## Chapter 2 – Tank Calibration

## CHAPTER 2.3 (API STANDARD 2552) – METHOD FOR MEASUREMENT AND CALIBRATION OF SPHERES AND SPHEROIDS

### 1. Scope

This standard describes the procedures and calculations for calibrating spheres and spheroids. ~~which are used as liquid containers. There are several methods for calibration. Each method is mentioned in this standard. Choosing a method to use will be determined on available equipment and tank status. The standard is presented in two parts: Part I outlines the procedures for the measurement and calibration of spherical tanks; Part II outlines the procedures for the measurement and calibration of spheroidal tanks.~~

### 2. Normative References

The are no~~following~~ documents that are considered indispensable for the application of this standard.~~referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For updated references, the latest edition of the referenced document (including any addenda) applies.~~

~~API *MPMS* Chapter 2.2A - *Measurement and Calibration of Upright Cylindrical Tanks by the Manual Tank Strapping Method*~~

~~API Standard 2555 - *Method for Liquid Calibration of Tanks*~~

~~API *MPMS* Chapter 2.2D - *Calibration of Upright Cylindrical Tanks Using the Electro-optical Distance Ranging Method*~~

### 3. Terms and Definitions

### ~~3.~~4. Safety

Before entering any tank, permission shall be obtained from the terminal supervisor, authorized official, or other person(s) in charge. This responsible person should supply information regarding particular materials and conditions as well as the applicable ~~Material~~ Safety Data Sheet (~~M~~SDS) if applicable.

Due consideration should be given to applicable safety procedures. Safety considerations include, but are not limited to, potential electrostatic hazards, potential personnel exposure (and associated protective clothing and equipment requirements), and potential explosive and toxic hazards associated with the tank's atmosphere. The physical characteristics of the product and existing operational conditions should be evaluated, and applicable international, federal, state, and local regulations should be observed.

In addition, before entering a tank, safety procedures designed by the employer, the terminal operator, and all other concerned parties should also be observed. It shall be indicated that the tank is "Safe for Workers" and/or "Safe for Hot Work", as prescribed in NFPA 306, U.S. Coast

Guard, OSHA, or other international, federal, state, or local regulations that may apply. Such testing shall be made at least every 24 hours or more frequent when conditions warrant.

Furthermore, another person should stand watch at the tank entrance for the duration and sound an alarm if an emergency occurs. Appropriate protective clothing and equipment should be used. Normal safety precautions with respect to staging and ladders shall also be observed.

## 4.5. PART I – SPHERICAL TANKS

### 5.1 Definition of Spherical Tank

A sphere is a stationary liquid storage tank, supported on columns so that the entire tank shell is above grade. There are, usually, no internal structural members. A typical sphere is shown in Ffigure 1.

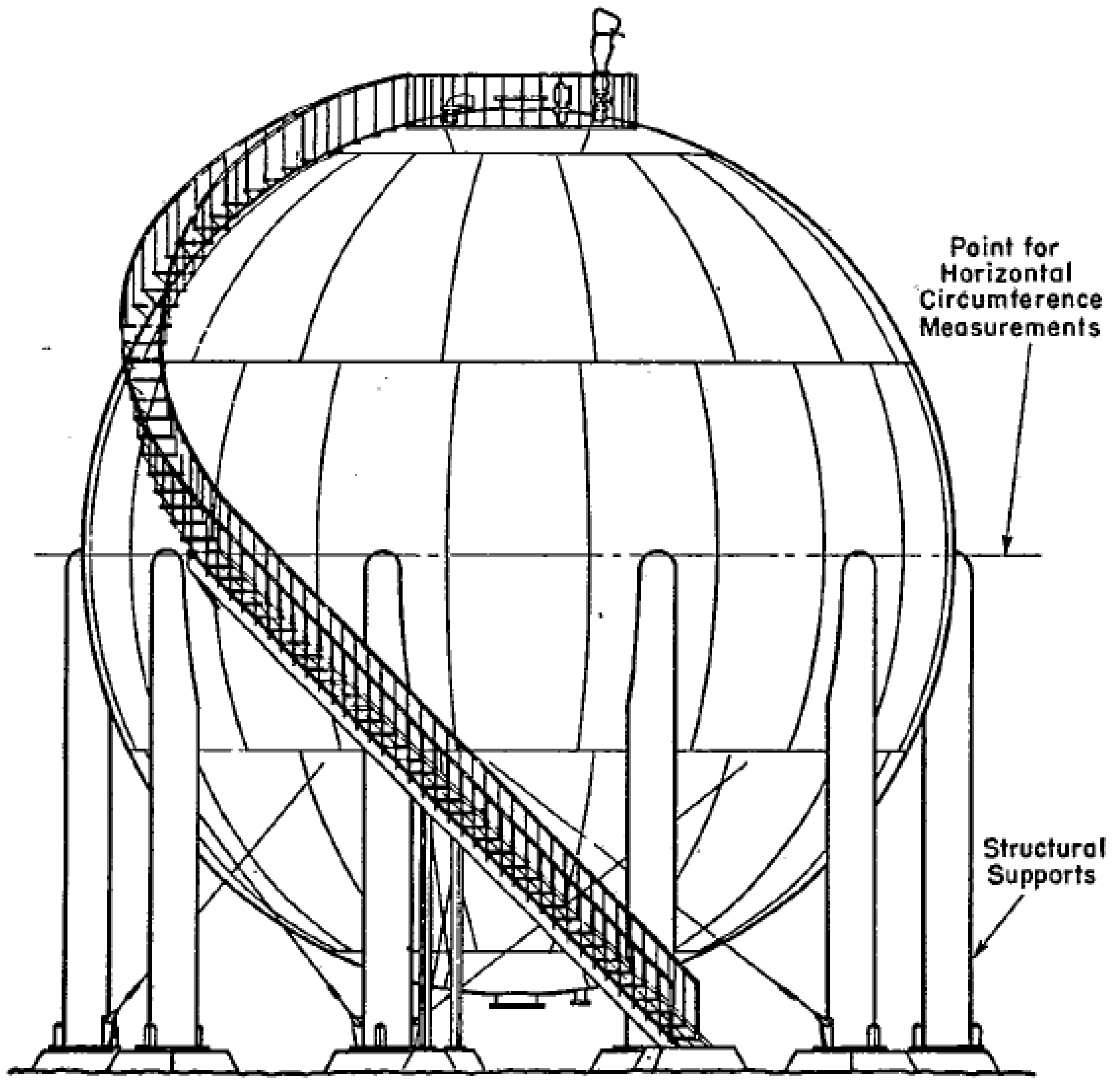


**Figure 1: Spherical Tank**

## 5.2 Tank Status Before Calibration

Before calibration, all tanks should have been filled at least once with a liquid at least as heavy as the liquid to be stored. The interior surface of the tank shall be clean and free from any foreign substance, such as the residue of commodities adhering to the tank shell. All internal and external fixtures (deadwood) should be installed.

## 5.3 Liquid Calibration Methods

Liquid calibration is preferred for any tank, or portion of a tank, not susceptible to adequate or accurate measurement. When visibly distorted, the sphere should be liquid calibrated. Liquid calibration may be performed by meter, or by volumetric containers. If performed by meter, then either water or a product of low volatility such as No. 2 fuel oil shall be used. If volumetric containers are used, the liquid should be water. After the calibration procedure, the capacity table should be prepared in any desired increments using graphs or mathematical methods to establish a smooth curve.

### 5.3.1 Liquid Calibration Equipment

The equipment used for liquid calibrating spherical tanks is the same as that described for upright cylindrical tanks in API Standard 2555~~ – Method for Liquid Calibration of Tanks~~. There will need to be a supply of liquid available to fill the entire tank.

If positive displacement meters are used, a calibration tank or a master meter will need to be placed near the working meters for meter calibration as described for upright cylindrical tanks in the API standard.

Equipment includes one or more meters, meter proving system, water supply, pump, hoses, fittings, and a gauge tape and bob, verified by a master tape.

### 5.3.2 Liquid Calibration by Meter

Initially, the sphere may be either empty or full; calibration should proceed by introducing or withdrawing liquid, respectively. Meter readings should be taken for each inch of the upper 25 percent and the lower 25 percent of the height of the tank and for each 2 inches of the segment height. The increments filled should be measured by means of a tape and bob or by gauge glass readings.

### 5.3.3 Liquid Calibration by Volumetric Containers

When calibrated volumetric containers are used, each container should be no smaller than one-half of the largest 1-inch increment of the sphere and should have a maximum capacity of the largest 1-inch increment of the sphere. Each volumetric container should have been accurately calibrated by NIST (or an equivalent national standard)~~M~~ or State Weights and Measures.

The sphere should be filled with water to the top capacity line. The water should be discharged into volumetric containers where it is accurately measured. Calibrations should be obtained for each inch of the upper 25 percent and the lower 25 percent height of the tank. For the remaining segments between the upper and lower 25 percent, calibrations should be obtained for each 2 inches. The increments discharged should be measured by means of tape and bob or by gauge glass readings and should be smoothed or corrected for the shape of the tank.

## 5.4 Measurement Calibration by Tapes Method

The total volume of the tank is calculated based on three measured external circumferences; one at the horizontal equator and two passing vertically through the poles at right angles to each other. These circumference locations are shown in ~~f~~Figure 2. Partial volumes are then distributed over the measured inside height by a formula or table based on the partial volume versus depth in a true sphere.

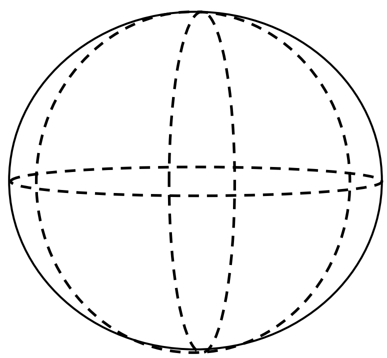

**Figure 2: Circumference Tape Paths**

### 5.4.1 Measurement Calibration Equipment

The equipment used for measuring spherical tanks is the same as that described for upright cylindrical tanks in API~~'s~~ *MPMS* Chapter 2.2A ~~Section 2A – Measurement and Calibration of Upright Cylindrical Tanks by the Manual Tank Strapping Method~~. The measurement of any one tank will not necessarily require the use of all the equipment listed. Therefore, individual tank and measurement procedure should be considered before selecting the equipment.

The equipment should include steel measuring tapes for both height and circumference measurements using the Continuous Wraparound Procedure. These tapes should be calibrated as described for upright cylindrical tanks in API *MPMS* Chapter 2.2A.~~the API standard.~~

### 5.4.2 Measurement Calibration Procedure

Measure the circumference of the horizontal equator using the Continuous Wraparound Procedure. The columns supporting a sphere usually extend a few inches above the equator. Where this occurs, a deduction for circumference tape rise will be required. Strapping poles, or a rope and ring, should be used to set the tape along the tape path. Both ends of the tape can be held by a person on the stairway. The tape should be slid slightly in both directions before the circumference is measured to break the friction and equalize the tension. If the circumference is taken over the support columns, the number of columns ~~must~~shall be counted, the thickness of the column from the tank shell ~~must~~shall be measured, and the width of the columns ~~must~~shall be measured.

It is permissible to make this circumference measurement at a location just above the tops of the columns where the tape path is clear. When this is done, record both the measured circumference and the height above the equator.

Measure the circumference on a vertical path passing through the columns. Both ends of the tape can be held by a person on top or bottom of the tank. The tape should be slid slightly in both directions before the circumference is measured. When a manhole is located at the vertical centerline on top and bottom, the tape path should be on opposite sides of the top and bottom manhole.

Measure the circumference of another vertical path that is perpendicular to the first vertical path.

Measure the total inside height at the vertical centerline of the sphere. If an inside height cannot be measured at the centerline, measure the vertical inside height at a convenient distance from the centerline. Then, using a horizontal level instrument, measure the height from the centerline to the point the height was taken. Take the same measurement on the bottom of the tank. Add the three measurements together to compute the overall height of the tank.

If a manual gauge point exists, physically measure the reference gauge height. Measure all internal and external deadwood.

**5.4.3 Measurement by Tapes Internal Circumference Calculations**

The three external circumferences that were obtained during the measurement calibration procedure shall be converted to three internal circumferences:

If the field measurement of the equator circumference was made over obstructions, first correct the external circumference before converting it to an internal circumference. Compute the deduction that needs to be made to the circumference due to tape rise as follows:

$$D = \frac{2Ntw}{d} + \frac{8Nt}{3} * \sqrt{\frac{t}{d}} \tag{1}$$

D = Deduction in inches
N = Number of obstructions
t = Amount of rise, or thickness of obstruction in inches
w = Width of obstruction in inches
d = Nominal diameter of tank in inches

If the field measurement of the equator circumference was made at a height above the equator to clear the tops of the columns, first correct the external circumference before converting it to an internal circumference. Compute the external circumference at the equator as follows:

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

$C_O$ = Corrected Circumference
C = Measured External Circumference of Equator
H = Height above Equator to Top of Columns

Convert each external circumference to the internal circumference by subtracting the weighted average thickness of the shell plates along each tape path as follows:

$$C_I = External\ Circumference - 2\pi t \tag{3}$$

I = 1, 2, and 3
$C_I$ = Internal Circumference
t = average thickness

Designate the internal circumferences $C_1$ (equator), $C_2$, and $C_3$. The vertical inside height was measured or previously calculated.

### 5.4.5 Volume Calculations

Compute the total volume as follows:

$$V = \frac{C_1 * C_2 * C_3}{6\pi^2} \tag{4}$$

Compute the partial volume at each desired incremental depth as follows:

Let: V = total volume of sphere
G = gauge increment
A = one half of the vertical inside height
H = elevation to bottom of increment.

$$K_1 = \frac{V}{4}\left(\frac{G}{A}\right)\left(3 - \left(\frac{G}{A}\right)^2\right) \tag{5}$$

$$K_2 = \frac{3V}{2}\left(\frac{G}{A}\right)^3 \tag{6}$$

$$M = \frac{A - H}{G} \tag{7}$$

For the bottom increment, H=0, and M is reduced to A/G. The volume at the bottom increment is as follows:

$$M = \frac{A}{G} \tag{8}$$

$$V_{hm} = K_1 - \frac{(M^2 - M)K_2}{2} \tag{9}$$

For each succeeding increment:

$$V_m = V_{m+1} + MK_2 \tag{10}$$

$$V_{h+1} = V_h + MK_2 \tag{11}$$

The volume of each increment above the bottom increment is MK2 greater than that of the increment directly below.

### 5.4.6 Capacity Table

Complete the capacity table by totaling the net incremental volumes starting at the lowest point in the sphere. Correct for deadwood. All deadwood should be accurately accounted for as to volume and location. If gauging is performed on a datum plate, adjust the volume at zero gauge and the remaining increments accordingly.

The capacity table may be prepared in any desired unit and increment. The capacity table should include the volume below the datum plate or bottom capacity line. The capacity table should state the measurement method used for calibration, along with the date of the calibration.

## 5.5 Internal Electro Optical Calibration Method

The total volume of the tank is calculated based on three computed internal circumferences; one at the horizontal equator and two passing vertically through the poles so that one is perpendicular to the other. Partial volumes are then distributed over the measured inside height by a formula or table based on the partial volume versus depth in a true sphere.

### 5.5.1 Internal Electro Optical Calibration Equipment

The equipment used for measuring spherical tanks is the same as that described for upright cylindrical tanks in API~~'s~~ *MPMS* Chapter 2.2D ~~Section 2D – Calibration of Upright Cylindrical Tanks Using the Electro-optical Distance Ranging Method~~. The Total Station should be calibrated as described for upright cylindrical tanks in API *MPMS* Chapter 2.2D~~the API standard~~.

### 5.5.2 Internal Electro Optical Calibration Procedure

The Total Station shall be set up inside the tank, in ato be stable and leveled position, at the point directly over the bottom centerline of the tank. Using the downward laser pointer on the instrument, or a plumb line attached to the bottom of the instrument, continue to adjust the tripod and relevel the instrument until this position is achieved.

When the Total Station is leveled at this location, switch on the instrument, bring to its operating temperature, and carry out the appropriate procedure given in Annexppendix A – Field Equipment Verification.

Using the instruments laser pointer, position the scope to take measurements at any point on the tank equator. Measure the Horizontal Distance and the Vertical Distance to this point. Adjust the instrument horizontally 45 degrees along the equator. Measure the Horizontal Distance and the Vertical Distance to this point. Continue this procedure until eight stations have been measured around the equator of the tank. These measurements will be used to compute the internal circumference at the equator.

Position the scope to take measurements near the original point on the tank equator. Measure the Horizontal Distance and the Vertical Distance to this point. Adjust the instrument vertically to a point halfway between the equator and the top of the tank. Measure the Horizontal Distance and the Vertical Distance to this point. Adjust the instrument vertically to the top of the tank. Measure the Vertical Distance (the Horizontal Distance will be zero). Continue rotating the scope vertically around the tank, measuring the Horizontal Distance and the Vertical Distance at a point halfway between the equator and the top of the tank, at the equator, and two halfway between the equator and the bottom of the tank. Then, with a tape, measure from the tank bottom to the center point of the scope. These eight measurements will be used to compute the internal circumference of the first vertical loop.
Position the scope to take measurements on the tank equator, at a point that is 90 degrees horizontally from the original point. Measure the Horizontal Distance and the Vertical Distance to this point. Repeat the steps mentioned in the previous paragraph. These eight measurements will be used to compute the internal circumference of the second vertical loop.

The measurements to the top of the tank and to the bottom of the tank will be used to compute the total inside height of the sphere.

All target points shall be at least 1 foot from any welded seam.

If a manual gauge point exists, physically measure the reference gauge height. Measure all internal and external deadwood.

### 5.5.3 Internal Electro Optical Circumference Calculations

Average the eight Horizontal Distance measurements taken at the equator. This is the average radius of the sphere's equator. Compute the internal circumference at the equator.

$$C_I = 2\pi r \tag{12}$$

$C_I$ = internal circumference
rR = average radius

Average the eight Vertical Distance measurements taken at the equator. This is the average height from the Total Station to the center of the tank. Subtract this vertical height from the Vertical Height measurement of each target point from the vertical loops individually. The absolute value of these calculations will be the vertical height of each target point from the center of the tank. The Horizontal Distance measurement of each target point from the vertical loops are the horizontal distance of each target point from the center of the tank. The radius of each target point is calculated as follows:

$$R = \sqrt{H^2 + V^2} \tag{13}$$

R = radius to each individual target point
H = horizontal distance to each individual target point
V = calculated vertical height to each individual target point

Average the eight radii in the first vertical loop. Compute the internal circumference. Average the eight radii in the second vertical loop. Compute the internal circumference.

Designate the corrected circumferences $C_1$, $C_2$, and $C_3$.

Compute the inside height of the tank by adding the Vertical Distance measurement to the top of the tank and the tape measurement from the tank bottom to the center point of the scope.

### 5.5.4 Volume Calculations

Compute the total volume as follows:

$$V = \frac{C_1 * C_2 * C_3}{6\pi^2} \tag{14}$$

Compute the partial volume at each desired incremental depth as follows:

Let: V = total volume of sphere
G = gauge increment
A = one half of the vertical inside height
H = elevation to bottom of increment.

$$K_1 = \frac{V}{4}\left(\frac{G}{A}\right)\left(3 - \left(\frac{G}{A}\right)^2\right) \tag{15}$$

$$K_2 = \frac{3V}{2}\left(\frac{G}{A}\right)^3 \tag{16}$$

$$M = \frac{A - H}{G} \tag{17}$$

For the bottom increment, H=0, and M is reduced to A/G. The volume at the bottom increment is as follows:

$$M = \frac{A}{G} \tag{18}$$

$$V_{hm} = K^1 - \frac{(M^2 - M)K_2}{2} \tag{19}$$

For each succeeding increment:

$$V_m = V_{m+1} + MK_2 \tag{20}$$

$$V_{h+1} = V_h + MK_2 \tag{21}$$

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

### 5.5.5 Capacity Table

Complete the capacity table by totaling the net incremental volumes starting at the lowest point in the sphere. Correct for deadwood. All deadwood should be accurately accounted for as to volume and location. If gauging is performed on a datum plate, adjust the volume at zero gauge and the remaining increments accordingly.

The capacity table may be prepared in any desired unit and increment. The capacity table should include the volume below the datum plate or bottom capacity line. The capacity table should state the measurement method used for calibration, along with the date of the calibration.

## 5.6 External Electro Optical Calibration Method

The total volume of the tank is calculated based on three computed external circumferences; one at the horizontal equator and two passing vertically through the poles perpendicular to each other (vertical loops). Partial volumes are then distributed over the calculated inside height by a formula or table based on the partial volume versus depth in a true sphere.

### 5.6.1 External Electro Optical Calibration Equipment

The equipment used for measuring spherical tanks is the same as that described for upright cylindrical tanks in API~~'s~~ *MPMS* Chapter 2.2D ~~Section 2D – Calibration of Upright Cylindrical Tanks Using the Electro-optical Distance Ranging Method~~. The Total Station should be calibrated as described for upright cylindrical tanks in API *MPMS* Chapter 2.2D.~~the API standard.~~ Also, a reflective flat scale board and carpenter's level will be used.

### 5.6.2 External Electro Optical Calibration Procedure

The Total Station shall be set up outside the tank, in a ~~to be~~ stable and level~~ed~~ position, at a point away from the tank~~,~~ so that a clear vertical path can be seen to nearly the top and bottom of the tank. This will be called Station 1. There shall be a total of eight stations, 45 degrees apart, starting at Station 1 and moving in a direction around the sphere.

When the Total Station is leveled at this location, switch on the instrument, bring to its operating temperature, and carry out the appropriate procedure given in Annex ~~Appendix A – Field Equipment Verification~~. A reflective flat scale board shall be held vertically, the zero end of the board against the tank bottom, at the center point of the tank. The scale board shall be held plumb with the use of a carpenter’s level.

Looking through the instruments scope, read the scale board at any point on the board. Then measure the Horizontal Distance and the Vertical Distance to this point. Adjust the instrument vertically to a point halfway between the equator and the bottom of the tank. Measure the Horizontal Distance and the Vertical Distance to this point. Adjust the instrument vertically to the equator. Measure the Horizontal Distance and the Vertical Distance to this point. Adjust the instrument vertically to a point halfway between the equator and the top of the tank. Measure the Horizontal Distance and the Vertical Distance to this point.

Stations 2 through 8 will be at similar locations around the tank, so that the vertical stations will be horizontally 45 degrees apart. Repeat the steps mentioned in the previous paragraph at stations 3, 5, and 7. At stations 2, 4, 6, and 8, the measurements at halfway between bottom of tank and equator, and halfway between top of tank and equator can be eliminated. The measurements taken at the equator will be used to compute the external circumference at the equator. The measurements taken on stations 1 and 5 will be used to compute the internal circumference of the first vertical loop. The measurements taken on stations 3 and 7 will be used to compute the external circumference of the second vertical loop.

With the Total Station set up outside the tank and the scale board held against the bottom of the tank, read the scale board through the scope. Then measure the Horizontal Distance and the Vertical Distance to this point. At the top of the tank, hold the scale board vertically, with the zero end of the board against the top of the tank, at the center point of the tank. These measurements will be used to compute the total inside height of the sphere.

All target points shall be at least 1 foot from any welded seam.

If a manual gauge point exists, physically measure the reference gauge height. Measure all internal and external deadwood.

### 5.6.3 Calculations

Compute the internal circumference of the three measured loops around the sphere: the horizontal equator, the first vertical loop, and the second vertical loop.

### 5.6.4 External Electro Optical Circumference Calculations

External equatorial radius: For each station, subtract the Horizontal Distance to the equator from the Horizontal Distance to the scale board. The difference will be the external radius at each station. Average the eight external radii. Compute the external circumference at the equator.

$$C = 2\pi R \tag{22}$$

C = External Circumference
R = average radius

Average vertical height at equator: For each station, find the elevation of the equator by subtracting the Vertical Distance to the scale board and the distance read on the scale board at the base of the tank from the Vertical Distance to the equator. These heights will be the vertical height of the equator above the bottom of the sphere at each station.

Vertical height of each target point: On stations 1, 3, 5, and 7, Subtract the Vertical Distance at halfway between the equator and the bottom from the Vertical Distance of the equator. Subtract the Vertical Distance of the equator from the Vertical Distance at halfway between the equator and the top. The absolute value of these calculations will be the vertical height of each target point from the center of the tank.

External vertical height of tank: Calculate the vertical height of the tank by using the scale board readings from paragraph 4 in the Procedure section. Subtract the scale board reading at the bottom of the tank and the scale board reading at the top of the tank and the Vertical Distance to the bottom scale board from the Vertical Distance to the top scale board. This is the external height of the tank. Calculate the vertical height from the center of the tank to the top of the tank by subtracting the average height of the equators from the height of the tank.

Horizontal distance to each target point: On stations 1, 3, 5, and 7, Subtract the Horizontal Distance at the equator from the Horizontal Distance at halfway between the equator and the bottom. Subtract the Horizontal Distance at the equator from the Vertical Distance at halfway between the equator and the top. The absolute value of these calculations will be the horizontal distance of each target point from the center of the tank. The horizontal distance for the top of the tank and the bottom of the tank is zero. The radius of each target point is calculated as follows:

$$R = \sqrt{H^2 + V^2} \tag{23}$$

R = radius to each individual target point
H = calculated horizontal distance to each individual target point
V = calculated vertical height to each individual target point

Compute the internal circumference at the equator. Average the eight radii in the first vertical loop. Compute the internal circumference. Average the eight radii in the second vertical loop. Compute the internal circumference.

Designate the corrected circumferences $C_1$, $C_2$, and $C_3$.

Compute the inside height of the tank by subtracting the sum of the bottom plate thickness and the top plate thickness from the computed external vertical height of the tank.

**5.6.5 Volume Calculations**

Compute the total volume as follows:

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

(24)

Compute the partial volume at each desired incremental depth as follows:

Let: V = total volume of sphere
G = gauge increment
A = one half of the vertical inside height
H = elevation to bottom of increment.

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

(25)

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

(26)

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

(27)

For the bottom increment, H=0, and M is reduced to A/G. The volume at the bottom increment is as follows:

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

(28)

$$V_{hm} = K_1 - \frac{(M^2 - M)K_2}{2}$$

(29)

For each succeeding increment:

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

(30)

$$V_{h+1} = V_h + MK_2$$

(31)

The volume of each increment above the bottom increment is MK2 greater than that of the increment directly below.

**5.6.6 Capacity Table**

Complete the capacity table by totaling the net incremental volumes starting at the lowest point in the sphere. Correct for deadwood. All deadwood should be accurately accounted for as to volume and location. If gauging is performed on a datum plate, adjust the volume at zero gauge and the remaining increments accordingly.

The capacity table may be prepared in any desired unit and increment. The capacity table should include the volume below the datum plate or bottom capacity line. The capacity table should state the measurement method used for calibration, along with the date of the calibration.

### 5.7 High Definition Survey Systems Method

A high definition survey system (HDSS) is a type of electro-optical distance ranging system that is used to scan a tank, record the image as a cloud of (x,y,z) coordinates, and produce a 3-D model of the tank. The total volume, cap volumes, and segment volume are computed using distance measurements between those (x, y, z) points in the cloud and reference the volume to the strike point within the tank.

#### 5.7.1 High Definition Survey Systems Equipment

The equipment used in a HDSS includes a scanner and computer aided design (CAD) software for computing distance measurements between (x, y, z) points and the strike point.

System accuracy shall have or use

- a compensator which assures that the point cloud model is plumb and level within +/-2 seconds of a degree.
- range of accuracy of 2mm +/- 10 ppm over full range
- angular accuracy of 8 seconds horizontally and vertically
- 3-D position accuracy of 3 mm at 50 m~~M~~ and 6 mm at 100 m~~M~~
- a target acquisition of +/-2 mm standard deviation at 50 m~~M~~
- Class 1 laser
- field of view of 360° horizontal and 290° vertical
- distance measuring with a +/- 2mm accuracy

A Stadia Rod will be used for field verification of the HDSS. A master working tape, as described in API~~'s~~ *MPMS* Chapter 2.2A~~ Section 2A – Measurement and Calibration of Upright Cylindrical Tanks by the Manual Tank Strapping Method~~ ~~will~~should be used to verify the stadia rod.

#### 5.7.2 Internal High Definition Scanning Procedure

Determine the location of at least two stations inside the tank to capture a 360 degree horizontal and vertical model. The tank surface shall be dry and free of vibration. Determine station layout, or survey workflow, to acquire all viewpoints of the tank shell including top and bottom. The HDSS shall be set up inside the tank, in a~~to be~~ stable and level~~ed~~ position, at one of the stations. Equipment shall be set up in accordance with the manufacturer's instructions. If targets are required for registering, targets shall be attached to the inside walls of the sphere, in a fashion that at least two sets of targets can be seen at each station. Targets should be placed at random elevations. Place the stadia rod inside the tank, either against tank shell or on supports, and visible from the first station. Perform a scan of the tank. Density of the scan shall be a minimum of 3.1mm : 10m. Move the equipment to another station and level. If using targets, at least one target from the previous scan, and another target, ~~must~~shall be visible. Perform a scan of the tank. Continue this process at each pre-determined station.

If a manual gauge point exists, physically measure the reference gauge height. It is recommended to physically measure all internal and external deadwood.

### 5.7.3 External High Definition Scanning Procedure

Determine the location of multiple external stations around the tank to capture a 360-degree horizontal and vertical model. The tank surface shall be dry and free of vibration. Determine station layout, or survey workflow, to acquire all viewpoints of the tank shell including top and bottom. The HDSS shall be set up in ato be stable and leveled position, at one of the stations. Equipment shall be set up in accordance with the manufacturer's instructions. If targets are required for registering, place targets on or near the tank in a fashion that at least two sets of targets can be seen at each station. Targets should be placed at random elevations. Place the stadia rod near the tank and visible from the first station. Perform a scan of the tank. Density of the scan shall be a minimum of 3.1mm : 10m. Move the equipment to another station and level. If using targets, at least one target from the previous scan, and another target, mustshall be visible. Perform a scan of the tank. Continue this process at each pre-determined station.

If a manual gauge point exists, physically measure the reference gauge height. It is recommended to physically measure all internal and external deadwood.

### 5.7.4 High Definition Survey Systems Exporting Data

Data shall be exported or transferred from the scanning software to complementary software that offers point cloud data management, 3-D modeling and data analytics. Minimally, (x,y,z) coordinates, known directional coordinates, and target coordinates and labels shall be exported in units of measure that are the same as the units of measure that will be used when importing data to the modeling and analytics software.

### 5.7.5 High Definition Survey Systems Data Management

Station Registration, or Data Alignment, from the scanning process shall be used to register, or align data from multiple scans. Clean or manage the point cloud in order to produce an accurate data set of (x,y,z) points for a sphere. The cleaning process shall involve removing noise from the point cloud that arises in the scanning process due to the position of the scanner, angle of inclination, and/or the presence of deadwood or other structures that block the view of the scanner.

After the cleaning process, data resulting from the scanning of the tank mustshall be registered to the point cloud and meshed into a solid, spherical object before coordinates can be used to measure distances. After meshing occurs, coordinates can be exported to a spreadsheet, resulting in thousands, or millions of (x,y,z) coordinates representing the tank shell and deadwood structures, and its reference to the strike point.

Horizontal and vertical angles, and distance-ranging shall be verified by comparing the actual length of the stadia rod, as measured by the master working tape, to the digital measurement of the stadia rod. The difference in lengths should not be more than +/-2 mm.

### 5.7.6 High Definition Survey Systems Volume Calculations

HDSS and complementary point cloud modeling and analytics software are used to visualize and to calculate cap volumes, segment volumes, and total volume. Many of the processes for calculations and analysis are automated.

#### ~~4.7.6.1~~5.7.6.1 Total Volume of a Sphere

The formula for the volume of a sphere is

$$V = \frac{4}{3}\pi abc \tag{32}$$

Where,

a = horizontal radius (x-axis)
b = vertical radius (y-axis)
c = height radius (z-axis)

Using the (x,y,z) coordinate file for the sphere, find the absolute values of the minimum and maximum X, Y, and Z coordinates. Sum the absolute values of min(X) and max(X) and divide by two to get the horizontal radius. Use the same approach for finding the lengths of the vertical and height radii.

$$a = \frac{|\min(x)| + |\max(x)|}{2} \tag{33}$$

#### ~~4.7.6.2~~5.7.6.2 Volume of the Bottom Spherical Cap

$$V = \pi ab\left(\frac{2c}{3} - x + \frac{x^3}{3c^2}\right) \tag{34}$$

where

V is the volume of the cap, a, b and c are lengths of the semi-axes, x = c – h, and h is the height of the bottom cap.

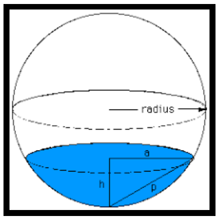


**Figure 3: Bottom Spherical Cap**

The same values for a, b, and c that were used to calculate total volume of a sphere shall be used to calculate the volume of the bottom cap of the sphere.

The height of the bottom cap, h, shall be equal to the distance between the strike point to the lowest elevation of the tank. The height shall be determined by taking the absolute value of the lowest elevation indicated by the minimum z coordinate in the point cloud of the tank.

### ~~4.7.6.3~~5.7.6.3 Volume of the Top Spherical Cap

$$V = \pi ab\left(\frac{2c}{3} - x + \frac{x^3}{3c^2}\right)$$

(35)

-where

V is the volume of the cap, a, b and c are lengths of the semi-axes, x = c – h, and h is the height of the top cap.

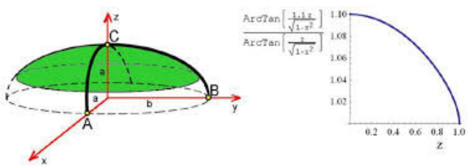


**Figure 4: Top Spherical Cap**

The same values for a, b, and c that were used to calculate total volume of the sphere shall be used to calculate the volume of the top cap of the sphere. However, the height of the top cap, h, is the fraction of a segment remaining after a series of equal segments starting from the top of the bottom cap and moving upward have been measured.

### ~~4.7.6.4~~5.7.6.4 Incremental Volume of a Sphere

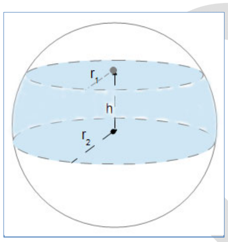


**Figure 5: Incremental Volume Sample**

For calculating incremental volume, HDSS shall model its data to fit a sphere. The modeler sets the segment height and other parameters, and the software produces a table of incremental volumes. This process corresponds to calculations facilitated by using spreadsheet functions and the formula for midsegment volume of a sphere to find incremental volume of a sphere as follows:

The volume of the $i^{th}$ segment, $V_i$, of a sphere with *n* midsegments is

$$V = \pi\left(\frac{h}{6}\right)\left(3r_i^2 + 3r_{i+1}^2 + h^2\right) \tag{36}$$

where h is the height of the segment, $r_i$ is the radius of the top of the segment and $r_{i+1}$ is the radius of the bottom of the segment for *i = 1, 2, 3, 4… n.*

### 5.7.7 Capacity Table

The total volume calculated in section 5.7.6.2, Bottom Spherical Cap, represents the total volume at the beginning of the capacity table, zero gauge. The incremental volumes calculated in section 5.7.6.4 are used to create the volumes from the zero gauge to the top of the tank. Complete the capacity table by adding the volume calculated in section 5.7.6.3, Top Spherical Cap, as the last increment. Correct for deadwood. All deadwood should be accurately accounted for as to volume and location.

The capacity table may be prepared in any desired unit and increment. The capacity table should include the volume below the datum plate or bottom capacity line. The capacity table should state the measurement method used for calibration, along with the date of the calibration.

### 5.8 Effect of Thermal Changes on Spherical Tank Shells

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

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

The coefficient, K, is based upon a low-carbon steel having a coefficient of thermal expansion of 0.00000065 per degree F. When the tank is constructed of a different metal, the coefficient of expansion shall be calculated in accordance with industry accepted values~~Appendix III~~.

For non-insulated metal tanks, the temperature of the shell may be taken as the average of the adjacent liquid and ambient air temperature on the inside and outside of the shell at the same location. In applying these principles to both spheres and spheroids, only the horizontal dimensions are functions of tank calibration corrections. The liquid height dimension is a function of gauging the liquid level; accordingly, the effect of thermal expansion or contraction on innage and ullage gauge readings should be considered separately.

### 5.9 Re-Calibration

Spherical tanks should be re-calibrated as a result of the following conditions:

1. When the deadwood is changed or altered inside the tank.
2. When the tank is repaired or changed in any manner which may affect the total incremental volume.
3. When the tank is moved.

## 6. ~~PART II –~~ SPHEROIDAL TANKS

### 6.1 Definition

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

A smooth spheroid, shown in Figure 6~~figure 3~~, usually has no inside structural members to support the shell or roof.

A noded spheroid, shown in Figure 7~~figure 4~~, has abrupt breaks in the vertical curvature called nodes which are supported by a circular girder and structural members inside the tank.

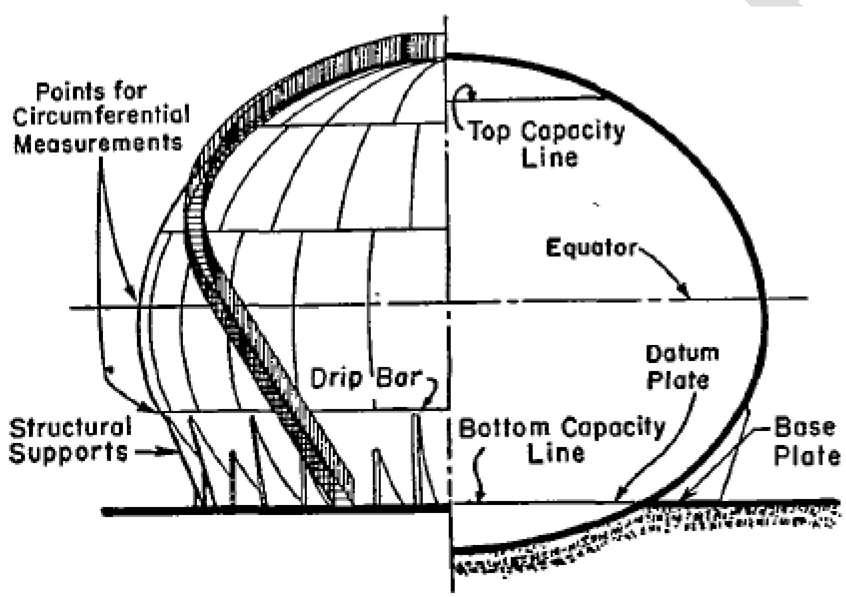


**Figure 6: Smooth Spheroidal Tank**

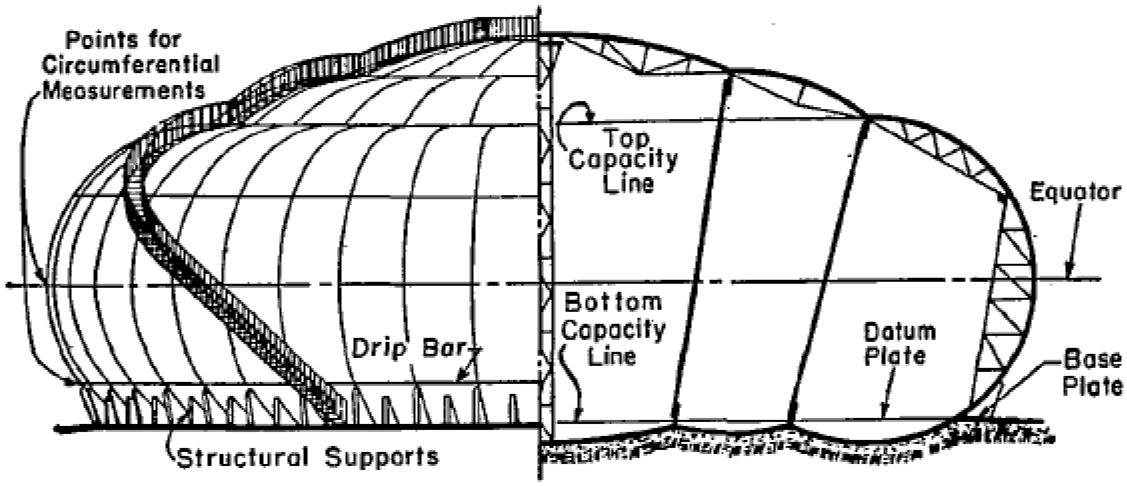


**Figure 7: Noded Spheroidal Tank**

### 6.2 Tank Status Before Calibration

Before calibration, all tanks should have been filled at least once with a liquid at least as heavy as the liquid to be stored.

### 6.3 Volume Below Bottom Capacity Line

In a noded spheroid, a datum plate should be installed at, or above, the bottom capacity line. In noded spheroids, a circular girder at the bottom node forms a dam which at very low levels would permit the product surface or the interface surface of a water bottom to stand at different levels at the bottom troughs. The main calibration table should be based from the datum plate. If a datum plate is not installed, the zero gauge, or gauge datum, should coincide with the level of the bottom capacity line.

The volume below the datum plate or the bottom capacity line should be noted on the capacity table. If the Liquid Calibration Method is used, this volume is measured. If the tank is not liquid calibrated, and if it is possible to enter the tank, this volume should be computed based on level elevations measured at various points on the bottom portion of the tank. Set a level instrument on a sturdy spot inside the tank. Measure survey elevations at the center of the tank and on the datum plate. Measure elevations at the bottom capacity line at eight equidistant points. Measure elevations on the lowest point of each node at eight equidistant points, along with the horizontal distance from center. Measure elevations on the highest point on the rim of each node at eight equidistant points, along with the horizontal distance from center. Use these measurements to compute the volume of each annular shaped node and the center node. If the tank cannot be entered, this volume may be computed based on the elevations given in the builder's drawings. If a supplement table, giving incremental volumes below the datum plate or the bottom capacity line is required, the elevation of the lowest point at which the water level will equalize between nodes should be noted on the supplement table. If a dam plate or weir is used to keep water away from the outlet connection, its elevation should be noted on the supplement table.

### 6.4 Liquid Calibration Method

Liquid calibration is preferred for any tank, or portion of a tank, not susceptible to adequate or accurate measurement. When visibly distorted, the spheroid should be liquid calibrated. Liquid calibration may be performed by meter or by volumetric containers. Either water or a product of low volatility such as No. 2 fuel oil shall be used. If volumetric containers are used, the liquid should be water. After the calibration procedure, the capacity table should be prepared in any desired increments using graphs or mathematical methods to establish a smooth curve.

### 6.4.1 Liquid Calibration Equipment

The equipment used for liquid calibrating spheroidal tanks is the same as that described for upright cylindrical tanks in API Standard 2555 – Method for Liquid Calibration of Tanks. There will need to be a supply of liquid available to fill the entire tank.

If positive displacement meters are used, a calibration tank or a master meter will need to be placed near the working meters for meter calibration as described for upright cylindrical tanks in the API standard.

### 6.4.2 Liquid Calibration by Meter

Initially, the spheroid may be either empty or full; calibration should proceed by introducing or withdrawing liquid, respectively. Meter readings should be taken for each inch of the upper 25 percent and the lower 25 percent of the height of the tank and for each 2 inches of the segment height. The increments filled should be measured by means of a tape and bob or by gauge glass readings.

### 6.4.3 Liquid Calibration by Volumetric Containers

When calibrated volumetric containers are used, each tank should be no smaller than one-half of the largest 1-inch increment of the sphere and should have a maximum capacity of the largest 1-inch increment of the spheroid. Each volumetric container should have been accurately calibrated by NIST (or an equivalent national standard)M or State Weights and Measures.
The spheroid should be filled with water to the top capacity line. The water should be discharged into volumetric containers where it is accurately measured. Calibrations should be obtained for each inch of the upper 25 percent and the lower 25 percent height of the tank. For the remaining segments between the upper and lower 25 percent, calibrations should be obtained for each 2 inches The increments discharged should be measured by means of tape and bob or by gauge glass readings and should be smoothed or corrected for the shape of the vessel.

### 6.5 Measurement Calibration by Tapes Method

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

### 6.5.1 Measurement Calibration Equipment

The equipment used for measuring spheroidal tanks is the same as that described for upright cylindrical tanks in API's *MPMS* Chapter 2.2A Section 2A – Measurement and Calibration of Upright Cylindrical Tanks by the Manual Tank Strapping Method. The measurement of any one tank will not necessarily require the use of all the equipment listed. Therefore, individual tank and measurement procedure should be considered before selecting the equipment.

The equipment should include steel measuring tapes for both height and circumference measurements using the Continuous Wraparound Procedure. These tapes should be calibrated as described for upright cylindrical tanks in API *MPMS* Chapter 2.2A the API standard.

### 6.5.2 Measurement Calibration Procedure

Measure the circumference of the horizontal equator using the Continuous Wraparound Procedure. Strapping poles, or a rope and ring, should be used to set the tape along the tape path. Both ends of the tape can be held by a person on the stairway. The tape should be slid slightly in both directions before the circumference is measured to break the friction and equalize the tension.

Measure the circumference on the shell at the upper edge of the drip bar using the Continuous Wraparound Procedure. Both ends of the tape can be held by a person on the stairway. The tape should be slid slightly in both directions before the circumference is measured to break the friction and equalize the tension.

Measure the total inside height at the vertical centerline of the sphere. If an inside height cannot be measured at the centerline, measure the vertical inside height at a convenient distance from the centerline. Then, using a horizontal level instrument, measure the height from the centerline to the point the height was taken. Take the same measurement on the bottom of the tank. Add the three measurements together to compute the overall height of the tank.

Using a horizontal level instrument, survey the interior tank bottom along eight equidistant radial paths. The points along the paths should start at the bottom capacity line and continue to the center of the tank. Survey points should be chosen to represent enough data to compute the volume of this area. Due to the difference in shape of a smooth spheroid and noded spheroid, more survey points should be performed on a noded spheroid to get the true configuration.

Measure all internal and external deadwood.

### 6.6 Internal Electro Optical Calibration Method

The total volume of the tank is calculated based on computed internal circumferences; one at the horizontal equator, a circumference every two feet in height below the equator, and a circumference every two feet in height above the equator. The incremental volume at the measured elevations will be computed. The incremental volumes at the intervening elevations are calculated and adjusted to conform to the measured circumferences.

### 6.6.1 Internal Electro Optical Calibration Equipment

The equipment used for measuring spheroidal tanks is the same as that described for upright cylindrical tanks in API~~'s~~ *MPMS* Chapter 2.2D~~ Section 2D – Calibration of Upright Cylindrical Tanks Using the Electro-optical Distance Ranging Method~~. The Total Station should be calibrated as described for upright cylindrical tanks in API *MPMS* Chapter 2.2D.~~the API standard.~~

### 6.6.2 Internal Electro Optical Calibration Procedure

The Total Station shall be set up inside the tank, in a~~to be~~ stable and level~~ed~~ position, at the point directly over the bottom centerline of the tank. Using the downward laser pointer on the instrument, or a plumb line attached to the bottom of the instrument, continue to adjust the tripod and relevel the instrument until this position is achieved.

When the Total Station is leveled at this location, switch on the instrument, bring to its operating temperature, and carry out the appropriate procedure given in Annex~~ppendix~~ A~~ – Field Equipment Verification~~.

Using the instruments laser pointer, position the scope to take measurements at any point on the tank equator. Measure the Horizontal Distance and the Vertical Distance to this point. Rotate the instrument horizontally 45 degrees along the equator. Measure the Horizontal Distance and the Vertical Distance to this point. Continue this procedure until eight stations have been measured around the equator of the tank. These measurements will be used to compute the internal circumference at the equator.

Position the scope to the original point on the tank equator. Using the original Vertical Distance to this point as reference, lower the scope till the Vertical Distance is two feet lower than the original Vertical Distance. Measure the Horizontal Distance and the Vertical Distance to this point. Rotate the instrument horizontally 45 degrees along this horizontal path. Measure the Horizontal Distance and the Vertical Distance to this point. Continue this procedure until eight stations have been measured around this horizontal path. These measurements will be used to compute the internal circumference at the computed vertical elevation.

Repeat the steps mentioned in the previous paragraph, lowering the scope an additional two feet in elevation before taking measurements on the horizontal path. Continue this process till the horizontal path is at the bottom capacity line.

Position the scope to the original point on the tank equator. Using the original Vertical Distance to this point as reference, raise the scope till the Vertical Distance is two feet higher than the original Vertical Distance. Repeat the previous steps mentioned, measuring all eight points along the horizontal paths, and raising the scope an additional two feet in elevation in between each horizontal path. Continue this process till the horizontal path is at the top capacity line.

Rotate the scope vertically to the top of the tank. Measure the Vertical Distance. With a tape, measure from the tank bottom to the center point of the scope. The measurement to the top of the tank and to the bottom of the tank will be used to compute the total inside height of the spheroid.

All target points shall be at least 1 foot from any welded seam.

Using a horizontal level instrument, survey the interior tank bottom along eight equidistant radial paths. The points along the paths should start at the bottom capacity line and continue to the center of the tank. Survey points should be chosen to represent enough data to compute the volume of this area. Due to the difference in shape of a smooth spheroid and noded spheroid, more survey points should be performed on a noded spheroid to get the true configuration.

Measure all internal and external deadwood.

### 6.7 External Electro Optical Calibration Method

The total volume of the tank is calculated based on computed external circumferences; one at the horizontal equator, a circumference every two feet in height below the equator, and a circumference every two feet in height above the equator. The incremental volume at the measured elevations will be computed. The incremental volumes at the intervening elevations are calculated and adjusted to conform to the measured circumferences.

### 6.7.1 External Electro Optical Calibration Equipment

The equipment used for measuring spherical tanks is the same as that described for upright cylindrical tanks in API~~'s~~ *MPMS* Chapter 2.2D ~~Section 2D – Calibration of Upright Cylindrical Tanks Using the Electro-optical Distance Ranging Method~~. The Total Station should be calibrated as described for upright cylindrical tanks in API *MPMS* Chapter 2.2D~~the API standard~~. Also, a reflective flat scale board and carpenter's level will be used.

### 6.7.2 External Electro Optical Calibration Procedure

The Total Station shall be set up outside the tank, in a~~to be~~ stable and level~~ed~~ position, at a point away the tank, and a clear vertical path can be seen to nearly the top of the tank. This will be called station 1. When the Total Station is leveled at this location, switch on the instrument, bring to its operating temperature, and carry out the appropriate procedure given in Annex~~ppendix~~ A ~~– Field Equipment Verification~~. A reflective flat scale board shall be held vertically, the zero end of the board against the top of the tank, at the center point.

Looking through the instruments scope, read the scale board at any point on the board. Then measure the Horizontal Distance and the Vertical Distance to this point. Rotate the instrument vertically to the equator. Measure the Horizontal Distance and the Vertical Distance to this point. Using the Vertical Distance at the equator as reference, lower the scope till the Vertical Distance is two feet lower than the equator. Measure the Horizontal Distance and the Vertical Distance to this point. Continue lowering the scope and measuring the Horizontal Distance and the Vertical Distance every two feet till a measurement is taken at the bottom capacity line.

Using the Vertical Distance at the equator as reference, raise the scope till the Vertical Distance is two feet above the equator. Measure the Horizontal Distance and the Vertical Distance to this point. Continue raising the scope and measuring the Horizontal Distance and the Vertical Distance every two feet till a measurement is taken at the top capacity line.

Stations 2 through 8 will be at similar locations around the tank, so that the vertical stations will be horizontally 45 degrees apart. Repeat the steps mentioned in the previous paragraph at all eight stations. The measurements taken at the equator will be used to compute the external circumference at the equator. The measurements taken along each horizontal path, in two feet vertical intervals will be used to compute the external circumference of each horizontal path. The vertical heights measured to the scale board, the vertical heights measured to the equator, and the actual scale board reading will be used to compute the total external height of the spheroid.

All target points shall be at least 1 foot from any welded seam.

Using a horizontal level instrument, survey the interior tank bottom along eight equidistant radial paths. The points along the paths should start at the bottom capacity line and continue to the center of the tank. Survey points should be chosen to represent enough data to compute the volume of this area. Due to the difference in shape of a smooth spheroid and noded spheroid, more survey points should be performed on a noded spheroid to get the true configuration.

Measure all internal and external deadwood.

### 6.7.3 Measurement Method and Electro Optical Method Calculations

If the tank is strapped internally, compute the internal height of the tank from the vertical measurements performed inside the tank. If the tank is strapped externally, compute the internal height of the tank by subtracting the average vertical distance to the equator from the average vertical height to the scale board. From this difference, subtract the average scale board reading and the plate thickness of the top plate. This will be the internal height from the equator to the top of the tank. Multiply this height by 2 to get the total tank height.

If the tank is strapped internally, all measurements taken on the tank shell are the horizontal internal radii for each corresponding horizontal circumference. If the tank is strapped externally, all measurements taken on the tank shell need to be converted to internal radii. At each vertical station, subtract each shell horizontal measurement from the scale board horizontal measurement. Subtract the plate thickness from this difference. This is the horizontal internal radius of the corresponding horizontal circumference. Use the plate thicknesses from the builder's drawings or from the most recent inspection report. The plate thickness may be different for each measurement.

Compute the average internal radius for each horizontal circumference. These horizontal circumferences are at the equator, every two feet vertically below the equator, and every two feet vertically above the equator. Using these internal radii, compute the internal radius of each one-inch increment of height above the capacity line by using proportional values between two known radii.

$$A = \frac{R_2 - R_1}{24} \tag{37}$$

Where,

$R_1$ = Known Radius at Known Elevation
$R_2$ = Known Radius at 2 Ft. Above Elevation of $R_1$

The first Radius above $R_1$ = $R_1$ + A

The second Radius above $R_1$ = $R_1$ + 2A
Etc.

Continue this process for each two-foot interval until there is a known radius for each vertical inch from the bottom capacity line to the top capacity line, or to the top of the tank.

Compute the volume of each one-inch vertical increment.

$$V_i = \pi(R_i)^2$$

(38)

For a smooth spheroid, calculate the total volume of the tank using the internal radius at the equator and the internal tank height.

$V_t$ = total volume of smooth spheroid
R = average horizontal internal radius at equator
H = internal tank height

$$V_t = \frac{4\pi R^2 H}{6}$$

(39)

Then compute the sum of all the incremental volumes created for each one-inch vertical increment.

$$V_s = \sum V_{i1} + V_{i2} + \cdots$$

(40)

Calculate a correction factor for the incremental volumes by dividing the total volume by the summation volume.

$$Factor = \frac{V_t}{V_s}$$

(41)

Adjust all the one-inch vertical increments of the smooth spheroid by multiplying the increment by this factor. This correction factor procedure can only be used on the noded spheroid if the total volume of the spheroid is known or can be calculated using mathematical methods.

### 6.7.4 Capacity Table

The volume calculated below the datum plate or bottom capacity line is not included on the capacity table. The zero gauge will not contain a volume. Complete the capacity table by totaling the net incremental volumes starting at the datum plate or bottom capacity line. Correct for deadwood. All deadwood should be accurately accounted for as to volume and location. On a noded spheroid, the capacity will not extend above the top of the bottom node.

The capacity table may be prepared in any desired unit and increment. The capacity table should include the volume below the datum plate or bottom capacity line as a reference note. The capacity table shall state the measurement method used for calibration, along with the date of the calibration.

## 6.8 High Definition Survey Systems Method

A high definition survey system (HDSS) is a type of electro-optical distance ranging system that is used to scan a tank, record the image as a cloud of (x,y,z) coordinates, and produce a 3-D model of the tank. The total volume, cap volumes, and segment volume are computed using distance measurements between those (x, y, z) points in the cloud and reference the volume to the strike point within the tank.

### 6.8.1 High Definition Survey Systems Equipment

The equipment used in a HDSS includes a scanner and computer aided design (CAD) software for computing distance measurements between (x, y, z) points and the strike point.

System accuracy shall have or use

- a compensator which assures that the point cloud model is plumb and level within +/-2 seconds of a degree.
- range of accuracy of 2mm +/- 10 ppm over full range
- angular accuracy of 8 seconds horizontally and vertically
- 3-D position accuracy of 3 mm at 50 m~~M~~ and 6 mm at 100 m~~M~~
- a target acquisition of +/-2 mm standard deviation at 50 m~~M~~
- Class 1 laser
- field of view of 360° horizontal and 290° vertical
- distance measuring with a +/- 2mm accuracy

A Stadia Rod will be used for field verification of the HDSS. A master working tape, as described in API~~'s~~ *MPMS* Chapter 2.2A ~~Section 2A – Measurement and Calibration of Upright Cylindrical Tanks by the Manual Tank Strapping Method~~ ~~will~~ should be used to verify the stadia rod.

### 6.8.2 Internal High Definition Scanning Procedure

Determine the location of multiple internal stations inside the tank to capture a 360 degree horizontal and vertical model. The tank surface shall be dry and free of vibration. Determine station layout, or survey workflow, to acquire all viewpoints of the tank shell including top and bottom. The HDSS shall be set up inside the tank, in a~~to be~~ stable and level~~ed~~ position, at one of the stations. Equipment shall be set up in accordance with the manufacturer~~'~~'s instructions. If targets are required for registering, targets shall be attached to the inside walls of the sphere, in a fashion that at least two sets of targets can be seen at each station. Targets should be placed at random elevations. Place the stadia rod inside the tank, either against tank shell or on supports, and visible from the first station. Perform a scan of the tank. Density of the scan shall be a minimum of 3.1mm : 10m. Move the equipment to another station and level. If using targets, at least one target from the previous scan, and another target, ~~must~~shall be visible. Perform a scan of the tank. Continue this process at each pre-determined station.

If a manual gauge point exists, physically measure the reference gauge height. It is recommended to physically measure all internal and external deadwood.

### 6.8.3 External High Definition Scanning Procedure

Determine the location of multiple external stations around the tank to capture a 360-degree horizontal and vertical model. The tank surface shall be dry and free of vibration. Determine station layout, or survey workflow, to acquire all viewpoints of the tank shell including top and bottom. The HDSS shall be set up in a~~to be~~ stable and level~~ed~~ position, at one of the stations. Equipment shall be set up in accordance with the manufacturer's instructions. If targets are required for registering, place targets on or near the tank in a fashion that at least two sets of targets can be seen at each station. Targets should be placed at random elevations. Place the stadia rod near the tank and visible from the first station. Perform a scan of the tank. Density of the scan shall be a minimum of 3.1mm : 10m. Move the equipment to another station and level. If using targets, at least one target from the previous scan, and another target, ~~must~~shall be visible. Perform a scan of the tank. Continue this process at each pre-determined station.

If a manual gauge point exists, physically measure the reference gauge height. It is recommended to physically measure all internal and external deadwood.

### 6.8.4 High Definition Survey Systems Exporting Data

Data shall be exported or transferred from the scanning software to complementary software that offers point cloud data management, 3-D modeling and data analytics. Minimally, (x,y,z) coordinates, known directional coordinates, and target coordinates and labels shall be exported in units of measure that are the same as the units of measure that will be used when importing data to the modeling and analytics software.

### 6.8.5 High Definition Survey Systems Data Management

Station Registration, or Data Alignment, from the scanning process shall be used to register, or align data from multiple scans. Clean or manage the point cloud in order to produce an accurate data set of (x,y,z) points for a spheroid. The cleaning process shall involve removing noise from the point cloud that arises in the scanning process due to the position of the scanner, angle of inclination, and/or the presence of deadwood or other structures that block the view of the scanner.

After the cleaning process, data resulting from the scanning of the tank ~~must~~shall be registered to the point cloud and meshed into a solid, spheroidal object before coordinates can be used to measure distances. After meshing occurs, coordinates can be exported to a spreadsheet, resulting in thousands, or millions of (x,y,z) coordinates representing the tank shell and deadwood structures, and its reference to the strike point.

Horizontal and vertical angles, and distance-ranging shall be verified by comparing the actual length of the stadia rod, as measured by the master working tape, to the digital measurement of the stadia rod. The difference in lengths should not be more than +/-2 mm.

### 6.8.6 High Definition Survey Systems Volume Calculations

HDSS and complementary point cloud modeling and analytics software are used to visualize and to calculate cap volumes, segment volumes, and total volume. Many of the processes for calculations and analysis are automated.

#### 6.8.6.1 Total Volume of a Smooth Spheroid

The formula for the volume of a smooth spheroid is

$$V = \frac{4}{3}\pi abc$$

(42)

where

a = horizontal radius (x-axis)
b = vertical radius (y-axis)
c = height radius (z-axis)

Using the (x,y,z) coordinate file for the spheroid, find the absolute values of the minimum and maximum X, Y, and Z coordinates. Sum the absolute values of min(X) and max(X) and divide by two (2) to get the horizontal radius. Use the same approach for finding the lengths of the vertical and height radii.

$$a = \frac{|\min(x)| + |\max(x\cancel{X})|}{2}$$

(43)

#### 6.8.6.2 Volume of the Bottom Spheroidal Cap

$$V = \pi ab\left(\frac{2c}{3} - x + \frac{x^3}{3c^2}\right)$$

(44)

where

V is the volume of the cap, a, b and c are lengths of the semi-axes, x = c – h, and h is the height of the bottom cap.

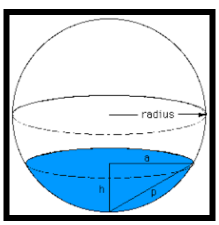


**Figure 8: Bottom Spheroidal Cap**

The same values for a, b, and c that were used to calculate total volume of a spheroid shall be used to calculate the volume of the bottom cap of the spheroid.

The height of the bottom cap, h, shall be equal to the distance between the datum plate or bottom capacity line to the lowest elevation of the tank. The height shall be determined by taking the absolute value of the lowest elevation indicated by the minimum z coordinate in the point cloud of the tank. This volume is only necessary on smooth spheroids.

#### 6.8.6.3 Volume of the Top Spheroidal Cap

$$V = \pi ab\left(\frac{2c}{3} - x + \frac{x^3}{3c^2}\right)$$

(45)

where

V is the volume of the cap, a, b and c are lengths of the semi-axes, x = c – h, and h is the height of the top cap.

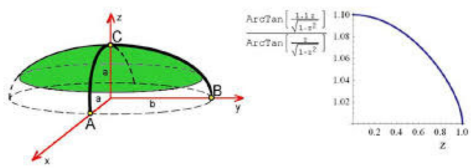


**Figure 9: Top Spheroidal Cap**

The same values for a, b, and c that were used to calculate total volume of the spheroid shall be used to calculate the volume of the top cap of the spheroid. However, the height of the top cap, h, is the fraction of a segment remaining after a series of equal segments starting from the top of the bottom cap and moving upward have been measured. This volume is only necessary on smooth spheroids.

### 6.8.6.4 Incremental Volume of a Spheroid

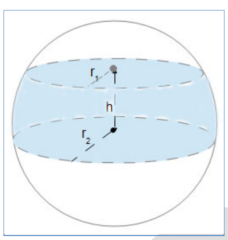


**Figure 10: Incremental Volume Sample**

For calculating incremental volume, HDSS shall model its data to fit a sphere or a spheroid. The modeler sets the segment height and other parameters, and the software produces a table of incremental volumes. This process corresponds to calculations facilitated by using spreadsheet functions and the formula for midsegment volume of a spheroid to find incremental volume of a spheroid as follows:

The volume of the $i^{th}$ segment, $V_i$, of a spheroid with *n* midsegments is

$$V = \pi\left(\frac{h}{6}\right)\left(3r_i^2 + 3r_{i+1}^2 + h^2\right)$$

(46)

where h is the height of the segment, $r_i$ is the radius of the top of the segment and $r_{i+1}$ is the radius of the bottom of the segment for *i = 1, 2, 3, 4… n.*

### 6.8.7 Capacity Table

On smooth spheroids, the total volume calculated in section 2, Bottom Spheroidal Cap, represents the total volume below the datum plate or bottom capacity line. However, this volume is not included on the capacity table. The zero gauge will not contain a volume. The incremental volumes calculated in section 4 are used to create the volumes from the zero gauge to the top of the tank. Complete the capacity table by adding the volume calculated in section 3, Top Spheroidal Cap, as the last increment. Correct for deadwood. All deadwood should be accurately accounted for as to volume and location.

On noded spheroids, the volume below the datum plate or bottom capacity line should be calculated mathematically based on the geometrical shape of the bottom area. However, this volume is not included on the capacity table. The zero gauge will not contain a volume. The incremental volumes calculated in section 4 are used to create the volumes from the zero gauge to the top of the bottom node. Correct for deadwood. All deadwood should be accurately accounted for as to volume and location.

The volume below the datum plate or bottom capacity line is not usually included in the tank capacity. Zero gauge should coincide with the level of the datum plate or bottom capacity line. The main capacity table should not include any volume below that level. On a noded spheroid, the capacity will not extend above the top of the bottom node.

The capacity table may be prepared in any desired unit and increment. The capacity table should include the volume below the datum plate or bottom capacity line as a reference note. The capacity table shall state the measurement method used for calibration, along with the date of the calibration.

### 6.9 Effect of Thermal Changes on Spheroi~~c~~dal Tank Shells

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

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

The coefficient, K, is based upon a low-carbon steel having a coefficient of thermal expansion of 0.00000065 per degree F. When the tank is constructed of a different metal, the coefficient of expansion shall be calculated in accordance with industry accepted values~~Appendix III~~.

For non-insulated metal tanks, the temperature of the shell may be taken as the average of the adjacent liquid and ambient air temperature on the inside and outside of the shell at the same location. In applying these principles to both spheres and spheroids, only the horizontal dimensions are functions of tank calibration corrections. The liquid height dimension is a function of gauging the liquid level; accordingly, the effect of thermal expansion or contraction on innage and ullage gauge readings should be considered separately.

## 6.10 Re-Calibration

Spheroi~~c~~dal tanks should be re-calibrated as a result of the following conditions:

1. When the deadwood is changed or altered inside the tank.
2. When the tank is repaired or changed in any manner which may affect the total incremental volume.
3. When the tank is moved.

# Annex A
(informative)
# FIELD EQUIPMENT VERIFICATION

## VERIFICATION OF TOTAL STATION

Date: ______________

Make: ___________________________

Model: ___________________________

Serial Number: ___________________________

Line 1: Distance To Tank at 0° Horiz & 90° Vert: _____________

Line 2: Distance To Tank at 180° Horiz & 270° Vert: _____________

Line 3: Deviation (Line 2 minus Line 1): _____________

Deviation Tolerance < or = .01 ft. or 1/8 in. or 3mm

Within Tolerance? Yes: ______ No: ______

Performed By: ___________________________

Witnessed By: ___________________________

# VERIFICATION OF SURVEY LEVEL

Date: ______________

Make: ___________________________

Model: ___________________________

Serial Number: ___________________________

Set Up Laser at First Location

Line 1: Elevation at Point A: ______________

Line 2: Elevation at Point B: ______________

Line 3: Delta (Line 1 minus Line 2): ______________

Set Up Laser at Second Location

Line 4: Elevation at Point A: ______________

Line 5: Elevation at Point B: ______________

Line 6: Delta (Line 4 minus Line 5): ______________

Line 7: Deviation (Line 3 minus Line 6):

Deviation Tolerance < or = .01 ft. or 1/8 in. or 3mm

Within Tolerance? Yes: ______ No: ______

Performed By: ___________________________

Witnessed By: ___________________________

## Bibliography

[1] API *MPMS* Chapter 2.2A, *Measurement and Calibration of Upright Cylindrical Tanks by the Manual Tank Strapping Method*

[2] API *MPMS* Chapter 2.2D, *Calibration of Upright Cylindrical Tanks Using the Electro-optical Distance Ranging Method*

[3] API Standard 2555, *Method for Liquid Calibration of Tanks*