A COMPARATIVE ANALYSIS METHODOLOGY OF CALCULATION OF STRENGTH TUBESHEETS BY EUROPEAN STANDARDS AND GUIDELINES FOR UDT

ANETA CELAREK, JAN TALAGA

Abstract

This paper presents comparison of calculation methods of the required thickness of the tube sheet in the shell and tube heat exchanger compatible with the standards of the European standard PN - EN 13445-3, and the guidelines of the Polish Office of Technical Inspection (UDT). Details of the methods are illustrated by numerical examples – (calculations) for the selected design of the tubesheet.

Keywords: heat exchangers, tubes, tubesheets

Streszczenie

W artykule przedstawiono porównanie metod obliczeniowych wymaganej grubości ściany sitowej w płaszczowo-rurkowym wymienniku ciepła zgodnych ze standardami normy europejskiej PN-EN 13445-3 i wytycznymi polskiego Urzędu Dozoru Technicznego. Szczegóły metod zilustrowano przykładami liczbowymi dla wybranych konstrukcji dna sitowego.

Słowa kluczowe: wymienniki ciepła, rurki, dna sitowe

DOI:

1. Introduction

The European standard PN-EN 13445-3 shows three primary distinctions in terms of shell and tube heat exchangers. In addition to the above standard PN-EN 13445-3 is Index 1, wherein it shows another design solution of a tubesheet. The analysis of strength calculations for the same configurations of tubesheet differs from those described in the Polish guidelines WUDT-UC. Polish guidelines WUDT-UC are treated as mandatory during the design of pressure equipment.

In the norm PN-EN 13445-3: 2002, rules for different types of heat exchangers were shown. According to the norm:

- U-tube heat exchanger (Figure 1);
- Fixed tubeshet heat exchanger (Figure 2);
- Floating head heat exchanger (Figure 3).

Floating head heat exchanger has three different configurations:

a) with an immersed floating head;

b) with an externally sealed floating head;

c) with an internally sealed floating tubesheet [3].

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**Table 1**

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>U-tube tubeshet heat exchanger</th>
<th>Fixed tubeshet heat exchanger</th>
<th>Floating head heat exchanger</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amount and shape tubeshet</td>
<td>One – flat, circular, uniform thickness</td>
<td>Two – flat, circular and identical (same materials, same connection with shell and channel)</td>
<td>Two – flat, circular, and identical connected by a bundle of straight tubes</td>
</tr>
<tr>
<td>Type of tubeshet (moving)</td>
<td>Stationary</td>
<td>Stationary</td>
<td>Stationary attached to the shell and channel Floating</td>
</tr>
<tr>
<td>Amount using configurations</td>
<td>6 (see Fig. 4)</td>
<td>6 (see Fig. 4)</td>
<td>6 stationary (Fig. 4) +3 floating (Fig. 5)</td>
</tr>
<tr>
<td>Loading conditions</td>
<td>3 cases</td>
<td>7 cases</td>
<td>3 cases</td>
</tr>
<tr>
<td>Tubeshet thickness</td>
<td>[ e = \frac{D_n}{4\mu(0.8f)} \left</td>
<td>P_r - P_f \right</td>
<td>]</td>
</tr>
</tbody>
</table>
Tab. 1 shows a comparison of the information and characteristics among the types of heat exchangers which are shown in European standards. Tab. 1 also groups the equation on how to calculate the tubesheet thickness and which pressure we have to use in each heat exchanger.

This article shows one of this type – U-tube heat exchanger and different uses of the configurations of tubesheets. According the norm PN-EN 13445-3, the tubesheet may have one of the six configurations (design solutions) shown in Fig 4.

![Fig. 4. Various types of configuration tubesheets [3]](image)

Configuration d covers the cases where the tubesheet is: extended as (d₁ as flange or not d₂)

In the floating tubesheet heat exchangers the floating tubesheet may have one of the 3 configurations shown in Fig 5.

- tubesheet integral (Fig. 5a).
- tubesheet gasketed, extended as a flange (Fig. 5b),
- tubesheet gasketed, not extended as a flange (Fig 5c).

![Fig. 5. Various types of configuration floating tubesheets [3]](image)

For each of these type configuration of tubesheet a different method of calculation is used. All of the methods were shown in European standards PE-EN 13445-3.

2. Examples of calculations for U-tube heat exchangers

Below is a numerical example (examples of calculations) of the method of strength calculations for tubesheet contained in European standards PN-EN 13445-3. The calculations were carried out for the tubesheet of configuration b shown in Fig. 6. Tab. 2
presents the type of material and properties which were selected in calculations. The assumed values of tubesheet were shown in Tab. 3 [7, 3].

Table 2

<table>
<thead>
<tr>
<th>Tubesheet - material</th>
<th>$R_m$ [MPa]</th>
<th>$R_p$ [MPa]</th>
<th>$R_{pt}$ [MPa]</th>
<th>$f$ [MPa]</th>
<th>$f_{20}$ [MPa]</th>
<th>$f_{out}$ [MPa]</th>
<th>$E$ [MPa]</th>
</tr>
</thead>
<tbody>
<tr>
<td>P280GH (1.0426)</td>
<td>460</td>
<td>280</td>
<td>225</td>
<td>150</td>
<td>186.67</td>
<td>266.67</td>
<td>198610</td>
</tr>
</tbody>
</table>

Table 3

<table>
<thead>
<tr>
<th>Input date of tubesheet</th>
<th>Value</th>
<th>Units</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$e_n$</td>
<td>100</td>
<td>mm</td>
<td>Nominal thickness of tubesheet (assume)</td>
</tr>
<tr>
<td>$c_t$</td>
<td>3</td>
<td>mm</td>
<td>Tubesheet corrosion allowance on the tube-side</td>
</tr>
<tr>
<td>$c_s$</td>
<td>3</td>
<td>mm</td>
<td>Tubesheet corrosion allowance on the shell-side</td>
</tr>
<tr>
<td>$p$</td>
<td>34</td>
<td>mm</td>
<td>Tube pitch</td>
</tr>
<tr>
<td>$d_t$</td>
<td>25</td>
<td>mm</td>
<td>Nominal outside diameter of tubes</td>
</tr>
<tr>
<td>$l_{tx}$</td>
<td>80</td>
<td>mm</td>
<td>Expanded length of tube in tubesheet</td>
</tr>
<tr>
<td>$e_a$</td>
<td>94</td>
<td>mm</td>
<td>Analysis thickness</td>
</tr>
<tr>
<td>$e_t$</td>
<td>2.3</td>
<td>mm</td>
<td>Nominal tube wall thickness</td>
</tr>
<tr>
<td>$E_t$</td>
<td>$1.9861 \cdot 10^5$ MPa</td>
<td></td>
<td>Elastic modulus of tube material at design temperature</td>
</tr>
<tr>
<td>$E$</td>
<td>198610</td>
<td>MPa</td>
<td>Elastic modulus of tubesheet material at design temperature</td>
</tr>
<tr>
<td>$f_t$</td>
<td>111.33</td>
<td>MPa</td>
<td>Nominal design stress of tube material at design temperature</td>
</tr>
<tr>
<td>$f$</td>
<td>150</td>
<td>MPa</td>
<td>Nominal design stress of tubesheet material at design temperature</td>
</tr>
<tr>
<td>$S$</td>
<td>178000</td>
<td>mm²</td>
<td>Total unperforated area of tubesheet</td>
</tr>
<tr>
<td>$D_{sh}$</td>
<td>1163.4</td>
<td>mm</td>
<td>Equivalent diameter of outer tube limit circle</td>
</tr>
<tr>
<td>$G_t$</td>
<td>1255</td>
<td>mm</td>
<td>Diameter of shell gasket load reaction</td>
</tr>
<tr>
<td>$G_c$</td>
<td>1255</td>
<td>mm</td>
<td>Diameter of channel gasket load reaction</td>
</tr>
<tr>
<td>$W_s$</td>
<td>181026</td>
<td>kN</td>
<td>Shell flange design bolt load for the assembly condition</td>
</tr>
<tr>
<td>$W_c$</td>
<td>1097.94</td>
<td>kN</td>
<td>Channel flange design bolt load for the assembly condition</td>
</tr>
</tbody>
</table>

Fig. 6. Tubesheet design for b configuration [3]

The results of calculations on the thickness of the tubesheet are shown in Tab. 4. At this state of calculations, there are no differences in the method of calculation. Despite the following example of the various assumed operating pressures of the tubesheet, the calculation is carried out in the same way [3].
The method of calculations concerning size of tubesheet

<table>
<thead>
<tr>
<th>Equation</th>
<th>Results/ value</th>
<th>Units</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>( e_s = e_n - c_n - c_i )</td>
<td>94 mm</td>
<td></td>
<td>Analyses thickness tubesheet (initial)</td>
</tr>
<tr>
<td>( \mu = \frac{p^* - d'}{p^*} )</td>
<td>0.2647</td>
<td></td>
<td>The basic ligament efficiency for shear</td>
</tr>
<tr>
<td>( \rho = \frac{l_{cs}}{e} )</td>
<td>0.8511</td>
<td></td>
<td>The tube expansion depth ratio ((0 \leq \rho \leq 1))</td>
</tr>
<tr>
<td>( d^* = \max \left[ \frac{d - 2 \cdot e_s \cdot \left( \frac{E_i}{E} \right) \left( \frac{f}{f_s} \right) \rho^*}{d - 2 \cdot e_s} \right] )</td>
<td>22.09 mm</td>
<td></td>
<td>The effective tube hole diameter</td>
</tr>
<tr>
<td>( p^* = \frac{p}{\sqrt{1 - 4 \cdot \min \left[ \frac{1}{S} \cdot (4 \cdot D_s \cdot p) \right] \pi \cdot D_s^2}} )</td>
<td>36.85 mm</td>
<td></td>
<td>The effective tube pitch</td>
</tr>
<tr>
<td>( \mu' = \frac{p^* - d'}{p^*} )</td>
<td>0.4005</td>
<td></td>
<td>The effective ligament efficiency of perforated tubesheet for bending</td>
</tr>
<tr>
<td>( \frac{E'}{E} = \alpha_1 + \alpha_2 \cdot \mu' + \alpha_3 \cdot \mu'^2 + \alpha_4 \cdot \mu'^3 + \alpha_5 \cdot \mu'^4 )</td>
<td>0.414</td>
<td></td>
<td>Determination of the graph</td>
</tr>
<tr>
<td>( E' = E \cdot 0.414 )</td>
<td>82227.64 MPa</td>
<td></td>
<td>The effective elastic modulus of the tubesheet at design temperature</td>
</tr>
<tr>
<td>( S^* = \beta_1 + \beta_2 \cdot \mu' + \beta_3 \cdot \mu'^2 + \beta_4 \cdot \mu'^3 )</td>
<td>0.3106</td>
<td></td>
<td>The effective Poisson’s ratio of tubesheet (Determination of the graph)</td>
</tr>
<tr>
<td>( D^* = \frac{E' \cdot e^{w}}{12 \cdot (1 - \delta^* \cdot \mu')} )</td>
<td>6.2993 \times 10^9 Nmm</td>
<td></td>
<td>The equivalent bending rigidity of tubesheet</td>
</tr>
<tr>
<td>( \rho_s = \frac{G_s}{D_s} )</td>
<td>1.0787</td>
<td></td>
<td>The shell diameter ratio</td>
</tr>
<tr>
<td>( \rho_c = \frac{G_c}{D_c} )</td>
<td>1.0787</td>
<td></td>
<td>The channel diameter ratio</td>
</tr>
<tr>
<td>( K = \frac{A}{D_s} )</td>
<td>1.1174</td>
<td></td>
<td>The tubesheet diameter ratio</td>
</tr>
<tr>
<td>( F = \frac{1 - \delta^*}{E} \left( E \cdot \ln K \right) )</td>
<td>0.1848</td>
<td></td>
<td>The coefficient</td>
</tr>
<tr>
<td>( W_{max} = \max \left[ W_i \cdot W_s \right] )</td>
<td>181026 kN</td>
<td></td>
<td>The maximum flange design bolt load for the assembly condition</td>
</tr>
</tbody>
</table>
After this stage, for future calculations, pressures operating at the side shell and tube should be selected. In this example, calculations of three types of pressures were carried out. Values of the operating pressure were assumed.

In first load case, the analysed negative pressure operated on the shell – side. In the second load case, the analysed negative pressure operated on the tube – side. In the third case, the negative pressure operating on the shell or the tube side was not taken into consideration.

**Table 5**

<table>
<thead>
<tr>
<th>ID</th>
<th>Load Case 1</th>
<th>LC2</th>
<th>LC3</th>
<th>Units</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ps</td>
<td>-0.1</td>
<td>1</td>
<td>1</td>
<td>MPa</td>
<td>Shell – Side Pressure</td>
</tr>
<tr>
<td>Pt</td>
<td>0.6</td>
<td>-1</td>
<td>0.6</td>
<td>MPa</td>
<td>Tube – Side Pressure</td>
</tr>
</tbody>
</table>

Below, Tab. 6 shows the procedure and the results of calculations carried out of the different load cases described in Tab. 5.

**Table 6**

<table>
<thead>
<tr>
<th>Equation</th>
<th>LC 1</th>
<th>LC 2</th>
<th>LC 3</th>
<th>Units</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>( M_{x} = \frac{D_{t}^2}{16} \cdot [(p_{s} - 1) \cdot p_{s}^2 + 1] \cdot P_{s} - (p_{s} - 1) \cdot p_{s}^2 + 1 \cdot P_{s} ] )</td>
<td>-10087.73</td>
<td>28822.08</td>
<td>5764.42</td>
<td>Nmm</td>
<td>The moment due to pressures ( P_{s} ) and ( P_{t} ) acting on the unperforated tubesheet rim</td>
</tr>
<tr>
<td>( M' = M_{x} + \frac{W_{s} (G_{s} - G_{t})}{2 \cdot \pi \cdot D_{t}} )</td>
<td>-10087.73</td>
<td>28822.08</td>
<td>5764.42</td>
<td>Nmm</td>
<td>The moment acting on the unperforated tubesheet rim</td>
</tr>
<tr>
<td>( M_{s} = \frac{M' - D_{t}^2 \cdot F \cdot (P_{s} - P_{t})}{32 \cdot 1 + F} )</td>
<td>-3894.83</td>
<td>11128.08</td>
<td>2225.62</td>
<td>Nmm</td>
<td>The moment acting at periphery of tubesheet</td>
</tr>
<tr>
<td>( M_{c} = M_{s} + \frac{D_{t}^2}{64} \cdot (3 + 9') \cdot (P_{s} - P_{t}) )</td>
<td>-52905.35</td>
<td>151160</td>
<td>30231.63</td>
<td>Nmm</td>
<td>The moment acting at centre of tubesheet</td>
</tr>
<tr>
<td>( M = \text{max}(</td>
<td>M_{1}</td>
<td>:</td>
<td>M_{4}</td>
<td>) )</td>
<td>52905.35</td>
</tr>
<tr>
<td>( \sigma = \frac{6 \cdot M}{\mu \cdot (e_{s} - h_{s})} )</td>
<td>97.86</td>
<td>279.59</td>
<td>55.92</td>
<td>MPa</td>
<td>The calculated stress in a component</td>
</tr>
<tr>
<td>( \tau = \left( \frac{1}{4 \cdot \mu} \right) \left( \frac{D_{t}}{e} \right)</td>
<td>-8.18</td>
<td>23.28</td>
<td>4.6756</td>
<td>MPa</td>
<td>The calculated shear stress in a component</td>
</tr>
</tbody>
</table>
Depending on the applied pressure, different torques were obtained. In any case, the strength conditions of the maximum radial bending stress in the tubesheet and the maximum shear stress in the tubesheet have been fulfilled. The designed tubesheet fulfilled strength conditions for pressures assumed in Tab. 5. The material and size of the tubesheet were well selected.

3. Example of calculation for U-tube heat exchanger tubesheet extended as a flange

This section shows a comparison of the results of calculations performed in accordance with the WUDT-UC [2, 4, 8] and European standards. Tab. 7 shows input dates of strength parameters for the material used in the calculations [7, 6]. Tables 9, 10 and 11 were shown the selected results of these calculations. The calculations were carried out for tubesheet extended as a flange [4, 8].

**Table 7**

<table>
<thead>
<tr>
<th>Tubesheet material</th>
<th>$R_m$ [MPa]</th>
<th>$R_p$ [MPa]</th>
<th>$R_{pt}$ [MPa]</th>
<th>$E$ [MPa]</th>
</tr>
</thead>
<tbody>
<tr>
<td>S235JRG2 (1.0038)</td>
<td>410</td>
<td>235</td>
<td>210</td>
<td>205000</td>
</tr>
</tbody>
</table>

Tab. 8 contains basic information about the value assumed during the design of tubesheet. The input dates of tubesheet were selected from the Polish standards for this project [1, 5].

**Table 8**

<table>
<thead>
<tr>
<th>WUDT-UC</th>
<th>PN-EN 13445-3</th>
<th>Units</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$d_l = 25$</td>
<td>$d_l = 25$</td>
<td>mm</td>
<td>The nominal outer diameter of the pipe</td>
</tr>
<tr>
<td>$t = 32$</td>
<td>$p = 32$</td>
<td>mm</td>
<td>The tube pitch</td>
</tr>
<tr>
<td>$g = 12$</td>
<td></td>
<td>mm</td>
<td>Initial thickness</td>
</tr>
<tr>
<td>$l_0 = 12$</td>
<td>$l_x = 12$</td>
<td>mm</td>
<td>The expanded length of tube in tubesheet</td>
</tr>
<tr>
<td>$U_L = 32$</td>
<td></td>
<td>mm</td>
<td>The large centre- to- centre distance between adjust tube rows</td>
</tr>
<tr>
<td>$f = 533.126$</td>
<td>$S = 533.126$</td>
<td>mm$^2$</td>
<td>The total unperforated area of tubesheet</td>
</tr>
</tbody>
</table>

Tab. 9 and 10 show the results of calculating assembly and operating the bolts loads, necessary for the appropriate operation of the flange connection.
Table 9

The results of calculations for the assembly in the event of a tubesheet used in connection flange – screw

<table>
<thead>
<tr>
<th>WUDT-UC</th>
<th>PN-EN 13445-3</th>
<th>Units</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$D_1 = 1400$</td>
<td>$d_1 = 1400$</td>
<td>mm</td>
<td>The nominal diameter of the tubesheet</td>
</tr>
<tr>
<td>$D_s = 1426$</td>
<td>$B = 1426$</td>
<td>mm</td>
<td>The inside diameter of the contact face between loose and stub flanges in a lap joint</td>
</tr>
<tr>
<td>$D_a = 1481$</td>
<td>$G = 1504.3$</td>
<td>mm</td>
<td>The diameter of gasket load reaction</td>
</tr>
<tr>
<td>$b_0 = 26$</td>
<td></td>
<td>mm</td>
<td>The basic gasket or joint seating width</td>
</tr>
<tr>
<td>$U = 54.5$</td>
<td>$w = 52$</td>
<td>mm</td>
<td>The contact width of gasket or joint seating pressure</td>
</tr>
<tr>
<td>$U_c = 25.61$</td>
<td>$b = 12.85$</td>
<td>mm</td>
<td>The effective gasket or joint seating width</td>
</tr>
<tr>
<td>$\sigma_r = 18.3$</td>
<td>$y = 26.20$</td>
<td>MPa</td>
<td>The minimum required gasket or joint seating pressure</td>
</tr>
<tr>
<td>$N_{m1} = 2502000$</td>
<td>$W_A = 104694$</td>
<td>N</td>
<td>The minimum required bolt load for assembly condition</td>
</tr>
<tr>
<td>$C = 1.4$</td>
<td>–</td>
<td>–</td>
<td>The correction coefficient used in WUDT-UC</td>
</tr>
<tr>
<td>$N_{m2} = 5618000$</td>
<td>–</td>
<td>N</td>
<td>The minimum required bolt load for assembly condition – used correction coefficient</td>
</tr>
</tbody>
</table>

Table 10

The results of calculations for operating in the event of a tubesheet used in connection flange – screw

<table>
<thead>
<tr>
<th>WUDT-UC</th>
<th>PN-EN 13445-3</th>
<th>Units</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$D_a = 1481$</td>
<td>$G = 1504.3$</td>
<td>mm</td>
<td>The inside diameter of the contact face between loose and stub flanges in a lap joint</td>
</tr>
<tr>
<td>$p_0 = 1.6$</td>
<td>$P = 1.6$</td>
<td>MPa</td>
<td>Design pressure</td>
</tr>
<tr>
<td>$b = 1.5$</td>
<td>–</td>
<td>–</td>
<td>The coefficient of hedging against a decline in the strength $S$ as a result of creep</td>
</tr>
<tr>
<td>$\sigma_r = 4.8$</td>
<td>$mP = 2.4$</td>
<td>MPa</td>
<td>The pressure on the gasket to guarantee tightness of the joint in the operating conditions</td>
</tr>
<tr>
<td>$U_c = 26.61$</td>
<td>$b = 12.85$</td>
<td>mm</td>
<td>The effective gasket or joint seating width</td>
</tr>
<tr>
<td>$P = 2754000$</td>
<td>$H = 2843667$</td>
<td>N</td>
<td>The total hydrostatic end force</td>
</tr>
<tr>
<td>$S = 953200$</td>
<td>$H_U = 22684$</td>
<td>N</td>
<td>The compression load on gasket to ensure tight joint</td>
</tr>
<tr>
<td>$N_r = 4013000$</td>
<td>$W_{op} = 2866351$</td>
<td>N</td>
<td>The minimum required bolt load for operating condition</td>
</tr>
</tbody>
</table>

Tab. 11 shows the final results for the calculation of the bottom sieve according to WUDT-UC and European standards.
The European standard PN-EN 13445-3 has procedures for the calculation of tubesheet for more structural solutions than Polish guidelines WUDT-UC. The calculations are dependent on the heat exchanger and the type of tubesheets. In the case of guidelines WUDT-UC, the amount of these solutions is very limited and reduced to a few cases. However, this greatly facilitates carrying out the calculations. All the values in the design are known.

Large difference were noted when comparing the two methods of calculating algorithms. For calculation algorithm strength WUDT-UC as the minimum thickness of the tube sheet assumes a value equal to 12 mm, regardless of the material from which the tube sheet and the diameter of the heat exchanger and the load applied pressure.

In the European standard PN-EN 13445-3, there is no requirement specifying the minimum size of the tubesheet. The calculation is carried out for the assumed thickness of the tubesheet. It is important only for the thickness to fulfil strength requirements. If these conditions are not fulfilled, the calculations must be repeated by increasing the thickness of the tubesheet.

When comparing the results of calculation for tubesheet extended as a flange, conducted for both of these documents, large differences are noted. The same situation occurs in the event of comparing the dimensions of sealing solutions for the flange connection. They relate to the average diameter of the seal $D_o$ and the inside diameter of the contact face between loose and stub flanges in a lap joint $G$.

According to the algorithm calculations WUDT-UC thickness of the tubesheet meets the conditions adopted in the project in the precinct flange connection and it is 26 mm. However, according to European standard PN-EN 13445-3, this value is higher, at 32 mm. In the precinct bundle of tubes, higher values in the calculation were obtained for the guidance WUDT-UC equal 20 mm. In the case of the European standard, this value was 12 mm. For the region outside the bundle of tubes, a similar situation was noted. For the European standard PN-EN 13445-3 there was a higher value – 32 mm than for the guidelines WUDT-UC – 12 mm.

### Table 11

Comparison of the results of calculated thickness of the tubesheet

<table>
<thead>
<tr>
<th>The calculated thickness of the tubesheet</th>
<th>WUDT-UC $g_o$ mm</th>
<th>PN-EN 13445-3 $e$ mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Precinct flange connection</td>
<td>26</td>
<td>32</td>
</tr>
<tr>
<td>2. Precinct bundle of tubes</td>
<td>20</td>
<td>12</td>
</tr>
<tr>
<td>3. Outside the bundle of tubes</td>
<td>34</td>
<td>12</td>
</tr>
<tr>
<td>The thickness of whole tubesheet *</td>
<td>34</td>
<td>32</td>
</tr>
</tbody>
</table>

* Industry seeks to standardise the thickness of the tube sheet for each of its area

4. Conclusion

The European standard PN-EN 13445-3 has procedures for the calculation of tubesheet for more structural solutions than Polish guidelines WUDT-UC. The calculations are dependent on the heat exchanger and the type of tubesheets.
Finally, the thickness of tubesheet for European standard PN-EN 13445-3 was equal to 34 mm. The calculations that were carried out for guidelines WUDT-UC amounted to 32 mm. It was found that the calculations performed according to the European standards PN-EN 13445-3 are more accurate and increase the strength of the structure. Due to the greater thickness of the tubesheet heat exchanger, it meets the requirements of safety and allows safe operation of the device.

In the analysed examples, an analogy on the section of the tubesheet into different areas was noted. Equation determination of tubesheet thickness have been summarised in below Tab. 12.

<table>
<thead>
<tr>
<th>Standards</th>
<th>Precinct flange connection</th>
<th>Outside the bundle of tubes</th>
<th>Precinct bundle of tubes</th>
</tr>
</thead>
<tbody>
<tr>
<td>WUDT-UC</td>
<td>$D_z = D_n + 2\cdot g_z$;</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>- assembly conditions:</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>$\sigma_{as} = 2\cdot N_{as} \cdot \frac{D_z - D_n - 2\cdot g_z}{\pi \cdot (D_z - 2\cdot d_t) \cdot h^2}$</td>
<td>$g_s = 0.45 \cdot \frac{p_m}{k}$</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- operating conditions:</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>$\sigma_{op} = 2\cdot N_{op} \cdot \frac{D_n - D_z - 2\cdot g_z}{\pi \cdot (D_n - 2\cdot d_t) \cdot h^2}$</td>
<td>$g = q_{max} / m$</td>
<td></td>
</tr>
<tr>
<td>PN-EN 13445-3</td>
<td>$e_{\beta, as} = \frac{12}{\pi \cdot D_n \cdot (1+9) \cdot (1-9) \left( \frac{D_n}{A} \right)^2} M_{\alpha}$</td>
<td>Assumed in the project, checked under the strength conditions and corrected when are not complied.</td>
<td>Assumed in the project, checked under the strength conditions and corrected when are not complied.</td>
</tr>
<tr>
<td></td>
<td>- assembly conditions:</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>$e_{\beta, op} = \frac{12}{\pi \cdot D_n \cdot (1+9) \cdot (1-9) \left( \frac{D_n}{A} \right)^2} f_{\alpha}$</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>- operating conditions:</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**References**


