

Australian Standard™

**Heat exchangers— Tubeplates—
Method of design**

This Australian Standard was prepared by Committee ME/1, Pressure Equipment. It was approved on behalf of the Council of Standards Australia on 16 April 1999 and published on 5 July 1999.

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Australian Standard™

Heat exchangers— Tubeplates— Method of design

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PREFACE

This Standard was prepared by the Joint Standards Australia/Standards New Zealand Committee ME/1, Pressure Equipment, to supersede AS 3857—1990, *Heat exchangers—Tubeplates—Method of design*. Acknowledgment is gratefully made of the considerable assistance provided by Orica Engineering Pty Ltd (formerly ICI Australia Engineering Pty Ltd) which developed this method of design.

This Standard is the result of a consensus among representatives on the Joint Committee to produce it as an Australian Standard. Consensus means general agreement by all interested parties. Consensus includes an attempt to remove all objection and implies much more than the concept of a simple majority, but not necessarily unanimity. It is consistent with this meaning that a member may be included in the Committee list and yet not be in full agreement with all clauses of this Standard.

The main change in this revision is the incorporation of Amendment No. 1 to AS 3857—1990.

The Standard covers a method for the design of heat exchanger tubeplates. The Standard was originally drafted with the intention that it would be incorporated into AS 1210, *Pressure vessels*, as a replacement for the method contained in the first and second editions of AS 1210 but the draft was subsequently terminated. However, during the course of development of the proposal, its content was extended and it is now a self-contained method of design, suitable for publication as a separate Standard.

The Standard provides an additional method to other methods specified in AS 1210 for the design of tubeplates for heat exchangers complying with that Standard. The method may also be suitable for the design of some boiler tubeplates.

Although the design method may appear to be somewhat complex, it is no more so than some design methods for other pressure vessel components such as flanges.

While the method is applicable to long-hand calculations, its most effective use will be achieved by programming a computer. An appendix provides a simple algorithm for calculating Lord Kelvin's modified Bessel functions and this algorithm allows programs to be compiled on a computer. Tabulated values of the functions are also provided in the appendix. Suggested worksheets and worked examples of calculations are included in another appendix.

As the proposed design method allows actual stresses at any location to be determined, it can be used for heat exchangers designed to AS 1210 Supplement 1, *Unfired Pressure vessels—Advanced design and construction* (Supplement to AS 1210—1997).

The theoretical background for the method given in this Standard is given in a technical paper titled 'Australian Tubesheet Code' by P McGowan and I Mirovics presented at the ASME Conference on Pressure Vessels and Piping at Nashville, Tennessee in June 1990.

The terms 'normative' and 'informative' have been used in this Standard to define the application of the appendix to which they apply. A 'normative' appendix is an integral part of a Standard, whereas an 'informative' appendix is only for information and guidance.

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STANDARDS AUSTRALIA

Australian Standard

Heat exchangers—Tubeplates—Method of design

1 SCOPE This Standard sets out a method for designing flat, circular tubeplates of the following configurations:

- (a) Fixed tubeplates as in heat exchangers consisting of two tubeplates clamped or welded to a shell between them, with or without an expansion joint in the shell.
- (b) Tubeplates of U-tube or bayonet heat exchangers.
- (c) Floating tubeplates.

Such tubeplates are used in shell-and-tube heat exchangers and in some types of boilers including fire-tube and waste heat boilers.

2 APPLICATION This Standard is intended for use in association with an appropriate pressure vessel or boiler Standard such as—

- (a) shell-and-tube heat exchangers AS 1210 or AS 1210 Supplement 1
- (b) boilers AS 1228.

Calculated and permissible stresses in the tubeplates, tubes and shell shall be determined from this Standard but all other design criteria specified in the relevant pressure vessel or boiler Standard shall apply.

In the application of this Standard it will also be necessary to determine metal temperature from other sources (see Clause 5.1).

3 REFERENCED DOCUMENTS The following documents are referred to in this Standard:

AS	
1210	Pressure vessels
1210 Supplement 1	Unfired pressure vessels—Advanced design and construction (Supplement to AS 1210—1997)
1228	Pressure equipment—Boilers
EJMA	Standards of the Expansion Joint Manufacturers Association, Inc.

4 MATERIALS AND COMPONENTS

4.1 Acceptable materials Materials for tubeplates and associated components shall comply with a material specification listed, or as otherwise permitted, in AS 1210, AS 1210 Supplement 1 or AS 1228, as appropriate.

4.2 Design strength The material design strengths, used in the analysis of the tubeplate, shall comply with the values specified, or as otherwise permitted, in AS 1210, AS 1210 Supplement 1 or AS 1228, as appropriate.

4.3 Coefficient of thermal expansion The values which shall be used for the mean coefficient of thermal expansion are given in Table 4.3.

4.4 Young modulus (modulus of elasticity) The values which shall be used for Young Modulus are given in Table 4.4.

4.5 Expansion joints Metallic expansion joints should comply with the requirements specified in the 'Standards of the Expansion Joint Manufacturers Associations, Inc.' or equivalent.

TABLE 4.3
MEAN COEFFICIENT OF THERMAL EXPANSION BETWEEN 25°C AND DESIGN TEMPERATURE

Material		Mean coefficient of thermal expansion between 25°C and temperature, $K^{-1} \times 10^{-6}$ ($\mu m/m.K$)											
		Design temperature, °C											
Type or grade	Nominal composition	-50	0	50	100	150	200	250	300	350	400	450	500
<i>Carbon and low alloy steels</i>	C, C-Mn, .5Ni-.2Mo-V, .75Ni-.2Mo-Cr-V, .75Ni-.5Mo.3Cr-V, .75Ni-1Mo-.75Cr, .75Ni-.5Cr-.5Mo-V, 1Ni-.5Cr-.5Mo, .5Ni-.5Cr-.25Mo-V, .75Ni-.5Cu-Mo .75Cr-.75Ni-Cu-Al, .75Cr-.5Ni-Cu	11.15	11.45	11.75	12.07	12.39	12.69	12.99	13.29	13.57	13.84	14.09	14.34
	C-Si, C-.5Mo, .5Cr-.5Ni-.2Mo, .5Cr-.5Mo, .5Cr-.2Mo-V, 1Cr-.5Mo-1Cr-.2Mo, 1Cr-.2Mo-Si, 1.75Cr-.2Mo-Cu	9.29	9.89	10.49	11.08	11.63	12.14	12.60	13.02	13.40	13.74	14.02	14.27
	C-Mn-Si,.5Cr-.25Mo-Si,1Cr-.Mo-V, 1.25Cr-.5Mo(+ Si), 2Cr-.5Mo, 3Mo-1Mo	8.96	9.56	10.16	10.77	11.34	11.86	12.34	12.77	13.16	13.51	13.82	14.08
	Mn-Mo, Mn-Mo-Ni	12.37	12.60	12.83	13.09	13.34	13.58	13.80	14.01	14.20	14.38	14.55	14.70
	1.25Ni-1Cr-.5Mo, 1.75Ni-.75Cr-.25Mo, 2Ni-.755Cr-.25Mo, 2Ni-.75Cr-.33Mo, 2.5Ni, 3.5Ni, 3.5 Ni-1.75Cr-.5Mo-V,	10.74	11.10	11.46	11.86	12.21	12.54	12.83	13.11	13.36	13.60	13.82	14.01
	2.25Cr-1Mo	11.13	11.50	11.87	12.15	12.46	12.75	13.01	13.24	13.46	13.64	13.82	13.98
	5Cr-.5Mo, (+Si, +Ti)	11.34	11.60	11.85	12.05	12.24	12.41	12.59	12.75	12.91	13.06	13.21	13.35
	7Cr-.5Mo, 7Cr-1Mo	10.18	10.40	10.62	10.83	11.04	11.24	11.43	11.62	11.80	11.97	12.14	12.29
	Mn-V	11.39	11.80	12.21	12.55	12.88	13.18	13.45	13.70	13.93	14.14	14.33	14.51
	5Ni-.25Mo	10.59	11.00	11.41	11.74	12.03	12.29	12.55	12.78	13.01	13.23	13.44	13.64
	8Ni, 9Ni	9.25	9.75	10.25	10.72	11.09	11.39	11.66	11.90	12.12	12.31	12.48	12.63
<i>Stainless steel</i>													
405, 410	12Cr-Al, 13Cr	10.25	10.55	10.85	11.08	11.27	11.44	11.58	11.70	11.81	11.91	12.02	12.13
429, 430	15Cr, 17Cr	9.66	9.70	9.74	9.94	10.13	10.31	10.49	10.65	10.81	10.96	11.11	11.24
304	18Cr-8Ni	14.67	15.10	15.53	15.90	16.24	16.55	16.84	17.11	17.36	17.59	17.81	18.00
316, 317	16Cr-12Ni-2Mo, 18Cr-13Ni-3Mo	14.45	14.95	15.45	15.86	16.26	16.63	16.96	17.25	17.52	17.77	18.00	18.23
321	18Cr-10Ni-Ti	15.99	16.12	16.25	16.41	16.57	16.72	16.85	16.98	17.10	17.22	17.34	17.45
347 and 348	18Cr-10Ni-Nb	14.64	15.15	15.66	16.14	16.58	16.97	17.30	17.59	17.85	18.08	18.29	18.51
309, 310	23Cr-12Ni, 25Cr-12Ni, 25Cr-20Ni	15.60	15.80	16.00	16.15	16.26	16.35	16.43	16.51	16.57	16.64	16.71	16.78
S31803, 2304	22Cr-5Cr-3Mo, 23Cr-4Ni	12.25	12.50	12.75	13.00	13.25	13.50	13.75	14.00	14.25	14.50		
N08904	25Ni-20Cr-4.5Mo-1.5Cu	13.50	14.00	14.50	15.00	15.50	16.00	16.25	16.50	16.75	17.00		
N08028	31Ni-27Cr-3.5Mo-1.0Cu	14.25	14.50	14.75	15.00	15.25	15.50	15.75	16.00	16.25	16.50		

(continued)

TABLE 4.3 (continued)

Material		Mean coefficient of thermal expansion between 25°C and temperature, K ⁻¹ × 10 ⁻⁶ (µm/m.K)											
		Design temperature, °C											
Type or grade	Nominal composition	-50	0	50	100	150	200	250	300	350	400	450	500
Aluminium alloys		21.75	22.25	22.75	23.23	23.72	24.21						
3003 and 3004		22.38	22.85	23.32	23.82	24.33	24.83						
5052 and 5454		22.54	23.05	23.56	24.06	24.57	25.08						
5083 and 5086		21.84	22.35	22.86	23.35	23.85	24.34						
6061		21.92	22.45	22.98	23.47	23.95	24.44						
6063													
Copper and copper alloys	Copper	16.30	16.50	16.70	16.90	17.10	17.30	17.50	17.70	17.90	18.10	18.30	18.50
	Brasses: 90Cu–10Zn	16.63	16.87	17.12	17.36	17.60	17.84	18.08	18.33	18.57	18.81	19.05	19.29
	80Cu–20Zn	16.96	17.25	17.53	17.82	18.10	18.38	18.67	18.95	19.24	19.52	19.81	20.09
	70Cu–30Zn	17.29	17.62	17.95	18.27	18.60	18.93	19.25	19.58	19.91	20.23	20.56	20.88
	60Cu–40Zn	17.62	17.99	18.36	18.73	19.10	19.47	19.84	20.21	20.57	20.94	21.31	21.68
	Cu–Ni 90Cu–10Ni	15.50	15.74	16.00	16.26	16.52	16.76	16.94	17.10	17.26	17.42	17.58	17.74
	80Cu–20Ni	14.56	14.85	15.18	15.51	15.84	16.13	16.28	16.40	16.51	16.62	16.73	16.85
	70Cu–30Ni	14.30	14.60	14.95	15.30	15.65	15.95	16.10	16.20	16.30	16.40	16.50	16.60
	Bronze	16.50	16.74	16.99	17.23	17.47	17.71	17.95	18.20	18.44	18.68	18.92	19.16
Nickel and nickel alloys													
200, 201	Ni, Low C–Ni	11.39	11.80	12.21	12.62	12.99	13.30	13.64	13.94	14.22	14.46	14.68	14.91
330	Ni–44Fe–18Cr–1Si	13.95	14.35	14.75	15.04	15.29	15.53	15.77	15.99	16.20	16.38	16.54	16.69
400 and 405	Ni–32Cu	13.44	13.75	14.06	14.36	14.65	14.92	15.16	15.37	15.56	15.73	15.88	16.02
600	Ni–15.5Cr–8Fe	11.41	11.95	12.49	12.96	13.35	13.67	13.94	14.17	14.36	14.52	14.68	14.82
800 and 800H	Ni–46Fe–21Cr	13.14	13.80	14.46	14.90	15.20	15.43	15.62	15.77	15.90	16.02	16.15	16.27
825	Ni–30Fe–21Cr–3Mo–2Cu	13.20	13.40	13.60	13.80	13.98	14.15	14.31	14.48	14.63	14.78	14.92	15.05
B	Ni–28Mo–5Fe	10.76	10.90	11.04	11.28	11.46	11.57	11.64	11.71	11.78	11.86	11.95	12.05
C–4	Ni–16Cr–16Mo	11.00	11.10	11.40	11.76	11.95	12.20	12.43	12.65	12.83	12.99	13.12	13.25
C–276	Ni–15.5Cr–16Mo–5.5Fe–4W	10.59	10.80	11.01	11.35	11.67	11.98	12.28	12.55	12.79	13.00	13.20	13.40
Titanium and titanium alloys													
1, 2, 3 and 7		8.40	8.40	8.40	8.46	8.53	8.59	8.66	8.73	8.80	8.86		
Zirconium and zirconium alloys													
702	Zr	5.85	5.87	5.89	5.89	5.89	5.89	5.89	5.89	5.89	5.89		
705 and 706	Zr–2.5Nb			6.30									

TABLE 4.4
YOUNG MODULUS (MODULUS OF ELASTICITY (*E*))

Material		Young modulus, GPa											
		Temperature, °C											
Type or grade	Nominal composition	−50	0	50	100	150	200	250	300	350	400	450	500
Carbon and low alloy steels	C ≤ .3%C	207	204	201	198	195	192	189	186	179	171	162	150
	C > .3%C	206	203	200	197	194	191	187	184	178	170	161	149
	C-.5Mo, Mn-.5Mo, Mn-.25Mo, Mn-V	205	202	199	196	193	190	187	184	178	170	160	150
	.5Ni-.5Mo-V, .5Ni-.5Cr-.25Mo-V	196	193	190	187	184	181	178	175	171	167	163	159
	.75Ni-.5Mo-Cr-V, .75Ni-1Mo-.75Cr,												
	.75Ni-.5Cu-Mo, 1Ni-.4Cr-.5Mo,												
	.75Cr-.5Ni-Cu, .75Cr-.75Ni-Cu-Al,												
	2Ni-1Cu, 2.5Ni, 3.5Ni												
Stainless steel	.5Cr-.5Mo, 1Cr-.5Mo,	210	207	204	200	196	193	190	187	183	179	174	170
	1.25Cr-.5Mo(+Si), 2Cr-.5Mo												
	2.25Cr-1Mo, 3Cr-1Mo	217	213	209	206	203	199	196	192	188	184	179	175
	5Cr-.5Mo(+Si, +Ti), 7Cr-.5Mo, 9Cr-Mo	219	215	211	207	204	201	198	194	190	184	176	168
	405, 410	205	202	199	196	192	189	185	181	178	174	166	156
	429, 430												
	304	202	198	194	190	186	183	179	175	172	169	164	161
	316, 317												
	321												
	347 and 348												
Aluminium alloys	309, 310	205	200	195	190	185	180	175	170	165	160	165	161
	S31803, 2304												
	N08904	200	196	193	190	185	180	175	170	167	165	165	161
	N08028	204	201	198	195	192	190	185	180	175	170	170	166
	3003, 3004,6061, 6063	71	70	68	66	63	60	60	60	60	60	60	60
	5052, 5054	73	71	69	67	65	62	62	62	62	62	62	62
	5083, 5086	74	72	70	68	65	62	62	62	62	62	62	62

(continued)

TABLE 4.4 (continued)

Material		Young modulus, GPa											
		Temperature, °C											
Type or grade	Nominal composition	−50	0	50	100	150	200	250	300	350	400	450	500
Copper and copper alloys	Copper > 95%	117	114	111	108	105	102	99	95	92	89	86	83
	Brasses: 10 and 20 Zn	105	103	100	97	95	92	89	86	83	80	77	75
	30 and 40 Zn	94	91	89	86	84	82	79	76	74	71	69	66
	Cu–Ni: 10Ni	140	137	133	130	126	122	119	114	110	107	103	100
	20 and 30 Ni	152	148	144	140	137	133	129	124	120	116	112	108
	Bronze	110	107	104	102	99	96	93	89	86	84	81	78
Nickel and nickel alloys	Ni and Low C Ni	211	208	205	202	199	197	194	192	189	186	182	179
	200, 201												
	330	197	194	191	188	185	183	181	179	177	174	170	167
	400 and 405	184	181	178	175	173	171	168	166	164	161	158	155
	600	219	215	211	208	206	204	201	199	196	192	189	185
	800 and 800H	200	197	194	191	189	187	185	183	180	177	174	170
	825	197	194	191	188	185	183	181	179	177	174	170	167
	B	218	215	212	209	206	204	201	199	197	193	189	185
	C–4	209	206	203	200	197	195	193	191	188	185	181	177
	C276	209	206	203	200	197	195	193	191	188	185	181	177
Titanium and titanium alloys													
	1, 2, 3 and 7	110	108	106	103	100	97	93	88	84	80		
Zirconium and zirconium alloys													
	702	101	100	98	95	92	86	80	74	68			
	705 and 706	103	102	100	93	86	80	75	71	67			

5 DESIGN

5.1 Analysis In the method of analysis in this Clause, moments, stresses and deflections across the tubeplate are calculated. To determine the maximum stresses, full moment and deflection curves shall be calculated and constructed for several cases for each design condition (see Clause 5.4).

NOTE: Such calculations are most effectively performed using a computer.

Permissible stresses shall be based on the design strengths specified in the pressure vessel or boiler Standard applicable to the equipment in which the tubeplate is to be a component, e.g. AS 1210, AS 1210 Supplement 1 or AS 1228.

To determine metal temperature, a heat transfer analysis shall be undertaken for each design condition.

NOTE: Guidance in estimating heat transfer coefficients and fouling resistances may be found in technical publications such as—

- (a) for pressure vessels—
 - (i) Tubular Exchanger Manufacturers Association (TEMA) Standards *;
 - (ii) Compact Heat Exchangers †; and
- (b) for boilers—AS 1228.

5.2 Assumptions The analysis is based on the following assumptions:

- (a) The tubeplates are flat, circular and the tube pattern is approximately axisymmetric.
- (b) The tube pattern is equilateral triangular (although some approximate results for square patterns are included).
- (c) $R > R_i - t_p$ and $R > 4.5t_p$.
- (d) $L_s > 6l_s$ (if an expansion joint is used, it is placed at least $3l_s$ from the tubeplate).
- (e) Channel shell length $> 2l_c$ (where channel shell is welded to tubeplate).
- (f)
$$t_p \geq \frac{(P - d_t)}{2}$$
- (g) $N_t \geq 37$.
- (h) $q > 0.09$.
- (i) The movement of the tubeplate is not obstructed by anything (e.g. channel baffles), except the tubes.
- (j) For fixed tubeplates—both have the same flexural rigidity.
- (k) Tube bending is ignored.
- (l) Stresses due to temperature gradient across the tubeplate are disregarded except as specified in Clause 5.8.

For situations falling outside the above, special analysis is required to accurately calculate stresses.

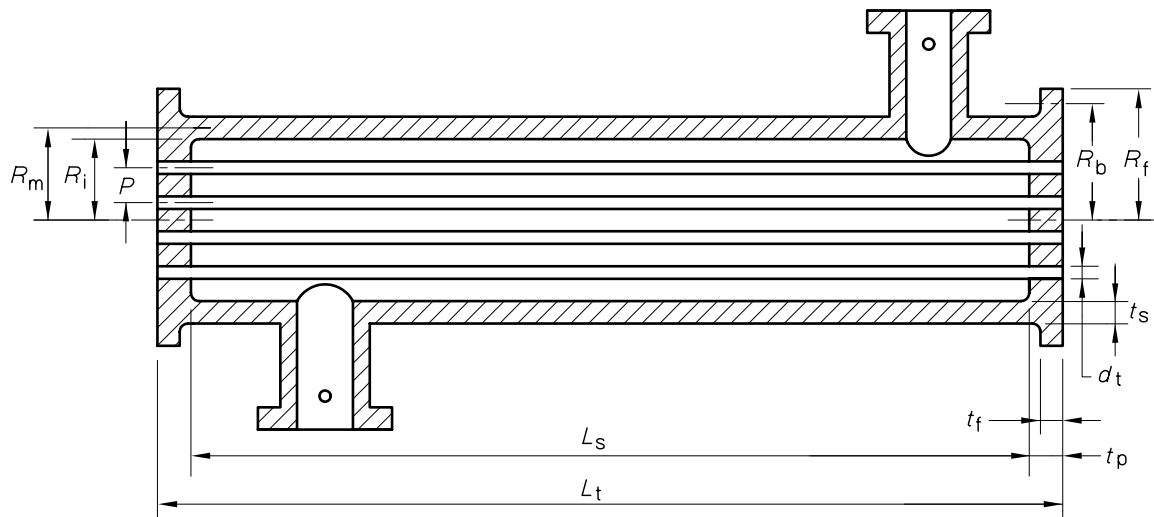
5.3 Notation and calculation parameters For the purpose of this Standard, notation and calculation parameters tabulated below apply. The notation for dimensions of components are shown on Figures 5.3(A), 5.3(B), and 5.3(C).

The symbols for units used in this Clause are combinations of the following:

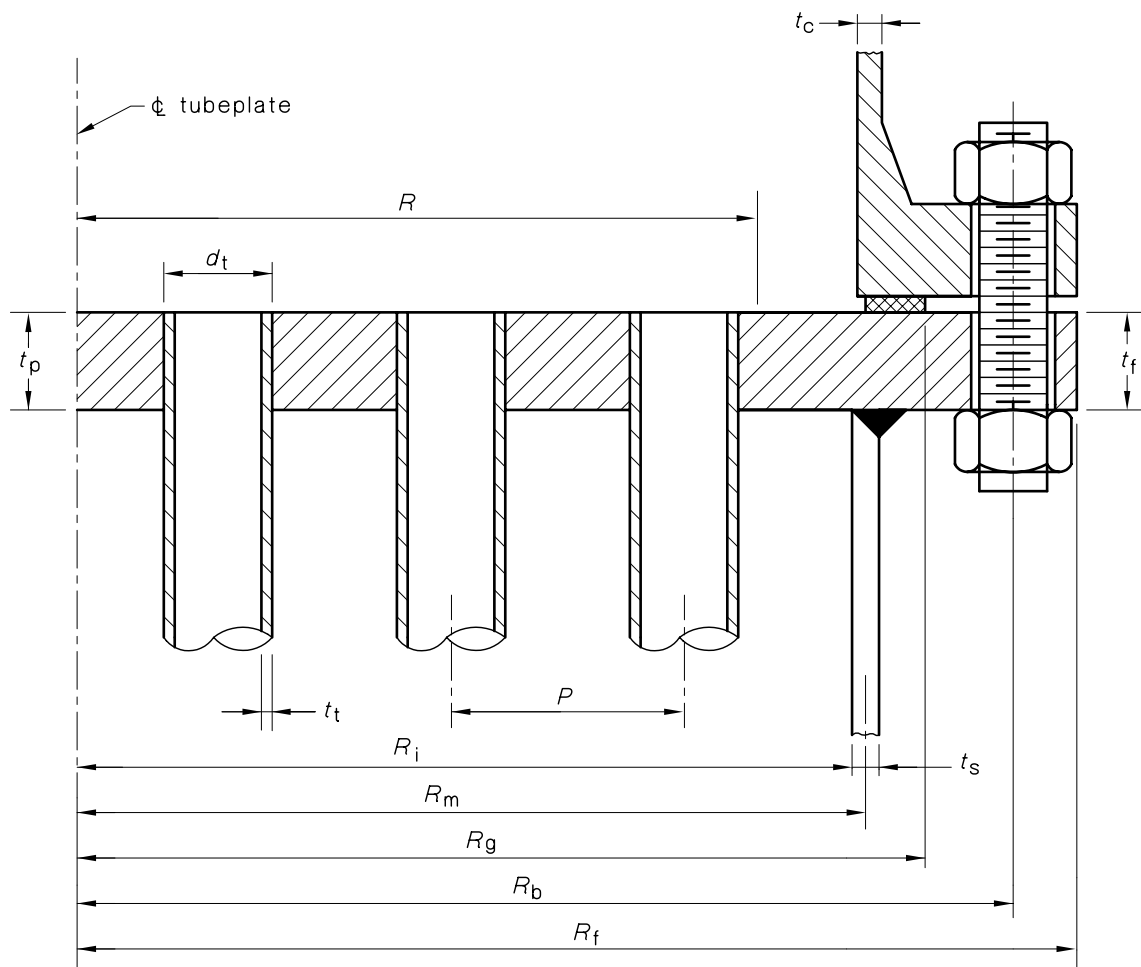
- (a) mm (millimetre).
- (b) N (newton).
- (c) MPa (megapascal).
- (d) °C (degrees Celsius).
- (e) K (kelvin).
- (f) rad (radian).

* Standards of Tubular Exchanger Manufacturers Association, Inc.

† Kays, W.M. and London, A.L. *Compact Heat Exchangers*. 3rd ed. New York: McGraw-Hill, 1984. p. 352.



(a) Shell and tubes



(b) Fixed tubeplate

FIGURE 5.3 (in part) NOTATION FOR DIMENSIONS OF HEAT EXCHANGER COMPONENTS