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Flat tubesheet for pressure vessels

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Foreword

This translation has been made based on the original Japanese Industrial Standard revised by the Minister of Health, Labour and Welfare and the Minister of Economy, Trade and Industry through deliberations at the Japanese Industrial Standards Committee, as the results of proposal for revision of Japanese Industrial Standard submitted by The High Pressure Gas Safety Institute of Japan (KHK)/Japanese Standards Association (JSA) with the draft being attached, based on the provision of Article 12 Clause 1 of the Industrial Standardization Law applicable to the case of revision by the provision of Article 14.

Consequently **JIS B 8274:2003** is replaced with this Standard.

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Flat tubesheet for pressure vessels

1 Scope

This Japanese Industrial Standard specifies the design method of flat tubesheet of the shell and tube heat exchanger, which shall apply to items related to the flat tubesheet. For the flat tubesheet specified in **JIS B 8265** or **JIS B 8266**, standards thereof shall apply respectively.

Requirements not specified in this Standard shall be in accordance with the agreement between the purchaser and the manufacturer.

2 Normative references

The following standards contain provisions which, through reference in this text, constitute provisions of this Standard. The most recent editions of the standards (including amendments) indicated below shall be applied.

JIS B 0190 *Glossary of terms used in construction of pressure vessels*

JIS B 8249 *Shell and tube heat exchangers*

JIS B 8265 *Construction of pressure vessel—General principles*

JIS B 8266 *Alternative standard for construction of pressure vessels*

JIS B 8267 *Construction of pressure vessel*

JIS B 8277 *Expansion joint for pressure vessels*

3 Terms and definitions

For the purposes of this Standard, the definitions given in **JIS B 0190** and **JIS B 8249**, and the following definitions apply.

3.1 stationary end flat tubesheet

flat tubesheet of the heat exchanger with the extractable tube bundle at the channel side

3.2 floating end flat tubesheet

flat tubesheet of the heat exchanger with the extractable tube bundle at the floating head side

4 Meanings of symbols

The meanings of symbols shall be as follows.

The allowable tensile stress, longitudinal elastic coefficient and linear expansion coefficient shall be in accordance with **JIS B 8265** and **JIS B 8267**.

d_o : outside diameter of heat exchanger tube (mm)

F : coefficient based on supporting method of tube and flat tubesheet (see table 3)

G : diameter of fixed circle of periphery of flat tubesheet (mm) (see table 3)

P : design pressure of flat tubesheet (MPa) (see table 3 and table 4)

- P_s : design pressure of shell side (for minus pressure, minus value) (MPa)
 P_t : design pressure of tube side (for minus pressure, minus value) (MPa)
 t_s : nominal thickness of shell (mm)
 t_t : nominal thickness of heat exchanger tube (mm)
 σ_a : allowable tensile stress at design temperature of material (N/mm²)
 τ_a : allowable shear stress at design temperature of flat tubesheet material (N/mm²)
 E : longitudinal elastic coefficient (N/mm²)
 α : linear expansion coefficient (1/°C)

5 Conditions for flat tubesheets to satisfy

5.1 General

To design a flat tubesheet, specifications in **5.2** to **5.5** shall be satisfied.

Other than the designing method of flat tubesheet specified in this Standard, Annex 7 of **JIS B 8265** and Annex 8 of **JIS B 8266** are applicable.

5.2 Design temperature of flat tubesheet

The design temperature of the flat tubesheet shall be either that of the shell side or of the tube side, at whichever temperature the thickness of the flat tubesheet is greater. However, the metallic temperature is obtained by the method specified in **6.1.3 e)** of **JIS B 8266**, it may be applied as a design temperature.

5.3 Construction of flat tubesheet

The construction of the flat tubesheet shall be as follows.

- a) The construction of the flat tubesheet shall be as shown in table 3 and table 4.
- b) The thickness of the flat tubesheet excluding the flange part shall be uniform.
- c) The tube holes of the flat tubesheet shall be bored uniformly and the range of tube holes shall be approximately circular. (However, in the case the pass partition groove as seen in multi-pass unit is provided, this may be ignored.)
- d) **Pitch of heat exchanger tube**
 - 1) The pitch of the heat exchanger tube (the distance between centres of tube holes) shall be 1.25 times the outside diameter of heat exchanger tube or more.
 - 2) When tubes are expanded, the pitch of the heat exchanger tube shall satisfy the specification of **1)** and shall be not less than $[d_o + 0.165 (d_o + 2t_t)]$.

However, the following items shall be satisfied.

- 2.1) It shall not be smaller than $(d_o + 2t_t)$ when it is not tested for the holding power specified in **5.5**.
- 2.2) For the whole machine finished flat tubesheet (except for the pass partition groove part), 96 % of ligament between the tube holes shall be $0.85 (p_t - d_o)$ or over.

where, p_t : pitch of heat exchanger tube (mm)
 d_o : outside diameter of heat exchanger tube (mm)
 t_t : nominal thickness of heat exchanger tube (mm)

- e) All dimensions of the heat exchanger tube shall be the same.
- f) When the bolt hole for hanging, the drain hole or the vent hole are provided, attention shall be paid not to reduce the strength of the flat tubesheet excessively.

5.4 Method of jointing heat exchanger tube and flat tubesheet

Method of jointing the heat exchanger tube and the flat tubesheet shall be as shown in table 1.

NOTE: Applicable examples of welding joint are shown in figure 1.

5.5 Holding power test of heat exchanger tube and flat tubesheet

5.5.1 General

For the heat exchanger, holding power test of the jointing part of the heat exchanger tube and the flat tubesheet shall be performed for the purpose of calculating the allowable load at the mounting part of the heat exchanger tube. However, the holding power test may be omitted if the equipment designed with the same condition has passed the holding power test specified in 5.5.2 in the past, or if the coefficient of joint strength in table 1 for the case of not conducting the holding power test is applied.

5.5.2 Testing method

The holding power test of the jointing part of the heat exchanger tube and the flat tubesheet shall satisfy the following.

- a) The construction of testing equipment shall be so that the load applied until the test piece having full scale of the joint to be tested breaks can be measured.
- b) When the test piece is broken because of the defect or the inherent cause of testing equipment, it may be replaced with a new test piece taken from the same melt.
- c) In the holding power test, the load shall be applied till the heat exchanger tube or the jointing part of the heat exchanger tube and the flat tubesheet is mechanically broken. The direction of loading shall be to the axis direction of the heat exchanger tube as well as the direction in which the tensile stress is generated on the heat exchanger tube.
- d) The shape of the test piece corresponding to the flat tubesheet shall be any one of circular, square or rectangular. The pattern of the tube holes and the pitch of tube holes shall be the same as that of the design condition. The heat exchanger tube supporting the load shall be placed to the centre of the test piece and this tube shall be surrounded by at least one line of neighbouring heat exchanger tubes. Further, a projection of at least one ligament width of the flat tubesheet shall be provided to the outside of the outermost heat exchanger tubes.
- e) The heat exchanger tube inside the test piece shall be taken from the same melt, and the jointing of the heat exchanger tube and the flat tubesheet shall be the same way as in actual production of the heat exchanger. The tubesheet of test

piece may be thinner than the actual flat tubesheet but shall not be thicker. For the expanding, the expansion area inside the test piece may be smaller than the actual expansion area but shall not be bigger.

The length of the heat exchanger tube of test piece is sufficient if the length may afford the test, and the length of the heat exchanger tube neighbouring the heat exchanger tube supporting the load shall be the same as or longer than the thickness of the flat tubesheet of test piece.

- f) The test piece loading rate shall be that at which the load can be measured correctly.
- g) If there are some defects on the test piece and the defects may affect the test result, the retest specified in **h)** shall be performed.
- h) The number of the test pieces for the joint type as shown in table 1 shall be 3 or more. For the retest, take 9 or more test pieces from the heat exchanger tube from which the first test piece was taken and the former test results shall be rejected.
- i) For the holding power test for the joint type not included in table 1 or for the case that the value f_{r3} in **5.5.3** is applied instead of the coefficient of joint strength f_{r1} shown in table 1, the holding power test shall be as follows.
 - 1) The number of the test pieces shall be 9 or more and all the test pieces shall be taken from one heat exchanger tube. If all the test results are applied, the additional test may be performed with the test piece taken from the same heat exchanger tube.

When the design of jointing method or the production procedure is changed to obtain the expected results, all the tests shall be retraced for the changed jointing method.

- 2) Calculate the mean value and the standard deviation σ of holding power obtained from each test piece, and decide the coefficient of joint strength f_{r3} using the mean value subtracted by 2σ as the minimum axis load when the breakage starts. However, the minimum value of holding power shall be effective only when it is equal to or greater than 50 % of the mean value.

5.5.3 Decision of coefficient of joint strength f_{r3} using holding power test

Decision of the coefficient of joint strength f_{r3} using the holding power test shall be as follows.

- a) for the joint type of a, b and c of table 1,

$$f_{r3} = \frac{L}{A_t S_u}$$

- b) for the joint type of d, e, f, g, h and i of table 1,

$$f_{r3} = \frac{L}{A_t S_u f_l f_y}$$

when f_{r3} is over 1.00, it shall be considered as 1.00.

- where, L : the minimum axis load when breakage starts on test piece (N)
- A_t : cross section area of heat exchanger tube (mm^2)
- f_1 : coefficient of length of expanded part. The smaller one of either $\frac{l}{d_o}$ or 1.0 for expanding to grooveless tube hole. 1.0 for expanding to grooved tube hole.
- where, l : length of expanded part (mm)
- d_o : outside diameter of heat exchanger tube (mm)
- f_y : coefficient based on the difference between mechanical strength of flat tubesheet and that of heat exchanger tube. In the case of expanding, the smaller one of either the ratio of specified minimum yield point at design temperature of tubesheet or that of heat exchanger tube or 1.0.
- S_u : specified minimum tensile strength of material of heat exchanger tube (N/mm^2)

Table 1 Applicable jointing method and coefficient of joint strength of heat exchanger tube and flat tubesheet †

Joint type	Jointing method ^{f)}	Note	Coefficient of joint strength f_r ^{a)}	
			f_{r1}	f_{r2}
a	Welding only $a \geq 1.4 t_t$	—	1.00	0.80
b	Welding only $t_t \leq a < 1.4 t_t$	c)	0.70	0.55
c	Expanding and welding $a \geq 1.4 t_t$	—	1.00	0.80
d	Expanding and welding with 2 or more grooves $a < 1.4 t_t$	b), d)	0.95	0.75
e	Expanding and welding with one groove $a < 1.4 t_t$	b), d)	0.85	0.65
f	Expanding and welding without groove $a < 1.4 t_t$	b), d)	0.70	0.50
g	Expanding with 2 or more grooves	b), d), e)	0.90	0.70
h	Expanding with one groove	b), d), e)	0.80	0.65
i	Expanding without groove	b), d), e)	0.60	0.50

Notes ^{a)} Coefficient of joint strength f_r shall be as follows.

It shall be f_{r2} when the holding power test of the heat exchanger tube and the flat tubesheet specified in **5.5** is not performed. It shall be the smaller one of f_{r1} or f_{r3} specified in **5.5.3** when the holding power test specified in **5.5** is performed. However, it shall be f_{r3} when the test is performed in accordance with **5.5.2 i)**.

^{b)} It shall not be applied when the prominent load is repeated.

^{c)} For $a < t_t$, $f_{r2} = 0$. In this case the holding power test specified in **5.5** shall be performed.

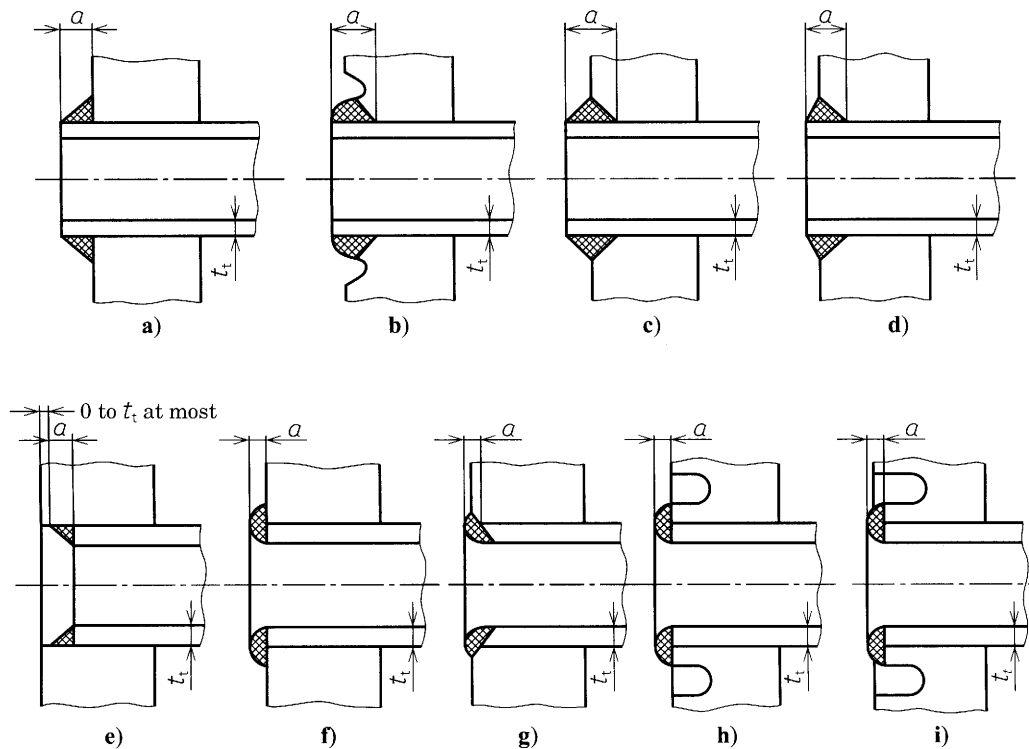
^{d)} The holding power test in accordance with **5.5** shall be performed when the ratio of nominal outside diameter and nominal inside diameter of the heat exchanger tube is smaller than 1.05 or larger than 1.41.

^{e)} When the linear expansion coefficient of the material of the heat exchanger tube and the flat tubesheet are not the same, the allowable operation temperature range shall be as follows depending on the degree of difference.

- When the ratio of linear expansion coefficient is 70 % to 90 %, the allowable range of operation temperature shall be -134 °C to 176 °C.
- When the ratio of linear expansion coefficient is 50 % to 70 %, the allowable range of operation temperature shall be -106 °C to 148 °C.
- When the ratio of linear expansion coefficient is under 50 %, the allowable range of operation temperature shall be -51 °C to 93 °C.

Ratio of linear expansion coefficient = (smaller linear expansion coefficient/larger linear expansion coefficient) × 110 (%)

^{f)} Welding dimension a shall be as shown in figure 1.



NOTE 1 $a \geq 1.4 t_t$ for types a) to d).

NOTE 2 $a < 1.4 t_t$ for types e) to i).

Figure 1 Examples of applicable type of welding joint of heat exchanger tube and flat tubesheet†

6 Thickness of flat tubesheet

6.1 Minimum thickness of expanding flat tubesheet

In the case that the heat exchanger tube is mounted on the expansion, the thickness of the expanding part of the flat tubesheet (excluding the corrosion allowance) shall be equal to or larger than the minimum value shown in table 2. The total flat tubesheet thickness including the corrosion allowance shall be 19 mm or more.

Table 2 Minimum thickness of flat tubesheet at expanding part

Unit: mm

Outside diameter of heat exchanger tube	Minimum value
25.4 or under	$0.75 d_o$
31.8 or under	22
38.1 or under	25
50.8 or under	32

6.2 Calculated thickness of flat tubesheet

The calculated thickness of the flat tubesheet shall be the larger one of the following t_1 or t_2 . However, calculated thickness of the flange part of the flat tubesheet shall be as shown in 6.3 when the flat tubesheet is bolted.

$$\text{Bending} \dots\dots\dots t_1 = \frac{FG}{3} \sqrt{\frac{P}{\eta \sigma_a}}$$

$$\text{Shearing} \dots\dots\dots t_2 = \frac{D_L P}{4 \left(1 - \frac{d_o}{p_t}\right) \tau_a}$$

where, t_1 : calculated thickness excluding corrosion allowance of flat tubesheet by bending. When grooves for pass partition plate or grooves for gasket are provided, the depth of those grooves is not included (mm).

t_2 : calculated thickness excluding corrosion allowance of flat tubesheet by shearing. When grooves for pass partition plate or grooves for gasket are provided, the depth of those grooves is not included (mm).

D_L : equivalent diameter of polygon formed by connecting sequentially the centres of outermost tubes, and shall be in accordance with table 4 (mm)

p_t : pitch of heat exchanger tube (mm)

η : efficiency used for thickness calculation of the flat tubesheet, and shall be according to the following formula

$$\text{For square pitch,} \quad \eta = 1 - \frac{0.785}{\left(\frac{p_t}{d_o}\right)^2}$$

$$\text{For triangular pitch,} \quad \eta = 1 - \frac{0.907}{\left(\frac{p_t}{d_o}\right)^2}$$

P , σ_a , τ_a , d_o , F and G shall be in accordance with clause 4.

NOTE 1 The calculation of t_1 and t_2 shall be performed for conditions of both sides of the flat tubesheet. Each dimension shall be the larger one of either the flat tubesheet of before corrosion or that after corrosion.

NOTE 2 For the fixed tubesheet type heat exchanger, t_1 and t_2 are calculated repeatedly, and when the difference between this calculated thickness and the thickness supposed in the calculation of F_q of 6.5 a) is equal to or smaller than ± 1.5 % of the supposed thickness, the calculation shall be considered as converged. However, the flat tubesheet thicker than the calculated thickness may be used when the shell and the heat exchanger tube is within the allowable limit in accordance with clause 7.

NOTE 3 If the following condition formula is satisfied, calculation of t_2 may be omitted.

$$\text{Condition formula } \frac{1.1}{\eta} \left(1 - \frac{d_o}{p_t} \right)^2 > \frac{P \sigma_a}{\tau_a^2}$$

NOTE 4 For the floating head extracting type heat exchanger, the thickness of the floating end flat tubesheet t_1 is the value calculated either according to 6.7 a) or b), whichever is the larger.

Table 3 Symbols used for construction and formula of bending††

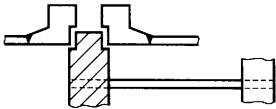
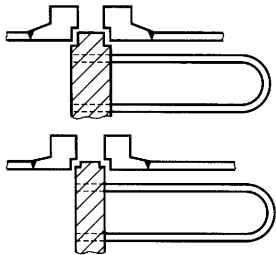
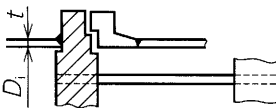
Construction of flat tubesheet	F	G		P
		Shell side	Tube side	
1 The case where flat tubesheet is not integrated with shell and channel, and straight tubes are applied 	1.0	Diameter of the circle passing through the position where the gasket reaction force works	Diameter of the circle passing through the position where the gasket reaction force works	Design pressure ^{a)} of shell side or tube side (excluding the case of differential pressure design)
2 The case where flat tubesheet is not integrated with shell and channel, and U-tubes are applied 	1.25	Diameter of the circle passing through the position where the gasket reaction force works	Diameter of the circle passing through the position where the gasket reaction force works	Design pressure ^{a)} of shell side or tube side (excluding the case of differential pressure design). However, when the moment occurs on the flat tubesheet by bolting, it shall be based on 6.6.
3a The case where flat tubesheet is integrated with channel, and straight tubes are applied 	The value F shall be obtained from the following formula or from figure 2. The maximum value of F shall be 1.0, and the minimum shall be 0.8. $F = \frac{17 - 100t / D_i}{15}$ where, D_i: inside diameter of shell or channel	Diameter of the circle passing through the position where the gasket reaction force works	Inside diameter of channel	Design pressure ^{a)} of shell side or tube side (excluding the case of differential pressure design). However, for fixed tubesheet type heat exchanger, it shall be based on 6.5 c) and 6.5 d).

Table 3 (continued)

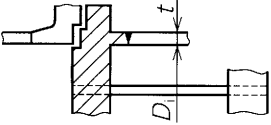
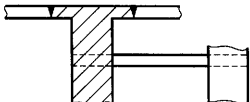
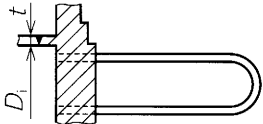
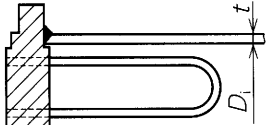
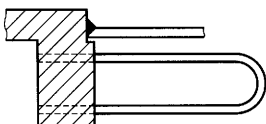
Construction of flat tubesheet	F	G		P
		Shell side	Tube side	
3b The case where flat tubesheet is integrated with shell, and straight tubes are applied 	The value F shall be obtained from the following formula or from figure 2. The maximum value of F shall be 1.0, and the minimum shall be 0.8. $F = \frac{17 - 100t / D_i}{15}$	Inside diameter of shell	Diameter of the circle passing through the position where the gasket reaction force works (for fixed tubesheet type heat exchanger, it shall be the inside diameter of shell.)	Design pressure ^{a)} of shell side or tube side (excluding the case of differential pressure design). However, for fixed tubesheet type heat exchanger, it shall be based on 6.5 c) and 6.5 d) .
3c The case where flat tubesheet is integrated with shell and channel, and straight tubes are applied 	where, D_i : inside diameter of shell or channel	Inside diameter of shell	Inside diameter of channel (for fixed tubesheet type heat exchanger, it shall be the inside diameter of shell.)	
4a The case where flat tubesheet is integrated with channel, and U-tubes are applied 	The value F shall be obtained from the following formula or from figure 2. The maximum value of F shall be 1.25, and the minimum shall be 1.0. $F = \frac{17 - 100t / D_i}{12}$	Diameter of the circle passing through the position where the gasket reaction force works	Inside diameter of channel	Design pressure ^{a)} of shell side or tube side (excluding the case of differential pressure design). However, when bolted, it shall be based on 6.6 .
4b The case where flat tubesheet is integrated with shell, and U-tubes are applied 	where, D_i : inside diameter of shell or channel	Inside diameter of shell	Diameter of the circle passing through the position where the gasket reaction force works	
4c The case where flat tubesheet is integrated with shell and channel, and U-tube are applied 		Inside diameter of shell	Inside diameter of channel	Design pressure ^{a)} of shell side or tube side (excluding the case of differential pressure design)

Table 3 (concluded)

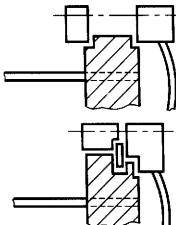
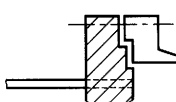
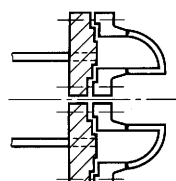
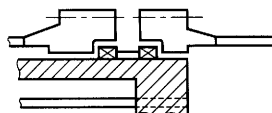
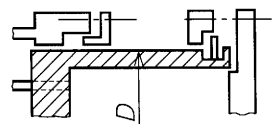
Construction of flat tubesheet	<i>F</i>	<i>G</i>		<i>P</i>
		Shell side	Tube side	
5a Floating head backing flange type 	1.0	Take the dimension of <i>G</i> of stationary end flat tubesheet.		Design pressure ^{a)} of shell side or tube side (excluding the case of differential pressure design)
5b Floating head extracted type 	1.0	According to 6.7 .		According to 6.7 .
5c Floating head extracted type (separate flat tubesheet) 	1.0	$G = 1.41S$ where, <i>S</i> : minimum spun measured on the centre line of gasket		Design pressure ^{a)} of shell side or tube side (excluding the case of differential pressure design)
6 Floating flat tubesheet type with lantern ring 	1.0	Take the dimension of <i>G</i> of stationary end flat tubesheet.		Design pressure of tube side. However, when shell side is minus pressure, absolute value of minus pressure is added to the tube side design pressure.
7 Floating head type with grand 	1.0	Take the dimension of <i>G</i> of stationary end flat tubesheet.		According to 6.4 a) .
NOTE 1 The diameter of the circle which passes the position where reaction force of the gasket works shall be <i>G</i> dimension specified in clause 2 of Annex 3 of JIS B 8265 .				
NOTE 2 In the construction of the flat tubesheet, stationary end flat tubesheets are shown in 1 to 4c , and floating end tubesheets are shown in 5a to 7 .				
Note ^{a)} When the shell side or the tube side is minus pressure, the absolute value of minus pressure is added to the design pressures of the opposite side and minus pressure side.				

Table 4 Symbols used for construction and formula of shearing^{††}

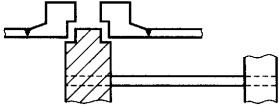
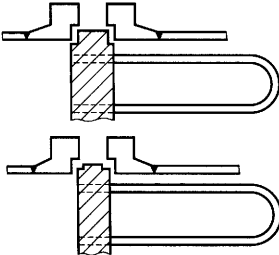
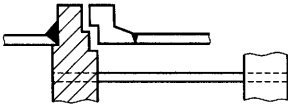
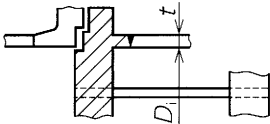
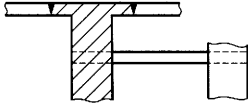
Construction of flat tubesheet	P	D_L
1 The case where flat tubesheet is not integrated with shell and channel, and straight tubes are applied 	Design pressure ^{a)} of shell side or tube side (excluding the case of differential pressure design)	$D_L = \frac{4A}{C}$ where, C : the circumference length of polygon which is framed connecting the centres of outermost tube holes (see figure 3). (mm) A : the area within the heavy line as shown in figure 3. (mm²)
2 The case where flat tubesheet is not integrated with shell and channel, and U-tubes are applied. 	Design pressure ^{a)} of shell side or tube side (excluding the case of differential pressure design)	
3a The case where flat tubesheet is integrated with channel, and straight tubes are applied 	Design pressure ^{a)} of shell side or tube side (excluding the case of differential pressure design). However, for fixed tubesheet type heat exchanger, it shall be based on 6.5 c) and 6.5 d) .	
3b The case where flat tubesheet is integrated with shell, and straight tubes are applied 		
3c The case where flat tubesheet is integrated with shell and channel, and straight tubes are applied 		

Table 4 (continued)

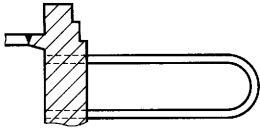
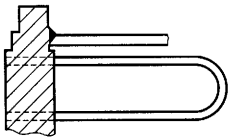
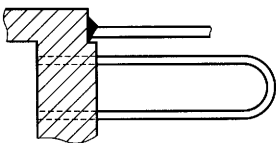
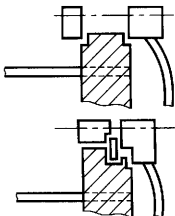
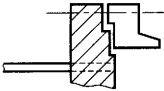
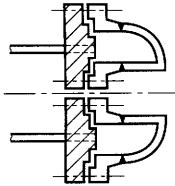
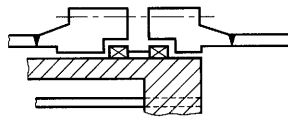
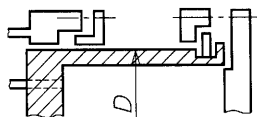
Construction of flat tubesheet	P	D_L
4a The case where flat tubesheet is integrated with channel, and U-tubes are applied 	Design pressure ^{a)} of shell side or tube side (excluding the case of differential pressure design)	$D_L = \frac{4A}{C}$ where, C : the circumference length of polygon which is formed by connecting sequentially the centres of outermost tube holes (see figure 3). (mm) A : the area within the heavy line as shown in figure 3. (mm ²)
4b The case where flat tubesheet is integrated with shell, and U-tubes are applied 		
4c The case where flat tubesheet is integrated with shell and channel, and U-tubes are applied 		
5a Floating head backing flange type 	Design pressure ^{a)} of shell side or tube side (excluding the case of differential pressure design)	
5b Floating head extracted type 		
5c Floating head extracted type (separated flat tubesheet) 		

Table 4 (concluded)

Construction of flat tubesheet	P	D_L
6 Floating tubesheet type with lantern ring 	Design pressure of tube side. However, when shell side is minus pressure, absolute value of minus pressure is added to the tube side design pressure.	$D_L = \frac{4A}{C}$ where, C : the circumference length of polygon which is formed by connecting sequentially the centres of outermost tube holes (see figure 3). (mm) A : the area within the heavy line as shown in figure 3. (mm ²)
7 Floating head type with grand 	According to 6.4 b).	
Note ^{a)} When the shell side or the tube side is minus pressure, the absolute value of minus pressure is added to the design pressures of the opposite side and minus pressure side.		

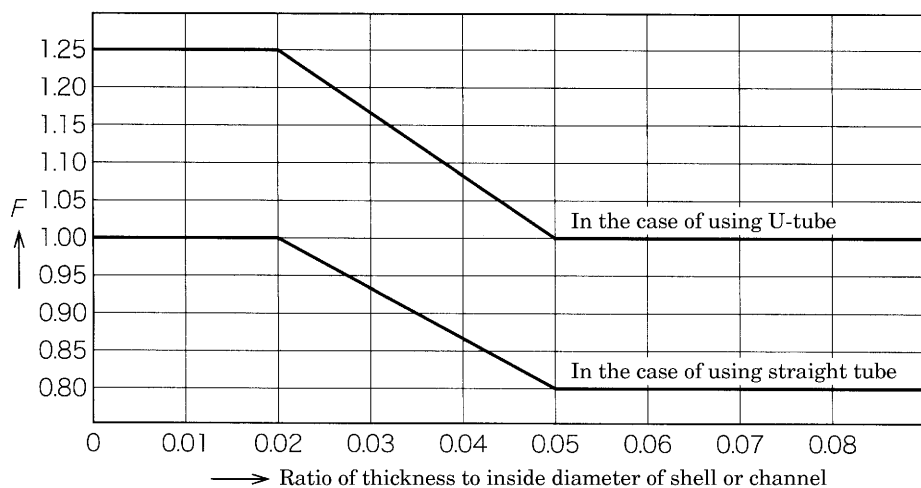


Figure 2 Value of $F^{\dagger\dagger}$

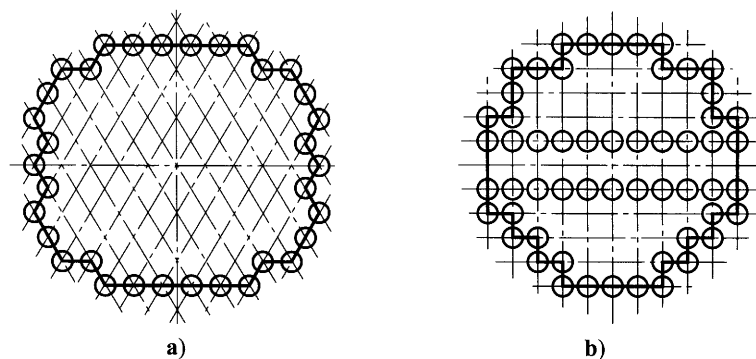


Figure 3 Polygon used for calculation of flat tubesheet^{††}

6.3 Calculated thickness of flange part of flat tubesheet

The calculated thickness of the flange part of the flat tubesheet (excluding the depth of the groove when the gasket grooves are provided) shall be based on the following formulae in **a)** or **b)**. For each dimension in the following formulae, comparing the values before and after corrosion, whichever is leading to the thicker flange part shall be chosen [see figures 4 a) and b)].

a) Fixed tubesheet type and floating head type heat exchanger

$$t_r = 0.98 \left[\frac{M(r^2 - 1 + 3.71r^2 l_n r)}{\sigma_a(D - G)(1 + 1.86r^2)} \right]^{\frac{1}{2}}$$

where, t_r : calculated thickness of flange part of flat tubesheet (mm)

D : outside diameter of flat tubesheet (mm)

M : M_g or M_o in **6.5 b)**, whichever is the larger moment (N·mm)

r : D/G

b) U-tube type heat exchanger

$$t_r = 1.38 \left[\frac{M^* + M + 0.39PG^2w}{\sigma_a(D - G)} \right]^{\frac{1}{2}}$$

where, t_r : calculated thickness of flange part of flat tubesheet (mm)

M^* : moment calculated according to the following formula (N·mm)

$$M^* = \frac{\frac{0.069}{\eta} w F^3 P G^3 \left(\frac{t_r}{t} \right)^3 - M G - 0.39 w P G^3}{G + \frac{1.37}{\eta} \left(\frac{t_r}{t} \right)^3 w}$$

P : pressure of the side where gasket is pinched (P_s or P_l). However, the absolute value of minus pressure shall be added when the opposite side is minus pressure. (MPa)

t : calculated thickness of flat tubesheet and shall be as specified in **6.2** (mm)

w : according to the following formula

$$w = \frac{(D - G)}{2} \text{ (mm)}$$

η shall be in accordance with **6.2** and D and M shall be in accordance with **6.3 a)**.

The calculation procedure for the above shall be as follows.

- 1) Suppose that $t_r/t = 1$, and obtain M^* .
- 2) Obtain P_b and P from **6.6**.
- 3) Obtain t from **6.2**.
- 4) Obtain t_r from **6.3 b**).
- 5) When $t > t_r$, the calculation is over, and the calculated value t shall be taken as the calculated thickness of the tube cluster part and the flange part.
- 6) When $t < t_r$ or t_r is expected to be smaller than t , suppose the plate thickness where $t_r/t < 1$ and repeat the calculation of procedure **1**) to **5**).

In this case, decide the thickness of the tube cluster part and the flange part so that they are in the same ratio as supposed t_r/t .

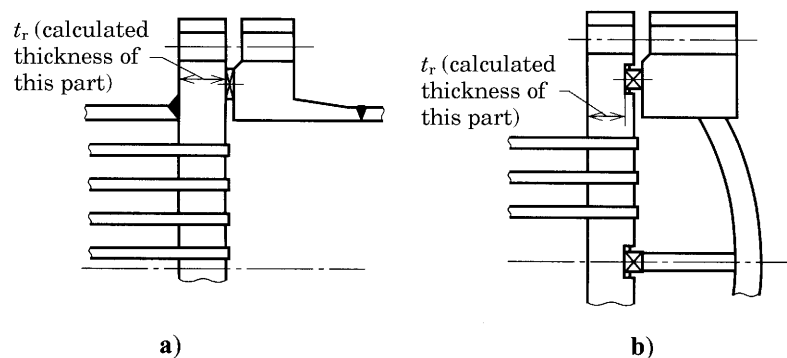


Figure 4 Bolted flat tubesheet

6.4 Effective design pressure of flat tubesheet used for floating head type with grand

The value of P used in the formula in **6.2** shall be based on the following.

a) Effective design pressure for bending

$$P = P_t + P_s \left[\frac{1.25(D^2 - D_c^2)(D - D_c)}{DF^2G^2} \right]$$

where, D : outside diameter of the floating head side flat tubesheet (see table 3) (mm)

D_c : equivalent diameter and is calculated according to the following formula.

$$D_c = \sqrt{\frac{4A}{\pi}} \text{ (mm)}$$

A shall be in accordance with table 4.

When P_s or P_t is minus pressure, the maximum effective design pressure shall be the largest absolute value of the following **1**) to **3**).

$$1) P \quad 2) P_t \quad 3) P_s \left[\frac{1.25(D^2 - D_c^2)(D - D_c)}{DF^2G^2} \right]$$

b) **Effective design pressure for shearing**

$$P = P_t + P_s \left(\frac{D^2 - D_c^2}{D_c^2} \right)$$

where, D and D_c shall be in accordance with **6.4 a**).

When P_s or P_t is minus pressure, the maximum effective design pressure shall be the largest absolute value of the following 1) to 3).

$$1) P \quad 2) P_t \quad 3) P_s \left(\frac{D^2 - D_c^2}{D_c^2} \right)$$

6.5 Effective design pressure of fixed tubesheet type head exchanger

The following formula shall be applied to the heat exchanger whose flat tubesheets are fixed to both ends of the shell. Both flat tubesheets shall have the same thickness.

- a) **Equivalent pressure caused by thermal expansion difference** The equivalent pressure caused by the difference of thermal expansion of the shell and that of the heat exchanger tube shall be according to the following formula.

$$P_e = \frac{4JE_s t_s \left(\frac{\Delta L}{L_t} \right)}{(D_o - 3t_s)(1 + JKF_q)}$$

where, P_e : equivalent pressure caused by thermal expansion difference (MPa)

D_o : outside diameter of shell (mm)

E_s : longitudinal elastic coefficient of shell material at the average metallic temperature (N/mm²)

F_q : according to the following formula. The minimum value shall be 1.0.

$$F_q = 0.25 + (F - 0.6) \left[\frac{300t_s E_s \left(\frac{D_1}{T} \right)^3}{Kl_o E} \right]^{\frac{1}{4}}$$

J : strength coefficient of expansion joint. In the case without expansion joint, $J = 1.0$.

In the case with expansion joint, $J = \frac{1}{1 + \frac{\pi(D_o - t_s)t_s E_s}{K_b l_o}}$,

and $J = 0$ if the following condition is satisfied.

$$K_b < \frac{(D_o - t_s)t_s E_s}{10l_o}$$

K : ratio of rigidity of shell to that of tube bundle, and shall be according to the following formula.

$$K = \frac{E_s t_s (D_o - t_s)}{E_t t_t N (d_o - t_t)}$$

ΔL : difference of thermal expansion of shell and that of heat exchanger tube according to the following formula (mm).

$$\Delta L = L_t (\alpha_s \theta_s - \alpha_t \theta_t)$$

L_t : length of heat exchanger tube between outer surface of flat tubesheet (mm)

D_1 : inside diameter of shell (mm)

E : longitudinal elastic coefficient of flat tubesheet material at design temperature (N/mm²)

E_t : longitudinal elastic coefficient of heat exchanger tube material at the average metallic temperature (N/mm²)

l_o : length of heat exchanger tube between inner surface of flat tubesheet (mm)

N : number of heat exchanger tubes

K_b : spring constant of expansion joint, and shall be as shown in Annex 10 of **JIS B 8265** or **JIS B 8277** (N/mm)

T : actual thickness of flat tubesheet. In the case of grooves for pass partition plate or for gasket, the depth of those grooves is excluded (mm)

θ_s : temperature given by subtracting 20 °C from the average metallic temperature of shell (°C)

θ_t : temperature given by subtracting 20 °C from the average metallic temperature of heat exchanger tube (°C)

α_s : linear expansion coefficient at the average metallic temperature of shell material (1/°C)

α_t : linear expansion coefficient at the average metallic temperature of heat exchanger tube material (1/°C)

- b) **Equivalent pressure caused by bolting** When the flat tubesheet is extended to the bolted flange part [see figure 4 a) and b)], the equivalent pressure caused by bolting shall be according to the following formulae.

$$P_{Bt} = \frac{6.2 M_o}{F^2 D_1^3}$$

$$P_{Bs} = \frac{6.2 M_g}{F^2 D_1^3}$$

where, P_{Bt} : equivalent bolting pressure with the pressure of tube side (MPa)

P_{Bs} : equivalent bolting pressure without the pressure of tube side (MPa)

M_o : total moment operating on flange part of flat tubesheet under operating condition (N·mm)

M_g : moment operating on flange part of flat tubesheet under the gasket pinched condition (N·mm)

D_1 shall be in accordance with **6.5 a**).

- c) **Effective design pressure of shell side** The effective design pressure P of the shell side shall be the largest absolute value of the following **1**) to **6**).

$$1) \frac{P'_s - P_e}{2} \quad 2) P'_s \quad 3) P_{Bs} \quad 4) \frac{P'_s - P_e - P_{Bs}}{2} \quad 5) \frac{P_{Bs} + P_e}{2} \quad 6) P'_s - P_{Bs}$$

where, P'_s : according to the following formula.

$$P'_s = P_s \left[\frac{0.4J[1.5 + K(1.5 + f_s)] - \left[\left(\frac{1-J}{2} \right) \left(\frac{D_j^2}{D_1^2} - 1 \right) \right]}{(1 + JK F_q)} \right] \quad (\text{MPa})$$

f_s : pressure receiving area ratio of shell side, and shall be according to the following formula.

$$f_s = 1 - N \left(\frac{d_o}{D_1} \right)^2$$

D_j : maximum inside diameter of expansion joint (mm)
(in the case without expansion joint, $D_j = D_1$)

D_1 , F_q , J , K , N and P_e shall be in accordance with **6.5 a**).

P_{Bs} shall be in accordance with **6.5 b**).

NOTE 1 The value of P used in the shearing formula shall be calculated as $P_{Bs} = 0$.

- d) **Effective design pressure of tube side** The effective design pressure P of the tube side shall be as follows.

- 1) When P'_s is a plus value, the largest absolute value of the following shall be applied.

$$\frac{P'_t + P_{Bt} + P_e}{2} \quad \text{or} \quad P'_t + P_{Bt}$$

- 2) When P'_s is a minus value, the largest absolute value of the following shall be applied.

$$\frac{P'_t - P'_s + P_{Bt} + P_e}{2} \quad \text{or} \quad P'_t - P'_s + P_{Bt}$$

where, P'_t : according to the following formula.

$$P'_t = P_t \left[\frac{1 + 0.4JK(1.5 + f_t)}{(1 + JK F_q)} \right] \quad (\text{MPa})$$

f_t : pressure receiving area ratio of the tube side, and shall be according to the following formula.

$$f_t = 1 - N \left(\frac{d_o - 2t_t}{D_i} \right)^2$$

D_i , F_q , J , K , N and P_c shall be in accordance with **6.5 a)**.
 P_{Bt} shall be in accordance with **6.5 b)** and P_s' shall be in accordance with **6.5 c)**.

NOTE 2 The value of P used in the shearing formula shall be calculated as $P_{Bt} = 0$.

NOTE 3 Plus and minus sign of P_s' shall be in accordance with **6.5 c)**.

NOTE 4 When $J = 0$ and both P_s and P_t are plus values, P shall be calculated with the following formula.

$$P = P_t + \frac{P_s}{2} \left[\left(\frac{D_j}{D_i} \right)^2 - 1 \right] + P_{Bt}$$

6.6 Design pressure of bolted flat tubesheet of U-tube type heat exchanger

When the periphery of the flat tubesheet reaches to the outside diameter of the flange and bolted, the design pressure P of the flat tubesheet used in the bending formula shall be in accordance with the following **a)** or **b)** according to the side to which gasket is pinched. In the case P is minus pressure, the absolute value shall be applied.

a) Gasket is pinched with the shell flange and the flat tubesheet

Shell side pressure: $P = P_s + P_b$

Tube side pressure: $P = P_t$

b) Gasket is pinched with the channel flange and the flat tubesheet

Shell side pressure: $P = P_s$

Tube side pressure: $P = P_t + P_b$

where, P_b : equivalent pressure with bolting and shall be according to the following formula

$$P_b = \frac{-6.2M^*}{F^2 G^3} \quad (\text{MPa})$$

M^* shall be in accordance with **6.3 b)**

NOTE : When the opposite side pressure of P_t or P_s is minus pressure, the absolute value of the minus pressure shall be added. F and G shall be in accordance with clause 4.

6.7 Design pressure and diameter of fixed circle of periphery of floating flat tubesheet of floating head extracted type heat exchanger

Design pressure P and diameter of fixed circle of periphery G used in the bending formula shall be in accordance with the following **a)** and **b)**.