Designation: D3299 − 18

Standard Specification for Filament-Wound Glass-Fiber-Reinforced Thermoset Resin Corrosion-Resistant Tanks[1]

This standard is issued under the fixed designation D3299; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the U.S. Department of Defense.

1. Scope

1.1 This specification covers cylindrical tanks fabricated by filament winding for above-ground vertical installation, to contain aggressive chemicals at atmospheric pressure as classified herein, and made of a commercial-grade polyester or vinylester resin. Included are requirements for materials, properties, design, construction, dimensions, tolerances, workmanship, and appearance.

1.2 This specification does not cover the design of vessels intended for pressure above atmospheric or under vacuum conditions, except as classified herein, or vessels intended for use with liquids heated above their flash points.

1.3 The values stated in inch-pound units are to be regarded as standard. The values given in parentheses are mathematical conversions to SI units that are provided for information only and are not considered standard.

1.4 Special design consideration shall be given to tanks subject to environmental and/or mechanical forces such as seismic, wind, ice, agitation, or fluid dynamic forces, to operational service temperatures greater than 180°F (82°C) and to tanks with unsupported bottoms.

1.5 The following safety hazards caveat pertains only to the test method portion, Section 11, of this specification: *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

NOTE 1—There is no known ISO equivalent to this standard.

1.6 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

C581 Practice for Determining Chemical Resistance of Thermosetting Resins Used in Glass-Fiber-Reinforced Structures Intended for Liquid Service
C582 Specification for Contact-Molded Reinforced Thermosetting Plastic (RTP) Laminates for Corrosion-Resistant Equipment
D618 Practice for Conditioning Plastics for Testing
D883 Terminology Relating to Plastics
D1599 Test Method for Resistance to Short-Time Hydraulic Pressure of Plastic Pipe, Tubing, and Fittings
D2150 Specification for Woven Roving Glass Fabric for Polyester-Glass Laminates (Withdrawn 1987)[3]
D2583 Test Method for Indentation Hardness of Rigid Plastics by Means of a Barcol Impressor
D2584 Test Method for Ignition Loss of Cured Reinforced Resins
D2996 Specification for Filament-Wound "Fiberglass" (Glass-Fiber-Reinforced Thermosetting-Resin) Pipe
D2997 Specification for Centrifugally Cast "Fiberglass" (Glass-Fiber-Reinforced Thermosetting-Resin) Pipe
D3892 Practice for Packaging/Packing of Plastics
D4024 Specification for Machine Made "Fiberglass" (Glass-Fiber-Reinforced Thermosetting Resin) Flanges
D5421 Specification for Contact Molded "Fiberglass" (Glass-Fiber-Reinforced Thermosetting Resin) Flanges
F412 Terminology Relating to Plastic Piping Systems

[1] This specification is under the jurisdiction of ASTM Committee D20 on Plastics and is the direct responsibility of Subcommittee D20.23 on Reinforced Plastic Piping Systems and Chemical Equipment.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] The last approved version of this historical standard is referenced on www.astm.org.

***A Summary of Changes section appears at the end of this standard**

2.2 *ANSI Standards:*

B 16.1 Cast Iron Pipe Flanges and Flanged Fittings, Class 25, 125, 250, and 800[4]

3. Terminology

3.1 *General*—Definitions are in accordance with Terminologies D883 and F412, unless otherwise indicated.

3.2 *filament-wound*—as applied to tanks, a process in which the principal circumferential load-bearing reinforcement is applied by continuous filament winding.

3.3 *contact molding*—a molding process that includes "hand lay-up," "spray-up," or a combination of these manufacturing processes.

4. Classification

4.1 Tanks meeting this specification are classified according to type as follows, and it is the responsibility of the purchaser to specify the requirement for Type II tanks, the operating pressure or vacuum levels, and the safety factor required for external pressure. Absence of a designation of type required shall imply that Type I is adequate.

4.1.1 *Type I*—Atmospheric pressure tanks vented directly to the atmosphere, designed for pressure no greater or lower than atmospheric.

4.1.2 *Type II*—Atmospheric pressure tanks vented directly into a fume conservation system, and designed to withstand the specified positive and negative pressure not to exceed 14 in. (355.6 mm) of water when all tie-down lugs are properly secured, in accordance with the fabricator's recommendations for flat-bottom tanks.

4.2 Tanks meeting this specification are classified according to grade as follows:

4.2.1 *Grade 1*—Tanks manufactured with a single generic type of thermoset resin throughout.

4.2.2 *Grade 2*—Tanks manufactured with different generic types of thermoset resin in the barrier and the structural portion.

NOTE 2—The external corrosive environment due to spillage or corrosive vapors should be considered when specifying Grade 2 tanks (see 7.1.3.3).

5. Materials and Manufacture

5.1 *Resin*—The resin used shall be a commercial-grade, corrosion-resistant thermoset that has either been evaluated in a laminate by test in accordance with 11.3 or that has been determined by previous documented service to be acceptable for the service conditions. Where service conditions have not been evaluated, a suitable resin also may be selected by agreement between fabricator and purchaser.

5.1.1 The resin shall contain no pigment, dyes, colorants, or filler, except as follows:

5.1.1.1 A thixotropic agent that does not interfere with visual inspection of laminate quality, or with the required corrosion resistance of the laminate, may be added for viscosity control.

NOTE 3—The addition of a thixotropic agent may reduce the resistance of many resin systems to certain corrosive chemical environments. It is the responsibility of the fabricator, using a thixotropic agent in the resin required for 7.1.1 and 7.1.2, to ascertain its compatibility with the corrosive environment when this has been reported to him by the purchaser.

5.1.1.2 Resin pastes used to fill crevices before overlay shall not be subject to the limitations of 5.1.1.

5.1.1.3 Resin may contain pigment, dyes, or colorants when agreed upon between fabricator and purchaser.

NOTE 4—The addition of pigment, dyes, or colorants may interfere with visual inspection of laminate quality.

5.1.1.4 Ultraviolet absorbers may be added to the exterior surface for improved weather resistance, if agreed upon between fabricator and purchaser.

5.1.1.5 Antimony compounds or other fire-retardant agents may be added to halogenated resins for improved fire resistance, if agreed upon between fabricator and purchaser.

NOTE 5—Because the addition of fire-retardant agents may interfere with visual inspection of laminate quality, they should not be used in the inner surface (7.1.1) or interior layer (7.1.2) unless their functional advantages would outweigh the loss of visual inspection.

5.2 *Reinforcement:*

5.2.1 *Chopped-Strand Mat*—Chopped-strand mat shall be constructed from chopped commercial-grade E-type glass strands bonded together using a binder. The strands should be treated with a sizing that is chemically compatible with the resin system used.

NOTE 6—The selection of the particular chopped-strand mat is dependent upon the performance characteristics required of the finished product and upon the processing techniques to be used.

5.2.2 *Continuous Roving*—Continuous roving shall be a commercial-grade of E-type glass fiber with a sizing that is chemically compatible with the resin system used.

5.2.3 *Nonwoven Biaxial or Unidirectional Fabric*—These products shall be a commercial Grade of E-type glass fiber with a sizing that is chemically compatible with the resin system used.

5.2.4 *Woven Roving*—Woven roving shall be in accordance with Specification D2150.

5.2.5 *Surface Mat*—The reinforcement used for the inner surface (7.1.1) shall be either a commercial-grade chemical resistant glass surface mat or an organic-fiber surface mat. In environments that attack glass, the use of an organic-fiber surface mat is required.

6. Design Requirements

6.1 *Filament-Wound Laminates—Design for Internal Pressure*—The maximum allowable stress of the total laminate (that is, filament winding plus the corrosion barrier, which is made up of the inner surface (7.1.1) and interior layer (7.1.2)) shall be limited by the allowable movement (strain) of the tank wall when filled with fluid.

6.1.1 The allowable strain of the tank wall shall not exceed 0.0010 in./in. (mm/mm) at 70°F (21°C).

6.1.2 Tanks shall have a longitudinal strength at least equal to that of a helically wound tank having a maximum angle of wind of 80° (measured from the tank axis, that is, 90° is hoop

[4] Available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036, http://www.ansi.org.

winding). For reference, the longitudinal tensile strength of a typical 80° helical winding is approximately 2200 psi (15,168 kPa).

6.1.3 *Hoop Design:*

6.1.3.1 *Normal Service (Structural Corrosion Barrier)*—When the product to be stored in the tank causes little or no degradation to the selected resin, the minimum required wall thickness shall be in accordance with Eq 1.

6.1.3.2 *Severe Service (Non-Structural Corrosion Barrier)*—When the product to be stored in the tank may cause degradation of the resin over time and with the agreement of the purchaser, the minimum required wall thickness of the tank shall be determined in accordance with Eq 2.

$$t_T = \frac{0.036*\gamma*H*D}{2*E_T*Z} \tag{1}$$

or

$$\left(t_T = \frac{0.2489*\gamma*H*D}{2*E_T*Z} \right)$$

$$t_T = t_{CB} + \frac{0.036*\gamma*H*D}{2*E_{FW}*Z} \tag{2}$$

or

$$\left(t_T = t_{CB} + \frac{0.2489*\gamma*H*D}{2*E_{FW}*Z} \right)$$

where:

t_T = total thickness, in. (mm),
t_{CB} = thickness of the corrosion barrier, in. (mm),
H = fluid head, in. (mm),
γ = specific gravity of fluid,
D = inside diameter of tank, in. (mm).
E_T = hoop tensile modulus of the total laminate (see Appendix X3), psi (kPa),
E_{FW} = hoop tensile modulus of the filament winding only psi (kPa), and
Z = allowable strain in accordance with 6.1.2.

6.1.3.3 The minimum total thickness of the tank shall be 0.1875 in. (4.76 mm).

NOTE 7—The use of an accepted analytical technique, such as laminated plate theory (LPT), for design and analysis of composite vessels may predict stresses, strains, and strength on a ply-by-ply basis, given some basic lamina properties.

NOTE 8—Tanks for installation outdoors shall be designed for the effect of wind loading and other environmental factors in accordance with sound design practice, including tank buckling analysis.

NOTE 9—Tanks with significant physical loadings other than fluid head (such as side-mounted equipment, violent agitation, unusually high flow rates, and unsupported bottoms) shall be given special design consideration.

6.2 *Design for External Pressure:*

6.2.1 *Cylindrical Shells*—For cylindrical shell, compute the value 1.73 $(D_o/t)^{0.5}$. If the result is less than L/D_o of the cylinder, compute P_a as follows:

$$P_a = 2.6(E/F)(D_o/L)(t/D_o)^{2.5} \tag{3}$$

If the result is greater than L/D_o of the cylinder, compute P_a as follows:

$$P_a = \frac{2.6(E/F)(D_o/L)(t/D_o)^{2.5}}{(L/D_o) - 0.45\,(t/D_o)^{0.5}} \tag{4}$$

where:

D_o = outside diameter, in. (mm),
E = lower of hoop tensile modulus or axial tensile modulus, psi (kPa),
F = design factor = 5,
L = design length, in., of a vessel section, taken as the largest of the following: (*a*) the distance between head-tangent lines plus one-third the depth of each formed head if there are no stiffening rings (excluding conical heads and sections); (*b*) the distance between cone-to-cylinder junctions for vessels with a cone or conical heads if there are no stiffening rings; (*c*) the greatest center-to-center distance between any two adjacent stiffening rings; (*d*) the distance from the center of the first stiffening ring to the formed head tangent line plus one-third the depth of the formed head (excluding conical heads and sections), all measured parallel to the axis of the vessel; (*e*) the distance from the first stiffening ring in the cylinder to the cone-to-cylinder junction,
P_a = allowable external pressure, psi (kPa), and
t = wall thickness, in. (mm) (nominal).

6.2.2 *Torispherical Heads*—For torispherical heads, compute the allowable external pressure P_a as follows:

$$P_a = 0.36(E/F)(t/R_o)^2 \tag{5}$$

where:

R_o = outside crown radius of head, in. (mm).

6.2.2.1 For torispherical heads subject to internal loading, the knucle radius shall be externally reinforced in accordance with Fig. 1. The reinforcement thickness shall be equal to the thickness of the head as calculated above. The thickness of a joint overlay near the knucle radius tangent line of a dished head contributes to the knucle reinforcement.

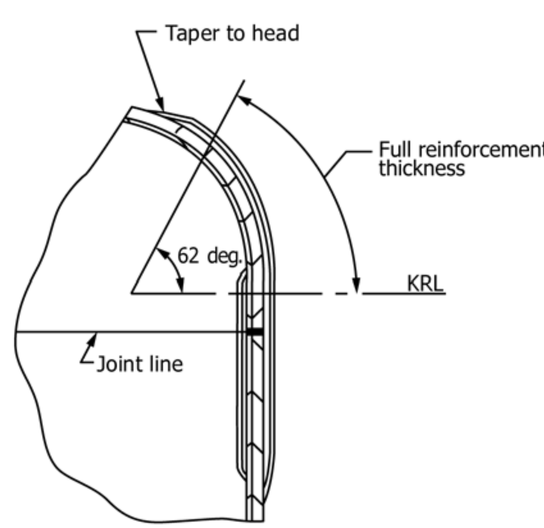


FIG. 1 Jointed Head Detail Sketch A

6.2.3 *Stiffening Rings*—The required moment of inertia, I_s, of a circumferential stiffening ring for cylindrical shells under external pressure or internal vacuum shall not be less than that determined by the following formula:

$$I_s = PL_s D_o^3 F/24E_h \quad (6)$$

where:

D_o = shell outside diameter, in. (mm),
E_h = hoop tensile modulus, psi (kPa),
F = design factor = 5,
I_s = moment of inertia, in.^{4} (mm^4), of stiffener and effective length of shell,
L_s = one-half of the distance from the centerline of the stiffening ring to the next line of support on one side, plus one-half of the centerline distance to the next line of support on the other side of the stiffening ring, both measured parallel to the axis of the cylinder, in. A line of support is the following: (*a*) a stiffening ring that meets the requirements of this paragraph; (*b*) a circumferential line on a head at one-third the depth of the head from the head tangent line; (*c*) a cone-to-cylinder junction, and
P = actual external pressure, psi (kPa).

Typical half-round stiffener sizes and dimensions for different values of I_s are shown in Fig. 2. Other stiffener profiles meeting the required moment of inertia may be used.

6.3 *Contact Molded Laminates*—Portions of the tank, such as joints, heads, nozzles, and supports, may be fabricated by contact molding. Contact-molded laminates shall satisfy the minimum property requirements listed in Specification C582, as shown in Table 1.

6.3.1 *Top Head*—The top head, regardless of shape, shall be able to support a single 250-lbf (113.4 kg) load on a 4 by 4-in. (100 by 100-mm) area without damage and with a maximum deflection of ½ % of the tank diameter at the area the load is applied.

6.3.1.1 The minimum thickness shall be 0.1876 in. (4.76 mm).

NOTE 10—Support of auxiliary equipment, snow load, or operation personnel may require additional reinforcement or the use of stiffener ribs, sandwich construction, or other stiffening systems. Type II tanks may also require additional reinforcement.

6.3.2 *Bottom Head*—The minimum thickness for a fully supported flat-bottom head for Type I tanks shall be as follows: 3⁄16 in. (4.8 mm) for 2 to 6 ft (0.6 to 1.8 m) diameter, ¼ in. (6.4 mm) for over 6 to 12 ft (1.8 to 3.7 m) diameter, and 3⁄8 in. (9.5 mm) for over 12 ft (3.7 m) diameter.

6.3.2.1 Deflection of the flat bottom when the tank is empty, commonly known as "oil canning," is permissible as long as the requirements of 6.3.2.4 are met.

6.3.2.2 Bottom heads may be molded integrally with the straight shell or may be molded separately with a straight flange length for subsequent joining to shell.

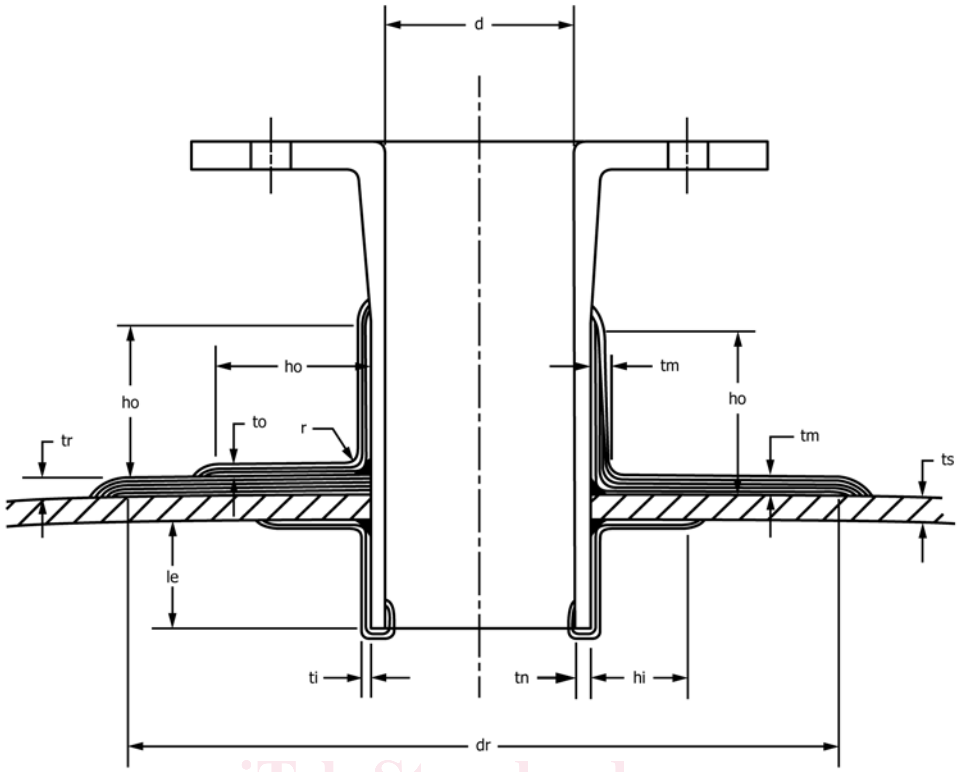
6.3.2.3 The radius of the bottom knuckle of a flat-bottom tank shall be not less than 1 in. (25 mm) on tanks 4 ft (1.22 m) or smaller in diameter and 1.5 in. (38 mm) on tanks larger than 4 ft (1.22 m) diameter. The minimum thickness of the radiused section shall be equal to the combined thickness of the shell wall and the bottom. The reinforcement of the knuckle-radius area shall taper so that it is tangent to the flat bottom, and shall not extend beyond the tangent line onto the tank bottom, unless methods of manufacture are used that maintain flat-bottom configuration, and shall extend up the vertical tank wall a minimum of 8 in. (200 mm) on tanks up to 4 ft (1.22 m) in diameter, and 12 in. (304 mm) on tanks over 4 ft (1.22 m) in diameter. The reinforcement shall then taper into the side wall over an additional length of 4 in. (102 mm) (see Fig. 3). Methods of manufacture that incorporate stiffening bands as a means of knuckle stabilization, are permissible alternatives by agreement between purchaser and fabricator, provided the fabricator can document the validity of the design.

6.3.2.4 The tank bottom shall not have variations from a nominally flat plane that would prevent uniform contact of the entire bottom surface with a properly prepared flat support surface when the tank is filled with liquid. The bottom laminate surface shall be a hand-work finish, and shall have no excessive laminate projections that would prevent uniform contact with a properly prepared flat support surface when the tank is filled with liquid.

NOTE 11—This requirement is not intended to exclude the use of drain nozzles which are commonly used at the bottom of the side shell. They do, however, require foundation cut-outs of the appropriate dimensions for the nozzle type and size.

6.3.2.5 The thickness of an elevated torispherical dished bottom, suitable for supporting the weight of the fluid head, shall be determined by the following equation, but shall not be less than 3⁄16 in. (4.8 mm):

$$t = \frac{0.885\,PR}{S} = \frac{0.885\,(0.036\gamma HR)}{S} \; or \left(\frac{0.885\,(0.2489\gamma HR)}{S}\right) \quad (7)$$



d = nozzle diameter
dr = cutout reinforcement diameter (greater of 2 times d or d + 6 in.) (see 7.3.2.3)
hi = liner bond (or inside installation laminate)(see 7.3.3.2)
ho = outside shear bond (see 7.3.3.3)
hs = shear bond length = ho or hi (see Table 6)
ti = liner thickness (or inside installation laminate thickness)(see 7.3.3.2)
to = outside installation laminate thickness (see 7.3.3.1)
tn = nozzle neck thickness (see Table 4)
tr = cutout reinforcement thickness (see 7.3.2.4)
tm = monolithic bond (greater of tr or to)(see 7.3.3.5)
ts = shell thickness (see 6.1.4)
le = penetration length 2 in. (50 mm) min.
r = fillet radius 3/8 in. (9.5 mm) min.

FIG. 2 Penetrating Nozzle Installation

TABLE 1 Minimum Contact-Molded Laminate Physical Properties[A]

NOTE 1— Based on use of woven roving in thickness ¼ in. (6mm) and above.

Property	Thickness, in. (mm)							
	⅛ to 3⁄16 (3.2 to 4.8)		¼ (6.4)		5⁄16 (7.9)		⅜ & up (9.5 and up)	
Ultimate tensile strength, min, psi (MPa)	9 000	(62.05)	12 000	(82.74)	13 000	(89.63)	15 000	(103.4)
Tensile modulus, psi (MPa)	1 000 000	(6895)	1 300 000	(8963)	1 400 000	(9653)	1 500 000	(10342)
Flexural strength, min, psi (MPa)	16 000	(110.3)	19 000	(131.0)	20 000	(137.9)	22 000	(151.7)
Flexural modulus of elasticity (tangent), min, psi (MPa)	700 000	(4826)	800 000	(5516)	900 000	(6205)	1 000 000	(6894)

[A] Laminates that do not meet the minimum values of Table 1 are considered acceptable, provided they are made to afford the same overall strength that would be obtained with a laminate meeting the specified thickness.

where:

t = thickness, in. (mm),
S = allowable tensile strength (not to exceed 1⁄10 of ultimate strength), psi (kPa) (see 11.6.1),
γ = specific gravity of fluid,
P = pressure, psi (kPa),
R = inside radius of dished head, in. (mm), and
H = distance from the top of the fluid to the deepest portion of the bottom, in. (mm).

For Elliptical Bottom Head:

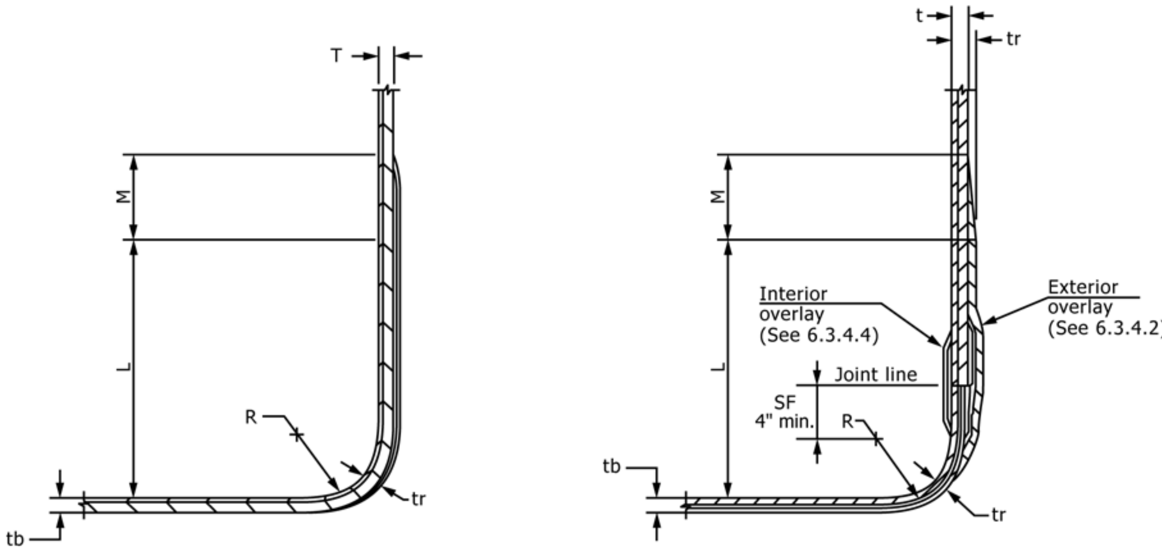
$$t = \frac{PD}{2S} \tag{8}$$

For Cone Bottom:

$$t = \frac{PD}{2S \cdot \cos(\alpha)} \tag{9}$$

where:

α = ½ the included (apex) angle of the cone at the centerline of the head. (Not greater than 30°)



Tank bottom must be flat over entire width.

Figure 1A
For Integral Head to Shell

Tank bottom must be flat over entire width.

Figure 1B
For Integral Head to Shell

Tank Dia. ft. (m)	R Min. in. (mm)	L Min. in. (mm)	M Min. in. (mm)
4(1.2) and under	1 (25.4)	8 (203)	3 (24)
over 4(1.2)	1 1/2 (38)	12 (305)	4 (102)

L = Length of double reinforcing
M = Length of thickness tansition (taper)
t = Shell thickness
tb = Bottom thickness
R = Inside corner radius
SF = Straight flange of bottom head
tr(min.) = t + tb

FIG. 3 Flat-Bottom Tank Corner Detail

NOTE 12—An alternative method for design of an elevated torispherical dished bottom is shown in Appendix X2.

6.3.2.6 The torispherical dished-bottom head shall have a radius of curvature that is equal to or less than the inside diameter of the tank straight shell, and a minimum knuckle radius of at least 6 % of the diameter of the head.

6.3.3 *Open-Top Tanks*—The top edge of open-top tanks shall have a horizontal reinforcing flange or other means of reinforcement sufficiently rigid to maintain the shape of the tank after installation, such as stiffener ribs. The flange shall be in accordance with Table 2.

6.3.4 *Joints:*

TABLE 2 Reinforcing Flange for Open-Top Tanks[A,B]

L,[C] ft (m)	Tank Diameter, ft (m)								Flange Type	Flange Dimensions			
										Width		Thickness[D]	
	2 (0.610)	4 (1.219)	6 (1.629)	8 (2.438)	9 (2.743)	10 (3.048)	11 (3.353)	12 (3.658)		in.	(mm)	in.	(mm)
2 (0.610)	A	A	A	C	D	E	F	G	A	2	(51)	¼	(5)
4 (1.212)	A	A	A	C	D	E	F	G	B	2	(51)	⅜	(10)
6 (1.829)	A	A	A	C	D	E	F	G	C	2	(51)	½	(13)
8 (2.438)	A	A	A	C	D	E	F	G	D	2½	(64)	⅜	(10)
10 (3.048)	A	A	B	C	D	E	F	G	E	2½	(64)	½	(13)
12 (3.658)	A	A	B	D	D	E	F	G	F	3	(76)	⅜	(10)
14 (4.267)	A	A	B	D	E	F	F	G	G	3	(76)	½	(13)
16 (4.877)	A	A	C	E	E	G	G	H	H	3	(76)	⅝	(16)
18 (5.486)	A	A	C	E	F	G	G	H	J	3	(76)	¾	(19)
20 (6.096)	A	A	D	E	F	G	H	J	K	3	(76)	1	(25)
24 (7.315)	A	B	D	F	G	H	J	K					
30 (9.144)	A	B	E	G	H	H	K	K					
36 (10.973)	A	B	E	H	J	K	K						
40 (12.192)	A	B	E	H	J	K							

[A] This table is based on handling considerations only. Significant superimposed loads, such as from wind or seismic conditions, should be considered independently.
[B] Reinforcement configurations other than a flange may be used if equal or greater stiffness is provided.
[C] *L* = maximum distance from flange to the tank bottom or to the uppermost shell stiffener when used.
[D] Flange thickness shall be at least equal to local vessel thickness.