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Experimental Study on The Influence of Baffles on Heat Transfer of Shell and Tube Heat Exchanger

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ABSTRACT
The research focuses on improving the heat transfer performance of a shell-and-tube heat exchanger by modifying the baffle design. This experimental work examines how different baffle layouts affect the heat exchanger's pressure drop and thermal performance at various mass flow rates. The experimental setup included stainless-steel baffle plates with three different cut percentages (15%, 25%, and 35%) to evaluate their effects on heat transfer rates under counterflow and parallel flow conditions. The findings indicate that heat transfer rates increase with higher mass flow rates across all baffle cuts. According to the experimental results, the 25% baffle cut demonstrates the best heat transfer performance. Furthermore, the analysis shows that single-segmental baffles with a helical configuration are more effective in enhancing heat exchanger performance, particularly in high-pressure environments. These findings present new opportunities for optimizing industrial heat exchanger designs in applications such as chemical processing, power generation, and renewable energy systems.

Keywords: Heat Exchangers; Baffle Design; Thermal Performance; Computational Fluid Dynamics (CFD); Pressure Drop

1. Introduction

Heat exchangers transport thermal energy between fluids or between solid particles and fluids of varying temperatures. Their design and efficiency, particularly in shell-and-tube heat exchangers, are critical in various applications, including chemical engineering, power generation, refrigeration, and renewable energy systems. Shell-and-tube heat exchangers are widely used in oil and chemical operations due to their efficiency and suitability for high-pressure applications [1]. Baffles are essential components of shell-and-tube heat exchangers (STHX), as they guide shell-side fluid flow over the tube bundle, improving heat transfer efficiency and providing structural support. According to B.I. Master et al. (2006), shell-and-tube heat exchangers account for over 30% of all heat exchangers [2].

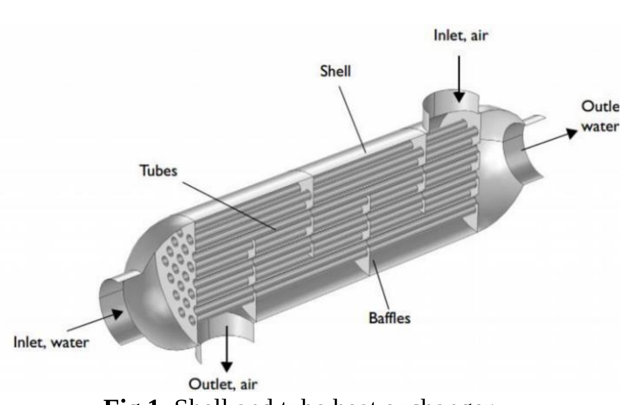


Fig.1. Shell and tube heat exchanger

Shell-and-tube heat exchangers are an excellent choice for high-pressure applications due to their durability and relatively low weight [3]. They require less frequent cleaning than other models because they are less prone to scale buildup [4]. Electric welded pipes are commonly used to manufacture tube heat exchangers [5–7]. However, immediately after the project is completed, the outer coating may diverge along the seam, leading to leaks. When water is heated, oxygen begins to escape [8], which promotes the development of metal corrosion [9]. Reducing fouling, minimizing leaks, and increasing the heat transfer coefficient can provide significant benefits [10]. These heat exchangers can handle various fluids, including corrosive and high-temperature compounds, making them versatile for numerous industrial applications [11]. Their design can also be optimized, such as by modifying baffle designs to improve flow dynamics and reduce pressure drops [12, 13]. This study develops a numerical model of a small shell-and-tube heat exchanger to analyze the shell-side design, focusing on a single-shell and single-pass parallel flow configuration. The research aims to enhance our understanding of the thermal performance and flow dynamics of this arrangement.

This paper investigates the impact of baffle design on the pressure drop and thermal performance of a shell-and-tube heat exchanger across a range of mass flow rates. A CFD model is employed to compare and analyze the influence of four baffle designs: single ten-segmental baffle, double segmental baffle, helical baffle, and single segmental + helical baffle. The simulations evaluate the effect of each baffle design on pressure drop and thermal performance. The results demonstrate that the single segmental + helical baffle reduces pressure drop and enhances overall system efficiency compared to the other designs. Thus, it is concluded that the single segmental + helical baffle is more efficient than the other three designs.

2. Methodology

2.1 Experimental Method

A stainless-steel plate with a diameter of 54 mm was used. The baffle end plate has nine holes, each with a diameter of 6.3 mm, arranged in a triangular tube layout pattern, as shown in Figure 2.

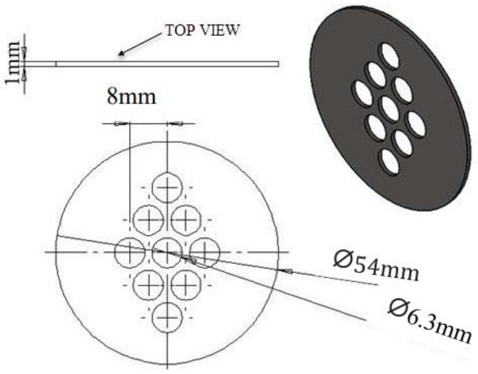


Fig.2. A schematic diagram of the baffle end plate

The baffle cuts can range from 15% to 45%. In this study, baffle cuts of 15%, 25%, and 35% are utilized. The baffle plate has a thickness of 1 mm. A schematic diagram of the baffle cut is shown in Figure 3.

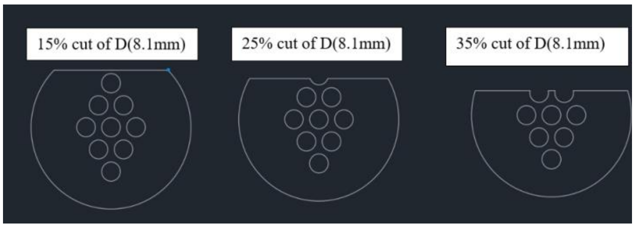


Fig.3. Schematic diagram of baffle cut

The setup consists of nine tubes with baffle end plates on both sides. Twelve baffles are used to support the tube bundles. Cold water flows on the shell side, outside the tubes, while hot water flows on the tube side, inside the tubes, as shown in Figure 4.

Fig.4. Photographic views of the tube bundle

The experimental setup involves several critical components and procedures. The baffle end plate, made of stainless steel, is cut and drilled to fit the tubes. A portion of the baffle end plate (25%) is removed to form the baffle. Tubes are inserted into the perforations, creating a tube bundle with baffles evenly distributed along its length. This tube bundle is placed inside a PVC pipe, which has two drilled holes on its outer circumference for nozzle insertion. Two plastic headers, secured to either end of the shell with screw threads, have drilled holes for nozzles. Hose pipes connect the nozzles to a pump that supplies water from a bucket. A water heater in the bucket provides hot water.

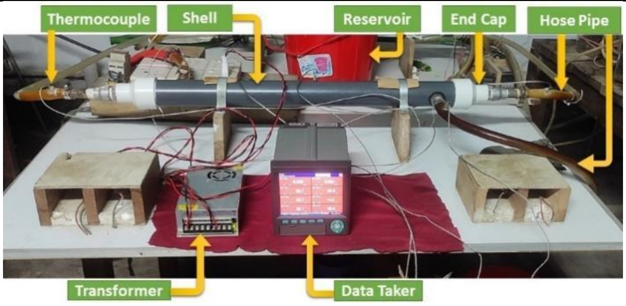


Fig.5. Final experimental setup

Temperature is monitored using thermocouples installed at each nozzle's inlet and outlet.

2.2 Design steps

The following procedures are used in this study to design the shell-and-tube heat exchanger:

1. Assume the tube diameter and Birmingham Wire Gauge (BWG), as well as the tube length (L).
2. Assume the fouling factors for the inside and outside of the tubes, h_i and h_o.
3. Assume the thermal conductivity of the material used for constructing the tubes.
4. Assume three known temperatures and calculate the fourth, or assume four temperature values and determine one of the shell-side or tube-side flow rates. Use the heat duty equation as

$$q = mc_{p_c}\left(T_{c_{out}} - T_{c_{in}}\right) = m_h c_{p_h}\left(T_{h_{out}} - T_{h_{in}}\right)$$

Here, the subscripts c and h refer to cold and hot water, respectively. Then, calculate the heat duty q.

5. Based on the type of flow, calculate the Log Mean Temperature Difference (LMTD).

$$\Delta T_{logmean} = \frac{\left(T_{h_{in}} - T_{c_{out}}\right) - \left(T_{h_{out}} - T_{c_{in}}\right)}{\ln \frac{\left(T_{h_{in}} - T_{c_{out}}\right)}{\left(T_{h_{out}} - T_{c_{in}}\right)}}$$

6. Based on the heat exchanger configuration, obtain the temperature correction factor (F_T) and find the mean temperature difference using the following formula:

$$\Delta T_{mean} = F_T \times \Delta T_{logmean}$$

7. Assume the overall heat transfer coefficient.
8. Calculate the number of tubes: $N_t = \frac{A}{\pi d_o L}$
9. Calculate the tube pitch and the bundle diameter by using the following formula:

$$p_t = 1.25 d_o \text{ , } D_b = d_o \left(\frac{N_t}{K_1}\right)^{1/n_1}$$

where,
$N_t =$ Number of tubes
$D_b =$ Bundle diameter,
$d_o =$ Tube outside diameter, mm

10. Assume the type of floating head of the exchanger and obtain the bundle diameter clearance (BDC) which is obtained from the chart.
11. Calculate the shell diameter. $D_s = D_b +$ Additional clearance.

12. Calculate the baffle spacing. $B_s = \frac{2}{3} D_s$
13. Calculate the area of cross-flow, $A_s = \frac{(p_t - d_o) D_s B_s}{p_t}$
14. Calculate the shell side mass velocity. $G_s = \frac{\dot{m}}{A_s}$
15. Calculate the shell equivalent diameter.
    A square pitch arrangement:
    $$d_e = \frac{4\left[\frac{1}{2}\times p_t \times \frac{\sqrt{3}}{2} \times p_t - \frac{1}{2}\times\frac{\pi\times {d_o}^2}{4}\right]}{\frac{\pi\times d_0}{2}}$$
    $d_e =$ Equivalent diameter
16. Calculate the shell-side Reynolds number,
    $$Re = \frac{\rho v d_e}{\mu}$$
17. Calculate the Prandtl number and Nusselt Number,
    $$Pr = \frac{\mu C_p}{k}, Nu = 1.86\left[Re.Pr.\frac{d}{L}\right]^{0.33} \times \left(\frac{\mu_b}{\mu_w}\right)^{0.14}$$
18. Obtain the shell-side heat transfer coefficient,
    $$N_u = \frac{h_s d_e}{k_f}$$
19. Calculate the pressure drop in the shell,
    $$\Delta P_s = \frac{f_s \times {G_s}^2 \times D_s (N+1)}{5.22\times 10^{10} \times D_e \times S \times \varphi_s}$$
20. Calculate the tube-side mass velocity,
    $$G_m = \frac{\dot{m}}{N_{tpp} \times \pi {d_t}^2/4}$$
21. Calculate tube-side velocity,
    $$v = \frac{\dot{m}}{\rho A}$$
22. Calculate Prandtl and Reynolds numbers for fluid inside tubes
    $Pr = \frac{\mu C_p}{k}$, $Re = \frac{\rho v d_i}{\mu}$, where subscript I refers to the fluid inside tubes
23. Calculate the overall heat transfer factor
    Based on inside tube flow,
    $$U = \frac{1}{h_o} + \frac{1}{h_i}$$
    Where h_i and h_o are the heat transfer coefficients for the scales (dirt) inside and outside tubes respectively.
24. Compare the calculated overall heat transfer coefficient obtained from the previous step to that assumed in step 8. If it is close to what was assumed, then it was a valid assumption. Then, the results are tabulated, including the total surface area of tubes, number of tubes, exchanger length and diameter, heat duty, and other design specifications. Otherwise, using the calculated value from Step 8, repeat iterations until the difference in the calculated U between successive iterations becomes insignificant.
25. The relationship may be used to determine the decrease in tube-side pressure.
    $$\Delta P_t = \frac{f_t \times {G_t}^2 \times Ln}{5.22\times 10^{10} \times D_e \times S \times \varphi_t} + \frac{4nv^2}{2Sg}$$

3. Results and Discussion

3.1 Counterflow condition

When there is counterflow, the cold and hot fluids enter the heat exchanger at different ends and move in opposite directions. The shell and tube side entrance value and exit temperatures, meticulously considered during the heat exchanger's design, form the precise theoretical temperature profile. The temperatures at the tube side entrance and outflow are 70 °C and 64 °C, respectively. The inlet temperatures on the shell side are 30 °C and 35 °C. The temperature profile for the theoretical temperature is shown in Figure 6 below.

The experimental temperature profile of the counterflow condition for a 15% baffle cut is drawn in Figure 7. It is seen from the figure that the temperature of the tube side inlet and outlet are 50°C and 42.5°C, respectively. The temperatures of the shell side inlet and outlet are 29°C and 38.2°C.

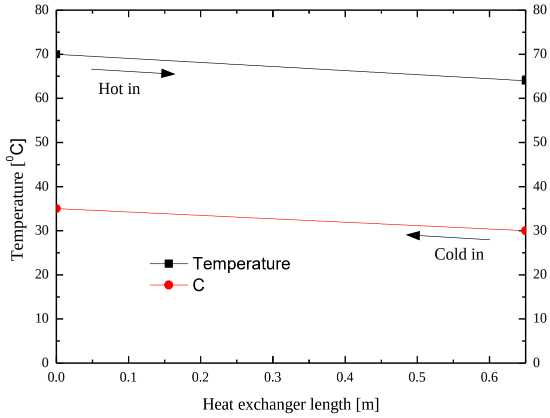


Fig. 6. Theoretical temperature variation along the heat exchanger length for counterflow condition

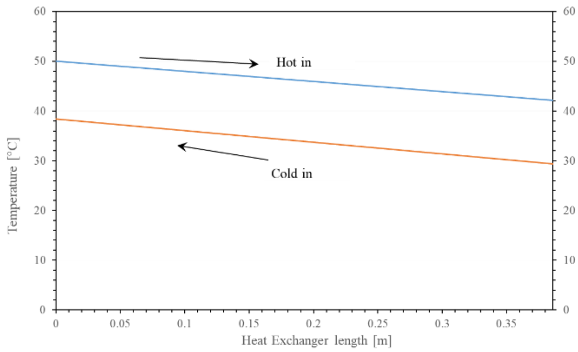


Fig.7. Experimental temperature variation with heat exchanger length

Table 1 Experimental data for Counterflow condition for various mass flow rates for 15% baffle cut:

Serial number	Hot water mass flow rate (kg/s)	Hot water inlet (°C)	Hot water outlet (°C)	Cold water inlet (°C)	Cold water outlet (°C)	Cold Water Mid-Point temp. (°C)	Heat transfer rate Q (KW)	Heat transfer rate mean (KW)
1		45	40.4	29.3	37.5	33.2	2.14	
2	0.0625	50	42.5	29	38.2	33.5	2.40	2.03
3		55	46.1	29.1	35	32	1.54	
4		45	40.2	29.3	37.5	33	3.43	
5	0.1	50	42.2	29.4	38.4	33.7	3.76	3.25
6		55	46	29.1	35.2	32.3	2.55	
7		45	40	29.3	37.5	33.7	4.90	
8	0.143	50	42	29.2	38	33.9	5.26	4.48
9		55	45.9	29.4	34.9	32.5	3.29	

Table 2 shows the heat transfer rate in a heat exchanger system for three distinct cold water mass flow rates: 0.0625, 0.1, and 0.143 kg/s, with hot water intake temperatures of 45°C, 50°C, and 55°C. For each mass flow rate, the table records the intake and outflow temperatures of hot and cold water and the cold water's midway temperature and computed heat transfer rates. More superior cold water flow rates result in higher heat transfer rates, with average values of 2.10 kW, 3.15 kW, and 3.49 kW for 0.0625, 0.1, and 0.143 kg/s, respectively, indicating that flow rate affects thermal performance.

Table 2 Experimental data for Counterflow condition for various mass flow rates for 25% baffle cut:

Serial number	Cold water mass flow rate (kg/s)	Hot water inlet (°C)	Hot water outlet (°C)	Cold water inlet (°C)	Cold water outlet (°C)	Cold Water Midpoint temp (°C)	Heat transfer rate Q (KW)	Heat transfer rate mean (KW)
1		45	40.4	28.4	34.6	31.8	1.61	
2	0.0625	50	43.7	28.6	36.6	33.4	2.09	2.10
3		55	47.1	28.8	38.6	34.3	2.59	
4		45	40.3	28.6	34.3	32.9	2.38	
5	0.1	50	43.8	28.5	36.4	33.8	3.30	3.15
6		55	47.2	28.7	37.7	34.5	3.76	
7		45	39.9	28	32.9	32.6	2.93	
8	0.143	50	43.2	28.1	34.2	33.6	3.65	3.49
9		55	46.3	28.2	34.7	34.5	3.89	

Table 3 shows the heat transfer rate in a heat exchanger system at three distinct cold water mass flow rates: 0.0625, 0.1, and 0.143 kg/s, with hot water intake temperatures of 45°C, 50°C, and 55°C, respectively. For each mass flow rate, the table shows the input and exit temperatures of hot and cold water and the cold water's midway temperature and computed heat transfer rates. More superior cold water flow rates result in higher heat transfer rates, with average values of 1.82 kW, 2.17 kW, and 2.69 kW for 0.0625, 0.1, and 0.143 kg/s, respectively, implying that flow rate impacts thermal performance.

Table 3 Experimental data for Counterflow condition for various mass flow rates for 35% baffle cut:

Serial number	Cold water mass flow rate (kg/s)	Hot water inlet (°C)	Hot water outlet (°C)	Cold water inlet (°C)	Coldwater outlet (°C)	Cold Water Midpoint temp (°C)	Heat transfer rate Q (KW)	Heat transfer rate mean (KW)
1		45	41.3	28.9	34.1	31.5	1.36	
2	0.0625	50	45	28.6	35.5	33.1	1.80	1.82
3		55	48.1	28.8	37.6	33.7	2.30	
4		45	39.8	28.2	30.4	31.2	1.32	
5	0.1	50	42.9	28.1	31.9	31.7	2.27	2.17
6		55	45.9	28.2	33.1	32.3	2.93	
7		45	41.2	28.6	33.2	32.5	1.92	
8	0.143	50	44.7	28.5	35.3	33.5	2.84	2.69
9		55	48.1	28.7	36.6	34.1	3.30	

3.2 Parallel flow condition

In a Parallel-flow heat exchanger, the hot and cold fluids flow in the same direction, with tube side temperatures decreasing from 50°C to 45°C and shell side temperatures increasing from 28.6°C to 35.5°C, as illustrated in the theoretical temperature profile shown in Figure 8 below.

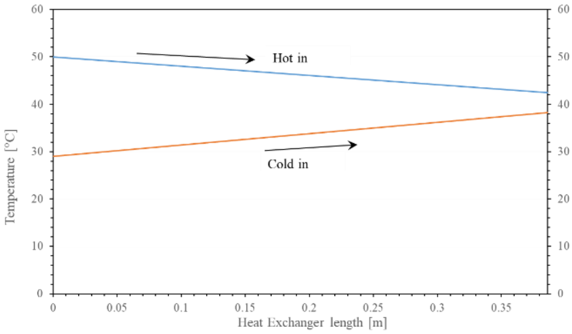


Fig.8. Experimental temperature variation along heat exchanger length.

Table 4 Experimental data for parallel flow conditions for various mass flow rates for 15% baffle cut.

Serial number	Cold water mass flow rate (kg/s)	Hot water inlet (°C)	Hot water outlet (°C)	Cold water inlet (°C)	Cold water outlet (°C)	Cold Water Mid Point temp.(°C)	Heat transfer rate Q (KW)	Heat transfer rate mean (KW)
1		45	40.4	29.3	37.5	33.2	1.14	
2	0.0625	50	42.5	29	38.2	33.5	1.04	1.04
3		55	46.1	29.1	35	32	0.94	
4		45	40.2	29.3	37.5	33	1.58	
5	0.1	50	42.2	29.4	38.4	33.7	1.53	1.53
6		55	46	29.1	35.2	32.3	1.48	
7		45	40	29.3	37.5	33.7	2.29	
8	0.143	50	42	29.2	38	33.9	2.21	2.21
9		55	45.9	29.4	34.9	32.5	2.13	

Table 5 shows the heat transfer rate in a heat exchanger system for three distinct cold water mass flow rates: 0.0625, 0.1, and 0.143 kg/s, with hot water intake temperatures of 45°C, 50°C, and 55°C. For each mass flow rate, the table records the intake and outflow temperatures of hot and cold water and the cold water's midway temperature and computed heat transfer rates. More superior cold water flow rates result in higher heat transfer rates, with average values of 1.36 kW, 2.52 kW, and 2.85 kW for 0.0625, 0.1, and 0.143 kg/s, respectively, indicating that flow rate affects thermal performance.

Table 5 Experimental data for Parallelflow condition for various mass flow rates for 25% baffle cut:

Serial number	Cold water mass flow rate (kg/s)	Hot water inlet (°C)	Hot water outlet (°C)	Cold water inlet (°C)	Coldwater outlet (°C)	Cold Water Midpoint temp (°C)	Heat transfer rate Q (KW)	Heat transfer mean (KW)
1		45	40.6	30.4	33.9	33.1	0.91	
2	0.0625	50	43.4	30.2	35.4	34	1.36	1.36
3		55	46.5	30.1	37	35.1	1.80	
4		45	40.2	29.2	33.7	32.4	1.88	
5	0.1	50	43.6	29.6	35.6	34	2.51	2.52
6		55	46.6	29.3	36.9	34.7	3.18	
7		45	39	28.2	31.3	31.5	1.85	
8	0.143	50	42.2	28.1	33.2	32	3.05	2.85
9		55	45.2	28.2	34.3	32.7	3.65	

Table 6 presents the heat transfer rate in a heat exchanger system at three different cold water mass flow rates: 0.0625, 0.1, and 0.143 kg/s, with hot water inlet temperatures of 45°C, 50°C, and 55°C. For each mass flow rate, the table records hot water and cold-water inlet and outlet temperatures, midpoint temperatures of the cold water, and calculated heat transfer rates. The heat transfer rate rises with greater cold water flow rates, with average values of 1.124 kW, 2.10 kW, and 2.98 kW for 0.0625, 0.1, and 0.143 kg/s, respectively, suggesting that flow rate influences thermal performance.

Table 6 Experimental data for Parallel flow condition for various mass flow rates for 35% baffle cut:

Serial number	Cold water mass flow rate (kg/s)	Hot water inlet (°C)	Hot water outlet (°C)	Cold water inlet (°C)	Coldwater outlet (°C)	Cold Water Midpoint temp (°C)	Heat transfer rate Q (KW)	Heat transfer rate mean (KW)
1		45	41.4	30.3	32.8	32.8	0.653	
2	0.0625	50	44.3	30.2	34.9	33.6	1.23	1.124
3		55	47.6	30.3	36.1	34.7	1.52	
4		45	41.3	29.1	32.6	32.1	1.46	
5	0.1	50	44.4	29.7	34.7	33.6	2.09	2.10
6		55	47.7	29.3	35.9	34.2	2.76	
7		45	40.8	28.1	32.2	32.1	2.45	
8	0.143	50	44.3	28.2	33.4	33.2	3.11	2.98
9		55	47.2	28.3	34	34.1	3.41	

3.3 Variation of heat transfer with mass flux at counter flow condition

As the mass flux rises in Figure 12, so does the heat transfer rate. The heat transfer rate is also 2.1 kW at a flow rate of 0.0625 kg/s, 3.15 kW at a flow rate of 0.1 kg/s, and 3.49 kW at a flow rate of 0.143 kg/s, as shown in Figure 9.

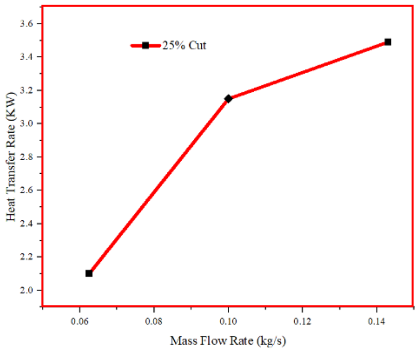


Fig.9. Variation of heat transfer with mass flux at counter flow condition for 25% baffle cut

As the flow rate rises in Table 7, so does the heat transfer rate. Furthermore, when the mass flow is 0.0625 kg/s, the heat transfer rate is 2.03 kW; when the flow rate is 0.1 kg/s, it is 3.25 kW; and when the mass flux is 0.143 kg/s, it is 4.48 kW.

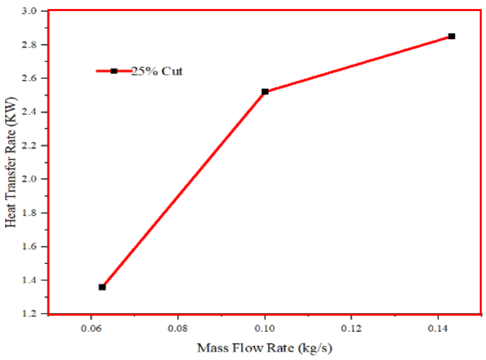
Table 7: Variation of mass transfer rate at counter flow condition

For 15% Cut		For 25% Cut		For 35% Cut	
Mass Flow Rate	Heat Transfer Rate	Mass Flow Rate	Heat Transfer Rate	Mass Flow Rate	Heat Transfer Rate
0.0625 kg/s	2.03 kW	0.0625 kg/s	2.1 kW	0.0625 kg/s	1.82 kW
0.1 kg/s	3.25 kW	0.1 kg/s	3.15 kW	0.1 kg/s	2.87 kW
0.143 kg/s	4.48 kW	0.143 kg/s	3.49 kW	0.143 kg/s	3.17

In Table 7, the heat transfer rate increases with the mass flow rate. According to Table 3, the heat transfer rate is also 1.82 kW at a flow rateof 0.0625 kg/s, 2.87 kW 0.1 kg/s as the flow rateand 3.17 kW at a flow rateof 0.143 kg/s.

3.4 Variation of heat transfer with mass flux for the parallel flow condition

In Figure 10, as the mass flux rises, so does the heat transfer rate.



3.5 **Fig.10.** Variation of heat transfer with flow rate for the parallel flow condition for 25% baffle cut

Furthermore, Figure 10 shows that the heat transfer rate is 1.36 kW at a mass flux of 0.0625 kg/s, 2.52 kW 0.1 kg/s as the mass flow rate, and 2.85 kW at a flow rate of 0.143 kg/s.

Table 8 shows that the heat transfer rate increases as the mass flux rises. Furthermore, the heat transfer rate is 1.04 kW at a flow rate of 0.0625 kg/s, 1.53 kW at a flow rate of 0.1 kg/s, and 2.21 kW at a flow rate of 0.143 kg/s.

Table 8: Variation of flow rateat parallel flow condition

For 15% Cut		For 25% Cut		For 35% Cut	
Mass Flow Rate	Heat Transfer Rate	Mass Flow Rate	Heat Transfer Rate	Mass Flow Rate	Heat Transfer Rate
0.0625 kg/s	1.04 kW	0.0625 kg/s	1.36 kW	0.0625 kg/s	1.124 kW
0.1 kg/s	1.53 kW	0.1 kg/s	2.52 kW	0.1 kg/s	2.1 kW
0.143 kg/s	2.21 kW.	0.143 kg/s	2.85 kW	0.143 kg/s	2.98 kW

Table 8 shows that the heat transfer rate increases as the flow raterises. Furthermore, the heat transfer rate is 1.124 kW at a mass flow of 0.0625 kg/s, 2.1 kW at a flow rate of 0.1 kg/s, and 2.98 kW at a flow rate of 0.143 kg/s.

4. Comparison of heat transfer for different baffle cut

Figures 11 and 12 compare heat transfer performance between counter-flow and parallel-flow configurations, illustrating the differences in efficiency between the two setups.

Figure 11 shows that the heat transfer performance of a shell-and-tube heat exchanger in counterflow conditions, demonstrating its improved thermal exchange efficiency due to the constant temperature gradient. The figure compares heat transfer rates against different mass flow rates, highlighting the impact of baffle design for different baffle cut percentages of 15%, 25%, and 35%.

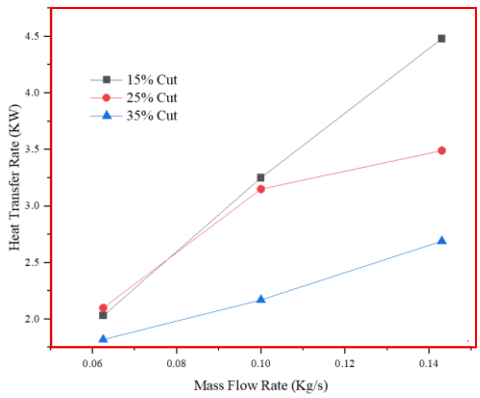


Fig.11. Comparison of heat transfer for counter flow

Figure 12 shows the heat transfer efficiency of a shell-and-tube heat exchanger operating in parallel flow due to decreasing temperature differences for different baffle cut percentages of 15%, 25%, and 35%. The figure compares heat transfer rates against mass flow rates, allowing comparison of baffle design's impact on thermal performance under parallel flow conditions.

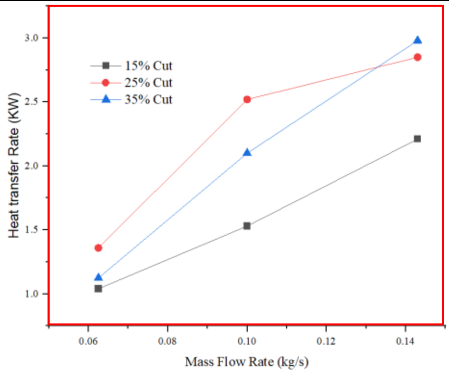


Fig.12. Comparison of heat transfer for parallel flow.

5. Conclusion

In this study, a shell-and-tube heat exchanger with one shell and one tube pass is designed and fabricated. The heat exchanger's performance is evaluated under different flow conditions. From the research the following conclusions can be drawn:

I. Considering pressure drop and heat transfer, a 25% baffle cut is the most suitable in this experiment.

II. The most significant heat transfer rate for a mass flow of 0.143 kg/s is 4.48 kW under counterflow conditions with a 15% baffle cut.

III. According to the experimental results, the parallel flow condition with a 35% baffle cut obtained a heat transfer rate of 2.98 kW, indicating its usefulness in moderate flow conditions.

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NOMENCLATURE

m	Mass flow rate of fluid (kg/s)
C_p	Specific heat of fluid (J/kg-K)
T	Temperature of fluid as used in designing (℃)
T	Experimental value of the temperature of the fluid (℃)
LMTD (or ΔT)	Logarithmic Mean Temperature Difference (℃)
q	Amount of heat transfer taking place (W)
U	Overall heat transfer coefficient (W/℃)
A	Area of heat exchanger (m^2)
d_i	Inner diameter (m)
d_o	Outer diameter (m)
L	Length of heat exchanger (m)
N_t	Number of tubes
B	Baffle spacing (m)
Pr	Prandtl number
Re	Reynold number
Nu	Nusselt number
h	Heat transfer coefficient (W/m^2K)
K	Conductivity of fluid and copper

Subscripts:

i	Inner surface parameter
o	Outer surface parameter
t	Tube side parameter
s	Shell side parameter
h	Hot fluid parameter
c	Cold fluid parameter
b	Tube bundle
s	Shell

k_1, n_1 are constants depending on the pitch and type of pass