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Optimization of baffle inclination in Shell and Tube Heat Exchanger

Rounak Mahakul[1], D.N. Thatoi[2], Upendra Kumar Mohanty[3*]

[1]B.Tech Student, Mechanical Engineering Department, Institute of Technical Education and Research, Siksha 'O' Anusandhan University, Bhubaneshwar, Odisha, India,

[2,3]Professor, Mechanical Engineering Department, Institute of Technical Education and Research, Siksha 'O' Anusandhan University, *Ex. Professor, NIT Rourkel

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Abstract:
The present investigation proposes at optimizing the inclination of the segmental baffles inside the shell and tube heat exchanger, for augmenting the functioning of the same. The shell and tube heat exchanger find their most common use in the commercial field, thus it is important to its functioning in details. The present work uses SOLIDWORKS software for numerical analysis and parametric study for understanding and optimizing inclination of the segmental baffles for an enhanced performance of the heat exchanger. In the analysis the segmental baffles are set at different angles to indicate the angle of inclination which yields the best heat-transfer coefficient. TEMA (Tubular Exchangers Manufacturers Association) standards are adopted for the sake of analysis. It is seen from the analysis results that best results are obtained at an baffle inclination of 5º. Experimental verifications confirm the results obtained through analysis establishing the robustness of the analytical verifications.

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Introduction:

The heat exchangers under investigation find their wide adoption in the industrial sector, such as petroleum refining, power generation industries etc. It is a counter flow type heat exchanger in which exchanges heat between the fluids flowing in opposite directions is actuated due to convection as well as conduction. These heat exchangers are classified according to the process of heat transfer, type of flow of the fluid through them, provisions for the flow of the fluid and heat transfer mechanism adopted. Baffles installed in the heat exchanger induce turbulence and generate a crossflow component in the heat exchanger which results an increase in the convection coefficient of fluid in the shell side. The tubes are supported by the baffles which reduces the vibrations of the tubes induced by the flow of the fluid [1]. Baffles also help in proper circulation of water throughout the heat exchanger. The Shell and Tube heat exchangers are mostly provided with angled baffles. The cover pipe is introduced inside the segmental baffles to increase the rate of heat transfer [2-6]. It is reported [7] an increase in the baffle inclination results in decrease in the drop of pressure in the flowing fluid inside the pipe and simultaneously increases the heat transfer rate. The coefficient of heat transfer is a function of logarithmic mean temperature difference (LMTD) being directly proportional to it [8]. It is concluded by Gay et. al.[9] and Mehrabin et. al. [10] that this coefficient of heat transfer directly increases with the insertion of baffles. Closely spaced baffles account for high heat transfer. However, these baffles lead to poor stream distribution and higher pressure drops [11]. The material and size of the tubes decides the maximum spacing between the baffles. The cut arrangement for the baffles in this type of heat exchanger affects its performance [12-13]. The cuts in the baffle enhance the rate of fluid flow in the shell diminishes the vibrations in the heat exchanger.

The present article makes an attempt at analysing and optimizing the inclination of the

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segmental baffles inside the Shell and Tube Heat Exchangers (STHEs). For the related studies, both computational and analytical (experimental) methods are adopted. Such a study undertaken is supposed to reflect the impact of baffle inclination in the heat exchanger, on the temperature alteration arrived on the basis of the rate of heat exchanges achieved.

1. RESULTS AND DISCUSSIONS

1.1. Physical Modelling

A heat exchanger with single-shell and single-tube is selected. Proper layouts of the tubes is chosen with the appropriate pitch. Length of the heat exchanger used is maximum 1.2m used because of space limitation. Proper tube material & size of tube are selected. Fouling Resistance is taken as 0.0002 m^2K/W. Maximum flow velocity through the tube is 0.75m/sec. Thermal analysis is performed. Figure 1(a) represents the geometrical model. The material of the tube is Copper. Overall coefficient of heat transferattains a maximum value with the maximization of the flow velocities in both, the shell side and the tube side.Figure 1(b) represents the geometrical model of tube bundle with 0º inclined segmented baffles designed in the SOLIDWORKS 2017 software. Figure 1(c) represents the geometrical model of tube bundle with 5º inclined segmented baffles. Fluid flowing through tubes and baffles is longitudinal. Figure 1(d) represents the end cap of the shell and tube heat exchanger. The detailed structural parameters are presented in Table 1. The physical parameters of hot water / cold water in shell and tube heat exchanger are listed in Table 2 and Table 3 respectively.

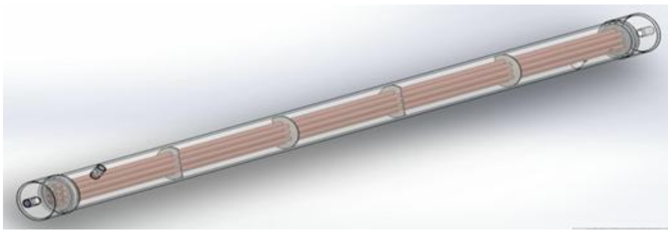

Figure 1.(a) Geometrical model of shell and tube heat exchanger

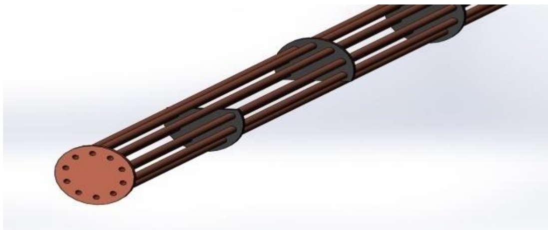

Figure 1.(b) Geometrical model of tube bundle with 0º inclined segmented baffle

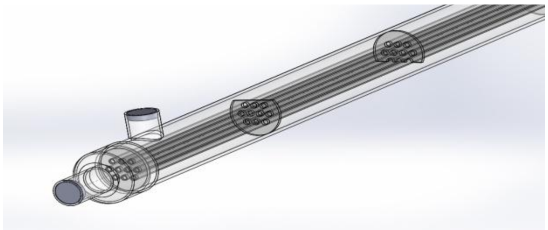

Figure 1.(c) Geometrical model of tube bundle with 5º inclined segmented baffle

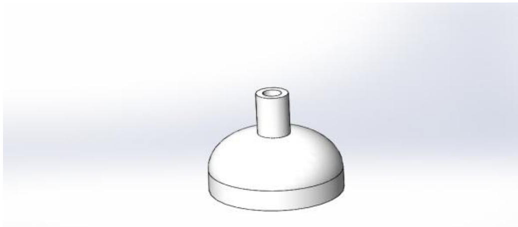

Figure 1.(d) End cap of shell and tube heat exchanger

Table 1: Geometrical parameters of shell and tube heat exchanger

Parameters	Value
ID of the tube in mm	6.25
OD of the tube in mm	4.25
Central distance of the tube/mm	9.40
Length of the tube/mm	1160
Tube number	10
Segmental baffle number	4
Segmented baffle cut	20%
Segmental baffle spacing/mm	232
Segmented baffle pitch/mm	1.25

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Thickness of segmental baffle/mm	3
Diameter of the shell/mm	56

Table 2: Physical parameters of hot water in shell and tube heat exchanger

Properties of Hot water	Value
Density of hot water	986.65 kg/m^3
Specific heat capacity of hot water	4182 J/kg-K
Thermal conductivity of hot water	0.6465 W/mK
Viscocity of hot water	0.525x10^{-3} kg/m-sec
Prandlt number of hot water	3.40
Coefficient of volume expansion	0.467x10^{-3} K^{-1}

Table 3: Physical parameters of cold water in shell and tube heat exchanger

Properties of Cold Water	Value
Density of cold water	995 kg/m^3
Sp. heat capacity of cold water	4178 J/kg-K
Thermal conductivity of cold water	0.619 W/mK
Viscocity of cold water	0.759x10^{-3} kg/m-sec
Prandlt number of cold water	5.125
Coefficient of volume expansion	0.3355x10^{-3} K^{-1}

2.2. Computational scheme of the baffle

The baffles are used in the heat exchanger for proper circulation of fluid for more effective heat transfer in the tube. A segmental baffle is cut away which allows the water to flow in a parallel as well as in an axial direction. Figure 2(a) represents the design of segmental baffle. The baffle cut design estimation for the water is 20% of the whole segmental baffle. Figure 2(b) represents the baffle cuts. The total number of tubes are 10 and preferred tube material is copper. The arrangement of the tubes is in a rotational regular triangular basis with orientation of 45° (Figure 2(c)). The dimensional analysis of baffle is described in Figure 5 respectively. The central distance between the tubes is 9.40mm and the thickness of the baffle is measure to be 3.0 mm.

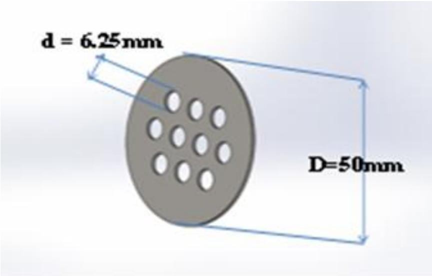

Figure 2.(a) Baffle design with tube orientation of 45º

Figure 2.(b) Baffle cuts (20%)

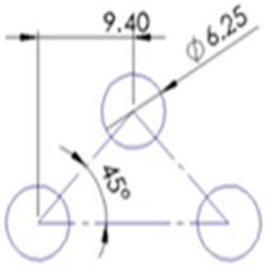

Figure 2.(c) Dimensional analysis of baffle

2.3. Mathematical modelling

The energy entering the surface per unit time plus the energy generated in the surface per unit time

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minus the energy leaving the surface in unit time = the energy stored in the surface per unit area.
According to the Energy-Balance Equation (1):

$$\dot{E}_{in} + \dot{E}_{gen} - \dot{E}_{out} = \dot{E}_{stored} \qquad (1)$$

where,
$\dot{E}_{in}$ = Energy entering in unit time in to the surface
$\dot{E}_{generated}$ = The amount of energy generated per unit time in the surface
$\dot{E}_{out}$ = Energy leaving in unit time off the surface
$\dot{E}_{stored}$ = Amount of energy stored per unit time in the surface

The average heat transfer rate between cold and hot fluid(Watt)

$$q = \frac{q_c + q_h}{2}$$

$$q = \dot{m}_c\, c_{p,c}\left(T_{co} - T_{ci}\right)$$

$$q_h = \dot{m}_h\, c_{p,h}\left(T_{hi} - T_{ho}\right)$$

$\dot{m}_c$ and $\dot{m}_h$ represent the cold and hot fluid mass flow rates respectively
c_{pc} and c_{ph} represent the specific heat capacity of cold and hot fluid respectively
A = Tube outside surface area (m^2)

A = (πDo L) N
where, N = count of tubes
Do = diameter of outlet tube(m)
L = Tube length (m)
ΔT_m = Logarithm mean temperature difference
The Nusselt number has been calculated from Dittus-Boelter Equation (2):

$$Nu_D = 0.027\,\mathrm{Re}^{0.08}\,\mathrm{Pr}^{n} \qquad (2)$$

where, n =0.333 for heating case
Re is Reynolds number for pipe flow
Nu is Nusselt number for pipe flow
Pr is Prandlt number for pipe flow

The average coefficient of heat transfer of the heat exchanger is

$$U = \frac{1}{\frac{d_o}{d_i h_i} + \frac{d_o}{2k_i}\log\frac{d_o}{d_i} + \frac{1}{h_o}}$$

where h_i and h_o are the heat transfer coefficient for the inner side that is tube side and the outer side that is the shell side in W/m^2K respectively
k_1 = Copper thermal conductivity(W/mK)

2.4. Numerical Modelling

The heat exchanger is modelled in SOLIDWORKS. Here, working fluid (clean water) has a specific heat capacity of 4185 J/kgK which is Newtonian /incompressible fluid for which the physical properties remain constant. The flow is observed to be turbulent in nature. The heat exchanger is considered to have a fouling resistance after several uses. Figure 3(a) and Figure 3(b) represents the temperature of hot water of inlet and outlet at 0° baffle inclination respectively. Figure 3(c) and Figure 3(d) represents the temperature of cold water of inlet and outlet at 0° baffle inclination respectively. Figure 4(a) represents the temperature of hot water inlet and cold water outlet having 5° baffle inclination whereas 4(b) represents the temperature of cold water inlet and hot water outlet having 5° baffle inclination in shell and tube heat exchanger respectively.

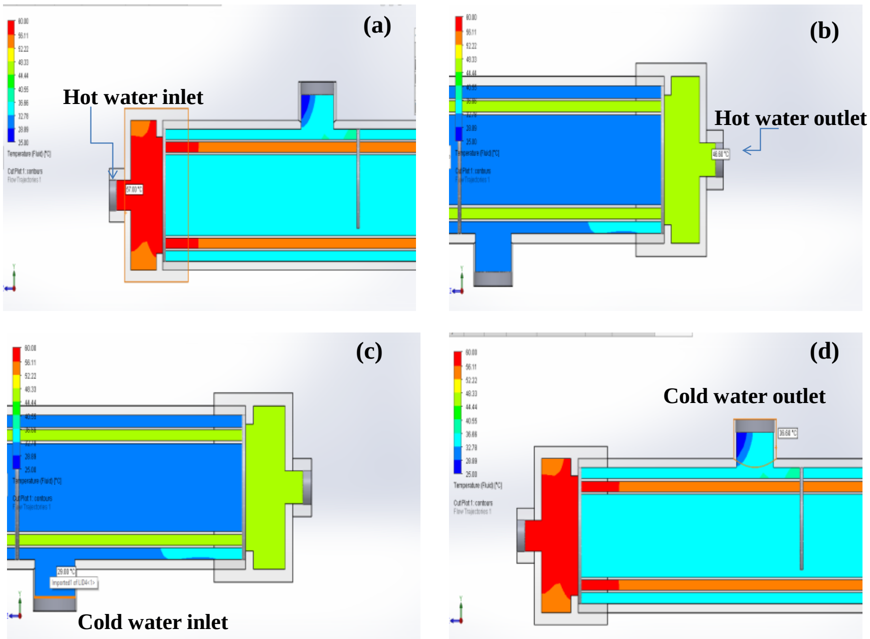

Figure 3.(a) Temperature of hot water at inlet having 0º baffle inclination in STHE
(b) Temperature of hot water outlet having 0º baffle inclination in STHE
(c) Temperature of cold water inlet having 0º baffle inclination in STHE
(d) Temperature of cold water outlet having 0º baffle inclination in STHE

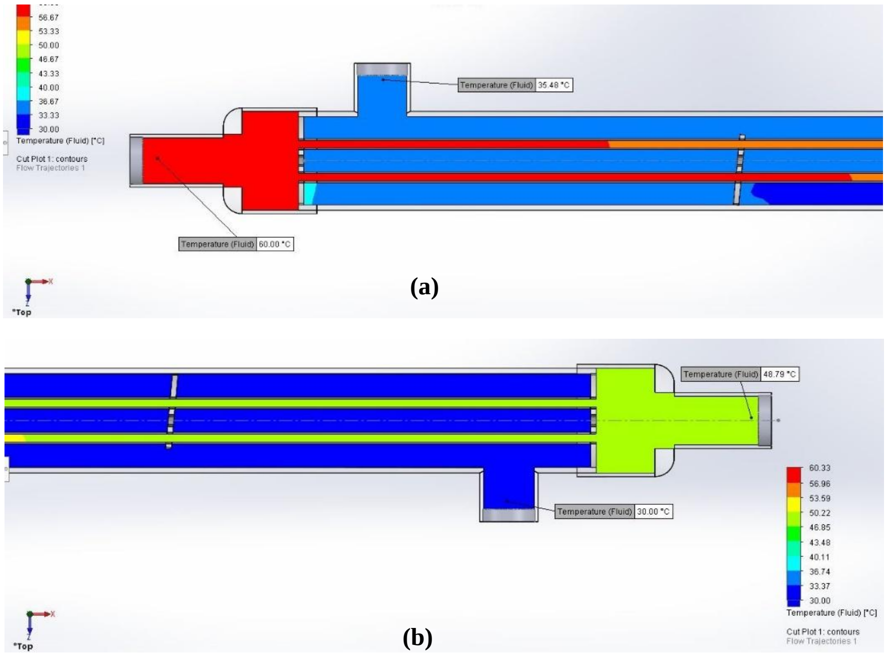

Figure 4. (a) Temperature of hot water inlet and cold water outlet having 5º baffle inclination in STHE
(b) Temperature of cold water inlet and hot water outlet having 5º baffle inclination in STHE

It is observed that the path line for water (incompressible fluid) having specific heat capacity4185J/kg-K flows through segmental baffles following a zig-zag pattern. Here, the fluid flow that

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is the counter flow is preferable because it has less temperature difference as compared to the parallel flow. The thermal results, geometrical results and experimental results have been calculated for the segmental baffle inclination in shell and tube heat exchanger. Figure 5(a) represents the temperature contours for hot water inlet and outlet at 0° segmental baffle inclination in heat exchanger where thermal result, geometrical result and experimental results of hot water outlet are shown respectively.The simulation was done to observe the temperature variation randomly and also due to baffle inclination at various angles. Figure 5(b) represents temperature contours for cold water inlet and outlet at 0° segmental baffle inclination in heat exchanger where thermal, geometrical and experimental results of cold water outlet is shown respectively. The heat transfer increase in the heat transfer rate can be seen when the baffle inclination increases from 0° to 5° as presented in Figure 5(c) the heat transfer rate of 4600.2 Watt at 0° inclination enhances to 4688.2 W at 5° inclination. Figure 6 represents the temperature domain of the shell and tube heat exchanger. Figure 7 represents flow trajectory of incompressible fluid water in 5° segmental baffle inclined in Shell and tube heat exchanger. The results of heat transfer coefficient with baffle inclination of 0° in a shell and tube heat exchanger is shown in Table 4. The simulations have been done for wide variation of baffle inclination (θ). The results are shown in Table 5. It is observed that when baffle is inclined at θ =7° and θ =9°, there is no such significant amount of heat transfer and the fluid does not mix thoroughly. Hence, the purpose of inclining the baffle at θ =7° and θ =9° respectively is not appropriate and accurate. At θ =-1°, θ = -3° and θ = -5°, the fluid flows through the tube and when the fluid hits the baffles, flow becomes adverse which results in pressure drop. For θ = 0°, θ = 3° and θ = 5°, it is observed that there is considerable increase in the rate of heat transfer and coefficient of heat transfer and logarithmic mean temperature difference. The thermal results for inclination of baffle atθ = 0°, θ = 3° and θ = 5° respectively in shell and tube heat exchanger is shown in Table 6. The best result is obtained at baffle inclination of θ = 5°.

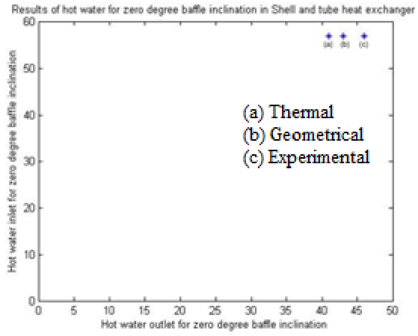

Figure 5.(a) Temperature contours for hot water inlet and outlet for 0° baffle inclination having (a) Thermal (b) Geometrical and (c) Experimental results respectively

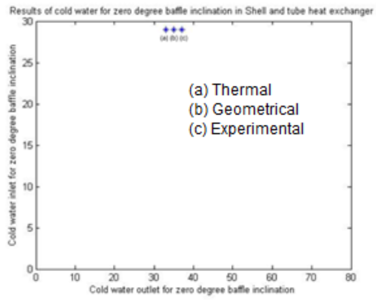

Figure 5.(b) Temperature contours for cold water inlet and outlet for 0°baffle inclination having (a) Thermal (b) Geometrical and (c) Experimental results respectively

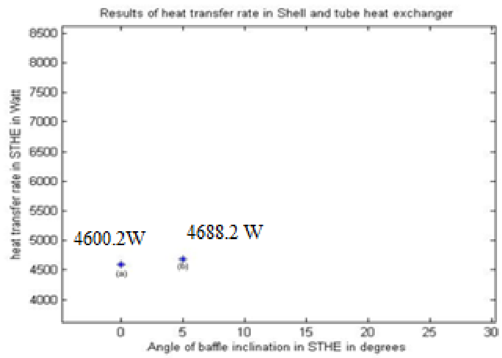

Figure 5.(c) Heat transfer rate for (a) 0° baffle inclination in a shell and tube heat exchanger (b) 5° baffle inclination

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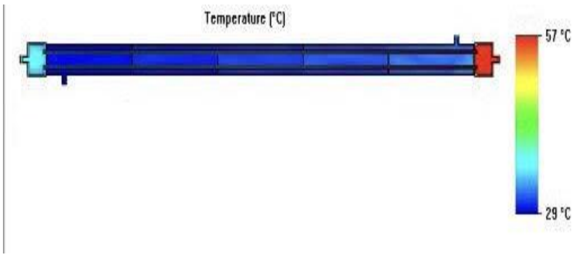

Figure 6: Temperature domain of shell and tube heat exchanger

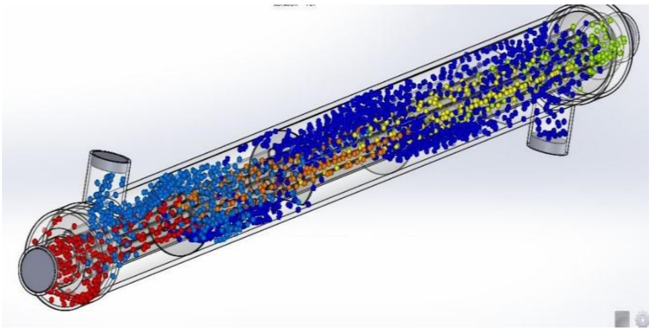

Figure 7: Flow trajectory of water having 5° baffle inclined in STHE

2. EXPERIMENTAL SETUP

The heat exchanger is having circular tubes at angle of 45° tube orientation for baffle. The baffle 20% cut chosen for experiment. The shell material is stainless steel and that of tube is copper. Experiment of fluid is clean water of specific heat capacity of 4185 J/kgK. The hot clean water is used inside the tubes and cold fluid is used in the shell, respectively. The material standard of polyvinyl chloride pipe confirms to American Society for Testing and Materials (ASTM). Water is pumped from the water tank. It is divided into two streams. The stream of hot fluid is heated by the electric heater which passes through the tube side of heat exchanger. The rate of flow is recorded by the flow meters and regulated by valves. The fluid flow here is turbulent in nature. The number of thermocouples used in the experiment is four. These measure the hot water/cold water inlet/outlet temperatures. Figure 8 represents experimental setup of heat exchanger photographically.

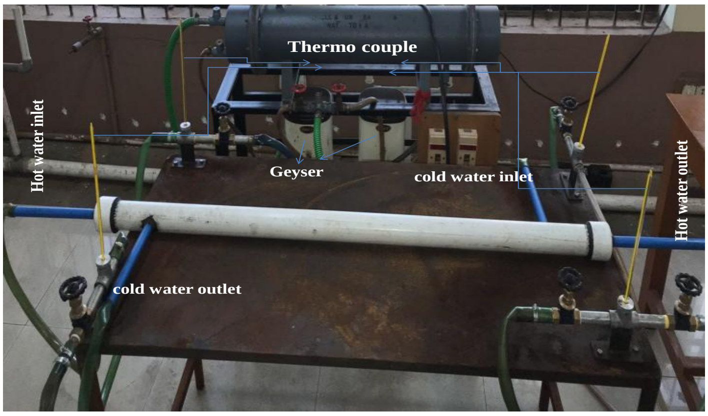

Figure 8: Experimental setup of shell and tube heat exchanger

Table 4. Results of heat transfer coefficient at 0° baffle inclination in shell and tube heat exchanger

Heat transfer coefficient (h)	**Numerical value**
Coefficient of heat transfer inside the tube	5833 W/m^2K
Heat transfer coefficient in the shell	3500 W/m^2K

Table 5. Results of LMTD for various baffle inclination

Baffle inclination (θ)	**Logarithmic Mean Temperature Difference**
0°	18.4594
3°	19.5775
5°	22.6653
7°	20.7453
9°	20.1043

Table 6. Thermal results with baffles angle orientation in shell and tube heat exchanger

	For 0° baffle inclination in STHE	For 3° baffle inclination in STHE	For 5° baffle inclination in STHE
Mean temperature of hot water (C)	51.500	52.995	54.395
Mean temperature of cold water(C)	33.00	32.760	32.590
Heat transfer rate (W)	4600.2	4638.6	4688.2
Mass flow rate cold (water) (kg/s)	0.1376	0.1876	0.2166
LMTD	18.4594	19.5775	22.6653

CONCLUSION

The numerical analysis pertaining to heat transfer the STHEs has been undertaken by inclining the segmental baffle at various angles to get optimum results. The following statements were drawn:

1) At a baffle inclination of θ = 5°, significant enhancement in the rate of heat transfer and heat transfer coefficient and logarithmic mean temperature difference has been observed.
2) It is observed that when baffle is inclined at θ = 7° and θ = 9°, there is no such significant amount of pressure drop and the fluid does not mix thoroughly. Hence, the inclination of the baffle at θ =7° and θ =9° respectively is not productive so far as the heat transfer is concerned.
3) At θ = -1°, θ = -3° and θ = -5°, when the fluid hits the baffles flowing through the tubes, flow becomes adverse and turbulence is created which results in pressure drop.

3. SUGGESTIONS FOR FUTURE INVESTIGATIONS

Adoption of more number of baffles with a baffle inclination of θ = 5°, is recommended. The material of construction should have a high thermal conductivity in order to attain a high rate of heat transfer.

Ribbed-tubes should be put in place of cylindrical tubes for enhancing effectiveness and rate of heat transfer in the heat exchanger.

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