

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

API STANDARD 2551
FIRST EDITION, 1965

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FOREWORD

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Suggested revisions are invited and should be submitted to the director of the Measurement Coordination Department, American Petroleum Institute, 1220 L Street N.W., Washington, D.C. 20005.

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Standard Method for MEASUREMENT AND CALIBRATION OF HORIZONTAL TANKS¹



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*

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.

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, $\frac{3}{8}$ or $\frac{1}{2}$ in. wide and approximately 0.008 to 0.012 in. thick—graduated in feet and inches to $\frac{1}{8}$ of an inch or graduated in feet, tenths, and hundredths of a foot—is recommended. Graduations shall be accurate to within $\frac{1}{32}$ 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

to the tank circumference, usually 100 ft in length, is recommended. The working tape should be not more than $\frac{1}{4}$ in. wide, and approximately 0.01 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 $\frac{1}{4}$ 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 $\frac{1}{4}$ 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 $\frac{1}{4}$ 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.

(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 ta-

bles 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 ($\frac{1}{16}$) 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 ($\frac{1}{64}$) of an inch.

(e) Deadwood should be measured and located to the nearest one-eighth ($\frac{1}{8}$) 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.

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)].

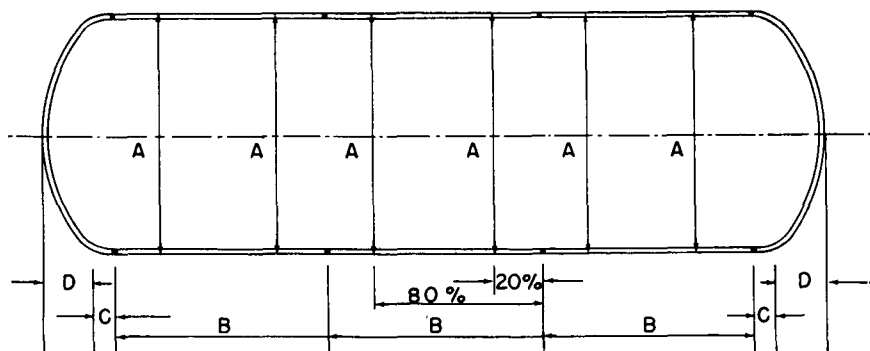
(3) If the obstruction cannot be conveniently spanned by a step-over, a substitute path, located as near as possible to the prescribed point but not on a joint, may be chosen. The strapping record should include the location of the substitute path and the reason for the departure.

(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).

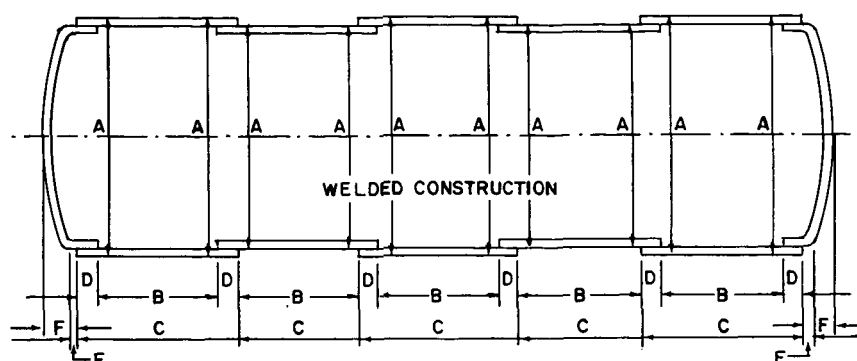
(1) If measurements taken on successive rings indicate unusual variations or distortions, additional measurements should be taken to satisfy the judgment of all strappers involved.

(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 $\frac{1}{8}$, $\frac{3}{8}$, $\frac{5}{8}$,

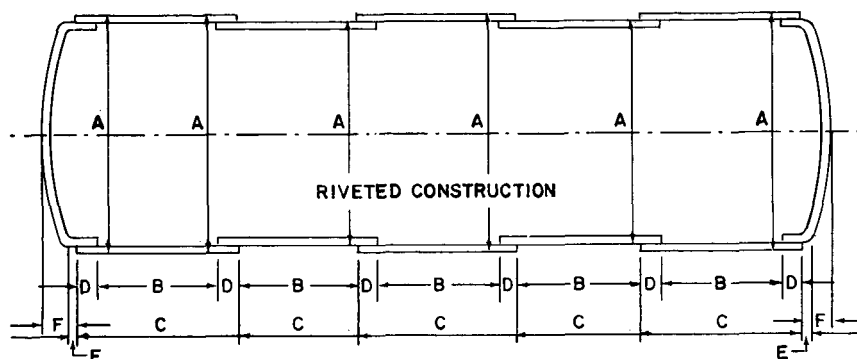


- A—Circumferences taken at 20 and 80 per cent of each ring.
 B—Measured length of cylinder rings.
 C—Distance from weld to tangent point.
 D—Head projection.

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



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—Unapped 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 $\frac{7}{8}$ points along the shell, as shown in Fig. 3.

(c) Procedures:

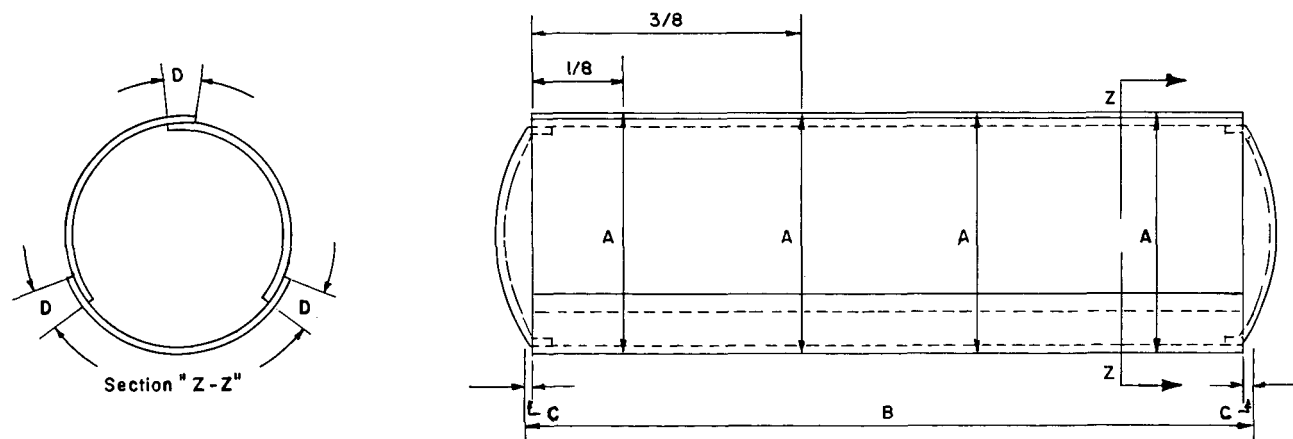
(1) General.—For the procedures discussed in Items (2) and (3), a circumferential tape of sufficient length to completely encircle the tank should be used and measurements of total circumference should be taken.

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 $\frac{1}{8}$, $\frac{3}{8}$, $\frac{5}{8}$, and $\frac{7}{8}$ 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.

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 $\frac{1}{4}$ 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 $\frac{1}{4}$ 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-

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 $\frac{1}{8}$ 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.

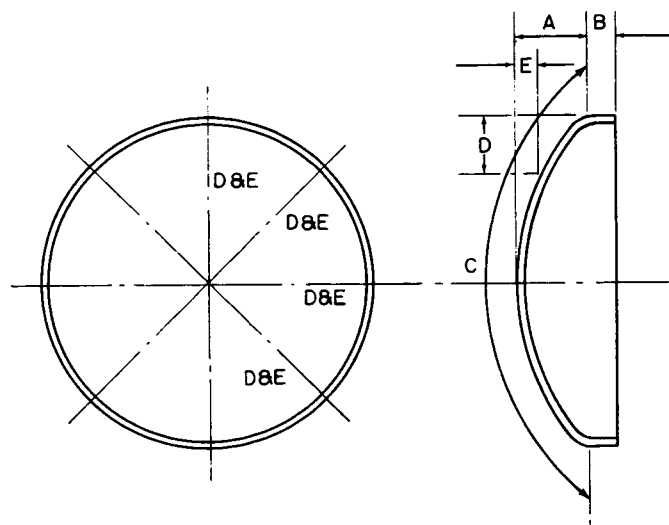
(d) Work sheets on which details of deadwood are sketched, dimensioned, and located should be clearly identified and should become a part of the strapping records.

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 de-



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.

scription. 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 $8\frac{1}{2}$ 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.

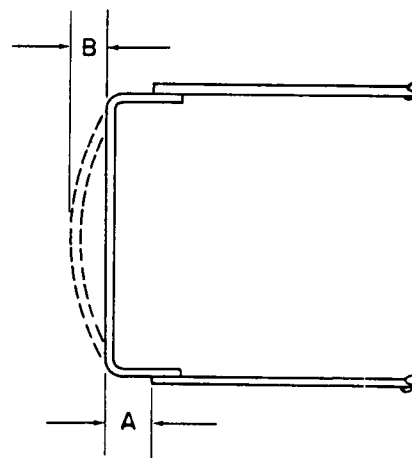
(5) Dents and bulges in shell plates.

(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—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 mathe-

matical 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.

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 1/8-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).

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

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.

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 marked to show adjustments which have been 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 points along its path, the amount of increase in circumference due to the tape rise at such

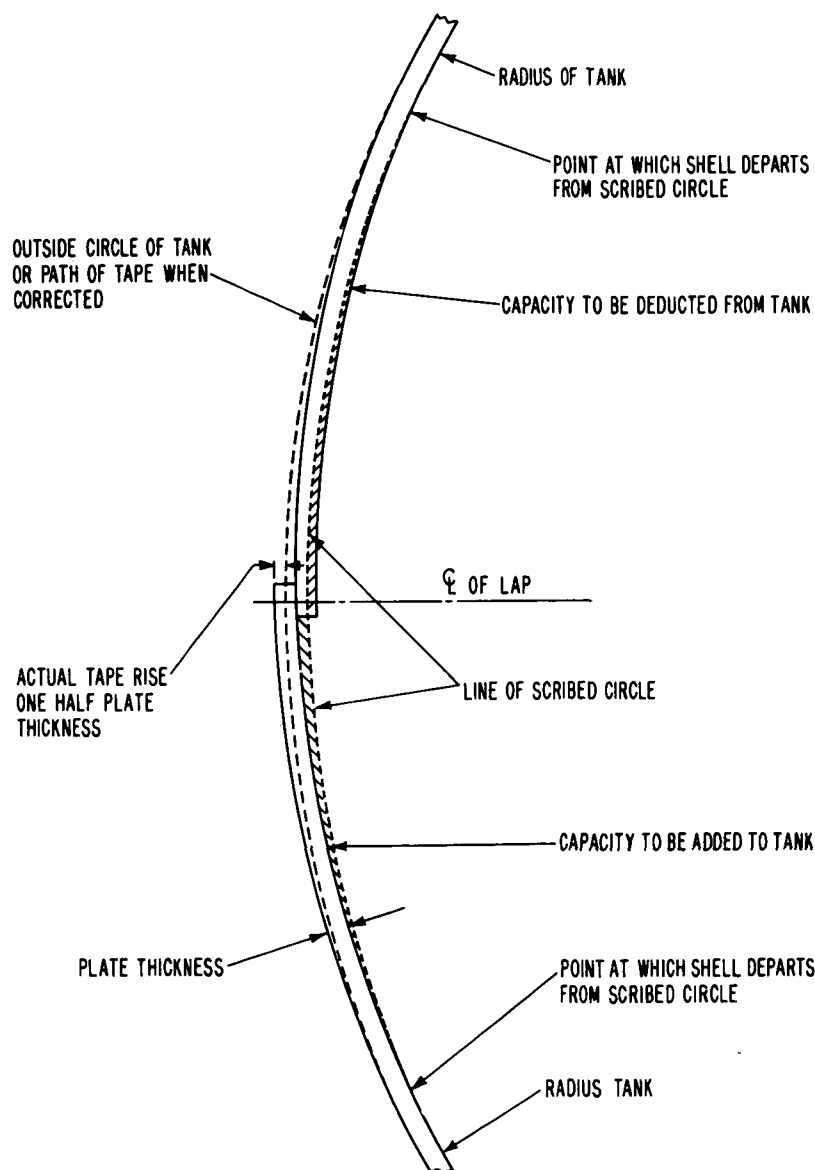


FIG. 6.—TRUE CIRCUMFERENCE *versus* TAPE PATH AT AXIAL LAP JOINT AWAY FROM CIRCUMFERENTIAL JOINT.

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 $t_s = t_L$.

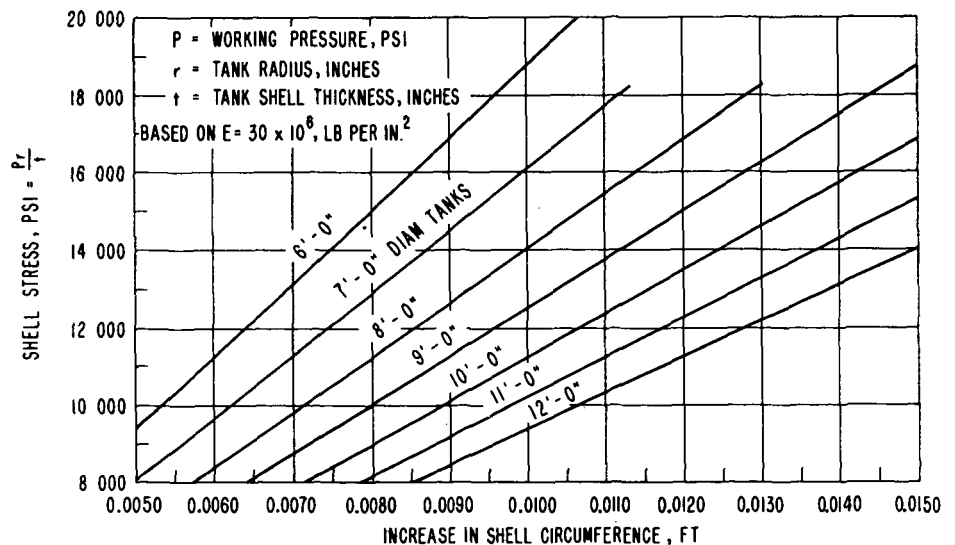
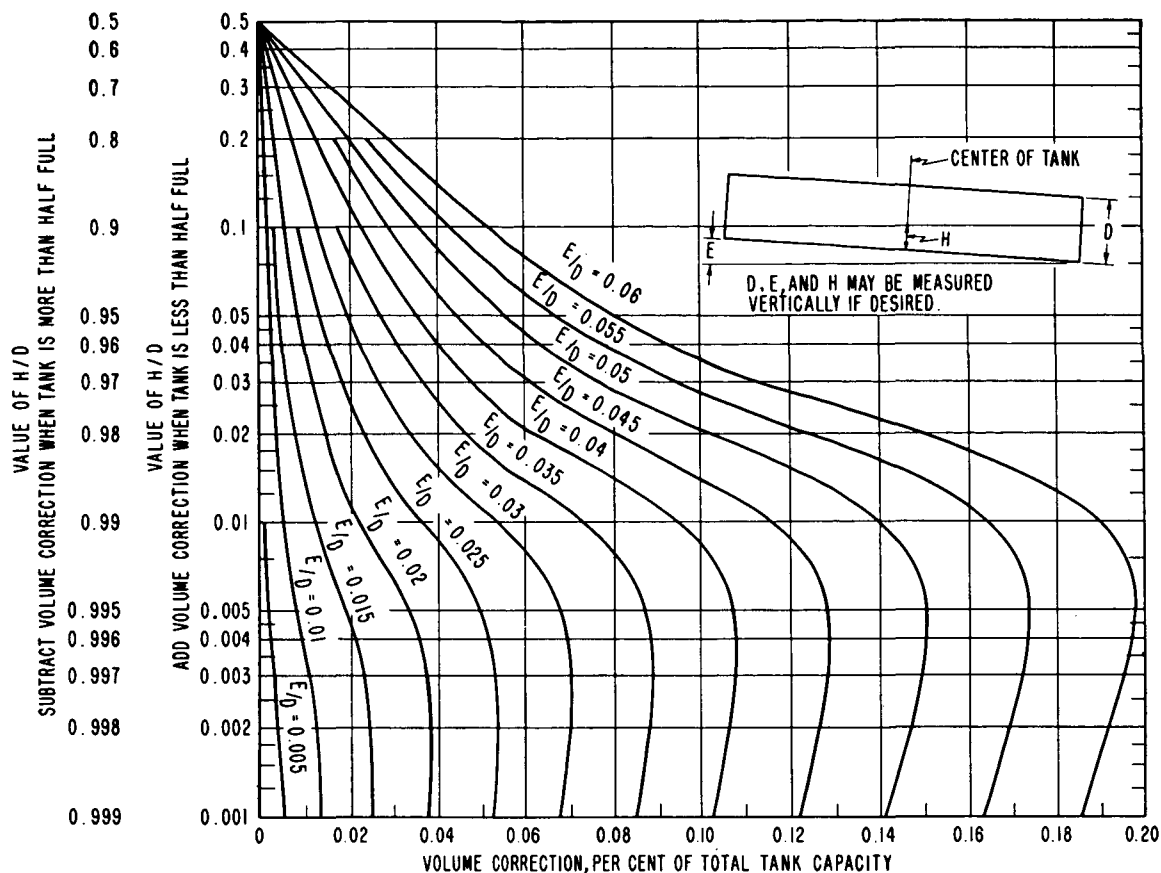


FIG. 7.—INCREASE IN SHELL CIRCUMFERENCE DUE TO PRESSURE.



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 cylin-

dricl 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 cylin-

dricl 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 The Institute of Petroleum*, Vol. 34, No. 297, September, 1948.