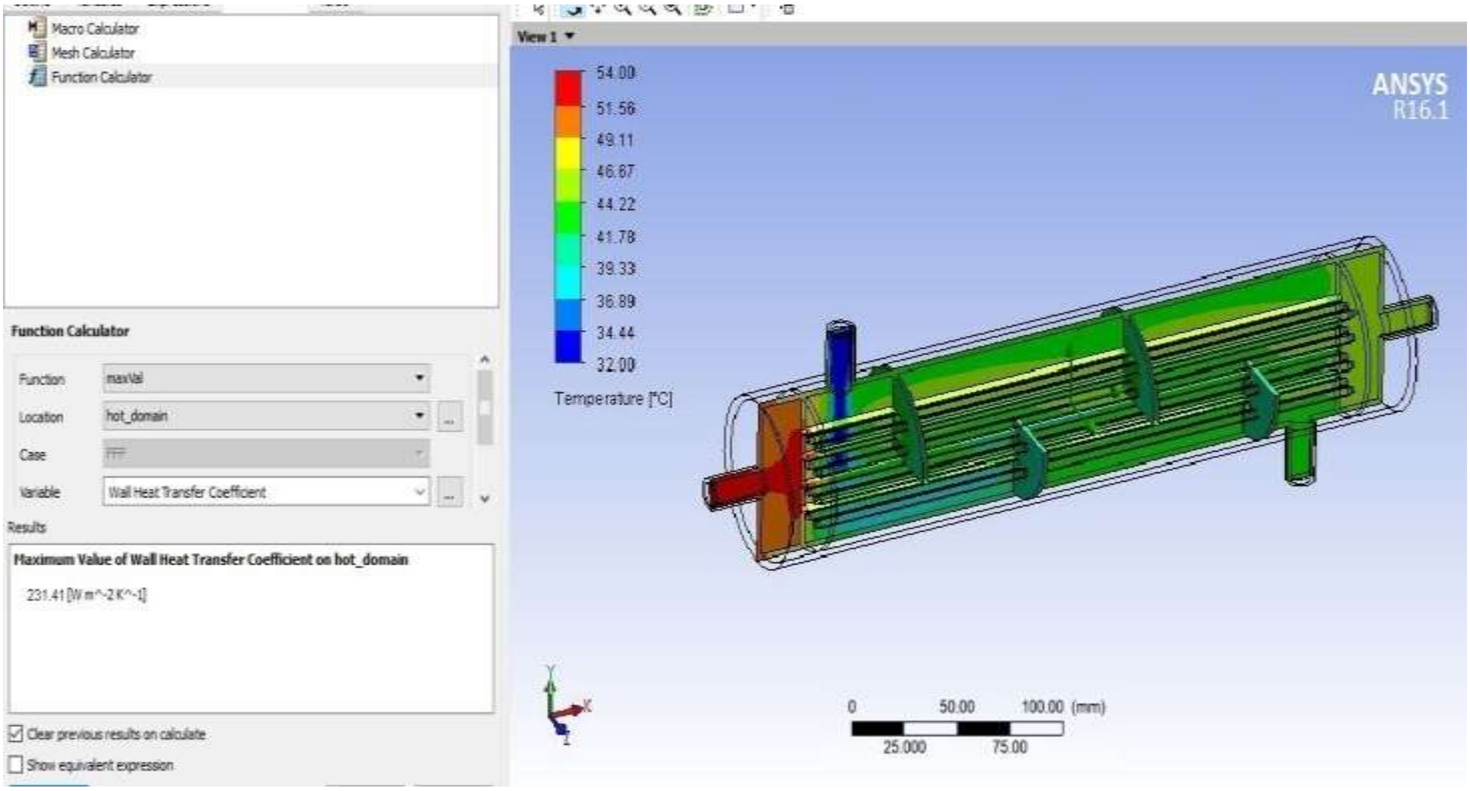

Fig 19: : Maximum Value of Wall Heat Transfer Coefficient on Hot domain

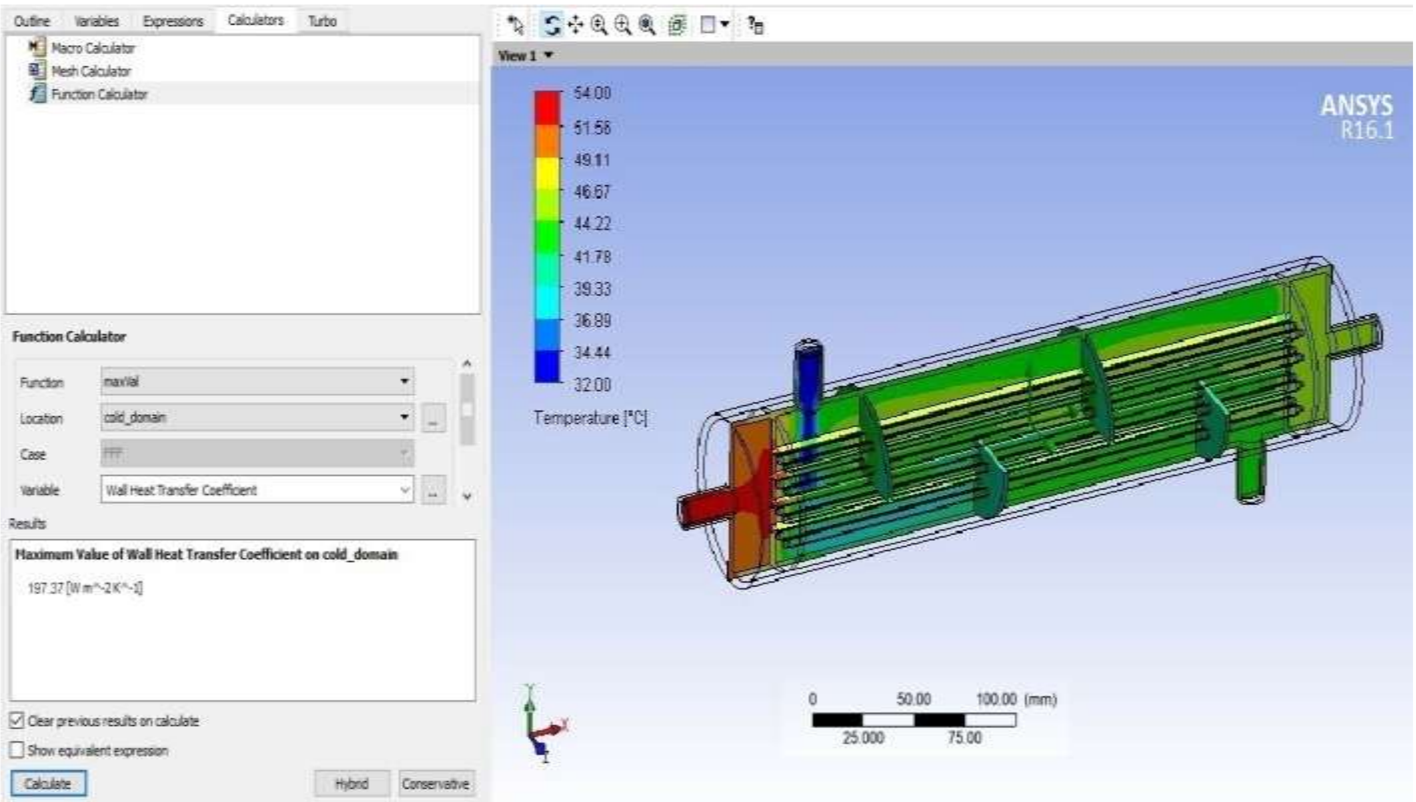

Fig 20: Maximum Value of Wall Heat Transfer Coefficient on Cold domain

3.6.6. Counter flow with 4 baffles:

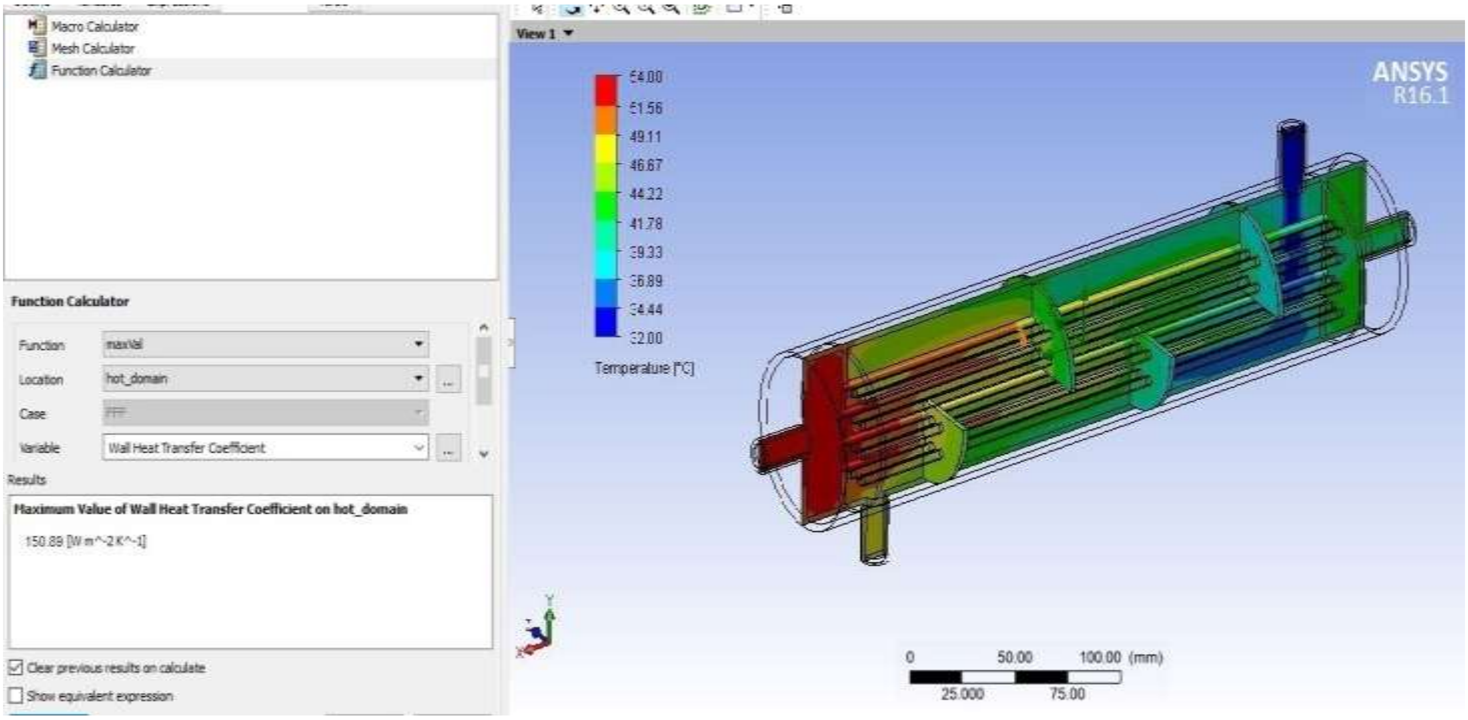

Fig 21: : Maximum Value of Wall Heat Transfer Coefficient on Hot domain

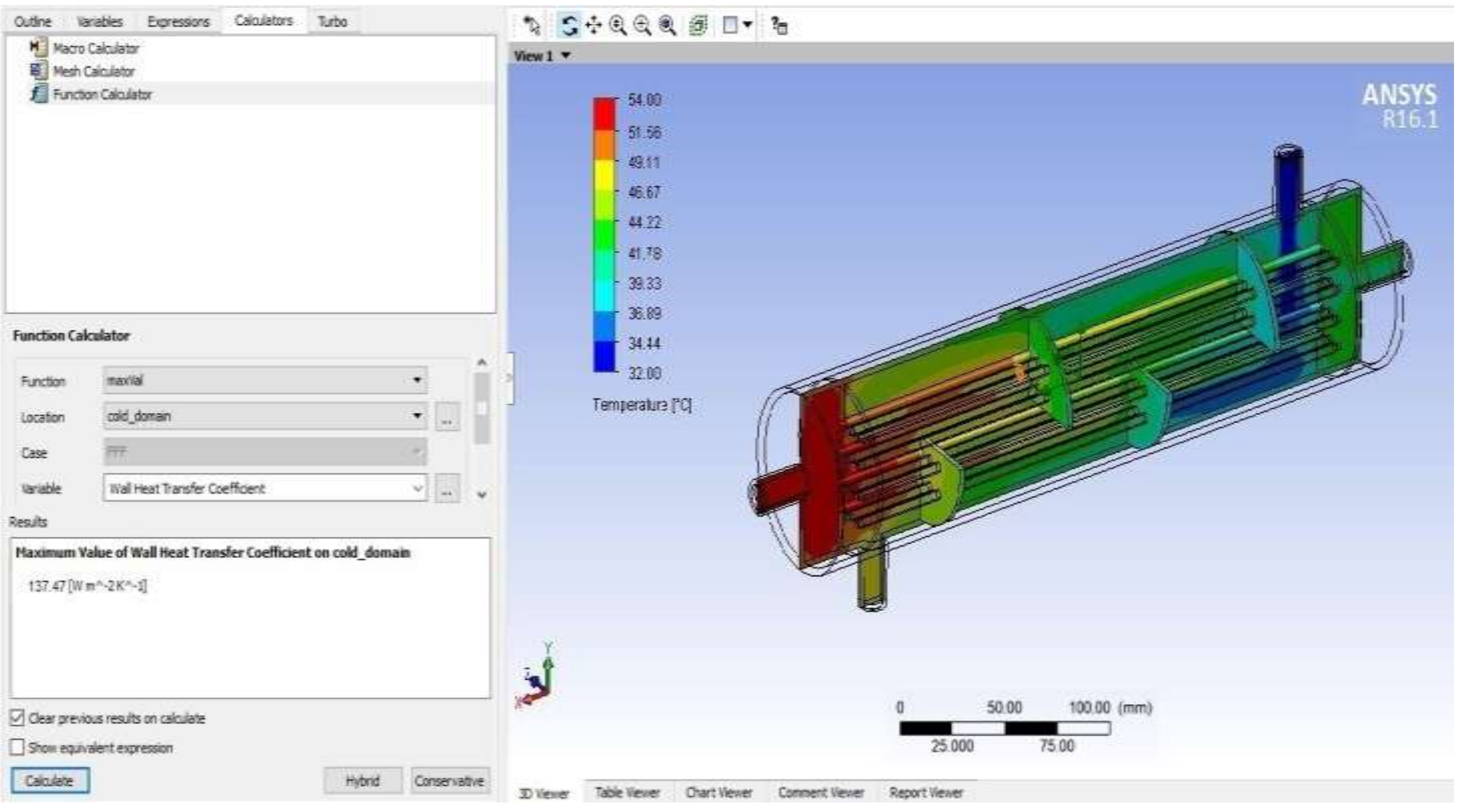

Fig 22: : Maximum Value of Wall Heat Transfer Coefficient on Cold domain

International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 07 Issue: 03 | Mar 2020 www.irjet.net p-ISSN: 2395-0072

3. Result and Discussion:

Here the analysis was performed for six arrangements. The readings obtained are shown in Table. It is clear from the result that for same flow rate and same boundary conditions for different arrangement the overall heat transfer coefficient has a noticeable change.

The heat transfer coefficient for hot domain and cold domain is obtained.

SR. NO.	Type of Flow and Configuration	Maximum Value of Wall Heat Transfer Coefficient on Hot Domain [W/m^{2}K]	Maximum Value of Wall Heat Transfer Coefficient on Cold Domain [W/m^{2}K]	Overall Heat Transfer Coefficient [W/m^{2}K]
1	Parallel flow	357.34	234.739	141.673
2	Counter flow	188.83	119.33	73.121
3	Parallel flow with 2 baffles	228.89	194.58	105.172
4	Counter flow with 2 baffles	168.32	147.49	78.60
5	Parallel flow with 4 baffles	231.41	197.37	106.51
6	Counter flow with 4 baffles	150.89	137.47	71.93

Table 4: Result obtained from analysis

4. CONCLUSIONS

In this investigation, the overall heat transfer coefficient for parallel flow for shell and tube heat exchanger were investigated numerically. The process with constant flow rate of hot and cold water as 0.028 and 0.022 respectively and inlet temperature of hot and cold water as 54°C and 32°C, for parallel and counter fluid flow, with and without baffles was studied on ANSYS software to validate the design. The results are as follows:

1. The overall heat transfer coefficient for parallel flow obtained numerically by LMTD and NTU method for all the readings, is maximum, for flow rate of hot and cold water of 0.021 and 0.0227 and inlet temperature of 49°C and 32°C for hot and cold water respectively, was 551.628 [W/m^{2}K] by NTU method.

2. The analysis performed on ANSYS for one reading, i.e. flow rate of 0.028 and 0.022 of hot and cold water, for parallel and counter flow without baffles, gives the overall heat transfer coefficient as

The equation for overall heat transfer coefficient is as follows:

$$\frac{1}{U} = \frac{1}{h_h} + \frac{1}{h_c} + R_f$$

Where,

h_h = hot side heat transfer coefficient [W/m^{2}K]

h_c = cold side heat transfer coefficient [W/m^{2}K]

R_f = Fouling coefficient [W/m^{2}K]

Fouling coefficient is neglected as it does not show any significant effect on the value.

141.673[W/m^{2}K] and 73.121[W/m^{2}K] for parallel and counter flow respectively.

3. The results obtained for parallel and counter flow with 2 baffles with same boundary conditions are 105.172[W/m^{2}K] and 78.60[W/m^{2}K] for parallel and counter flow respectively.

4. For 4 baffles configuration with same boundary conditions, the result for parallel flow was 106.51[W/m^{2}K] and 71.93[W/m^{2}K] for counter flow.

From the above obtained results it can be seen that the maximum overall heat transfer coefficient is for Parallel flow without baffles configuration i.e. 141.673[W/m^{2}K]

The addition of baffles in the existing model did not showed any positive results. The overall heat transfer coefficient decreased as number of baffles increased for the same boundary condition for both parallel and counter flow. Comparing the results of numerical calculation and simulation result it can be seen that the value is greater for numerical calculation i.e. by NTU method.

Hence it can be concluded that if the boundary condition of parallel flow without baffles is taken for other different configuration, it will not increase the overall heat transfer coefficient.

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