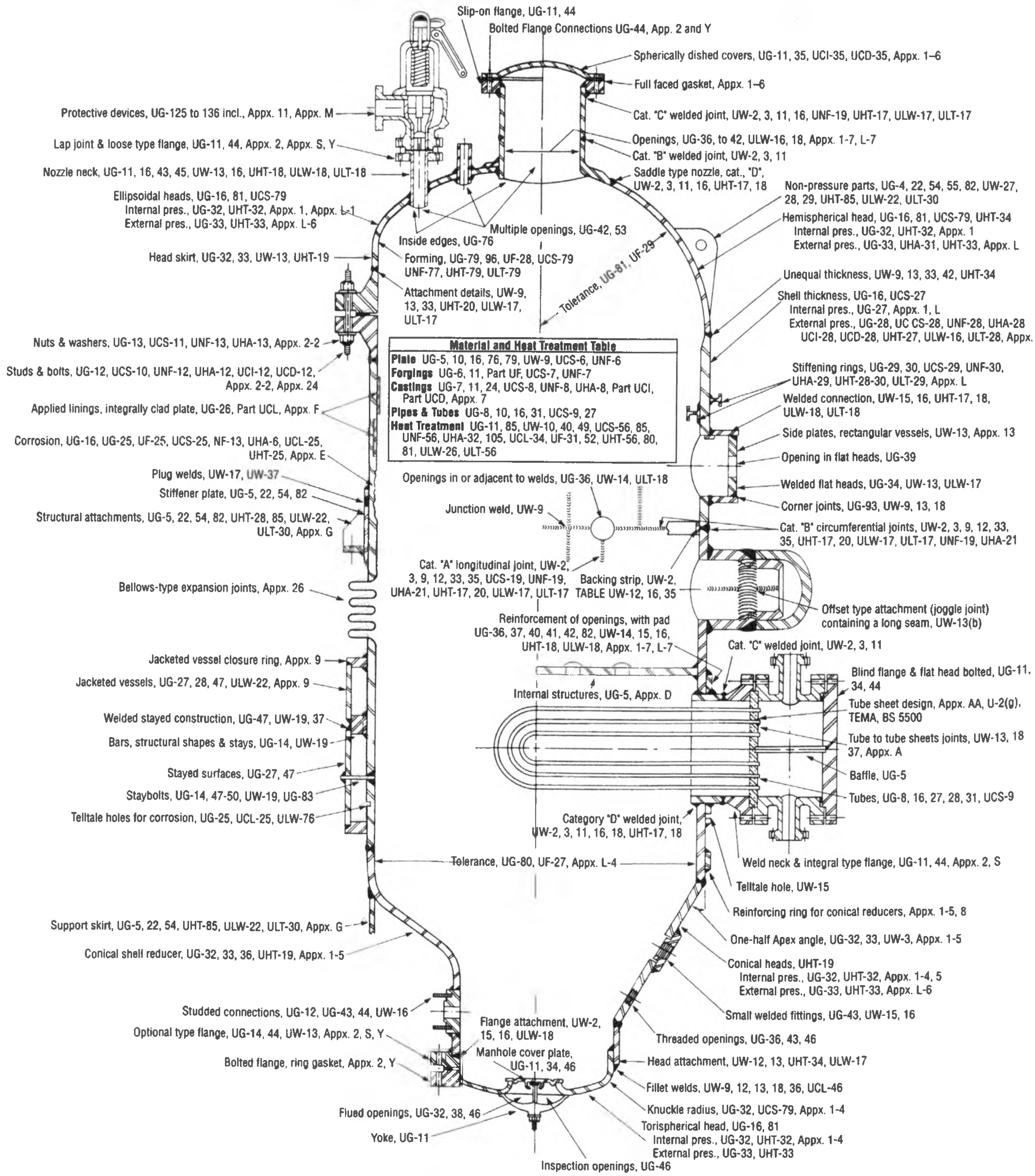
Appendices

Appendix A: Guide to ASME Section VIII, Division 1



Organization of Section VIII, Div. 1

Introduction—Scope and Applicability
Subsection A—part UG—General requirements for all construction and all materials.
Subsection B—Requirements for method of fabrication
- Part UW—Welding
- Part UF—Forging
- Part UB—Brazing

Subsection C—Requirements for classes of material.
- Part UCS—Carbon and low alloy steels
- Part UNF—Nonferrous materials
- Part UHA—High alloy steels
- Part UCI—Cast iron
- Part UCL—Clad plate and corrosion resistant liners
- Part UCD—Cast ductile iron
- Part UHT—Ferritic steels with tensile properties enhanced by heat treatment
- Part ULW—Layered construction
- Part ULT—Low Temperature Materials

Mandatory appendices—1through 29
Nonmandatory appendices—A through Y, AA, CC, DD, EE

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(b) Forgings	UG-6
(c) Castings	UG-7
(d) Pipe & Tubes	UG-8
(e) Welding	UG-9
(f) Bolts & Studs	UG-12
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(h) Rods & Bars	UG-14
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(c) Magnetic Particle	Appx. 6
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Porosity Charts	Appx. 4
Code Jurisdiction Over Piping	U-1
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Material Identification, Marking and Certification	UG-77, 93, 94
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Courtesy of Hartford Steam Boiler Inspection and Insurance Company

Appendix B: Design Data Sheet for Vessels

1 Customer/Client				
2 Customer Order No.				
3 Shop Order No.				
4 Design Drawing				
5 Specifications				
6 Vessel Name				
7 Equipment/Item Number				
8 Design Code & Addenda				
9 Design Pressure & Temperature	Internal		External	
10 Operating Pressure & Temperature				
11 Vessel Diameter				
12 Volume				
13 Design Liquid Level				
14 Contents & Specific Gravity				
15 Service				
16 MAWP (Corrosion at Design Temperature)			Limited by	
17 MAP (N & C)				
18 Test pressures	Shop		Field	
19 Heat treatment				
20 Joint efficiencies	Shell			
	Heads			
21 Corrosion allowance	Shell		**22 Flange ratings**	
	Heads		MAP:	psig at Ambient
	Nozzles		MAWP:	psig at D.T.
	Boot		Hydro:	psig
23 Materials		**24 Allowable Stress**	Ambient	D.T.
Shell				
Heads				
Nozzles				
Flanges				
Bolting				
Supports				
25 Weights	Fabricated	Operating		
	Empty	Test		
26 Notes/remarks				

Appendix C: Joint Efficiencies (ASME Code) [3]

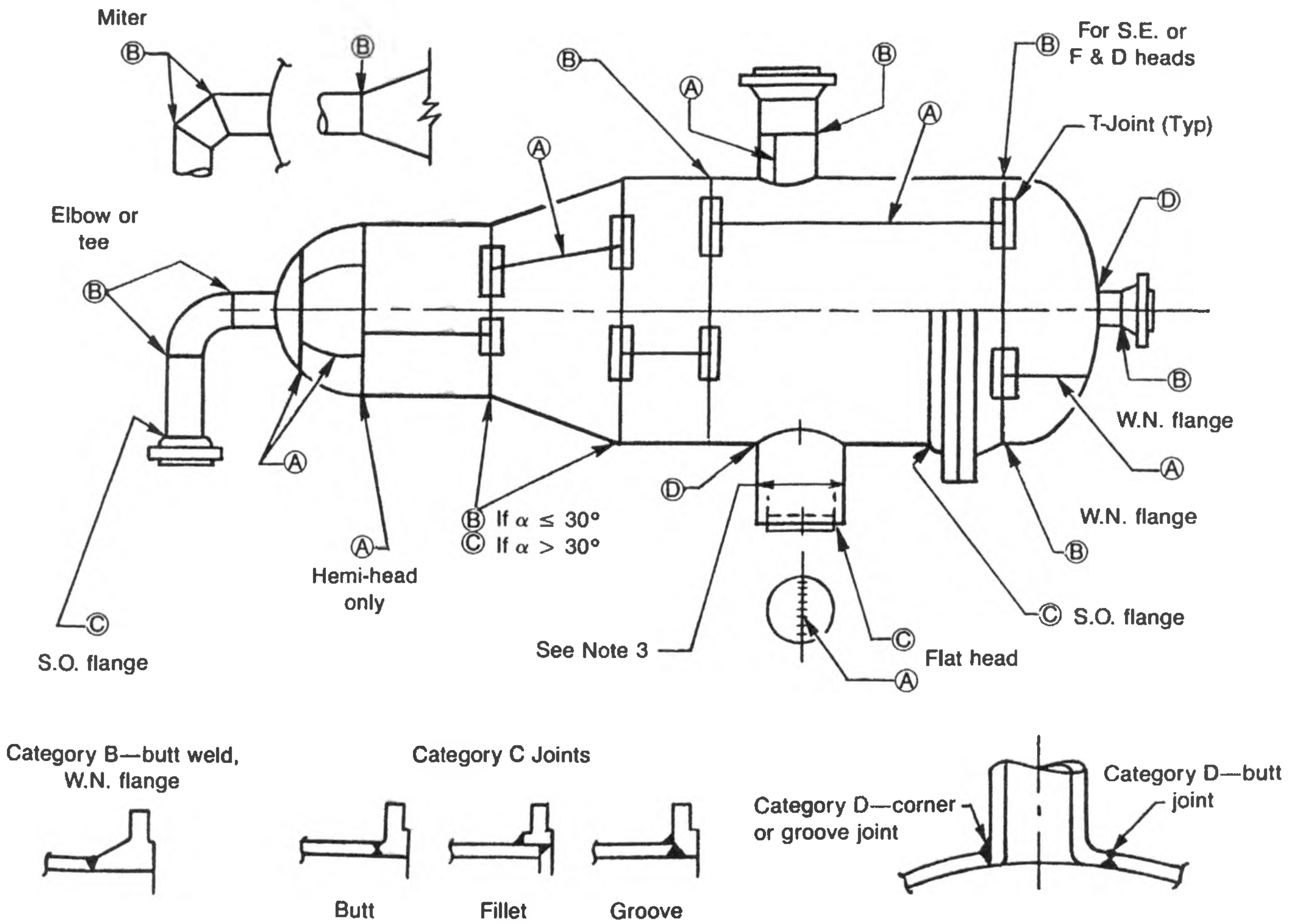


Figure C-1. Categories of welded joints in a pressure vessel.

Table C-1
Types of joints and joint efficiencies

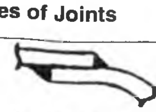
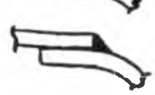
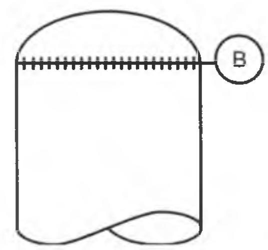
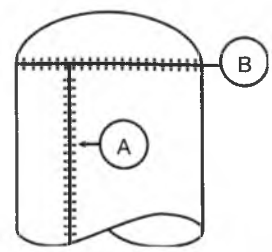
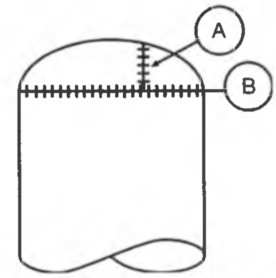
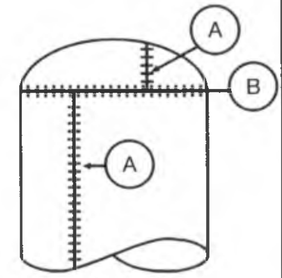
Types of Joints			Full	X-Ray Spot	None	Types of Joints			Full	X-Ray Spot	None
1		Single- and double-butt joints	1.0	0.85	0.7	4		Double full fillet lap joint	—	—	0.55
2		Single-butt joint with backing strip	0.9	0.8	0.65	5		Single full fillet lap with plugs	—	—	0.5
3		Single butt joint without backing strip	—	—	0.6	6		Single full fillet lap joint	—	—	0.45

Table C-2
Application of joint efficiencies

Extent of Radiography		Case 1		Case 2		Case 3		Case 4	
		Seamless Head Seamless Shell		Seamless Head Welded Shell		Welded Head Seamless Shell		Welded Head Welded Shell	
									
		Head	**Shell**	**Head**	**Shell**	**Head**	**Shell**	**Head**	**Shell**
Full	Cat. A and B	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Spot	Cat. A only	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85
	(4)	1.0	1.0	1.0	0.85	0.85	1.0	—	—
Part	(2)	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
None	Cat. A and B	0.85	0.85	0.85	0.7	0.7	0.85	0.7	0.7

Notes

1. In Table C-2 joint efficiencies and allowable stresses for shells are for longitudinal seams only and all joints are assumed as Type 1 only.
2. *"Part" radiography:* Applies to vessels *not* fully radiographed where the designer wishes to apply a joint efficiency of 1.0 per ASME Code, Table UW-12, for only a specific part of a vessel. Specifically for any part to meet this requirement, you must perform the following:
   - *(ASME Code, Section UW(5))*: Fully x-ray any Category A or D *butt* welds.
   - *(ASME Code, Section UW-11(5)(b))*: Spot x-ray any Category B or C *butt* welds attaching the part.
   - *(ASME Code, Section UW-11(5)(a))*: All butt joints must be Type 1 or 2.
3. Any Category B or C butt weld in a nozzle or communicating chamber of a vessel or vessel part which is to have a joint efficiency of 1.0 and exceeds either 10-in. nominal pipe size or 1⅛ in. in wall thickness shall be fully radiographed. See ASME Code, Sections UW-11(a)(4).
4. In order to have a joint efficiency of 1.0 for a seamless part, the Category B seam attaching the part must, as a minimum, be spot examined.

Appendix D: Properties of Heads

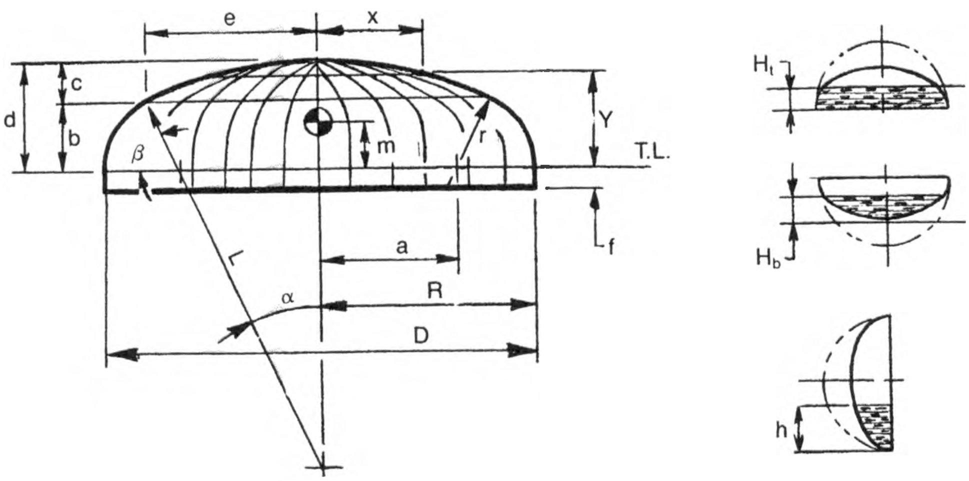


Figure D-1. Dimensions of heads.

Formulas

$$a = \frac{D - 2r}{2}$$
$$\alpha = \arcsin\left(\frac{a}{L - r}\right)$$
$$\beta = 90 - \alpha$$
$$b = \cos\alpha\, r$$
$$c = L - \cos\alpha\, L$$
$$e = \sin\alpha\, L$$
$$\phi = \frac{\beta}{2}$$

Volume

$$V_1 = (\text{frustum}) = 0.333b\pi(e^2 + ea + a^2)$$
$$V_2 = (\text{spherical segment}) = \pi c^2\left(L - \frac{c}{3}\right)$$
$$V_3 = (\text{solid of revolution})$$
$$= \frac{120r^3\pi \sin\phi \cos\phi + a\phi\pi^2 r^2}{90}$$

TOTAL VOLUME: $V = V_1 + V_2 + V_3$

Depth of Head

$$A = L - r$$
$$B = R - r$$
$$d = L - \sqrt{A^2 - B^2}$$

Table D-1
Partial volumes

Type	Volume to H_t	Volume to H_b	Volume to h
HEMI	$\frac{\pi D^2 H_t}{4}\left[1 - \frac{4H_t^2}{3D^2}\right]$	$\frac{\pi D H_b^2}{2}\left[1 - \frac{2H_b}{3D}\right]$	$\frac{\pi h^2(1.5D - h)}{6}$
2:1 S.E.	$\frac{\pi D^2 H_t}{4}\left[1 - \frac{16H_t^2}{3D^2}\right]$	$\pi D H_b^2\left[1 - \frac{4H_b}{3D}\right]$	$\frac{\pi h^2(1.5D - h)}{12}$
100%–6% F & D	$\frac{3VH_t}{2d}\left[1 - \frac{H_t^2}{3d^2}\right]$	$\frac{3VH_b^2}{2d^2}\left[1 - \frac{H_b}{3d}\right]$	$\frac{3Vh^2}{D^2}\left[1 - \frac{2h}{3D}\right]$

Table D-2
General data

			C.G.-m			Points on heads	
Type	Surf. Area	Volume	Empty	Full	Depth of head-d	X=	Y =
HEMI	$\pi D^2/2$	$\pi D^3/12$	0.2878D	0.375D	0.5D	$\sqrt{R^2 - Y^2}$	$\sqrt{R^2 - X^2}$
2:1 S.E.	$1.084D^2$	$\pi D^3/24$	0.1439D	0.1875D	0.25D	$0.5\sqrt{D^2 - 16Y^2}$	$0.25\sqrt{D^2 - 4X^2}$
100%–6% F&D	$0.9286D^2$	$0.0847D^3$	0.100D		0.162D		

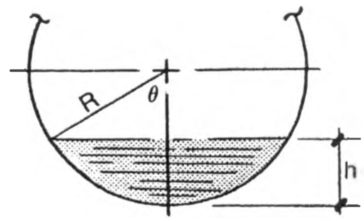
Appendix E: Volumes and Surface Areas of Vessel Sections

Notation

ℓ = height of cone, depth of head, or length of cylinder
α = one-half apex angle of cone
D = large diameter of cone, diameter of head or cylinder
R = radius
r = knuckle radius of F & D head
L = crown radius of F & D head
h = partial depth of horizontal cylinder
K, C = coefficients
d = small diameter of truncated cone
V = volume

$$K = \frac{L}{R} - \sqrt{\left(\frac{L}{R} - 1\right)\left(\frac{L}{R} + 1 - \frac{2r}{R}\right)}$$

$$e = \sqrt{1 - \frac{\ell^2}{R^2}}$$



$$\theta = \arccos\frac{R-h}{R}$$

$$V = R^2\ell\left[\left(\frac{\pi\theta^\circ}{180}\right) - \sin\theta\cos\theta\right]$$

or

$V = \pi R^2 \ell c$ (See Table E-3 for values of c.)

Figure E-1. Formulas for partial volumes of a horizontal cylinder.

Table E-1
Volumes and surface areas of vessel sections

Section	Volume		Surface area	
	Diameter	Radius	Diameter	Radius
Sphere	$\pi D^3 / 6$	$4 \pi R^3 / 3$	πD^2	$4 \pi R^2$
Hemi Head	$\pi D^3 / 12$	$2 \pi R^3 / 3$	$\pi D^2 / 2$	$2 \pi R^2$
2:1 S.E. Head	$\pi D^3 / 24$	$\pi R^3 / 3$	$1.084 D^2$	$4.336 R^2$
Ellipsoidal Head	$\pi D^2 h / 6$	$2 \pi R^2 h / 3$	$.5 [.5\pi D^2 + (\pi h^2/e) \mathrm{Ln} (1 + e / 1 - e)]$	$.5 [2\pi R^2 + (\pi h^2/e) \mathrm{Ln} (1 + e / 1 - e)]$
100% - 6% F&D Head	$.08467 D^3$	$.6774 R^3$	$.9286 D^2$	$3.7144 R^2$
F&D Head	$\pi D^3 K / 12$	$2 \pi R^3 K / 3$	$.25 \pi D^2[1 + 4h^2/D^2 (2 - 2h/D)]$	$\pi R^2[1 + h^2/R^2 (2 - h/R)]$
Cone	$\pi D^2 h / 12$	$\pi R^2 h / 3$	$\pi Dh / 2 \cos \alpha$	$\pi Rh / \cos \alpha$
Truncated Cone	$.0833[\pi h (D^2 + Dd + d^2)]$	$.33[\pi h (R^2 + Rr + r^2)]$	$\pi [.5(D + d)] [h^2 + .5 (D - d)^2]^{1/2}$	$\pi (R + r) [h^2 + (R - r)^2]^{1/2}$
30° Truncated Cone	$.227 (D^3 - d^3)$	$1.826 (R^3 - r^3)$	$.5 \pi (D^2 - d^2)$	$2 \pi (R^2 - r^2)$
Cylinder	$\pi D^2 h / 4$	$\pi R^2 h$	πDh	$2 \pi Rh$

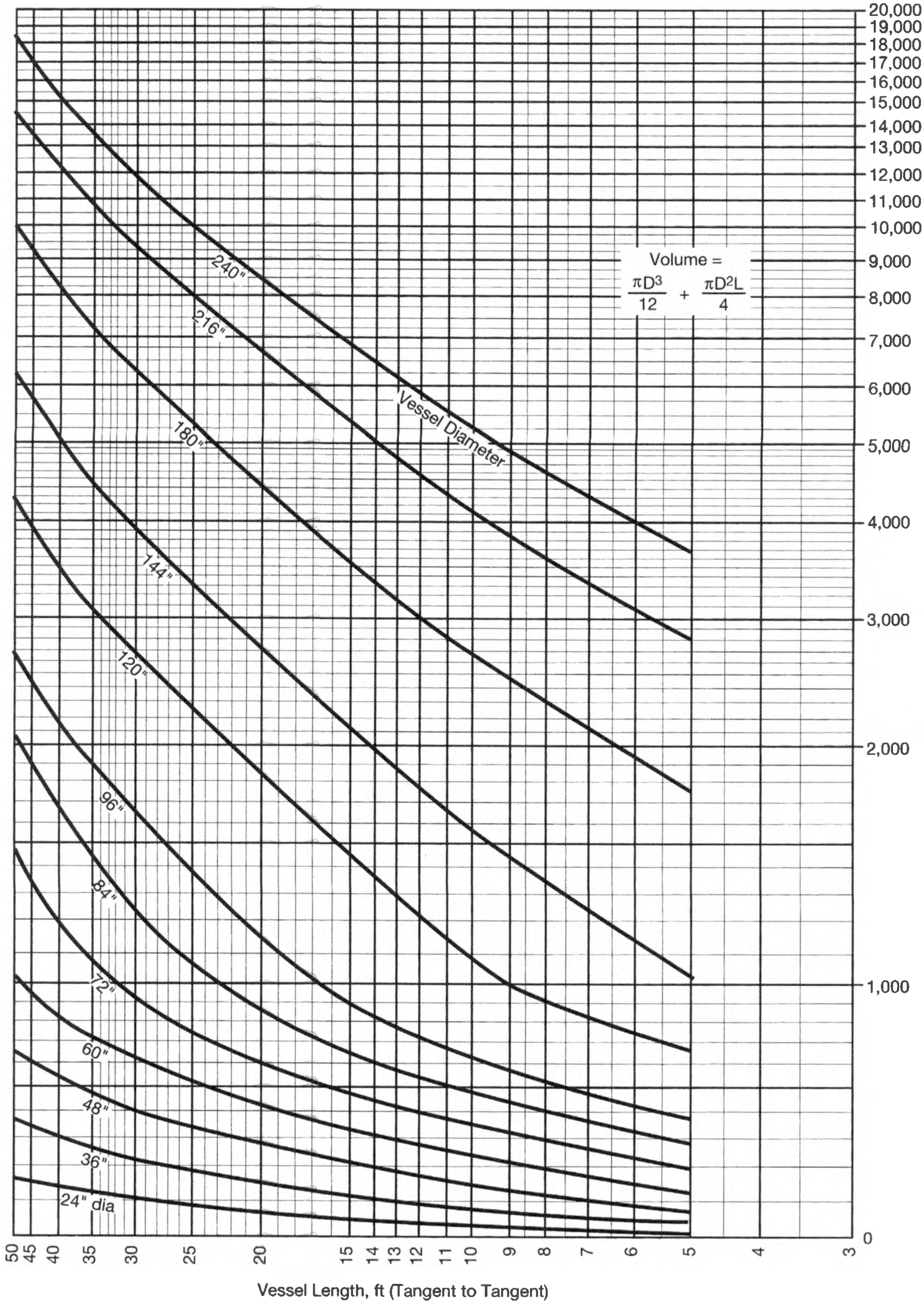


Figure E-2. Volume of vessels (includes shell plus (2) 2:1 S.E. Heads).

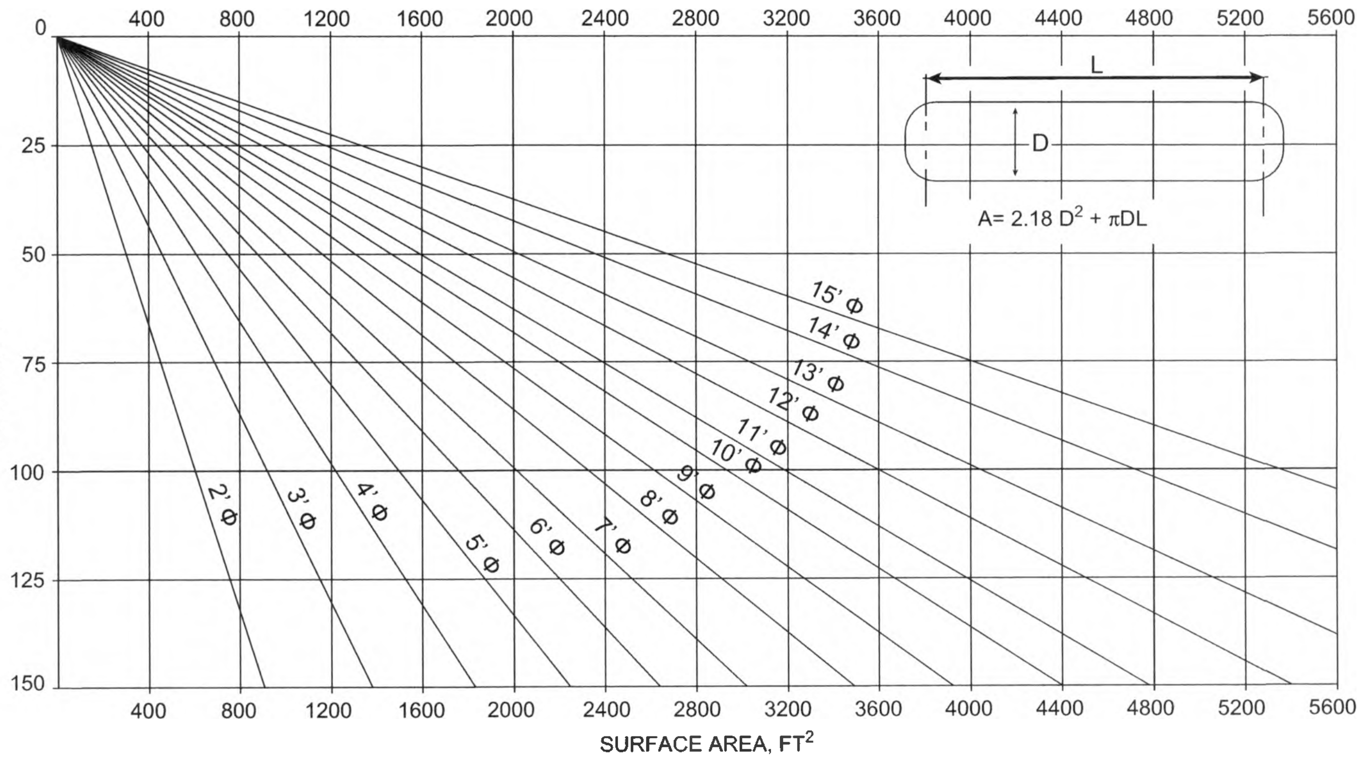


Figure E-3. Surface area of vessel with (2) 2:1 S.E. Heads.

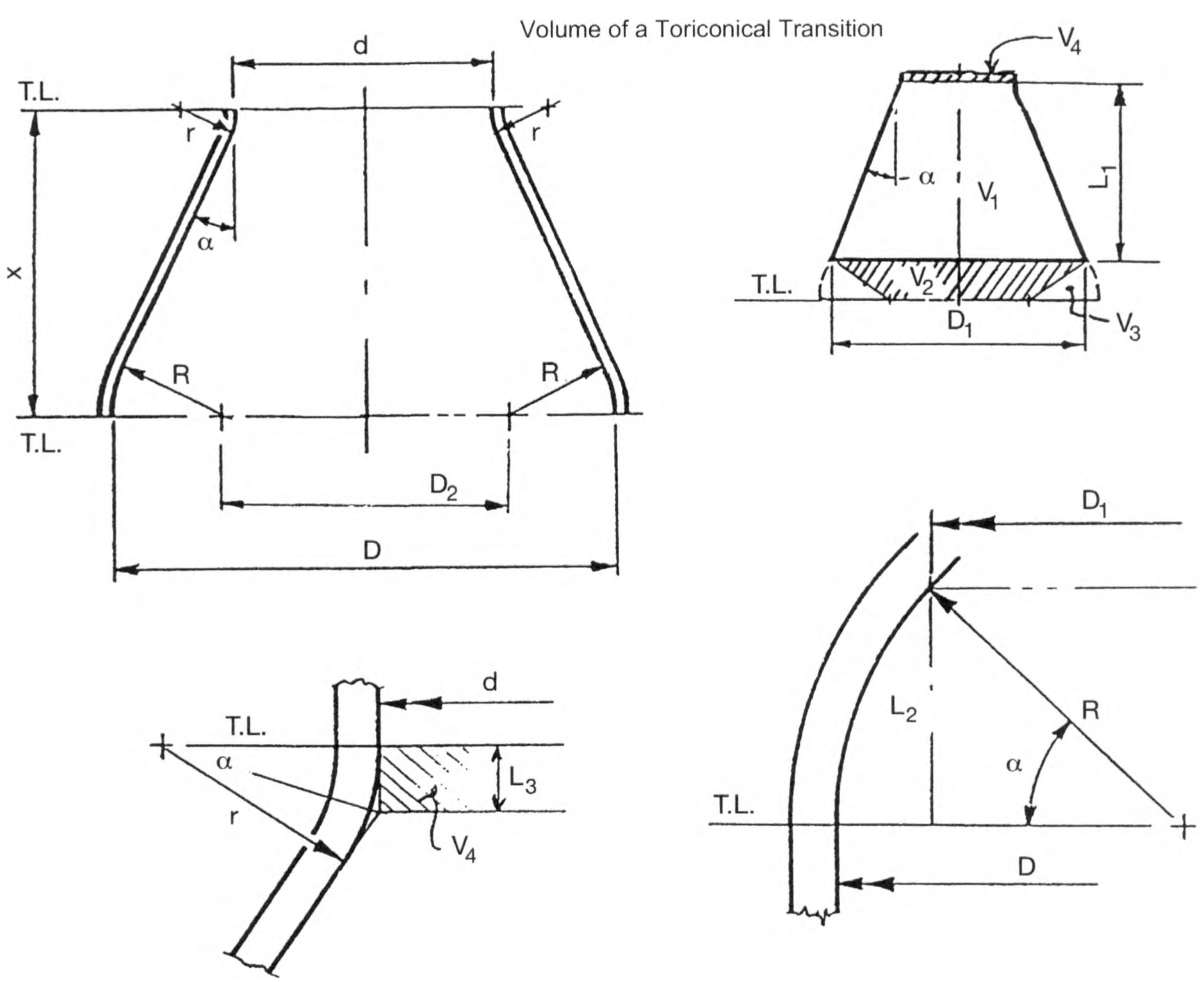


Figure E-4. Volume of a toriconical transition.

Dimensions

$D =$
$d =$
$R =$
$r =$
$x =$
$\alpha =$
$L_2 = \sin\alpha\, R =$
$L_3 = \tan\frac{\alpha}{2}(r) =$
$L_1 = x - L_2 - L_3 =$
$D_1 = D - 2(R - R\cos\alpha) =$
$D_2 = D - 2R =$

Volumes

$$V_1 = \frac{\pi L_1\left(D_1^2 + D_1 d + d^2\right)}{12} =$$

$$V_2 = \frac{\pi L_2\left(D_1^2 + D_1 D_2 + D_2^2\right)}{12} =$$

$$V_3 = \frac{120R^3\pi \sin(\alpha/2)\cos(\alpha/2) + .25D_2R^2(\alpha/2)}{90} =$$

$$V_4 = \frac{\pi d^2 L_3}{4} =$$

$$\sum V = V_1 + V_2 + V_3 + V_4 =$$

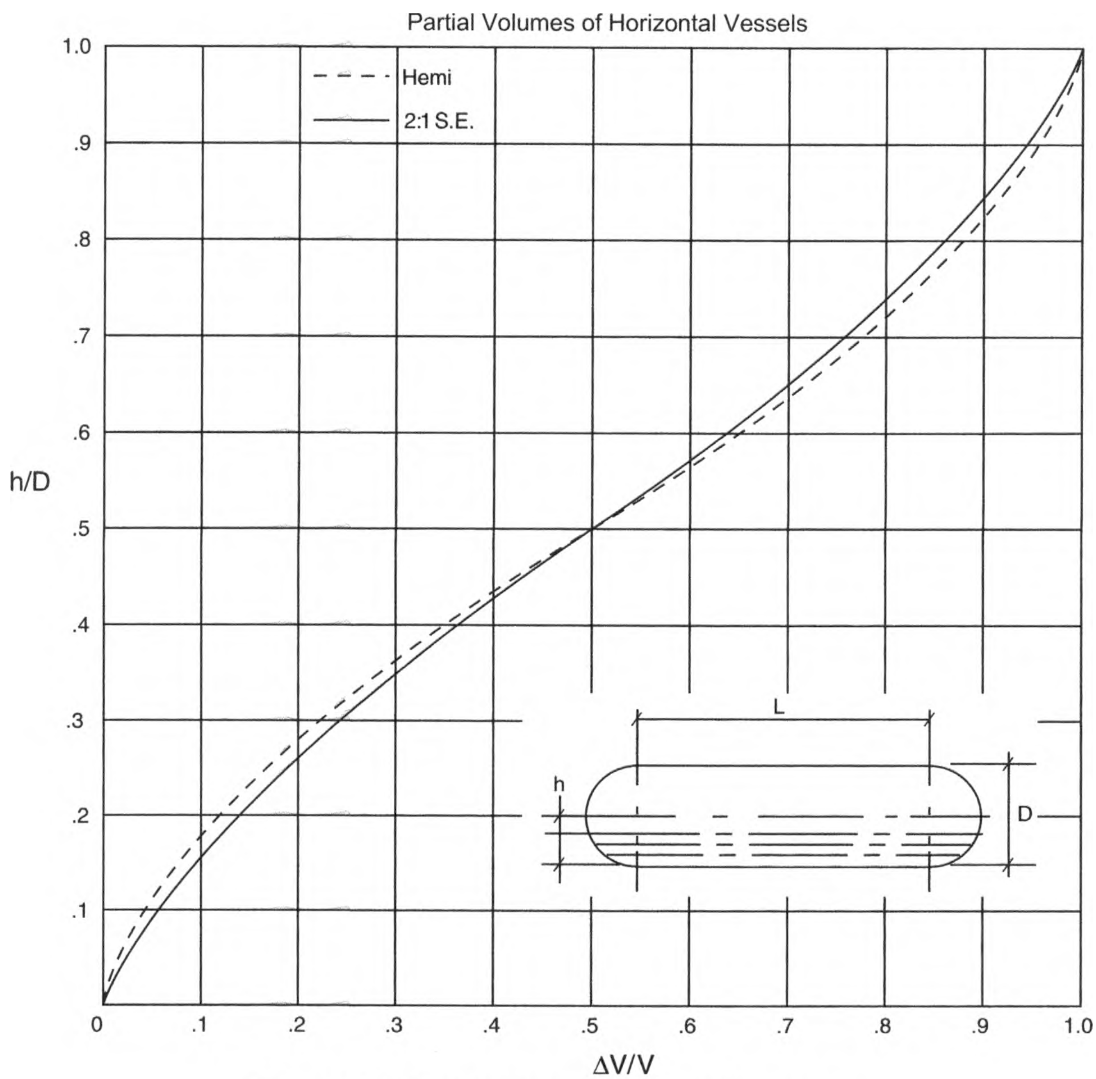
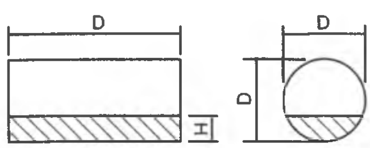


Figure E-5. Partial volumes of horizontal vessels.

Table E-2
Formulas for full and partial volumes

	Full Volume, V	Partial Volume, ΔV
Cylinder	$\frac{\pi D^2 L}{4}$	$\frac{\pi D^2 LC}{4}$
(2) Hemi-heads	$\frac{\pi D^3}{6}$	$\frac{\pi h^2(1.5D - h)}{6}$
(2) 2:1 S.E. Heads	$\frac{\pi D^3}{12}$	$\frac{\pi h^2(1.5D - h)}{3}$

Table E-3
Partial volumes in horizontal cylinders



Partial volume in height (H) = cylindrical coefficient for H/D × total volume

$$\text{Total volume} = \frac{\pi L D^2}{4}$$

Coefficients for Partial Volumes of Horizontal Cylinders, C

H/D	0	1	2	3	4	5	6	7	8	9
0.00	0.000000	0.000053	0.000151	0.000279	0.000429	0.000600	0.000788	0.000992	0.001212	0.001445
0.01	0.001692	0.001952	0.002223	0.002507	0.002800	0.003104	0.003419	0.003743	0.004077	0.004421
0.02	0.004773	0.005134	0.005503	0.005881	0.006267	0.006660	0.007061	0.007470	0.007886	0.008310
0.03	0.008742	0.009179	0.009625	0.010076	0.010534	0.010999	0.011470	0.011947	0.012432	0.012920
0.04	0.013417	0.013919	0.014427	0.014940	0.015459	0.015985	0.016515	0.017052	0.017593	0.018141
0.05	0.018692	0.019250	0.019813	0.020382	0.020955	0.021533	0.022115	0.022703	0.023296	0.023894
0.06	0.024496	0.025103	0.025715	0.026331	0.026952	0.027578	0.028208	0.028842	0.029481	0.030124
0.07	0.030772	0.031424	0.032081	0.032740	0.033405	0.034073	0.034747	0.035423	0.036104	0.036789
0.08	0.37478	0.038171	0.038867	0.039569	0.040273	0.040981	0.041694	0.042410	0.043129	0.043852
0.09	0.044579	0.045310	0.046043	0.046782	0.047523	0.048268	0.049017	0.049768	0.050524	0.051283
0.10	0.052044	0.052810	0.053579	0.054351	0.055126	0.055905	0.56688	0.057474	0.058262	0.059054
0.11	0.059850	0.060648	0.061449	0.062253	0.063062	0.063872	0.064687	0.065503	0.066323	0.067147
0.12	0.067972	0.068802	0.069633	0.070469	0.071307	0.072147	0.72991	0.073836	0.074686	0.075539
0.13	0.076393	0.077251	0.078112	0.078975	0.079841	0.080709	0.081581	0.082456	0.083332	0.084212
0.14	0.085094	0.085979	0.086866	0.087756	0.088650	0.089545	0.090443	0.091343	0.092246	0.093153
0.15	0.094061	0.094971	0.095884	0.096799	0.097717	0.098638	0.099560	0.100486	0.101414	0.102343
0.16	0.103275	0.104211	0.105147	0.106087	0.107029	0.107973	0.108920	0.109869	0.110820	0.111773
0.17	0.112728	0.113686	0.114646	0.115607	0.116572	0.117538	0.118506	0.119477	0.120450	0.121425
0.18	0.122403	0.123382	0.124364	0.125347	0.126333	0.127321	0.128310	0.129302	0.130296	0.131292
0.19	0.132290	0.133291	0.134292	0.135296	0.136302	0.137310	0.138320	0.139332	0.140345	0.141361
0.20	0.142378	0.143308	0.144419	0.145443	0.146468	0.147494	0.148524	0.149554	0.150587	0.151622
0.21	0.152659	0.153697	0.154737	0.155779	0.156822	0.157867	0.158915	0.159963	0.161013	0.162066
0.22	0.163120	0.164176	0.165233	0.166292	0.167353	0.168416	0.169480	0.170546	0.171613	0.172682
0.23	0.173753	0.174825	0.175900	0.176976	0.178053	0.179131	0.180212	0.181294	0.182378	0.183463
0.24	0.184550	0.185639	0.180729	0.187820	0.188912	0.190007	0.191102	0.192200	0.193299	0.194400
0.25	0.195501	0.196604	0.197709	0.198814	0.199922	0.201031	0.202141	0.203253	0.204368	0.205483
0.26	0.206600	0.207718	0.208837	0.209957	0.211079	0.212202	0.213326	0.214453	0.215580	0.216708
0.27	0.217839	0.218970	0.220102	0.221235	0.222371	0.223507	0.224645	0.225783	0.226924	0.228065
0.28	0.229209	0.230352	0.231408	0.232644	0.233791	0.234941	0.236091	0.237242	0.238395	0.239548

(Continued)

Table E-3
Partial volumes in horizontal cylinders—cont'd

0.29	0.240703	0.241859	0.243016	0.244173	0.245333	0.246494	0.247655	0.248819	0.249983	0.251148
0.30	0.252315	0.253483	0.254652	0.255822	0.256992	0.258165	0.259338	0.260512	0.261687	0.262863
0.31	0.264039	0.265218	0.266397	0.267578	0.268760	0.269942	0.271126	0.272310	0.273495	0.274682
0.32	0.275869	0.277058	0.278247	0.279437	0.280627	0.281820	0.283013	0.284207	0.285401	0.286598
0.33	0.287795	0.288992	0.200191	0.291300	0.292591	0.293793	0.294995	0.296198	0.297403	0.298605
0.34	0.299814	0.301021	0.302228	0.303438	0.304646	0.305857	0.307068	0.308280	0.309492	0.310705
0.35	0.311918	0.313134	0.314350	0.315566	0.316783	0.318001	0.319219	0.320439	0.321660	0.322881
0.36	0.324104	0.325326	0.326550	0.327774	0.328999	0.330225	0.331451	0.332678	0.333905	0.335134
0.37	0.336363	0.337593	0.338823	0.340054	0.341286	0.342519	0.343751	0.344985	0.346220	0.347455
0.38	0.348690	0.349920	0.351164	0.352402	0.353640	0.354879	0.356119	0.357359	0.358599	0.359840
0.39	0.361082	0.362325	0.363568	0.364811	0.366056	0.367300	0.368545	0.369790	0.371036	0.372282
0.40	0.373530	0.374778	0.376026	0.377275	0.378524	0.379774	0.381024	0.382274	0.383526	0.384778
0.41	0.386030	0.387283	0.388537	0.389790	0.391044	0.392298	0.393553	0.394808	0.396063	0.397320
0.42	0.398577	0.399834	0.401092	0.402350	0.403608	0.404866	0.406125	0.407384	0.408645	0.409904
0.43	0.411165	0.412426	0.413687	0.414949	0.416211	0.417473	0.418736	0.419998	0.421261	0.422525
0.44	0.423788	0.425052	0.426316	0.427582	0.428846	0.430112	0.431378	0.432645	0.433911	0.435178
0.45	0.436445	0.437712	0.438979	0.440246	0.441514	0.442782	0.444050	0.445318	0.446587	0.447857
0.46	0.449125	0.450394	0.451663	0.452932	0.454201	0.455472	0.456741	0.458012	0.459283	0.460554
0.47	0.461825	0.463096	0.464367	0.465638	0.466910	0.468182	0.469453	0.470725	0.471997	0.473269
0.48	0.474541	0.475814	0.477086	0.478358	0.479631	0.480903	0.482176	0.483449	0.484722	0.485995
0.49	0.487269	0.488542	0.489814	0.491087	0.492360	0.493633	0.494906	0.496179	0.497452	0.498726
0.50	0.500000	0.501274	0.502548	0.503821	0.505094	0.506367	0.507640	0.508913	0.510186	0.511458
0.51	0.512731	0.514005	0.515278	0.516551	0.517824	0.519097	0.520369	0.521642	0.522914	0.524186
0.52	0.525459	0.526731	0.528003	0.529275	0.530547	0.531818	0.533090	0.534362	0.535633	0.536904
0.53	0.538175	0.539446	0.540717	0.541988	0.543259	0.544528	0.545799	0.547008	0.548337	0.549606
0.54	0.550875	0.552143	0.553413	0.554682	0.555950	0.557218	0.558486	0.559754	0.561021	0.562288
0.55	0.563555	0.564822	0.566089	0.567355	0.568622	0.569888	0.571154	0.572418	0.573684	0.574948
0.56	0.576212	0.577475	0.578739	0.580002	0.581264	0.582527	0.583789	0.585051	0.586313	0.587574
0.57	0.588835	0.590096	0.591355	0.592616	0.593875	0.595134	0.596392	0.597650	0.598908	0.600166
0.58	0.601423	0.602680	0.603937	0.605192	0.606447	0.607702	0.608956	0.610210	0.611463	0.612717
0.59	0.613970	0.615222	0.616474	0.617726	0.618976	0.620226	0.621476	0.622725	0.623974	0.625222
0.60	0.626470	0.627718	0.628964	0.630210	0.631455	0.632700	0.633944	0.635189	0.636432	0.637675
0.61	0.638918	0.640160	0.641401	0.642641	0.643881	0.645121	0.646360	0.647598	0.648836	0.650074
0.62	0.651310	0.652545	0.653780	0.655015	0.656249	0.657481	0.658714	0.659946	0.661177	0.662407
0.63	0.663637	0.664866	0.666095	0.667322	0.668549	0.669775	0.671001	0.672226	0.673450	0.674674
0.64	0.675896	0.677119	0.678340	0.679561	0.680781	0.681999	0.683217	0.684434	0.685650	0.686866
0.65	0.688082	0.689295	0.690508	0.691720	0.692932	0.694143	0.695354	0.696562	0.697772	0.698979
0.66	0.700186	0.701392	0.702597	0.703802	0.705005	0.706207	0.707409	0.708610	0.709809	0.711008
0.67	0.712205	0.713402	0.714599	0.715793	0.716987	0.718180	0.719373	0.720563	0.721753	0.722942
0.68	0.724131	0.725318	0.726505	0.727690	0.728874	0.730058	0.731240	0.732422	0.733603	0.734782
0.69	0.735961	0.737137	0.738313	0.739488	0.740662	0.741835	0.743008	0.744178	0.745348	0.746517
0.70	0.747685	0.748852	0.750017	0.751181	0.752345	0.753506	0.754667	0.755827	0.756984	0.758141
0.71	0.759297	0.760452	0.761605	0.762758	0.763909	0.765059	0.766209	0.767356	0.768502	0.769648
0.72	0.770791	0.771935	0.773076	0.774217	0.775355	0.776493	0.777629	0.778765	0.779898	0.781030
0.73	0.782161	0.783292	0.784420	0.785547	0.786674	0.787798	0.788921	0.790043	0.791163	0.792282
0.74	0.793400	0.794517	0.795632	0.796747	0.797859	0.798969	0.800078	0.801186	0.802291	0.803396
0.75	0.804499	0.805600	0.806701	0.807800	0.808898	0.809993	0.811088	0.812180	0.813271	0.814361
0.76	0.815450	0.816537	0.817622	0.818706	0.819788	0.820869	0.821947	0.823024	0.824100	0.825175
0.77	0.826247	0.827318	0.828387	0.829454	0.830520	0.831584	0.832647	0.833708	0.834767	0.835824
0.78	0.836880	0.837934	0.838987	0.840037	0.841085	0.842133	0.843178	0.844221	0.845263	0.846303
0.79	0.847341	0.848378	0.849413	0.850446	0.851476	0.852506	0.853532	0.854557	0.855581	0.856602
0.80	0.857622	0.858639	0.859655	0.860668	0.861680	0.862690	0.863698	0.864704	0.865708	0.866709
0.81	0.867710	0.868708	0.869704	0.870698	0.871690	0.872679	0.873667	0.874653	0.875636	0.876618
0.82	0.877597	0.878575	0.879550	0.880523	0.881494	0.882462	0.883428	0.884393	0.885354	0.886314

Table E-3
Partial volumes in horizontal cylinders—cont'd

0.83	0.887272	0.888227	0.889180	0.890131	0.891080	0.892027	0.892971	0.893913	0.894853	0.895789
0.84	0.896725	0.897657	0.808586	0.899514	0.900440	0.901362	0.902283	0.903201	0.904116	0.905029
0.85	0.905939	0.906847	0.907754	0.908657	0.909557	0.910455	0.911350	0.912244	0.913134	0.914021
0.86	0.914906	0.915788	0.916668	0.917544	0.918410	0.919291	0.920159	0.921025	0.921888	0.922749
0.87	0.923607	0.924461	0.925314	0.926164	0.927000	0.927853	0.928693	0.929531	0.930367	0.931198
0.88	0.932028	0.932853	0.933677	0.934497	0.935313	0.936128	0.936938	0.937747	0.938551	0.939352
0.89	0.940150	0.940946	0.941738	0.942526	0.943312	0.044095	0.944874	0.945649	0.946421	0.947190
0.90	0.947956	0.948717	0.949476	0.950232	0.950983	0.951732	0.952477	0.953218	0.953957	0.954690
0.91	0.955421	0.956148	0.956871	0.957590	0.958306	0.959019	0.959757	0.960431	0.961133	0.961829
0.92	0.962522	0.963211	0.963896	0.964577	0.9665253	0.965927	0.966595	0.967260	0.967919	0.968579
0.93	0.969228	0.969876	0.970519	0.971158	0.971792	0.972422	0.973048	0.973669	0.974285	0.974897
0.94	0.975504	0.976106	0.976704	0.977297	0.977885	0.978467	0.979045	0.979618	0.980187	0.980750
0.95	0.981308	0.981859	0.982407	0.982948	0.983485	0.984015	0.984541	0.985060	0.985573	0.986081
0.96	0.986583	0.987080	0.987568	0.988053	0.988530	0.989001	0.989466	0.989924	0.990375	0.990821
0.97	0.991258	0.991690	0.992114	0.992530	0.992939	0.993340	0.993733	0.994119	0.994497	0.994866
0.98	0.995227	0.995579	0.995923	0.996257	0.996581	0.996896	0.997200	0.997493	0.997777	0.998048
0.99	0.998308	0.998555	0.998788	0.999008	0.999212	0.999400	0.999571	0.999721	0.999849	0.999047
1.00	1.000000									

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Appendix F: Vessel Nomenclature and Definitions

Types of Vessels

Shop-Fabricated Pressure Vessels

1. Process vessels
   a. Trayed columns
   b. Reactors
   c. Packed columns
2. Drums and miscellaneous vessels
   a. Horizontal
   b. Vertical
3. Storage vessels
   a. Bullets
   b. Spheres

Field-Fabricated Pressure Vessels

- Any of the above listed vessels can be field fabricated; however, normally only those vessels that are too large to transport in one piece are field fabricated.
- Although it is significantly more expensive to field fabricate a vessel, the total installed cost may be cheaper than a shop fabricated vessel that is erected in a single piece due to the cost of transportation and erection.
- There are always portions of field fabricated vessels that are shop fabricated. These can be as small as nozzle assemblies or as large as major vessel portions.

Classification of Vessels

Function: Type of vessel, i.e., reactor, accumulator, column, or drum

Material: Steel, cast iron, aluminum, etc.

Fabrication Method: Field/shop fabricated, welded, cast forged, multi-layered, etc.

Geometry: Cylindrical, spherical, conical, etc.

Pressure: Internal, external, atmospheric

Heating Method: Fired or unfired

Orientation: Vertical, horizontal, sloped

Installation: Fixed, portable, temporary

Wall Thickness: Thin/thick walled

Example: Vertical, unfired, cylindrical, stainless steel, heavy-walled, welded reactor for internal pressure

Vessel Parts

Vessel Heads (End Closures)

1. Types
   a. Hemi
   b. Elliptical
   c. Torispherical (flanged and dished)
   d. Conical, toriconical

e. Flat (bolted or welded)
f. Miscellaneous (flanged and flued)
g. Spherically dished covers
h. Closures (T-bolt, finger pin, quick opening)

2. Types of manufacture
   a. Pressed
   b. Spun
   c. Bumped
   d. Forged
   e. Hot or cold formed
3. Terminology
   a. Knuckle radius
   b. Crown radius
   c. Dished portion
   d. Straight flange

Vessel Supports

1. Types
   a. Skirt (straight or conical)
   b. Legs (braced or unbraced)
   c. Saddles (attached or loose)
   d. Rings
   e. Lugs
   f. Combination (lugs and legs, rings and legs, rings and skirt)

Nozzles

1. Types
   a. Integrally reinforced
   b. Built-up construction
   c. Pad type (studding outlet)
   d. Sight glasses
   e. Elliptical manways
2. Types of service
   a. Manways
   b. Inspection openings
   c. PSV
   d. Instrument connections
   e. Vents
   f. Drains
   g. Process connections

Flanges

1. Types
   a. Slip on
   b. Weld neck, long weld neck
   c. Lap joint
   d. Blind
   e. Screwed
   f. Plate flanges
   g. Studding outlets
   h. Reverse-type flange
   i. Reducing flange
   j. Graylock hub connector
   k. Socket weld
2. Flange Facing
   a. Flat face
   b. Raised face
   c. Finish (smooth, standard, serrated)
   d. Ring joint
   e. Tongue and groove
   f. Male and female

Gaskets

1. Types
   a. Ring, non-asbestos sheet
   b. Flat metal
   c. Spiral wound
   d. Metal jacketed
   e. Corrugated metal
   f. Rings (hexagonal or oval)
   g. Yielding metal gaskets (lens ring, delta ring, rectangular ring)
   h. Elastomeric (rubber, cork, etc.)

Internals

1. Types
   a. Trays, seal pans
   b. Piping distributors
   c. Baffles
   d. Demisters
   e. Packing
   f. Liquid distributors
   g. Vortex breakers
   h. Bed supports
   i. Coils

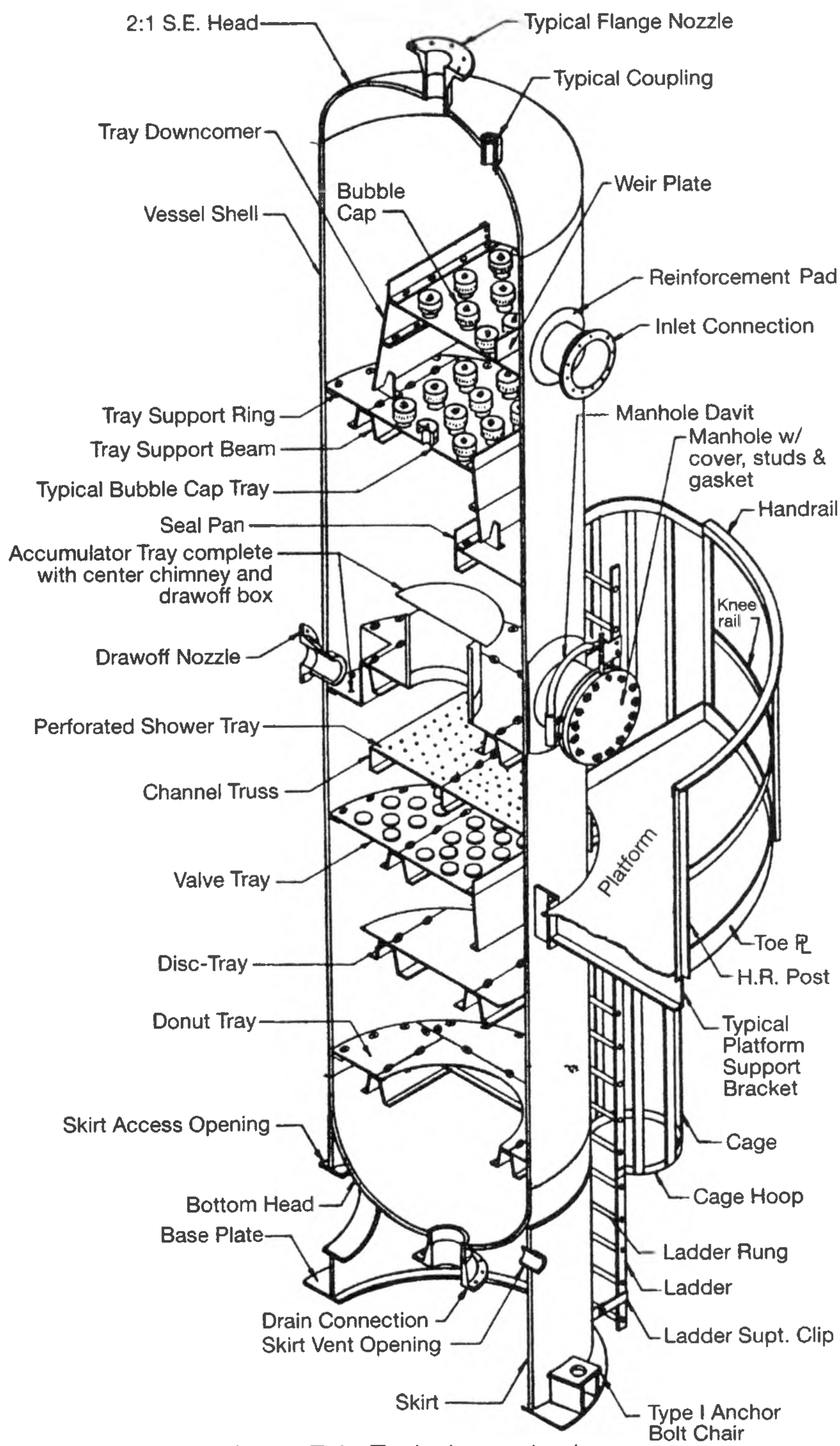


Figure F-1. Typical trayed column.

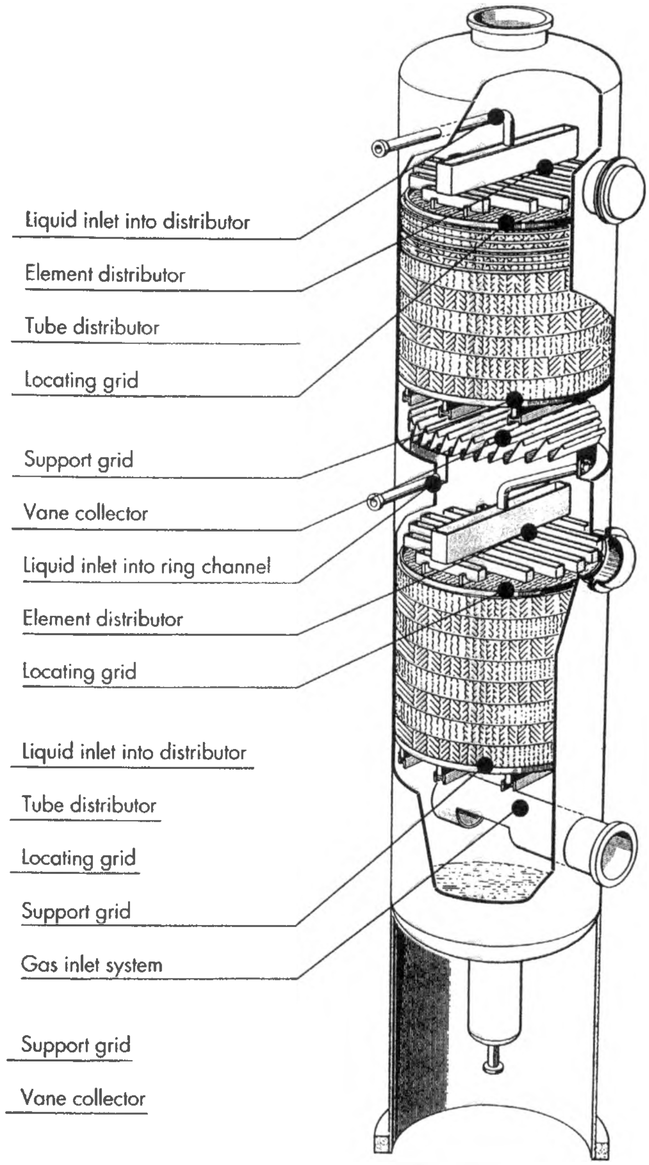


Figure F-2. Typical packed column.

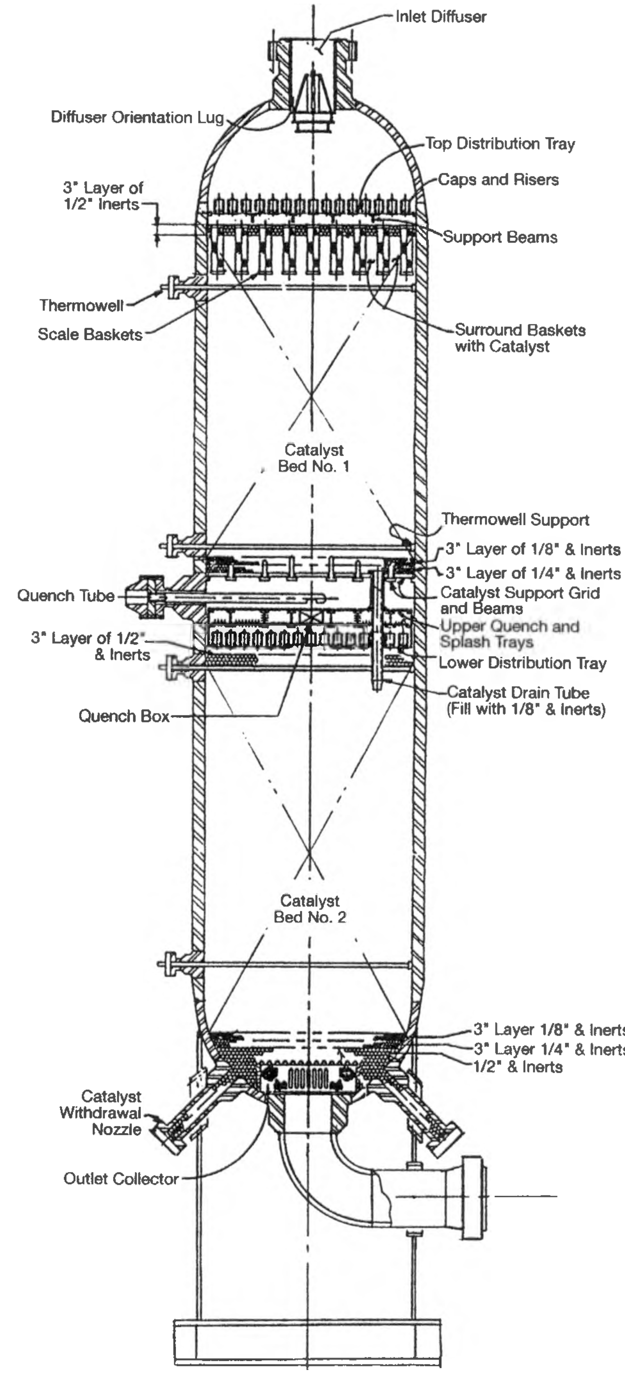
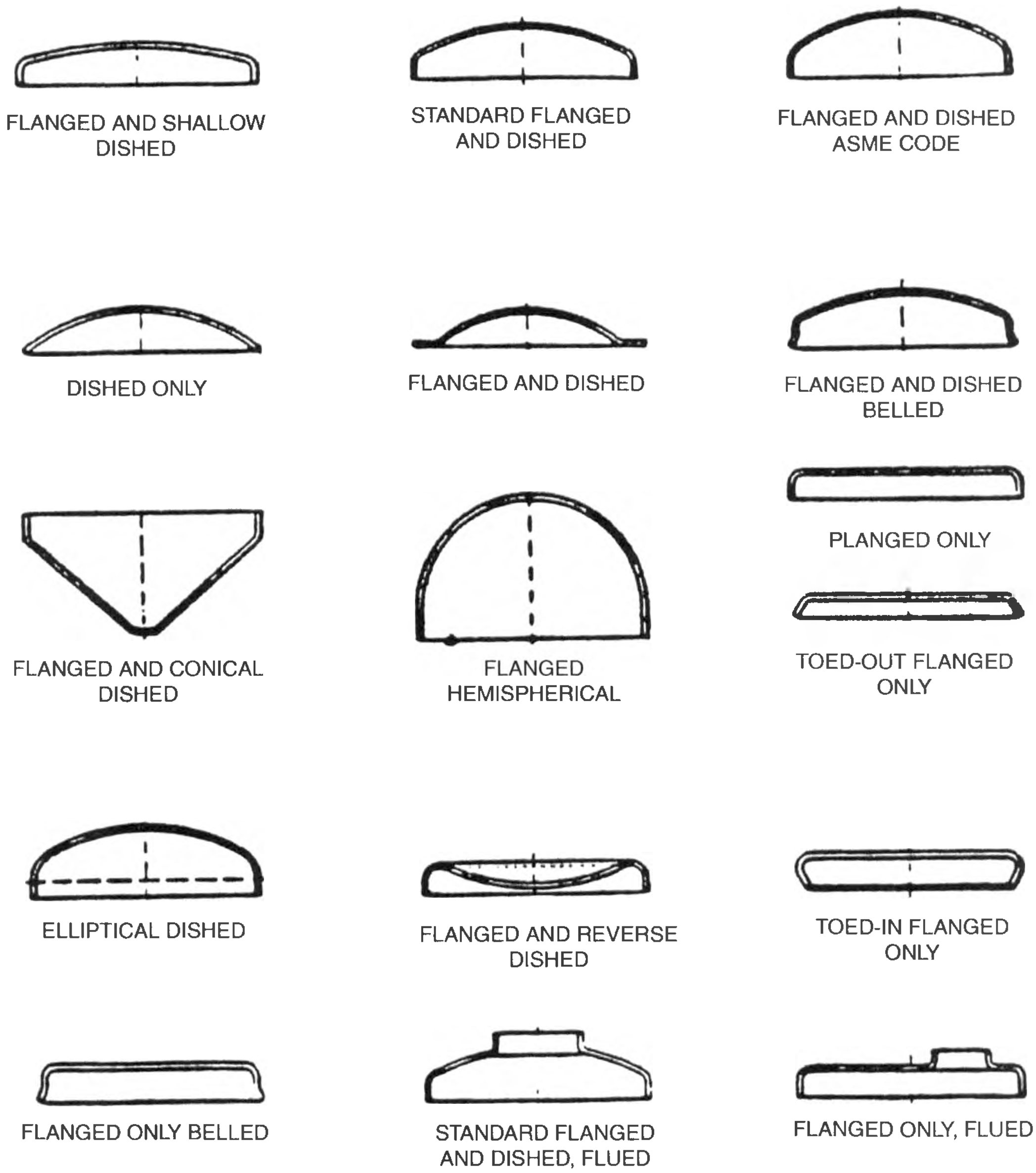
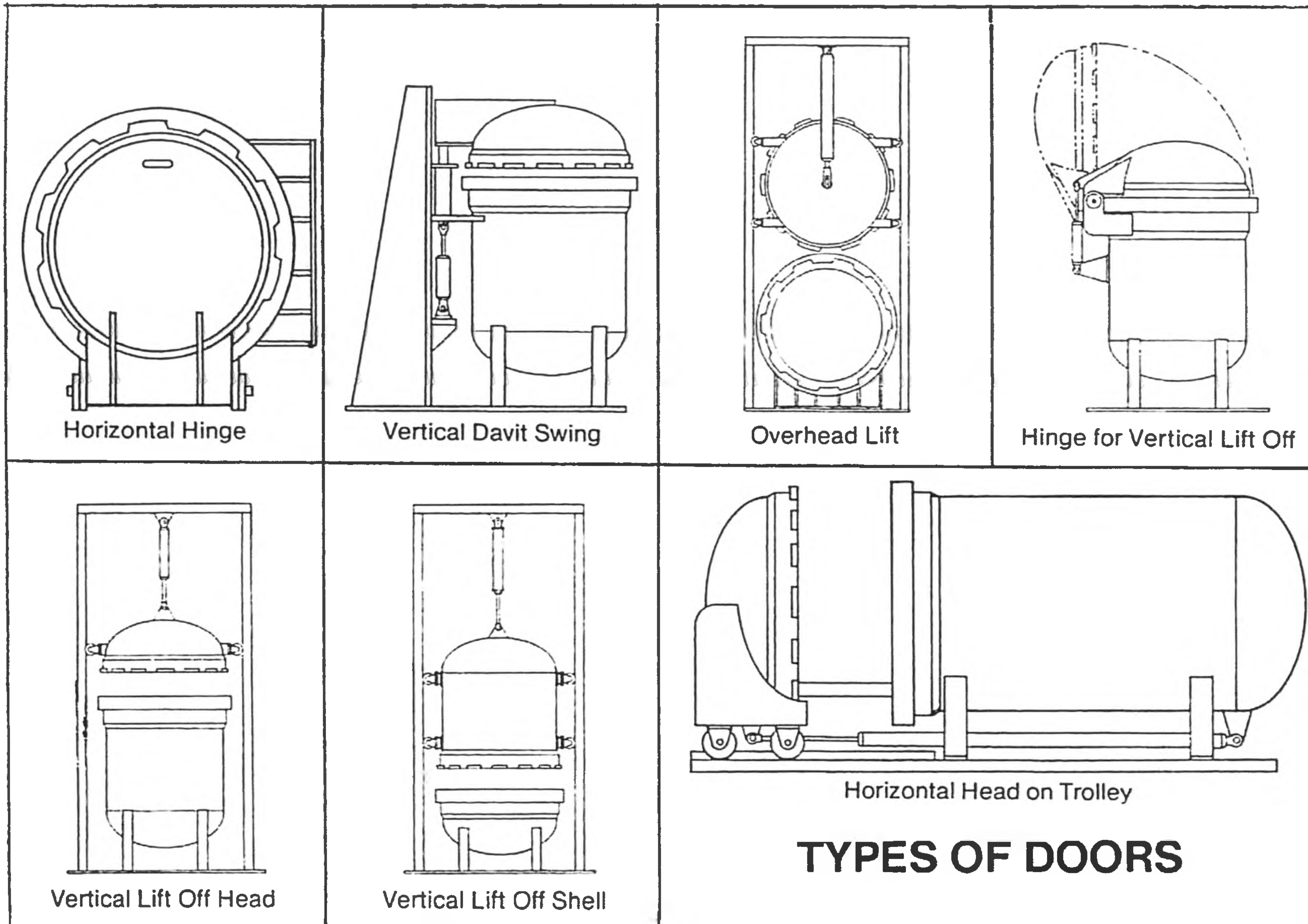


Figure F-3. Typical reactor internals.



Commonly used formed closure heads



TYPES OF DOORS

Glossary of Vessels Parts

Anchor Bolt Chairs: Gussets and plates welded to base plate and skirt to provide for anchor bolt attachment.

Anchor Bolts: Bolts embedded in concrete foundation and bolted to vessel anchor bolt chairs.

Base Plate: Flat plate welded to the bottom of vessel supports and bearing on the foundation.

Chimney Tray: A tray composed of chimneys extending above the liquid level of the tray, permitting passage of the vapors upward. The tray collects and removes all liquid product from a specific portion of the vessel.

Column Davit: A hoisting device attached by means of a socket to the top of fractionation columns. Used for handling relief valves, bubble trays, bubble caps, etc.

Conical Head: Head formed in the shape of a cone.

Coupling: A fitting welded into the vessel to which the piping is connected either by screwing or welding. This type of fitting is generally used for pipe sizes 1½ in. and smaller.

Distributor Tray: A perforated tray that provides equal distribution of liquid over the vessel area. Risers on the tray extend above the liquid level to permit passage of vapors rising upward.

Downcomers: Rectangular flat plates bolted, welded or clamped to shell and trays inside of fractionation columns. Used to direct process liquid and to prevent bypassing of vapor.

Flanged and Dished (Torispherical) Head: Head formed using two radii, one radius called crown radius, and another called knuckle radius, which is tangent to both the crown radius and the shell.

Flanges (or Pipe Flanges): Fittings used to connect pipes by bolting flanges together.

Flat Head (or Cover Plate): Flat plate welded or bolted to the end of a shell.

Fractionating Trays: Circular flat plates bolted, welded or clamped to rings on the inside of fractionation columns. Used to obtain vapor liquid contact, which results in fractionation.

Head: The end closure of a vessel.

Hemispherical Head: Head formed in the shape of a half sphere.

Insulation Rings: Rings made of flat bar or angle attached around the girth (circumference) of vertical vessels. Used to support the weight of the vessel insulation.

Ladders and Cages: Rung-type ladders with cages built of structural shapes to prevent a person from falling when climbing the ladder. Bolted to and supported by clips on the outside of the vessel. Used for vertical access to the platforms.

Manhole Hinges or Davits: Hinges or davits attached to manhole flange and cover plate which allow cover plate to swing aside from the manhole opening.

Mist Eliminator (or Demister): A wire mesh pad held in place between two light grids. The mist eliminator disengages liquids contained in the vapor.

Nozzle: Generally consists of a short piece of pipe welded in the shell or head with a flange at the end for bolting to the Piping.

Pipe Supports and Guides: Supports and guides for attached piping that is bolted to clips, which are welded to the vessel.

Platforms: Platforms bolted to and supported by clips on the outside of the vessel. Generally located just below a manhole, at relief valves, and other valves or connections that need frequent service.

Reinforcing Pad: Plate formed to the contour of shell or head, welded to nozzle and shell or head.

Saddles: Steel supports for horizontal vessels.

Seal Pans: Flat plates bolted, welded, or clamped to rings inside of fractionation column shell below downcomer of lowest tray. Used to prevent vapor from bypassing up through the downcomer by creating a liquid seal.

Shell: The cylindrical portion of a vessel.

Skirt: Cylinder similar to shell, which is used for supporting vertical vessels.

Skirt Access Opening: Circular holes in the skirt to allow workers to clean, inspect, etc., inside of skirt.

Skirt Fireproofing: Brick or concrete applied inside and outside of skirt to prevent damage to skirt in case of fire.

Skirt Vents: Small circular holes in the skirt to prevent collection of dangerous gases within the skirt.

Stub-end: A short piece of pipe or rolled plate welded into the vessel to which the piping is connected by welding.

Support Grid: Grating or some other type of support through which vapor or liquid can pass. Used to support tower packing (catalyst, raschig rings, etc.).

Support Legs: Legs made of pipe or structural shapes that are used to support vertical vessels.

Toriconical Head: Head formed in the shape of a cone and with a knuckle radius tangent to the cone and shell.

2:1 Semi-Elliptical Head: Head formed in the shape of a half ellipse with major to minor axis ratio of 2:1.

Vacuum Stiffener Rings: Rings made of flat bar or plate, or structural shapes welded around the circumference of the vessel. These rings are installed on vessels operating under external pressure to prevent collapse of the vessel. Also used as insulation support rings.

Vessel Manhole: Identical to a nozzle except it does not bolt to piping and it has a cover plate (or blind flange), which is bolted to the flange. When unbolted it allows access to the inside of the vessel. Generally 18 in. or larger in size.

Vortex Breaker: A device located inside a vessel at the outlet connection. Generally consisting of plates welded together to form the shape of a cross. The vortex breaker prevents cavitation in the liquid passing through the outlet connection.

Definitions

1. Butt Joint: A butt joint is a connection between two members with a full penetration weld.
2. Corner Joint: A corner joint is a connection between two members at right angles to each other that is made with a full penetration weld, partial penetration weld or fillet welds.
3. Angle Joint: An angle joint is a connection between the edges of two members with a full penetration weld with one of the members consisting of a transition of diameter.
4. Spiral weld: A weld joint having a helical seam.
5. Fillet weld: A fillet weld is a weld that is approximately triangular in cross section that joins two surfaces at approximately right angles to each other.
6. Gross Structural Discontinuity: A gross structural discontinuity is a source of stress or strain intensification which affects a relatively large portion of a structure and has a significant effect on the overall stress or strain pattern or on the structure as a whole. Examples of gross structural discontinuities are as follows;
   a. Head to shell junctions
   b. Flange to shell junctions
   c. Nozzles
   d. Junctions between shells of different diameters or thickness
7. Lightly Loaded Attachments: A lightly loaded attachment is one where the weld stress due to mechanical loads is not over 25% of the allowable stress for fillet welds and the temperature difference between the shell and attached member is not more than 14° C (25° F).
8. Minor Attachments: Minor attachments are small parts attached to the pressure boundary that carry no load or insignificant load. They are less than 3/8 in (10 mm) in thickness or less than 5 in^3 (82 cm^3) in size. Some examples are nameplates, insulation supports and locating lugs.
9. Major Attachments: Any part that is not a minor attachment or lightly loaded by definition.
10. Design Pressure: The pressure used in the design of a vessel component together with the coincident design metal temperature, for the purpose of determining the minimum permissible thickness or physical characteristics of the different zones of the vessel. Where applicable, the static head and other static or dynamic loads shall be included in addition to the specified design pressure in the determination of the minimum permissible thickness or physical characteristics of a particular zone of the vessel.
11. Maximum Allowable Working Pressure (MAWP): The maximum gage pressure permissible at the top of a completed vessel in its normal operating position in the hot and corroded condition. The pressure is the least of the values for the internal or external pressure to be determined by the Code rules for any of the pressure boundary parts, considering static head, using nominal thicknesses.
12. Maximum Allowable Pressure (MAP): Not an ASME Code requirement or definition. This is an “optional” pressure that was historically used as a basis for calculating test pressures. The MAP is the maximum pressure allowed in the new and cold condition (N&C). This is calculated from the ASME equations using the new nominal thickness and the allowable stress at ambient temperature.
13. Test Pressure: The test pressure is the pressure applied at the top of the vessel during the test. The test can be either hydrotest or pneumatic test.
14. Maximum Allowable Temperature (MAT): This is not an ASME Code definition and is not required to be calculated by the ASME Code or stamped on the nameplate. However, certain client specifications request that the stamping of the nameplate include the highest permissible temperature for which the vessel is acceptable. The MAT is the maximum allowable temperature allowed for the vessel and shall be the lesser of the following;
    a. The highest temperature corresponding to the maximum allowable tensile stress. Used when tensile stress is governing all thicknesses.

b. The highest temperature corresponding to the maximum allowable compressive stress.
c. The highest temperature allowed based on the flange pressure and temperature ratings.

15. Minimum Design Metal Temperature (MDMT): The MDMT is an ASME Code requirement and must be stamped on the nameplate. the lower of the following;
    a. The lowest temperature expected in normal service (Service MDMT).
    b. The qualification of temperature based on charpy impact testing of the base materials (Qualified MDMT).
    c. The lowest ambient temperature of the atmospheric conditions (Arbitrary MDMT).
16. Nil Ductility Transition Temperature (NDT): Also known as DBTT (ductile-brittle transition temperature): The temperature above which the material is predominantly ductile and below which it is predominantly brittle. The NDT represents the point at which the fracture energy passes below a predetermined point, i.e. 15 ft-lbs (20 joules) for ordinary steel or 40 ft-lbs (54 joules) for Cr-Mo steels.
17. Fracture Appearance Transition Temperature (FATT): On a toughness curve (a plot of impact values at various temperatures), it is the point at which the specimen fracture surface is 50% shear (brittle fracture) and 50% cleavage (brittle fracture).
18. Minimum Pressurization Temperature (MPT): This is not an ASME Code requirement and is not stamped on the nameplate. This is the lowest temperature that will allow full pressurization for a vessel that has been subject to the long term effects of embrittlement. Embrittlement can be the result of temperature, hydrogen or irradiation. The temperature is either determined by calculation or testing methods.

Bolting Definitions

19. ***Cut Threads***: Threads may be either cut or rolled. Cut threads are machined from a piece of bar stock by removal of material by machining. The distinctive feature being that the shank of the bolt is the same diameter as the OD of the threads.
20. ***Rolled Threads***: Rolled threads are formed from a piece of round bar stock by die rolling or upsetting the threads. Rolled threads are cheaper to manufacture than cut threads. No machining, therefore no waste. The distinctive feature is that the shank is always slightly smaller in diameter than the OD of the threads. Thus, to make a 1 inch dia bolt, you start with a 0.913 inch diameter bar.
21. ***Strain Hardening***: This effect is produced in austenitic stainless steels by reducing over-sized bars to the desired size by cold drawing or other process. Strain hardening is the increase in strength and hardness that results from plastic deformation below the recrystallization temperature (cold work). The degree of strain hardening achievable in any alloy is limited by its strain hardening characteristics and the amount of reduction.
22. ***Carbide Solution Treated***: Carbide solution treatment is a heat treatment for austenitic stainless steel materials equivalent to solution annealing. The purpose is to reheat materials to a level that will cause chromium carbides to go into solution. This is followed by a rapid quench that prevents the precipitation of carbides into the grain boundaries where it would have a detrimental effect.
23. ***Quench & Tempered***: A two step heat treatment for carbon and low alloy steels. The first step is to quench the material to develop hardness and strength. This is followed by a subsequent treatment that tempers the material to develop toughness. Since high hardness and strength are often brittle, the quenching reforms the material to restore toughness while retaining some of the strength, thus giving the material the right balance of properties.
24. ***Precipitation Hardening***: Precipitation hardening is only possible in certain alloys, such as 17-7 SST, maraging steel, various aluminum alloys, copper, nickel (Inconel 718 & Inconel x-750) and magnesium. It is hardening of a material caused by the precipitation of a constituent to form a separate phase which is an intermetallic compound. This can occur at room temperature or at elevated temperatures. The solute will precipitate (leave the supersaturated condition) by either migration or diffusion. By this method the tensile strength of 2024 Al can be doubled from 30 ksi to 60 ksi. The heat treatment is usually a two step process. Step one is a solution heat treatment followed by a rapid quench. Step two, is an aging or precipitation treatment to cause separation of a second phase.

Appendix G: Useful Formulas for Vessels [1,2]

1. Properties of circle. (See Figure G-1.)

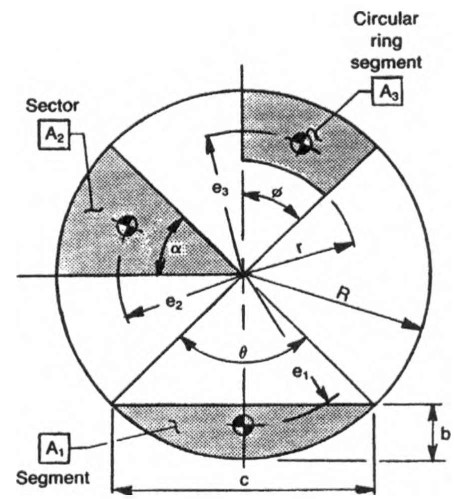


Figure G-1. Dimensions and areas of circular sections.

- *C.G. of area.*

$$e_1 = \frac{C^3}{12A_1}$$

$$e_2 = \frac{120C}{\alpha\pi}$$

$$e_3 = \frac{38.197(R^3 - r^3)\sin\phi/2}{(R^2 - r^2)\phi/2}$$

- *Chord, C.*

$$C = 2R\sin\frac{\theta}{2}$$

$$C = 2\sqrt{2bR - b^2}$$

- *Rise, b.*

$$b = 0.5C\tan\frac{\theta}{4}$$

$$b = R - 0.5\sqrt{4R^2 - C^2}$$

- *Angle, θ*

$$\theta = 2\arcsin\frac{C}{2R}$$

- *Area of sections.*

$$A_1 = \frac{\theta\pi R^2 - 180C(R - b)}{360}$$

$$A_2 = \frac{\pi R^2 \alpha}{360}$$

$$A_3 = \frac{(R^2 - r^2)\pi\phi}{360}$$

2. Properties of a cylinder.
   - *Cross-sectional metal area, A.*

$$A = 2\pi R_m t$$

- *Section modulus, Z.*

$$Z = \pi R_m^2 t = \frac{\pi D_m^2 t}{4} = \frac{\pi(D^4 - d^4)}{32d}$$

- *Polar moment of inertia, J.*

$$J = \frac{\pi(D^4 - d^4)}{32}$$

- *Moment of inertia, I.*

$$I = \pi R_m^3 t = \frac{\pi D_m^3 t}{8} = \frac{\pi(D^4 - d^4)}{64}$$

- *Radius of gyration, r.*

$$r = \sqrt{\frac{I}{A}}$$

3. Radial displacements due to internal pressure.
   - *Cylinder.*

$$\delta = \frac{PR^2}{Et}(1 - 0.5v)$$

   - *Cone.*

$$\delta = \frac{PR^2}{Et \cos \alpha}(1 - 0.5v)$$

   - *Sphere/hemisphere.*

$$\delta = \frac{PR^2}{2Et}(1 - v)$$

   - *Torispherical/ellipsoidal.*

$$\delta = \frac{R}{E}(\sigma_\phi - v\sigma_x)$$

where P = internal pressure, psi
R = inside radius, in.
t = thickness, in.
v = Poisson's ratio (0.3 for steel)
E = modulus of elasticity, psi
α = ½ apex angle of cone, degrees
σ_ϕ = circumferential stress, psi
σ_x = meridional stress, psi

4. Longitudinal stress in a cylinder due to longitudinal bending moment, M_L.
   - *Tension*

$$\sigma_x = \frac{M_L}{\pi R^2 t}$$

   - *Compression*

$$\sigma_x = (-)\frac{M_L}{\pi R^2 t}$$

where
R = inside radius, in.
M_L = bending moment, in.-lb
t = thickness, in.

5. Thickness required heads due to external pressure.

$$t_h = \frac{L}{\sqrt{\frac{E}{16P_e}}}$$

where L = crown radius, in.
P_e = external pressure, psi
E = modulus of elasticity, psi

6. Equivalent pressure of flanged connection under external loads.

$$P_e = \frac{16M}{\pi G^3} + \frac{4F}{\pi G^2} + P$$

where P = internal pressure, psi
F = radial load, lb
M = bending moment, in.-lb
G = gasket reaction diameter, in.

7. Bending ratio of formed plates.

$$\% = \frac{100t}{R_f}\left(1 - \frac{R_f}{R_o}\right)$$

where R_f = finished radius, in.
R_o = starting radius, in. (∞ for flat plates)
t = thickness, in.

8. Stress in nozzle neck subjected to external loads.

$$\sigma_x = \frac{PR_m}{2t_n} + \frac{F}{A} + \frac{MR_m}{I}$$

where R_m = nozzle mean radius, in.
t_n = nozzle neck thickness, in.
A = metal cross-sectional, area, in.^{2}
I = moment of inertia, in.^{4}
F = radial load, lb
M = moment, in.-lb
P = internal pressure, psi

9. Circumferential bending stress for out of round shells [2].

$$D_1 - D_2 > 1\% \, D_{nom}$$

$$R_1 = \frac{D_1 + D_2}{2}$$

$$R_a = \frac{D_1 + D_2}{4} + \frac{t}{2}$$

$$\sigma_b = \frac{1.5PR_1t(D_1 - D_2)}{t^3 + 3\left(\frac{P}{E}\right)R_1R_a^2}$$

where D_1 = maximum inside diameter, in.
D_2 = minimum inside diameter, in.
P = internal pressure, psi
E = modulus of elasticity, psi
t = thickness, in.

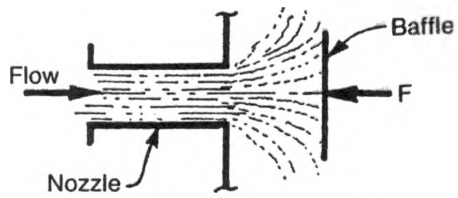


Figure G-2. Typical nozzle configuration with internal baffle.

10. Equivalent static force from dynamic flow.

$$F = \frac{V^2Ad}{g}$$

where F = equivalent static force, lb
V = velocity, ft/sec
A = cross-sectional area of nozzle, ft^2
d = density, lb/ft^3
g = acceleration due to gravity, 32.2 ft/sec^2

11. Allowable compressive stress in cylinders [1].

$$\text{If } \frac{t}{R} \le 0.015,\ X = \frac{10^6 t}{R}\left(2 - \frac{200t}{3R}\right)$$

$$\text{If } \frac{t}{R} > 0.015,\ X = 15{,}000$$

$$\text{If } \frac{L}{R} \le 60,\ Y = 1$$

$$\text{If } \frac{L}{R} > 60,\ Y = \frac{21{,}600}{18{,}000 + \left(\frac{L}{R}\right)^2}$$

$$F_a = \frac{Q}{A} = XY$$

where t = thickness, in.
R = outside radius, in.
L = length of column, in.
Q = allowable load, lb
A = metal cross-sectional area, $in.^2$
F_a = allowable compressive stress, psi

12. Unit stress on a gasket, S_g.

$$S_g = \frac{A_b S_a}{.785\left[(d_o - .125)^2 - d_i^2\right]}$$

where A_b = area of bolt, $in.^2$
d_o = O.D. of gasket, in.
d_i = I.D. of gasket, in.
S_a = bolt allow. stress, psi

13. Determine fundamental frequency of a vertical vessel on skirt, f.

$$I = \frac{\pi D_m^3 t}{8}$$

$$m = \frac{\pi D_m t d}{g}$$

$$f = \frac{.560}{(12H)^2}\sqrt{\frac{EI}{m}}$$

where I = moment of inertia, $in.^4$
D_m = mean vessel diameter, in.
t = vessel thickness, in.
d = density of steel 0.2833 $lbs/in.^3$
g = acceleration due to gravity, 386 $in./sec^2$
E = modulus of elasticity, psi
H = vessel height, ft
m = mass of vessel per unit length, $lbf\text{-}sec^2/in.^2$
f = fundamental frequency, Hertz (cycles/second)

14. Maximum quantity of holes in a perforated circular plate.

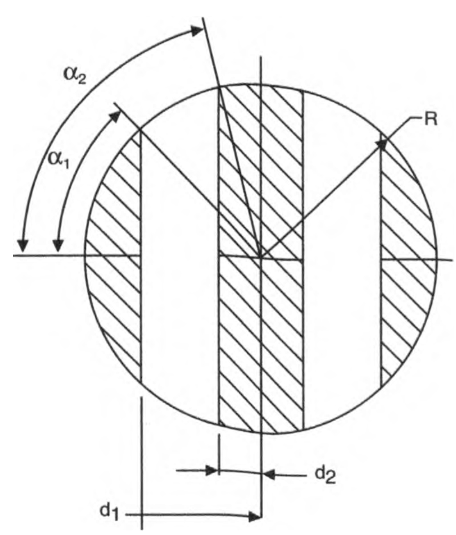
A = area of circular plate, $in.^2$
D = diameter of circular plate, in.
d = diameter of holes, in.
p = pitch, in.
Q = quantity of holes
K = constant (0.86 for triangular pitch)
R = practical physical radius to fully contain all holes

$$A = \pi R^2$$

$$R = \frac{D - d}{2}$$

$$Q = \frac{A}{Kp^2}$$

15. Divide a circle into "N" equal number of parallel areas.

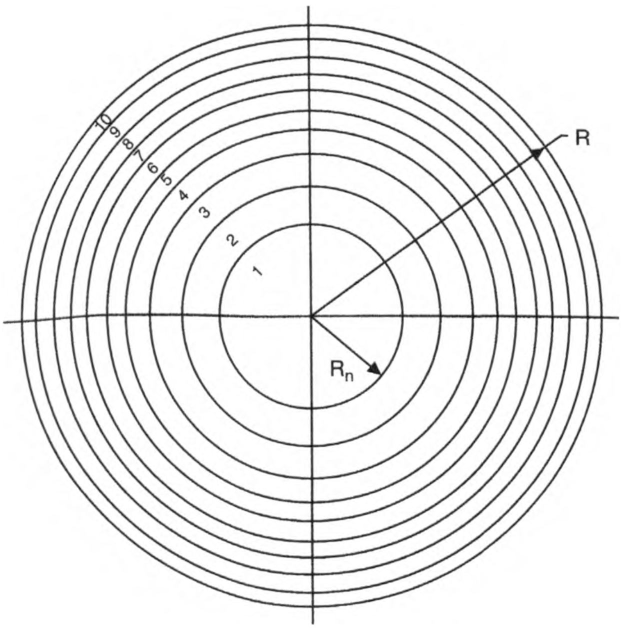


Multiply d_n times R to get actual distances.

Table G-1
Dimensions for equal areas

"N" Areas	α_1	α_2	α_3	d_1	d_2	d_3
3	74.65	NA	NA	0.2647	NA	NA
4	66.18	NA	NA	0.4038	NA	NA
5	60.55	80.9	NA	0.4917	0.1582	NA
6	56.4	74.65	NA	0.5534	0.2647	NA
7	53.2	69.6	83.55	0.599	0.3485	0.1123
8	50.63	66.18	78.6	0.6343	0.4038	0.1977

16. Divide a circle into "N" equal number of circular areas.
A_T = total area, in.^{2}
A_n = area of equal part, in.
R = radius to circle, in.
R_n = radius to equal part, in.
N = number of equal parts



$$A = \pi R^2$$

$$A_n = \frac{A_T}{N}$$

$$R_n = \sqrt{\frac{A_n N}{\pi}}$$

Example: Divide a circle into (10) equal areas.
Answer:
$R_1 = 0.3163R$
$R_2 = 0.4472R$
$R_3 = 0.5477R$
$R_4 = 0.6325R$
$R_5 = 0.7071R$
$R_6 = 0.7746R$
$R_7 = 0.8367R$
$R_8 = 0.8944R$
$R_9 = 0.9487R$
$R_{10} = R$

17. Maximum allowable beam-to-span ratios for beams.
L = unsupported length, in.
d = depth of beam, in.
b = width of beam, in.
t = thickness of compression flange, in.

If $\frac{Ld}{bt} \leq 600$, then the allowable stress = 15,000 psi

If $\frac{Ld}{bt} > 600$,

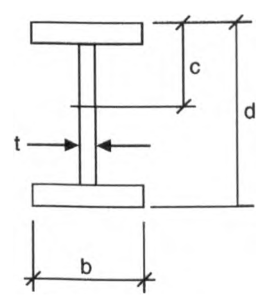
then the allowable stress $= \frac{9,000,000}{Ld/bt}$

18. Properties of a built-up "I" beam.

$$Z = \frac{td}{6}(6b + d)$$

$$I = ZC$$

t = same thk. for all parts



19. Volume required for gas storage.
V = volume, in.^{3}
m = mole weight of contents
R = gas constant
T = temperature, Rankine
P = pressure, psi

$$V = \frac{mRT}{P}$$

Appendix H: Metric Guidelines and Conversions

Table H-1
Metric guideline

Quantity		Typical US Units	SI Units
1	Force	Lbs	N (Newtons)
2	Mass	Lbs	Kg (Kilograms)
3	Distance	Ft, In	M or mm (Meter or Millimeter)
4	Section Modulus	In^3	mm^3
5	Moment of Inertia	In^4	mm^4
6	Moment	Ft-Lbs, In- Lbs	N-M or KN-M (Newton-Meter or Kilo Newton-Meter)
7	Pressure	PSI	Bar, Pa, KPa, Kg/cm^2, N/cm^2
8	Thermal Conductivity	BTU-in/hr/ft^2/°F	W / M- °C (Watts per Meter-Centigrade)
9	Thermal Expansion	In/In/°F	mm/mm/°C
10	Density	PCI, PCF	Kg / mm^3, Kg/M^3
11	Area	Ft^2, In^2	mm^2, M^2
12	Modulus of Elasticity	PSI	MPa, N/M^2, N/mm^2
13	Stress	PSI	Mpa
14	Torque	Ft-Lbs, In-Lbs	N-M
15	Mass per Area	PSF	Kg/M^2
16	Mass per length	Lbs / Ft	Kg / M
17	Volume	Ft^3	M^3
18	Temperature	°F	°C
19	Misc	NA	NA

Table H-2
Metric conversions

Quantity		Unit	Multiply by...	To Obtain...
1	Force	Lbs	4.448222	Newtons
		Kg	9.80666	Newtons
		KN	224.8089	Lbs
		KN	102	Kgs
		N	0.1019716	Kgs
		N	0.2248089	Lbs
2	Mass	Lbs	0.4536	Kg
		Kg	2.204623	Lbs
		Metric Ton (MT)	1000	Kg

(Continued)

Table H-2
Metric conversions—cont'd

Quantity		Unit	Multiply by...	To Obtain...
		Metric Ton	2204.623	Lbs
		Metric Ton	1.1023	US Ton
		US Tons	2000	Lbs
		US Tons	907.2	Kg
		US Tons	0.90718	Metric Ton
3	Distance	In	25.4	mm
		Ft	0.3048	M
		M	3.2808	Ft
		M	39.37	In
4	Section Modulus	In^3	16,387.06	mm^3
		mm^3	6.1163 (10^{-5})	In^3
5	Moment of Inertia	In^4	416,231.43	mm^4
		mm^4	2.4025 (10^{-6})	In^4
6	Moment	In-Lbs	11.52124	Kg-mm
		In-Lbs	1.35582	N-M
		Ft-lbs	1.35582 (10^{-3})	KN-M
		N-M	8.85075	In-Lbs
		N-M	0.737561	Ft-Lbs
		KN-M	737.561	Ft-Lbs
		Kg-M	7.233	Ft-Lbs
		N-mm	8.85075 (10^{-3})	In-Lbs
		N-mm	7.375 (10^{-4})	Ft-Lbs
7	Pressure	Bar	1.019716	Kg/Cm^2
		Bar	0.010197	Kg/mm^2
		Bar	14.50377	PSI
		Bar	0.1	Mpa
		Bar	100	Kpa
		Pascals	0.000145038	PSI
		Pascals	1	N/M^2
		KPa	0.1450377	PSI
		KPa	4.014743	In-H_2O
		MPa	145.0377	PSI
		Kg/mm^2	1422.334	PSI
		Kg/mm^2	9806.65	KPa
		Kg/Cm^2	98.0665	KPa
		Kg/Cm^2	393.7115	In-H_2O
		PSI	6.894757	KPa

(*Continued*)

Table H-2
Metric conversions—cont'd

Quantity		Unit	Multiply by...	To Obtain...
		PSI	0.006894757	MPa
		PSI	0.070307	Kg/Cm^2
		PSI	0.000703	Kg/mm^2
		PSI	0.068947	Bar
		Millibar	0.0001	MPa
		Millibar	0.1	KPa
		Millibar	100	Pa
		Millibar	0.01450377	PSI
		Millibar	0.001	Bar
		Millibar	0.02952999	In-Hg
		Millibar	0.401474	In-H2O
		Newton/Cm^2	1.450377	PSI
		Newton/Cm^2	10	KPa
		Newton/Cm^2	0.01	Mpa
		Newton/mm^2	145.0377	PSI
		Newton/mm^2	1000	KPa
		Newton/mm^2	1	MPa
8	Thermal Conductivity	BTU-ft/hr-ft^2-°F	1.731	W/m·K
		W/m·K	0.5777	BTU-ft/hr-ft^2-°F
9	Thermal Expansion	In/In/ °F	1.8	mm/mm/ °C
		mm/mm/ °C	0.5556	In/In/ °F
10	Density	PCI	2.768 (10^{-5})	Kg/mm^3
		PCF	16.01846	Kg/M^3
		Kg/mm^3	36045	PCI
		Kg/Cm^3	62,427.96	PCF
		Kg/M^3	0.062427	PCF
11	Area	mm^2	1.55 (10^{-3})	In^2
		Cm^2	0.155	In^2
		M^2	1550	In^2
		M^2	10.764	Ft^2
		In^2	64,516	mm^2
		In^2	6.4516	Cm^2
		Ft^2	0.0929	M^2
12	Modulus of Elasticity	PSI	0.006894757	MPa
		MPa	145.0377	PSI
13	Stress	PSI	0.006894757	MPa
		MPa	145.0377	PSI

(*Continued*)

Table H-2
Metric conversions—cont'd

Quantity		Unit	Multiply by…	To Obtain…
14	Torque	SEE MOMENT		
15	Mass / Area	Kg/mm^2	1422.334	PSI
		Kg/Cm^2	204,386.69	PSF
		Kg/M^2	0.2048	PSF
		Kg/M^2	0.001422	PSI
		Kg/M^2	0.0001	Kg/Cm^2
		Kg/M^2	0.001422334	PSI
		Kg/M^2	0.2048161	PSF
		PSF	4.882428	Kg/M^2
		PSI	$7.0307\ (10^{-4})$	Kg/mm^2
		PSI	0.070307	Kg/Cm^2
		N/M^2	1	Pa
16	Mass / Length	Lbs/Ft	14.59385	N/M
		Lbs/ In	0.17513	KN/M
		N/M	0.068522	Lbs/Ft
		KN/M	68.523	Lbs/Ft
17	Volume	In^3	16,387.06	mm^3
		Ft^3	0.028317	M^3
		mm^3	$6.1163\ (10^{-5})$	In^3
		Cm^3	0.061024	In^3
		M^3	35.31467	Ft^3
		M^3	61023.74	In^3
18	Temperature	°F	1.8 C + 32	
		°C	.556 (F -32)	
		°K	C + 273.18	
		°R	F + 459.72	
19	Misc	Weight of Steel	490 PCF	
			.2833 PCI	
			$7.858\ (10^{-6})$ Kg / mm^3	
			$7.858\ (10^{-3})$ Kg / Cm^3	
		Weight of Water	62.4 PCF	
			1001 Kg/ M^3	
			8.33 Lbs Water /Gal	
		Volume of Contents	7.481 Gallons/ Ft^3	
			5.614 Ft^3/BBL	
			6.29 BBL/ M^3	
			.1781 BBL/ Ft^3	
			42 Gallons/ BBL	
			264.189 Gallons/ M^3	

Appendix I: Allowable Compressive Stress for Columns, F_A

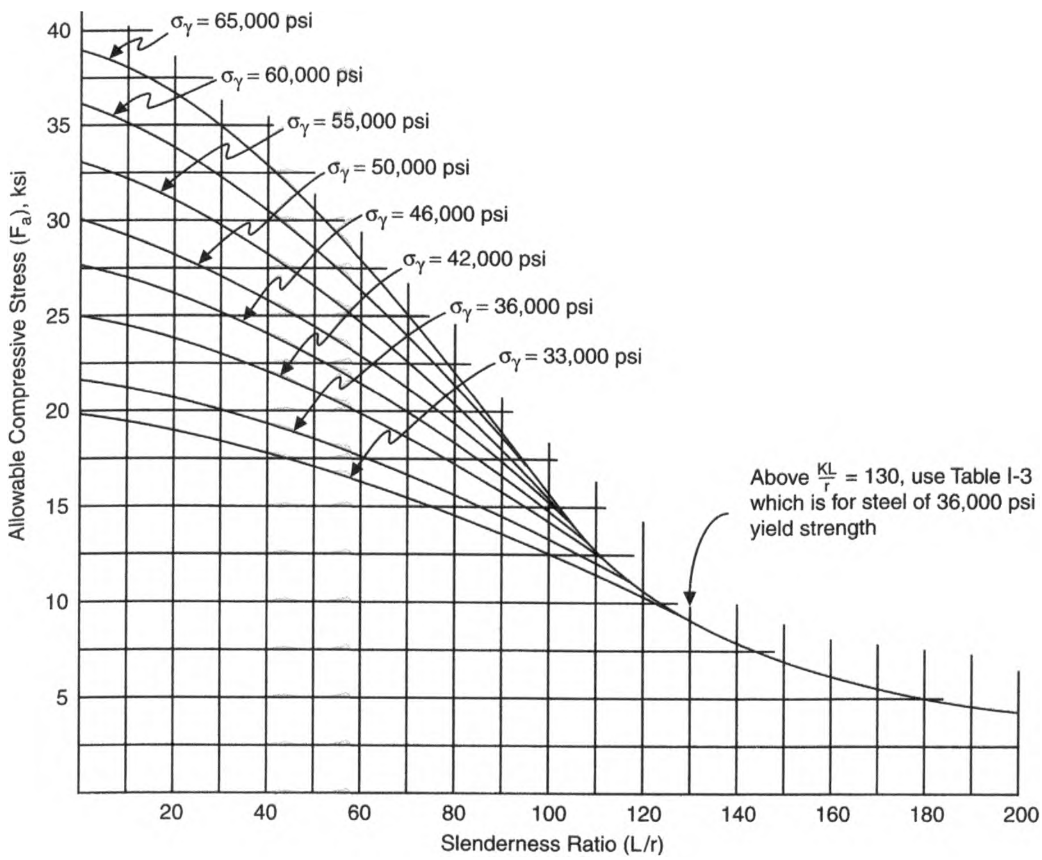


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Table I-1
End connection coefficients

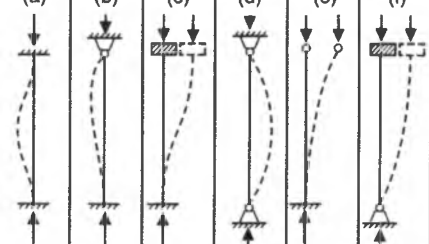
	(a)	(b)	(c)	(d)	(e)	(f)
Buckled shape of column is shown by dashed line						
Theoretical K value	0.5	0.7	1.0	1.0	2.0	2.0
Recommended design value when ideal conditions are approximated	0.65	0.80	1.2	1.0	2.10	2.0
End condition code		Rotation fixed and translation fixed Rotation free and translation fixed Rotation fixed and translation free Rotation free and translation free				

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Table I-2
33,000-psi-Yield steel

L/r Ratio		1	2	3	4	5	6	7	8	9
		19,770	19,730	19,690	19,660	19,620	19,580	19,540	19,500	19,460
10	19,410	19,370	19,320	19,280	19,230	19,180	19,130	19,080	19,030	18,980
20	18,930	18,880	18,820	18,770	18,710	18,660	18,600	18,540	18,840	18,420
30	18,360	18,300	18,240	18,180	18,110	18,050	17,980	17,920	17,850	17,780
40	17,710	17,640	17,570	17,500	17,430	17,360	17,290	17,220	17,140	17,070
50	16,990	16,920	16,840	16,760	16,680	16,600	16,520	16,440	16,360	16,280
60	16,200	16,120	16,030	15,950	15,860	15,780	15,690	15,610	15,520	15,430
70	15,340	15,250	15,160	15,070	14,980	14,890	14,800	14,700	14,610	14,510
80	14,420	14,320	14,230	14,130	14,030	13,930	13,840	13,740	13,640	13,530
90	13,430	13,330	13,230	13,130	13,020	12,920	12,810	12,710	12,600	12,490
100	12,380	12,280	12,170	12,060	11,950	11,830	11,720	11,610	11,900	11,380
110	11,270	11,150	11,040	10,920	10,800	10,690	10,570	10,450	10,330	10,210
120	10,090	9,996	9,840	9,720	9,590	9,470	9,340	9,220	9,090	8,960
130	8,830	8,700	8,570	8,440	8,320	8,190	8,070	7,960	7,840	7,730
140	7,620	7,510	7,410	7,300	7,200	7,100	7,010	6,910	6,820	6,730
150	6,640	6,550	6,460	6,380	6,300	6,220	6,140	6,060	5,980	5,910
160	5,830	5,760	5,690	5,620	5,550	5,490	5,420	5,350	5,290	5,230
170	5,170	5,110	5,050	4,990	4,930	4,880	4,820	4,770	4,710	4,660
180	4,610	4,560	4,510	4,460	4,410	4,360	4,320	4,270	4,230	4,180
190	4,140	4,090	4,050	4,010	3,970	3,930	3,890	3,850	3,810	3,770
200	3,730									

Above L/r of 130, the higher-strength steels offer no advantage as to allowable compressive stress (f_a). Above this point, use Table I-3 for the more economical steel of 36,000-psi-yield strength.

Table I-3
36,000-psi-Yield steel

L/r Ratio		1	2	3	4	5	6	7	8	9
		21,560	21,520	21,480	21,440	21,390	21,350	21,300	21,250	21,210
10	21,160	21,100	21,050	21,000	20,950	20,890	20,830	20,780	20,720	20,660
20	20,600	20,540	20,480	20,410	20,350	20,280	20,220	20,150	20,080	20,010
30	19,940	19,870	19,800	19,730	19,650	19,580	19,500	19,420	19,350	19,270
40	19,190	19,110	19,030	18,950	18,860	18,780	18,700	18,610	18,530	18,440
50	18,350	18,260	18,170	18,080	17,990	17,900	17,810	17,710	17,620	17,530
60	17,430	17,330	17,240	17,140	17,040	16,940	16,840	16,740	16,640	16,530
70	16,430	16,330	16,220	16,120	16,010	15,900	15,790	15,690	15,580	15,470
80	15,360	15,240	15,130	15,020	14,900	14,790	14,670	14,560	14,440	14,320
90	14,200	14,090	13,970	13,840	13,720	13,600	13,480	13,350	13,230	13,100
100	12,980	12,850	12,720	12,590	12,470	12,330	12,200	12,070	11,940	11,810
110	11,670	11,540	11,400	11,260	11,130	10,990	10,850	10,710	10,570	10,430
120	10,280	10,140	9,990	9,850	9,700	9,550	9,410	9,260	9,110	8,970
130	8,840	8,700	8,570	8,440	8,320	8,190	8,070	7,960	7,840	7,730
140	7,620	7,510	7,410	7,300	7,200	7,100	7,010	6,910	6,820	6,730
150	5,640	6,550	6,460	6,380	6,300	6,220	6,140	6,060	5,980	5,910
160	5,830	5,760	5,690	5,620	5,550	5,490	5,420	5,350	5,290	5,230
170	5,170	5,110	5,050	4,990	4,930	4,880	4,820	4,770	4,710	4,660
180	4,610	4,560	4,510	4,460	4,410	4,360	4,320	4,270	4,230	4,180
190	4,140	4,090	4,050	4,010	3,970	3,930	3,890	3,850	3,810	3,770
200	3,730									

Above L/r of 130, the higher-strength steels offer no advantage as to allowable compressive stress (f_a). Above this point, use this table.

Table I-4
42,000-psi-Yield steel

L/r Ratio		1	2	3	4	5	6	7	8	9
		25,150	25,100	25,050	24,990	24,940	24,880	24,820	24,760	24,700
10	24,630	24,570	24,500	24,430	24,360	24,290	24,220	24,150	24,070	24,000
20	23,920	23,840	23,760	23,680	23,590	23,510	23,420	23,330	23,240	23,150
30	23,060	22,970	22,880	22,780	22,690	22,590	22,490	22,390	22,290	22,190
40	22,080	21,980	21,870	21,770	21,660	21,550	21,440	21,330	21,220	21,100
50	20,990	20,870	20,760	20,640	20,520	20,400	20,280	20,160	20,030	19,910
60	19,790	19,660	19,530	19,400	19,270	19,140	19,010	18,880	18,750	18,610
70	18,480	18,340	18,200	18,060	17,920	17,780	17,640	17,500	17,350	17,210
80	17,060	16,920	16,770	16,620	16,470	16,320	16,170	16,010	15,860	15,710
90	15,550	15,390	15,230	15,070	14,910	14,750	14,590	14,430	14,260	14,090
100	13,930	13,760	13,590	13,420	13,250	13,080	12,900	12,730	12,550	12,370
110	12,190	12,010	11,830	11,650	11,470	11,280	11,100	10,910	10,720	10,550
120	10,370	10,200	10,030	9.870	9,710	9,560	9,410	9,260	9,110	8,970

Above L/r of 130, the higher-strength steels offer no advantage as to allowable compressive stress (f_a). Above this point, use Table I-3 for the more economical steel of 36,000-psi-yield strength.

Table I-5
46,000-psi-Yield steel

L/r Ratio		1	2	3	4	5	6	7	8	9
		27,540	27,480	27,420	27,360	27,300	27,230	27,160	27,090	27,020
10	26,950	26,870	26,790	26,720	26,630	26,550	26,470	26,380	26,290	26,210
20	26,110	26,020	25,930	25,830	25,730	25,640	25,540	25,430	25,330	25,230
30	25,120	25,010	24,900	24,790	24,680	24,560	24,450	24,330	24,210	24,100
40	23,970	23,850	23,730	23,600	23,480	23,350	23,220	23,090	22,960	22,830
50	22,690	22,560	22,420	22,280	22,140	22,000	21,860	21,720	21,570	21,430
60	21,280	21,130	20,980	20,830	20,680	20,530	20,370	20,220	20,060	19,900
70	19,740	19,580	19,420	19,260	19,100	18,930	18,760	18,600	18,430	18,260
80	18,080	17,910	17,740	17,560	17,390	17,210	17,030	16,850	16,670	16,480
90	16,300	16,120	15,930	15,740	15,550	15,360	15,170	14,970	14,780	14,580
100	14,390	14,190	13,990	13,790	13,580	13,380	13,170	12,960	12,750	12,540
110	12,330	12,120	11,900	11,690	11,490	11,290	11,100	10,910	10,720	10,550
120	10,370	10,200	10,030	9,870	9,710	9,560	9,410	9,260	9,110	8,970

Above L/r of 130, the higher-strength steels offer no advantage as to allowable compressive stress (f_a). Above this point, use Table I-3 for the more economical steel of 36,000-psi-yield strength.

Table I-6
50,000-psi-Yield steel

L/r Ratio		1	2	3	4	5	6	7	8	9
		29,940	29,870	29,800	29,730	29,660	29,580	29,500	29,420	29,340
10	29,260	29,170	29,080	28,990	28,900	28,800	28,710	28,610	28,510	28,400
20	28,300	28,190	28,080	27,970	27,860	27,750	27,630	27,520	27,400	27,280
30	27,150	27,030	26,900	26,770	26,640	26,510	26,380	26,250	26,110	25,970
40	25,830	25,690	25,550	25,400	25,260	25,110	24,960	24,810	24,660	24,510
50	24,350	24,190	24,040	23,880	23,720	23,550	23,390	23,220	23,060	22,890
60	22,720	22,550	22,370	22,200	22,020	21,850	21,670	21,490	21,310	21,120
70	20,940	20,750	20,560	20,380	20,190	19,990	19,800	19,610	19,416	19,210
80	19,010	18,810	18,610	18,410	18,200	17,990	17,790	17,580	17,370	17,150
90	16,940	16,720	16,500	16,290	16,060	15,840	15,520	15,390	15,170	14,940
100	14,710	14,470	14,240	14,000	13,770	13,530	13,290	13,040	12,800	12,570
110	12,340	12,120	11,900	11,690	11,490	11,290	11,100	10,910	10,720	10,550
120	10,370	10,200	10,030	9,870	9,710	9,560	9,410	9,260	9,110	8,970

Above L/r of 130, the higher-strength steels offer no advantage as to allowable compressive stress (f_a). Above this point, use Table I-3 for the more economical steel of 36,000-psi-yield strength.
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Appendix J: Design of Flat Plates

Table J-1
Flat plate formulas

Shape	Loading	Edge Fixation	Maximum Fiber Stress, f, psi	Center Deflection, Δ, in.	Remarks
Circle radius R.	Uniform p	Fixed	$0.75p\frac{R^2}{t^2}$	$0.17\left(\frac{p}{E}\right)\frac{R^4}{t^3}$	f max. at edge
		Simply Supported	$1.24p\frac{R^2}{t^2}$	$0.695\left(\frac{p}{E}\right)\frac{R^4}{t^3}$	f max. at center
	Central concentrated P on r	Fixed	$1.43\left[\log_{10}\left(\frac{R}{t}\right)+0.11\left(\frac{r}{R}\right)^2\right]\frac{P}{t^2}$	$0.22\left(\frac{P}{E}\right)\frac{R^2}{t^3}$	P uniform over circle, radius r Center stress
		Simply Supported	$1.43\left[\log_{10}\left(\frac{R}{t}\right)+0.334+0.06\left(\frac{r}{R}\right)^2\right]\frac{P}{t^2}$	$0.55\left(\frac{P}{E}\right)\frac{R^2}{t^3}$	As above center stress
Ellipse 2A × 2a a < A	Uniform p	Fixed	$\frac{6}{3n^4+2n^2+3}p\frac{a^2}{t^2}$	$\frac{1.365}{3n^4+2n^2+3}\left(\frac{p}{E}\right)\frac{a^4}{t^3}$	$n=\frac{a}{A}$, exact solution
		Simply Supported	$\frac{3}{0.42n^4+n^2+1}p\frac{a^2}{t^2}$ (1)		$n=\frac{a}{A}$, approximate fits n = 0 and n = 1
	Central concentrated p	Fixed	$\frac{50}{3n^4+2n^2+12.5}\frac{P}{t^2}$ (2)		$n=\frac{a}{A}$, approximate Fits n = 0 and n = 1 Load over 0.01% of area
		Simply Supported	$\frac{13.1}{0.42n^4+n^2+2.5}\frac{P}{t^2}$ (2)		$n=\frac{a}{A}$, approximate Fits n = 1 Load over 0.01% of area
Rectangle B × b b < B	Uniform p	Fixed	$B_1p\frac{b^2}{t^2}$	$\phi_1\left(\frac{p}{E}\right)\frac{b^4}{t^3}$	ϕ_1 and B_1 depend on B/b, See Table J-2.
		Simply Supported	$B_2p\frac{b^2}{t^2}$	$\phi_2\left(\frac{p}{E}\right)\frac{b^4}{t^3}$	ϕ_2 and B_2 depend on B/b. See Table J-2.
	Central concentrated p	Fixed	$\frac{4.00}{1+2n^2}\frac{P}{t^2}$ (3)	$\phi_3\left(\frac{p}{E}\right)\frac{b^2}{t^3}$	$\frac{b}{B}$ = n, approximate Fits n=1 and n=0
		Simply Supported	$\frac{5.3}{1+2.4n^2}\frac{P}{t^2}$ (3)		$\frac{b}{B}$ = n, approximate Fits n=1 and n=0
Square B × B	Uniform p	Fixed	$0.308p\frac{B^2}{t^2}$	$0.0138\left(\frac{p}{E}\right)\frac{B^4}{t^3}$	f max. at center of side
		Simply Supported	$0.287p\frac{B^2}{t^2}$	$0.0443\left(\frac{p}{E}\right)\frac{B^4}{t^3}$	f max. at center
	Central concentrated p	Fixed	$1.32\frac{P}{t^2}$		As above deflection nearly exact
		Simply Supported	$1.58\frac{P}{t^2}$	$0.125\left(\frac{P}{E}\right)\frac{B^2}{t^3}$	Approximate for f area of contact not too small
Flat Stayed Plate	Uniform p	Staybolts spaced at corners of square of side S	$0.228p\frac{S^2}{t^2}$	$0.0284\left(\frac{p}{E}\right)\frac{S^4}{t^3}$	If plate as a whole deforms, superimpose the stresses and deflections on those for flat plate when loaded
Circular Flanged	Uniform p	Fastened to shell	$p\left[\frac{r}{2t}+\phi\left(\frac{R-\frac{r}{2}1+\frac{r}{R}}{t}\right)^2\right]$		ϕ varies with shell and joint stiffness from 0.33 to 0.38 knuckle radius, r'

1. Formula of proper form to fit circle and infinite rectangle as n varies from 1 to 10.
2. Formulas for load distributed over 0.0001 plate area to match circle when n = 1. They give reasonable values for stress when n = 0. Stress is lower for larger area subject to load.
3. Formulas of empirical form to fit Hutte values for square when n = 1. They give reasonable values when n = 0. Assume load on 0.01 of area.
4. Only apparent stresses considered.
5. These formulas are not to be used in determining failure.

Table J-2
Flat plate coefficients

Stress Coefficients—Circle with Concentrated Center Load											
r/R	1.0	0.10	0.09	0.08	0.07	0.06	0.05	0.04	0.03	0.02	0.01
Fixed[1]	0.157	1.43	1.50	1.57	1.65	1.75	1.86	2.00	2.18	2.43	2.86
Supported[2]	0.563	1.91	1.97	2.05	2.13	2.23	2.34	2.48	2.66	2.91	3.34
Stress and Deflection Coefficients—Ellipse											
A/a	1.0	1.2	1.4	1.6	1.8	2.0	2.5	3.0	4.0	5.0	∞
Uniform Load											
Fixed											
Stress[3]	0.75	1.03	1.25	1.42	1.54	1.63	1.77	1.84	1.91	1.95	2.00
Deflection[4]	0.171	0.234	1.284	0.322	0.350	0.370	0.402	0.419	0.435	0.442	0.455
Uniform Load											
Supported[5]	1.24	1.58	1.85	2.06	2.22	2.35	2.56	2.69	2.82	2.88	3.00
Central Load											
Fixed[6]	2.86	3.26	3.50	3.64	3.73	3.79	3.88	3.92	3.96	3.97	4.00
Supported[7]	3.34	3.86	4.20	4.43	4.60	4.72	4.90	5.01	5.11	5.16	5.24
Stress and Deflection Coefficients—Rectangle											
B/b	1.0	1.25	1.5	1.6	1.75	2.0	2.5	3.0	4.0	5.0	∞
Stress B_1	0.308	0.399	0.454		0.490	0.497					0.500
Stress B_2	0.287	0.376	0.452	0.517	0.569	0.610	0.650	0.713	0.741	0.748	0.750
$\frac{4}{1+2n^2}$	1.33	1.75	2.12	2.25	2.42	2.67	3.03	3.27	3.56	3.70	4.00
$\frac{5.3}{1+2.4n^2}$	1.56	2.09	2.56	2.74	2.97	3.31	3.83	4.18	4.61	4.84	5.30
Deflection ϕ_1	0.0138	0.0199	0.0240		0.0264	0.0277					0.0284
Deflection ϕ_2	0.0443	0.0616	0.0770	0.0906	0.1017	0.1106	0.125	0.1336	0.1400	0.1416	0.1422
Deflection ϕ_3	0.1261		0.1671			0.1802		0.1843	0.1848		0.1849

[1]*Values of* $1.43\,[\log_{10}R/r + 0.11\,(r/R)^2]$
[2]*Values of* $1.43\,[\log_{10}R/r + 0.334 + 0.06(r/R)^2]$
[3]*Values of* $6/(3n^4 + 2n^2 + 3)$
[4]*Values of* $1{,}365/(3n^4 + 2n^2 + 3)$
[5]*Values of* $3/(0.42n^4 + n^2 + 1)$
[6]*Values of* $50/(3n^4 + 2n^2 + 12.5)$
[7]*Values of* $13.1/(0.42n^4 + n^2 + 2.5)$

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Appendix K: Time Required to Drain Vessels

Notation

q = discharge rate, cu ft/sec
g = acceleration due to gravity, ft/sec
D = diameter of vessel, ft
R = radius of sphere, ft
L = length of horizontal vessel, ft
H = height of liquid in vessel, ft
d = diameter of drain, in.
c = coefficient of discharge
T = time to drain, min

Notes

1. It is assumed that the flow has a Reynolds number greater than 1000.

   General Equation.

   $$q = dc\sqrt{2gH}$$

- *For sphere.*

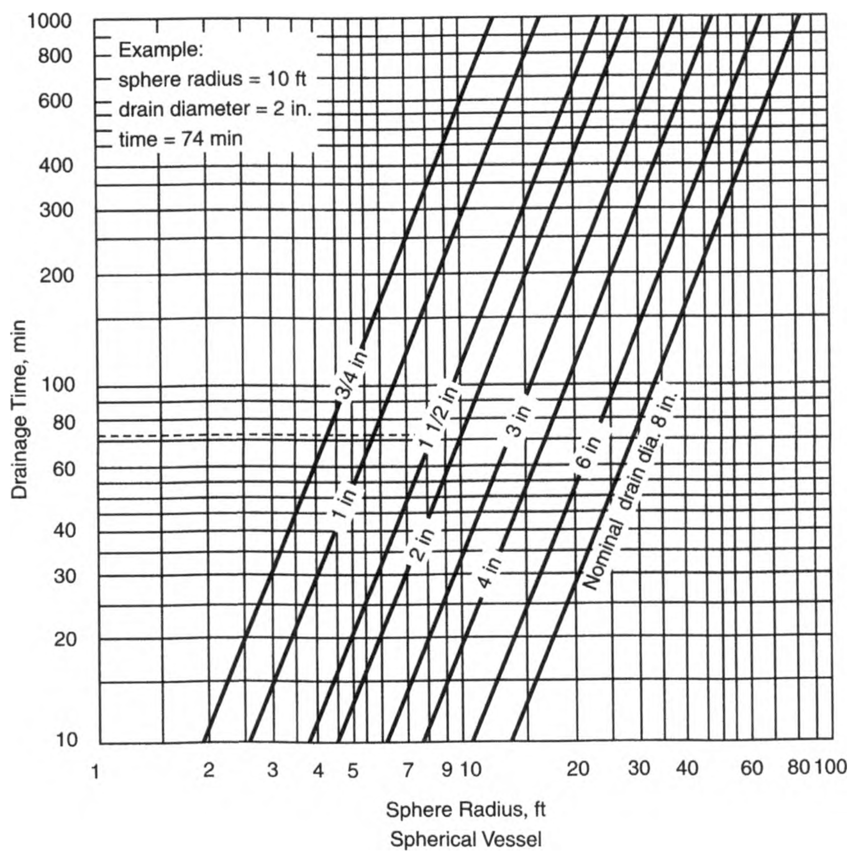
$$T = \frac{R^{2.5}}{d^2}$$

- *For horizontal vessel*

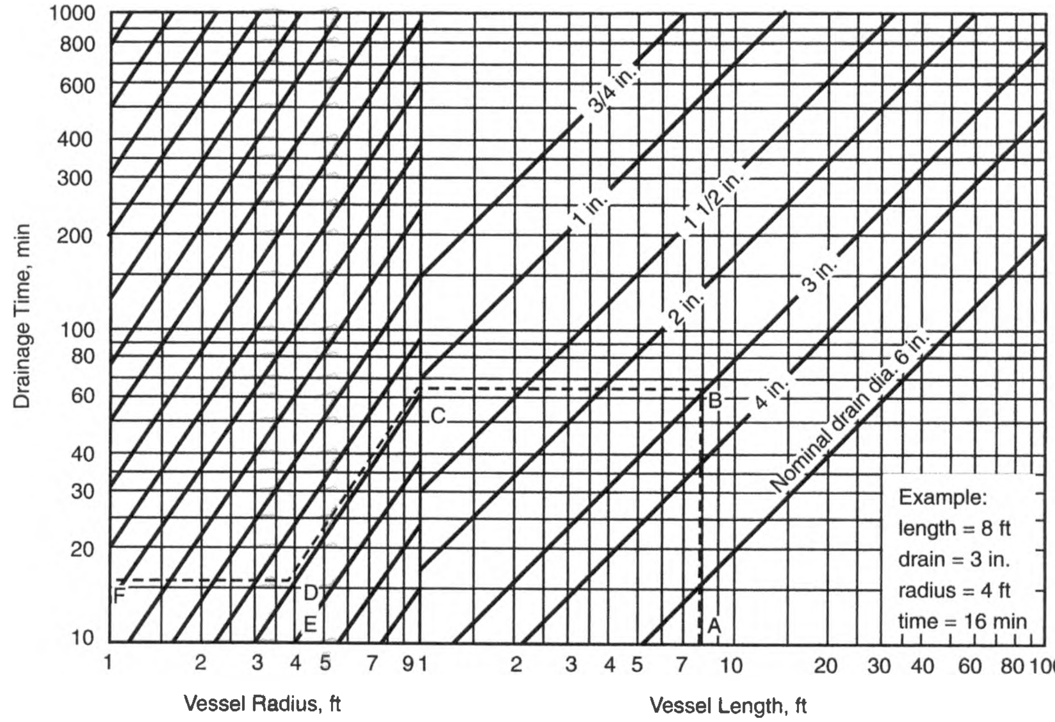
$$T = 2.4\left(\frac{L \cdot D^{1.5}}{d^2}\right)$$

- *For vertical vessels.*

$$T = D^2\sqrt{\frac{H}{D^2}}$$



Source: Ray Elshout,Union Oil Co, Brea,CA. *Reprinted by Permission of Gulf Publishing Co.*



Horizontal Cylinder

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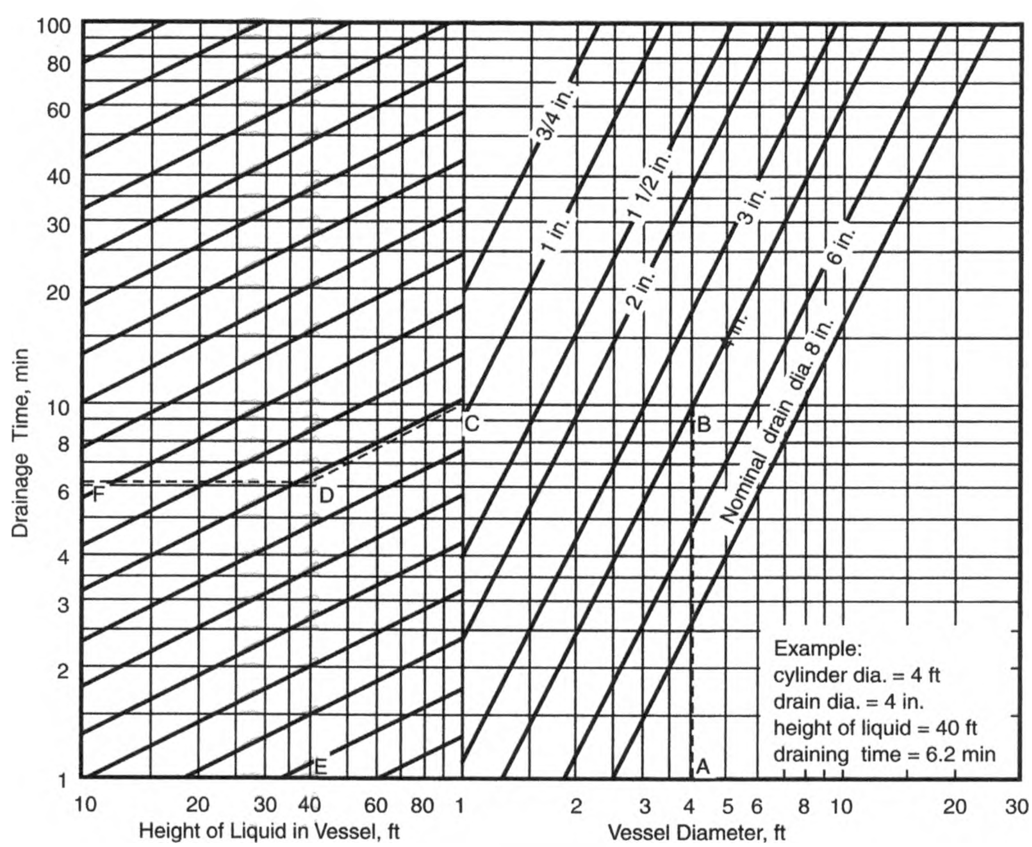

Vertical Cylinder

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Appendix L: Vessel Surge Capacities and Hold-Up Times

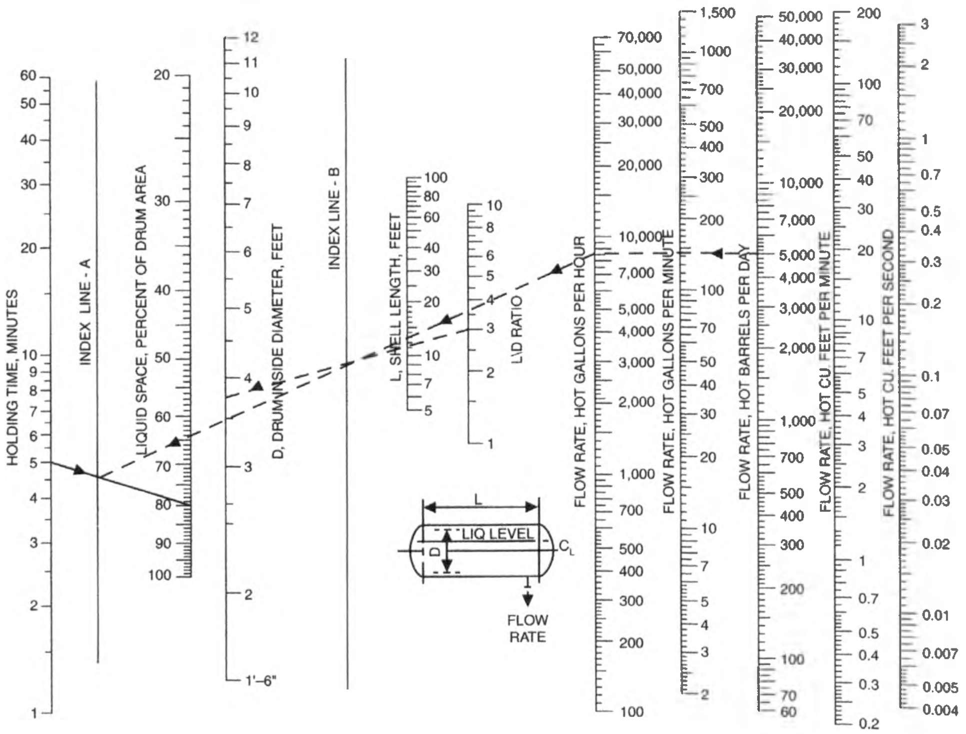


Figure L-1. Nomograph to find drum size for holding time. *Reprinted by permission of Gulf Publishing Co.*

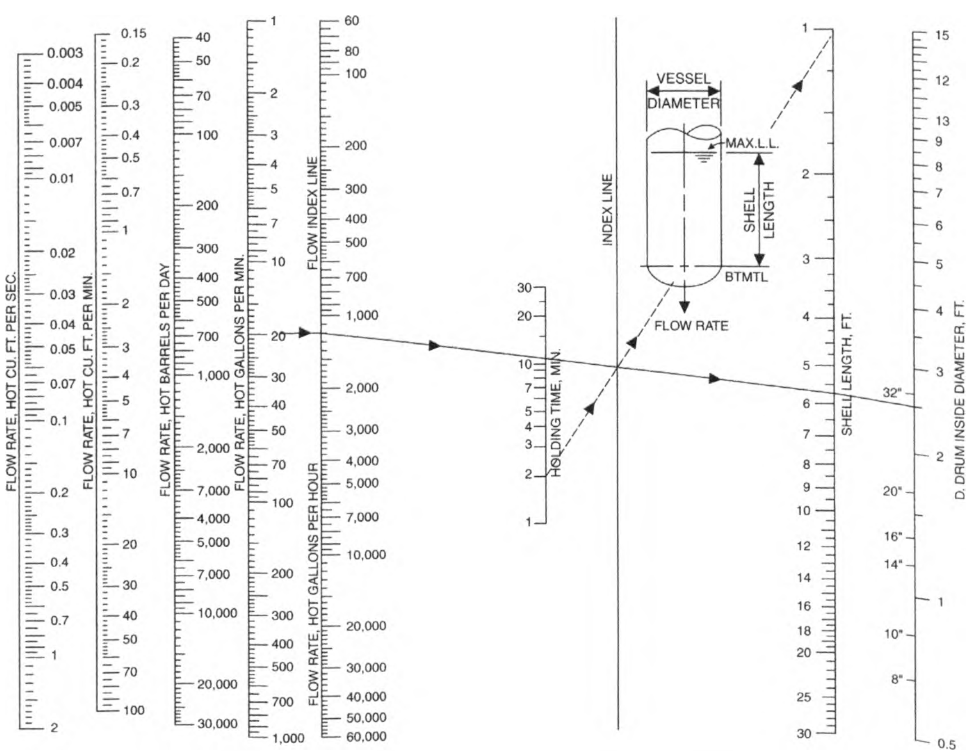
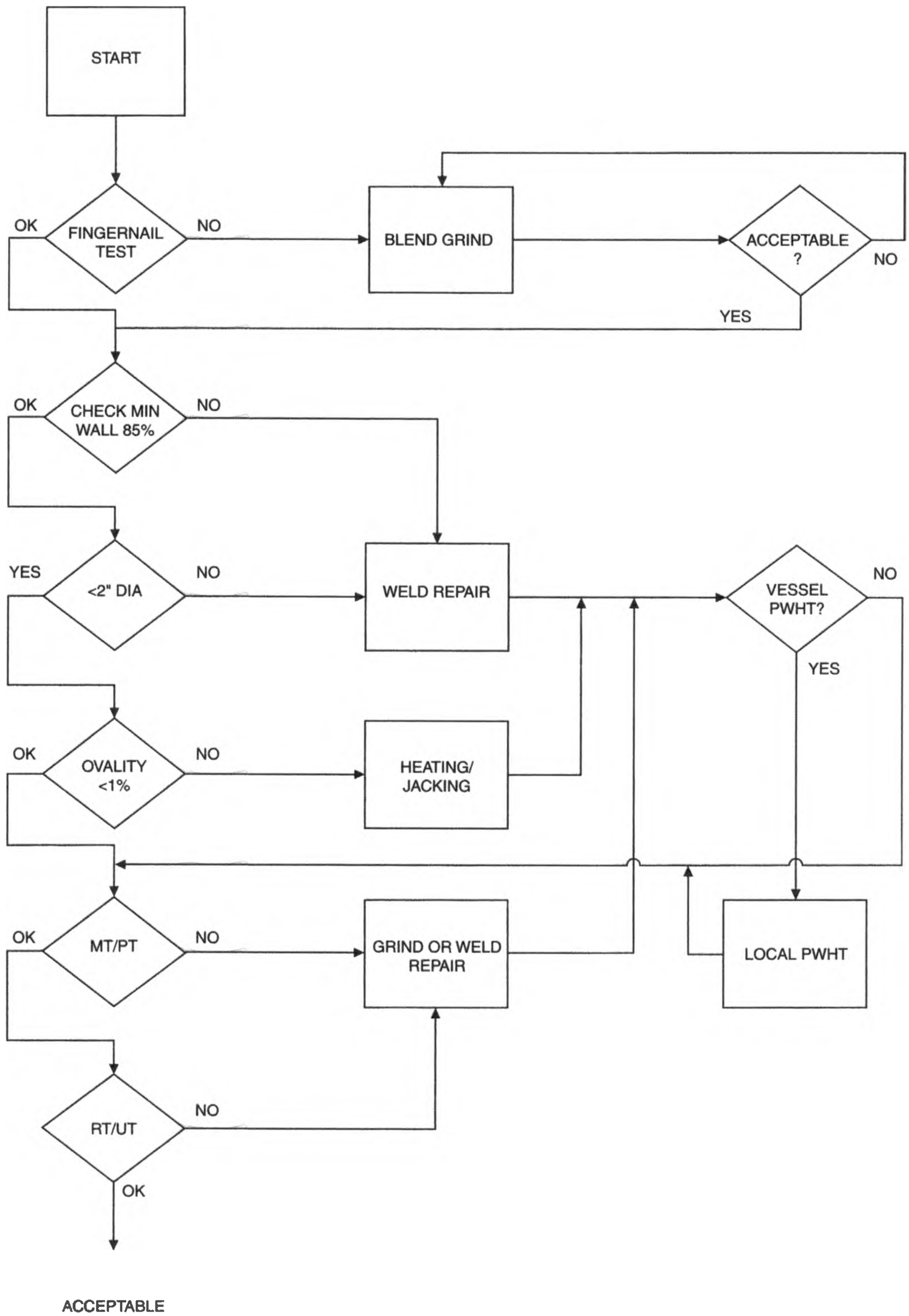


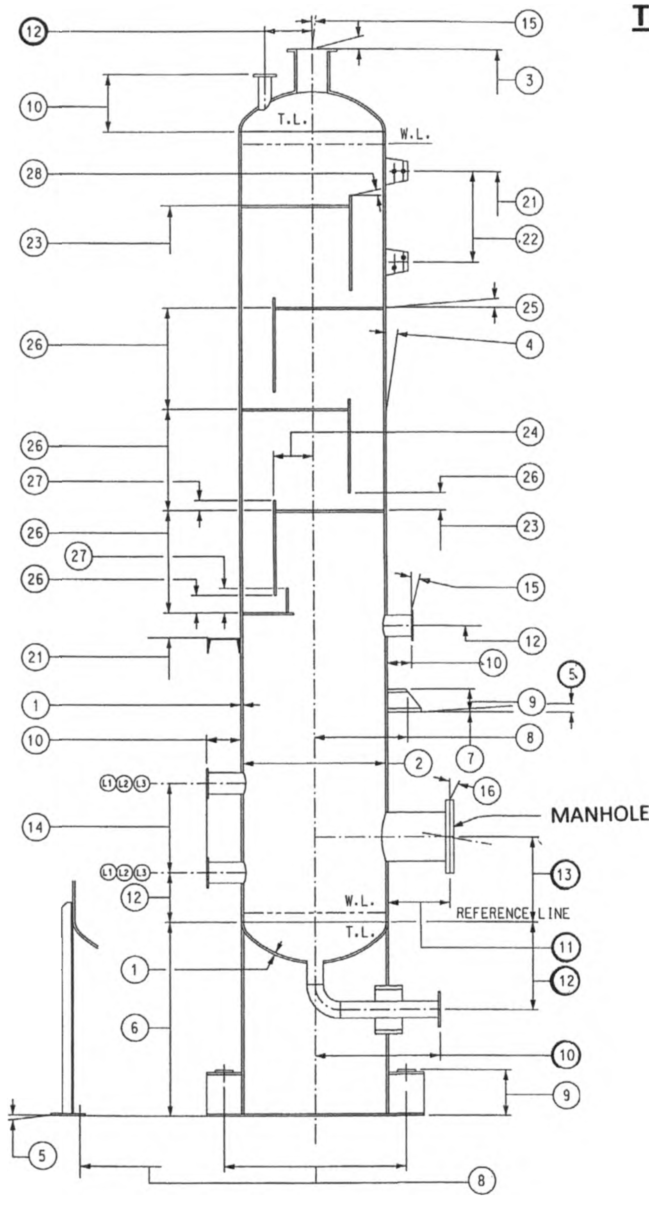
Figure L-2. Nomograph to find shell length for desired holding time. *Reprinted by permission of Gulf Publishing Co.*

Appendix M: Minor Defect Evaluation Procedure

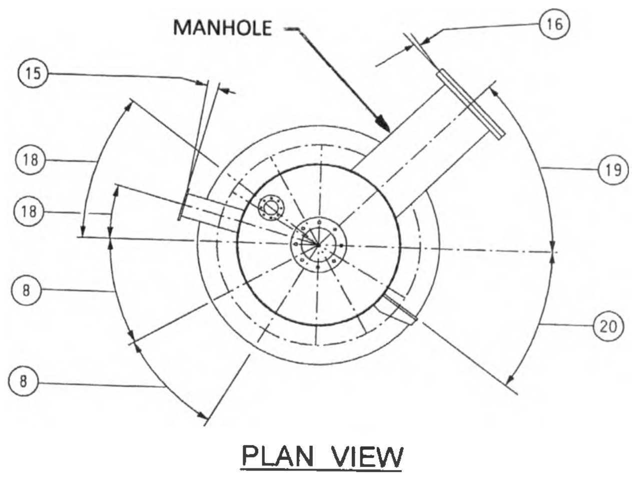


Appendix N: Tolerances

TOLERANCES FOR VERTICAL VESSELS



ELEVATION



PLAN VIEW

Tolerance for Vertical Vessels

Notes:

1. Minimum thickness as specified.
2. Out of roundness is defined by ASME VIII-1, Para. UG 80 and is +/- 1% of the diameter. The following tolerances are recommended to provide stricter control of diametral difference;

SHELL DIA	<48" (1200)	48" - 84" (1200 - 2100)	84"- 180" (2100- 4800)	>180" (4800)
TOLERANCE	± .125" (3mm)	± .188" (4.5mm)	± .25" (6mm)	± .313(7.5mm)

3. Distance from reference tangent line and top flange Face: 0.015 in / Ft (1mm / 1m) < 0.5 in (12mm)
4. Shell & skirt tolerance: Max slope from straight line is 0.125 in / 10 feet (3mm / 3050mm). The total maximum deviation allowed is as follows; (also see table for maximum permissible bow)

Tan-Tan Length	Total Max Deviation
<50' (15240 mm)	.5" (13 mm)
50' - 100' (15240 mm - 30480 mm)	.75" (19 mm)
>100' (30480 mm)	1" (25 mm)

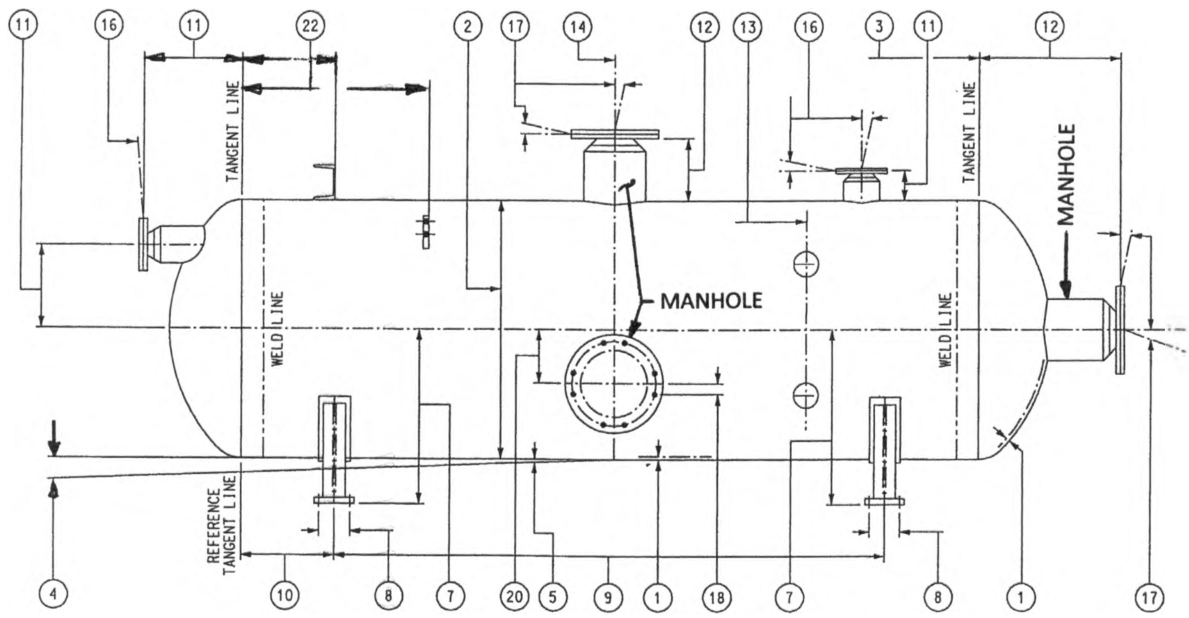
5. Out of levelness over a horizontal plane;

VESSEL DIAMETER	<48" (1200 mm)	48" -84" (1200-2100)	84" - 120" (2100-3000)	>120" (3000 mm)
TOLERANCE	± .06" (1.5 mm)	± .125" (3 mm)	± .188" (5 mm)	± .25" (6 mm)

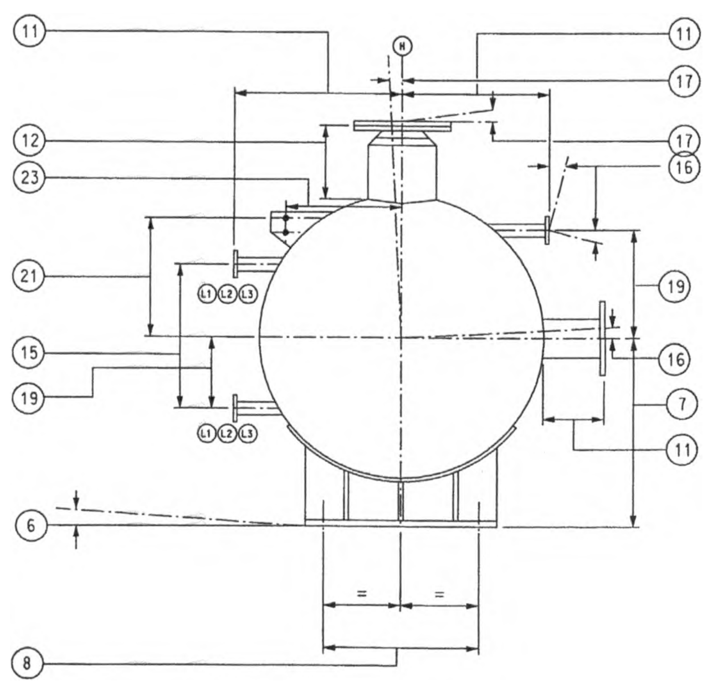
		± inches	± mm
6.	Height of Skirt or Support Legs	+ 0 (-) .125	+ 0 (-) 3
7.	Levelness of Support Lugs	0.125	3
8.	Bolt Circle Diameter for Anchor Bolts	0.125	3
9.	Height of Anchor Chairs	0.125	3

10.	Nozzle projection	0.125	3
11.	Projection of Manhole	0.25	6
12.	Location of Nozzle	0.125	3
13.	Location of Manhole	0.25	6
14.	Distance beween matched instrument connections	0.04	1
15.	Tilt of Nozzle	+/- .5 Degree	
16.	Tilt of Manhole	+/- 1 Degree	
17.	Permissible deviation of bolt holes from C.L.	0.06	1.5
18.	Orientation of Nozzle	0.125	3
19.	Orientation of Manhole	0.25	6
20.	Orientation of Clips & Gussets	0.125	3
21.	Location of Stiffening rings	0.25	6
22.	C-C location of bolt holes in clips	0.125	3
23.	Elevation of Tray Supports from Ref Tan Line	0.25	6
24.	Location of Downcomer Support bars from C.L.	+ .375 (-) .125	+ 9 (-) 3
25.	Out of level of Tray Support Rings	See Tolerances for Trays	
26.	Distance beween trays or DC Clearance	0.125	3
27.	Weir height	0.06	1.5
28.	Levelness of Downcomer Supports	0.125	3

TOLERANCES FOR HORIZONTAL VESSELS



ELEVATION



END VIEW

Tolerance for Horizontal Vessels

Notes:

1. Minimum thickness as specified.
2. Out of roundness is defined by ASME VIII-1, Para. UG 80 and is +/- 1% of the diameter. The following tolerances are recommended to provide stricter control of diametral difference;

Shell dia	<48" (1200)	48" - 84" (1200 - 2100)	>84" (2100)
Tolerance	± .125" (3)	± .188" (4.5)	± .25" (6)

3. Distance between Reference Line and far end of shell.
4. Deviation from horizontal plane.

Shell Length	< 50' (15000)	>50' (15000)
Tolerance	.015"/Ft (1 mm/M)	.01"/Ft (.8 mm / M)

5. Maximum Permissible Bow: <.15% of length <1.5" (40 mm) (See also Table for Maximum Bow)
6. Out of levelness of supports;

Vessel Diameter	< 48" (1200 mm)	48" -84" (1200-2100)	84" - 120" (2100-3000)	>120" (3000 mm)
Tolerance	± .06" (1.5 mm)	± .125" (3 mm)	± .188" (5 mm)	± .25" (6 mm)

		+/- inches	+/- mm
7.	Height of supports	0.13	3
8.	Distance between hole centers for Anchor Bolts	0.06	1.5
9.	Distance between supports	0.13	3
10.	Distance from C.L. Support to Reference Tangent Line	0.13	3
11.	Nozzle projection	0.13	3
12.	Projection of Manhole	0.25	6
13.	Location of Nozzle	0.13	3
14.	Location of Manhole	0.25	6
15.	Distance beween matched instrument connections	0.04	1
16.	Tilt of Nozzle	+/- .5 Degree	
17.	Tilt of Manhole	+/- 1 Degree	

(*Continued*)

18.	Permissible deviation of bolt holes from C.L.	0.04	1
19.	Location of Nozzle from C.L.	0.13	3
20.	Location of Manhole from C.L.	0.25	6
21.	Location of bolt holes of clip from C.L.	0.13	3
22.	Location of clips and stiffening rings from Reference Tangent Line	0.25	6
23.	Projection of bolt holes in clips from C.L.	0.13	3

Tolerances for trayed columns fabricated in multiple sub-assemblies

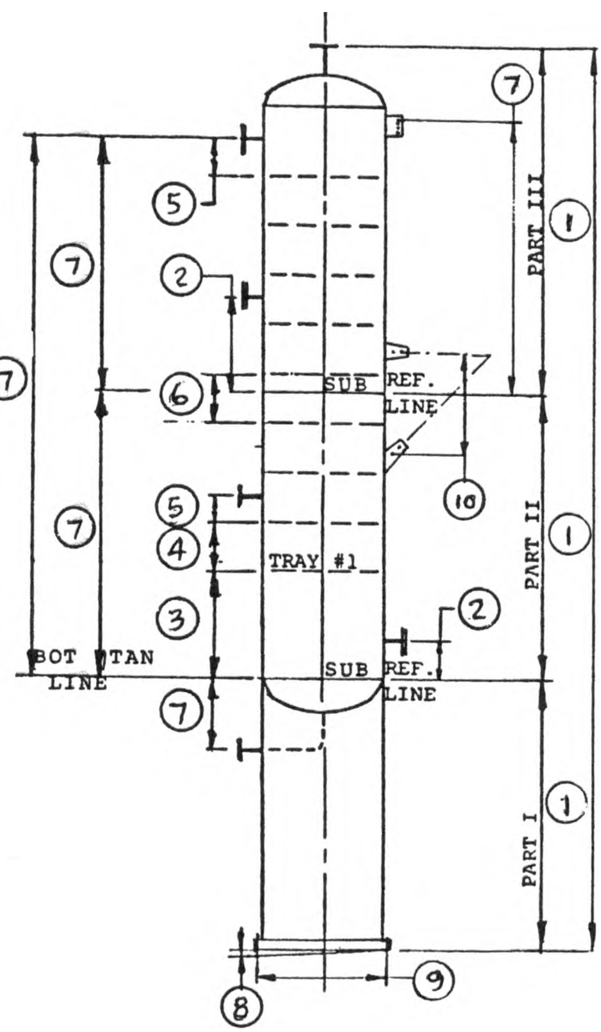
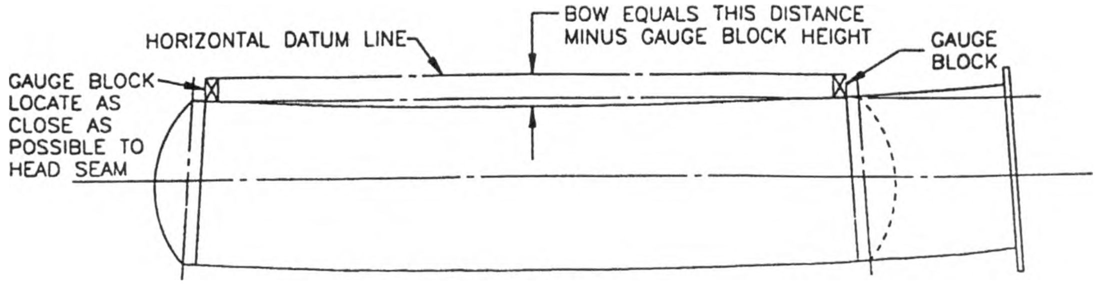


Table N-1
Tolerances for trayed columns fabricated in multiple sub-assemblies

Note	Item	Description/Notes		Tolerance INCHES	Tolerance mm
1	Sub-Assy	Length			
		Ft	mm		
		<5	<1525	+/- .125	+/- 6
		5-10	1525-3045	+/- .25	+/- 6
		10-15	3045-4575	+/- .375	+/- 6
		>15	>4575	+/- .5	+/- 6
2	Manways	From Reference Tangent Line		+/-0.375	+/- 10
3	First Tray	Elevation		+/- .25	+/- 6
4	Tray Spacing	Non-Cumulative		+/- .125	+/- 3
5	Nozzle	Above Tray		+/- .125	+/- 3
6	Tray Spacing	At Girth Seam Sub-Assembly		+/- .375	+/- 10
7	Nozzle Clips & Elevations	LENGTH			
		Ft	mm		
		<5	<1525	+/- .125	+/- 3
		5-10	1525-3045	+/- .25	+/- 6
		10-15	3045-4575	+/- .375	+/- 10
		15-20	4575-6100	+/- .5	+/- 13
		20-40	6100-12200	+/- .75	+/- 19
		40-80	12200-24400	+/- 1	+/- 25
		80-160	24400-48800	+/- 1.5	+/- 38
		>160	>48800	+/- .75%	+/- .75%
8	Out of level Slope	For Skirt Diameter >20' (6 M)		1/500	1/500
9	Anchor Bolt Circle	.5" (12 mm) Max Total		+/- .25	+/- 6
10	Bolt Hole Location-Clips	Non-Cumulative		+/- .25	+/- 6

Maximum Permissible Bow



Note: For permissible bow see Tables below. Measurements shall be taken at approximately 10' (3000 mm) apart, lengthwise, and 90° apart around the circumference.

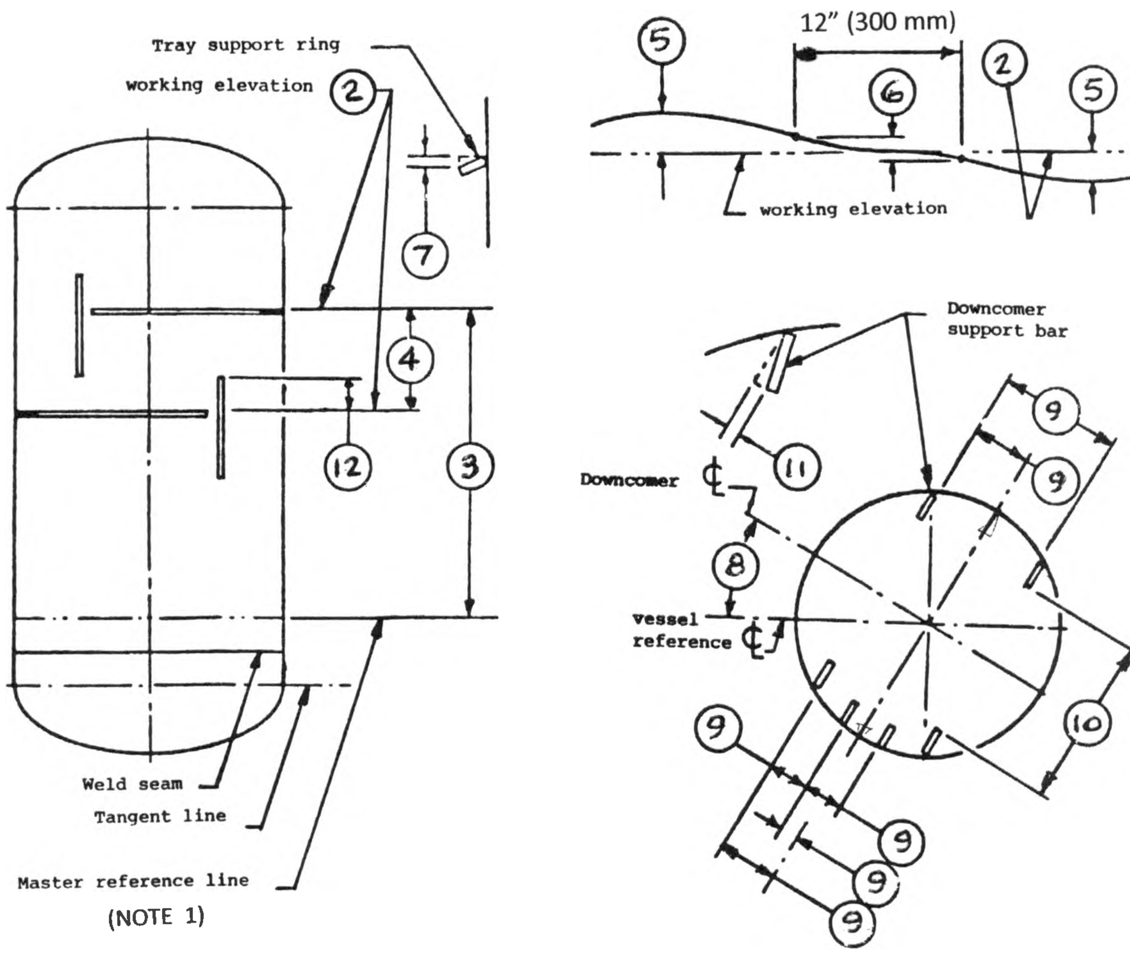
Table N-2
US units

Vessel Length Tan-Tan (Ft)	Vessel Diameter & Maximum Permissible Bow			
	<48"	48" to 72"	72" to 96"	>96"
<10	0.12	0.09	0.06	0.06
10-20	0.25	0.18	0.15	0.1
20-30	0.35	0.25	0.23	0.15
30-40	0.5	0.34	0.3	0.2
40-50	0.6	0.4	0.35	0.25
50-60	0.7	0.5	0.4	0.3
60-70	0.85	0.6	0.45	0.35
70-80	1	0.67	0.53	0.4
80-90	1.1	0.8	0.6	0.45
90-100	1.2	0.9	0.67	0.5
>100	1.5	1	0.75	0.55

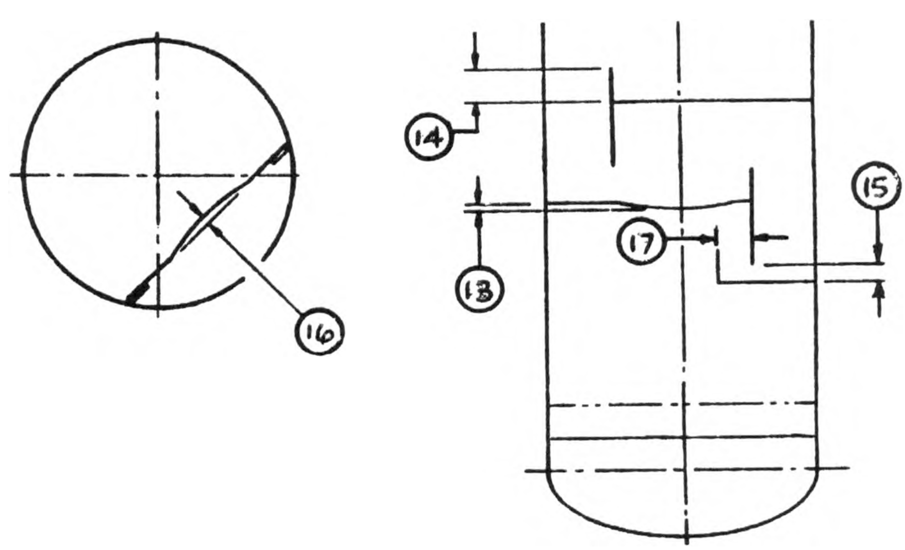
Table N-3
Metric units

Vessel Length Tan-Tan (mm)	Vessel Diameter & Maximum Permissible Bows			
	<1200	1200-1800	1800-2400	>2400
<3000	4	2.4	1.6	1.6
3000-6000	8	4.7	4	2.4
6000-9000	11	8	5.5	4
9000-12000	15	10	8	4.7
12000-15000	19	13	9.5	6
15000-18000	23	15	11	8
18000-21000	27	17	13.5	9
21000-24000	30	21	15	10
24000-27000	34	23	17	11
>27000	38	25	19	13

Tolerances for Trays, Tray Support Rings and Downcomers



Vessel Trays Supports
(Weld in Parts)



TRAY TOLERANCES

Tolerances for Trays, Tray Support Rings and Downcomers

1. The Master Reference Line (MRL) shall be established by the vessel manufacturer and clearly marked inside and outside of the vessel prior to attaching the bottom head. It shall be parallel to the root land of the bottom seam weld, and perpendicular to the longitudinal axis of the vessel.
2. The working elevation of a tray support ring shall be the elevation specified on the outline drawing. It shall be a level plane parallel to the MRL.
3. The distance from the MRL to the working elevation of any tray support ring shall be within +/- 1/4 in. (6mm) of the nominal distance.
4. The distance between the working elevations of any two adjacent tray support rings shall be within +/- 1/8 in. (3mm) of the nominal distance, and the accumulated tolerances between tray support rings shall not exceed the tolerances in Note 3.
5. The highest and lowest points of a tray support ring, measured adjacent to the vessel shell, shall not exceed the following deviations from the working elevations;

Vessel Dia	Tolerance
48" (1200 mm) and smaller	1/16" (1.5 mm)
48" to 84" (1200 – 2100 mm)	3/32" (2.5 mm)
Over 84"	1/8" (3 mm)

6. Tray support rings shall not have a waviness exceeding 1/16 in. (1.5mm) for any 1 foot (300mm) of circumferential length.
7. Tilt of a tray support ring over its width shall not exceed 1/16 in. (1.5mm)
8. Orientation of the downcomer centerline shall be within 1/8 in. (3mm) of its nominal distance from the Vessel Reference Centerline, VRC, for vessels up to 72 in. (1800mm) dia and within ¼" (6mm) for vessels over 72 in. (1800mm) dia.
9. Distance from downcomer support bar to VRC shall be within +/- 1/8 in. (3mm) of the nominal distance. On a multipass tray, the distance between downcomer support bars shall also be within +/- 1/8 in. (3mm) of the nominal distance.
10. Deviation from nominal distance between downcomer support bars shall be subject to vessel out-of-roundness tolerance. Facility for adjustment must be provided in the downcomer and weir plates.
11. Tilt of downcomer support bars over its width shall not exceed 1/16 in. (1.5mm)
12. Distance between top of downcomer (weir) support bar and top of tray support ring shall be within +/- 1/16 in. (1.5mm) of the nominal distance.
13. Tray decks shall have a flat surface within 1/16 in. (1.5mm) measured across a 1 ft (300mm) square surface.
14. The difference in height between the highest and lowest points of the weir, measured to a level plane, shall not exceed;

Vessel Dia	Tolerance
72" (1800 mm) and smaller	1/8" (3 mm)
72" to 108" (1800 – 2700 mm)	3/16" (5 mm)
Over 108"	1/4" (6 mm)

15. Clearance between bottom of downcomer and top of tray or seal pan below shall not deviate from the nominal clearance by more than;

Vessel Dia	Tolerance
72" (1800 mm) and smaller	+/- 1/8" (3 mm)
72" to 108" (1800 – 2700 mm)	+/- 3/16" (5 mm)
Over 108"	+/- 1/4" (6 mm)

16. The bowing of a downcomer in a horizontal plane shall not deviate from the straight by more than +/- 1/8 in. (3mm)
17. Downcomer horizontal clearances, measured from the bottom edge of downcomer to recessed seal pan or inlet weir, shall be within +/- 1/8 in. (3mm) of nominal.

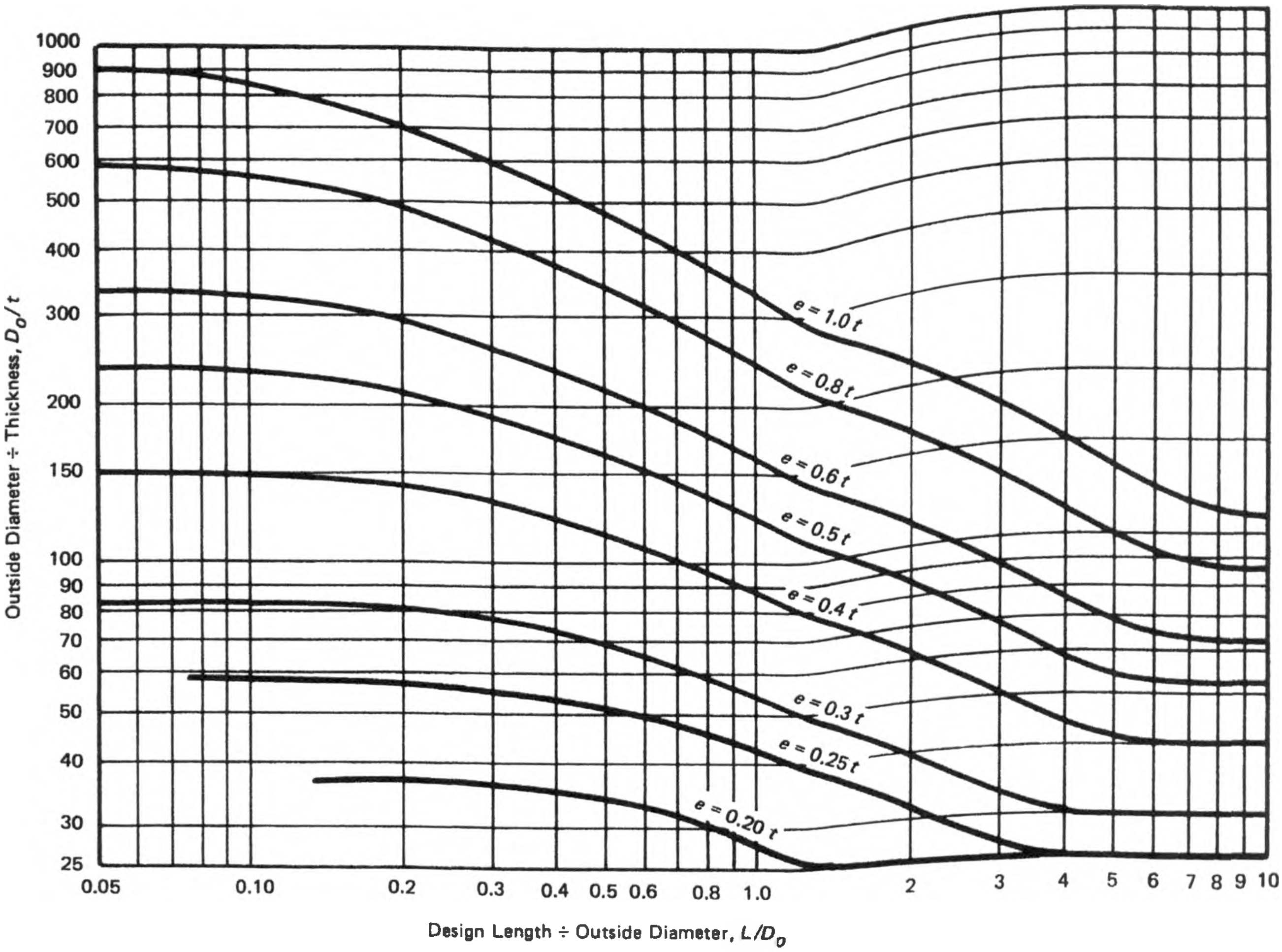


Figure N-1. Maximum permissible deviation from a circular form e for vessels under external pressure. *Source: Reprinted by permission of ASME.*

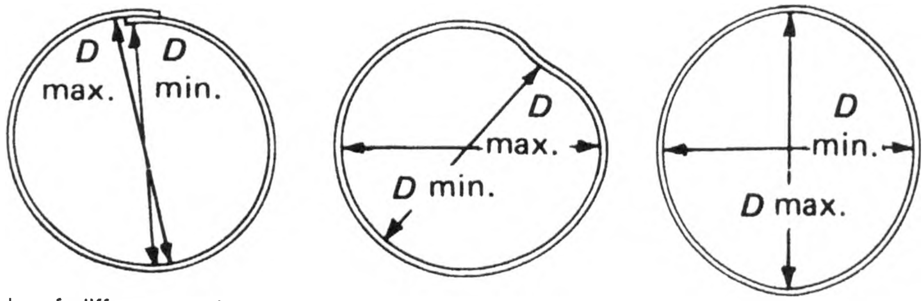
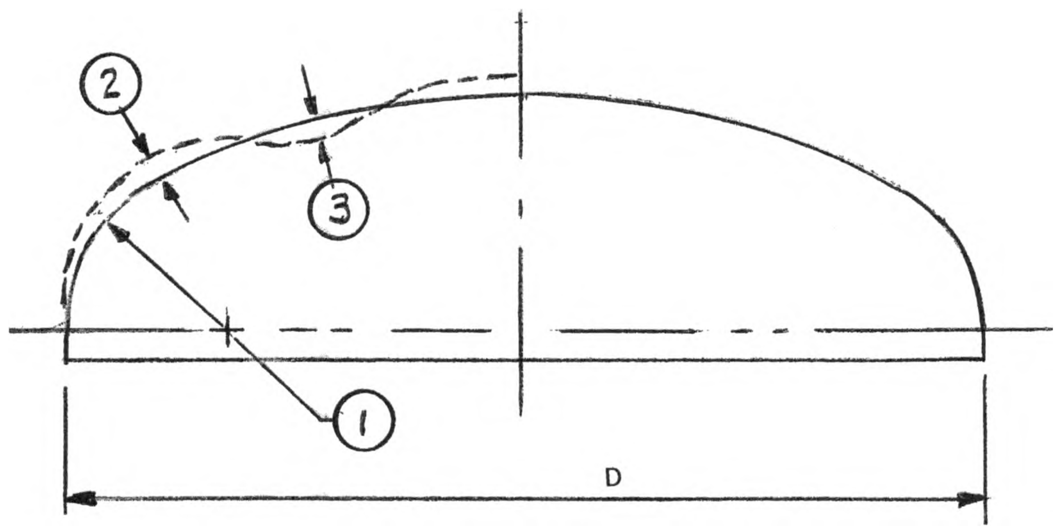


Figure N-2. Example of differences between maximum and minimum inside diameters in cylindrical, conical, and spherical shells. *Source: Reprinted by permission of ASME.*

Tolerances for Shape of Heads

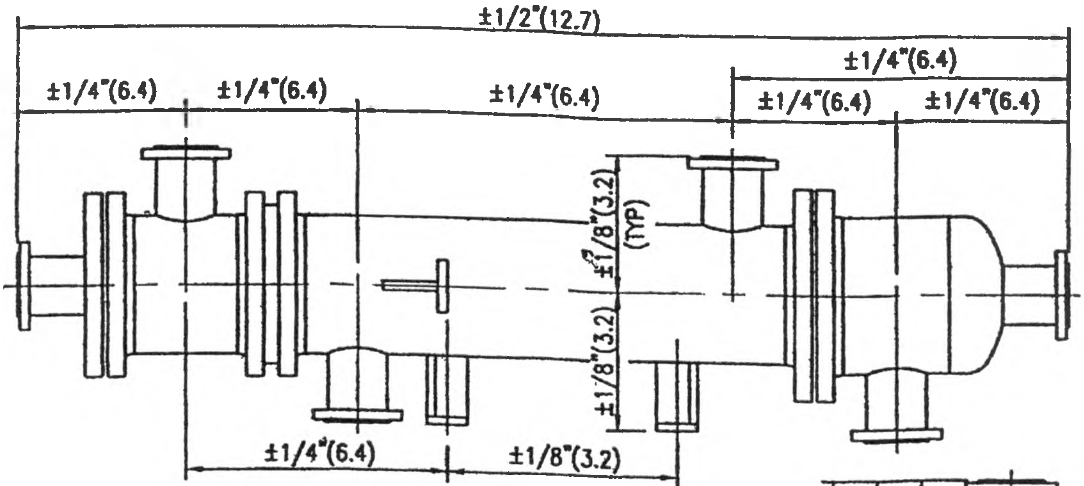


(1) Knuckle Radius: Not less than minimum specified

(2) Outside Surface: .0125 D

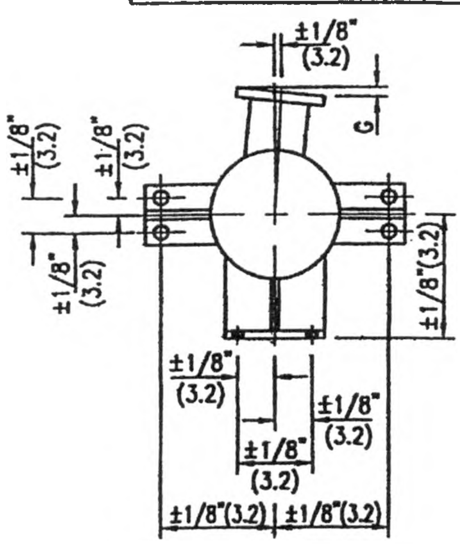
(3) Inside Surface: .00625 D

Tolerances for Heat Exchangers

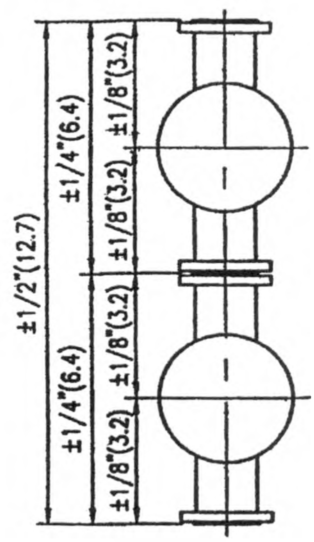


NOMINAL NOZZLE SIZE	G MAX
2"–4" INCLUSIVE	1/16"(1.6)
6"–12" INCLUSIVE	3/32"(2.4)
14"–36" INCLUSIVE	3/16"(4.8)
OVER 36"	1/4"(6.4)

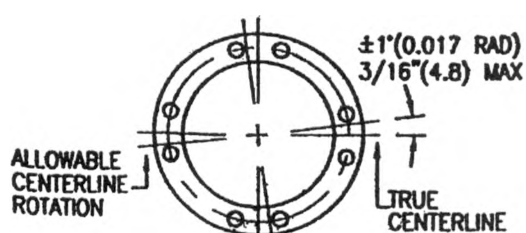
NOTE: This table applies to nozzles connecting to external piping only.



CONNECTION NOZZLE ALIGNMENT AND SUPPORT TOLERANCES



STACKED EXCHANGERS



ROTATIONAL TOLERANCE ON NOZZLE FACES AT BOLT CIRCLE

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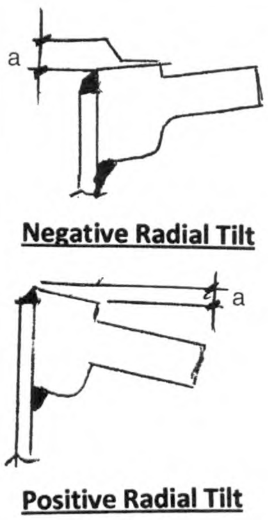
Table N-4
Tolerances for flanges

Threaded, Slip-on, Lap Joint and Blind				Welding Neck			
Outside Diameter	OD 24" & Less	+/- .06		**Outside Diameter**	OD 24" & Less	+/- .06	
	OD > 24"	+/- .125			OD > 24"	+/- .125	
Inside Diameter	Threaded	To Standard Gage Limits		**Inside Diameter**	10" & Smaller	+/- .03	
	SLIP-ON & LAP JOINT	10" & Smaller, +.03, -0			12" thru 18"	+/- .06	
		12" & Larger, +.06, -0			20" thru 42"	+.125, - .06	
Outside Diameter of Hub	12" & Smaller	+.09, -.06		**Diameter of Contact Face**	.0625 RF	+/- .03	
	14" thru 42"	+/- .125			.25" RF, T&G, M&F	+/- .015	
Diameter of Contact Face	.0625 RF	+/- .03		**Diameter of Hub at Base**	When "X" is 24" or Smaller	+/- .06	
	.25" RF, T&G, M&F	+/- .015			When "X" is over 24"	+/- .25	
Diameter of Counterbore	10" & Smaller	+.03, -0		**Diameter of Hub at Point of Welding**	5" & Smaller	+.09, -.03	
	12" thru 42"	+.06, -0			6" & Larger	+.156, -.03	
Drilling	Bolt Circle	.5" thru 24", +/- .06	26" thru 42", +/- .06	**Drilling**	Bolt Circle	.5" thru 24", +/- .06	26" thru 42", +/- .06
	Bolt Hole Spacing	+/- .03	+/- .03		Bolt Hole Spacing	+/- .03	+/- .03
	Eccentricity of Bolt Circle with Respect to Bore	.03 Max			Eccentricity of Bolt Circle with Respect to Bore	.03 Max	
	Eccentricity of Facing with Respect to Bore				Eccentricity of Facing with Respect to Bore		
Thickness	18" & Smaller	+.125, -0		**Thickness**	18" & Smaller	+.125, -0	
	20" thru 42"	+.188, -0			>18"	+.188, -0	
Length Thru Hub	10" & Smaller	+/- .06		**Length thru Hub**	10" & Smaller	+/- .06	
	12" thru 42"	+/- .125			12" thru 42"	+/- .125	
Ring Joint Facing				**Ring Joint Gasket**			
Depth	Dim L	+.015, -0		**Ring Width**	Dim A	+/-0.008	
Width	Dim D	+/-0.008		**Ring Depth**	Dim B&H	+/-0.015	
Pitch Diameter	Dim P	+/-0.005		**Width Octagonal Flat**	Dim C	+/-0.008	
Radius at Bottom	Dim r	Max		**Pitch Diameter**	Dim P	+/-0.007	
Angle	23° Angle	+/- .5°		**Radius**	Dim r	+/-0.015	
				Angle	23° Angle	+/-0.5°	

Notes:

1. All tolerances per Tube-Turn Catalog
2. See ASME B16.5 for flange dimensions and tolerances

Table N-5
Flange face tolerances



Maximum Tolerances			
Flange Rating	**Nominal Size**	**Waviness T.I.R. (In)**	**Positive Radial Tilt (a)**
150	<24"	0.016	0.009
	>24"	0.012	0.012
300-600	All Sizes	0.006	0.012
900-2500	All Sizes	0.005	0.003
75, 125, 175, 250, 350	>26"	0.006	0.018

Notes:

1. Negative radial tilt is not allowed

Table N-6
Maximum permissible offset in butt welding

Thickness		**Joint category, UW-33**			
		A		**B, C, D**	
Inches	mm	Inches	mm	Inches	mm
<.5	<12.5	.25 T	.25 T	.25 T	.25 T
.5 to .75	12.5 to 19	0.125	3.2	.25 T	.25 T
.75 to 1.5	19 to 38	0.125	3.2	0.188	4.8
1.5 to 2	38 to 50	0.125	3.2	0.125 T	.125 T
>2	>50	.06 T < b < .37	.06 T < b < .75	.125 T < b < .75	.125 T < b < 19

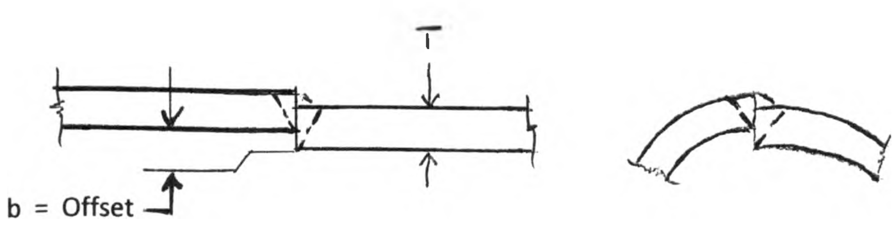
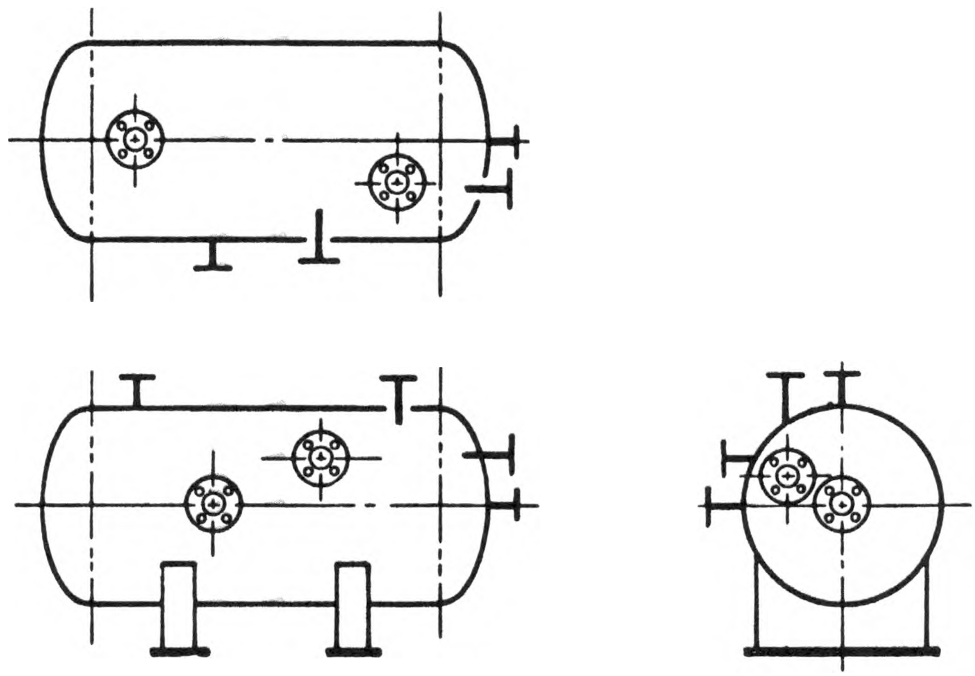


Table N-7
General tolerances: For machined or fabricated parts

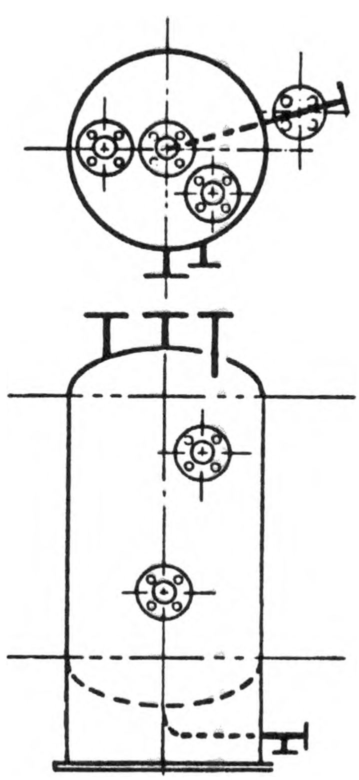
1.0 Machined Parts												
1.1 Linear Dimensions and Diameters												
Distance, mm	.5 to 3	3 to 6	6.1 to 30	31 to 120	121 to 400	401 to 1000	1001 to 2000	2001 to 4000	4001 to 8000	8001 to 12000	12001 to 16000	16001 to 20000
Tolerance + or - mm	0.15	0.2	0.5	0.8	1.2	2	3	4	5	6	7	8
Distance, Inches	.2" to .125"	.126 to .25	0.26 to 1.25	1.26 to 4.75	4.76 to 15.75	15.76 to 39.5	39.51 to 78.75	78.76 to 157.5	157.51 to 315	315.1 to 472	472.1 to 630	630.1 to 787
Tolerance + or - inches	0.01	0.01	0.02	0.03	0.05	0.08	0.12	0.16	0.2	0.24	0.28	0.3
1.2 Radii												
Radii, mm	.5 to 3	3 to 6	6 to 30	30 to 120	120 to 400	400 to 1000	1000 to 2000	2000 to 4000				
Tolerance + or - mm	0.2	0.5	1	2	4	6	8	10				
Radii, Inches	.2" to .125"	.126 to .25	0.26 to 1.25	1.26 to 4.75	4.76 to 15.75	15.76 to 39.5	39.51 to 78.75	78.76 to 157.5				
Tolerance + or - inches	0.01	0.01	0.04	0.08	0.16	0.24	0.3	0.39				
1.3 Angular Dimensions												
Angle, Degrees	0 to 10	10.1 to 20	20.1 to 40	40.1 to 60	60.1 to 90							
Tolerance + or - minutes	15	20	30	45	90							
1.4 Straightness/Planeness (Maximum distance between a straight line and actual line or plane surface and actual surface)												
Length, mm	0 to 6	6.1 to 30	31 to 120	121 to 400	401 to 1000	1001 to 2000	2001 to 4000	4001 to 8000	Above 8001			
Tolerance + or - mm	0.1	0.25	0.5	1	1.5	2.5	3.5	5	7			
Length, Inches	0 to .25	.26 to 1.25	1.26 to 4.75	4.76 to 15.75	15.76 to 39.5	39.6 to 78.75	78.76 to 157.5	157.6 to 315	Above 315.1			
Tolerance + or - inches	0.005	0.01	0.02	0.04	0.06	0.1	0.14	0.2	0.28			
1.5 Rectangularity (Maximum difference in length between the diagonals)												
Distance, mm	0 to 120	121 to 400	401 to 1000	1001 to 2000	2001 to 3000	3001 to 4000	4001 to 5000	5001 to 6000	6001 to 7000	7001 to 8000	8001 to 9000	9001 to 10000
Tolerance + or - mm	2	3	4	7	10	14	18	21	24	28	31	35
Distance, Inches	0 to 4.75	4.76 to 15.75	15.78 to 39.5	39.6 to 78.75	78.76 to 118	118.1 to 157	157.1 to 197	197.1 to 236	236.1 to 275	275.1 to 315	315.1 to 355	355.1 to 395
Tolerance + or - inches	0.08	0.12	0.16	0.28	0.4	0.55	0.7	0.8	1	1.1	1.2	1.4
2.0 Fabricated Parts												
2.1 Linear Dimensions and Diameters												
Distance, mm	0 to 30	31 to 120	121 to 400	401 to 1000	1001 to 2000	2001 to 4000	4001 to 8000	8001 to 12000	12001 to 16000	16001 to 20000	Above 20001	
Tolerance + or - mm	1	2	2	3	4	6	8	10	12	14	16	
Distance, Inches	0 to 1.25	1.26 to 4.75	4.76 to 15.75	15.76 to 39.5	39.6 to 78.75	78.76 to 157.5	157.6 to 315	315.1 to 475	475.1 to 630	630.1 to 790	Above 791	

Tolerance + or - inches	0.04	0.08	0.08	0.12	0.16	0.24	0.31	0.39	0.47	0.55	0.63	
2.2 Radii												
Radii, mm	30 to 120	121 to 400	401 to 1000	1001 to 2000	2001 to 4000							
Tolerance + or - mm	3	6	9	12	15							
Radii, Inches	1.26 to 4.75	4.76 to 15.75	15.76 to 39.5	39.51 to 78.75	78.76 to 157.5							
Tolerance + or - inches	0.12	0.25	0.38	0.5	0.6							
2.3 Angular Dimensions												
Angle, Degrees	0 to 10	10.1 to 20	20.1 to 40	40.1 to 60.	60.1 to 90							
Tolerance + or - minutes	30	45	60	90	120							
2.4 Straightness/Planeness (Maximum distance between a straight line and actual line or plane surface and actual surface)												
Length, mm	30 to 120	121 to 400	401 to 1000	1001 to 2000	2001 to 4000	4001 to 8000	8001 to 12000	12001 to 16000	Above 16001			
Tolerance + or - mm	1	1.5	3	4.5	6	8	10	12	14			
Length, Inches	1.2 to 4.75	4.76 to 15.75	15.76 to 39.5	39.51 to 78.75	78.76 to 157.5	157.6 to 315	315.1 to 472	472.1 to 630	Above 631			
Tolerance + or - inches	0.04	0.08	0.12	0.18	0.24	0.31	0.4	0.47	0.55			
2.5 Rectangularity (Maximum difference in length between the diagonals)												
Distance, mm	30 to 120	121 to 400	401 to 1000	1001 to 2000	2001 to 3000	3001 to 4000	4001 to 5000	5001 to 6000	6001 to 7000	7001 to 8000	8001 to 9000	9001 to 10000
Tolerance + or - mm	2	3.5	7	14	21	28	35	42	49	56	63	70
Distance, Inches	1.2 to 4.75	4.76 to 15.75	15.76 to 39.5	39.6 to 78.75	78.76 to 118	118.1 to 157	157.1 to 197	197.1 to 236	236.1 to 275	275.1 to 315	315.1 to 355	355.1 to 395
Tolerance + or - inches	0.08	0.14	0.28	0.55	0.83	1.1	1.38	1.65	1.93	2.2	2.5	2.75

Flange Bolt Hole Orientation



HORIZONTAL VESSEL



VERTICAL VESSEL

Stress Due to Out of Tolerance Condition

Notation

d = Peaking or banding measurement
d = for peaking;
$.5\ (a_1 + a_2)$ or
$.25\ (b_1 + b_2)$
d = For banding;.
$.5\ (a_1 + b_1)$
e = Amount of offset, in
E = Modulus of elasticity, PSI
L = Half the length of gauge, in
P = Internal pressure, PSIG
R_m = Mean vessel radius, in
t = Vessel thickness, in
β = Factor
ν = Poisson's ratio
σ_P = Stress due to peaking, PSI
σ_O = Stress due to offset, PSI
σ_X = Longitudinal stress, PSI
σ_ϕ = Circumferential Stress, PSI

Note: Peaking and banding are for longitudinal seams only. Offset can be for longitudinal seams or circumferential seams.

Calculations

STRESS DUE TO PEAKING OR BANDING

- Circumferential stress due pressure, σ_ϕ

$$\sigma_\phi = P\,R_m/t$$

- Factor β

$$\beta = \left[2\,L/t\right]\left[\left(3\left(1-\nu^2\right)\sigma_\phi\right)/E\right]^{1/2}$$

For $\nu = .3$;

$$\beta = \left[3.3\,L/t\right]\left[\sigma_\phi/E\right]^{1/2}$$

- Stress due to peaking or banding, σ_P

$$\sigma_P = \left(6\sigma_\phi d\tanh\beta\right)/\left(t\left(1-\nu^2\right)\beta\right)$$

For $\nu = .3$;

$$\sigma_P = \left(6.59\,\sigma_\phi d\tanh\beta\right)/\left(t\,\beta\right)$$

STRESS DUE TO OFFSET

- Circumferential stress due pressure, σ_ϕ

$$\sigma_\phi = P\,R_m/t$$

- Longitudinal stress due pressure, σ_X

$$\sigma_X = P\,R_m/2\,t$$

- Stress due to offset, σ_O

$$\sigma_O = \left(3\,e\,\sigma\right)/\left(t\left(1-\nu^2\right)\right)$$

For $\nu = .3$;

$$\sigma_O = (3.3\,e\,\sigma)/t$$

where σ = Applicable case of σ_X or σ_ϕ

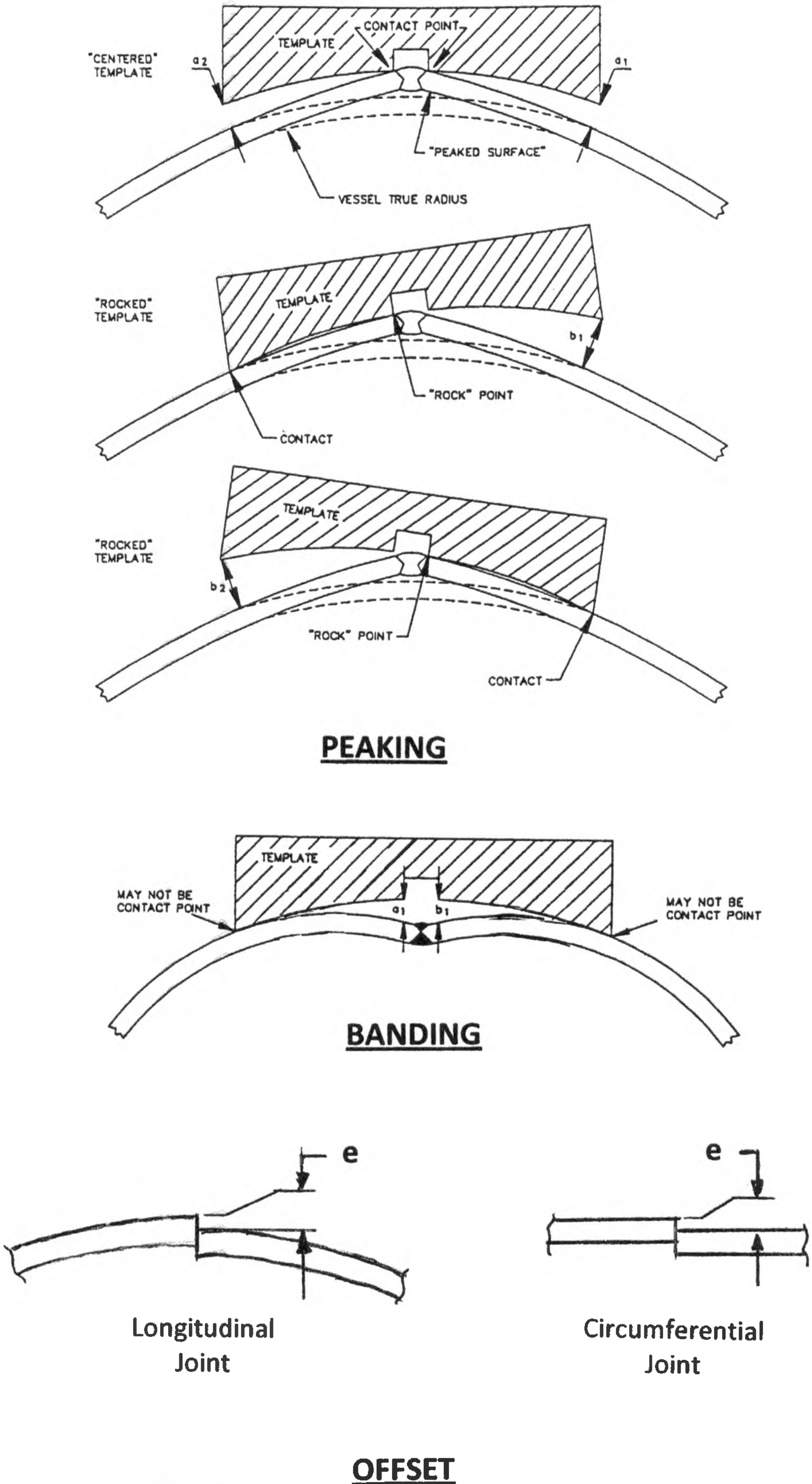
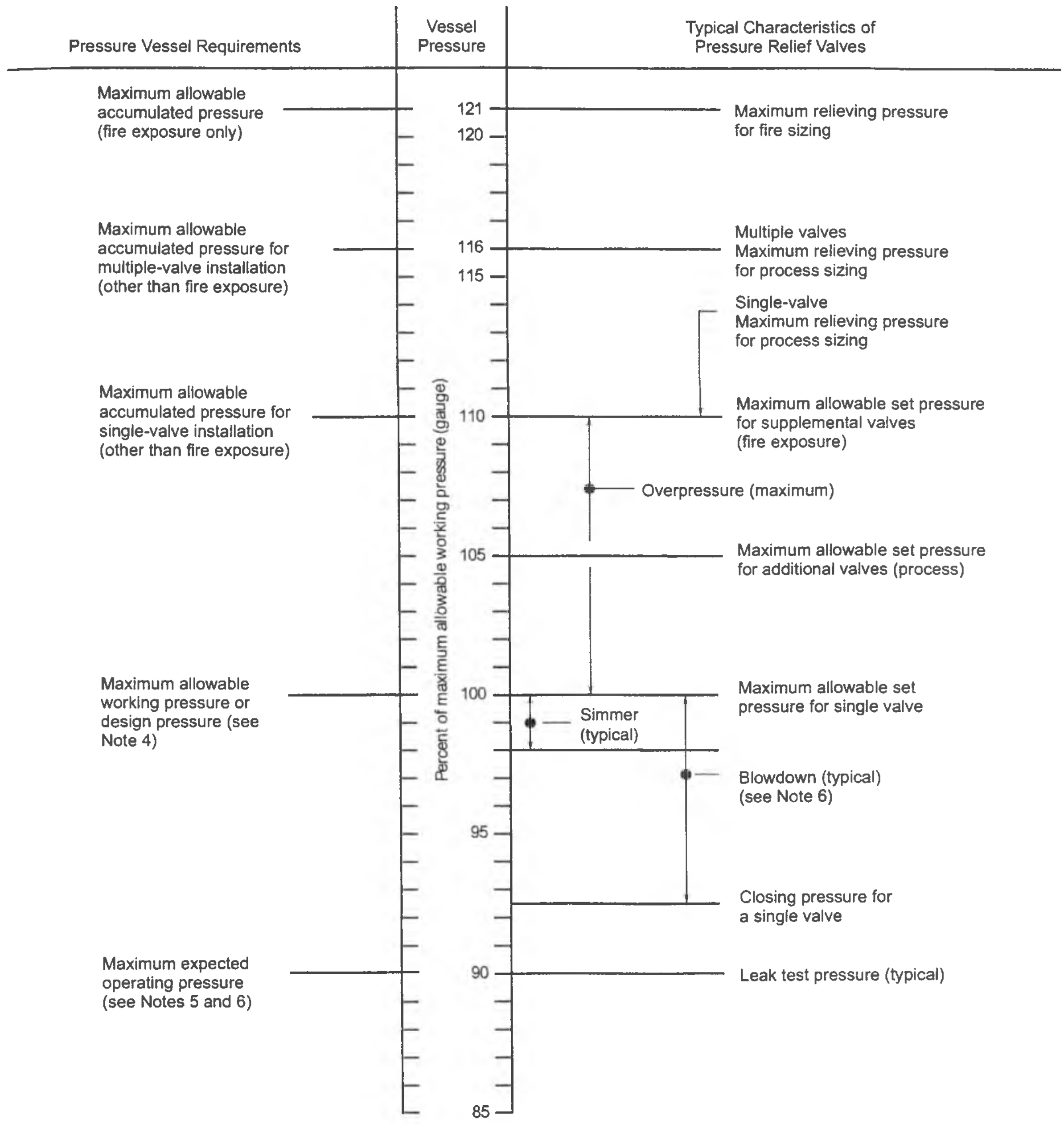


Figure N-3. Measurement of out of tolerance conditions.

Appendix O: Guideline for Application of Pressure Relief Values (PRVs)



NOTES
1. This figure conforms with the requirements of Section VIII of the ASME *Boiler and Pressure Vessel Code* for MAWPs greater than 30 psig.
2. The pressure conditions shown are for pressure relief valves installed on a pressure vessel.
3. Allowable set-pressure tolerances will be in accordance with the applicable codes.
4. The maximum allowable working pressure is equal to or greater than the design pressure for a coincident design temperature.
5. The operating pressure may be higher or lower than 90 %.
6. Section VIII, Division 1, Appendix M of the ASME Code should be referred to for guidance on blowdown and pressure differentials.

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References

[1] Roark RJ. Formulas for Stress and Strain. 5th Edition. McGraw-Hill Book Co; 1975.
[2] ASME Code, Section VIII, Division 2.
[3] ASME Code, Section VIII, Division 1.