USA STANDARD

METHOD FOR MEASUREMENT AND CALIBRATION OF SPHERES AND SPHEROIDS

API Standard 2552
ASTM Designation: D 1408—65
(Date of Joint API/ASTM Approval, 1965)

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NOTE: *API Standard 2552-ASTM D 1408* was approved as a USA Standard Dec. 30, 1966.

FOREWORD

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Suggested revisions are invited and should be submitted to the director of the Division of Science and Technology, American Petroleum Institute, 1271 Avenue of the Americas, New York, N. Y. 10020.

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Standard Method for

MEASUREMENT AND CALIBRATION OF SPHERES AND SPHEROIDS[1]

API Standard: 2552

ASTM Designation: D 1408 – 65

ADOPTED, 1965.[2,3]

This standard of the American Petroleum Institute issued under the fixed designation API 2552 is also a standard of the American Society for Testing and Materials issued under the fixed designation D 1408; the final number indicates the year of original adoption as standard, or, in the case of revision, the year of last revision.

This method was adopted as a joint API-ASTM standard in 1965.

Scope

1. This standard describes the procedures for calibrating spheres and spheroids which are used as liquid containers. It is presented in two parts: Part I (Sections 2 to 10) outlines the procedures for the measurement and calibration of spherical tanks; Part II (Sections 11 to 20) outlines the procedures for the measurement and calibration of spheroidal tanks.

NOTE 1.—Calibration procedures for other types of tanks are contained in the following standards:
API Standard 2550—ASTM D 1220: Measurement and Calibration of Upright Cylindrical Tanks
API Standard 2551—ASTM D 1410: Measurement and Calibration of Horizontal Tanks
API Standard 2553—ASTM D 1407: Measurement and Calibration of Barges
API Standard 2554—ASTM D 1409: Measurement and Calibration of Tank Cars
API Standard 2555—ASTM D 1406: Liquid Calibration of Tanks

PART I. SPHERICAL TANKS

Definition

2. A *Sphere* is a stationary liquid storage tank, supported on columns so that the entire tank shell is abovegrade. There are, usually, no internal structural members. A typical sphere is shown in Figs. 1 and 2.

Outline of Procedure

3. (*a*) Practical difficulties limit tape paths for measuring great circles on the sphere where the tape will lie flat and not tend to slip sidewise. Three representative great circles are chosen—one at the horizontal equator and two passing vertically through the poles at right angles to each other. The total volume is calculated based on these three measurements. Partial volumes are then distributed over the measured inside height by a formula or table based on the partial volume *versus* depth in a true sphere.

(*b*) In a sphere the bottom capacity line is the lowest point of the spherical shell inside the sphere. No water bottom or dead capacity exists. This same point is zero gage.

Liquid Calibration

4. (*a*) Liquid calibration is preferred for any tank or portion of a tank not susceptible to adequate or accurate measurement (see API Standard 2555—ASTM D 1406).

(*b*) *Capacity Table.*—The capacity table should be prepared in any desired increments (usually ⅛ in.) using graphs or mathematical methods to establish a smooth curve.

Calibration by Meter

5. The sphere may initially be either empty or full. Calibration should proceed by introducing or withdrawing liquid. Meter readings should be taken for each inch of the upper 25 per cent

[1] Under the standardization procedures of the API and the ASTM, this standard is under the jurisdiction of the API Central Committee on Petroleum Measurement and the ASTM Committee D-2 on Petroleum Products and Lubricants.

[2] The API method was adopted as API Standard 2552 in October, 1965.

Prior to its present publication, the API Recommended Practice 50B was originally adopted as tentative in November, 1937, and as final in November, 1941; the second edition was issued in May, 1942; the third edition was issued in June, 1949, and reissued in January, 1952; the fourth edition was issued in June, 1957.

[3] Revised and adopted as standard June, 1965, by action of the ASTM at the Annual Meeting and confirming letter ballot.

Prior to adoption as ASTM standard, this method was published as tentative from 1956 and revised in 1958.

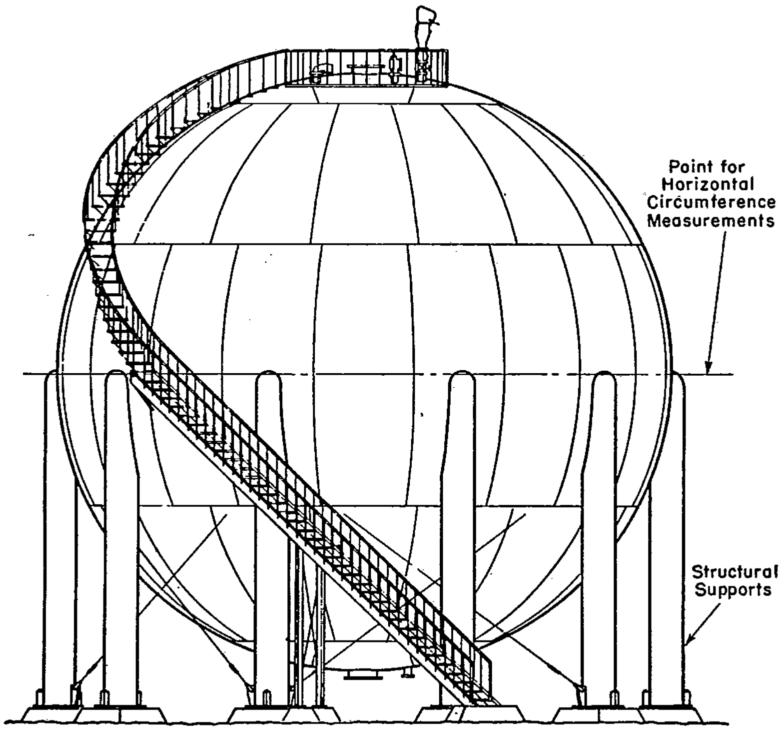

FIG. 1.—SPHERICAL TANK.

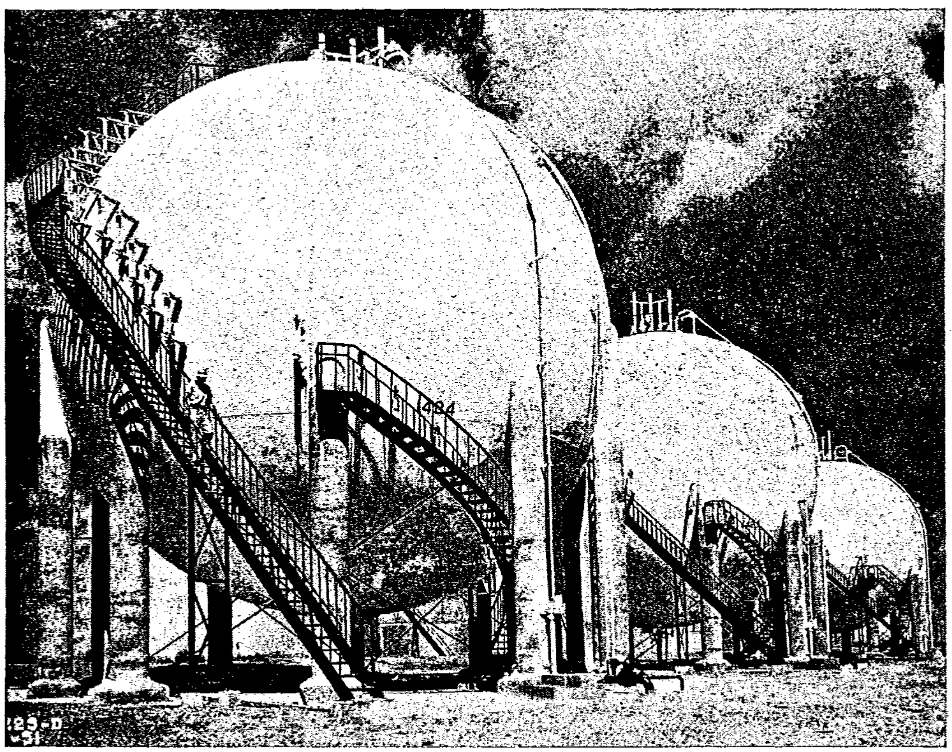

FIG. 2.—SPHERICAL TANKS.

and the lower 25 per cent of the height between the bottom and top capacity lines and for each 2 in. of the intervening height. The increments filled should be measured by means of a tape and bob or by gage glass readings.

Calibration by Tank

6. (*a*) When calibration tanks are used, each tank should be no smaller than one-half of the largest 1-in. increment of the sphere and should have a maximum capacity of the largest 1-in. increment of the sphere. Each calibration tank should have been accurately calibrated.

(*b*) The sphere should be filled with water to the top capacity line. The water should be discharged into calibration tanks where it is accurately measured. Calibrations should be obtained for each inch of the upper 25 per cent and the lower 25 per cent of the height between the bottom and top capacity lines and for each 2 in. of the intervening height. The increments discharged should be gaged by means of tape and bob or by gage glass readings.

Tank-Measuring Equipment

7. (*a*) The equipment used for measuring spherical tanks is the same as that described for upright cylindrical tanks in API Standard 2550—ASTM D 1220. The measurement of any one tank will not necessarily require the use of all of the equipment listed. Therefore, the individual tank and the measurement procedure should be considered before selecting the equipment.

(*b*) The equipment should include steel measuring tapes for both height and circumference measurements. These tapes should be calibrated as described for upright cylindrical tanks in API Standard 2550—ASTM D 1220.

(*c*) Other equipment such as reels, tape, clamps, rope, seat, 6-ft rulers, and spirit level should be as described for upright cylindrical tanks in API Standard 2550—ASTM D 1220.

(*d*) To facilitate the measurement of the largest horizontal circumference, the builder should tack-weld short rods perpendicular to the shell at the point where the shell is tangent to a vertical line, and spaced not more than 10 ft apart to support the tape at that location.

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Field Measurements

8. (*a*) Measure the circumference of the horizontal great circle at the equator. The columns supporting a sphere usually extend a few inches above the equator; where this occurs step-overs will be required. It is permissible to make this circumference measurement at a location just above the tops of the columns where the tape path is clear. When this is done, record the measured circumference, C, and the height, H, above the equator at which C was measured.

(*b*) Measure the circumference of a vertical great circle passing through the poles.

(*c*) Measure the circumference of another vertical great circle at right angles to the first vertical great circle.

(*d*) Measure the total inside height, D, at the vertical centerline of the sphere.

(*e*) There is usually a manhole or other fitting at this centerline. In this event, measure the vertical inside height, D_m, at a convenient distance, m, from the centerline. Record D_m and m for later calculation of the centerline height.

(*f*) Spherical tanks should be re-calibrated as a result of the following conditions:

(*1*) When the deadwood is changed, or additional deadwood such as concrete is installed inside the tank.

(*2*) When the tank is repaired or changed in any manner which may affect the total or incremental volume.

(*3*) When the tank is moved.

Calculations

9. (*a*) If the field measurement of the outside circumference [Section 8(*a*)] was made at a height, H, above the equator to clear the tops of the columns, compute the outside circumference, C_0, at the equator as follows:

$$C_0 = \sqrt{C^2 + (2\pi H)^2}$$

(*b*) Correct each outside circumference to the inside of the shell plates, by subtracting $2\pi t$. For t, use the weighted average thickness along each tape path. Designate the corrected circumferences C_1, C_2, and C_3.

(*c*) Compute the total volume as follows:

$$V = \frac{C_1 \times C_2 \times C_3}{6\pi^2}$$

(*d*) If the vertical inside height, D_m, was measured at a distance, m, from the centerline of the sphere to a manhole or other fitting [Section 8(*e*)], calculate the total inside height, D, at the centerline as follows:

$$D = \sqrt{D_m^2 + 4m^2}$$

(*e*) Compute the partial volume at each desired incremental depth. A method employing a calculating machine may be set up as follows:

Let:

V = total volume of sphere.
G = gage increment.
A = one-half of the vertical inside height.

$$K_1 = \frac{V}{4}\left(\frac{G}{A}\right)\left[3 - \left(\frac{G}{A}\right)^2\right]$$

$$K_2 = \frac{3V}{2}\left(\frac{G}{A}\right)^3$$

$$M = \frac{A - H}{G}$$

H = gage height to bottom of increment.

For the bottom increment:

$$M = \frac{A}{G}$$

$$V_m = K_1 - \left(\frac{M^2 - M}{2}\right) K_2$$

For each succeeding increment:

$$V_m = V_{m+1} + MK_2$$

The volume of each increment above the bottom increment is MK_2 greater than that of the increment directly below.

NOTE 2.—Tables of partial volumes are available but the interpolations required are often more laborious than machine calculation using the foregoing procedure. A sample calculation for a 38-ft-diameter spherical tank is shown in Appendix I.

Effect of Thermal Changes on Spherical Tank Shells

10. (*a*) The effect of expansion or contraction of tanks containing liquids at normal temperature may be disregarded. Correction for expansion or contraction will not be necessary except under conditions of use requiring very accurate results as to the partial or total volumes of heated or refrigerated contents.

(*b*) When corrections for temperature effect are required, it is necessary to estimate the service temperature of the contents and compute volume corrections due to the difference in temperature from 60 F, the normal calibration temperature. Compute the volume correction as follows:

Volume correction, per cent $= K\ (t_s - 60)$

where:

K = a coefficient (see Appendix III).
t_s = service temperature of tank shell, in degrees Fahrenheit.

The coefficient, K, is based upon a low-carbon steel having a coefficient of thermal expansion of 0.0000065 per deg F. When the tank is constructed of a different metal, the coefficient of expansion shall be calculated in accordance with Appendix III.

(*c*) For noninsulated metal tanks, the temperature of the shell may be taken as the mean of the adjacent liquid and ambient air temperatures on the inside and the outside of the shell at the same location. In applying these principles to both spheres and spheroids, only the horizontal dimensions are functions of tank calibration corrections. The liquid height dimension is a function of gaging the liquid level; accordingly, the effect of thermal expansion or contraction on innage and outage gage readings should be considered separately.

PART II. SPHEROIDAL TANKS

Definitions

11. (*a*) A *Spheroid* is a stationary liquid storage tank having a shell of double curvature. Any horizontal cross-section is circular and a vertical cross-section is a series of circular arcs. The height is reduced compared with that of a sphere. The bottom rests directly on a prepared grade. The spheroid has a base plate resting on the grade and projecting beyond the shell. Structural members rest on the base plate and support the overhanging part of the shell for a short distance above the base plate. A drip bar is welded to the shell in a horizontal circle just above the

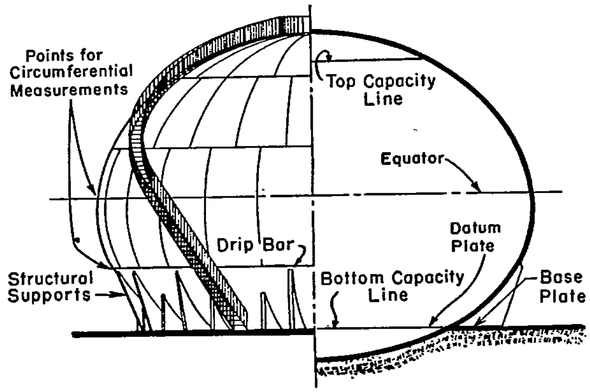

FIG. 3.—SMOOTH SPHEROIDAL TANK.

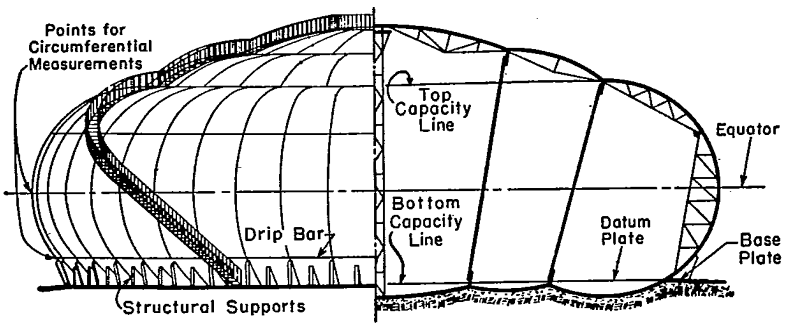

FIG. 4.—NODED SPHEROIDAL TANK.

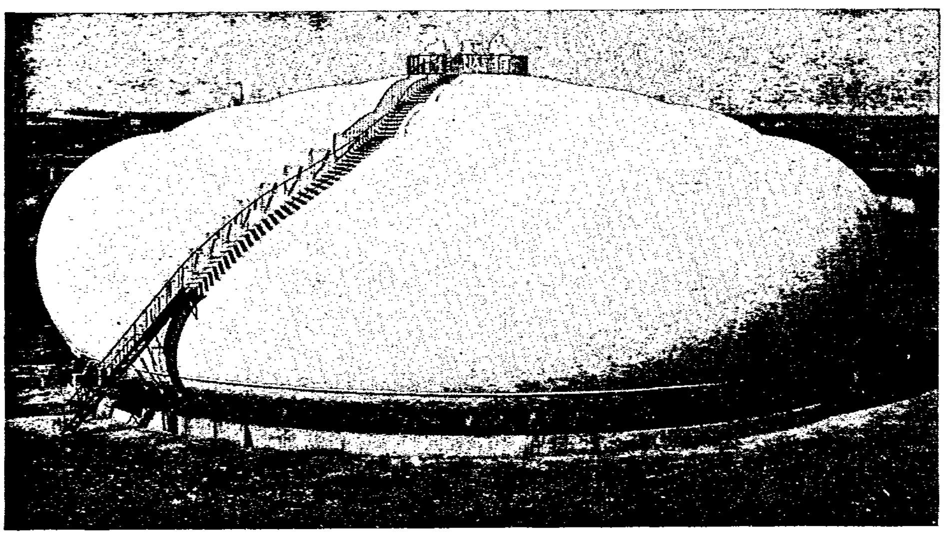

FIG. 5.—NODED SPHEROIDAL TANK.

structural supports to intercept rain water.

NOTE 3.—Since the drip bar is used as a tape path in measuring, the builder should exercise care to locate it accurately.

(*b*) A *Smooth Spheroid,* shown in Fig. 3, usually has no inside structural members to support the shell or roof.

(*c*) A *Noded Spheroid*, shown in Figs. 4 and 5, has abrupt breaks in the vertical curvature called nodes which are supported by a circular girder and structural members inside the tank.

Outline of Procedure

12. Practical difficulties prohibit measuring a spheroid except at two locations. One of these is on the shell at the upper edge of the drip bar; the other is at the largest horizontal circumference where the shell is tangent to a vertical line. At other locations it would be difficult, if not impossible, to support the measuring tape. The theoretical horizontal radii are calculated and then adjusted to conform with the measured circumferences.

Liquid Calibration

13. (*a*) Liquid calibration is preferred for any tank or portion of a tank not susceptible to adequate or accurate measurement. Because circumferential measurements on a spheroid are limited to two, liquid calibration (see API Standard 2555—ASTM D 1406) is preferred to the measurement procedure.

(*b*) Adequate facilities are not always available and the measurement procedure is given as a satisfactory alternative for spheroids. When visibly distorted, the spheroid should be liquid calibrated.

(*c*) Liquid calibration may be performed by meter, using either water or a product of low volatility such as No. 2 fuel oil. If calibration tanks are used, the liquid should be water.

(*d*) When calibrated by liquid, the spheroid should have been filled at least once with a liquid at least as heavy as the liquid to be stored.

(*e*) When calibration tanks are used, they shall be accurately calibrated by the critical measurement procedure (as outlined in API Standard 2550—ASTM D 1220), or by the water draw procedure, into National Bureau of Standards standardized measures (as outlined in *API Standard 1101: Measurement of Petroleum Liquid Hydrocarbons by Positive Displacement Meter*).

(*f*) When meters are used, they should be installed, operated, and proved according to the systems outlined in API Standard 1101 (see also API Standard 2555—ASTM D 1406).

(*g*) *Capacity Table.*—The capacity table should be prepared in any desired increments (usually ⅛ in.) using graphs or mathematical methods to establish a smooth curve.

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Calibration by Meter

14. The spheroid may initially be either empty or full. Calibration should proceed by introducing or withdrawing liquid. Meter readings should be taken for each inch of the upper 25 per cent and the lower 25 per cent of the height between the bottom and top capacity lines and for each 2 in. of the intervening height. The increments filled should be measured by means of a tape and bob or by gage glass readings. After emptying the spheroid, the elevation of the datum plate relative to the bottom capacity line should be checked.

Calibration by Tank

15. (*a*) When calibration tanks are used, each tank should be no smaller than one-half of the largest 1-in. increment of the spheroid and should have a maximum capacity of the largest 1-in. increment of the spheroid. Each calibration tank should have been accurately calibrated.

(*b*) The spheroid should be filled with water to the top capacity line. The water should be discharged into calibration tanks where it is accurately measured. Calibrations should be obtained for each inch of the upper 25 per cent and the lower 25 per cent of the height between the bottom and top capacity lines and for each 2 in. of the intervening height. The increments discharged should be gaged by means of a tape and bob or by gage glass readings. After the water is discharged, the level of the datum plate relative to the bottom capacity line should be checked.

Tank-Measuring Equipment

16. (*a*) The equipment used for measuring spheroids is the same as that described for upright cylindrical tanks in API Standard 2550—ASTM D 1220. The measurement of any one tank will not require the use of all of the equipment listed. Therefore, the individual tank and the measurement procedure should be considered before selecting the equipment.

(*b*) The equipment should include steel measuring tapes for both height and circumference measurements. These tapes should be calibrated as described for upright cylindrical tanks in API Standard 2550—ASTM D 1220.

(*c*) Other equipment such as reels, tape, clamps, rope, seat, 6-ft rulers, and spirit level should be as described for upright cylindrical tanks in API Standard 2550—ASTM D 1220.

(*d*) To facilitate the measurement of the largest horizontal circumference, the builder should tack-weld short rods perpendicular to the shell at the point where the shell is tangent to a vertical line and spaced no more than 10 ft apart to support the tape at that location.

Volume Below Bottom Capacity Line

17. (*a*) The volume below the bottom capacity line is not usually included in the tank capacity. Zero gage or the gage datum should coincide with the level of the bottom capacity line. The main calibration table should not include any volume below that level.

(*b*) In noded spheroids, a circular girder at the bottom node forms a dam which at very low levels would permit the product surface or the interface surface of a water bottom to stand at different levels in the bottom troughs. To avoid this condition, equalization holes should be provided in the circular girder by the builder, and the bottom capacity line should be above these holes. The elevation below datum of the lowest point at which the water level will equalize between nodes should be noted on the calibration table.

(*c*) If a dam plate or weir is used to keep water away from the outlet connection, its elevation relative to the datum should be noted on the calibration table.

(*d*) The volume below the bottom capacity line should be noted on the calibration table. It should be marked "approximate," unless it was obtained by liquid calibration. An auxiliary table giving incremental volumes below the bottom capacity line may be furnished if required.

Field Measurements

18. (*a*) Measure the elevation of the datum plate relative to the bottom capacity line.

(*b*) Measure the elevation of the top of the drip bar at four points equally spaced around the spheroid, relative to the bottom capacity line.

(*c*) Measure the outside circumference of the spheroid at the largest horizontal circumference where the shell is tangent to a vertical line, supporting the tape on the rods provided by the builder.

(*d*) Measure the outside circumference of the spheroid on the shell at the upper edge of the drip bar.

NOTE 4.—During the measurements prescribed in Paragraphs (*c*) and (*d*), the spheroid should be approximately 75 per cent full.

(*e*) Spheroidal tanks should be recalibrated as a result of the following conditions:

(*1*) When the deadwood is changed, or additional deadwood such as concrete is installed inside the tank.

(*2*) When the tank is repaired or changed in any manner which may affect the total or incremental volume.

(*3*) When the tank is moved.

Calculations

19. (*a*) Using dimensions from the builder's drawings, compute the horizontal radius to the inside of the shell at the midheight of each 1-in. increment of depth above the capacity line.

(*b*) Similarly compute the inside horizontal radius at the largest horizontal circle and at the elevation of the top of the drip bar.

(*c*) Divide the field measurements [Section 18(*c*) and (*d*)] by 2π to get the average outside radius at each of these locations and subtract the *horizontal* thicknesses to get the inside radius.

(*d*) Adjust all horizontal radii computed in Paragraph (*a*) by multiplying by the inside radius from Paragraph (*c*) and dividing by the corresponding calculated inside radius from Paragraph (*b*). Use the drip bar adjustment to an elevation midway between the drip bar and the largest horizontal circumference. Use the largest horizontal circumference adjustment for all higher increments.

(*e*) Using the adjusted radii, compute the volume of each 1-in. increment assuming that each is a cylinder.

(*f*) Correct for deadwood.

(*g*) Complete the gage table by totaling the net incremental volumes, starting with zero at the bottom capacity line. The gage table may be prepared in any desired increments (usually ⅛ in.) using graphs or mathematical methods to establish a smooth curve.

(*h*) Record on the gage table the elevation of the datum plate with relation to the bottom capacity line.

(*i*) The capacity table should bear a notation stating whether it was prepared from data obtained by water calibration or by the measurement method.

NOTE 5.—A sample calculation for a 5000-bbl spheroidal tank is shown in Appendix II.

Effect of Thermal Changes on Smooth Spherical Tank Shells

20. The effect of volume changes in the shell of smooth spheroidal tanks, causing changes in the incremental or total tank volumes as a result of differences in temperature, may be computed as described for spherical tanks in Section 10.

APPENDIX I

SAMPLE CALCULATION FOR A 38-FT-DIAMETER SPHERICAL TANK

FROM REPORT OF FIELD MEASUREMENTS:

Horizontal circumference, $C_1 = 119.680$ ft
Circumference taken in a vertical plane, $C_2 = 119.760$ ft
Circumference taken 90 deg from C_2 in a vertical plane, $C_3 = 119.740$ ft
Inside vertical height measured 34 in. off centerline, $D_m = 37$ ft 6¾ in.
Distance C was taken above equator, $H = 10$ in.

CORRECTED HORIZONTAL CIRCUMFERENCE:

$$C_0 = 2\pi \sqrt{\left(\frac{C_1}{2\pi}\right)^2 + H^2} = 6.283186 \sqrt{(19.04766)^2 + (0.8333333)^2}$$

$$C_0 = 119.7945 \text{ ft}$$

INSIDE CIRCUMFERENCES:

$C_1 = 119.7945$ ft $- (0.72 \text{ in.} \times \pi/6) = 119.4175$ ft. (Plate thickness = 0.68 in. and 0.76 in.; Average = 72 in.)
$C_2 = 119.760$ ft $- (0.6783333 \text{ in.} \times \pi/6) = 119.4048$ ft
$C_3 = 119.740$ ft $- (0.6783333 \text{ in.} \times \pi/6) = 119.3848$ ft. (Plate thickness = 0.65 in., 0.68 in., and 0.72 in.; Weighted average = 0.6783333 in.)

VERTICAL CENTERLINE DIAMETER:

$$D = \sqrt{D_m^2 + 4m^2} = \sqrt{(37.56250)^2 + 4(2.833333)^2} = 37.98754 \text{ ft}$$

where:
m = distance off centerline, in feet.
D = vertical diameter at centerline, in feet.

VOLUME OF SPHERE:

$$V = \frac{C_1 \times C_2 \times C_3}{6\pi^2} = \frac{119.4175 \times 119.4048 \times 119.3848}{59.21764} = 28{,}746.68 \text{ cu ft}$$

$$V = 28{,}746.68 \times \frac{1728}{231 \times 42} = 5120.002 \text{ bbl}$$

PARTIAL VOLUMES FOR INCREMENTAL VALUES (⅛-IN. INCREMENTS):

$V = 5120.002$ bbl
$G = 1$ in.

$$A = \frac{37.98754}{2} \times 12 = 227.9252 \text{ in.}$$

Inside height = 37.98754 ft

where:
G = incremental height, in inches.
A = one-half vertical height of tank, in inches.

$$\frac{G}{A} = 0.004387404$$

$$\left(\frac{G}{A}\right)^2 = 0.00001924932$$

$$\left(\frac{G}{A}\right)^3 = 0.00000008445453$$

$$3 - \left(\frac{G}{A}\right)^2 = 2.999981$$

$$K_1 = \frac{V}{4}\left(\frac{G}{A}\right)\left[3 - \left(\frac{G}{A}\right)^2\right] = 16.84753$$

$$K_2 = \frac{3}{2V}\left(\frac{G}{A}\right)^3 = 0.0006486110$$

VOLUME OF BOTTOM INCREMENT:

$$V_m = K_1 - \left(\frac{M^2 - M}{2}\right)K_2$$

$$M = \frac{A}{G} = 227.9252$$

$$V_m = 16.84753 - 16.77372 = 0.07381 \text{ bbl}$$

VOLUME OF EACH SUCCEEDING INCREMENT:

$$V_m = V_{m+1} + MK_2$$

Incremental Height	M	ΣMK_2	Partial Volume	Barrels per ⅛ in. (Diff. Vol. ÷ 8)
0 ft 1 in.	...	0.07381*	0.07381	0.0092
0 ft 2 in.	226.9252	0.22100	0.29481	0.0276
0 ft 3 in.	225.9252	0.36753	0.66234	0.0459
0 ft 4 in.	224.9252	0.51342	1.17576	0.0642
0 ft 5 in.	223.9252	0.65866	1.83442	0.0823
...	...	...	...	...

* Volume of bottom increment included in ΣMK_2.

APPENDIX II

SAMPLE CALCULATION FOR A 5000-BBL SPHEROIDAL TANK

FROM REPORT OF FIELD MEASUREMENTS:

(*a*) Datum plate set at elevation of bottom capacity line.
(*b*) Top of drip bar to bottom capacity line:
  (*1*) 5 ft 8⅞ in.
  (*2*) 5 ft 9 in.
  (*3*) 5 ft 9 in.
  (*4*) 5 ft 9⅛ in.
  Average = 5 ft 9 in. (checks with blueprint).
(*c*) Maximum horizontal circumference = 129.680 ft.
(*d*) Circumference at drip bar = 118.330 ft.

CALCULATIONS:

Inside radius at maximum circumference $= 129.680 \div 2\pi - 0.0225$ ft (plate)
$= 20.61671$ ft

Inside radius at maximum circumference (from blueprint) $= 20.60680$ ft

Multiplier for adjusting radii in upper portion of tank $= \frac{20.61671}{20.60680} = 1.000481$

Inside radius at drip bar $= (118.330 \div 2\pi) -$ (horizontal thickness of plate)
$= 18.83280 - 0.03222 = 18.80058$ ft

Horizontal thickness of plate $= \frac{175.1425}{149.5008} \times \frac{0.33}{12} = 0.03222$ ft

where:
175.1425 = outside radius of vertical curvature, in inches.
149.5008 = horizontal distance from drip bar to center of radius of vertical curvature, in inches.
0.33 = plate thickness at drip bar, in inches.

Inside radius at drip bar (from blueprint) = 18.78130 ft

$$\text{Multiplier for adjusting radii in lower portion of tank} = \frac{18.80058}{18.78130} = 1.001027$$

EXAMPLE OF RUN SHEET (PARTIAL)

Incremental Height	h	a	R	$\sqrt{R^2 - a^2}$	L	Horizontal Radius $\sqrt{R^2 - a^2} + L$
0 ft 1 in.	0 ft 0½ in.	157.9688 in.	174.8125 in.	74.86834 in.	75.8750 in.	150.7433 in.
0 ft 2 in.	0 ft 1½ in.	156.9688 in.	174.8125 in.	76.94287 in.	75.8750 in.	152.8179 in.
0 ft 3 in.	0 ft 2½ in.	155.9688 in.	174.8125 in.	78.95026 in.	75.8750 in.	154.8253 in.
....	....	....	....	....	....	....

Horizontal Radius × Applicable Radius Multiplier	Gross, bbl per ⅛ in. (0.00004047610 R)	Deadwood, bbl per ⅛ in.	Net, bbl per ⅛ in.	Total, bbl
150.8981 in.	0.9217	0.0023	0.9194	7.3552
152.9748 in.	0.9472	0.0023	0.9449	14.9144
154.9843 in.	0.9722	0.0023	0.9699	22.6736
....	....	....	....	....

where (see Fig. 6):
h = vertical distance from center of segment to bottom capacity line.
a = vertical distance from center of segment to center of radius of vertical curvature.
R = radius of vertical curvature.
L = horizontal distance from centerline of tank to center of radius of vertical curvature.

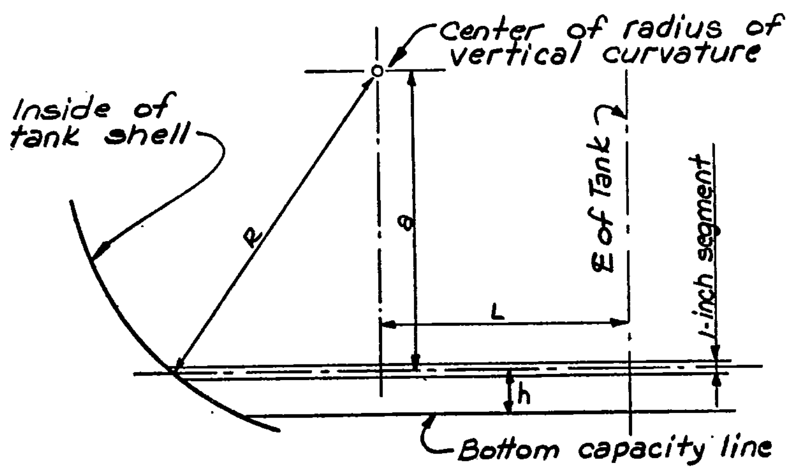

FIG. 6.

APPENDIX III

PROCEDURE FOR COMPUTING THE VOLUME CORRECTION FOR THERMAL EXPANSION OR CONTRACTION OF SPHERICAL AND SMOOTH SPHEROIDAL TANKS

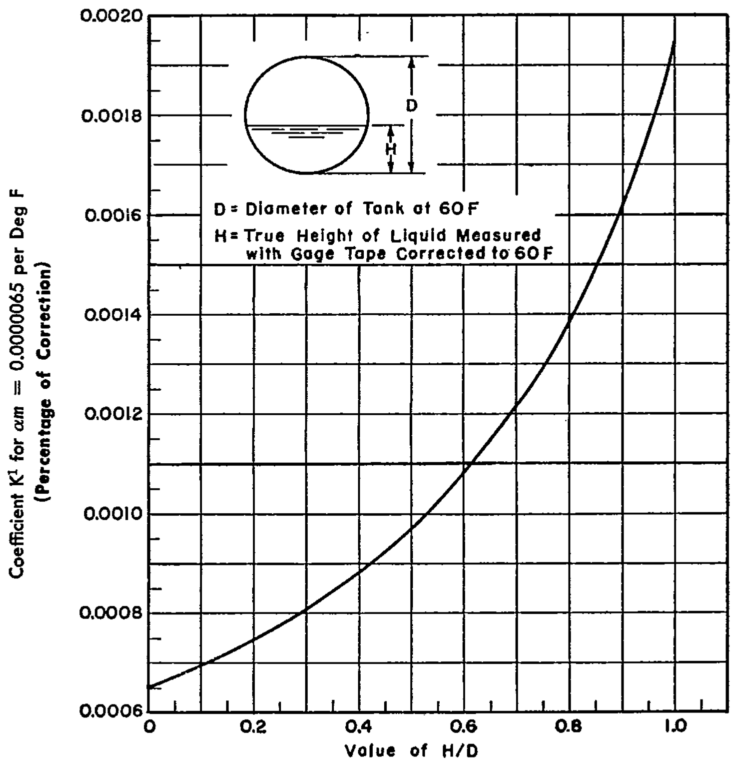

FIG. 7.—VOLUME CORRECTION COEFFICIENT FOR THERMAL EXPANSION OR CONTRACTION OF SPHERICAL AND SMOOTH SPHEROIDAL TANKS CONSTRUCTED OF LOW-CARBON STEEL.

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The basis and method of correcting the volume of spherical and smooth spheroidal tanks which have been affected by changes in temperature is described in Section 10. The coefficient, K^1, is obtained from the curve shown in Fig. 7 which is based on a mean thermal expansion coefficient, αm, of 0.0000065 per deg F. The value, K^1, taken from the curve must be adjusted to the actual thermal expansion, αm, of the tank material at the actual tank temperature, t. For low-carbon steel and structural aluminum the values of αm are:

Tank Shell Temperature, t, °F	Value of αm per °F
Steel	
−70 to −21	0.0000060
−20 to +28	0.0000061
+29 to 78	0.0000062
79 to 128	0.0000063
129 to 177	0.0000064
178 to 227	0.0000065
228 to 276	0.0000066
277 to 326	0.0000067
327 to 376	0.0000068
377 to 425	0.0000069
Aluminum	
−70 to −11	0.0000122
−10 to +49	0.0000124
+50 to 109	0.0000126
110 to 169	0.0000128
170 to 229	0.0000130
230 to 289	0.0000132
290 to 349	0.0000134
350 to 409	0.0000136

The value of K for use in Section 10 is equal to K^1 from the curve shown in Fig. 7, divided by 0.0000065 per deg F and multiplied by the proper value of αm for the tank shell material and temperature; that is:

$$K = K^1 \frac{\alpha m}{0.0000065}$$

where:

αm = the mean coefficient of linear expansion between temperatures, t, and 60 F.

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