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

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, 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.

NOTE 1—Special design consideration should be given to vessels subject to superimposed mechanical forces, such as earthquakes, wind load, or agitation, and to vessels subject to service temperature in excess of 180°F (82°C), and to vessels with unsupported bottoms.

NOTE 2—There is no similar or equivalent ISO standard.

1.4 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 and health practices and determine the applicability of regulatory limitations prior to use.*

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D2150 Specification for Woven Roving Glass Fabric for Polyester-Glass Laminates (Withdrawn 1987)[3]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

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.

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

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 3—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 4—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 5—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 6—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 7—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 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.

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

or

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

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

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 8—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 9—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 10—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:

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

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

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

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:

$$P_a = 0.36(E/F)(t/R_o)^2 \qquad (5)$$

where:

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

6.2.2.1 For torispherical heads subject to internal loading, the knuckle 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 knuckle radius tangent line of a dished head contributes to the knuckle reinforcement.

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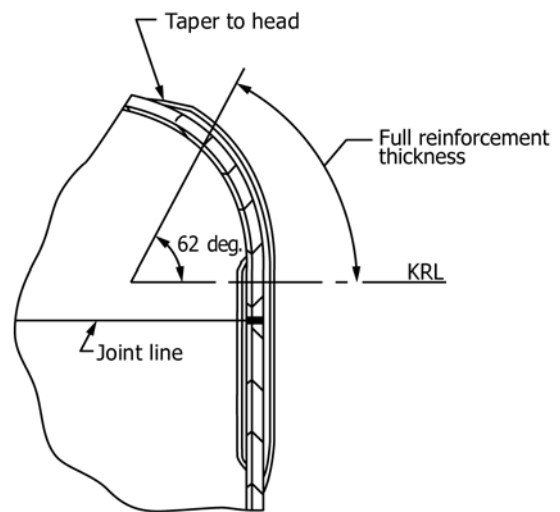
$$I_s = PL_s D_o^3 F/24E_h \qquad (6)$$

FIG. 1 Jointed Head Detail
Sketch A

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 11—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.
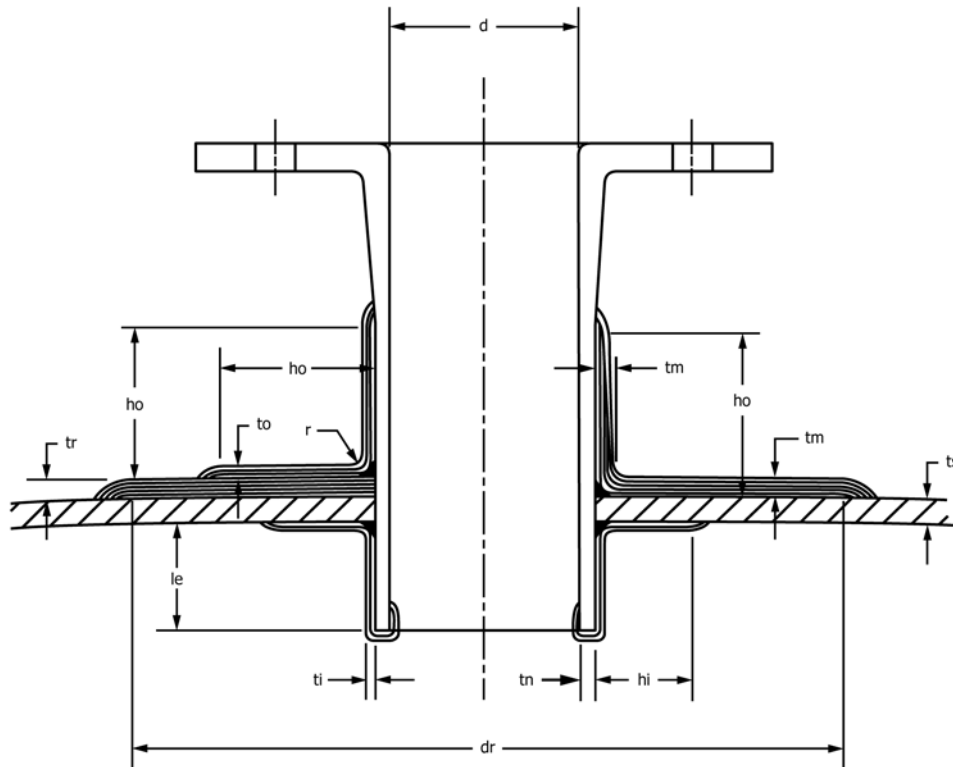
d = nozzle diameter
dr = cutout reinforcement diameter (greater of 2 times d or d + 6 in.) (see 7.3.2.3)
hi = liner bond (or inside installation laminate)(see 7.3.3.2)
ho = outside shear bond (see 7.3.3.3)
hs = shear bond length = ho or hi (see Table 6)
ti = liner thickness (or inside installation laminate 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.

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
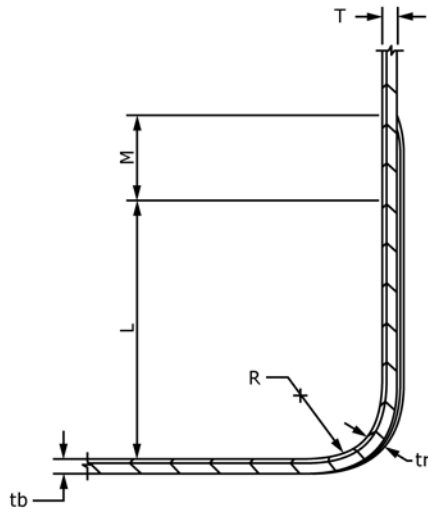
Tank bottom must be flat over entire width.

Figure 1A
For Integral Head to Shell
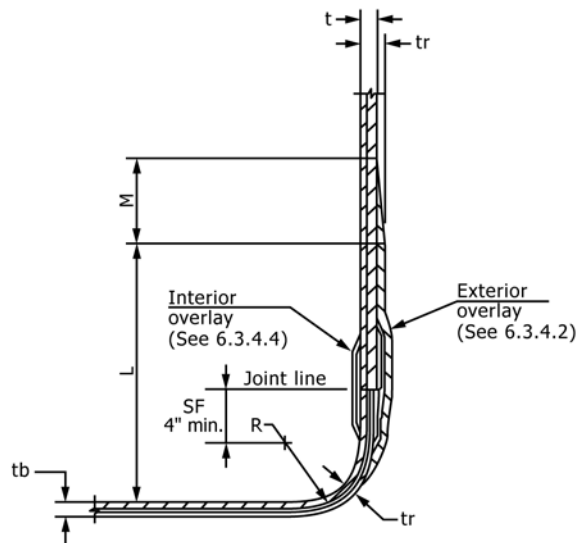
Tank bottom must be flat over entire width.

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

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 12—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 $\frac{3}{16}$ in. (4.8 mm):

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

where:
t = thickness, in. (mm),
S = allowable tensile strength (not to exceed $\frac{1}{10}$ 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:

$$t = \frac{PD}{2S} \quad (8)$$

For Cone Bottom:

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

where:
α = $\frac{1}{2}$ the included (apex) angle of the cone at the centerline of the head. (Not greater than 30°)

NOTE 13—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:*

6.3.4.1 The cured resin surfaces to be overlaid shall be roughened using 36 or coarser grit abrasive media and shall extend beyond the lay-up area so that no reinforcement is applied to an unroughened surface. Surfaces shall be clean and dry before lay-up. The entire roughened area shall be coated with paraffinated resin after the joint lay-up is made.

6.3.4.2 Joints between tank-wall sections shall be overwound to a thickness as calculated in 6.1.3.2, or they may be overlaid by a contact-molded laminate. When contact-molded laminate joints are used to join hoop segments of the straight shell, or to join the bottom or top head to the shell, the thickness of the structural joint overlay shall be determined by the following equation, but shall not be less than $\frac{3}{16}$ in. (4.8 mm):

$$t = \frac{PD}{2S_h} = \frac{0.036\gamma HD}{2S_h} \; or \left(\frac{0.2489\gamma HD}{2S_h} \right) \quad (10)$$

where:
t = wall thickness, in. (mm),
S_h = allowable hoop tensile strength (not to exceed $\frac{1}{10}$ of the ultimate hoop strength), psi (kPa),
P = pressure, psi (kPa),
H = fluid head, in. (mm),
γ = specific gravity of fluid, and
D = inside diameter of tank, in. (mm).

6.3.4.3 The minimum width of the structural joint overlay for bottom-supported tanks is shown in Table 3.

6.3.4.4 The corrosion-resistant barrier component of the joint shall be formed in the same manner as the inner surface and the interior layer (7.1.1 and 7.1.2) and the minimum

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

| L,[C] ft (m) | Tank Diameter, ft (m) | | | | | | | | Flange Type | Flange Dimensions | | | |
	2 (0.610)	4 (1.219)	6 (1.629)	8 (2.438)	9 (2.743)	10 (3.048)	11 (3.353)	12 (3.658)		Width		Thickness[D]	
										in.	(mm)	in.	(mm)
2 (0.610)	A	A	A	C	D	E	F	G	A	2	(51)	$\frac{1}{4}$	(5)
4 (1.212)	A	A	A	C	D	E	F	G	B	2	(51)	$\frac{3}{8}$	(10)
6 (1.829)	A	A	A	C	D	E	F	G	C	2	(51)	$\frac{1}{2}$	(13)
8 (2.438)	A	A	A	C	D	E	F	G	D	$2\frac{1}{2}$	(64)	$\frac{3}{8}$	(10)
10 (3.048)	A	A	B	C	D	E	F	G	E	$2\frac{1}{2}$	(64)	$\frac{1}{2}$	(13)
12 (3.658)	A	A	B	D	D	E	F	G	F	3	(76)	$\frac{3}{8}$	(10)
14 (4.267)	A	A	B	D	E	F	F	G	G	3	(76)	$\frac{1}{2}$	(13)
16 (4.877)	A	A	C	E	E	G	G	H	H	3	(76)	$\frac{5}{8}$	(16)
18 (5.486)	A	A	C	E	F	G	G	H	J	3	(76)	$\frac{3}{4}$	(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.

TABLE 3 Minimum Widths of Joint Overlay for Circumferential Joints
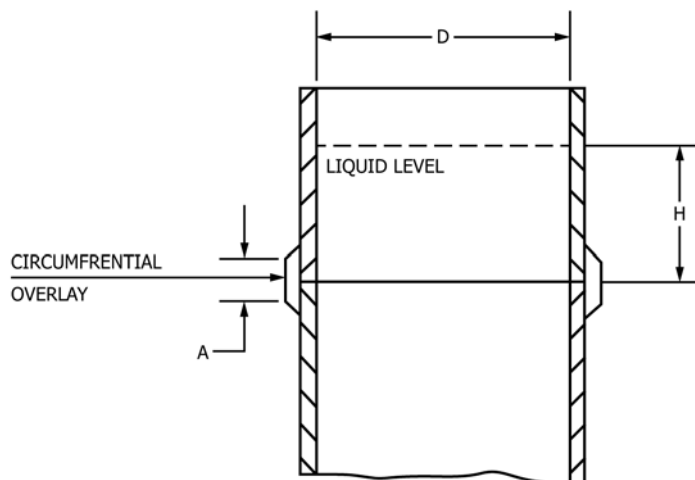
$H \times D^A$ = minimum width of outside^B	60	100	140	180	220	260	300	340	380	420	460	500
in.	4	4	5	6	7	8	9	10	11	12	13	14
(mm)	(102)	(102)	(127)	(152)	(178)	(203)	(229)	(254)	(279)	(305)	(330)	(356)

^{A}where: H = distance from the top of the liquid level to the joint, ft (m) and
D = inside diameter of the tank, ft (m).
^{B}Axial joint overlay widths shall be twice the width shown in table.

overlay width shall be 4 in. (100 mm). This internal overlay shall not be considered a structural element in determining joint thickness.

6.3.4.5 The thickness of a joint near the bottom tangent line shall not be considered to contribute to the knuckle reinforcement of 6.3.2.3, but shall be additive thereto.

6.3.5 *Fittings:*

6.3.5.1 The more common method of fabricating nozzles is by contact molding both the nozzle neck and flange to the dimensions shown in Specification D5421 and Table 4. The corrosion-resistant barrier of the nozzle shall be at least equivalent to the inner surface and interior layer (7.1.1 and 7.1.2) and shall be fabricated from the same resin as the tank head or shell to which it is attached.

6.3.5.2 Acceptable alternative methods to be agreed upon between fabricator and purchaser are the use of contact-molded pipe, filament-wound pipe, in accordance with Specification D2996, or centrifugally cast pipe, in accordance with Specification D2997, joined to a suitable contact-molded (Specification D5421), or filament-wound flange (Specification D4024). The corrosion-resistant barrier of the contact-molded portions of such nozzles shall be equivalent to the inner surface and interior layer (7.1.1 and 7.1.2) and shall be fabricated from the same resin as the tank head or shell to which they are attached.

6.3.5.3 Nozzles 4 in. (100 mm) and smaller shall be supported by a suitable gusseting technique, using plate gussets or conical gussets, as shown in Fig. 4 and Fig. 5. Plate gussets, where needed, shall be evenly spaced around the nozzle and are to be added after complete assembly by the nozzle on the shell. Larger nozzles, subject to superimposed mechanical forces, require special consideration.

6.3.5.4 Manways installed in top heads may be of the flanged or nonflanged design, as agreed upon between the fabricator and purchaser.

6.3.5.5 Side-shell manways shall be installed in accordance with 7.3.2, 7.3.3, and Fig. 6.

6.3.5.6 Typical manway dimensions are shown in Table 5.

Note 14—Tanks over 6 ft (1.8 m) straight-shell height may need both top- and side-shell opening manways for safety and maintenance considerations.

6.4 *Vents:*

6.4.1 Vents that discharge freely into the atmosphere must be provided in all Type I closed-top tanks. Minimum vent size shall be sufficient to handle the flow displacement of all combined inlet or outlet nozzles without creating any pressure above atmospheric, or any vacuum condition.

Note 15—Special vent sizing consideration should be given to the numerous operating situations that could otherwise cause a positive or a negative pressure in a closed tank. Since overfilling a closed tank with the vent on the top can cause the tank to be over-pressured, a suitably sized overflow, properly located, or other appropriate protection, may be required to prevent over-pressuring the tank.

6.4.2 Type II tanks shall be designed to withstand the specified positive or negative pressures not to exceed 14 in. (355.6 mm) of water. Special design consideration must be given to buckling of tank wall and heads, the hold-down lug system, and top and bottom knuckle requirements. Fluid level in the tank is an important consideration in the analysis.

6.4.2.1 Flat-bottom Type II tanks must have all hold-down lugs properly secured to the foundation, in accordance with the tank fabricator's recommendation for the design of the lugs used and for the tank installation and operation.

TABLE 4 Dimensions for Contact-Molded Flanged Nozzles (25 psi Rating)
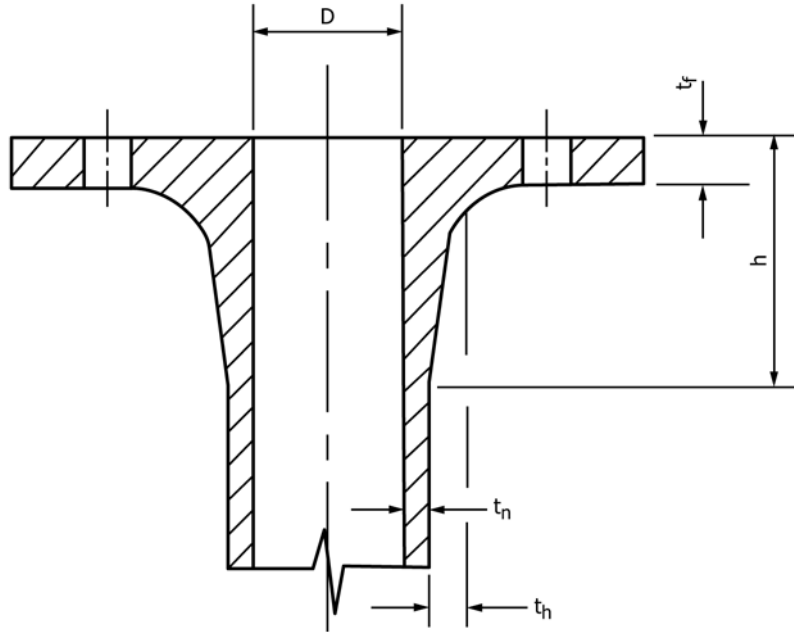
| Nozzle Inside Diameter (D), in. (mm)	Minimum Wall Thickness (t_n), in. (mm)	Minimum Flange Thickness (t_f), in. (mm)	Minimum Hub Thickness (t_h), in. (mm)	Minimum Hub Length (h), in. (mm)
1 (25)	3/16 (5)	1/2 (13)	1/4 (6)	2 (51)
1 1/2 (38)	3/16 (5)	1/2 (13)	1/4 (6)	2 (51)
2 (51)	3/16 (5)	1/2 (13)	1/4 (6)	2 (51)
3 (76)	3/16 (5)	1/2 (13)	1/4 (6)	2 (51)
4 (102)	3/16 (5)	1/2 (13)	1/4 (6)	2 (51)
6 (152)	3/16 (5)	1/2 (13)	1/4 (6)	2 (51)
8 (203)	3/16 (5)	9/16 (14)	5/16 (8)	2 1/2 (57)
10 (254)	3/16 (5)	11/16 (17)	3/8 (10)	2 3/4 (70)
12 (305)	3/16 (5)	3/4 (19)	3/8 (10)	3 (76)
14 (356)	1/4 (6)	13/16 (21)	7/16 (11)	3 1/4 (83)
16 (406)	1/4 (6)	7/8 (22)	7/16 (11)	3 1/2 (89)
18 (457)	1/4 (6)	15/16 (24)	1/2 (13)	3 3/4 (95)
20 (508)	1/4 (6)	1 (25)	1/2 (13)	4 (102)
24 (610)	1/4 (6)	1 1/8 (29)	9/16 (14)	4 1/2 (114)
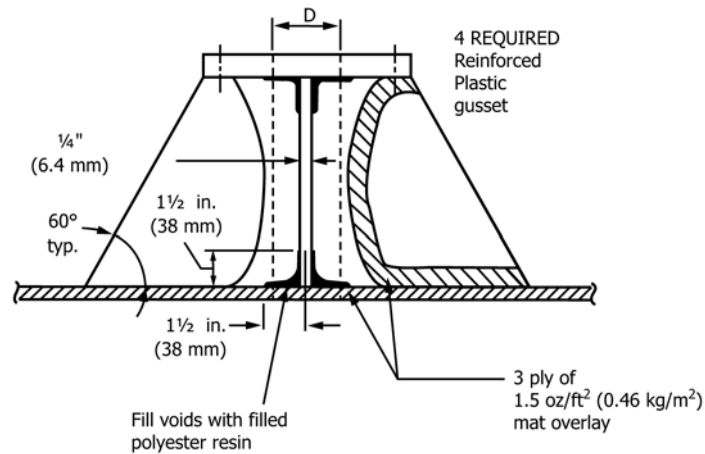
**FIG. 4 Plate-Type Gussets**

6.5 *Hold-Down Lugs*—Hold-down lugs shall be a requirement on all tanks for outdoor service, on all Type II tanks, and on tanks subject to seismic loads or vibrations. The design number and attachment of such lugs is the responsibility of the fabricator, based on the wind, seismic, and other loads specified by the purchaser.
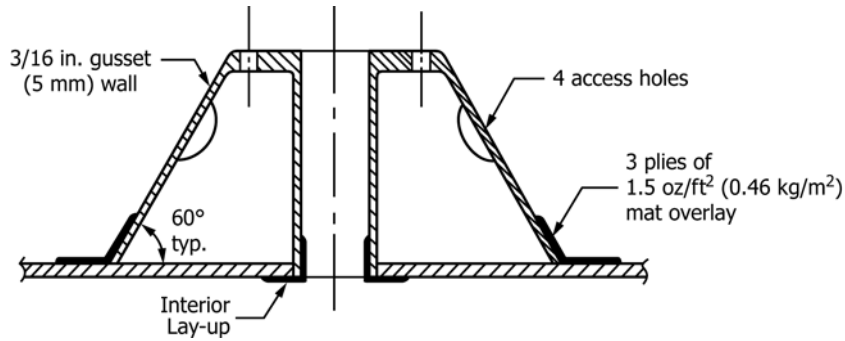
Note 1—This design does not require lay-up of nozzle neck to exterior of tank wall. Nozzle may be penetrating type or flush type as illustrated.

FIG. 5 Conical Type Gussets
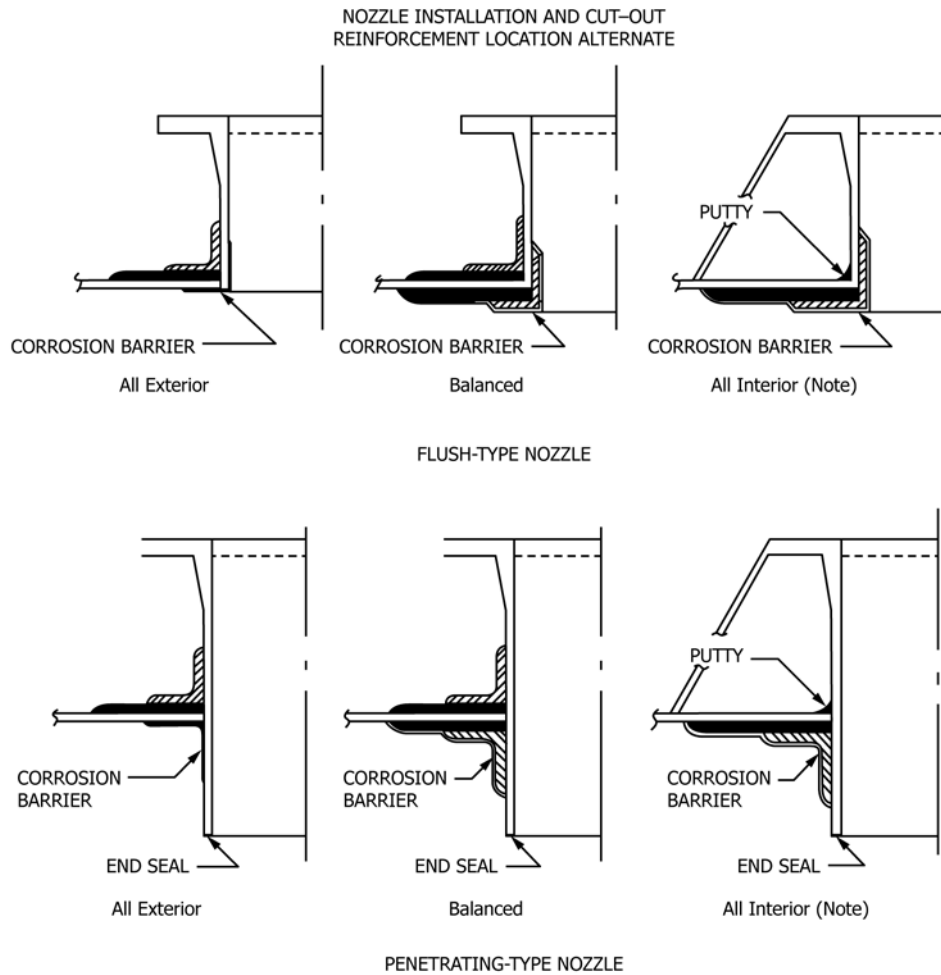
Note 1—This installation method is used only when the nozzle is being installed with an integral conical gusset which would prevent application of an exterior laminate.

FIG. 6 Nozzle Installation and Cutout Reinforcement Location Alternative

6.5.1 Hold-down lugs shall be placed on the tank in such a way that they do not protrude below the bottom surface of the tank.

6.6 *Lifting Lugs*—Lifting lugs or other provisions for lifting tanks (see Appendix X1) shall be provided for tanks over 500 lb (227 kg) in weight.

7. Laminate Construction Requirements

7.1 *Structural Tank*—The laminate comprising the structural tank (bottom, cylindrical shell, top head) shall consist of a corrosion-resistant barrier (also known as "liner") comprised of an inner surface and interior layer, and a structural layer.

TABLE 5 Typical Dimensions of Manways

NOTE 1— Bolt size equals bolt hole diameter minus ⅛ in. (3 mm).

NOTE 2—Gaskets shall be ⅛ in. thick full-face elastomeric material having a hardness of Shore A80 ± 5.

Minimum Size, in. (mm)	Minimum Diameter of Flange and Cover, in. (mm)	Minimum Thickness of Flange and Cover, in. (mm)	Minimum Manway Wall Thickness, in. (mm)	Diameter of Bolt Circle, in. (mm)[ABC]	Number of Bolts	Bolt Hole Diameter, in. (mm)
Pressurized Manway—up to 15 psig					
20 (508)	27½ (699)	1 (25.4)	⅜ (9.5)	25 (635)	20	¾ (19)
22 (559)	30 (762)	1 (25.4)	⅜ (9.5)	27 (686)	20	¾ (19)
24 (610)	32 (813)	1¼ (31.8)	⅜ (9.5)	29½ (749)	20	¾ (19)
Manway—Atmospheric Pressure up to 0.5 psig					
20 (508)	27½ (699)	⅜ (9.5)	¼ (6.4)	25 (635)	20	½ (12.7)
22 (559)	30 (762)	⅜ (9.5)	¼ (6.4)	27 (686)	20	½ (12.7)
24 (610)	32 (813)	⅜ (9.5)	¼ (6.4)	29½ (748)	20	½ (12.7)

[A]±0.06 in. (1.5 mm) (ASME/ANSI B 16.5).
[B]±0.03 in. (0.76 mm) center to center of adjacent bolt holes (ASME/ANSI B 16.5).
[C]±0.06 in. (1.5 mm) eccentricity between bolt circle and center of nozzle.

7.1.1 *Inner Surface*—The inner surface exposed to the chemical environment shall be a resin-rich layer 0.010 to 0.020 in. (0.25 to 0.5 mm) thick, reinforced with a suitable chemical-resistant glass fiber surface mat or with an organic fiber surface mat, in accordance with 5.2.5.

NOTE 16—This resin-rich inner surface will usually contain less than 20 % by weight of reinforcing material.

7.1.2 *Interior Layer*—The inner surface layer exposed to the corrosive environment shall be followed with a layer composed of resin, reinforced only with noncontinuous glass-fiber strands applied in a minimum of two plies of chopped-strand mat equivalent to a total of 3 oz/ft^2 (0.92 kg/m^2). As an alternative, a minimum of two passes of chopped roving of minimum length 0.5 in. (13 mm) to a maximum length of 2.0 in. (50.8 mm), shall be applied uniformly to an equivalent weight of 3 oz/ft^2 (0.92 kg/m^2). Each ply of mat or pass of chopped roving shall be well-rolled prior to the application of additional reinforcement. The combined thickness of the inner surface and interior layer shall not be less than 0.10 in. (2.5 mm).

7.1.2.1 Glass content of the inner liner and the interior layer combined shall be 27 ± 5 % by weight when tested in accordance with 11.4.

7.1.2.2 The degree of cure of the laminate shall be such as to exhibit a Barcol hardness on the inner surface of at least 90 % of the resin manufacturer's minimum specified hardness for the cured resin, when tested in accordance with 11.5 and Note 19, Note 20, and Note 21.

7.1.3 *Structural Layer:*

7.1.3.1 *Filament-Wound Structural Layer*—Subsequent reinforcement shall be continuous-strand roving in accordance with 5.2.2, that is needed to satisfy the requirements of 6.1.3.2. The thickness of the filament-wound portion of the tank shell may be varied with tank height (tapered-wall construction), provided these requirements are met at any height level. If additional longitudinal strength is required, the use of other reinforcements, such as woven fabric, nonwoven unidirectional or bidirectional fabric, chopped-strand mat, or chopped strands, may be interspersed in the winding to provide additional strength. Glass content of this filament-wound structural layer shall be 50 to 80 % by weight. Only those constructions evaluated for design properties in 11.6 shall be used.

7.1.3.2 *Contact-Molded Structural Layer in Top and Bottom Heads*—Subsequent reinforcement shall be comprised of 1.5 oz/ft^2 (0.46 kg/m^2) chopped-strand mat or equivalent weight of chopped roving, or shall be comprised of chopped-strand mat or chopped roving and such additional number of alternating plies of 24 oz/yd^2 (0.81 kg/m^2) woven roving 18 oz/yd^2 (0.61 kg/m^2) nonwoven biaxial fabric to a thickness as required to meet the physical properties that are used for the design. The use of woven roving is optional. The designations of these specific weights of glass reinforcement are for reference only and may be comprised of other weight combinations of reinforcement materials, when agreed to between the fabricator and purchaser. Each successive ply or pass of reinforcement shall be well-rolled prior to the application of additional reinforcement. Where woven roving is used, chopped-strand glass reinforcement shall be used as alternating and final layers. All woven roving, nonwoven fabric, and surfacing mat shall be overlapped. Laps in subsequent layers shall be staggered at least 2.25 in. (60 mm) from laps in the preceding layer.

7.1.3.3 When the outer surface of this structural layer is to be subject to spillage or a corrosive environment, a resin-rich layer, in accordance with 7.1.1, shall be applied over the final layer of reinforcement.

7.1.3.4 Tanks used for outdoor service or subject to ultraviolet exposure shall incorporate provisions to minimize ultraviolet degradation. Suitable methods include use of ultraviolet absorbers, incorporation of pigment of sufficient opacity in the outer surface resin-rich layer, or use of resins inherently resistant to ultraviolet degradation. Since pigmentation makes inspection difficult, it shall be added after inspection or otherwise by agreement between the purchaser and fabricator.

7.1.3.5 Where air-inhibited resin is exposed to air, full surface cure of the inner surface shall be obtained by coating such surface with a coat of resin containing 0.2 to 0.6 % paraffin wax, having a melting point between 122 and 126°F (50 and 52°C). Other techniques such as sprayed, wrapped, or overlaid films are also acceptable methods to attain surface cure.

7.2 *Joints:*

7.2.1 The width of the first layer of joint overlay shall be 3 in. (76 mm) minimum. Successive layers shall uniformly increase in width in that specified in Table 3 to form a smooth contour laminate that is centered on the joint.

7.2.2 A highly filled resin paste shall be placed in the crevices between joined pieces, leaving a smooth surface for lay-up.

7.2.3 The cured resin surfaces of parts to be joined shall be roughened using 36 or coarser abrasive grit media to expose glass fibers. This roughened area shall extend beyond the lay-up areas so that no reinforcement is applied to an unprepared surface. The entire roughened area shall be coated with paraffinated resin after joint overlay is made.

7.2.4 The interior overlay of a joint shall consist of a minimum of two plies of 1.5 oz/ft^2 (0.46 kg/m^2) chopped-strand mat reinforcement, followed by a resin-rich layer reinforced with surfacing mat. This overlay shall be the equivalent of 7.1.1 and 7.1.2 combined, and shall be centered on the joint. It shall be finished in accordance with 7.1.3.5.

7.2.5 The outer structural overlay of a joint shall be centered on the joint, fabricated in accordance with 6.3.4.2, and shall be finished in accordance with 7.1.3.5.

7.3 *Fittings and Accessories:*

7.3.1 The surfaces of fittings, tank accessories, and the laminates required for their installation that are exposed to the corrosive media, shall be constructed in accordance with 7.1.1 and 7.1.2, except for those fitting surfaces which are made by manufacturing processes other than contact molding (see 6.3.5.2).

7.3.1.1 The cut edges of all laminates exposed to the chemical environment shall be sealed with a laminate conforming to 7.1.1 and 7.1.2. Where shape, thickness, or other restrictions preclude covering the edges with the preceding laminate, such cut edges and any machined flange faces shall be at least coated with resin. In either case, the resin used shall be that used in the equipment laminate and finished in accordance with 7.1.3.5.

7.3.2 *Nozzle and Manway Installation*—Flanged nozzles may be installed with the pipe stub flush with the inside of the tank shell (flush type, Fig. 4) or projecting inside the tank (penetrating type, Fig. 5).

7.3.2.1 *Nozzle Projection*—The installed nozzle shall maintain a minimum clearance of 3 in. (76 mm) between the back face of the flange and the exterior of the cutout opening reinforcement. In addition, this clearance shall not be less than the shear distance required for proper installation of the nozzle (see 7.3.3).

7.3.2.2 *Cutout Reinforcement Laminate*— When a vessel shell or head is cut in an area bearing hydrostatic pressure, P, the cutout shall be reinforced on a circular area concentric with the cutout, as shown in Fig. 4 and Fig. 5. Acceptable patterns of reinforcement placement are shown in Fig. 2.

7.3.2.3 *Cutout Reinforcement Diameter*—The outer diameter of the cutout reinforcing laminate, d_r, shall not be less than two times the nominal nozzle diameter. For nozzles less than 6 in. (152 mm) in diameter, the minimum cutout reinforcement diameter, d_r, shall be the nominal nozzle size plus 6 in. (152 mm).

7.3.2.4 *Cutout Reinforcement Thickness*—The thickness, t_r, of the cutout reinforcement laminate for nozzles installed in cylindrical shells or dished heads shall be determined as follows:

$$t_r = PDK/2S_r \qquad (11)$$

where:
K = 1.0 for nozzles 6 in. (152 mm) diameter and larger,
K = $d/(d_r - d)$ for nozzles less than 6 in. (152 mm) diameter,
P = hydrostatic pressure at the point of nozzle installation, psi (kPa),
D = inside diameter of tank, in. (mm),
S_r = allowable tensile stress (not to exceed $\frac{1}{10}$ of the ultimate strength of the cutout reinforcing laminate); see Table 1,
d = nominal nozzle diameter, in. (mm), and
d_r = cutout reinforcement diameter, in. (mm).

This thickness, t_r, may be applied to the outer or inner surfaces, or be divided between them as shown in Fig. 6.

NOTE 17—When t_r is calculated to be $\frac{1}{8}$ in. (3.2 mm) or less, it can be disregarded, as the strength requirements will be met by t_0 (see Figs. 2 and 7).

7.3.2.5 When reinforcing materials are cut to facilitate placement around an installed nozzle, joints in successive reinforcing layers should be staggered to avoid overlapping and (on cylindrical shell installations) shall not be placed so they parallel the axis of the tank. The intent of these requirements is to avoid orienting joints in reinforcing layers perpendicular to the maximum load-bearing direction (circumferential).
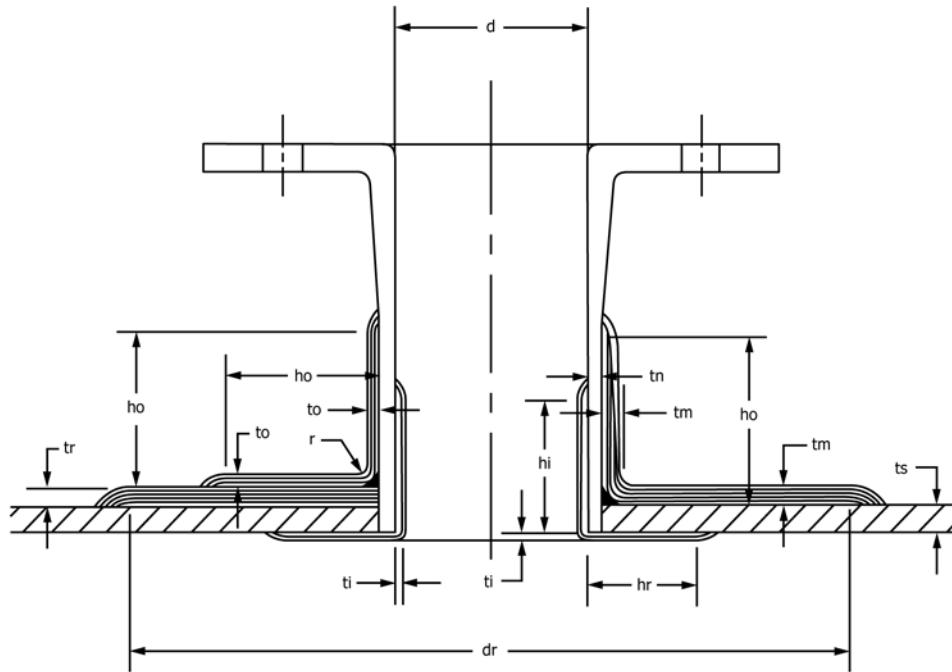
7.3.3 *Nozzle Installation Laminates*—Nozzle installation laminate dimensions are shown in Fig. 2 and Fig. 7. Installation laminate placements are shown in Fig. 6. The all-interior installation laminate placement is used only when the nozzle being installed has an integral conical gusset preventing application of an exterior laminate.

7.3.3.1 *Installation Laminate Thickness*—The inside and outside installation thicknesses (t_i and t_o) combined shall be at least as thick as the nozzle neck.

7.3.3.2 *Inside Installation Laminate Construction*—The inside installation laminate shall be constructed using only noncontinuous glass reinforcements, except that when woven roving is included to strengthen the laminate, it shall be preceded and followed by a layer of 1½ –oz (0.458 kg/m^2) mat and then covered with a laminate equivalent to 7.1.1 and 7.1.2. When the inside laminate consists only of a corrosion barrier, the length of the laminate, h_r shall be a minimum of 3 in. and h_i shall be the lesser of 3 in. (76mm) or the nominal radius of the nozzle.

7.3.3.3 *Installation Laminate Lengths*—The length of the outside laminate, h_o, and the inside laminate, h_i, shall each be equal to the shear length, h_s, given in Table 6 based on the thickness of the individual laminates.

7.3.3.4 In nozzle installations where the installation overlay is installed before the cutout reinforcement has fully cured, that portion of the overlay which extends onto the tank shell may be considered to become a part of the cutout reinforcement

d = nozzle diameter
dr = cutout reinforcement diameter (greater of 2 times d or d + 6 in.) (see 7.3.2.3)
hi = nozzle neck liner bond (or inside installation laminate)(see 7.3.3.2)
ho = outside shear bond (see 7.3.3.3)
hr = tank wall liner bond (or installation laminate) length
hs = shear bond length = ho or hi (see Table 6)
ti = liner thickness (or inside installation laminate)(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)
r = fillet radius 3/8 in. (9.5 mm) min.

FIG. 7 Flush Nozzle Installation

TABLE 6 Shear Bond Length (see Figs. 2 and 7)

Note 1— When internal overlay serves only as a corrosion barrier, the total shear length must be placed on the exterior overlay.

					Inch-Pound Units						
Overlay thickness, in.	1/4	5/16	3/8	7/16	1/2	9/16	5/8	11/16	3/4	7/8	1
h^A (shear length), in.	3	3	3	3½	4	4½	5	5½	6	7	8
					SI Units						
Overall thickness, mm	6.4	8	9.5	11	13	14	16	17.5	19	22	25.4
h (shear length), mm	76	76	76	90	100	114	127	140	152	178	203

[A] h = total shear length ($h_o + h_i$) (Fig. 4).

laminate if the installation laminate length is extended to the required cutout reinforcement diameter, d_r.

7.3.3.5 *Monolithic Installation*—The total bond thickness, t_m, shall be the greater of either the cutout reinforcement thickness, t_r, or the outside bond thickness, t_o.

7.3.4 *Gussets*—If gussets (either plate or conical) are used to stiffen the installed nozzle, gusset installation laminates are in addition to the requirements of 7.3.3. Typical plate type and conical type gussets are shown in Fig. 6 and Fig. 7. Other gusseted nozzle installations may be used as agreed upon between fabricator and purchaser.

7.3.5 *Location of Cutouts on the Shell*—For cutouts made within 6 in. (152 mm) of the knuckle radius area of a head or within 6 in. (152 mm) of a shell-to-shell or shell-to-head joint,

additional hole-cutout reinforcement is required, unless the area of installation is at a point within the vessel that is not exposed to hydrostatic pressure.

7.3.6 All nozzles and manways shall be installed in accordance with Fig. 2 and Fig. 7. The interior overlay shall present the same corrosion resistance to the fluid as specified in 7.1.1 and 7.1.2.

8. Dimensions and Tolerances

8.1 Standard tank diameters, based on internal measurements with the tank in the vertical position, are listed in Table 7. Tolerance on the inside diameter, including out-of-roundness, shall be ± 1 %.

TABLE 7 Standard Tank Inside Diameter

in.	mm
24	(610)
30	(762)
36	(914)
42	(1067)
48	(1219)
54	(1372)
60	(1524)
66	(1676)
72	(1829)
84	(2134)
96	(2438)
108	(2743)
120	(3048)
132	(3353)
144	(3658)

8.2 Where employed, shell taper shall be additive to the figure used for the tank diameter, unless otherwise specified by the manufacturer and accepted by the purchaser. The shell taper shall not exceed ½ ° per side.

8.3 Tolerance on overall tank height shall be ½ %, but shall not exceed ±½ in. (12.7 mm).

8.4 Nozzle flange faces shall be perpendicular to the axis of the pipe within tolerances shown in Fig. 8, and shall be flat within ±1/32 in. (0.8 mm) through 18 in. (457 mm) nozzle size and ±1/16 in. (1.6 mm) for large nozzle sizes. Tolerances on installation are shown in Fig. 8.

8.5 The standard orientation of flanges shall provide bolt holes straddling the normal centerlines of the tank. Bolt holes of flanges located on the tank top or bottom, shall straddle the principal centerline of the vessel or lines parallel to it as shown in Fig. 8.

Nozzle Inside Diameter	Permissible Angular Deviation, −0
Up to 10 in. (254mm)	1°
10 in. (254mm) and larger	½ °

NOTE 1—Larger tolerances may be agreed upon between purchaser and fabricator for tanks over 12 ft in diameter.

FIG. 8 Nozzle Location and Orientation Tolerances

8.6 An alternative method of orientation of flanges on the tank top or bottom, with the bolt holes straddling the radial centerlines, shall be by agreement between the purchaser and fabricator.

8.7 The location of nozzles shall be held to the tolerance shown in Fig. 8.

9. Workmanship, Finish, and Appearance

9.1 The minimum acceptable level for workmanship and finish of the finished laminate shall conform to the requirements specified in Section 9 of Specification C582.

NOTE 18—A representative laminate sample may be used for determination of an acceptable surface finish and acceptable level of visual imperfections.

10. Requirements

10.1 *Degree of Cure*—Degree of cure of the laminate shall be found by determining the Barcol hardness as indicated in 11.5.

NOTE 19—A useful technique to check the cure of a non-molded surface of a polyester resin is as follows: Rub a few drops of acetone on the laminate surface until it evaporates. If the surface becomes softened or tacky, it is and indication of under cure.

NOTE 20—The use of organic reinforcing materials may reduce the Barcol hardness readings without necessarily indicating undercure.

NOTE 21—Barcol hardness values may vary when tests are conducted at temperatures that differ from those shown in 11.2.

11. Test Methods

11.1 *Conditioning*—Condition the specimens prior to test at 70 to 77°F (23 ± 2°C) for not less than 40 h in accordance with Procedure A of Methods D618, for those tests when conditioning is required, and in all cases of disagreement.

11.2 *Test Conditions*—Conduct the test in a laboratory temperature of 70 to 77°F (23 ± 2°C), unless otherwise specified.

11.3 *Chemical Resistance of Resin*—Determine the chemical resistance of the resin in accordance with Practice C581.

11.4 *Glass Content*—Determine the glass content of the inner liner and interior layer combined. Obtain a test sample by carefully splitting these combined areas from the structural layer. The glass content of the separated sample shall be determined in accordance with Test Method D2584.

11.5 *Degree of Cure*—Degree of cure of the laminate shall be found by determining the Barcol hardness using Barcol Model No. GYZJ934.1. Instrument calibration and method shall be as described in Test Method D2583.

11.6 *Physical Properties:*

11.6.1 *Contact Molded Laminates*—Where required, physical properties of contact-molded laminates shall be determined in accordance with the test methods listed in Specification C582.

11.6.2 *Filament-Wound Laminates*—Verify design stresses and moduli of elasticity of filament-wound tanks by manufacturer's test data based upon:

11.6.2.1 Strain (that is, modulus) measurements of small-diameter filament-wound cylinders made to the same laminate construction, helix angle, glass content, liner construction, and resin as the full-size tank, in accordance with Test Method D1599 with restrained end closures that prevent the application of axial tensile stress, or:

11.6.2.2 Strain-gage (hoop-elongation) tests on tanks filled with water.

NOTE 22—Practical test methods on samples cut from filament-wound specimens are not available to cover all cases of testing filament-wound laminates. Other test methods for determination of hoop properties may be used when the fabricator can verify the validity of the selected method.

12. Product Marking

12.1 The tank shall be marked to identify the producer, date of manufacture, capacity, all resins used, inner surface reinforcements, specific gravity, design temperature, and the words "Pressure-Atmospheric," or the operating pressure and vacuum, shall be imprinted on the tank.

12.2 Additional marking requirements may be needed for compliance with local codes. It is the responsibility of the purchaser/user to specify additional labeling requirements for the vessel, such as liquid content, operating and safety instructions, and any other warnings necessitated by local codes.

13. Packaging and Package Marking

13.1 All packing, packaging, and marking provisions of Practice D3892 shall apply to this specification.

14. Shipping

14.1 Since there are variations in the design of support cradles, lifting- and hold-down lugs, and methods of shipping, the manufacturer's special instructions shall be followed in all cases.

14.2 Tanks shall be mounted on cradles if shipping horizontally, or on a suitable skid or pallet if shipping in the vertical position. The cradles or skid shall be padded and secured to the bed of the vehicle in such a manner that will prevent damage to the tank with normal handling. The tank shall be secured to the cradles or skid so that there can be no movement of the tank in relation to the skid or cradle under normal handling.

14.3 A suitable means shall be provided at the open end of open-top tanks to keep the loaded tank rigid.

14.4 Tanks shall be loaded to provide at least 2 in. (51 mm) clearance between the tank (including fittings) and the bulkheads or bed of the vehicle.

14.5 When two or more tanks are shipped on the same vehicle, sufficient clearance or padding shall be provided between tanks to prevent contact in transit.

14.6 Upon arrival at the destination, the purchaser shall be responsible for inspection for damage in transit. If damage has occurred, a claim should be filed with the carrier by the purchaser, and the supplier should be notified. If the damage is not first repaired by the fabricator prior to the tank being put into service, the purchaser accepts all future responsibility for the effects of tank failure resulting from such damage.

15. Keywords

15.1 above ground; atmospheric; filament wound; polyester; tank; vinylester

APPENDIXES

(Nonmandatory Information)

X1. HANDLING AND INSTALLATION

X1.1 Handling

X1.1.1 The following normal precautions should be taken in handling the tank at the destination:

X1.1.1.1 Proper rigging practices should be observed at all times. Hoisting equipment operators should attach a guide line to prevent tank from swinging out of control.

X1.1.1.2 The tank should not be dropped or allowed to strike any other object. Damage caused by such action may result in cracking the inner corrosion-resistant liner, as well as the structural portion of the tank.

X1.1.1.3 The tank should not be rolled or slid on rough ground. Never set a tank upon a fitting or other protrusion that may be attached to the shell.

X1.1.1.4 In working around the tank, care should be exercised to prevent tools, scaffolding, or other objects from striking the tank or being dropped on, or inside the tank. Soft-soled shoes should be worn by workmen entering the tank. Where ladders are used (inside and outside), all points of contact with the tank should be cushioned to protect the surface from scratching or point loading.

X1.1.1.5 The use of a crane is recommended, both in lifting and positioning the tank. The clearance between the head shackle of the crane and the tank should be at least equal to the span between the lugs used for lifting. If this is not possible, a spreader bar must be used to approximate the same angle in lifting.

X1.1.1.6 Where tanks are not equipped with lifting lugs, it is recommended that such tanks be lifted with canvas or rope slings (over 1 in. (25 mm) in diameter) positioned near each end of the tank. Tanks can be moved by positioning fork-lift trucks on either side of the tank with forks padded.

X1.1.1.7 Under no conditions should chains or cables be allowed to contact a tank. Full protection must be provided when using chains or cables. Do not attach lifting devices to any fitting other than lifting lugs.

X1.1.1.8 When storing the tank on the ground prior to installation, it should be placed on the shipping cradles and tied down so that it cannot roll, due to wind or sloping ground.

X1.2 Installation

X1.2.1 Vertical flat bottom tanks should be installed on a base provided continuous support and having sufficient strength to support the weight of the tank full of liquid with negligible deflection. Full support of the bottom should be obtained by one of the following:

X1.2.1.1 If the surface of the pad and the bottom of the tank are flat and have no projections from the plane surface, the tank may be set on such a surface.

X1.2.1.2 If the conditions of X1.2.1.1 cannot be met, methods of support recommended by the manufacturer should be used.

X1.2.2 If the tank has a bottom drain, a hole should be provided in the pad with sufficient clearance so that the drain and its flange will not contact the base at any point.

X1.2.3 *Erection of Vertical Tank:*

X1.2.3.1 Tanks should be handled with a crane, using the lifting lugs provided. Do not attempt to lift tank by attaching to other fittings. Prior to hoisting the top end, a suitable protection pad of material should be placed under the bottom pivot point of tank so that as the tank rises, the strain is taken on the pad. The hoist wire should be connected to the top lifting lugs, and the tank should be raised carefully, using guide ropes to prevent sudden swinging.

X1.2.3.2 All hold-down lugs supplied should be utilized to secure the tank to its pad. Hold-down lugs should be grouted or shimmied to prevent excessive loads being transferred to the tank shell.

X1.2.3.3 Valves, controllers, or other heavy items connected to tank nozzle should be independently supported.

X1.2.3.4 When agitators, mixers, or cooling/heating coils are to be installed, special design considerations must be used.

X2. DISHED BOTTOM

X2.1 An alternative method for calculating the thickness of an elevated dished torispherical bottom head is as follows (refer to 6.3.4 and see Fig. X2.1):

$$t_c = \frac{PR_c}{2S} = \frac{0.036\gamma\, HR_c}{2S} \left(or\; \frac{0.2489\gamma HR_c <}{2S} \right) \qquad (X2.1)$$

$$t_i = \frac{PR_cW}{2S} = \frac{0.036\gamma HR_cW}{2S} \left(or\; \frac{0.2489\gamma\, HR_cW}{2S} \right) \qquad (X2.2)$$

where:

t_c = head thickness in area of the crown radius, in. (mm),
t_i = head thickness in area of the knuckle radius, in. (mm),
S = allowable stress, psi (kPa),
γ = specific gravity of fluid,
P = pressure, psi (kPa),
R_c = crown radius of dished head, in. (m),
H = fluid head, in. (mm),
W = stress intensification factor =

$$\left(\frac{1}{4} \right) \left(3 + \sqrt{R_c/r_i} \right),$$

and
r_i = knuckle radius of the dished head, in. (mm).
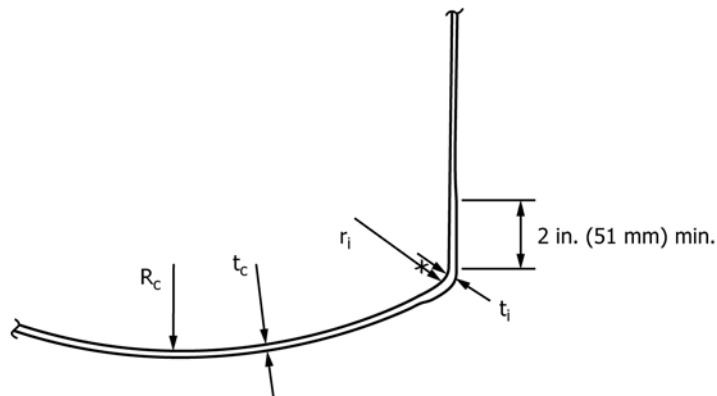
FIG. X2.1 Thickness of Dished-Bottom Head

X3. EXPRESSION OF HOOP TENSILE MODULUS OF A LAMINATE

X3.1 The hoop tensile modulus of a laminate, composed partially of filament winding and partially of a contact molded corrosion barrier, is expressed by:

$$E_T = \frac{E_{FW} * t_{FW}}{t_T} + \frac{E_{CB} * t_{CB}}{t_T} \qquad (X3.1)$$

where:

E_T = hoop modulus of total laminate,

E_{FW} = hoop modulus of filament winding,
E_{CB} = modulus of corrosion barrier,
t_L = corrosion barrier thickness,
t_{FW} = filament winding thickness,
t_T = total thickness, = $t_{CB} + t_{FW}$

This expression will give a good approximation of total laminate modulus for values of E_{FW} of 3.0–6.0 × 10^6 psi (20.7–41.4 GPa).