

Effect of baffle cut and baffle spacing on pressure drop in shell and tube heat exchanger with U tubes

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Abstract. A general procedure for heat exchanger design has been presented in the Heat Exchanger Design Handbook (HEDH) [1], but no precise criterion for determining baffle cut nor baffle spacing has been offered, and the emphasis is only on heat exchanger's permissible range of application. In this paper, an optimization program has been used to calculate pressure drop, fluid velocity, heat power, overall heat transfer coefficient and middle temperature difference for various baffle cut and baffle spacing for the same type of heat exchanger, using the procedure in HEDH. This could be considered as complementary to the HEDH recommendations and can be used by designers and, generally, engineers for determining the right baffle cut and baffle spacing for their specific cases.

Keywords. baffle cut, baffle spacing, pressure drop, shell and tube heat exchanger

1. Introduction

According to Tubular Exchanger Manufacturing Association (TEMA) [2], three principal types of shell-and-tube heat exchangers (STHE) are: fixed tube-sheet exchangers, U-tube exchangers and floating head exchangers.

Shell types are one pass shell, two pass shell with longitudinal baffle, split flow, double split flow, divided split flow, kettle type reboiler and cross flow, with the following marks respectively, E, F, G, H, J, K and X. Baffles can be transverse or longitudinal. Transverse baffles can be plate and rod. Plate baffles can be segmental (single, double, triple), disk and doughnut, and orifice baffles. Front head can be channel and removable cover, bonnet, channel integral with removable bundle, channel integral without removable bundle and special high pressure closure, with the following marks respectively, A, B, C, N, D. Rear types are fixed tubesheet like A stationary head, fixed tubesheet like B stationary head, fixed

tubesheet like N stationary head, outside packed floating head, floating head with backing device, pull through floating head, U tube bundle and externally sealed floating head, with the following marks respectively, L, M, N, P, S, T, U and W.

In this paper the following combinations has been analyzed, U-tube type, shell type E, segmental single baffle type, front head type B, rear head type U. The analyzed STHE are shown in Figure 1 [3].

The baffles are primarily used in STHE for supporting the tubes, to maintain the tubes distance and for inducing cross flow over the tubes, resulting in improved heat transfer performance. In practice this objective is not quite achieved due to departure from cross flow, and due to several leakages and bypass stream through clearance required for the construction of the exchanger. The aim of the heat exchanger optimization is to minimize the costs of investing and operating the exchanger. One feature of shell and tube heat exchanger optimization is to select the optimum inter-baffle spacing and the baffle cut. Taborek [4] suggested that the space between the baffles could vary between a minimum of 20% of inner shell diameter and a maximum equal to the inner shell diameter. Recommendation for baffle cut could vary between a minimum of 15% of inner shell diameter and a maximum of 45% of inner shell diameter. As mentioned before, range of application for baffle space and baffle cut is quite wide.

In this paper, values of pressure drop, fluid velocity, heat power, overall heat transfer coefficient and middle temperature difference versus baffle spacing and baffle cut are given as a part of the guideline by which the optimal design is made. The aim of this paper is baffle optimization, hence pressure drop and fluid velocity has been analyzed only for shell side.

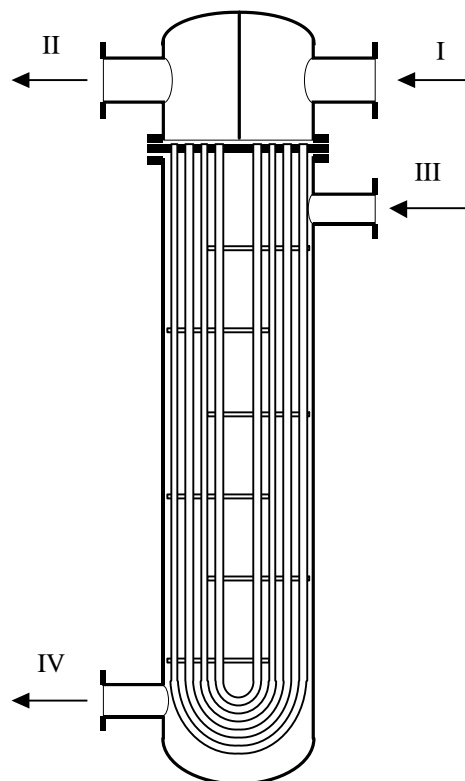


Figure 1. STHE with U tubes, I - inlet of cold fluid, II - outlet of cold fluid, III - inlet of hot fluid, IV - outlet of hot fluid

2. Analysis & Simulation

The dimensions of the STHE are: nominal diameter DN500mm, with 150 “U” tubes, outer diameter 18mm and width 2mm, length 1300mm and triangular pattern with pitch 22.5mm.

Every components are made of the same material stainless steel AISI SS304. Fluid for both side (tube and shell) is water with the fouling resistance 0.00035W/m²K. Mass flow is 10000kg/h for the shell side, while for the tube side is 20000kg/h. Nominal temperature regimes are 107/56°C and 17/43°C for the shell and the tube side, respectively. Surface for heat transfer is 21.3m². Position of STHE is vertical.

Basic equations for pressure drop from the shell side for turbulent fluid flow of STHE are represented [4], [5], [6]

$$\Delta p_{tot} = \Delta p_c + \Delta p_w + \Delta p_e \quad (1)$$

$$\Delta p_c = \Delta p_{bi} \cdot (N_b - 1) \cdot R_l \cdot R_b \quad (2)$$

$$\Delta p_w = N_b \cdot \left[(2 + 0.6 \cdot N_{tcw}) \cdot m_w^2 / 2 \cdot \rho_s \cdot 10^{-3} \right] R_l \quad (3)$$

$$\Delta p_e = \Delta p_{bi} \cdot (1 + N_{tcw} / N_{tcc}) \cdot R_b \cdot R_s \quad (4)$$

where:

- Δp_{tot} is the total pressure drop from the shell side of the STHE, including nozzles (kPa),
- Δp_{bi} is the pressure drop in an equivalent ideal tube bank for the cross-flow sections (kPa),
- Δp_{wi} is the pressure drop in an equivalent ideal tube bank for the baffle window sections (kPa),
- Δp_c is the combined pressure drop for all the interior cross-flow sections (kPa),
- Δp_w is the combined pressure drop for all the window sections (kPa),
- Δp_e is the combined pressure drop for all the entrance and exit sections (kPa),
- N_b is number of baffles,
- N_c is number of tube rows crossed in the exchanger,
- N_{tcw} is number of tube rows crossed includes the tube rows in the entry or exit window,
- N_{tcc} is number of tube rows crossed between baffle tips of one baffle compartment,
- R_l is the correction factor for baffle leakage effect (A and E streams from [1]),
- R_b is the correction factor for bypass flow (B and C streams from [1]),
- R_s is the correction factor for entrance and exit sections,

- m_w is the shell side flow mass velocity through segmental baffle window, (kg/sm^2),
- ρ_s is the shell side fluid density, (kg/m^3).

The following values for baffle cut have been investigated: 16%, 21%, 28%, 34%, 39% and 45%. Only these cuts were possible due to pitch and tubes diameter. For baffle spacing there were not any limitations, but only the following values have been investigated: 75mm, 100mm, 150mm, 200mm, 250mm, 300mm, 350mm, 400mm, 450mm and 500mm. These values are with recommendations of Taborek [4]. With 6 baffle cut and 10 baffle spacing, matrix of 60 combinations are formed. Values of pressure drop and fluid velocity from shell side heat power, overall heat transfer coefficient and middle temperature difference are shown in next chapter.

3. Results

As were expected, all parameters that have been analysed in this paper i.e. pressure drop, fluid velocity, heat power and overall heat transfer coefficient are indirectly proportional to baffle cut and baffle spacing except middle temperature difference.

In the phase of designing STHE, we want smaller values of pressure drop, and, at the other side, we want bigger values of fluid velocity, heat power, overall heat transfer coefficient and middle temperature difference. Designers of STHE are always balancing between these two criterions.

Values of pressure drop, fluid velocity, heat power, overall heat transfer coefficient and middle temperature difference versus to baffle cut and baffle spacing are shown graphically in Table 1, Table 2, Table 3, Table 4 and Table 5, respectively.

Table 1. Total pressure drop (Δp_{tot}) from shell side versus baffle cut and baffle spacing, units kPa.

Baffle cut	16%	21%	28%	34%	39%	45%
Baffle spacing						
75mm	1.559	1.531	1.512	1.511	1.514	1.522
100mm	1.131	1.111	1.092	1.086	1.083	0.778
150mm	0.833	0.815	0.8	0.79	0.785	0.788
200mm	0.794	0.781	0.764	0.588	0.75	0.743
250mm	0.727	0.714	0.699	0.692	0.688	0.68
300mm	0.655	0.632	0.623	0.618	0.615	0.609
350mm	0.737	0.67	0.657	0.651	0.647	0.614
400mm	0.89	0.785	0.726	0.716	0.711	0.701
450mm	0.657	0.616	0.58	0.576	0.574	0.57
500mm	0.706	0.652	0.593	0.588	0.586	0.581

Table 2. Fluid velocity (w) from shell side versus baffle cut and baffle spacing, units m/s.

Baffle cut	16%	21%	28%	34%	39%	45%
Baffle spacing						
75mm	0.13	0.12	0.12	1.511	0.11	0.1
100mm	0.11	0.11	0.1	1.086	0.09	0.07
150mm	0.08	0.08	0.08	0.79	0.08	0.07
200mm	0.07	0.07	0.07	0.588	0.07	0.06
250mm	0.06	0.06	0.06	0.692	0.06	0.06
300mm	0.06	0.06	0.06	0.618	0.05	0.05
350mm	0.05	0.05	0.05	0.651	0.05	0.05
400mm	0.05	0.05	0.05	0.716	0.05	0.05

450mm	0.04	0.04	0.04	0.576	0.04	0.04
500mm	0.04	0.04	0.04	0.588	0.04	0.04

Table 3. Heat power (Q) versus baffle cut and baffle spacing, units kW.

Baffle cut	16%	21%	28%	34%	39%	45%
Baffle spacing						
75mm	607.3	606.5	605	602.7	601.2	596.9
100mm	603.5	603.1	601.5	599.6	598.1	590.4
150mm	597.3	597.3	596.2	594.6	593.5	590.4
200mm	596.5	596.5	595.8	595	593.8	591.2
250mm	591.5	591.9	591.9	591.2	590.4	588.1
300mm	584.2	585	585.4	584.6	584.2	581.9
350mm	585.8	586.5	587.3	586.9	586.5	584.6
400mm	585	586.2	587.3	587.3	586.5	585
450mm	575.8	577.3	578.9	578.9	578.5	577.3
500mm	578.1	579.6	581.2	581.5	581.2	580.4

Table 4. Overall heat transfer coefficient (U) versus baffle cut and baffle spacing, units W/m^2K .

Baffle cut	16%	21%	28%	34%	39%	45%
Baffle spacing						
75mm	637.9	636.1	632.3	626.8	623.2	613.3
100mm	628.7	627.7	624.1	619.6	616	598.5
150mm	614.2	614.2	611.5	608	605.4	598.5
200mm	612.4	612.4	610.7	608.9	606.3	600.2
250mm	601.1	601.9	601.9	600.2	598.5	593.4
300mm	585	586.6	587.5	585.8	585	580
350mm	588.3	590	591.7	590.8	590	585.8
400mm	586.6	589.1	591.7	591.7	590	586.6
450mm	567	570.2	573.5	573.5	572.6	570.2
500mm	571.8	575.1	578.4	579.2	578.4	576.7

Table 5. Middle temperature difference (MDT) versus baffle cut and baffle spacing, units $^{\circ}C$.

Baffle cut	16%	21%	28%	34%	39%	45%
Baffle spacing						
75mm	44.64	44.71	44.86	45.08	45.23	45.64
100mm	45.01	45.05	45.19	45.38	45.53	46.25
150mm	45.6	45.6	45.71	45.86	45.96	46.25
200mm	45.67	45.67	45.75	45.82	45.93	46.18
250mm	46.15	46.11	46.11	46.18	46.25	46.47
300mm	46.83	46.76	46.72	46.8	46.83	47.05
350mm	46.69	46.62	46.54	46.58	46.62	46.8
400mm	46.76	46.65	46.54	46.54	46.62	46.76
450mm	47.61	47.47	47.33	47.33	47.37	47.47
500mm	47.4	47.26	47.12	47.08	47.12	47.19

4. Conclusion

The aim of this paper is to give narrow range for recommendations from Taborek [4] for baffle cut and baffle spacing.

Simulation has been made for the shell and tube heat exchanger with above mentioned parameters. Exact values for pressure drop are given in Table 1. The one can see influence of baffle cut and baffle spacing to pressure drop and use the results when deal with design stage of shell and tube heat exchanger.

According to results, authors can recommend that the space between the baffles could vary between a minimum of 30% of inner shell diameter, or 150mm, and a maximum of 60% of inner shell diameter, or 300mm. Baffle cut does not have a significant influence to pressure drop in this study.

The group of authors recommend to use results from this paper only for the same or very similar conditions.

For other works for optimum baffle dimensions of STHE authors can recommend papers from M. Saffar – Avval and E. Damangir [7], Huadong Li, Volker Kottke [8], Dogan Eryener [9] and B. Khalifeh Soltan, M. Saffar-Avval, E. Damangir [10].

The work with effects of baffle inclination angle at STHE performance authors can recommend paper from Rajagopal T. K. Raj and Srikanth Ganne [11].

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Nomenclature

- Q heat power (kW),
- U overall heat transfer coefficient (kPa),
- w shell side fluid velocity (m/s),
- MDT middle temperature difference ($^{\circ}C$),
- Δp_{tot} total pressure drop from the shell side of the STHE, including nozzles (kPa),
- Δp_{bi} pressure drop in an equivalent ideal tube bank for the cross-flow sections (kPa),
- Δp_{wi} pressure drop in an equivalent ideal tube bank for the baffle window sections (kPa),
- Δp_c combined pressure drop for all the interior cross-flow sections (kPa),
- Δp_w combined pressure drop for all the window sections (kPa),
- Δp_e combined pressure drop for all the entrance and exit sections (kPa),
- N_b number of baffles,
- N_c number of tube rows crossed in the exchanger,
- N_{icw} number of tube rows crossed includes the tube rows in the entry or exit window,
- N_{icc} number of tube rows crossed between baffle tips of one baffle compartment,
- R_l correction factor for baffle leakage effect (A and E streams from [1]),
- R_b correction factor for bypass flow (B and C streams from [1]),
- R_s correction factor for entrance and exit sections,
- m_w shell side flow mass velocity through segmental baffle window, (kg/sm²),
- ρ_s shell side fluid density, (kg/m³).

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