Measurement and Calibration of Horizontal Tanks

API STANDARD 2551
FIRST EDITION, 1965
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Standard Method for Measurement and Calibration of Horizontal Tanks

Measurement Coordination/Industry Affairs

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Standard Method for

MEASUREMENT AND CALIBRATION OF HORIZONTAL TANKS[1]

API Standard: 2551

ASTM Designation: D 1410 – 65

ADOPTED, 1965.[2,3]

This standard of the American Petroleum Institute issued under the fixed designation API 2551 is also a standard of the American Society for Testing and Materials issued under the fixed designation D 1410; 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 external measurement procedures for calibrating horizontal aboveground stationary tanks larger than a barrel or drum.

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 2552—ASTM D 1408: Measurement and Calibration of Spheres and Spheroids

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

Outline of Procedures

2. This standard is presented in two parts.

Part I (Sections 7 to 21) includes procedures for the measurement of horizontal, and tilted, cylindrical aboveground tanks with various types of heads; descriptions of tank-measuring equipment and procedures for the calibration of those items of equipment for which calibration is required; and suggestions for the orderly and complete recording of field measurement data, including tank measurement record forms.

Part II (Sections 22 to 44) includes procedures for calculating the incremental tank capacities from the field data, suitable for the preparation of incremental capacity gage tables. Typical examples of calculations are included in Appendix I, as are convenient tables of shape factors for determining contained liquid volume in horizontal cylinders and in formed heads at any liquid depth.

Tank-Measuring Equipment and Its Calibration

3. The equipment to be used for tank calibration work is discussed in Sections 4 and 5. The measurement of any one tank will not require the use of all the equipment listed. Therefore, the tank construction and the proper calibration procedure must be considered carefully before selecting the equipment needed. All equipment shall be in good condition. All tapes shall be in one piece (unmended) and free of kinks.

Measuring Tapes

4. (*a*) *Tapes for Length, Diameter, or Height Measurements.*—A steel tape of convenient length, ⅜ or ½ in. wide and approximately 0.008 to 0.012 in. thick—graduated in feet and inches to ⅛ of an inch or graduated in feet, tenths, and hundredths of a foot—is recommended. Graduations shall be accurate to within 1/32 in. or 0.05 ft throughout that portion of the tape length to be used. The working tape shall be calibrated in position against a "standard" tape with tension on the standard tape equal to that at which it was standardized. Tension should be applied to the working tape sufficient to align it with the standard tape. This amount of tension shall be applied to the working tape when making measurements.

(*b*) *Tapes for Circumference Measurements:*

(*1*) For circumference measurements, a steel tape of convenient length relative

[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 2551 in October, 1965.

Prior to their present publication, the API methods of test were issued in December, 1929 as API Code 25. API Code 25 was reissued in 1930, 1931, 1933, 1935, 1940, and 1948. The material was revised and reissued in September, 1955 as API Standard 2501, and the second edition was issued in July, 1961.

[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.

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to the tank circumference, usually 100 ft in length, is recommended. The working tape should be not more than ¼ in. wide, and approximately 0.01[illegible] in. thick. The tape may be graduated in feet, with an extra 1-ft length at the zero end graduated in tenths and hundredths of a foot, or it may be graduated in feet, tenths, and hundredths of a foot throughout its length. The tape shall be calibrated (for required tension) by matching it against the standard tape in the following manner: Place the standard tape around the tank on the proper tape path and exert the specified tension, slide the tape a few inches each way, and pull into reading position. Place the working tape around the tank adjacent to the standard tape, slide the tape a few inches each way, and apply tension to the working tape sufficient to align it with the standard tape. The amount of tension required for alignment shall be applied to the working tape when determining circumference measurements. When making "critical measurements," this procedure shall be carried out for each tank of different diameter where the circumference differs by more than 20 per cent from the calibrated tape section, and where tank surfaces are different. It should be noted that circumferential measurements may be made with working tapes which have been calibrated by a standard tape of length based on 68 F. Such measurements recorded on that temperature basis must be mathematically corrected to a 60 F basis prior to use in computing gage tables.

(*2*) If the preceding calibration procedure is not practicable, a suitable flat, horizontal surface, such as a railroad rail, may be substituted for the tank shell surface. In either case, if two or more successive check readings are taken, the frictional resistance of the supporting surface to movement of the working tape should be broken between such successive readings.

(*c*) *Tape Calibration.*—The standard tape for calibrating tank-measuring (working) tapes shall be identified with a Report of Calibration at 68 F by the National Bureau of Standards attesting to the standard tape accuracy within 0.001 ft (approximately 1/64 in.) per 100 ft of length. The Report of Calibration for a standard tape shall include these factors and/or formulas necessary to correct the tape length for use:

(*1*) At 60 F.

(*2*) Under tension differing from that used in calibration.

(*3*) Under conditions of sag in an unsupported tape.

(*d*) *Reels.*—Tapes shall be equipped with appropriate reels and handles.

(*e*) *Tape Clamps.*—For assurance of a positive grip on the tape, clamps shall be used.

NOTE 2.— The National Bureau of Standards provides for standard tapes (NBS "reference" tapes) only a Report of Calibration at 68 F when the tape is completely supported in a horizontal position and subject to horizontal tension as prescribed in *National Bureau of Standards Test Fee Schedule 202.404—Steel Tapes.* The additional data indicated in Section 4(*c*), Items (*1*), (*2*), and (*3*), are included in the NBS Report of Calibration only when requested by the applicant and to the extent specifically requested.

Accessory Equipment

5. (*a*) *Depth Gage.*—Depth gage of case-hardened steel, 6 in. in length, graduated in 1/64 in.

(*b*) *Calipers, Step-Overs, and Special Clamps.*—For spanning obstructions in making circumference measurements, the following are recommended:

(*1*) Six-inch maximum expansion calipers for spanning the smaller obstructions, such as vertical flanges, bolt heads, etc.

(*2*) Special clamps may be substituted for calipers in measuring projecting flanges.

(*3*) Fixed- or adjustable-span steel step-overs may be used instead of calipers or special clamps.

(*4*) To measure the span of a step-over or caliper, apply the instrument in a horizontal position, as determined by use of a level, against the shell of the tank being strapped, near the center of a shell plate, and scribe marks on the shell with the two scribing points. Apply the circumferential working tape, under required tension, to the tank shell in such a position that the distance between the scribed lines, along the shell surface, may be estimated to the nearest 0.001 ft (approximately 1/64 in.).

(*c*) *Straightedges:*

(*1*) Metal, 36 in. long.

(*2*) Engineer's straightedge, 10 ft long, for measuring heads.

(*d*) *Miscellaneous:*

(*1*) Six-foot ruler.

(*2*) Four-foot crowbar.

(*3*) Spirit level.

(*4*) Awl and scriber.

(*5*) Marking crayon.

(*6*) Record paper.

(*7*) Cleaning instruments—such as a putty knife and a hard-bristle brush for eliminating dirt, grease, paint scale, rust particles, etc., from the path of circumference measurements.

(*8*) A combined transit and level.

(*9*) Ladders to facilitate handling of tapes and equipment.

(*10*) Plumb line.

(*11*) Spring tension scale.

(*12*) Dynamometer.

(*e*) *Equipment for Determining Temperature and Gravity:*

(*1*) *Sample Can.*—A clean container of suitable size.

(*2*) *Hydrometer Cylinder.*—Preferably of nonbreakable material, diameter 1 in. greater than the outside diameter of the hydrometer to be used, height 1 in. greater than the portion of the hydrometer which is immersed beneath the surface of the liquid.

(*3*) *Hydrometer.*—Plain form or combined thermometer and hydrometer known as a thermohydrometer, calibrated in terms of API gravity, the range to be a suitable portion of the interval between 0 and 100° API and graduated in 0.1° API and conforming to Specifications E 100 for ASTM Hydrometers.[4]

NOTE 3.—For making gravity measurements, reference should be made to *API Standard 2544—ASTM D 287: Test for API Gravity of Crude Petroleum and Petroleum Products.*

(*4*) *Thermometer.*—ASTM Gravity Thermometer, total immersion, graduated in Fahrenheit, having a range of −5 to 215 F, and conforming to the requirements for Thermometer 12 F, as prescribed in Specifications E 1 for ASTM Thermometers.[4]

NOTE 4.—For obtaining temperature measurements, reference should be made to *API Standard 2543—ASTM D 1086: Measuring the Temperature of Petroleum and Petroleum Products.*

General Practices

6. (*a*) Prevailing safety practices should be observed at all times.

[4] 1966 Book of ASTM Standards, Part 18.

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(*b*) The number of men required in a measuring crew will depend upon conditions to be encountered, such as the experience of the men, the weather, measuring schedule, rigging available, and the size of tank. As a general rule, two men may be considered adequate if at least one man has had previous tank-measuring experience. It would also be desirable if the previous experience included the calculation of gage tables.

(*c*) Do not use ropes, ladders, or other rigging of questionable strength or condition. This is particularly important in regard to rope that has been stored while wet, saturated with oil or gasoline, or used on an acid tank.

(*d*) If ladders are used, all rungs should be inspected and tested at ground level. Ladders should not be extended beyond their normal safe working range. It should be understood that the inherent danger in ladders may be increased considerably by conditions on a tank job, such as possible soggy footing, relatively smooth upper bearing surface, strong gusts of wind, and sudden slack or pull of circumference tape.

(*e*) All measurements and descriptive data taken at the tank site should be checked and legibly recorded immediately, preferably by one man.

(*f*) Take time to do a good job.

(*g*) Liquid calibration of the entire or partial volume of tanks is sometimes recommended in lieu of physical measurement of dimensions and calibration of tank volumes. Instructions for liquid calibration for these or any other reasons may be found in API Standard 2555—ASTM D 1406.

PART I. MEASUREMENT PROCEDURES

Conditions of Measurements

7. (*a*) All data, and procedures whereby they are obtained, necessary for the preparation of gage tables should be supported by sound engineering principles.

(*b*) Measurements should be taken only after the tank has been stressed at least once to its maximum working pressure or filled to a maximum depth of liquid at least as dense as it is expected to contain. The usual shop or field test will meet this requirement.

(*c*) Measurements may be taken at any condition of fill encountered (except flat-head tanks). Flat-head tanks have a tendency to expand outward when the tank is filled (Section 17).

NOTE 5.—The calibrating procedures which are outlined herein require that the interior surface of the tank be clean and free from any foreign substance, including the residue of commodities adhering to the bottom and sides of the tank, dirt, and rust. Examination and inspection of a tank may indicate the need for thorough cleaning if the correct capacity is to be established.

Classification of Tank Services

8. (*a*) The degree of accuracy desired, or required, in the completed gage table for a specific tank will be the governing factor in determining the procedure to be followed to assure the desired end result. It should be remembered that maximum obtainable accuracy in gage tables, regardless of service, is desirable.

(*b*) Tanks may be considered to fall within two broad classifications:

(*1*) Tanks used in intraplant or intradepartmental service, wherein gage tables are usually considered in the light of the "operating control" procedure.

(*2*) Tanks used in intercompany or interdepartmental service, wherein gage tables of liquid volume are usually considered in the light of the "critical measurements" procedure.

(*c*) A critical measurements gage table is a more precise calibration of a container than a minimum operating control gage table, because adjustments for the effects of additional variables are considered therein.

(*d*) For measurements determined by the operating control procedure, the effect of the following variables should be considered:

(*1*) Effect of inclination from a horizontal position.

(*2*) Effect of deadwood.

(*e*) For measurements determined by the critical measurements procedure, the effect of the following variables may be considered in addition to the two previous items:

(*1*) Effect of different shell temperatures on tank volume.

(*2*) Effect of liquid head and working pressure on tank shell and heads.

a. Tolerances for measurements and calculations included in this standard are intended to apply to the development of gage tables for both operating control and critical measurements tables.

b. Adjustment for effect of such variables may be incorporated in gage tables for operating control tanks. The gage table should indicate the adjustments which have been incorporated.

Tolerance in Measuring

9. (*a*) All tape measurements for circumference should be read and recorded to the nearest five-thousandths (0.005) of a foot. Therefore, all circumferential measurements should be recorded in the third decimal place, the figure in the third decimal place being either zero or five.

(*b*) Tape measurements for diameter, length of cylinder, off-level, and so forth should be read and recorded to the nearest one-sixteenth (1/16) of an inch, or 0.005 ft.

(*c*) Thermometers should be read to the nearest scale division (1 F or less).

(*d*) Tank plate thickness should be determined to the nearest one-sixty-fourth (1/64) of an inch.

(*e*) Deadwood should be measured and located to the nearest one-eighth (1/8) of an inch.

Recalibration

10. (*a*) In order to obtain a check on the accuracy of existing records of circumferential measurements, the tank circumference in question should be measured as close to the original circumferential locations as possible.

(*b*) If the check measurements do not fall within the tolerances shown in the following tabulation, a complete recalibration, and new gage tables based thereon, should be prepared:

Tolerances for Circumferences Not Over 100 Ft

	Circumference Difference, ft
Welded Steel Tanks	0.010
Riveted Steel Tanks	0.020

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(*c*) If previous circumferential measurements were taken at points other than recommended in this standard, or if deadwood has been changed, then a recalibration and new tables should be prepared.

(*d*) After extended service, a tank sometimes deforms at the saddle or other supports. If the deformation is easily noticeable, recalibration, preferably by liquid, is desirable. If liquid calibration is not practicable, the capacity tables should be revised with the deformations treated as additional plus or minus deadwood.

(*e*) Stationary horizontal tanks should be recalibrated under the following conditions:

(*1*) Whenever deadwood is changed or additional deadwood such as concrete is installed inside a tank.

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

(*3*) Whenever a tank is moved.

Shell Plate Thickness

11. (*a*) Plate thicknesses obtained from the fabricator's drawings should be acceptable and so identified in the calculation report.

(*b*) Alternatively, where no fabricator's drawings are in the file and the type of construction leaves the plate edges exposed, a minimum of one measurement should be made for each ring. All thickness measurements, properly identified, should be noted on a supplemental data sheet which shall form a part of the measurements record. Care should be taken to avoid plate thickness measurements at locations where edges have been distorted by welding or caulking.

(*c*) Notes concerning paint thickness on the various rings shall be included in the measurement records, and may be based on observation rather than actual measurement.

Horizontal Tank Measurements

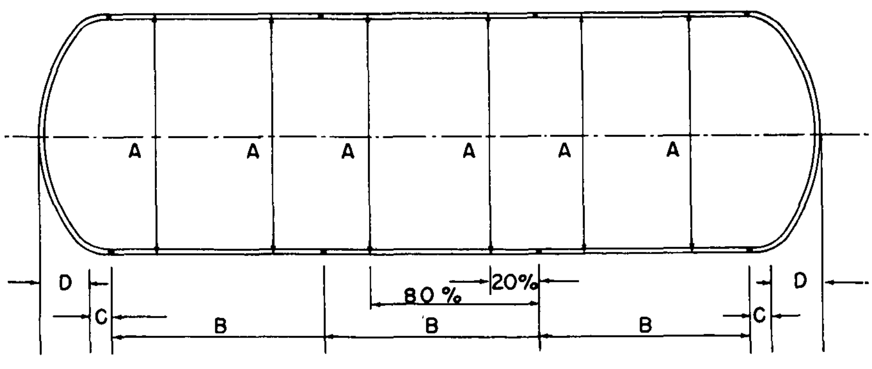
12. (*a*) The total length of the cylinder is the sum of the length of the main cylinder and the two lengths of the head cylinder (straight flange of the head). Record (measure, if possible) the total length of the tank heads, plus the main cylinder, plus the straight flanges.

(*b*) Two sets of reference points, 180 deg apart, should be established at the ends of the main cylinder. Reference points should be marked in a clear and unmistakable manner.

(*c*) If the tank is either of butt-welded construction or constructed of a bottom sheet and two longitudinal top sheets, the length of the main cylinder is obtained by measuring the distances between the two sets of reference points. The average of these measurements should be taken as the length of the main cylinder (Figs. 1, 2, and 3).

(*d*) If the tank is of lap-welded construction, consisting of a bottom sheet and several partial rings or a number of complete rings, the same measurement procedure should be followed. However, with this type of construction, the net widths of the several rings shall also be measured, and the sum of these partial lengths of the main cylinder must be equal to the overall length as measured between the reference points at the heads of the tank (see Fig. 2).

(*e*) The theoretical length of the head cylinder may be determined from the manufacturer's drawings.



A—Circumferences taken at 20 and 80 per cent of each ring.
B—Measured length of cylinder rings.
C—Distance from weld to tangent point.
D—Head projection.

FIG. 1.—HORIZONTAL BUTT-WELDED CYLINDRICAL STEEL TANK.

Circumferential Measurements

13. (*a*) *Preparation for Measurements.*—The tank construction and the characteristics of the joints should be determined by close examination in order to establish the method of measurement, the equipment required, and the applicable drawing—either Fig. 1, 2, or 3.

(*1*) Circumferential tape paths located as shown on the pertinent drawing should be examined for obstructions and type of joints. Projections of dirt and scale should be removed along each path. Occasionally, some feature of construction—such as a manway, nozzle, reinforcing pad, davit, or saddle—may make it impracticable to obtain a circumferential measurement as shown in the diagram.

(*2*) If the obstruction can be spanned by a step-over, the circumference should be measured at the prescribed point, using a suitable procedure [Paragraph (c)].

(*3*) If the obstruction cannot be conveniently spanned by a step-over, a substitute path, located as near as possible to the prescribed point but not on a joint, may be chosen. The strapping record should include the location of the substitute path and the reason for the departure.

(*4*) The amount of tension, in pounds, to be applied to the measuring tape in all cases should have been determined previously in accordance with a procedure described in Section 4.

(*b*) *Measurement Locations.*—If the tank is formed of complete rings, circumferential measurements should be taken at 20 and 80 per cent of the width of each ring (Figs. 1 and 2).

(*1*) If measurements taken on successive rings indicate unusual variations or distortions, additional measurements should be taken to satisfy the judgment of all strappers involved.

(*2*) If the tank is composed of a bottom sheet and two longitudinal top sheets or a bottom sheet and several partial rings, circumferential measurements shall be taken at the ⅛, ⅜, ⅝,

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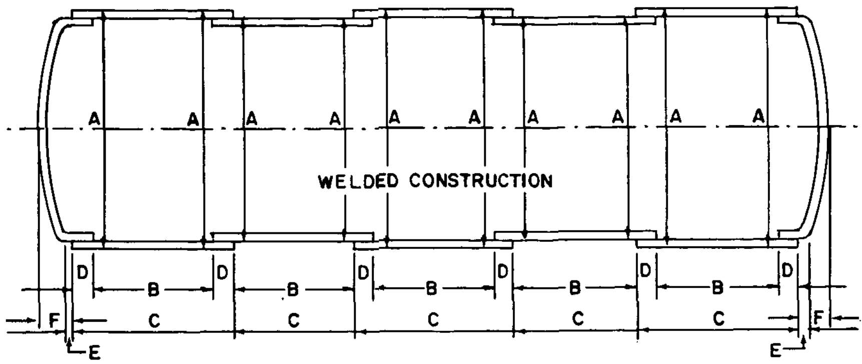
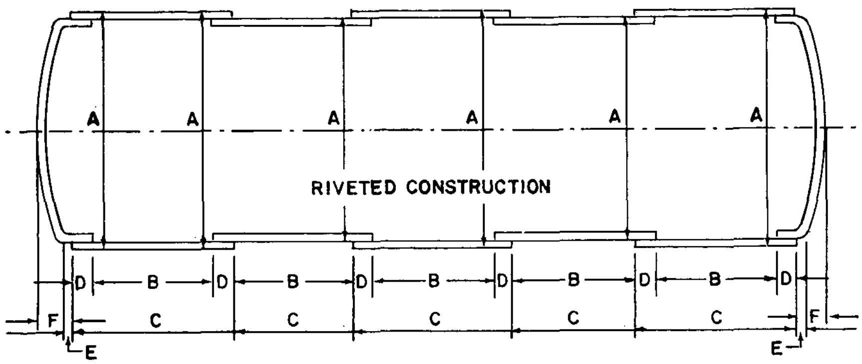


A—Circumferences taken at 20 and 80 per cent of each ring.



A—Circumference taken next to joint of each ring, if tank is of riveted construction.

Notes to both sketches:

B—Unlapped lengths of rings.
C—Exposed lengths of rings.
D—Width of laps.
E—Distance from joint to tangent point.
F—Projection of head from joint.

FIG. 2.—HORIZONTAL IN-AND-OUT LAP-WELDED CYLINDRICAL STEEL TANK.

and ⅞ points along the shell, as shown in Fig. 3.

(*c*) *Procedures:*

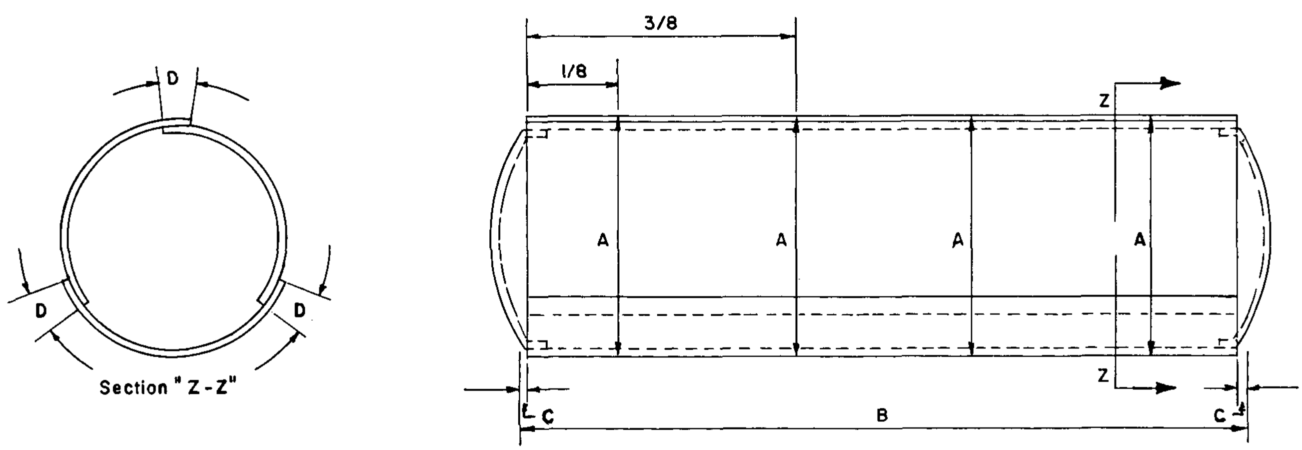
(*1*) *General.*—For the procedures discussed in Items (*2*) and (*3*), a circumferential tape of sufficient length to completely encircle the tank should be used and measurements of total circumference should be taken.

a. In all cases the tape to be used should be applied to the tank surface at the prescribed locations by the wraparound procedure; i.e., the required length of tape should be applied in a slack condition, positioned, and tightened by the application of the proper tension, in pounds, and in accordance with the procedure used in checking the working tape against the standard tape.

b. After a circumferential measurement reading has been taken, the tension should be reduced sufficiently to permit the tape to be shifted. It should then be returned to position with required tension, and another reading should be taken. This procedure should be repeated until two equal readings have been obtained. The equal readings should be recorded as the circumferential measurement at that location.

(*2*) *Constant Contact:*

a. In a case in which the circumferential measuring tape is in contact with the tank surface at all points



A—Circumferential measurements taken at ⅛, ⅜, ⅝, and ⅞ points along the length of the shell.
B—Length of cylinder.
C—Length of exposed straight flange of head.
D—Amount of horizontal lap.

FIG. 3.—HORIZONTAL CYLINDRICAL STEEL TANK WITH SHELL HORIZONTALLY LAPPED.

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along its path, circumferential measurements should be made and checked in accordance with the procedure in Item (*1*). The checked measurements should be recorded as final measurements.

b. In a case in which butt straps or lap joints cause uniform voids between the tape and the tank shell at each joint, circumferential measurements should also be made in accordance with Item (*1*).

c. In addition, the width and thickness of the butt straps and the thickness of exposed lapped plate at not less than two joints in each ring about the circumference should be measured and recorded—the number of such joints in each ring should also be recorded. The measured circumferences, properly checked, should be corrected for tape-rise effect by calculation as described in Part II, Section 34.

(*3*) *Intermittent Contact*.—In a case in which butt straps or lap joints, or the tank shell, contain rivets or other features which exert uneven effects on the resultant void between the tape and the tank, from joint to joint, a step-over will be required. The span of the instrument should be measured prior to use.

a. The step-over must be of sturdy construction, either adjustable or fixed in spread; however, an adjustable step-over is preferable. The two legs must be separated by a distance sufficient to span each void encountered between the tape and the shell. The legs must be of sufficient length to prevent contact between the interconnecting member and the tank plate or obstruction. The manner in which the step-over may be used is related to the type of measuring tape used; i.e., whether the tape is graduated in hundredths of a foot throughout its length, or whether the tape is graduated in feet only, with an extra 1-ft length at the zero end graduated in tenths and hundredths of a foot.

b. If the circumferential measurements are made with a step-over and with a tape graduated in hundredths of a foot throughout its length, the tape should be stretched over the joints in accordance with the procedure in Item (*1*). The step-over should be placed in position at each location of void between the tape and the shell, completely spanning the void, so that the scribing points will contact the shell at an edge of the tape. With the tape maintained in proper position and tension, the length of tape encompassed by the scribing points should be estimated to the nearest 0.001 ft (approximately 1/64 in.) per 100 ft of length.

c. At each step-over location, therefore, the difference between the length of tape encompassed by the scribing points and the known span of the instrument is the effect of the void, at that point, on the circumference as measured. The sum of such differences in any given path, subtracted from the measured circumference, will give the corrected circumference.

d. If the circumferential measurements are made with a step-over and with a tape graduated in feet only, with an extra 1-ft length at the zero end graduated in tenths and hundredths of a foot, the tape should be stretched over the joints in accordance with the procedure in Item (*1*). The step-over should be placed in position at each location of void between the tape and the shell. The tank shell should then be marked at the points of contact of the scribing points to the shell. Each location so marked should then be measured with the same tape. For each separate measurement, the tape should be reapplied in proper tension against the tank and so adjusted that a whole-foot marking lies opposite one of the scribed marks. The location for the whole-foot marking should be so chosen that the other scribed mark will lie within the graduated 1-ft extra length at the zero end. The tape length between the scribed marks should be estimated to the nearest 0.001 ft (approximately 1/64 in.) per 100 ft of length.

e. At each step-over location, therefore, the difference between the length of tape encompassed by the scribing points and the known span of the instrument is the effect of the void, at that point, on the circumference as measured. The sum of such differences in any given path, subtracted from the measured circumference, will give the corrected circumference.

Expansion and Contraction of Steel Shells Due to Liquid Pressure and/or Working Pressure

14. Record the liquid head, pressure, and tank contents (gravity and temperature) as well as the normal operating pressure (see Part II, Section 35).

Expansion and Contraction of Steel Shells Due to Temperature Changes

15. No field observations need be recorded on nonartificially heated or cooled tanks (see Part II, Section 37).

Head Measurements

16. (*a*) Manufacturer's specifications for tank heads—the contours of which consist of compound curves, ellipses, or segments of spheres—should be used, when available, in lieu of field measurements.

(*b*) Field measurements on such heads are of doubtful accuracy because it is very difficult to determine the exact point of tangent between the straight flanges and the various curves of the heads. The strapper should make field measurements on all such heads to be used by the tank table engineer to check the manufacturer's drawings and to be used as a basis of calculation when the drawings or specifications are not available [see application of this principle in Part II, Section 41, Example No. 1, Item *1*(*d*)].

(*c*) The various heads should be measured as follows:

(*1*) For a spherical segment head with knuckle radius (if the manufacturer's drawings are not available) or an ellipsoidal head, measure the projection from the straight flange (Figs. 1, 2, and 4). Measure the chords and rises with a straightedge in four planes separated by 45-deg angles. Measure the length of the straight flange. Measure the length of the arc.

(*2*) For a flat head, measure the bulge or projection, if any, and measure the length of the straight flange (Fig. 5).

Expansion of Heads Due to Liquid Pressure or Working Pressure

17. (*a*) For the operating control procedure, disregard all head changes due to pressure.

(*b*) For the critical measurements procedure, the bulge in flat heads due to liquid pressure must be considered. Meas-

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ure bulge (Fig. 5) and diameter of head when tank is both full and empty.

Effects of Tank Off-Level

18. (*a*) Tables made for horizontal tanks will not give accurate capacities per unit of depth if the tanks are off level. If the gage location is not located at the midpoint, it should be located by measurement and shown on a supplemental sketch.

(*b*) The amount of off-level should be measured and recorded.

Deadwood

19. (*a*) Deadwood should be accurately accounted for, as to size and location, to the nearest ⅛ in. in order to provide adequate allowance for the volume of liquid displaced or admitted by the various parts and to provide adequate allocation of the effects of various elevations within the tank.

(*b*) Deadwood should be measured within the tank, if possible. Dimensions shown on the manufacturer's drawings are acceptable if actual measurement is impossible.

(*c*) Measurements of deadwood should show both the lowest and the highest level, measured from the tank bottom, at which elevation the deadwood affects the capacity of the tank.

(*d*) Work sheets on which details of deadwood are sketched, dimensioned, and located should be clearly identified and should become a part of the strapping records.

Interruption of Measurements

20. Tank measurement work which has been interrupted may be continued at a later date without repeating the work previously completed, provided all records of the work are complete and legible. Movement of liquid into or out of the tank may be tolerated.

Descriptive Data

21. (*a*) Descriptive data should be entered on the tank measurement record form. The commonly used name for the contents of the tank is a sufficient description. If a more accurate description is desired—as for example in critical measurements, or by agreement between the buyer and the seller—a hydrometer reading shall be obtained and recorded with the temperature of the sample.

(*b*) Supplemental pencil sketches, preferably on sheets of paper 8½ by 11 in. in size, each completely identified, dated, and signed, will form an important part of the field data.

The sketches should show:

(*1*) Typical horizontal and circumferential seams.

(*2*) Number and size of plates per ring.

(*3*) Location of rings at which the thickness of the plates changes.

(*4*) Arrangement and size of nozzles and manways.

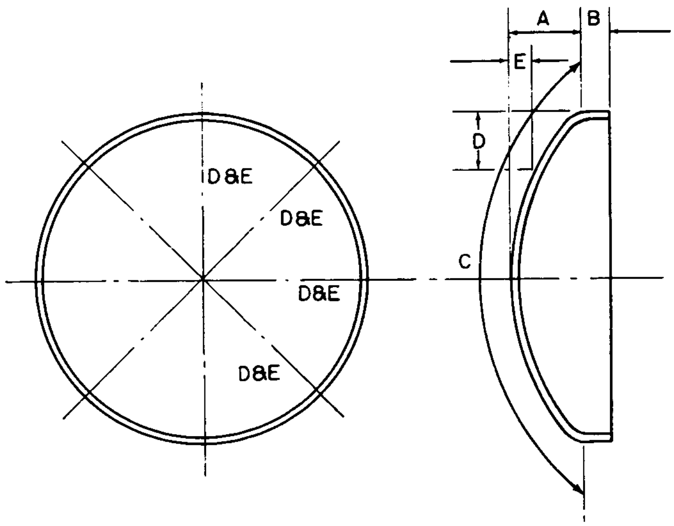
(*5*) Dents and bulges in shell plates.

(*6*) Amount of off-level from a horizontal position.

(*7*) Method used in bypassing an obstruction in the path of a circumferential measurement.

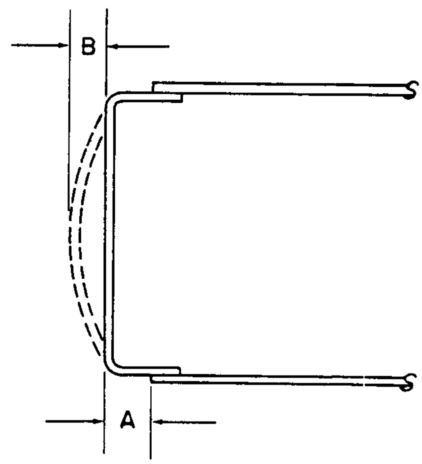
(*8*) Location of tape path different from that shown on guide sheets.

(*9*) Location and estimated size of a gaging shelf.



A—Projection of head beyond tangent point.
B—Length of straight flange.
C—Arc length of head (tangent point to tangent point).
D and E—Measurements taken along four lines (45 deg to each other) to establish shape of head.

FIG. 4.—SPHERICAL SEGMENT HEADS FOR HORIZONTAL CYLINDRICAL TANKS.



A—Length of exposed portion of straight flange.
B—Amount of bulge in head when tank is full.

FIG. 5.—FLAT HEAD FOR HORIZONTAL CYLINDRICAL STEEL TANKS.

PART II. TANK CAPACITY CALCULATION PROCEDURE

GENERAL

Engineering and Mathematical Principles

22. (*a*) True engineering and mathematical principles should be used throughout. These should include those given specifically hereinafter for application to this particular type of work.

(*b*) The derivation of some of the formulas and factors used in the calculation examples in this section may be found in Sections 42 to 44, inclusive.

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Capacity Units on Gage Tables

23. Capacity should be expressed in whole gallons, or in whole barrels and decimal parts of a barrel, and should be tabulated in ⅛-in. increments.

Conversion of Outside to Inside Circumference

24. Plate thicknesses should be taken from the manufacturer's drawings, or should be measured (see Section 11).

$$C_i = C_o - (\pi)\frac{t}{6} \qquad (1)$$

where:
C_i = inside circumference, in feet.
C_o = outside circumference, in feet.
t = plate thickness, in inches.

Significant Figures

25. All calculations for incremental or total volume should be carried to seven significant figures. Corrections to incremental or total volume calculations need be carried only to the number of significant figures consistent with the seventh in the quantity corrected.

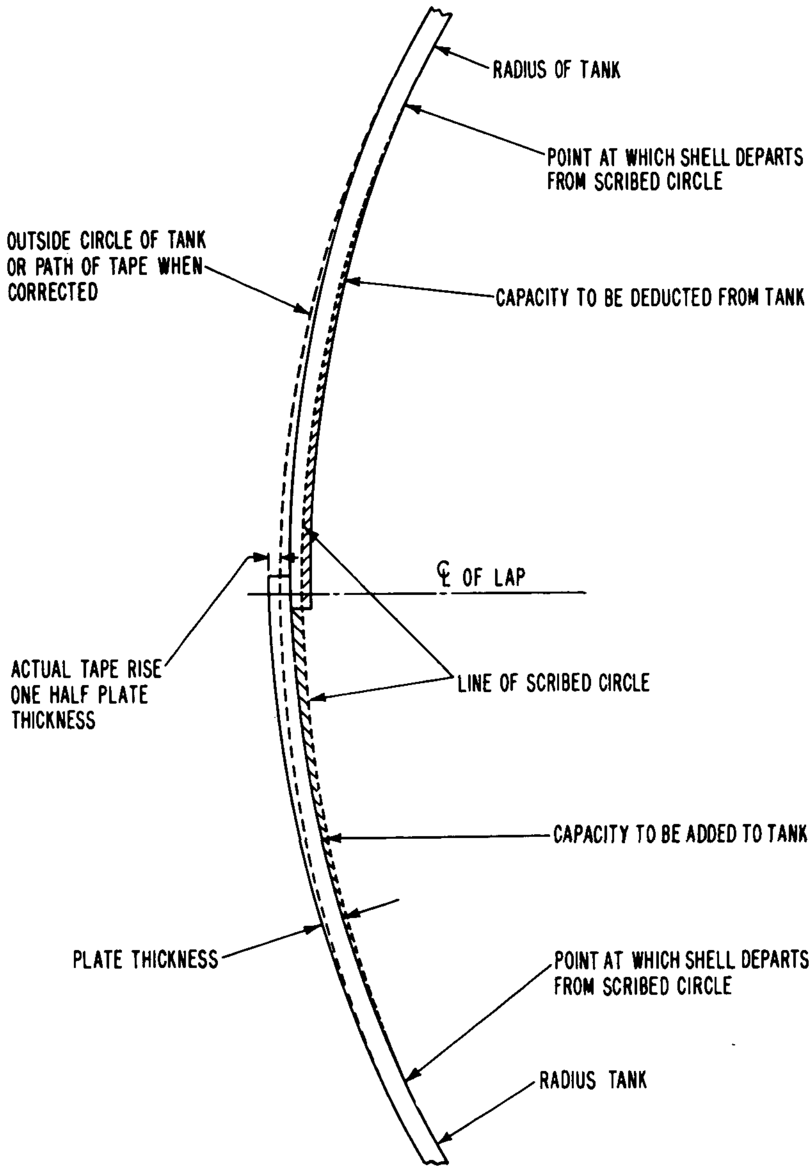

FIG. 6.—TRUE CIRCUMFERENCE *versus* TAPE PATH AT AXIAL LAP JOINT AWAY FROM CIRCUMFERENTIAL JOINT.

Interpolations

26. Interpolations for tank volume determinations preferably should be made on circumference (or diameter) rather than on capacity.

Extrapolations

27. Extrapolations should be avoided, if possible. If required, they should be accomplished either by the graphic or the algebraic procedure.

Weighted Averages

28. Weighted averages, where applicable, should be used in circumference interpolation rather than simple averages.

Tolerances

29. Tolerances for measurements and calculations included in this standard are intended to apply to the development of both operating control and critical measurement gage tables.

Adjustments for Variables

30. Adjustments for the effect of any variables may be incorporated in gage tables for the operating control tanks. It is recommended that gage tables be marke to show adjustments which have bee incorporated therein.

Deadwood Deductions

31. All deadwood should be accurately accounted for as to volume and location, in order to provide adequate allowance for the volume of liquid displaced by the various parts and to provide allocation of the effects of various elevations within the tank.

Incremental Height Capacity Basis

32. Capacities for incremental heights of horizontal cylindrical tanks should be computed as a percentage of the total tank capacity. The total tank capacity should be based on calculations considering each ring as a horizontal cylinder.

DEDUCTIONS FOR CIRCUMFERENCE TAPE RISES

Deductions for Projections

33. In the event projections from the tank shell, such as butt straps or lap joints, prevent the tape from being in contact with the tank shell at all poin' along its path, the amount of increase circumference due to the tape rise at such

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projections should be determined. Circumference as measured on a given ring should be corrected by deducting the sum of the increases in circumference at each tape-rise location on the ring.

Computed Tape-Rise Deductions

34. (*a*) Correction for tape rise may be computed from the "tape-rise correction formulas," or it may be measured with step-over calipers where practicable to do so. Because of the very small correction for tape rise at a low projection, such as a lap joint or butt strap, it is impracticable to measure accurately the correction with a step-over; therefore, the tape-rise correction formula method is preferred for such projections.

(*b*) *Tape-Rise Correction Formulas:*

(*1*) *For Butt Straps.*—The tape-rise correction formula for butt straps or similar projections is as follows:

Correction (in feet)

$$= \frac{2Ntw}{12d} + \frac{8Nt}{(3)(12)}\sqrt{\frac{t}{d}} \quad (2)$$

where:

N = number of butt straps or projections per ring.
t = amount of rise (thickness of straps or projections), in inches.
w = width of straps or projections, in inches.
d = nominal diameter of tank, in inches.

(*2*) *For Lap Joints.*—Application of Equation (2), in modified form, to tape rise at lap joints is explained in Fig. 6.

a. In Fig. 6 the locations of the plates in the lap joint are shown as positioned by the plates in the rings directly above and below the lap joint. The position of the plate in the ring, if no joint existed, is shown by the broken lines, in relation to the plates in the lap joint.

b. The circumference, as measured over the lap joint, is corrected to the true circumferential path the tape would take if no joint existed. As shown in Fig. 6, this requires correction for only one-half of the tape rise; and, with the width, w, eliminated, Equation (2) becomes:

Correction (in feet)

$$= \frac{8N}{(12)(3)}\left(\frac{t}{2}\right)\sqrt{\frac{t}{2d}} = \frac{Nt}{9}\sqrt{\frac{t}{2d}} \quad (3)$$

EXPANSION AND CONTRACTION OF STEEL SHELLS

Expansion and Contraction Due to Liquid Pressure and/or Working Pressure

35. (*a*) For operating control accuracy, expansion of the shell caused by liquid pressure and working pressure is usually disregarded. Shell expansion, though small, is consistent as to direction and need be taken into consideration only if greater accuracy in gage tables is desired.

(*b*) The effect of expansion should be introduced into critical measurement gage tables in either of two ways:

(*1*) By measuring the tank circumferentially, as in Section 13, Paragraph (c), Item (*1*), with tank at zero pressure and then at its full working pressure. After the two measurements are obtained, the average of the two should be used for the volume calculations.

(*2*) If the working pressure, tank radius, and shell thickness of the tank are known, the increase in shell circumference, because of internal pressure, may be read from Fig. 7. If the increase in circumference is less than 0.01 ft, it should be ignored. If it is 0.01 ft or more, it should be averaged with the zero pressure circumference and this average used in the volume calculations as in Item (*1*).

Expansion of Flat Heads Due to Liquid Pressure

36. To determine the increase in volume, the head should be considered as a dished head with the radius of the dish calculated from the measured bulge.

Effects of Internal Temperature on Tank Volume

37. The effects of internal temperatures on tanks in nonartificially heated or cooled service may be disregarded. When very accurate measurements are required for the contents of steel tanks, it will be necessary to obtain the shell temperature at the time a gage is taken and compute a volume correction for the expansion or contraction of the tank shell. This volume correction may be found in *API Standard 2541—ASTM D 1750: ASTM Tables for Positive Displacement Meter Prover Tanks.*

The temperature of the shell (t_S) in degrees Fahrenheit may be determined as follows: t_S = temperature of the steel, in degrees Fahrenheit.

If t_L and t_A differ less than 75 F:

$$t_S = \frac{t_L + t_A}{2} \quad (4)$$

where:

t_L = temperature of the liquid, in degrees Fahrenheit.
t_A = temperature of the ambient air, in degrees Fahrenheit.

If t_L and t_A differ by more than 75 F, measure t_S at four or more points equally spaced around the tank and then use the average t_S.

For tanks with insulated shells, use $t_S = t_L$.

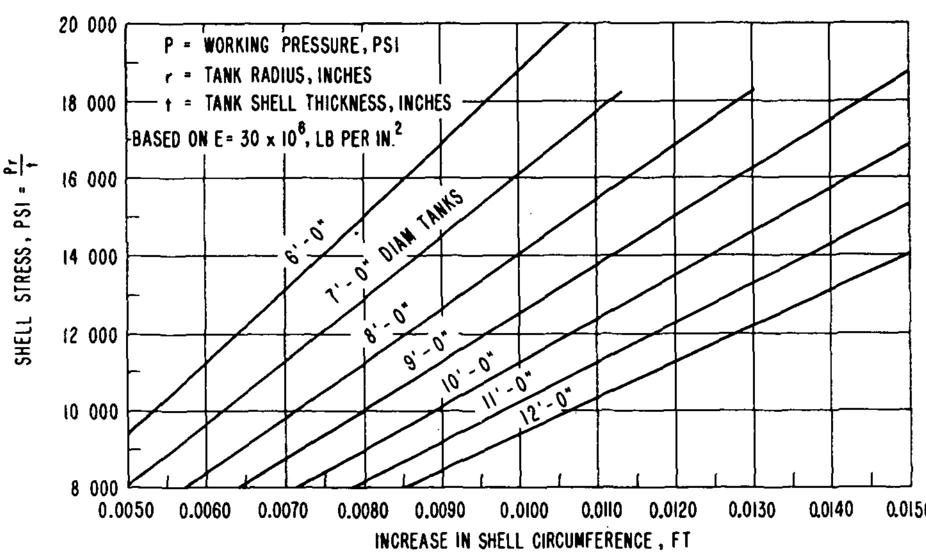

FIG. 7.—INCREASE IN SHELL CIRCUMFERENCE DUE TO PRESSURE.

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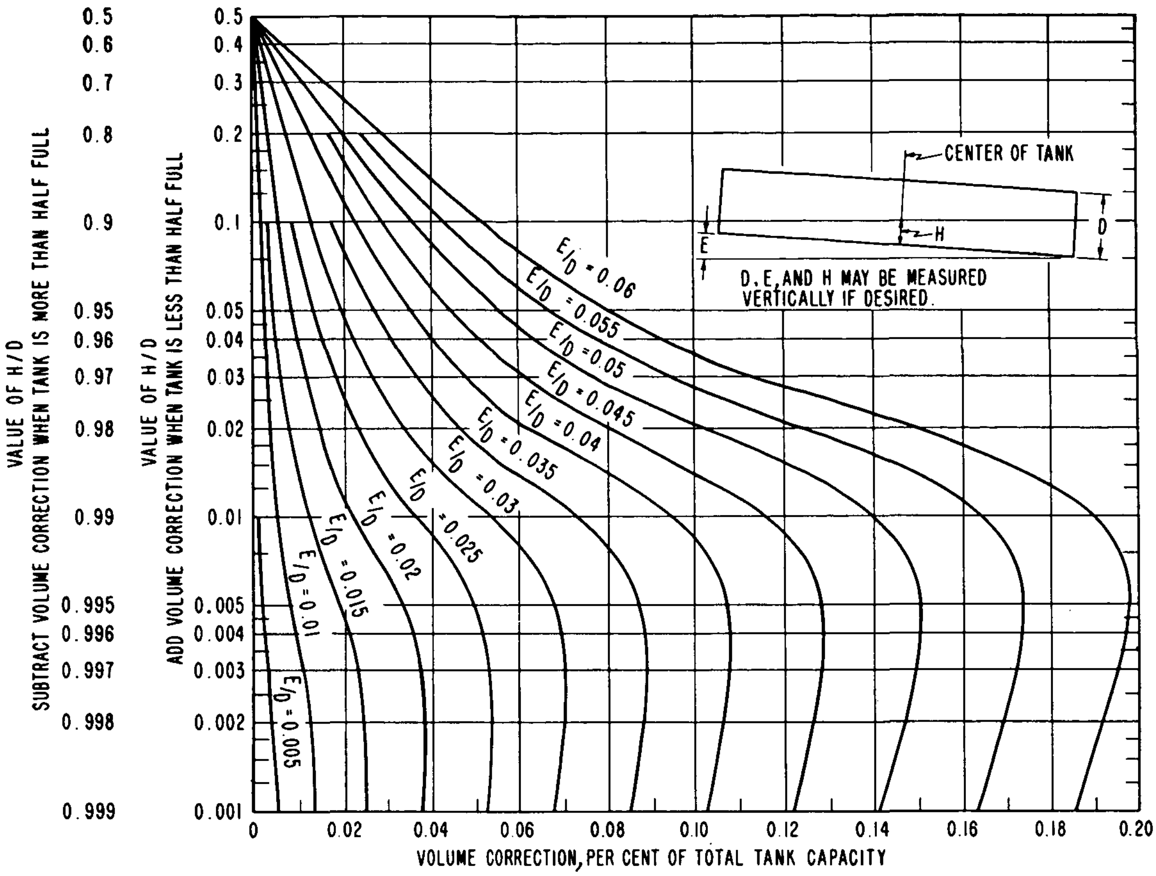

NOTE: Based on "Calibration of Cylindrical Tanks with Axis Inclined," by W. L. Coats, *Journal of The Institute of Petroleum*, Vol. 34, No. 297, September, 1948.

FIG. 8.—VOLUME CORRECTION FOR CYLINDRICAL TANKS WITH AXIS INCLINED.

The foregoing correction may be handled as a footnote to the capacity table. For additional information on temperature correction procedures, see Appendix IV. Where temperatures remain fairly constant, the correction may be applied to the table.

NOTE 6.—If the tank is fabricated of materials other than steel, appropriate correction coefficients should be applied to the respective formulas.

EFFECTS OF TANK OFF-LEVEL

For Operating Control Gage Tables

38. (*a*) Disregard the effect of slope if the value of *E/D*, as in Fig. 8, is less than 0.012.

(*b*) When the gaging of the tank is done in the center (longitudinally), an alternative method based on measurements and computations may be used. Compute the total volume of the cylindrical section of the tank. Incremental volumes for the inclined position are determined by taking percentages of the total volume. Fig. 8 gives satisfactory correction factors for the volume at any point for inclined tanks. This procedure applies only to the cylindrical sections of off-level tanks.

For Critical Measurements

39. (*a*) Disregard the effect of slope if the value of *E/D*, as in Fig. 8, is less than 0.012.

(*b*) For tanks with slopes exceeding the limit in the previous paragraph, liquid calibration in accordance with the procedures outlined in API Standard 2555—ASTM D 1406 should be used.

(*c*) When the gaging of the tank is done in the center (longitudinally), an alternative procedure based on measurements and computations may be used. Compute the total volume of the cylindrical section of the tank. Incremental volumes for the inclined position are determined by taking percentages of the total volume. Fig. 8 gives satisfactory correction factors for the volume at any point for inclined tanks. This procedure applies only to the cylindrical sections of off-level tanks.

(*d*) The incremental head volumes of off-level tanks may be computed, using the actual liquid depth in each head. The effect of slope upon the volume of the head is negligible.

(*e*) When the gaging of a tank is done at some point other than the center (longitudinally), an alternative procedure based on measurements and computations may be used.[5]

[5] See W. L. Coats, "Calibration of Cylindrical Tanks with Axis Inclined," *Journal of Th Institute of Petroleum*, Vol. 34, No. 297, Septem ber, 1948.

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CALCULATIONS

40. The following examples are used to illustrate procedures for determining various features of butt-welded and lap-welded horizontal cylindrical tanks. These examples demonstrate how incremental volumes for the cylindrical portion of the tank are determined from calculation and Appendix I. They also demonstrate how the incremental volumes for the heads are determined from calculations and Appendix II which applies to elliptical or spherical heads, or Appendix III which applies to bumped heads.

41. **Examples**

EXAMPLE NO. 1

Strapping Form for Butt-Welded Horizontal Tank

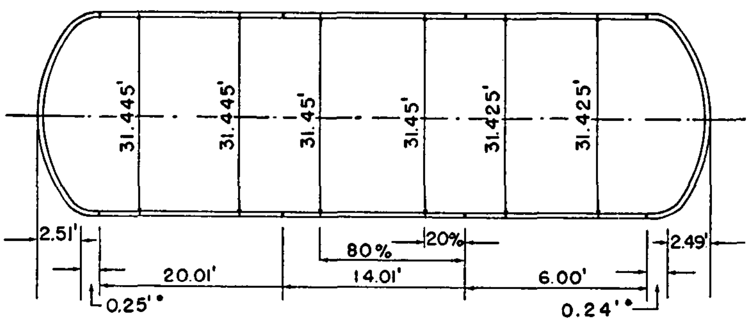
TANK NO.________

OWNER____

PLANT____

LOCATION OF PLANT ________________ STRAPPED BY ________________ DATE ______

			2:1 ratio, semielliptical
(NAME OF BUILDER)	(CONTRACTOR'S NO.)	(SERIAL NO.)	(TYPE OF HEAD)



TANK LEVEL:____

PLATE THICKNESS: ________________ COMMODITY STORED: Casinghead gasoline

CYLINDER: 5/16 in. (per manufacturer's drawings) LIQUID GAGE AT STRAPPING: 9 ft 5 in.

HEADS: 3/8 in. (per manufacturer's drawings)

CYLINDRICAL SECTION OF HEAD: 3 in. (per manufacturer's drawings)

LOCATE AND ORIENT GAGING POINT: Gage glass and board on east end of tank. East is right-hand side of sketch. The 0 ft 0 in. on gage board equals inside bottom of tank.

TEMPERATURE: Atmospheric PRESSURE: Atmospheric

NOTE 7.—Length measurements are recorded as values taken with a tape of length based on 68 F calibration. Each value thus recorded shall be mathematically corrected to the equivalent 60 F value for use in computing gage tables.

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Sample Calculations

1. Calculate Volume of Main Cylinder

a. Find weighted average measured outside circumferences:

$$\frac{(6.00)(31.445)+(8.01)(31.45)+(6.00)(31.425)}{6.00+8.01+6.00}=31.4410 \text{ ft}$$

b. Find average inside diameter of main cylinder, in inches:

$$\frac{[\text{Circumference from } (a)](12)}{\pi}-(2)(\text{shell thickness})$$

Or,

$$\frac{(31.4410)(12)}{\pi}-(2)(0.3125)=119.4708 \text{ in.}$$

c. Find average inside diameter of straight-flange sections of heads, in feet:

$$(31.445+31.425)\frac{0.5}{\pi}-\frac{2(0.375)}{12}=9.9436 \text{ ft}$$

d. Length of cylinder equals overall length, minus two heads, including straight-flange sections:

$$(20.01+0.25+0.24+2.49+2.51)-(2)\left(0.25+\frac{0.375}{12}\right)-(2)\left(\frac{9.9436}{4}\right)=19.9657 \text{ ft}$$

e. Volume of cylinder including straight-flange sections:

$$(31.4410-0.1636)^2(0.595280826)(19.9657)+\left(\frac{31.445+31.425}{2}-0.1963\right)^2(0.595280826)(2)(0.25)$$
$$=11{,}917.4562 \text{ gal}$$

2. Calculate Volume of Two Heads

a. Take average inside diameter from item 1(*c*) = 9.9436 ft.

b. Volume 1.95839542 (9.9436^3) = 1,925.4462 gal.

3. Total Volume of Tank

Item 1(*e*) + item 2(*b*) = 11,917.4562+1,925.4462 = 13,842.9024 gal

4. Choose Spread Diameter

Item 1(*b*) = 119.4708 in. or, say, 119½ in.

5. Compute Partial Volumes of Tank and Extract Increments

a. Find $\frac{1}{D}=\frac{1}{119.5}=0.008368200837$.

b. In the tabulation under item 6, "Cumulation of Volumes," set up heights in Column 1 at which partial volumes are desired.

c. Multiply Column 1 (in inches) by $\frac{1}{D}$ [see item 5(*a*)] to obtain Column 2.

d. Convert Column 2 to coefficients in Columns 3 and 5 by use of appropriate tables (see Appendixes I and II).

e. Multiply Column 3 by item 1(*e*) (11,917.4562) to get Column 4.

f. Multiply Column 5 by item 2(*b*) (1,925.4462) to get Column 6.

g. Add Columns 4 and 6 to get Column 7 (partial volumes).

h. Subtract partial volumes to obtain interval volume (Column 8).

i. Divide interval volume (Column 8) by 8 if ⅛-in. increments are desired or by 4 for ¼-in. increments.

j. If greater accuracy is desired, each tank table increment, such as ¼ in. or ⅛ in., may be determined individually following the foregoing procedural steps [except item 5(*i*)] for the entire tank or for the critical lower or upper ranges of the tank where the foregoing procedure [item 5(*i*)] introduces a greater percentage of error.

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6. Cumulation of Volumes

1	2	3	4	5	6	7	8	9
Height (Inches)	$\frac{M}{D}$	*K* of Cylinder	K_3 Times Volume of Cylinder	*K* of Head	K_5 Times Volume of Heads	Partial Volumes (Columns 4 + 6)	Interval Volumes	Gallons per $\frac{1}{8}$ in.
0	0.00000	0.000000	0.0000	0.000000	0.0000	0.0000		
1	0.00837	0.001298	15.4689	0.000210	0.4043	15.8732	15.8732	1.9842
2	0.01674	0.003659	43.6060	0.000832	1.6020	45.2080	29.3348	3.6668
3	0.02510	0.006700	79.8470	0.001859	3.5794	83.4264	38.2184	4.7773
4	0.03347	0.010291	122.6425	0.003286	6.3270	128.9695	45.5431	5.6929
5	0.04184	0.014346	170.9678	0.005106	9.8313	180.7991	51.8296	6.4787

EXAMPLE NO. 2

Strapping Form for Butt-Welded Horizontal Tank

TANK NO.________

OWNER ____

PLANT ____

LOCATION OF PLANT ____________________ STRAPPED BY ________________ DATE ______

(NAME OF BUILDER)	(CONTRACTOR'S NO.)	(SERIAL NO.)	(TYPE OF HEAD)

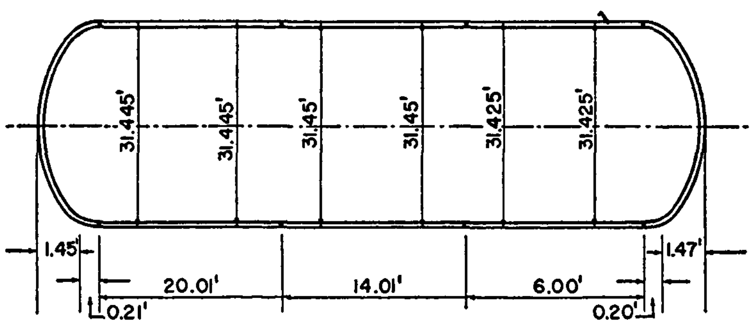

PLATE THICKNESS: ____________________ COMMODITY STORED: Casinghead gasoline

CYLINDER: $\frac{5}{16}$ in. (per manufacturer's drawings) LIQUID GAGE AT STRAPPING: 9 ft 5 in.

HEADS: $\frac{3}{8}$ in. (per manufacturer's drawings)

LOCATE AND ORIENT GAGING POINT: See strapping form for heads

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Strapping Form for Horizontal Tank Heads

(Spherical Segment, with Knuckle Radius, Ellipsoidal, and Hemispherical Heads)

TANK NO.________

OWNER ____

PLANT ____

LOCATION OF PLANT ____________________ STRAPPED BY ________________ DATE ______

________________	________________	________________	3-ring butt weld
(NAME OF BUILDER)	(CONTRACTOR'S NO.)	(SERIAL NO.)	(TYPE OF CYLINDER)

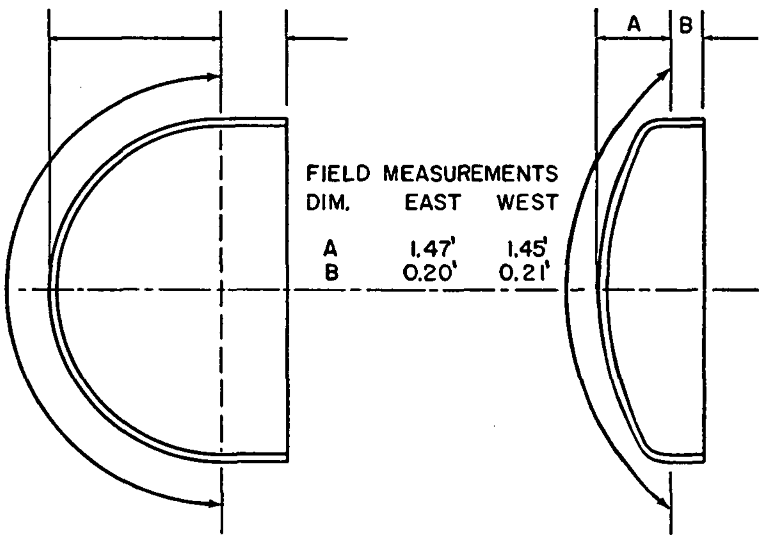

PLATE THICKNESS OF HEADS: ⅜ in.

SHOW DIMENSIONS FOR BOTH AND ORIENT: Radius of spherical segment, 10 ft 0 in.; knuckle radius, 1½ in.; straight flange, 2½ in. as per manufacturer's drawings. Tank is level with gage board and glass on east end of tank. The 0 ft 0 in. point on board is set even with inside bottom of tank.

NOTE 8.—Length measurements are recorded as values taken with a tape of length based on 68 F calibration. Each value thus recorded shall be mathematically corrected to the equivalent 60 F value for use in computing gage tables.

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Sample Calculations

1. Calculate Volume of Main Cylinder

a. through *c.*—Use same procedure as given in Example No. 1, items 1(*a*) through 1(*c*).

d. Length of vessel from field measurements = cylinder plus straight flanges plus heads:

$$(20.01+0.21+0.20+1.45+1.47) = 23.34 \text{ ft}$$

Adjusted to the builder's head specifications (2 steel plus 2 AG plus 2 straight flanges) to obtain length of cylinder:

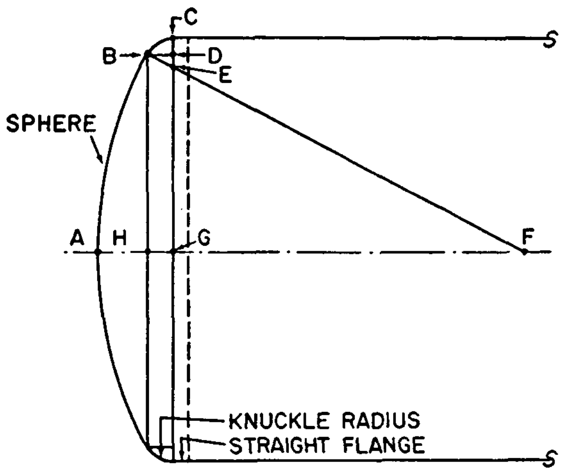
$$23.34-(0.0625+2.7926+0.4166) = 20.0683 \text{ ft}$$

$$AG = AH + HG = 1.3963 \text{ ft}$$

e. Volume of cylinder including straight-flange section:

$$(31.4410-0.1636)^2(0.595280826)(20.0683)+\left(\frac{(31.445+31.425)}{2}-0.1963\right)^2(0.595280826)(2)(0.2083)$$
$$= 11{,}928.7569 \text{ gal}$$

2. Calculate Volume of Heads



Dish radius $(BF) = 10$ ft

Knuckle radius $(EB) = 0.125$ ft

$EF = 10-0.125 = 9.875$ ft

$GC = \dfrac{9.9436}{2} = 4.9718$ ft

$GE = 4.9718-0.125 = 4.8468$ ft

$GF = \sqrt{9.875^2-4.8468^2} = 8.6037$ ft

$HG = \dfrac{(0.125)(8.6037)}{9.875} = 0.1089$ ft

$HF = 8.6037+0.1089 = 8.7126$ ft

$HB = \sqrt{10^2-8.7126^2} = 4.9082$ ft

$AH = 10-8.7126 = 1.2874$ ft

$$\text{Sin}^{-1}\frac{HG}{BE} = \sin^{-1}\frac{0.1089}{0.125} = \sin^{-1}(0.8712) = 60.5989 \text{ deg} = 1.057650 \text{ radians}$$

a. Compute volume[6] of knuckle section (2 times $BCGH$):

$$\text{Volume} = 7.48051948\,\pi\left[EG^2(HG)+BE^2(HG)-\frac{HG^3}{3}+EG(HG)\sqrt{BE^2-HG^2}+EG(BE)^2\left(\sin^{-1}\frac{HG}{BE}\right)\right]$$

$$= 7.48051948\,\pi\left[(4.8468)^2(0.1089)+(0.1250)^2(0.1089)-\frac{0.1089^3}{3}+(4.8468)(0.1089)\sqrt{0.125^2-0.1089^2}+(4.8468)(0.125)^2\left(\sin^{-1}\frac{0.1089}{0.125}\right)\right] = 62.8137 \text{ gal}$$

b. Compute volume of spherical segment:

$$\text{Volume} = \frac{\pi(AH)}{6}(3BH^2+AH^2)$$

$$= \frac{7.48051948\,\pi(1.2874)}{6}[(3)(4.9082)^2+1.2874^2] = 372.8335 \text{ gal}$$

c. Volume of heads:

$$2(62.8137+372.8335) = 871.2944 \text{ gal}$$

3. Total Volume of Tank:

$$1(e)+2(c) = 11{,}928.7569+871.2944 = 12{,}800.0513 \text{ gal}$$

4. Choose Spread Diameter

Use same procedure as given in Example No. 1, item 4.

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5. Compute Partial Volumes and Extract Increments

a. through *i.*—Use same procedure as given in Example No. 1, items 5(*a*) through 5(*i*).

6. Cumulation of Volumes

1	2	3	4	5	6	7	8	9
Height (Inches)	$\frac{M}{D}$	K of Cylinder	K_3 Times Volume of Cylinder	K of Head	K_5 Times Volume of Heads	Partial Volumes (Columns 4 + 6)	Interval Volumes	Gallons per ⅛ in.
0	0.00000	0.000000	0.0000	0.000000	0.0000	0.0000		
1	0.00837	0.001298	15.4835	0.000210	0.1830	15.6665	15.6665	1.9583
2	0.01674	0.003659	43.6473	0.000832	0.7249	44.3722	28.7057	3.5882
3	0.02510	0.006700	79.9227	0.001859	1.6197	81.5424	37.1702	4.6463
4	0.03347	0.010291	122.7588	0.003286	2.8631	125.6219	44.0795	5.5099
5	0.04184	0.014346	171.1299	0.005106	4.4488	175.5787	49.9568	6.2446

If greater accuracy is desired, the volumes in Column 8 may be determined for each individual tank table increment for the entire tank or for critical areas of the tank, as shown in Example No. 1, item 5(*i*).

EXAMPLE NO. 3

Strapping for Horizontal Tank Heads

Horizontal Cylindrical Steel Tank Shell with Lapped In-and-Out Construction

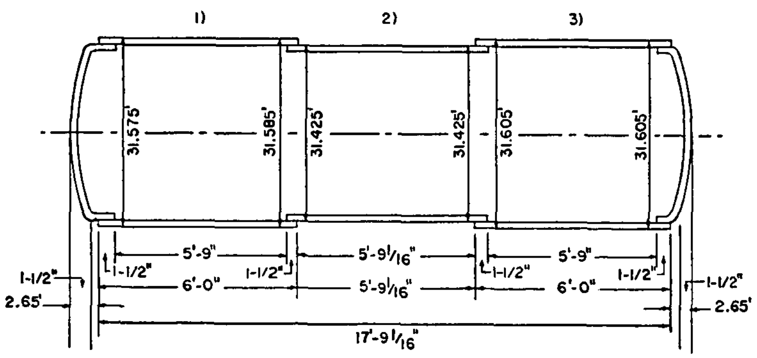
TANK NO. ________

OWNER ______________________________

PLANT ______________________________

LOCATION OF PLANT ______________ STRAPPED BY ______________ DATE ______

______ (NAME OF BUILDER) ______ (CONTRACTOR'S NO.) ______ (SERIAL NO.) 2:1 ratio, semielliptical (TYPE OF HEAD)



TANK LEVEL: ______________________________

PLATE THICKNESS: ______________ COMMODITY STORED: Casinghead gasoline

CYLINDER: 5/16 in. (per manufacturer's drawings) LIQUID GAGE AT STRAPPING: 9 ft 5 in.

HEADS: ⅜ in. (per manufacturer's drawings)

LOCATE AND ORIENT GAGING POINT: Gage glass and board on east end of tank. East is right-hand side of sketch. The 0 ft 0 in. on gage board equals inside bottom of tank.

TEMPERATURE: Atmospheric PRESSURE: Atmospheric

NOTE 9.—Length measurements are recorded as values taken with a tape of length based on 68 F calibration. Each value thus recorded shall be mathematically corrected to the equivalent 60 F value for use in computing gage tables.

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Sample Calculations

1. Calculate Volume of Main Cylinder

a. Use weighted average of measured circumferences.

b. Find inside diameter of cylinder, in inches $= D$.

c. Use length of cylinder, in inches, equal to sum of inside lengths of rings $= L$.

d. Volume, in gallons $= 0.595280826\, D^2L$.

MAIN CYLINDER

Inside Length of Rings, in Feet

Ring No. 1 = 6.0000 − 0.2500 = 5.7500
Ring No. 2 = 5.7552 + 0.2500 = 6.0052
Ring No. 3 = 6.0000 − 0.2500 = 5.7500

Total length 17.5052

Weighted Average Measured Circumference, in Feet

Ring No. 1 = (31.580) (5.7500) = 181.58500
Ring No. 2 = (31.425) (6.0052) = 188.71341
Ring No. 3 = (31.605) (5.7500) = 181.72875

Total 552.02716

Average outside circumference $= \frac{552.02716}{17.5052} = 31.535038$ ft

Average inside circumference $= 31.53504 = \left(\frac{\pi\, 0.3125}{6}\right) = 31.53504 - 0.16362 = 31.37142$ ft

Average inside diameter $= \frac{(31.37142)\,(12)}{\pi} = 119.83000$ in.

Length of cylinder = 17.5052 ft
Volume of cylinder $= (31.37142)^2 (0.595280826)\,(17.5052) = 10{,}255.5115$ gal

2. Calculate Volume of Head Cylinders

a. Average inside circumference $= (31.605 + 31.575)\ 0.5 - \left(\frac{\pi\,(0.375 + 0.3125)}{6}\right) = 31.59000 - 0.35998 = 31.23002$ ft.

b. Average inside diameter $= \frac{31.23002}{\pi} = 9.94080$ ft.

c. Length, twice the straight flange = (2 in.) (3 in.) = 6 in. = 0.50 ft.

d. Volume of head cylinders $= (31.23002)^2\ (0.595280826)\,(0.50) = 290.2929$ gal.

3. Add Volumes of Main and Head Cylinders

10,255.5115 + 290.2929 = 10,545.8044 gal

4. Calculate Volume of Two Heads

a. Average inside diameter from item 2(*b*) = 9.94080 ft.

b. Volume $= (2)\left(\frac{1.958839542}{2}\right)(9.94080)^3 = 1{,}923.8198$ gal.

5. Total Volume of Tank

Item 3 + item 4(*b*) = 10,545.8044 + 1,923.8198 = 12,469.6242 gal

6. Choose Spread Diameter

Item 1(*b*) = 119.83000 in. or, say, 119⅞ in.

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7. Compute Partial Volumes of Tank and Extract Increments

a. Find $\frac{1}{D} = \frac{1}{119.875} = 0.008342022941.$

b. In the tabulation under item 8, "Cumulation of Volumes," set up heights in Column 1 at which partial volumes are desired.

c. Multiply Column 1 (in inches) by $\frac{1}{D}$ [see item 7(*a*)] to obtain Column 2.

d. Convert Column 2 to coefficients in Columns 3 and 5 by use of appropriate tables (see Appendixes I and II).

e. Multiply Column 3 by item 3 (10,545.8044) to get Column 4.

f. Multiply Column 5 by item 4(*b*) (1,923.8198) to get Column 6.

g. Add Columns 4 and 6 to get Column 7 (partial volumes).

h. Subtract partial volumes to obtain interval volume (Column 8).

i. Divide interval volume (Column 8) by 8 if ⅛-in. increments are desired or by 4 for ¼-in. increments.

j. If greater accuracy is desired, each tank table increment, such as ¼ in. or ⅛ in., may be determined individually following the foregoing procedural steps [except item 7(*i*)] for the entire tank or for the critical lower or upper ranges of the tank where the foregoing procedure [item 7(*i*)] introduces a greater percentage of error.

8. Cumulation of Volumes

1 Height (Inches)	2 $\frac{M}{D}$	3 K of Cylinder	4 K_3 Times Volume of Cylinder	5 K of Head	6 K_5 Times Volume of Heads	7 Partial Volumes (Columns 4 + 6)	8 Interval Volumes	9 Gallons per ⅛ in.
0	0.00000	0.000000	0.0000	0.000000	0.0000	0.0000		
1	0.00834	0.001291	13.6146	0.000208	0.4002	14.0148	14.0148	1.7519
2	0.01668	0.003639	38.3762	0.000826	1.5891	39.9653	25.9505	3.2438
3	0.02503	0.006672	70.3616	0.001848	3.5552	73.9168	33.9515	4.2439
4	0.03337	0.010245	108.0418	0.003267	6.2851	114.3269	40.4101	5.0513
5	0.04171	0.014280	150.5941	0.005075	9.7634	160.3575	46.0306	5.7538

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EXAMPLE NO. 4

Strapping Form for Butt-Welded Horizontal Tank

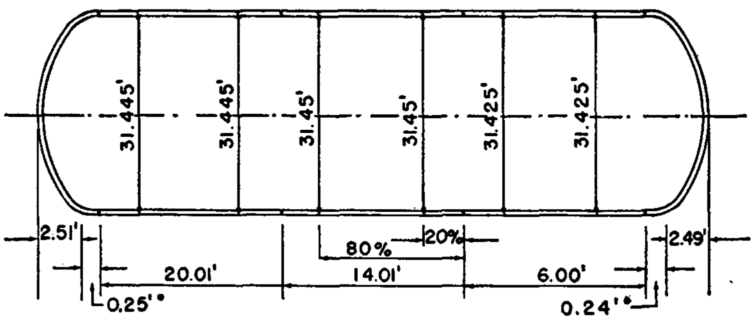
TANK NO.________

OWNER____________________

PLANT____________________

LOCATION OF PLANT __________ STRAPPED BY __________ DATE ______

(NAME OF BUILDER)	(CONTRACTOR'S NO.)	(SERIAL NO.)	2:1 ratio, semielliptical (TYPE OF HEAD)



East end of tank is 4 in. lower than west end.

PLATE THICKNESS: __________ COMMODITY STORED: Casinghead gasoline

CYLINDER: $\frac{5}{16}$ in. (per manufacturer's drawings) LIQUID GAGE AT STRAPPING: 9 ft 5 in.

HEADS: $\frac{3}{8}$ in. (per manufacturer's drawings)

CYLINDRICAL SECTION OF HEAD: 3 in. (per manufacturer's drawings)

LOCATE AND ORIENT GAGING POINT: Gage glass and board on east end of tank. East is right-hand side of sketch. The 0 ft 0 in. on gage board equals inside bottom of tank.

TEMPERATURE: Atmospheric PRESSURE: Atmospheric

NOTE 10.—Length measurements are recorded as values taken with a tape of length based on 68 F calibration. Each value thus recorded shall be mathematically corrected to the equivalent 60 F value for use in computing gage tables.

Sample Calculations

1. Calculate Volume of Main Cylinder

a. through *e.*—Use same procedure as given in Example No. 1, items 1(*a*) through 1(*e*).

2. Calculate Volume of Heads

a. and *b.*—Use same procedure as given in Example No. 1, items 2(*a*) and (*b*).

3. Total Volume of Tank

Same as shown in Example No. 1, item 3.

4. Choose Spread Diameter

Same as shown in Example No. 1, item 4.

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5. Compute Partial Volumes of Tank and Extract Increments [7]

a. $\frac{C}{S}(P_1 - P_2)$ = gallons at any specified level.

where:

C = total capacity of cylinder, in gallons.

$S = \frac{L}{D}\tan\theta$.

P_1 and P_2 = coefficients of capacity.

$$CF^2 = EF^2 - EC^2$$

EF = 19.9657 ft [see Example No. 1, item 1(*d*)]

$CF = \sqrt{[(19.9657)(12)]^2 - 4^2} = 239.5550071$ in.

$$\text{Cos } \theta = \frac{239.5550071}{(12)(19.9657)} = 0.9998606239$$

D = 119.4708 in. [see Example No. 1, item 1(*b*)]

$$\frac{1}{D \cos\theta} = 0.008371412895$$

$S = (4)(0.008371412895) = 0.0334856516$

C = 11,917.4562 gal [see Example No. 1, item 1(*e*)]

$$\frac{C}{S} = 355{,}897$$

b. See Table IV, Coats[7]:

Column 1 = depth of liquid at gage point.
Column 2 of Coats' Table IV is omitted since gaging is at low end of tank.
Other columns, same as in Table IV, Coats.[7]

6. Cumulation of Volumes

1	2	3	4	5	6	7	8	9	10	11
Height (Inches)	$m_1 = \frac{\text{Column 1}}{D \text{ Cos } \theta}$	$m_2 = m_1 - S$	$\frac{P_1}{P_2}$	$P_1 - P_2$	Volume of Cylinder $\frac{C}{S}(P_1 - P_2)$	Volume of West (High) Head	Volume of East (Low) Head	Total (Columns 6 + 7 + 8)	Difference	Gallons per ⅛ in.
0	0.0000000	0.0000000	0.000000000	0.000000000	0.0000	0.0000	0.0000	0.0000		
1	0.0083714	0.0000000	0.000004374 0.000000000	0.000004374	1.5567	0.0000	0.2022	1.7589	1.7589	0.2199
2	0.0167428	0.0000000	0.000024573 0.000000000	0.000024573	8.7455	0.0000	0.8010	9.5465	7.7876	0.9735
3	0.0251142	0.0000000	0.000067528 0.000000000	0.000067528	24.0330	0.0000	1.7897	25.8227	16.2762	2.0345
4	0.0334857	0.0000000	0.000138387 0.000000000	0.000138387	49.2515	0.0000	3.1635	52.4150	26.5923	3.3240
5	0.0418571	0.0083714	0.000241242 0.000004374	0.000236868	84.3006	0.2022	4.9159	89.4185	37.0035	4.6254

For tilted tanks the incremental volumes for the head capacities must be computed separately as shown in Columns 7 and 8.

[7] "Calibration of Cylindrical Tanks with Axis Inclined," by W. L. Coats, *Journal of The Institute of Petroleum*, Vol. 34, No. 297, September, 1948.

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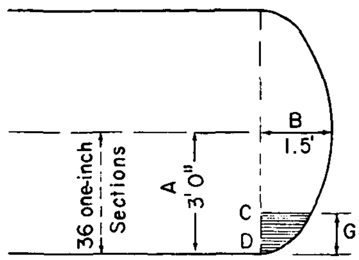
42. Distribution of Elliptical Heads[8]



A = one-half the major axis.
B = one-half the minor axis.
G = distance between limits C and D.
F = volume factor (as 7.4805, the number of gallons per cubic foot).

For example, in the sketch:
A = 3 ft
B = 1.5 ft
G = 1 in. = 0.083333 ft
F = 7.4805 gal per cu ft

To find the individual and cumulative volumes of the 36 one-inch sections first it is necessary to find K_4 and K_5 :

$$K_4 = \pi \frac{BGFA}{2} = 4.4064; \quad K_5 = \pi \frac{BG^3F}{A} = 0.0068; \quad V_{36} = K_4 - \left(\frac{36^2 - 36}{2}\right)$$

K_6 = 0.122 gal (multiply by 2 for both bulges = 0.244 gal)

In the application of the foregoing formulas to the calculating machine, the value V_{36} is placed in the lower dial and K_5 (multiply by 2 for both bulges) is placed on the keyboard. Then multiply by one section less each time: 35, 34, 33, etc. Do not clear lower dial or keyboard. Following are calculations for 6 of the 36 one-inch sections:

Section No.	Volume of Section, gal	Cumulative Volumes, gal
36	0.244	0.24
35	0.720	0.96
34	1.18	2.14
33	1.63	3.77
32	2.07	5.84
31	2.49	8.33
Etc., down to one		

To check: $\pi\ (BF/6)(4A^2)$ = volume of one bulge.

(*a*) *Volume Increment Factors:*

Values for K in the foregoing formulas:

$$\text{Volume} = C^2(K)$$

where:

C = measurement in feet.

Increment	U.S. Gallons	Increment	Barrels
⅛ in.	= 0.006200841938	⅛ in.	= 0.000147639094
¼ in.	= 0.01240168	¼ in.	= 0.0002952782
1 in.	= 0.0496067355	1 in.	= 0.001181112749
1 ft	= 0.595280826	1 ft	= 0.01417335299

[8] Source: T. F. Phillians, "Volume Determination of Tanks," *The Petroleum Engineer*, Vol. XIX, No. 6, March, 1948.

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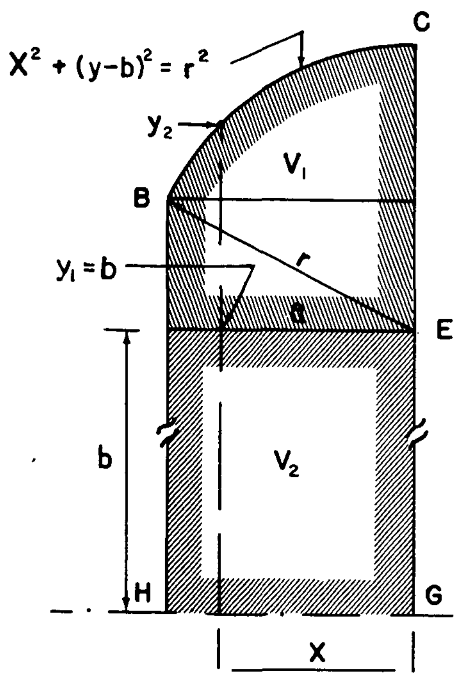
(*b*) *Volume of Hemispherical Heads:*

1.958395421 (D^3), in ft = gallons in one head
0.0466284628 (D^3), in ft = barrels in one head
0.001133330683 (D^3), in in. = gallons in one head
0.00002698406389 (D^3), in in. = barrels in one head

(*c*) *Volume of 2:1 Ratio, Semielliptical Heads:*

Divide any of the constants in Paragraphs *a* and *b* by 2.

43. **Derivation of Formula for Volume of Knuckle Section**



$$\text{Arc } CB = X^2 + (y - b)^2 = r^2$$

$$y_2 = b + \sqrt{r^2 - X^2}$$

$$y_1 = b$$

$$V_1 = \pi \int_{X=0}^{X=a} (y_2^2 - y_1^2)\, dX$$

$$V_1 = \pi \int [(b + \sqrt{(r^2 - X^2)})^2 - b^2] dX$$

$$V_1 = \pi \int_{X=0}^{X=a} (b^2 + 2b\sqrt{r^2 - X^2} + r^2 - X^2 - b^2) dX$$

$$V_1 = \pi \left[r^2X - \frac{X^3}{3} + 2b\left(\frac{X}{2}\sqrt{r^2 - X^2} + \frac{r^2}{2}\sin^{-1}\frac{X}{r}\right)\right]_0^a$$

$$V_1 = \pi \left[r^2a - \frac{a^3}{3} + ba\sqrt{r^2 - a^2} + r^2b\sin^{-1}\frac{a}{r}\right]$$

$$V_2 = \pi b^2 a$$

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$$V_{TOTAL} = V_2 + V_1 = \pi \left[b^2 a + r^2 a - \frac{a^3}{3} + ba \sqrt{r^2 - a^2} + br^2 \sin^{-1} \frac{a}{r} \right]$$

where:

$a = \overline{HG}$

$b = \overline{EG}$

$r = \overline{BE}$

$$V_T = \pi \left[(\overline{EG})^2 (\overline{HG}) + (\overline{BE})^2 (\overline{HG}) - \frac{\overline{HG}^3}{3} + (\overline{EG}) (\overline{HG}) \sqrt{\overline{BE}^2 - \overline{HG}^2} + (\overline{EG}) (\overline{BE})^2 \text{ arc sin } \frac{\overline{HG}}{\overline{BE}} \right]$$

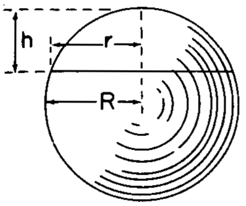
where:

$\frac{\overline{HG}}{\overline{BE}}$ is expressed in radians.

V_T = cubic units, or cubic feet as used in calculations herein.

$$\text{Gallons} = \frac{1{,}728}{231} = 7.48051948 \text{ times cubic feet.}$$

44. **Formula for Volume of Spherical Segment**



$$\frac{\pi}{2}\left(r^2 + \frac{h^2}{3}\right) h = \frac{\pi h}{2}\left(r^2 + \frac{h^2}{3}\right) = \frac{\pi h r^2}{2} + \frac{\pi h^3}{6} = \frac{3\pi h r^2}{6} + \frac{\pi h^3}{6} = \frac{\pi h}{6}(3r^2 + h^2)$$

(*a*) *Development of Factor 0.595280826.*—The development of factor 0.595280826, as used in Example No. 1, Item 1(*e*); Example No. 2, Item 1(*e*); and Example No. 3, Items 1(*d*) and 2(*d*), follows:

Let A = area.
R = radius.
C = circumference.
L = length of cylinder, in feet.
π = 3.141592.

From $A = \pi R^2$,

$$R, \text{ in terms of } C, A = \frac{C^2}{4\pi}$$

$$\text{Volume} = \frac{LC^2}{4\pi} \text{ cu ft}$$

$$\text{Volume, in gallons} = \frac{LC^2 \; 1{,}728}{(4)\,(3.141592)\,(231)} = LC^2\,(0.595280826)$$

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(*b*) *Development of Factor 1.95839542.*—The development of factor 1.95839542 (D^3) = gallons for two semielliptical heads, as used in Example No. 1, Item 2(*b*); and Example No. 3, Item 4(*b*), follows:

The volume of an ellipsoid made by an ellipse being revolved about its short diameter is:

Let D = long diameter.
d = short diameter.
π = 3.141592.

$$\text{Volume} = \pi D^2 \frac{d}{6}$$

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

Then,

$$\text{Volume} = \pi \frac{D^3}{12} \text{ or } \frac{\pi}{12} D^3 \text{ cu ft}$$

$$\text{Volume, in gallons} = \frac{\pi 1{,}728}{(12)\ (231)} D^3 = 1.958395\ D^3$$

(in two semielliptical heads)

(*c*) *Development of Factor 7.48051948:*

$$\text{Cubic feet to gallons} = \frac{1{,}728}{231} = 7.480519$$

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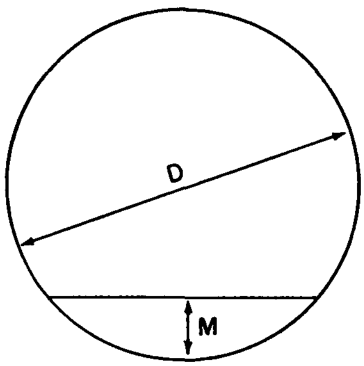
APPENDIX I

AREAS OF CIRCULAR SEGMENTS



Use of Table

In the table find the value of coefficient K for the value of $\frac{M}{D}$ desired. The full area of the circle multiplied by the coefficient equals the area of the segment.

Area segment $=K$ times area full circle

This table also applies for segments of cylinders, thus:

Volume segment $=K$ times volume of full cylinder

$\frac{M}{D}$	K	Difference	$\frac{M}{D}$	K	Difference	$\frac{M}{D}$	K	Difference
0.000	0.000000	53	0.020	0.004773	361	0.040	0.013417	502
0.001	0.000053	99	0.021	0.005134	369	0.041	0.013919	508
0.002	0.000152	127	0.022	0.005503	378	0.042	0.014427	513
0.003	0.000279	150	0.023	0.005881	386	0.043	0.014940	520
0.004	0.000429	171	0.024	0.006267	393	0.044	0.015460	526
0.005	0.000600	188	0.025	0.006660	401	0.045	0.015986	529
0.006	0.000788	204	0.026	0.007061	409	0.046	0.016515	538
0.007	0.000992	220	0.027	0.007470	416	0.047	0.017053	541
0.008	0.001212	233	0.028	0.007886	424	0.048	0.017594	547
0.009	0.001445	247	0.029	0.008310	432	0.049	0.018141	551
0.010	0.001692	260	0.030	0.008742	437	0.050	0.018692	558
0.011	0.001952	271	0.031	0.009179	445	0.051	0.019250	563
0.012	0.002223	284	0.032	0.009624	451	0.052	0.019813	569
0.013	0.002507	293	0.033	0.010075	459	0.053	0.020382	573
0.014	0.002800	304	0.034	0.010534	464	0.054	0.020955	578
0.015	0.003104	315	0.035	0.010998	471	0.055	0.021533	582
0.016	0.003419	324	0.036	0.011469	478	0.056	0.022115	588
0.017	0.003743	334	0.037	0.011947	485	0.057	0.022703	593
0.018	0.004077	344	0.038	0.012432	489	0.058	0.023296	598
0.019	0.004421	352	0.039	0.012921	496	0.059	0.023894	602

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APPENDIX I (*Continued*)

$\frac{M}{D}$	K	Difference	$\frac{M}{D}$	K	Difference	$\frac{M}{D}$	K	Difference
0.060	0.024496	607	0.097	0.049767	756	0.134	0.079841	868
0.061	0.025103	613	0.098	0.050523	759	0.135	0.080709	873
0.062	0.025716	616	0.099	0.051282	762	0.136	0.081582	874
0.063	0.026332	620	0.100	0.052044	766	0.137	0.082456	876
0.064	0.026952	626	0.101	0.052810	769	0.138	0.083332	880
0.065	0.027578	631	0.102	0.053579	772	0.139	0.084212	882
0.066	0.028209	634	0.103	0.054351	775	0.140	0.085094	885
0.067	0.028843	639	0.104	0.055126	779	0.141	0.085979	888
0.068	0.029482	643	0.105	0.055905	783	0.142	0.086867	890
0.069	0.030125	647	0.106	0.056688	786	0.143	0.087757	894
0.070	0.030772	652	0.107	0.057474	788	0.144	0.088651	895
0.071	0.031424	657	0.108	0.058262	792	0.145	0.089546	897
0.072	0.032081	659	0.109	0.059054	796	0.146	0.090443	901
0.073	0.032740	665	0.110	0.059850	798	0.147	0.091344	902
0.074	0.033405	668	0.111	0.060648	801	0.148	0.092246	907
0.075	0.034073	674	0.112	0.061449	805	0.149	0.093153	908
0.076	0.034747	676	0.113	0.062254	808	0.150	0.094061	910
0.077	0.035423	681	0.114	0.063062	810	0.151	0.094971	913
0.078	0.036104	685	0.115	0.063872	815	0.152	0.095884	915
0.079	0.036789	689	0.116	0.064687	816	0.153	0.096799	918
0.080	0.037478	692	0.117	0.065503	820	0.154	0.097717	921
0.081	0.038170	697	0.118	0.066323	824	0.155	0.098638	922
0.082	0.038867	701	0.119	0.067147	825	0.156	0.099560	925
0.083	0.039568	705	0.120	0.067972	830	0.157	0.100485	929
0.084	0.040273	708	0.121	0.068802	831	0.158	0.101414	929
0.085	0.040981	713	0.122	0.069633	836	0.159	0.102343	932
0.086	0.041694	715	0.123	0.070469	838	0.160	0.103275	936
0.087	0.042409	719	0.124	0.071307	840	0.161	0.104211	936
0.088	0.043128	724	0.125	0.072147	844	0.162	0.105147	939
0.089	0.043852	727	0.126	0.072991	845	0.163	0.106086	943
0.090	0.044579	731	0.127	0.073836	850	0.164	0.107029	943
0.091	0.045310	733	0.128	0.074686	853	0.165	0.107972	947
0.092	0.046043	738	0.129	0.075539	854	0.166	0.108919	949
0.093	0.046781	741	0.130	0.076393	858	0.167	0.109868	951
0.094	0.047522	745	0.131	0.077251	861	0.168	0.110819	952
0.095	0.048267	749	0.132	0.078112	863	0.169	0.111771	957
0.096	0.049016	751	0.133	0.078975	866	0.170	0.112728	957

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APPENDIX I (*Continued*)

$\frac{M}{D}$	K	Difference	$\frac{M}{D}$	K	Difference	$\frac{M}{D}$	K	Difference
0.171	0.113685	960	0.208	0.150587	1,036	0.245	0.190007	1,095
0.172	0.114645	961	0.209	0.151623	1,036	0.246	0.191102	1,097
0.173	0.115606	966	0.210	0.152659	1,038	0.247	0.192199	1,099
0.174	0.116572	966	0.211	0.153697	1,040	0.248	0.193298	1,102
0.175	0.117538	968	0.212	0.154737	1,041	0.249	0.194400	1,101
0.176	0.118506	971	0.213	0.155778	1,043	0.250	0.195501	1,104
0.177	0.119477	973	0.214	0.156821	1,046	0.251	0.196605	1,105
0.178	0.120450	975	0.215	0.157867	1,047	0.252	0.197710	1,105
0.179	0.121425	978	0.216	0.158914	1,048	0.253	0.198815	1,108
0.180	0.122403	979	0.217	0.159962	1,051	0.254	0.199923	1,110
0.181	0.123382	982	0.218	0.161013	1,053	0.255	0.201033	1,110
0.182	0.124364	983	0.219	0.162066	1,054	0.256	0.202143	1,112
0.183	0.125347	985	0.220	0.163120	1,055	0.257	0.203255	1,114
0.184	0.126332	988	0.221	0.164175	1,057	0.258	0.204369	1,114
0.185	0.127320	990	0.222	0.165232	1,060	0.259	0.205483	1,117
0.186	0.128310	992	0.223	0.166292	1,060	0.260	0.206600	1,118
0.187	0.129302	994	0.224	0.167352	1,063	0.261	0.207718	1,119
0.188	0.130296	995	0.225	0.168415	1,065	0.262	0.208837	1,120
0.189	0.131291	999	0.226	0.169480	1,065	0.263	0.209957	1,122
0.190	0.132290	1,000	0.227	0.170545	1,067	0.264	0.211079	1,123
0.191	0.133290	1,001	0.228	0.171612	1,070	0.265	0.212202	1,124
0.192	0.134291	1,005	0.229	0.172682	1,071	0.266	0.213326	1,127
0.193	0.135296	1,006	0.230	0.173753	1,072	0.267	0.214453	1,127
0.194	0.136302	1,008	0.231	0.174825	1,074	0.268	0.215580	1,128
0.195	0.137310	1,010	0.232	0.175899	1,076	0.269	0.216708	1,131
0.196	0.138320	1,012	0.233	0.176975	1,077	0.270	0.217839	1,130
0.197	0.139332	1,013	0.234	0.178052	1,079	0.271	0.218969	1,134
0.198	0.140345	1,017	0.235	0.179131	1,081	0.272	0.220103	1,133
0.199	0.141362	1,017	0.236	0.180212	1,082	0.273	0.221236	1,135
0.200	0.142379	1,020	0.237	0.181294	1,084	0.274	0.222371	1,136
0.201	0.143399	1,021	0.238	0.182378	1,084	0.275	0.223507	1,138
0.202	0.144420	1,024	0.239	0.183462	1,088	0.276	0.224645	1,139
0.203	0.145444	1,024	0.240	0.184550	1,088	0.277	0.225784	1,141
0.204	0.146468	1,027	0.241	0.185638	1,090	0.278	0.226925	1,140
0.205	0.147495	1,030	0.242	0.186728	1,092	0.279	0.228065	1,144
0.206	0.148525	1,030	0.243	0.187820	1,092	0.280	0.229209	1,143
0.207	0.149555	1,032	0.244	0.188912	1,095	0.281	0.230352	1,146

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APPENDIX I (*Continued*)

M/D	K	Difference	M/D	K	Difference	M/D	K	Difference
0.282	0.231498	1,146	0.319	0.274681	1,187	0.356	0.319220	1,220
0.283	0.232644	1,147	0.320	0.275868	1,189	0.357	0.320440	1,221
0.284	0.233791	1,150	0.321	0.277057	1,189	0.358	0.321661	1,221
0.285	0.234941	1,150	0.322	0.278246	1,191	0.359	0.322882	1,223
0.286	0.236091	1,151	0.323	0.279437	1,190	0.360	0.324105	1,222
0.287	0.237242	1,153	0.324	0.280627	1,193	0.361	0.325327	1,223
0.288	0.238395	1,154	0.325	0.281820	1,193	0.362	0.326550	1,224
0.289	0.239549	1,155	0.326	0.283013	1,195	0.363	0.327774	1,225
0.290	0.240704	1,156	0.327	0.284208	1,194	0.364	0.328999	1,226
0.291	0.241860	1,157	0.328	0.285402	1,197	0.365	0.330225	1,226
0.292	0.243017	1,157	0.329	0.286599	1,197	0.366	0.331451	1,228
0.293	0.244174	1,160	0.330	0.287796	1,196	0.367	0.332679	1,227
0.294	0.245334	1,161	0.331	0.288992	1,200	0.368	0.333906	1,229
0.295	0.246495	1,162	0.332	0.290192	1,199	0.369	0.335135	1,228
0.296	0.247657	1,163	0.333	0.291391	1,201	0.370	0.336363	1,230
0.297	0.248820	1,164	0.334	0.292592	1,202	0.371	0.337593	1,230
0.298	0.249984	1,165	0.335	0.293794	1,202	0.372	0.338823	1,231
0.299	0.251149	1,166	0.336	0.294996	1,203	0.373	0.340054	1,233
0.300	0.252315	1,168	0.337	0.296199	1,204	0.374	0.341287	1,232
0.301	0.253483	1,169	0.338	0.297403	1,205	0.375	0.342519	1,233
0.302	0.254652	1,170	0.339	0.298608	1,206	0.376	0.343752	1,234
0.303	0.255822	1,170	0.340	0.299814	1,207	0.377	0.344986	1,235
0.304	0.256992	1,173	0.341	0.301021	1,207	0.378	0.346221	1,235
0.305	0.258165	1,172	0.342	0.302228	1,209	0.379	0.347456	1,235
0.306	0.259337	1,174	0.343	0.303437	1,209	0.380	0.348691	1,236
0.307	0.260511	1,176	0.344	0.304646	1,210	0.381	0.349927	1,238
0.308	0.261687	1,176	0.345	0.305856	1,211	0.382	0.351165	1,237
0.309	0.262863	1,176	0.346	0.307067	1,212	0.383	0.352402	1,238
0.310	0.264039	1,179	0.347	0.308279	1,213	0.384	0.353640	1,239
0.311	0.265218	1,180	0.348	0.309492	1,213	0.385	0.354879	1,240
0.312	0.266398	1,180	0.349	0.310705	1,213	0.386	0.356119	1,240
0.313	0.267578	1,181	0.350	0.311918	1,216	0.387	0.357359	1,240
0.314	0.268759	1,182	0.351	0.313134	1,216	0.388	0.358599	1,242
0.315	0.269941	1,184	0.352	0.314350	1,216	0.389	0.359841	1,241
0.316	0.271125	1,184	0.353	0.315566	1,217	0.390	0.361082	1,243
0.317	0.272309	1,186	0.354	0.316783	1,219	0.391	0.362325	1,242
0.318	0.273495	1,186	0.355	0.318002	1,218	0.392	0.363567	1,243

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APPENDIX I (*Continued*)

$\frac{M}{D}$	K	Difference	$\frac{M}{D}$	K	Difference	$\frac{M}{D}$	K	Difference
0.393	0.364810	1,245	0.429	0.409904	1,261	0.465	0.455474	1,269
0.394	0.366055	1,244	0.430	0.411165	1,261	0.466	0.456743	1,271
0.395	0.367299	1,245	0.431	0.412426	1,261	0.467	0.458014	1,270
0.396	0.368544	1,246	0.432	0.413687	1,262	0.468	0.459284	1,271
0.397	0.369790	1,246	0.433	0.414949	1,262	0.469	0.460555	1,271
0.398	0.371036	1,247	0.434	0.416211	1,263	0.470	0.461826	1,270
0.399	0.372283	1,247	0.435	0.417474	1,262	0.471	0.463096	1,272
0.400	0.373530	1,248	0.436	0.418736	1,263	0.472	0.464368	1,271
0.401	0.374778	1,248	0.437	0.419999	1,263	0.473	0.465639	1,272
0.402	0.376026	1,249	0.438	0.421262	1,264	0.474	0.466911	1,272
0.403	0.377275	1,249	0.439	0.422526	1,263	0.475	0.468183	1,271
0.404	0.378524	1,250	0.440	0.423789	1,264	0.476	0.469454	1,272
0.405	0.379774	1,251	0.441	0.425053	1,265	0.477	0.470726	1,272
0.406	0.381025	1,250	0.442	0.426318	1,265	0.478	0.471998	1,272
0.407	0.382275	1,252	0.443	0.427583	1,265	0.479	0.473270	1,272
0.408	0.383527	1,251	0.444	0.428848	1,265	0.480	0.474542	1,273
0.409	0.384778	1,252	0.445	0.430113	1,266	0.481	0.475815	1,272
0.410	0.386030	1,253	0.446	0.431379	1,267	0.482	0.477087	1,272
0.411	0.387283	1,254	0.447	0.432646	1,265	0.483	0.478359	1,273
0.412	0.388537	1,253	0.448	0.433911	1,267	0.484	0.479632	1,272
0.413	0.389790	1,254	0.449	0.435178	1,267	0.485	0.480904	1,273
0.414	0.391044	1,254	0.450	0.436445	1,267	0.486	0.482177	1,274
0.415	0.392298	1,255	0.451	0.437712	1,267	0.487	0.483451	1,271
0.416	0.393553	1,256	0.452	0.438979	1,267	0.488	0.484722	1,274
0.417	0.394809	1,255	0.453	0.440246	1,268	0.489	0.485996	1,273
0.418	0.396064	1,257	0.454	0.441514	1,268	0.490	0.487269	1,273
0.419	0.397321	1,257	0.455	0.442782	1,268	0.491	0.488542	1,272
0.420	0.398578	1,256	0.456	0.444050	1,268	0.492	0.489814	1,273
0.421	0.399834	1,258	0.457	0.445318	1,270	0.493	0.491087	1,274
0.422	0.401092	1,258	0.458	0.446588	1,268	0.494	0.492361	1,273
0.423	0.402350	1,258	0.459	0.447856	1,269	0.495	0.493634	1,273
0.424	0.403608	1,258	0.460	0.449125	1,270	0.496	0.494907	1,273
0.425	0.404866	1,259	0.461	0.450395	1,269	0.497	0.496180	1,273
0.426	0.406125	1,260	0.462	0.451664	1,269	0.498	0.497454	1,273
0.427	0.407385	1,260	0.463	0.452922	1,270	0.499	0.498727	1,273
0.428	0.408645	1,259	0.464	0.454203	1,271	0.500	0.500000	1,273

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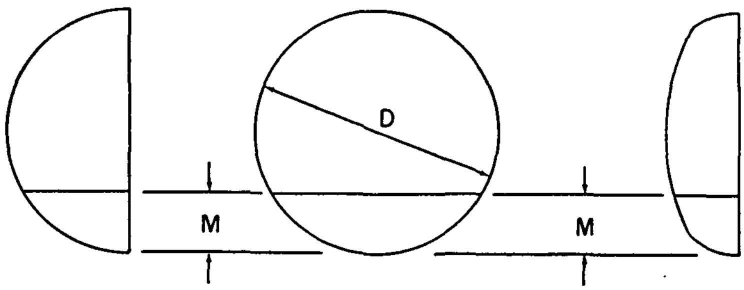
APPENDIX II

COEFFICIENTS FOR PARTIAL VOLUMES OF SPHERES AND HEMISPHERICAL OR SEMIELLIPSOIDAL HEADS



Use of Table

For semielliptical heads, multiply total volume of head, or heads, by the coefficient K taken from the table for any proportion of $\frac{M}{D}$ to find volume to any given depth, M.

Volume of one head $= \frac{\pi D^2 H}{6} = 0.52359878 D^2 H$

For spherical tanks, multiply total volume of sphere by the coefficient K taken from the table for any proportion of $\frac{M}{D}$ to find volume to any given depth, M.

Volume of sphere $= \frac{\pi D^3}{6} = 0.52359878 D^3$

$\frac{M}{D}$	K	Difference	$\frac{M}{D}$	K	Difference	$\frac{M}{D}$	K	Difference
0.000	0.000000	3	0.017	0.000857	103	0.034	0.003389	200
0.001	0.000003	9	0.018	0.000960	109	0.035	0.003589	206
0.002	0.000012	15	0.019	0.001069	115	0.036	0.003795	211
0.003	0.000027	21	0.020	0.001184	120	0.037	0.004006	216
0.004	0.000048	27	0.021	0.001304	127	0.038	0.004222	222
0.005	0.000075	33	0.022	0.001431	132	0.039	0.004444	228
0.006	0.000108	38	0.023	0.001563	137	0.040	0.004672	233
0.007	0.000146	45	0.024	0.001700	144	0.041	0.004905	239
0.008	0.000191	51	0.025	0.001844	149	0.042	0.005144	244
0.009	0.000242	56	0.026	0.001993	155	0.043	0.005388	250
0.010	0.000298	62	0.027	0.002148	160	0.044	0.005638	255
0.011	0.000360	69	0.028	0.002308	166	0.045	0.005893	260
0.012	0.000429	74	0.029	0.002474	172	0.046	0.006153	266
0.013	0.000503	80	0.030	0.002646	177	0.047	0.006419	272
0.014	0.000583	85	0.031	0.002823	183	0.048	0.006691	277
0.015	0.000668	92	0.032	0.003006	189	0.049	0.006968	282
0.016	0.000760	97	0.033	0.003195	194	0.050	0.007250	288

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APPENDIX II (*Continued*)

$\frac{M}{D}$	K	Difference	$\frac{M}{D}$	K	Difference	$\frac{M}{D}$	K	Difference
0.051	0.007538	293	0.088	0.021869	484	0.125	0.042969	658
0.052	0.007831	298	0.089	0.022353	489	0.126	0.043627	663
0.053	0.008129	304	0.090	0.022842	494	0.127	0.044290	668
0.054	0.008433	309	0.091	0.023336	499	0.128	0.044958	672
0.055	0.008742	315	0.092	0.023835	503	0.129	0.045630	676
0.056	0.009057	320	0.093	0.024338	509	0.130	0.046306	681
0.057	0.009377	325	0.094	0.024847	513	0.131	0.046987	685
0.058	0.009702	330	0.095	0.025360	519	0.132	0.047672	690
0.059	0.010032	336	0.096	0.025879	523	0.133	0.048362	694
0.060	0.010368	341	0.097	0.026402	528	0.134	0.049056	698
0.061	0.010709	346	0.098	0.026930	532	0.135	0.049754	703
0.062	0.011055	352	0.099	0.027462	538	0.136	0.050457	707
0.063	0.011407	357	0.100	0.028000	542	0.137	0.051164	712
0.064	0.011764	362	0.101	0.028542	548	0.138	0.051876	716
0.065	0.012126	367	0.102	0.029090	552	0.139	0.052592	720
0.066	0.012493	372	0.103	0.029642	556	0.140	0.053312	725
0.067	0.012865	378	0.104	0.030198	562	0.141	0.054037	728
0.068	0.013243	383	0.105	0.030760	566	0.142	0.054765	734
0.069	0.013626	388	0.106	0.031326	571	0.143	0.055499	737
0.070	0.014014	393	0.107	0.031897	576	0.144	0.056236	742
0.071	0.014407	399	0.108	0.032473	580	0.145	0.056978	746
0.072	0.014806	403	0.109	0.033053	585	0.146	0.057724	750
0.073	0.015209	409	0.110	0.033638	590	0.147	0.058474	754
0.074	0.015618	413	0.111	0.034228	594	0.148	0.059228	759
0.075	0.016031	419	0.112	0.034822	599	0.149	0.059987	763
0.076	0.016450	424	0.113	0.035421	604	0.150	0.060750	767
0.077	0.016874	429	0.114	0.036025	608	0.151	0.061517	771
0.078	0.017303	434	0.115	0.036633	613	0.152	0.062288	776
0.079	0.017737	439	0.116	0.037246	618	0.153	0.063064	779
0.080	0.018176	444	0.117	0.037864	622	0.154	0.063843	784
0.081	0.018620	449	0.118	0.038486	627	0.155	0.064627	788
0.082	0.019069	454	0.119	0.039113	631	0.156	0.065415	792
0.083	0.019523	460	0.120	0.039744	636	0.157	0.066207	796
0.084	0.019983	464	0.121	0.040380	640	0.158	0.067003	801
0.085	0.020447	469	0.122	0.041020	645	0.159	0.067804	804
0.086	0.020916	474	0.123	0.041665	650	0.160	0.068608	808
0.087	0.021390	479	0.124	0.042315	654	0.161	0.069416	813

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APPENDIX II (*Continued*)

$\frac{M}{D}$	K	Difference	$\frac{M}{D}$	K	Difference	$\frac{M}{D}$	K	Difference
0.162	0.070229	817	0.199	0.103042	958	0.236	0.140799	1,083
0.163	0.071046	820	0.200	0.104000	962	0.237	0.141882	1,087
0.164	0.071866	825	0.201	0.104962	965	0.238	0.142969	1,090
0.165	0.072691	829	0.202	0.105927	969	0.239	0.144059	1,093
0.166	0.073520	832	0.203	0.106896	973	0.240	0.145152	1,096
0.167	0.074352	837	0.204	0.107869	976	0.241	0.146248	1,099
0.168	0.075189	840	0.205	0.108845	979	0.242	0.147347	1,102
0.169	0.076029	845	0.206	0.109824	984	0.243	0.148449	1,105
0.170	0.076874	849	0.207	0.110808	986	0.244	0.149554	1,109
0.171	0.077723	852	0.208	0.111794	990	0.245	0.150663	1,111
0.172	0.078575	857	0.209	0.112784	994	0.246	0.151774	1,114
0.173	0.079432	860	0.210	0.113778	997	0.247	0.152888	1,118
0.174	0.080292	864	0.211	0.114775	1,001	0.248	0.154006	1,121
0.175	0.081156	868	0.212	0.115776	1,004	0.249	0.155127	1,123
0.176	0.082024	873	0.213	0.116780	1,007	0.250	0.156250	1,126
0.177	0.082897	875	0.214	0.117787	1,011	0.251	0.157376	1,130
0.178	0.083772	880	0.215	0.118798	1,015	0.252	0.158506	1,132
0.179	0.084652	884	0.216	0.119813	1,017	0.253	0.159638	1,136
0.180	0.085536	888	0.217	0.120830	1,022	0.254	0.160774	1,138
0.181	0.086424	891	0.218	0.121852	1,024	0.255	0.161912	1,142
0.182	0.087315	895	0.219	0.122876	1,028	0.256	0.163054	1,144
0.183	0.088210	899	0.220	0.123904	1,031	0.257	0.164198	1,147
0.184	0.089109	903	0.221	0.124935	1,035	0.258	0.165345	1,150
0.185	0.090012	906	0.222	0.125970	1,038	0.259	0.166495	1,153
0.186	0.090918	910	0.223	0.127008	1,041	0.260	0.167648	1,156
0.187	0.091828	915	0.224	0.128049	1,045	0.261	0.168804	1,159
0.188	0.092743	917	0.225	0.129094	1,048	0.262	0.169963	1,161
0.189	0.093660	922	0.226	0.130142	1,051	0.263	0.171124	1,165
0.190	0.094582	925	0.227	0.131193	1,054	0.264	0.172289	1,167
0.191	0.095507	929	0.228	0.132247	1,058	0.265	0.173456	1,170
0.192	0.096436	933	0.229	0.133305	1,061	0.266	0.174626	1,173
0.193	0.097369	936	0.230	0.134366	1,064	0.267	0.175799	1,175
0.194	0.098305	940	0.231	0.135430	1,068	0.268	0.176974	1,179
0.195	0.099245	944	0.232	0.136498	1,070	0.269	0.178153	1,181
0.196	0.100189	947	0.233	0.137568	1,074	0.270	0.179334	1,184
0.197	0.101136	951	0.234	0.138642	1,077	0.271	0.180518	1,187
0.198	0.102087	955	0.235	0.139719	1,080	0.272	0.181705	1,189

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APPENDIX II (*Continued*)

$\frac{M}{D}$	K	Difference	$\frac{M}{D}$	K	Difference	$\frac{M}{D}$	K	Difference
0.273	0.182894	1,192	0.311	0.230003	1,286	0.349	0.280386	1,364
0.274	0.184086	1,195	0.312	0.231289	1,289	0.350	0.281750	1,366
0.275	0.185281	1,198	0.313	0.232578	1,292	0.351	0.283116	1,368
0.276	0.186479	1,200	0.314	0.233870	1,293	0.352	0.284484	1,369
0.277	0.187679	1,203	0.315	0.235163	1,296	0.353	0.285853	1,371
0.278	0.188882	1,206	0.316	0.236459	1,298	0.354	0.287224	1,373
0.279	0.190088	1,208	0.317	0.237757	1,300	0.355	0.288597	1,375
0.280	0.191296	1,211	0.318	0.239057	1,302	0.356	0.289972	1,376
0.281	0.192507	1,213	0.319	0.240359	1,305	0.357	0.291348	1,378
0.282	0.193720	1,217	0.320	0.241664	1,307	0.358	0.292726	1,380
0.283	0.194937	1,218	0.321	0.242971	1,309	0.359	0.294106	1,382
0.284	0.196155	1,222	0.322	0.244280	1,311	0.360	0.295488	1,383
0.285	0.197377	1,224	0.323	0.245591	1,313	0.361	0.296871	1,385
0.286	0.198601	1,226	0.324	0.246904	1,315	0.362	0.298256	1,387
0.287	0.199827	1,229	0.325	0.248219	1,317	0.363	0.299643	1,388
0.288	0.201056	1,232	0.326	0.249536	1,319	0.364	0.301031	1,390
0.289	0.202288	1,234	0.327	0.250855	1,322	0.365	0.302421	1,391
0.290	0.203522	1,237	0.328	0.252177	1,323	0.366	0.303812	1,393
0.291	0.204759	1,239	0.329	0.253500	1,326	0.367	0.305205	1,395
0.292	0.205998	1,241	0.330	0.254826	1,328	0.368	0.306600	1,396
0.293	0.207239	1,245	0.331	0.256154	1,329	0.369	0.307996	1,398
0.294	0.208484	1,246	0.332	0.257483	1,332	0.370	0.309394	1,399
0.295	0.209730	1,249	0.333	0.258815	1,334	0.371	0.310793	1,401
0.296	0.210979	1,252	0.334	0.260149	1,335	0.372	0.312194	1,403
0,297	0.212231	1,254	0.335	0.261484	1,338	0.373	0.313597	1,404
0,298	0.213485	1,256	0.336	0.262822	1,339	0.374	0.315001	1,405
0.299	0.214741	1,259	0.337	0.264161	1,342	0.375	0.316406	1,407
0.300	0.216000	1,261	0.338	0.265503	1,344	0.376	0.317813	1,409
0.301	0.217261	1,264	0.339	0.266847	1,345	0.377	0.319222	1,410
0.302	0.218525	1,266	0.340	0.268192	1,347	0.378	0.320632	1,411
0.303	0.219791	1,268	0.341	0.269539	1,350	0.379	0.322043	1,413
0.304	0.221059	1,271	0.342	0.270889	1,351	0.380	0.323456	1,414
0.305	0.222330	1,273	0.343	0.272240	1,353	0.381	0.324870	1,416
0.306	0.223603	1,275	0.344	0.273592	1,355	0.382	0.326286	1,417
0.307	0.224878	1,278	0.345	0.274948	1,357	0.383	0.327703	1,419
0.308	0.226156	1,280	0.346	0.276305	1,358	0.384	0.329122	1,420
0.309	0.227436	1,282	0.347	0.277663	1,361	0.385	0.330542	1,421
0.310	0.228718		0.348	0.279024		0.386	0.331963	

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APPENDIX II (*Continued*)

M/D	K	Difference	M/D	K	Difference	M/D	K	Difference
0.387	0.333386	1,424	0.425	0.388344	1,467	0.463	0.444601	1,492
0.388	0.334810	1,425	0.426	0.389811	1,468	0.464	0.446093	1,493
0.389	0.336235	1,427	0.427	0.391279	1,468	0.465	0.447586	1,493
0.390	0.337662	1,428	0.428	0.392747	1,469	0.466	0.449079	1,493
0.391	0.339090	1,429	0.429	0.394216	1,470	0.467	0.450572	1,494
0.392	0.340519	1,431	0.430	0.395686	1,471	0.468	0.452066	1,494
0.393	0.341950	1,432	0.431	0.397157	1,472	0.469	0.453560	1,494
0.394	0.343382	1,433	0.432	0.398629	1,473	0.470	0.455054	1,495
0.395	0.344815	1,435	0.433	0.400102	1,473	0.471	0.456549	1,495
0.396	0.346250	1,435	0.434	0.401575	1,474	0.472	0.458044	1,495
0.397	0.347685	1,437	0.435	0.403049	1,475	0.473	0.459539	1,496
0.398	0.349122	1,439	0.436	0.404524	1,476	0.474	0.461035	1,496
0.399	0.350561	1,439	0.437	0.406000	1,477	0.475	0.462531	1,497
0.400	0.352000	1,441	0.438	0.407477	1,477	0.476	0.464028	1,496
0.401	0.353441	1,441	0.439	0.408954	1,478	0.477	0.465524	1,497
0.402	0.354882	1,443	0.440	0.410432	1,479	0.478	0.467021	1,498
0.403	0.356325	1,444	0.441	0.411911	1,479	0.479	0.468519	1,497
0.404	0.357769	1,446	0.442	0.413390	1,480	0.480	0.470016	1,498
0.405	0.359215	1,447	0.443	0.414870	1,481	0.481	0.471514	1,498
0.406	0.360662	1,447	0.444	0.416351	1,482	0.482	0.473012	1,498
0.407	0.362109	1,448	0.445	0.417833	1,482	0.483	0.474510	1,498
0.408	0.363557	1,450	0.446	0.419315	1,483	0.484	0.476008	1,499
0.409	0.365007	1,451	0.447	0.420798	1,483	0.485	0.477507	1,498
0.410	0.366458	1,452	0.448	0.422281	1,484	0.486	0.479005	1,499
0.411	0.367910	1,453	0.449	0.423765	1,485	0.487	0.480504	1,499
0.412	0.369363	1,454	0.450	0.425250	1,485	0.488	0.482003	1,500
0.413	0.370817	1,455	0.451	0.426735	1,486	0.489	0.483503	1,499
0.414	0.372272	1,456	0.452	0.428221	1,487	0.490	0.485002	1,499
0.415	0.373728	1,457	0.453	0.429708	1,487	0.491	0.486501	1,500
0.416	0.375185	1,459	0.454	0.431195	1,487	0.492	0.488001	1,500
0.417	0.376644	1,459	0.455	0.432682	1,488	0.493	0.489501	1,499
0.418	0.378103	1,460	0.456	0.434170	1,489	0.494	0.491000	1,500
0.419	0.379563	1,461	0.457	0.435659	1,489	0.495	0.492500	1,500
0.420	0.381024	1,462	0.458	0.437148	1,490	0.496	0.494000	1,500
0.421	0.382486	1,463	0.459	0.438638	1,490	0.497	0.495500	1,500
0.422	0.383949	1,464	0.460	0.440128	1,491	0.498	0.497000	1,500
0.423	0.385413	1,465	0.461	0.441619	1,491	0.499	0.498500	1,500
0.424	0.386878	1,466	0.462	0.443110	1,491	0.500	0.500000	1,500

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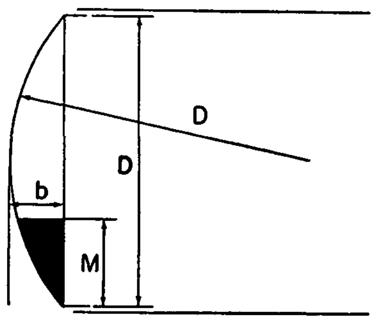
APPENDIX III

VOLUMES OF BUMPED HEADS



Use of Table

In the table find the value of coefficient K for the value of $\frac{M}{D}$ desired. The full volume multiplied by the coefficient equals the volume of the segment.

$$V = \frac{1}{24}\pi b(3D^2+4b^2)$$

Volume of segment $= KV$

$\frac{M}{D}$	K	Difference	$\frac{M}{D}$	K	Difference	$\frac{M}{D}$	K	Difference
0.001	0.00000	0	0.022	0.00040	5	0.043	0.00208	12
0.002	0.00000	0	0.023	0.00045	5	0.044	0.00220	12
0.003	0.00000	1	0.024	0.00050	5	0.045	0.00232	13
0.004	0.00001	0	0.025	0.00055	6	0.046	0.00245	13
0.005	0.00001	1	0.026	0.00061	6	0.047	0.00258	14
0.006	0.00002	0	0.027	0.00067	5	0.048	0.00272	14
0.007	0.00002	1	0.028	0.00072	7	0.049	0.00286	14
0.008	0.00003	1	0.029	0.00079	7	0.050	0.00300	15
0.009	0.00004	2	0.030	0.00086	7	0.051	0.00315	15
0.010	0.00006	1	0.031	0.00093	8	0.052	0.00330	16
0.011	0.00007	2	0.032	0.00101	8	0.053	0.00346	16
0.012	0.00009	2	0.033	0.00109	8	0.054	0.00362	17
0.013	0.00011	2	0.034	0.00117	9	0.055	0.00379	17
0.014	0.00013	3	0.035	0.00126	9	0.056	0.00396	17
0.015	0.00016	2	0.036	0.00135	9	0.057	0.00413	18
0.016	0.00018	3	0.037	0.00144	10	0.058	0.00431	18
0.017	0.00021	3	0.038	0.00154	10	0.059	0.00449	19
0.018	0.00024	4	0.039	0.00164	10	0.060	0.00468	19
0.019	0.00028	4	0.040	0.00174	11	0.061	0.00487	19
0.020	0.00032	4	0.041	0.00185	11	0.062	0.00506	20
0.021	0.00036	4	0.042	0.00196	12	0.063	0.00526	21

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APPENDIX III (*Continued*)

$\frac{M}{D}$	K	Difference	$\frac{M}{D}$	K	Difference	$\frac{M}{D}$	K	Difference
0.064	0.00547	20	0.101	0.01629	39	0.138	0.03387	57
0.065	0.00567	22	0.102	0.01668	39	0.139	0.03444	58
0.066	0.00589	21	0.103	0.01707	39	0.140	0.03502	58
0.067	0.00610	23	0.104	0.01746	40	0.141	0.03560	59
0.068	0.00633	22	0.105	0.01786	40	0.142	0.03619	59
0.069	0.00655	23	0.106	0.01826	41	0.143	0.03678	59
0.070	0.00678	24	0.107	0.01867	42	0.144	0.03737	61
0.071	0.00702	24	0.108	0.01909	42	0.145	0.03798	60
0.072	0.00726	25	0.109	0.01951	42	0.146	0.03858	61
0.073	0.00751	25	0.110	0.01993	43	0.147	0.03919	62
0.074	0.00776	25	0.111	0.02036	44	0.148	0.03981	63
0.075	0.00801	26	0.112	0.02080	44	0.149	0.04044	62
0.076	0.00827	26	0.113	0.02124	44	0.150	0.04106	64
0.077	0.00853	27	0.114	0.02168	45	0.151	0.04170	63
0.078	0.00880	27	0.115	0.02213	45	0.152	0.04233	65
0.079	0.00907	28	0.116	0.02258	46	0.153	0.04298	64
0.080	0.00935	28	0.117	0.02304	47	0.154	0.04362	66
0.081	0.00963	29	0.118	0.02351	47	0.155	0.04428	66
0.082	0.00992	29	0.119	0.02398	47	0.156	0.04494	66
0.083	0.01021	30	0.120	0.02445	48	0.157	0.04560	67
0.084	0.01051	30	0.121	0.02493	49	0.158	0.04627	67
0.085	0.01081	31	0.122	0.02542	49	0.159	0.04694	68
0.086	0.01112	31	0.123	0.02591	49	0.160	0.04762	68
0.087	0.01143	31	0.124	0.02640	50	0.161	0.04830	69
0.088	0.01174	32	0.125	0.02690	51	0.162	0.04899	69
0.089	0.01206	33	0.126	0.02741	51	0.163	0.04968	70
0.090	0.01239	33	0.127	0.02792	51	0.164	0.05038	70
0.091	0.01272	34	0.128	0.02843	53	0.165	0.05108	71
0.092	0.01306	34	0.129	0.02896	52	0.166	0.05179	71
0.093	0.01340	34	0.130	0.02948	53	0.167	0.05250	72
0.094	0.01374	35	0.131	0.03001	54	0.168	0.05322	73
0.095	0.01409	36	0.132	0.03055	54	0.169	0.05395	72
0.096	0.01445	35	0.133	0.03109	54	0.170	0.05467	74
0.097	0.01480	37	0.134	0.03163	55	0.171	0.05541	74
0.098	0.01517	37	0.135	0.03218	56	0.172	0.05615	74
0.099	0.01554	37	0.136	0.03274	56	0.173	0.05689	75
0.100	0.01591	38	0.137	0.03330	57	0.174	0.05764	75

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APPENDIX III (*Continued*)

$\frac{M}{D}$	K	Difference	$\frac{M}{D}$	K	Difference	$\frac{M}{D}$	K	Difference
0.175	0.05839	76	0.212	0.08973	94	0.249	0.12750	111
0.176	0.05915	76	0.213	0.09067	94	0.250	0.12861	111
0.177	0.05991	77	0.214	0.09161	95	0.251	0.12972	111
0.178	0.06068	78	0.215	0.09256	95	0.252	0.13083	112
0.179	0.06146	77	0.216	0.09351	96	0.253	0.13195	112
0.180	0.06223	79	0.217	0.09447	96	0.254	0.13307	113
0.181	0.06302	78	0.218	0.09543	96	0.255	0.13420	113
0.182	0.06380	80	0.219	0.09639	97	0.256	0.13533	113
0.183	0.06460	80	0.220	0.09736	98	0.257	0.13646	114
0.184	0.06540	80	0.221	0.09834	98	0.258	0.13760	115
0.185	0.06620	81	0.222	0.09932	98	0.259	0.13875	115
0.186	0.06701	81	0.223	0.10030	99	0.260	0.13990	115
0.187	0.06782	82	0.224	0.10129	100	0.261	0.14105	115
0.188	0.06864	82	0.225	0.10229	100	0.262	0.14220	116
0.189	0.06946	83	0.226	0.10329	100	0.263	0.14336	117
0.190	0.07029	83	0.227	0.10429	101	0.264	0.14453	117
0.191	0.07112	84	0.228	0.10530	101	0.265	0.14570	117
0.192	0.07196	84	0.229	0.10631	102	0.266	0.14687	118
0.193	0.07280	85	0.230	0.10733	102	0.267	0.14805	118
0.194	0.07365	85	0.231	0.10835	103	0.268	0.14923	119
0.195	0.07450	86	0.232	0.10938	103	0.269	0.15042	118
0.196	0.07536	86	0.233	0.11041	103	0.270	0.15160	120
0.197	0.07622	87	0.234	0.11144	104	0.271	0.15280	119
0.198	0.07709	87	0.235	0.11248	105	0.272	0.15399	121
0.199	0.07796	88	0.236	0.11353	104	0.273	0.15520	120
0.200	0.07884	88	0.237	0.11457	106	0.274	0.15640	121
0.201	0.07972	88	0.238	0.11563	105	0.275	0.15761	121
0.202	0.08060	90	0.239	0.11668	106	0.276	0.15882	122
0.203	0.08150	89	0.240	0.11774	107	0.277	0.16004	122
0.204	0.08239	90	0.241	0.11881	107	0.278	0.16126	123
0.205	0.08329	91	0.242	0.11988	108	0.279	0.16249	123
0.206	0.08420	90	0.243	0.12096	108	0.280	0.16372	123
0.207	0.08510	92	0.244	0.12204	108	0.281	0.16495	124
0.208	0.08602	92	0.245	0.12312	109	0.282	0.16619	124
0.209	0.08694	92	0.246	0.12421	109	0.283	0.16743	124
0.210	0.08786	93	0.247	0.12530	110	0.284	0.16867	125
0.211	0.08879	94	0.248	0.12640	110	0.285	0.16992	125

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APPENDIX III (*Continued*)

$\frac{M}{D}$	K	Difference	$\frac{M}{D}$	K	Difference	$\frac{M}{D}$	K	Difference
0.286	0.17117	126	0.323	0.22007	138	0.360	0.27341	149
0.287	0.17243	126	0.324	0.22145	139	0.361	0.27490	150
0.288	0.17369	126	0.325	0.22284	140	0.362	0.27640	150
0.289	0.17495	127	0.326	0.22424	139	0.363	0.27790	151
0.290	0.17622	127	0.327	0.22563	140	0.364	0.27941	150
0.291	0.17749	128	0.328	0.22703	141	0.365	0.28091	151
0.292	0.17877	127	0.329	0.22844	140	0.366	0.28242	151
0.293	0.18004	129	0.330	0.22984	141	0.367	0.28393	152
0.294	0.18133	128	0.331	0.23125	141	0.368	0.28545	151
0.295	0.18261	129	0.332	0.23266	142	0.369	0.28696	152
0.296	0.18390	130	0.333	0.23408	142	0.370	0.28848	152
0.297	0.18520	129	0.334	0.23550	142	0.371	0.29000	153
0.298	0.18649	130	0.335	0.23692	142	0.372	0.29153	152
0.299	0.18779	131	0.336	0.23834	143	0.373	0.29305	153
0.300	0.18910	131	0.337	0.23977	143	0.374	0.29458	153
0.301	0.19041	131	0.338	0.24120	144	0.375	0.29611	153
0.302	0.19172	131	0.339	0.24264	143	0.376	0.29764	154
0.303	0.19303	132	0.340	0.24407	144	0.377	0.29918	154
0.304	0.19435	132	0.341	0.24551	144	0.378	0.30072	154
0.305	0.19567	133	0.342	0.24695	145	0.379	0.30226	154
0.306	0.19700	133	0.343	0.24840	145	0.380	0.30380	154
0.307	0.19833	133	0.344	0.24985	145	0.381	0.30534	155
0.308	0.19966	134	0.345	0.25130	145	0.382	0.30689	155
0.309	0.20100	134	0.346	0.25275	146	0.383	0.30844	155
0.310	0.20234	134	0.347	0.25421	146	0.384	0.30999	155
0.311	0.20368	135	0.348	0.25567	146	0.385	0.31154	156
0.312	0.20503	135	0.349	0.25713	147	0.386	0.31310	156
0.313	0.20638	135	0.350	0.25860	147	0.387	0.31466	156
0.314	0.20773	136	0.351	0.26007	147	0.388	0.31622	156
0.315	0.20909	136	0.352	0.26154	147	0.389	0.31778	156
0.316	0.21045	136	0.353	0.26301	148	0.390	0.31934	157
0.317	0.21181	137	0.354	0.26449	148	0.391	0.32091	157
0.318	0.21318	137	0.355	0.26597	148	0.392	0.32248	157
0.319	0.21455	138	0.356	0.26745	149	0.393	0.32405	157
0.320	0.21593	137	0.357	0.26894	149	0.394	0.32562	157
0.321	0.21730	138	0.358	0.27043	149	0.395	0.32719	158
0.322	0.21868	139	0.359	0.27192	149	0.396	0.32877	158

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APPENDIX III (*Continued*)

$\frac{M}{D}$	K	Difference	$\frac{M}{D}$	K	Difference	$\frac{M}{D}$	K	Difference
0.397	0.33035	158	0.431	0.38506	164	0.466	0.44299	167
0.398	0.33193	158	0.432	0.38670	164	0.467	0.44466	167
0.399	0.33351	159	0.433	0.38834	164	0.468	0.44633	167
0.400	0.33510	158	0.434	0.38998	164	0.469	0.44800	167
0.401	0.33668	159	0.435	0.39162	164	0.470	0.44967	168
0.402	0.33827	159	0.436	0.39326	164	0.471	0.45135	167
0.403	0.33986	159	0.437	0.39490	164	0.472	0.45302	168
0.404	0.34145	160	0.438	0.39654	165	0.473	0.45470	167
0.405	0.34305	159	0.439	0.39819	165	0.474	0.45637	167
0.406	0.34464	160	0.440	0.39984	164	0.475	0.45804	168
0.407	0.34624	160	0.441	0.40148	165	0.476	0.45972	168
0.408	0.34784	160	0.442	0.40313	165	0.477	0.46140	167
0.409	0.34944	160	0.443	0.40478	165	0.478	0.46307	168
0.410	0.35104	160	0.444	0.40643	165	0.479	0.46475	168
0.411	0.35264	161	0.445	0.40808	165	0.480	0.46643	168
0.412	0.35425	161	0.446	0.40974	165	0.481	0.46811	167
0.413	0.35586	161	0.447	0.41139	165	0.482	0.46978	168
0.414	0.35747	161	0.448	0.41304	165	0.483	0.47146	168
0.415	0.35908	161	0.449	0.41470	166	0.484	0.47314	168
0.416	0.36069	162	0.450	0.41636	166	0.485	0.47482	168
0.417	0.36231	161	0.451	0.41802	165	0.486	0.47650	168
0.418	0.36392	162	0.452	0.41967	166	0.487	0.47818	168
0.419	0.36554	162	0.453	0.42133	167	0.488	0.47986	168
0.420	0.36716	162	0.454	0.42300	166	0.489	0.48154	168
0.421	0.36878	162	0.455	0.42466	166	0.490	0.48322	168
0.422	0.37040	162	0.456	0.42632	166	0.491	0.48490	168
0.423	0.37202	163	0.457	0.42798	167	0.492	0.48658	168
0.424	0.37365	163	0.458	0.42965	166	0.493	0.48827	168
0.425	0.37528	162	0.459	0.43131	167	0.494	0.48995	168
0.426	0.37690	163	0.460	0.43298	166	0.495	0.49163	168
0.427	0.37853	163	0.461	0.43464	167	0.496	0.49331	168
0.428	0.38016	164	0.462	0.43631	167	0.497	0.49499	168
0.429	0.38180	163	0.463	0.43798	167	0.498	0.49667	168
0.430	0.38343	163	0.464	0.43965	167	0.499	0.49835	165
			0.465	0.44132	167	0.500	0.50000	165

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APPENDIX IV

PROCEDURE FOR COMPUTING THE VOLUME CORRECTION FOR THERMAL EXPANSION OR CONTRACTION OF CYLINDRICAL HORIZONTAL TANKS

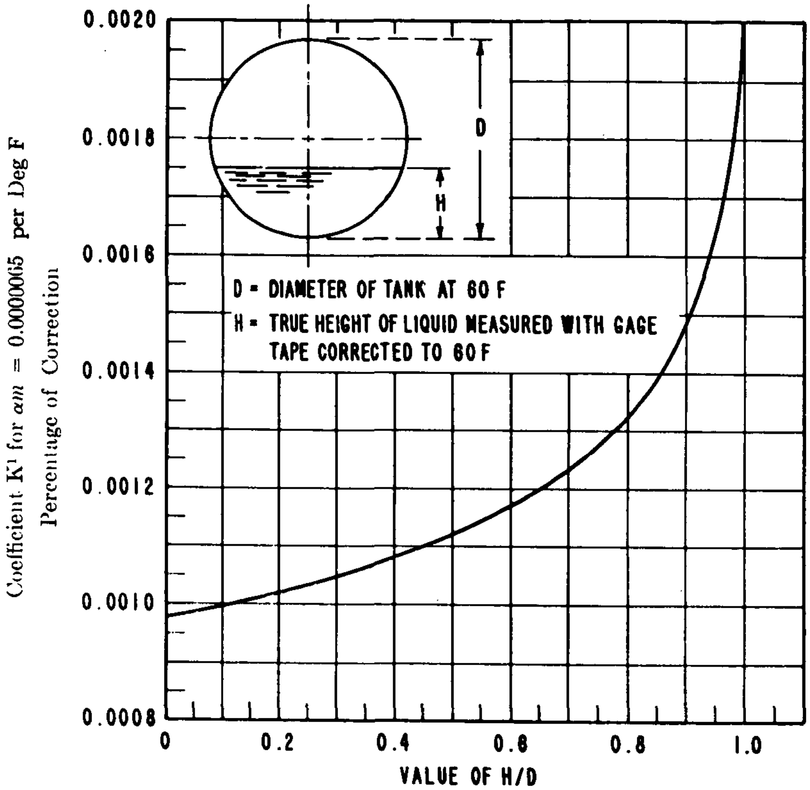

FIG. 9.—VOLUME CORRECTION COEFFICIENT FOR THERMAL EXPANSION OR CONTRACTION OF CYLINDRICAL HORIZONTAL TANKS CONSTRUCTED OF LOW-CARBON STEEL.

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The basis and method of correcting the volume of cylindrical horizontal tanks which have been affected by changes in temperature is described in Section 37. The coefficient, K^1, is obtained from the curve shown in Fig. 9 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 37 is equal to K^1 from the curve (Fig. 9), 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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