Table of Contents

Table of Figures

Introduction

The purposes of tank cars are to provide secure and safe transportation of petroleum and petrochemical materials and as measurement devices for those contents. This document addresses the development and standardization of the capacity tables used for these measurements. The actual determination of volume of material contained in a tank car is addressed in API Manual of Petroleum Measurement Standards Chapter 3, Section 2.

1 Scope

This standard describes the procedures required to produce a capacity table for a tank car. Calibration procedures for pressure and non-pressure tank cars are addressed within this document.

2 Normative References

The following documents are 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 Strapping Method*

API *MPMS* Chapter 2.2D/ISO 7507-4 *Tank Calibration by Internal Electro-Optical Distance-Ranging Method*

API *MPMS* Chapter 2.2E/ISO 12917-1:2002 *Petroleum and Liquid Petroleum Products—Calibration of Horizontal Cylindrical Tanks—Part 1: Manual Methods (ANSI/API MPMS Ch. 2.2E)*

API *MPMS* Chapter 2.2F/ISO 12917-2:2002, *Petroleum and Liquid petroleum products—Calibration of Horizontal Cylindrical Tanks—Part 2: Internal Electro-Optical Distance-Ranging Method (ANSI/API MPMS Ch. 2.2F)*

API *MPMS* Chapter 2.2G *Calibration of Upright Cylindrical Tanks using the Total Station Reference Line Method*

API *MPMS* Chapter 4 (all sections), *Proving Systems*

API *MPMS* Chapter 4.5, *Master Meter Provers*

API *MPMS* Chapter 21 (all sections), *Electronic Measurement*

3 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 (MSDS) if applicable.

Due consideration should be given to applicable safety procedures. Safety considerations include, but not limited to, potential electrostatic hazards, potential personnel exposure (and associated protective clothing and equipment requirements), and potential explosive and toxic hazards associated with a tank car'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 car, 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 Terms and Definitions

For the purpose of this document, the following definitions apply. Terms of more general use may be found in the API *MPMS* Chapter 1, Online Terms and Definitions Database.

4.1 Bad Order Car

An interchange freight car which is in need of mechanical attention and/or repairs

4.2 Calibration

A set of operations which establish, under specified conditions, the relationship between the values indicated by a measuring device and the corresponding known values indicated when using a suitable measuring standard.

NOTE The method used to determine the volume capacity of a tank car. Each tank car is calibrated to accurately measure its shell-full capacity.

4.3 Calibration, bottom

Bottom calibration of a tank is either:

a. The determination of the tank volume below the strike plate, which is considered to be zero on the tank gauge table.

b. The quantity of liquid contained in a tank below the gauge point.

4.4 Capacity

The volume of a container or tank filled to a specified level.

4.5 Tank Car Capacity Table

Table showing the liquid volume capacities, on an innage or ullage (outage) basis, and the corresponding vapor space capacities, in a tank, tank car or vessel compartment, at various liquid levels, which are measured at the reference gauge point: from the datum up to the liquid surface level for innage gauges; or, from the reference gauge point down to the liquid surface level for ullage (outage) gauges.

4.6 Continuous Wraparound

The measurement of a tank circumference with a tape that is long enough to span the entire circumference of the tank.

4.7 Class

A grouping of tank cars considered to be dimensionally similar.

4.8 Class exemplar

The specific tank car capacity table chosen to represent any tank car in the same class

4.9 Clean the Scan

The process of eliminating point-cloud noise or irrelevant data points in a scan

4.10 Cut Cylinder wedge

The gap between left and right halves of the sloping tank.

4.11 Deadwood

Any tank fitting, appurtenance, structural member, floating roof or other object within the tank which displaces liquid and reduces the capacity of the tank; or, any permanent appurtenances on the outside of the tank, such as cleanout boxes and manholes, which increase the capacity of the tank.

4.12 Dome tank car

Non-pressure tank cars with an expansion trunk (dome) at the top center of the tank car to provide space for expansion of the liquid in the car. The manway opening is on the dome.

4.13 Domeless tank cars

Tank cars with the manway opening attached directly to the top of the tank car shell.

NOTE See Figure 1.

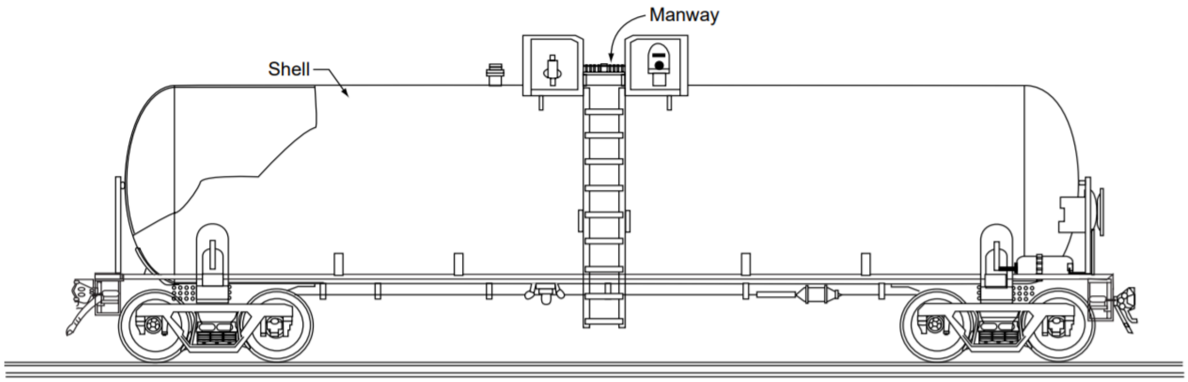

Figure 1 Non-Pressure Tank Car

4.14 End

The space from the top of the knuckle-dish to the top of the non-cylindrical end.

4.15 Finishing tanks

Calibrated measures intended to measure smaller quantities using a calibrated volume and a level measurement.

4.16 Gauging tanks

Calibrated measures used for the determination of a tank car volume, usually calibrated as to-deliver and without intermediate volume measuring capacity.

4.17 Head

The space consisting of the knuckle-dish and end.

4.18 Into Service

When a tank car has:

- completed qualification
- completed requalification
- completed certified shop inspection
- been authorized to ship cargo

4.19 Interior lining

The surface coating applied to the interior of a tank car shell to prevent the contents from contacting the metal shell. Linings may be damaged if gauging equipment is not used carefully. The thickness of the lining is included in the calculation of the tank's capacity table. If a lining is removed, replaced, or added at a later date by the car's owner, the capacity table should be recalculated.

4.20 Knuckle-dish

The space between the top of the cylinder and bottom of the end.

4.21 Level the scans

The process of adjusting the model coordinates so it is horizontally and vertically level.

4.22 Linear Measurement Method

The method of collecting linear measurements, such as length and diameter, using NIST-traceable (or equivalent national standard) hand tapes and then inputting those values into a mathematical formula for volume.

4.23 Magnetic float gauging device

Consists of a float with an interior magnet that moves up and down a hollow tube (sealed to the outside) as the liquid level changes. Another magnet is attached to the bottom of a graduated gauge rod located in the hollow tube and accessible from the outside. When the gauge rod is manually pulled up until the two magnets link, the liquid level's outage may be read off the rod. An outage offset may have to be calculated if the gauge's reference relative density (specific gravity) is different from that of the product to be measured, or if the temperature of the liquid differs substantially from the temperature at which the gauge is calibrated.

4.24 Tank measurement calibration method

The method of tank calibration in which volume capacities are calculate from external and/or internal measurements of the tank dimensions.

4.25 Mesh

To connect points in a 3-D point-cloud to create a closed surface.

4.26 Noise

A word used in modeling to represent data points that don't represent the object being modeled.

4.27 Nozzle

A subassembly consisting of a pipe or tubular section with or without a welded or forged flange on one end.

4.28 Over-calibrated tank

A tank for which the actual capacity is less than that shown on its calibration table.

4.29 Plumb

When the y-plane meets a level x-plane at a 90-degree angle.

4.30 Point cloud

A visual representation of 3-D coordinates.

4.31 Qualification

An event that consists of one or more inspections and tests to determine if the item conforms to the applicable requirements and to the owner's acceptance criteria.

4.32 Reference Gauge point

The point from which all liquid level measurements shall be taken:

a.) as determined at the time of the tank calibration and as reflected by the tank capacity table; or,
b.) as modified in keeping with guidelines in API *MPMS* Chapters 2 and 3, and for which either adjustment calculations shall be made, or a new tank capacity table issued reflecting the new location of the reference gauge point.

4.33 Reference gauge height

The vertical distance, noted on the tank capacity table and stenciled on the tank near the hatch, between the reference gauge point on the gauge hatch and the datum strike point on the tank floor or the gauge datum plate.

4.34 Shape recognition registration

A type of registration process that uses shapes that appear in multiple scans as a way to merge two or more scans into a single model.

4.35 Shell Full Capacity

The liquid volume at the transition point at which air or vapor becomes entrapped in a location that is not in direct communication with all top fittings.

4.36 Sloped Distance

The length measured from the electro-optical distance-ranging instrument to a target point on any given ring of the tank car wall or head.

4.37 Stadia

A rigid bar with a NIST-traceable (or equivalent national standard) known length, usually 2 m long, that is used for field verification of the instrument to measure the model coordinates.

4.38 Stilling well

Stilling wells are tubes within a tank that are used for gauging activities including sampling and the determination of level and temperature.

4.39 Straight Flange

The space between the top of the straight flange and the bottom of the knuckle-dish.

4.40 Strike point

The elevation of 00’-00” as determined by the location of the hand-gauged tape bob.

4.41 Target

A specific location that is recognizable in the overlap area between two or more scans. A target can be a traditional survey target or a natural target such as a surface, corner, or edge.

4.42 Under-calibrated tank

A condition where the capacity of a tank is greater than that shown by its calibration table.

4.43 Water-tight solid (surface)

A model where spaces (e.g., a shadow of a pipe inside the tank car) in the point cloud are digitally filled with 3-dimensional coordinates in order to create a representative surface of the model.

5 Symbols and Abbreviations

A is the area of the flooded cross-section at the level

d is the cross-sectional diameter dimension of the tank as measured in sections 9.2.2.5, or 9.2.4.2 in cm (inches)

E is the full depth of the head in cm (in.) as measured

H is the dimensionless ratio of the liquid height to the radius

h is the fluid height as measured at the center of the tank in cm (in.)

h_s is the fluid height in a finite element slice in cm (in.)

$h_{s,center}$ is the fluid height in a finite element slice within the center section of the tank in cm (in.)

$h_{s,head}$ is the fluid height in a finite element slice within the head section of the tank in cm (in.)

k is the distance above the centerline and increasing towards the top of the tank in cm (in.)

L is the average length of the half tank as measured in cm (in.)

L_{center} is the length of the center section in cm (in.)

$L_{cylinder}$ is the length of the cylinder section in cm (in.)

n is the distance below the midline and increasing towards the bottom of the tank in cm (in.)

NIST National Institute of Standards and Technology[1]

R is the radius of the main cylinder of the tank in cm (in.)

R_s is the radius of a slice in cm (in.)

$R_{s,head}$ is the radius of the slice within the elliptical head in cm (in.)

s is the average slope of the tank from the lowest point to the end of the cylindrical section in cm (in.). Other than a slope of zero, all slopes are related to the distance over which they are measured.

V_{50} is the volume of the tank with the liquid level at the vertical midline in cm^3 ($in.^3$)

$V_{cylinder}$ is the volume of the cylinder at level h in cm^3 ($in.^3$)

V_h is the total volume of the tank at level h in cm^3 ($in.^3$)

V_{head} is the volume of the head at level h in cm^3 ($in.^3$)

V_k is the volume to be estimated bounded by the tank midline and the plane n increment away from the midline

V_n is the volume bounded by the tank midline plane and the plane n increment below centerline

x is the distance from the end of the previous section to the center of the slice in cm (in.)

x_{center} is the distance from the center of the tank to the center of the slice

α is the segment included angle in radians

θ is the angle of the tank slope in radians

gpm gallons per minute in

6 General Considerations

For tank cars placed into service after this standard has been published, tank cars shall be individually calibrated to have their own unique capacity table that reflects the tank car number and the date it was calibrated to be used as a custody transfer document.

For the purposes of this document any reference to a tank(s) is in respect to the tank(s) on the tank car.

For custody transfer of petroleum and petrochemical material, tank car grouping of car classes shall not be allowed as a prerequisite for applying a single capacity table to more than a single tank car.

[1] 100 Bureau Drive, Gaithersburg, Md. 20899. https://www.nist.gov/

For tank cars placed into service prior to the publication of this document, once the tank car has been cleaned it shall be recalibrated before placing it back into service and requires its own capacity table to be used as a custody transfer document for measurement purposes.

All tank cars under the scope of this document placed back into service will require their own capacity table and corresponding calibration method as outlined within this document, for the capacity table to be used for measurement purposes.

If damage which could impact the accuracy of the calibration table is identified when a tank car is removed from service, a re-calibration shall be performed after any applicable repair and prior to returning the tank car to service.

7 Determining Reference Gauge Point Location

The reference point for gauging tank cars sets the maximum capacity of a tank car. At that point, additional liquid volume cannot be added to the level tank that uniformly increases the liquid level across the entire free surface of the liquid. Depending on the configuration of the tank, this could be set either by the overflow of the nozzle or by the potential isolation of an air pocket of any size. Manual venting of a contained pocket does not change the reference gauge point, though a permanent vent hole might.

The reference gauge point shall be a permanent, stationary, fixture located on top of the tank car where a straight vertical path to the bottom of the tank car, or datum plate, can be achieved with a measuring device. The strike point on the bottom of the tank car, or datum plate, should be at the deepest possible location in the tank car. The strike point shall be on a level datum plate or a point on the tank car bottom where slippage of the measuring device will not occur. A gauge point directly centered over the width of the tank is preferred to prevent slippage. The reference gauge point can be to the top lip of the manway, the top lip of a vapor vent valve, an established gauge clip mounted to an internal fixture, or any location that satisfies the description mentioned and where shell full capacity is reached. The reference gauge point location can also be established in other locations like vent valves or other nozzles on the tank car that facilitate gauging of liquid during normal operation. If closed system gauging devices are to be used, references for any corrections to reference gauge heights shall be made on the capacity tables.

The reference gauge point can be established by the manufacturer, owner, lessor/lessee, or calibration company. This point is determined at the time of the calibration procedure. The reference gauge point, along with the reference gauge height, shall be printed on the capacity table.

If the reference gauge point is modified or moved after calibration, measurements shall be made to create an updated capacity table to reflect measurements taken at the new gauge point.

The shell-full capacity of several potential configurations is shown in Figure 2. Shell-full capacity refers to the liquid volume at the transition point at which air or vapor becomes entrapped in a location that is not in direct communication with all top fittings.

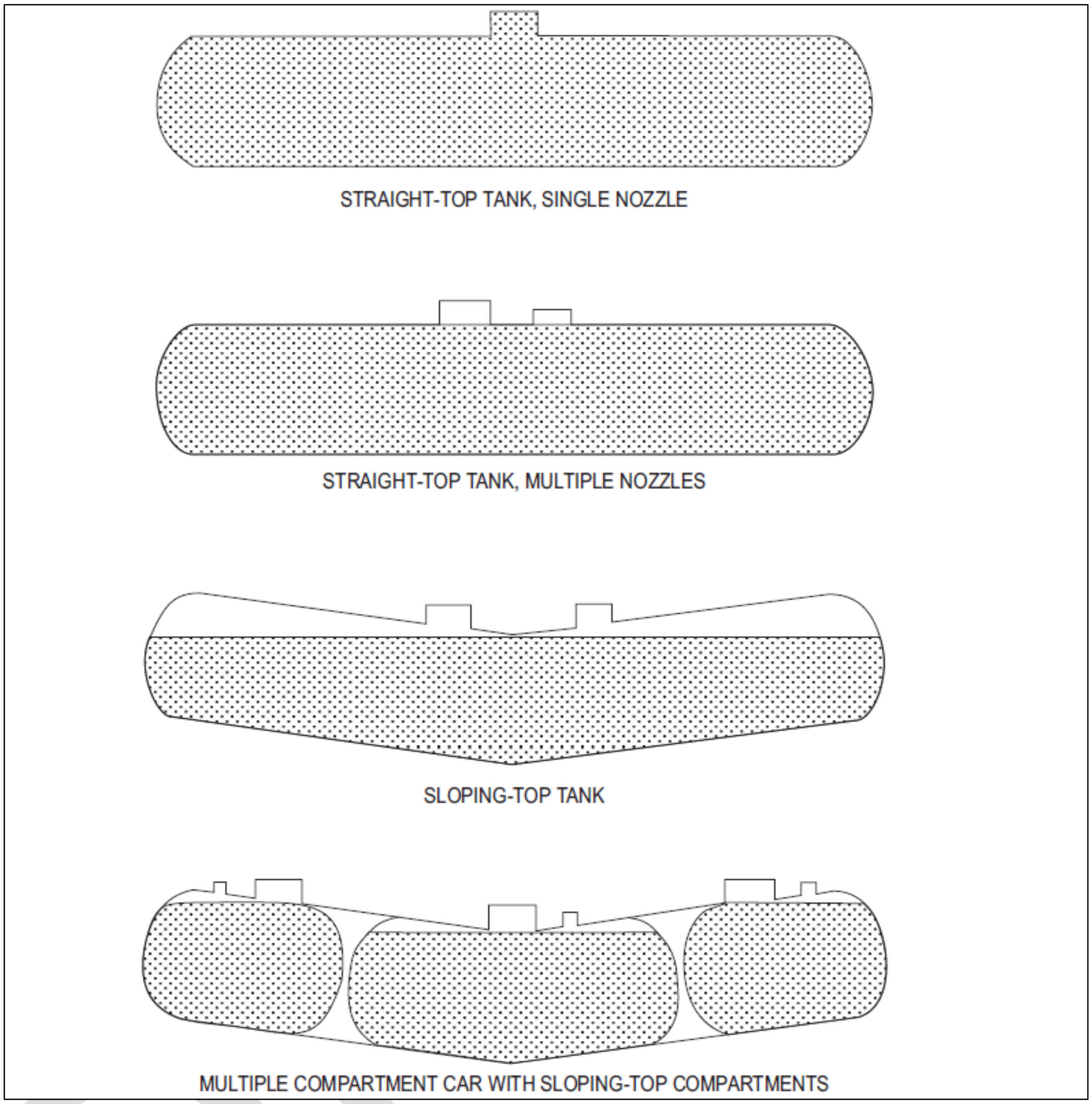

Figure 2 Shell Full Capacity of Tank Cars

8 Procedures for Calibrating Tank Cars

This section describes the different procedures recommended for calibration of all tank cars. The procedures for determining all measurements shall be those described in the applicable sections of API *MPMS* Chapter 2.2E, except as modified here.

The calibration procedures outlined herein require that the interior surface of the tank shall be clean and free from any foreign substance, such as the residue of commodities adhering to the bottom and sides of the tank-dirt, rust, and the like. Examination and the inspection of a tank car may indicate the need for thorough cleaning if the correct established capacity is to be assured.

The capacity of the tank car to be gauged shall be determined as it stands on a non-rolling grade which cannot exceed 0.5 % degrees of grade. Before gauging commences, it is important that the gauge track be checked to ascertain that it is level within tolerance stated here in.

This procedure is described for calibrating single-compartment tank cars. The same procedure is applicable to multiple-compartment tank cars, by considering each compartment individually as a single-compartment tank.

All measurements and derived dimensions shall be recorded on suitable record forms and retained. The measurements shall be recorded in written form immediately after the readings are made but may be transferred to permanent record forms subsequently.

8.1 Liquid Metering Procedure

Metering allows dynamic measurement principles to capture the volume segments and mechanical measurements needed to generate a tank car capacity table.

8.1.1 Equipment

Equipment should meet appropriate custody transfer recommendations. Only measurement equipment that yields results that are reproducible and traceable to NIST standards (or an equivalent national standard) and for which calibration records are available should be used to measure liquid levels and volumes.

There are multiple meter types that are applicable for custody transfer, but due the calibration process requiring multiple starts and stops there can be measurement error due to slippage. Coriolis and displacement meters are recommended for the metering method in this section.

NIST (or an equivalent national standard) traceable calibration tape shall be verified by a master tape. Daily inspection is required for the master tape. For recommended methods for manual gauging tank cars see API *MPMS* Chapter 3.2 [1].

8.1.2 Metering System Design Considerations

For guidelines with a loading rack metering system design, reference API *MPMS* Chapter 6.2A [3].

Meters shall be operated with the manufacturer's recommended accessory equipment and within the range of flow rates specified by the manufacturer.

The metering system should be able to deliver accurate quantities of water into the tank car being calibrated. Such metering systems may consist of single or dual meters to measure the delivered volume being loaded into the tank car at multiple flow rates. Consideration shall be given in the design criteria for accurate temperature, pressure, and density measurement during the calibration process. Such measurements can be accomplished during flow using devices within the metering system.

For guidelines for temperature and density determination, see API *MPMS* Chapter 7 [4] and API *MPMS* Chapter 9.4 [5], respectively.

Proving of the loading meter will be required so consideration of prover connection location may be needed depending on the preferred proving method. Sufficient piping shall be included to allow water to not flow into the tank car, during all proving's. The loading operation can be controlled by an electronic preset. This electronic preset has the ability to control flow at multiple flow rates, start and stop flow, provide feedback to the user during the loading operation and maintain the flow rate within the recommended operating range of the meter. The calibration process will require a controlled loading process with multiple starts and stops to obtain the manual gauging measurements throughout the load, so having the ability to control flow is needed.

Safety systems such as grounding and overfill protection systems can be utilized as a part of the metering system as needed. Top and bottom loading can be used for this method.

Installation of a filtration system shall be upstream of the metering system to maintain clean water that is free of foreign substances, such as water, dirt, loose scale, debris, etc. that may impact the metering process.

8.1.3 Liquid Meter

All meters should be proved with the liquid to be measured and at the operating flow rate, pressure, and temperature according to API *MPMS* Chapter 4.

A liquid meter shall be verified and proven quarterly per API *MPMS* Chapter 4. Proving of the meter at multiple flow rates shall be required if the filling process of the cars under calibration requires multiple flow rates.

8.1.4 Preliminary Preparations

Tank shall be gauged in a level position.

Connection, whether hose or piping, should be installed so that air traps will be eliminated. The system should be purged of all air in the in the lines prior to commencing a calibration.

The overall accuracy of measurement depends on the condition of the meter and its accessories, the temperature, pressure and density corrections, the proving system, the frequency of proving, and the variations, if any, between operating and proving conditions.

Water meter shall be proved prior to every filling of the tank car. An additional proving is required after the last fill is completed. For proving requirements and recommendations see API *MPMS* Chapter 4.8 [2].

A minimum of 2 total fillings of the tank car shall occur.

Meter temperature shall be flow weighted averaged per API *MPMS* Chapter 21.

For proving reports reference API *MPMS* Chapter 12.2 [7].

Water used for gauging should be clean and at a temperature as near as possible to 60 °F, but in no case less than 36 °F or greater than 100 °F.

The inside of the tank shall be examined for the purpose of removing any foreign substances, such as water, dirt, loose scale, debris, etc.

Sufficient water supply is required to complete the water loading process so that the tank car can be filled to shell full capacity.

The meter used for filling the tank car shall be proven prior to filling the first two times.

Water being used for calibration of the tank car shall be clean and free of debris.

Apply top or bottom closures, as applicable, with gaskets to ensure sealing of the joint.

Incremental points will not be achieved precisely by throttling flow, but rather the flow will be maintained at calibrated flowrate to the approximate incremental point and then stopped as quickly as practical. Intermediate calibration table points shall be calculated by interpolation.

A minimum of 6 stops is required; 3 at the top and 3 at the bottom.

A temperature shall be taken for every incremental volume in the tank car.

The number of incremental level measurements shall be greater than 6 at approximately equal volume increments. If increments starting from a drained tank car are below the minimum gaugeable height, these increments may be skipped.

Incremental measurement points shall not be less than that required to generate 10,000 pulses of the meter if it is a pulse generating meter.

The metered GSV shall be adjusted to the temperature of the tank car during the capacity calculations.

The table incremental volume levels shall be calculated by fitting the measured height and volume data pairs to a cubic polynomial function.

Handline manual gauges shall be read to nearest 1/16th inch, temperatures to nearest 0.1 °F, and meter to the nearest gallon.

The following readings should be taken at each stop:

- Handline gauge of liquid in tank car (receiving tank).
- Tank liquid temperature of tank car (receiving tank).
- Meter indicated volume reading
- Meter temperature

Determine gauging level based on Figure 2.

8.1.5 Instructions

8.1.5.1 Set the fill pipe inside the manway nozzle or securely connect to the BOV and fill to shell full capacity per Figure 2.

8.1.5.2 Ensure the water gauge reading is valid based on the tank car design capacity.

8.1.5.3 Input predetermined gallons into load controller, based on the tank car design capacity. Attention to overfill prevention at the final filling portion will be needed as the metered volume and tank car design capacity won't be exact during the filling of the tank car.

8.1.5.4 An electronic preset will authorize, if any safety devices are being utilized on the metering system and commence flow once the operator hits the start flow button. The predetermined batch (equal load volume increments) amount will be loaded into the tank car.

8.1.5.5 Once the flow has stopped, gauge the tank car per API *MPMS* Chapter 3.2 [1]. Either Innage or Ullage of liquid methods shall be used for gauging and the corresponding volume calculations.

8.1.5.6 Repeat steps 8.1.5.3 through 8.1.5.5 until reaching the shell full capacity with the calibration water.

8.1.5.7 Once all desired batches have been loaded into the tank car and all tank car gauges have been obtained, volume calculations need to be performed to calculate the corresponding volumes at each incremental level for the measurements taken during the calibration process. See API *MPMS* Chapters 12.1.2 [6] and 12.2 [7] for tank car and meter QTR (quantity total record) generation.

8.1.5.8 All QTR's for the tank car manual measurements and metered volumes shall be stored for auditing purposes.

8.1.6 Meter Calibration

The meter shall be operated nominally within +/- 10 % of its calibrated rate (see API *MPMS* Chapter 4.8 [2]), except during the brief period while flow is started or stopped.

Meter factor linearization shall be utilized within the preset controller if multiple flow rates are going to be used for the calibration process. For minimum number of proven flow rates, it's recommended to establish the lowest flow meter based off of the manufacturer's recommendations and prove the meter at that flow rate.

The meter shall have a minimum repeatability of 0.02 %, or the statistical equivalent in delivered volume.

The meter shall be traceable to a NIST (or equivalent national standard) volume measure or mass standard with agreement within 0.1 %.

The meter shall be operated within +/- 10 % of its calibrated rate in accordance with API *MPMS* Chapter 4.5, except for the final trimming of the level at an increment point.

8.1.7 Calculations

The following example in Figure 3 shows the steps required when calculating a metering method calibration. The examples shown apply when calibrating a tank by withdrawal of liquid from the tank to be calibrated and measuring the volume of the increment withdrawn by a meter. All other gauges and corresponding volumes within the capacity table shall be extrapolated per the incremental requirements within this document.

The calculations for tank car calibration can take place for water delivered into a tank car. The flow computer calculates the ΔGSV_i increment between preset flow stops, and total GSV_i delivered at the preset flow stop points from the start to the finish of the process. Rail car hand gauge measurements h_i and temperature measurements T_i are made at each of the preset flow stop points and recorded. The volume associated with each hand gauged point are calculated from:

$$GOV_i = GSV_i / CTL(T_i)$$

at hand gauge measurement h_i.

Example[2]:

Tank car is filled from the bottom with six preset points. The volume at the six gauge points as an innage is calculated in the following table:

	GSV_i	h_i	T_i	$CTL(T_i)$	GOV_i
Point	GAL	Inches	°F		GAL
EMPTY	0.00	0.00	60.0	1.0000	0.00
1	6,000.00	15.01	58.7	1.0004	5,997.34
2	9,000.00	30.02	61.3	0.9996	9,004.00
3	12,000.00	45.03	67.7	0.9974	12,031.70
4	18,000.00	75.04	71.4	0.9961	18,070.51
5	21,000.00	90.05	73.1	0.9955	21,094.59
6	24,000.00	105.06	74.6	0.9950	24,120.57
FULL	30,000.00	120.06	75.0	0.9949	30,154.86

Figure 3 Metering Method Calculation Table

NOTE From the table, there are eight total gauge height points with corresponding volumetric values to use for the final calibration.

8.2 Mechanical Measurement Method

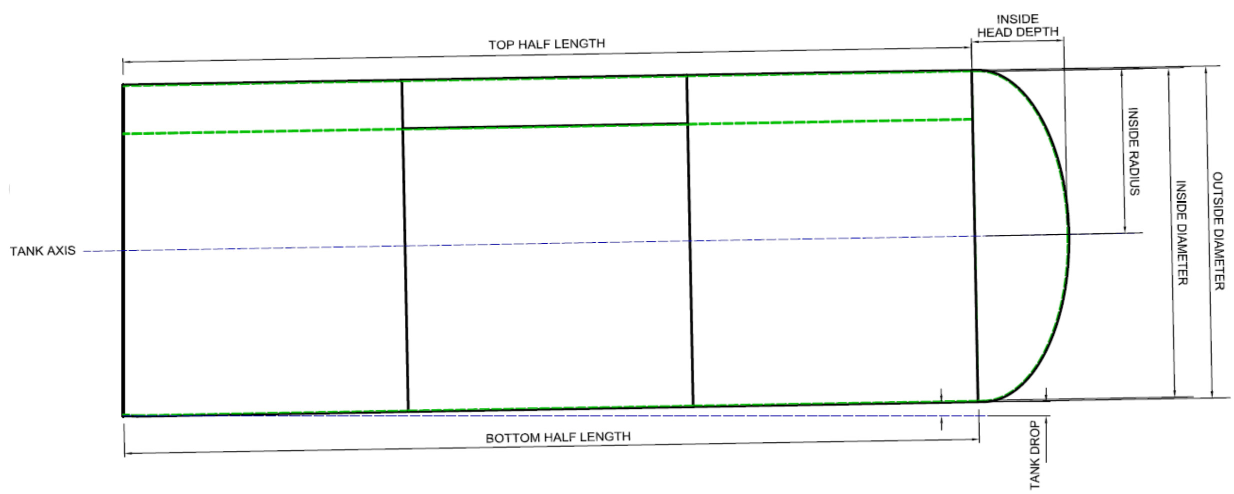

Figure 4 Tank Head

[2] This is an example for illustration purposes only. Each company should develop its own approach. It is not to be considered exclusive or exhaustive in nature. API makes no warranties, express or implied for reliance on or any omissions from the information contained in this document.

8.2.1 Calibrating Tank Cars by Internal Strapping Procedure

8.2.1.1 Acceptable Assumptions

Assumptions are made in order to calculate tank and water volumes. The following non-exclusive list of assumptions are acceptable.

8.2.1.1.1 Circular Shell Profile

The profile of a segment at any given location along its axis is assumed to be circular. The segment can be considered either a cylinder or a cone.

8.2.1.1.2 Co-axial Segments

For non-sloping (straight) tanks, all segments and the heads are assumed to be co-axial. For sloping tanks, all segments and the head forming one half of the tank are assumed to be co-axial.

8.2.1.1.3 As-designed Head Profile

Head profiles are assumed to match the as-designed profile.

8.2.1.1.4 Determination of Head and Shell Thicknesses

Head and shell thicknesses are assumed to be nominal design thickness.

8.2.1.2 Measurement Locations

Mechanical measurements, either internal or external, shall be made for each segment. If a single segment measurement is used, it should be taken at the approximate center of the segment and the segment will be considered a cylinder with the measured diameter. If two measurements are taken for a segment, the measurements should be made at no more than 25% of the segment length from the girth seam. The segment can be considered as a cylinder using the average of the two measurements or as a cone based on the measurement locations.

Head strapping and/or diameter measurements should be located approximately in the middle of the straight flange.

For tank slope and bottom half lengths the top centerline and bottom centerline shall be established on the tank car. These reference lines are also referred to as Top Dead Center and Bottom Dead Center. All measurements to seams shall be made in the middle of the weld seam.

8.2.1.3 Tank Drop (Refer to Figure 5)

For sloped tanks, measure the tank drop at the bottom centerline with the nozzles facing upwards. The tank support tooling should be located near the ends of the tank where the body bolsters will be located. On the interior of the tank, start at the head seam of section A and pull a string, or comparable method, to the head seam of section B. Verify the string is tight with no discernable sag and measure down to the center seam. Similar methods for exterior determination of drop are allowed.

8.2.1.4 Bottom and Top Half Lengths (Refer to Figure 5)

In this same tank orientation for measuring drop, measure the bottom half length of each half by pulling a tape measure from the head seams to the center seam. These measurements can now be used in the volumetric calculations to determine tank slope. In this same manner the top half lengths can be measured.

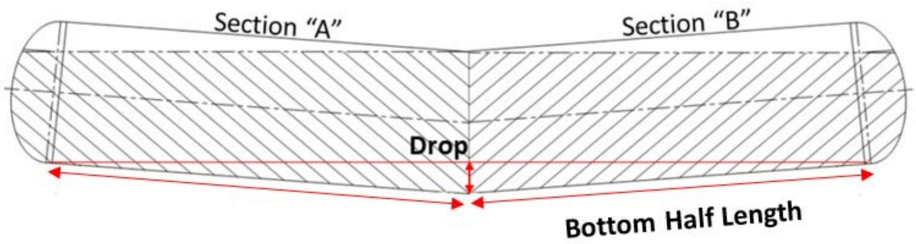

Figure 5 Sloped Tank Diagram

8.2.1.5 External Strappings

For straight and sloped tanks consisting of a number of complete rings, the external circumference and thickness shall be determined for each ring. The thickness may use nominal or can be measured. When measuring outside circumference verify that the tape measure is pulled tight and does not have kinks or obstructions. The tape should be pulled perpendicular to the top and bottom of the shell rings near the center of each ring. Using the measured circumference and thickness for each ring, the inside radius and/or diameter can now be calculated.

8.2.1.6 Head Depth

The head depth may be measured prior to joining the head on the tank car provided that records show the traceability of the head being installed on the tank car. It may be measured by placing a straight edge across the head straight flange and measuring the inside head depth at the lowest point at the middle of the head. Head depth may be measured on the assembled tank car using a string or straight edge to a location on the head seam. Special care should be taken to locate and measure from the center of the weld seam to the center of the head deducting the straight flange length.

8.2.1.7 Internal Diameter Measurements

Internal dimensions to establish inside diameter may be used in lieu of exterior strapping measurements. Extendable measuring sticks or digital measuring tools are required to accurately measure the inside diameter. Each ring and head should be measured to determine inside diameter. Measurements should be taken near girth seams to provide a reference point at top and bottom that helps to verify the measurement device perpendicular to the tank car shell in the longitudinal direction. Each dimension should be checked three times and special care taken that the measurement device is projecting straight across the tank. Take measurements in the vertical orientation and the transverse orientation and those two numbers averaged produce the average diameter.

8.2.1.8 Flat Pattern Measurements for Diameter

Flat pattern of shell rings may be measured prior to rolling to a specified diameter. In the flat, the measured length of the shell ring is the circumference of the neutral axis when formed. Segment diameters may be determined from the flat pattern, but overall length and slope shall be measured on the assembled tank. To establish the tank inside diameter:

$$Flat\ Pattern/\pi - thickness = \ Tank\ Inside\ Diameter$$

8.2.1.9 Recording of Data for Mechanical Measurements

An example[3] form is illustrated below, but the form may vary based on calculation methodology.

Circumference and Radius of Main Cylinder			
Ring No.	Outside Circ. (inch)	Thickness	Theoretical Inside Radius, R
1			
2			
3			
4			
5			
6			
Average			

Average Half Tank Straight Length		
	A-End	B-end
Top length		
Bottom Length		
Average		
Average Head Straight Flange		
Average Half Tank Straight Length		
Total Average		

Head Depth	
A-End	
B-End	
Average	

Tank Slope	
A-end	
B-end	
Average	

Head Radius	

Shell Full Height	

Figure 6 Metering Method Calculation Table

8.2.2 Calibrating Tank Cars by External Strapping Procedure

8.2.2.1 General

The procedures for determining all measurements shall be those described in the applicable sections of API *MPMS* Chapter 2.2E, except as modified here. All readings except thicknesses shall be made to the nearest 1 mm (1/16 in.); thickness measurements shall be made to the nearest 0.5 mm (1/64 in.).

---

[3] This is an example for illustration purposes only. Each company should develop its own approach. It is not to be considered exclusive or exhaustive in nature. API makes no warranties, express or implied for reliance on or any omissions from the information contained in this document.

The tape used for calibrating tanks shall be traceable to the National Institute of Standards and Technology (or equivalent national standard) and comply with the requirements of API *MPMS* Chapter 2.2G.

Steel rulers used may be verified against the calibrated tape to read the same over their marked length by the operator with the comparison documented locally. The rulers used in making measurements, except for plate thicknesses, shall be of steel and of such thickness as to ensure that they will not bend in ordinary use.

Plate thicknesses shall be measured using ultrasonic thickness testing. The ultrasonic thickness equipment shall be calibrated and capable of accurately measuring the thickness to within ± 0.05 mm (0.002 in.).

Straightedges used in making measurements at the heads of tanks or at manways shall be of wood, metal, or other suitable material of sufficient width and thickness to maintain a deflection of less than 1.5 mm (1/16 in.) when held flat in a horizontal position and supported only at its ends. The length of the straightedge should be at least 12 in. greater than the span of the tank or manway on which it is to be used.

All measurements shall be made and recorded to the marked resolution of the device being used. All rounding shall be done only during the calculation steps and according to the rounding procedures specified elsewhere in this standard.

8.2.2.2 Instructions

8.2.2.2.1 The external circumference and plate thickness shall be measured for each ring of the main cylinder according to the procedures in API *MPMS* Chapter 2.2E as modified by this standard. Each ring circumference shall be measured in two places approximately at the 20 % and 80 % of ring width, the measurements repeated and the results for each ring averaged. If successive measurements of the same circumference differ by more than ±3 mm (±1/8 in.) those measurements shall be ignored, and the measurement repeated until two successive measurements agree within ±3 mm (±1/8 in.).

8.2.2.2.2 The plate thickness of each ring shall be measured approximately on the 20 % line on one side of the tank and on the 80 % line on the other side on each ring and the values averaged for each ring.

8.2.2.2.3 Establish reference points at ends of main cylinder as shown as “X” in Figure 7. Establish six (6) reference points two (2) at each end of the car and two (2) at the center. These points will be in the middle of the weld seam of the head to the first tank shell, at the Top Dead Center and Bottom Dead Center locations, and at the center of the tank at Top Dead Center and Bottom Dead Center locations. In addition, establish two additional reference points at each end of the car in the middle of the weld seam on the tank longitudinal centerlines (quarter points).

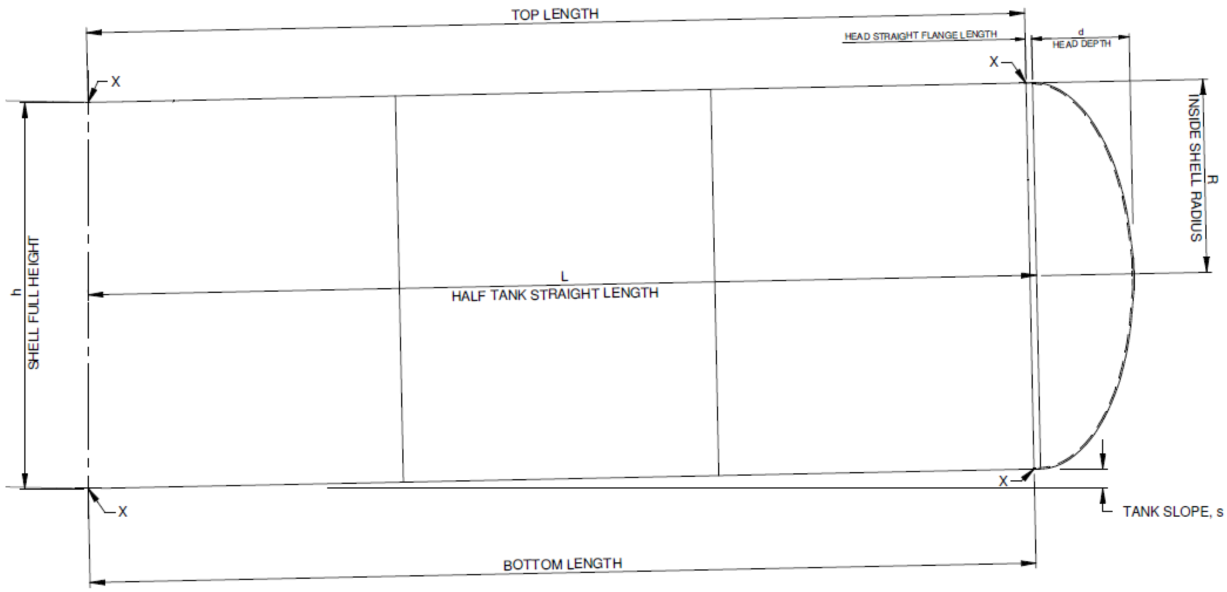

Figure 7 Reference Points and Named Dimension of a Tank

8.2.2.2.4 Establish the length of the head straight flange length by measuring the head straight flange length in the four reference locations per head marked according to the section above. The measurement will be from the reference point until the head transitions from straight tangent to curved surface. The average of these measurements shall be the “head straight flange” length.

8.2.2.2.5 Determine average half tank straight length (dimension *L*) by measuring the distance from the top reference point on the head-to-shell weld seam to the top reference point at the middle of the car. Repeat for the bottom of the tank and then calculate the average of the top and bottom measurements for one end. Add the head straight flange length to obtain the half tank straight length for one end. Repeat for the other end of the tank and average the two halves for the average half tank straight length measurement, *L*.

8.2.2.2.6 Determine the head depth (*d*) and straight flange length. Using a level straightedge held against the center of the head, and two rulers perpendicular to that straight edge, and along the head straight flange at the reference points, measure the depth of the head to the reference points.

8.2.2.2.7 Measure the straight flange length, the distance from the reference point(s) to the point at which the ellipse starts. Subtract the head straight flange measurement from the measured head depth including the flange to obtain the inside head depth.

8.2.2.2.8 Measure the thickness of the head in four (4) places on the curved portion and spaced equally around the axis to obtain an average.

8.2.2.2.9 The head depth may be measured prior to joining the head to the tank on the tank car provided that records show the traceability of the head being installed on the tank car. It may be measured by placing a straight edge across the head straight flange and measuring the inside head depth at the lowest point at the middle of the head.

8.2.2.2.10 Using a tape or steel ruler, measure the distance from the bottom of the tank car shell at center to the shell-full height.

8.2.2.2.11 Determine the radius of the tank car head. The theoretical head radius shall be taken from a Certificate of Construction or other comparable documents**.**

8.2.2.2.12 Determine the slope of the tank on the tank car, using any device capable of accurately defining a datum level over a distance at least the length of the tank car. The accuracy of any level measuring instrument used shall be 0.5 mm/m (0.5 in./100ft). For straight tanks, the slope is assumed to be zero (0). For sloped tanks, the tank shall be level within acceptable tolerance to ground and the datum used shall also be level relative to ground. Measure the difference in vertical drop of the tank from the end of the main cylinder (at head bottom reference point) and at the center of the tank at Bottom Dead Center reference point to the datum. Record this difference as the slope for the respective half tank. Repeat the measurements for the other end and record the values obtained. The tank slope shall be the average of the slopes of the two half tanks.

8.2.3 Recording of Data

All measurements and derived dimensions shall be recorded on suitable record forms and retained. The measurements shall be recorded in written form immediately after the readings are made but may be transferred to permanent record forms subsequently. A suggested form is illustrated in Annex A.

Calculation of tank volume and capacity tables shall be generated by the procedures in this section. The specific method chosen depends to some extent on the measurements obtained in Sections 8.1 or 8.2. If the external strapping method is used, all measurements shall be made and recorded to the marked resolution of the device being used, then the capacity table is calculated as shown below using either geometric formulas or a finite element method. If capacity measurements were made using either of the procedures in Section 8.2.1 or Section 8.2.2 then the method detailed in Section 8.3 and Section 8.4 shall be used.

If only the total contained volume and shell-full height was measured as in Section 8, then a suitable capacity table shall be chosen from existing tables using the criteria in Section 8.3 a new table is not calculated.

Multiple compartment tanks shall be calibrated as individual tanks.

8.3 Calculation of Tank Volume Using the Geometric Method

The measurements obtained in Section 8.2.2.2.12, shall be used in this procedure.

A straight tank can be broken into three sections for the volume calculations; the cylinder section, the wedge, and the head section. The calculation inputs are all based on half tank measurements but are doubled within the equations to yield the full tank volume. It is recommended to measure both halves of the tank as it will produce more precise data for volume calculations. Figure 8 provides an overview of the dimensions used and their relationships.

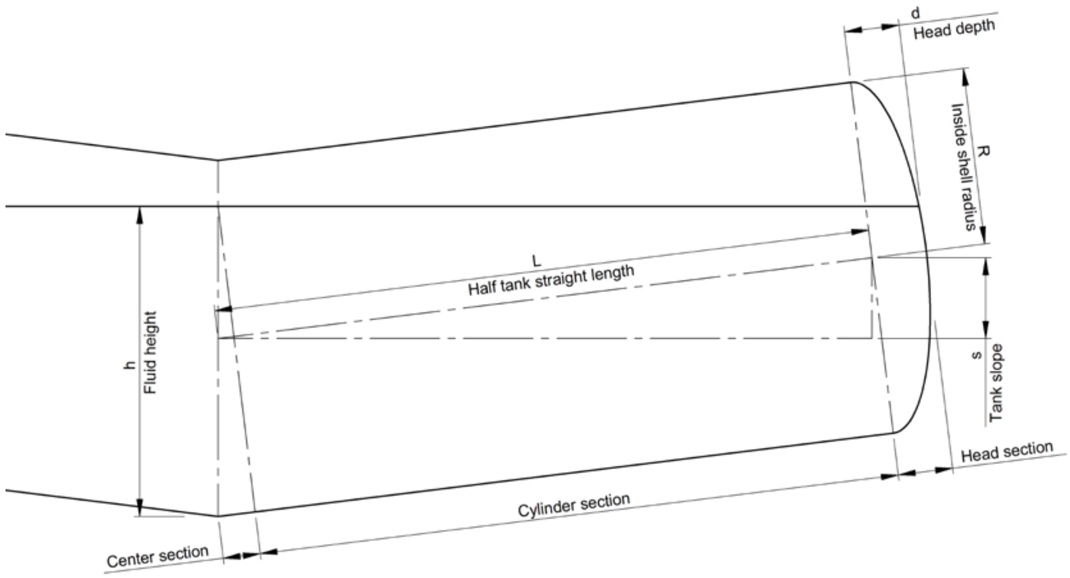

Figure 8 Variables and Nomenclature for Tank Calculations

Using the measured circumference and thickness for each ring, determine the theoretical inside radius for each ring, and then obtain an average inside radius for the tank. The theoretical inside radius can be calculated using equation 1.

$$R = \left(\frac{Outside\ Circumference.}{2\pi}\right) - Thickness \quad (1)$$

Where:

R	is the radius of the main cylinder of the tank in cm (in.)
$Outside\ Circumference$	is the average of all the circumference measurements of the cylindrical rings in cm (in.)
$Thickness$	is average wall thickness of the cylindrical rings in cm (in.)

For every level (*h*) from zero (0) to the shell-full height by 0.5 cm (one-quarter inch) increments calculate the volume of the cylindrical and head portions of the tank. Each equation is presented individually for clarity, but the calculation shall be carried out using the full unrounded result of the previous equation.

For the cylinder section calculate the cross-sectional area of the tank that is filled with fluid to a height of *h*. Note that equation 5 calculates the volume of the full tank cylinder but uses the half tank length as an input.

$$H = \frac{h}{R} \tag{2}$$

$$\alpha = 2\,cos^{-1}(1 - H) \tag{3}$$

$$A = \frac{R^2}{2}(\alpha - sin\,\alpha) \tag{4}$$

$$V_{cylinder} = A \times 2L \tag{5}$$

Where:

H	is the relative height of the fluid to the radius
h	is the fluid height at specific level in cm (inches)
α	is the segment included angle in radians
A	is the area of the flooded cross-section at the level h in squared cm (squared inches)
$V_{cylinder}$	is the volume of the cylinder at level h in cubic cm (cubic inches)

For the head section, each head of the tank is considered identical, and the volume of the combined two heads is to be calculated. The necessary dimensions and formula are shown in equation 7.

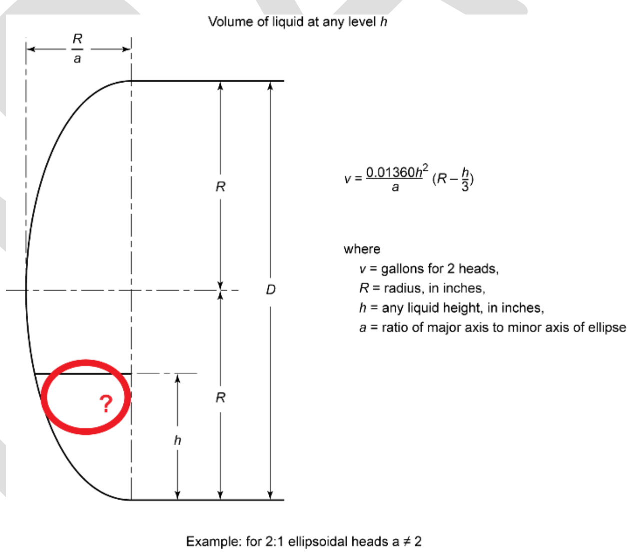

Figure 9 Dimensions of Elliptical Head

$$V_{head} = \frac{\pi d(3R - h)h^2}{3R} \tag{6}$$

$$V_h = V_{cylinder} + V_{head} \tag{7}$$

Where:

L is the half tank length as measured

V_{head} is the volume of the cylinder at level h in cubic cm (cubic in)

V_h is the total volume of the tank at level h in cubic cm (cubic in)

The total volume is obtained by adding the volumes of the cylinder section and the head section, and if applicable, the volume contained in nozzles, manways, etc.

Outage tables are calculated by first calculating the capacity table (innage) as detailed above and then restating each level as an outage. The outage shall be calculated as follows:

$$Outage\ Level = shell\ full\ level - h \tag{8}$$

Where:

h is the innage liquid level for which the volume was calculated

The outage table is formatted such that an outage of 0” is the shell-full volume, with the outage increasing as the volume decreases.

Example[4]:

A straight tank on the tank car is constructed with an inside diameter of 100 in, an average half tank straight length of 200 in, with 2:1 ellipsoidal heads having a depth of 25 in. The tank is filled to a fluid height of 75 in. Determine the volume in the tank. All calculations are carried through as a chain with no intermediate rounding.

Volume of cylinder section:

$$H = \frac{h}{R} = \frac{75}{50} = 1.5 \tag{9}$$

$$\alpha = 2\cos^{-1}(1 - H) = 2\cos^{-1}(1 - 1.5) = 4.188\,790205\ radians \tag{10}$$

$$A = \frac{R^2}{2}(\alpha - \sin\alpha) = \frac{50^2 * (4.188790205 - \sin⟦4.188790205)⟧}{2} = 6318.519510714\ in^2 \tag{11}$$

$$V_{cylinder} = A \times 2L = 6318.519510714 \times 2(200) = 2{,}527{,}407.804285420 in^3 \underset{231}{\Longleftrightarrow} 10{,}941.159325911\ gal \tag{12}$$

Volume of Tank Heads:

[4] This is an example for illustration purposes only. Each company should develop its own approach. It is not to be considered exclusive or exhaustive in nature. API makes no warranties, express or implied for reliance on or any omissions from the information contained in this document.

$$V_{head} = \frac{\pi d(3R - h)h^2}{3R} = \frac{\pi(25)[3(50) - 75](75^2)}{3(50)} = 220{,}893.233455532 in^3 \underset{231}{\Longleftrightarrow} 956.247763877\ gal \quad (13)$$

Total Volume at 75 in:

$$V_{Total} = V_{cylinder} + V_{head} = 10{,}941.159325911 + 956.247763877 = 11{,}897.407089788\ gal = 11{,}897.41\ gal \quad (14)$$

By industry standard, tank car volumes are expressed in liters (1000 cu cm / 1 liter) or gallons (231 cubic inches / 1 gallon).

Based on the precision of the measurements made in the calculation, the total volume is rounded to whole gallon.

8.4 Calculation of Tank Volume Using the Finite Element Method

8.4.1 General Considerations

For a sloped tank, the surface of the fluid is not parallel with the bottom of the tank. However, for the purpose of measurement, the fluid height, h, is taken at the center of the tank. The liquid surface is truly horizontal and of equal elevation referenced to the earth, but to simplify the calculations, the half tank is assumed to be horizontal with the liquid level changing along its axis according to the slope of the tank. This is accomplished by considering the tank as made up in a series of small slices (finite elements) whose properties approximate a two-dimensional geometrical figure. Each slice is a cross-section of the tank and is normal to the tank, but not normal to the liquid level (in a sloped tank).

If enough slices are used (the length of a slice is small) the error in the volume will be small.

For calculation purposes, the tank car is separated into three sections: the center section, the cylinder section, and the head section (see Figure 10).

Each section (center, cylinder, and head) is divided into slices that are perpendicular to the axis of the tank cylinder. Slices in each section shall be of equal thickness (Length of section / number of slices). Some reduction in the number of calculations can be achieved by using more slices in the center and head sections where the geometry is more complicated and fewer slices in the cylinder section, but the reduction in computer computation time is almost unnoticeable at the precision levels suggested. The same slice size for the entire tank is recommended. Geometry should be calculated at the center of each slice to reduce total error. See Figure 10. For a straight tank, the method is the same, but the center section is of zero length.

The number of slices in each section of the tank shall be sufficient to give a total error of less than 0.1%. As an example, using a personal computer and spreadsheet macros, the calculations for 1000 uniform slices produced a total volume result within 0.00008 % of the result obtained with 10,000 slices and required about 0.3 seconds per incremental level.

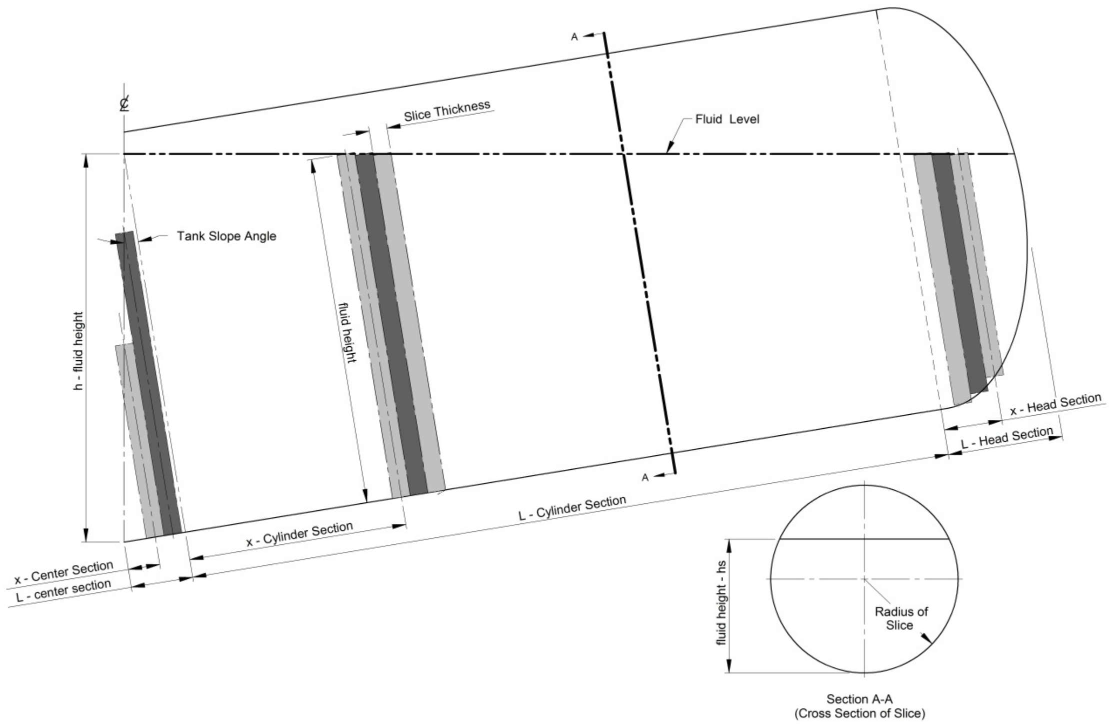

Figure 10 Volume Calculation Methodology for Finite Element

Each slice has a circular cross-section of radius, R_s, that is partially filled with fluid to a height of h_s, measured from the bottom of the circle. The fluid height for each slice will vary and shall be calculated, and then the area can be found. The volume of each slice is calculated by multiplying the area by the thickness of the slice. The volume from each segment is added to produce the final tank volume.

Each section is characterized by constraints of its geometry. The center section height (h_s) of a slice is constrained to the intersection of the center cross-sectional plane of the tank. The cylindrical section h_s is set by the height of the liquid at the beginning of the cylinder, reduced by the angle of the tank slope. Within the head section, the apparent liquid level also is reduced by the slope and the radius of the slice also varies.

8.4.2 Tank Slope

The angle of the tank is calculated based on the tank slope, *s*, and the half tank straight length, *L*:

$$\theta = sin^{-1}\frac{s}{L} \tag{15}$$

Where:

θ is the angle of the tank slope in radians

s is the averaged rise of the tank as measured

L is the average length of the half tank

NOTE s/L is calculated within the measurement procedure.

8.4.3 Section Lengths

The lengths of each section change for each incremental level and are calculated for each level.

The boundary between the center section and the cylinder section depends on fluid height. The boundary is placed normal to the tank's axis and positioned to pass through the point where the fluid level intersects the centerline of the tank. The center section has a total length of:

$$L_{center} = h \sin\theta \tag{16}$$

Where:

- L_{center} is the length of the center section in cm (in.)
- h is the height of the liquid in the increment in cm (in.)
- θ is the angle of the tank slope in radians from equation 10

The cylinder section encompasses the remaining straight length before reaching the head section, given by:

$$L_{cylinder} = L + R\tan\theta - L_{center} \tag{17}$$

Where:

- $L_{cylinder}$ is the length of the center section in cm (in.)
- L is the length of the half tank as measured in Section 8.2.2.2.5
- R is the radius of the cylindrical portion
- θ is the angle of the tank slope in radians from equation 10

The length of the head section is the head depth from the start of the tangent curve of the head to the inside surface of the head as measured in Section 8.2.2.2.4. The head section slices are designated by how far they are into the elliptical portion of the head. Both the apparent liquid level and the radius change with the distance into the ellipse.

8.4.4 Slice Radius

In the center and cylinder sections of the tank, the radius of the slice is equal to the measured tank radius.

$$R_s = R \tag{18}$$

In the head section, R_s decreases elliptically as the slices approach the end. If “x” is the distance from the end of the cylinder section to the slice in the head section, then:

$$R_{s,head} = R\sqrt{1-\left(\frac{x}{E}\right)^2} \quad (19)$$

Where:

$R_{s,head}$ is the radius of the slice within the elliptical head in cm (in.)

x is the distance from the end of the cylinder section to the slice in cm (in.)

E is the full depth of the head in cm (in.) as measured in Section 8.2.2.2.9

8.4.5 Apparent Fluid Level

Determining the apparent fluid level of a specific slice, h_s, is also dependent on the section of the tank in which the slice is located.

For the center section, fluid height is a function of both the actual free liquid level and the slope of the tank. Because the orientation of the slices is normal to the sloped axis of the tank, the center slices of sloped tanks are bounded by the distance from the bottom of the circular slice to the centerline of the tank car, given by:

$$h_{s,center} = \frac{x_{center}}{\tan\theta} \quad (20)$$

Where:

$h_{s,center}$ is the fluid height in cm (in.)

x_{center} is the distance from the center of the tank to the center of the slice

θ is the angle of the tank slope in radians from equation 10

For a straight tank, the length of the center section is zero (see Equation 10) and the x_{center} and h_s are meaningless.

For the cylinder and head section, the fluid level is given by:

$$h_s = h\,cos\,\theta - x\,tan\,\theta \quad (21)$$

Where:

$h_{s,}$ is the fluid height in cm (in.)

h is the fluid height as measured at the center of the tank in cm (in.)

x is the distance from the end of the previous section to the center of the slice in cm (in.)

θ is the angle of the tank slope in radians from equation 10

$L_{cylinder}$ is the length of the center section in cm (in.) from equation 11

NOTE The fluid height will decrease as the slices move towards the head of the tank.

For the head section, the apparent fluid level is complicated by the decreasing radii of the slice. For straight tanks the problem is simpler, but for sloped tanks the entire wetted segment is vertically displaced by different amounts for each slice. The simplest method to handle this complication is to calculate the area of the slice by defining the axial liquid height to be the distance of the liquid height from the center of the tank axis. Centering the slice concentric with the axis of the tank, the fluid level relative to the center of the tank can then be calculated. The top and bottom of the head slice determine boundary conditions for 0 % and 100 % full.

Using the R_s for the slice calculated in equation 13 and the fluid height h_s at the slice using equation 15, determine if the fluid level is above or below the level of the slice radius. If h_s is not outside the boundaries identified in equations 16a and 16c the h_s remains as calculated in equation 15 (equation 16b).

$$If\ h_s \leq (R - R_s)\ then\ h_{s,head} = 0 \tag{22}$$

$$If\ (R - R_s) \leq h_s \leq (R + R_s)\ then\ h_{s,head} = h_s - (R - R_s) \tag{23}$$

$$If\ h_s \geq (R + R_s)\ then\ h_{s,head} = 2 \times R_s \tag{24}$$

Where:

- $h_{s,head}$ is the fluid height in cm (in.)
- R is the tank shell radius as measured
- $R_{s,head}$ is the radius of the slice within the elliptical head in cm (in.)

8.4.6 Slice Area and Volume

Using the above calculated values, the cross-sectional area (A) of each slice can be calculated using equations 17 through 20.

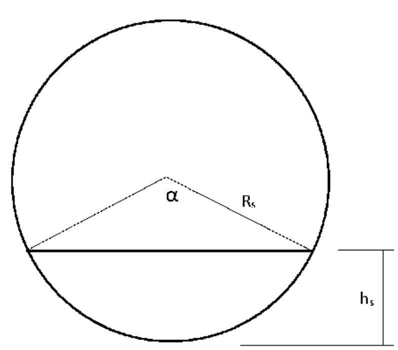

Figure 11 Area of Segment Within Circle

The relationship among the liquid level, the wetted segment, and the included triangle and sector are shown in section 8.4.5. The area of the wetted circle segment is calculated by determining the difference between the areas of the angular sector of a circle and the triangle formed by the sides of the sector and the liquid level (h_s) using theorems from plane geometry.

The height of the liquid is converted to a dimensionless fraction of the radius per equation 25.

$$H = \frac{h_s}{R_s} \tag{25}$$

Where:

- H is the dimensionless ratio of the liquid height to the radius
- h_s is the fluid height in cm (in.)
- R_s is the radius of the slice within the elliptical head in cm (in.)

Using the geometric properties of a unit circle, H defines the length of a chord that would be the top of the segment. It also therefore defines the angle α which is central angle of both the sector containing the wetted segment and the triangle that excludes it.

$$\alpha = 2\,cos^{-1}(1 - H) \tag{26}$$

Where α is in radians.

The angle α and the radii R_s completely define both the areas of the sector and the triangle, whose difference is calculated using equation 27 to provide the area of the specific slice.

$$A_s = \frac{R_s^2}{2}(\alpha - sin\,\alpha) \tag{27}$$

The area of each slice is multiplied by the thickness of each slice to give the volume. The volumes of all slices are added together to give the overall volume for the specific fluid height. If different thickness slices are used in the analysis, take care to ensure that the correct thickness is used for each specific slice.

8.4.7 Completion of the Table

The table shall be in increments of the value h by the specified amount and repeat the procedure in sections 8.2.2.2.1 through sections 8.2.2.2.12 for each capacity table level from the bottom of the tank (zero) to the shell-full level. The final increment that includes the shell-full level could be a lesser increment than the specified increment depending on actual tank dimensions.

Shell-full volume is calculated using the shell-full height from Section 8 as the fluid height.

8.5 Calibrating by High Definition Survey System (HDSS) Method

8.5.1 General

The procedures for determining all measurements shall be those described in the applicable sections of API *MPMS* Chapter 2.2E, except as modified here.

High Definition Survey Systems produce high-density scans and translate those scans into three-dimensional coordinates that form a point cloud. The point cloud shall be closed by skilled professionals using software to make a water-tight solid. Once a solid has been developed, complementary scanner/analytics software can be used to find the total and incremental volumes or the HDSS software can be used to export key variables to be used as inputs to formulas for total and incremental volumes.

HDSS-calculated total volume shall be compared with the formula-calculated total volume where inputs to that formula are obtained by using a NIST-certified (or equivalent national standard) tape, except if a prior comparison of same tank car class volumes showed a difference within tolerance between the two methods for calculating volume without manipulating the model.

8.5.2 Scanning Tank Cars (Straight and Sloping)

8.5.2.1 Equipment

The equipment required are a high-definition laser scanner, a tripod for the scanner, optional laptop for scanner control, one field stadia that has been verified against a NIST-certified (or equivalent national standard) stadia, three or more registration constraint targets (not needed if using shape recognition method), computer aided design (CAD) software for computing distance measurements between (x, y, z) points and the strike point, and a NIST-certified (or equivalent national standard) tape.

The HDSS accuracy should have or use:

- a compensator which has an accuracy of ±2.0 seconds of a degree
- 3-D position accuracy of 2 mm at operating range
- Class 1 laser
- field of view of 360 ° horizontal and 270 ° vertical

8.5.2.2 Preparation

The tank car shall be out of service. The tank car shall be scanned internally and externally. An external scan of the tank car is also required so points of contact between the tank car and the rail may be identified and used for leveling purposes during the modeling of point cloud data.

Access the interior of the tank car via the manway. Examine the inside surface of the tank; it shall be clean, dry, free of residue, scale, and vibration before setting up the scanning instrument and determining your station layout.

8.5.2.3 Station Layout

8.5.2.3.1 Target Registration Method

If target-registration is used, then set up two or more stations inside the tank, at opposing ends of the tank, to capture a complete scan (i.e., target-all, 360 ° horizontal and 270 ° vertical scanner setting). Set up multiple stations outside the tank to capture a complete (i.e., top, bottom, left, right, front, and back) view of the exterior of the tank car. A multiple station layout should be designed with a 30 % overlap between adjacent (i.e., foresight and backsight) stations to reduce shadow areas in the model and to support the registration process.

Assure the scanner head has been leveled within according to the manufacturer's recommendations. The instruments shall be set up on a stable surface to maintain level during scanner operations and shall have the appropriate angle of inclination to avoid false returns. Three or more physical reference targets shall be securely placed so that horizontal and vertical distances between targets are maximized.

Set the scanner at the appropriate resolution setting; the minimum point cloud density of the scan shall be equal to or greater than the incremental segments to be calculated, and it shall be a minimum of 10 m : 3.1 mm. The operator should avoid obstructing the scanner's line of sight during the scanning process. After the first scan, acquire the targets of the stadia, and confirm distances between targets are within ±2 mm of the master NIST-certified (or equivalent national standard) stadia (i.e., perform field verification of instrument). After each scan (including the initial scan) is completed, a minimum of three foresight and three backsight reference targets shall be acquired and labeled as registration constraints. This will allow multiple scans to be registered and unified into one model.

Place the scanner head at the next station. Repeat the scanning and target acquisition process.

8.5.2.3.2 Shape Recognition Method

If shape registration is used, set up two or more stations inside the tank and make adjacent stations with a minimum overlap of at least 50 % in the scanned area. Registrations of multiple stations and overlap eliminate shadow areas.

Assure the scanner head has been leveled within according to the manufacturer's recommendations. The instruments shall be set up on a stable surface to maintain level during scanner operations and shall have the appropriate angle of inclination to avoid false returns.

Before initiating the scan, acquire the targets of the stadia, and confirm distances between targets are within 2 mm of the master/field verification measurement. Initiate the scan at the appropriate resolution setting; the minimum point cloud density of the scan shall be equal to or greater than the incremental segments to be calculated, and it shall be a minimum of 10 m : 3.1 mm. The operator should avoid obstructing the scanner's line of sight during the scanning process. Once the scan is completed, verify that the model has a 50 % overlap.

Place the scanner head at a second internal location. Repeat the scanning process and verification.

8.5.3 Point Cloud Data Management & Modeling

Point cloud management is a reiterative process of registering, leveling, and cleaning a scan to create a model. The software may offer diagnostic tools that help guide the modeler in revisiting the registering, leveling, and/or cleaning stages in order to produce the model.

8.5.3.1 Registering scans

Registering scans is the process of unifying multiple stations into a single point cloud by using a combination of common reference target constraints, digital constraints, and shape recognition.

Registration shall be done for external stations using common constraints (target or digital). Registration shall be done for internal stations using common internal constraints (target or digital). External and internal registered models shall be combined into a single point cloud using common internal-external constraints (e.g., common horizontal and vertical weld seams) specified by the modeler.

Some software use shape recognition alone (i.e., without targets) to register multiple stations into a single model.

8.5.3.2 Leveling models using external scans

Scans shall be leveled. Leveling scans is the process of using external scans and adjusting the model's coordinates, so the model is horizontally level and vertically plumb (i.e., points of contact are at the same elevation, within an acceptable tolerance). The external scans shall be reviewed by examining the four points of contact between the tank wheels and the rail. The model should be adjusted so that points of contact are at the same elevation within the acceptable tolerance stated in section 9 in this document.

8.5.3.3 Cleaning scans

Cleaning a scan is also referred to eliminating noise in a model. The purpose of cleaning the scan is to digitally remove ***x-y-z*** coordinates that don't represent the surface of the tank car (e.g., obstructions or deadwood) and would affect the volume calculations. The end result of cleaning a scan shall be a true representation of the tank car model surface.

Once the model is clean, the strike point shall be assigned the (0,0,0) coordinate in the model. Because the elevation of the strike point can be above the bottom of the tank car, there can be a volume of product below the strike point. In some software, this would be the final step prior to calculating volumes. In other software, the next step would be to mesh the point cloud to create a water-tight surface.

8.5.3.4 Creating a water-tight surface

A water-tight surface refers to a model where spaces (e.g., a shadow of a pipe inside the tank car) in the point cloud are digitally filled with 3-dimensional coordinates in order to create a representative surface of the tank car. A water-tight or solid mesh shall be created before volume calculations can be made.

8.5.4 Calculating of Tank Volume

8.5.4.1 General

High definition survey systems either have integrated analytics capabilities or they work with complementary (i.e., add-on), menu-driven software to compute total and incremental volumes. In some HDSS systems, total and incremental volumes can only be computed using a closed (i.e., watertight) model. The HDSS Method shall be verified once per tank car class type per manufacturer. Once a company can show that their HDSS method produces a total volume that is within acceptable tolerance of the total volume found by the Mechanical Measurement Method (MMM) in Section 8.2 without model manipulation, subsequent tanks with the same tank car class type number are not required to repeat the volume verification process; however, circumferences obtained by the HDSS and MMM shall be within tolerance.

8.5.4.2 Calculating Total Volume and Incremental Volumes using the HDSS Method

Total volume shall be computed directly through the menus provided in the software.

Horizontal planes shall be inserted into the water-tight model, slicing the model into increments, to find incremental volumes. If the HDSS software doesn't compute incremental volumes, then incremental volumes shall be found by taking the difference of cumulative volume between successive incremental heights. Measurements for total volume and incremental volumes shall all be made using the same model; total and incremental volumes shall be adjusted for deadwood.

A consistency check shall be performed showing that the sum of incremental volumes is within ±0.2 % of the total volume computed by HDSS. If there is more than a ±0.2 % difference, the difference shall be evaluated and resolved. Verify that partial increments (i.e., the vapor space) that may occur at either end of the tank have been included in the comparison.

8.5.4.3 Verifying of HDSS Method

8.5.4.3.1 Circumference

Before calculating the total volume, the circumferences using HDSS and MMM shall be found and compared for all tank cars, even for those previously verified. Use HDSS software to find a circumference for the tank at a known location. Next, use NIST-certified (or equivalent national standard) strapping tapes and standard procedures for measuring the external circumference at the known location on the tank. The calculated internal circumference, C_i, is equal to the external circumference, C_e, minus a fraction of the plate thickness,

$$C_i = C_e - \left(\frac{\pi t}{6}\right)\text{, where t is plate thickness in inches.}$$

If internal circumference calculated by HDSS is not within ±3mm of the internal circumference found by using the MMM, then identify issues that might cause the discrepancy and order them from most to least likely to contribute to the difference in circumferences. Systematically, review each issue, and adjust, if appropriate. At a minimum:

1. Review the tank, images, and field forms of the tank, and the HDSS model of the tank for irregularities in the tank shell, tape path obstructions, temperature corrections, shell thickness, internal scale, and external paint.
2. Verify that circumferences and steel thickness are in consistent units and the external-to-internal circumference calculation has been applied.
3. Verify that standards for measuring were followed for each method used.
4. Verify that equipment used for each method was in good working order.

If the difference can't be reconciled, then the HDSS model shall be adjusted so that the circumference is within ±3 mm of the circumference found by using the MMM. The HDSS model can be adjusted by shrinking or expanding the mesh by a specific percentage or by adjusting the point-cloud coordinates within a meshed model.

8.5.4.3.2 Total Volume

If calibrating a new tank car class type for the first time, then total volume obtained by HDSS shall be verified by the MMM. Calculate total volume of a straight or sloping tank by choosing an appropriate method as mentioned in this standard where the MMM is described in section 8.2.

If the total volume obtained by HDSS doesn't match the total volume obtained by the MMM, the HDSS model shall be modified so that the HDSS total volume is within ±0.2 % of the total volume obtained by the MMM. The HDSS model can be adjusted by shrinking or expanding the mesh by a specific percentage or by adjusting the point-cloud coordinates within a meshed model.

8.5.5 Verifying HDSS Computations After Updating Software

After updating HDSS software or scanner firmware, a reproducibility study on tank cars of various tank car classes shall be run. A reproducibility study involves identifying tanks cars that already have a verified model from the previous version of the software and recalibrating those models using the new version of software. Total and segment volumes computed by the new version of software should be within ±0.05 % of the total and segment volumes calculated with the older software.

8.6 Total Station Scanning Method

This standard acknowledges the accuracy and validity of surveying technology to create internal measurement data. The subsequent data can be used to calibrate tank cars by calculating shell full capacity and creating capacity tables of the volume per height. Electro-optical equipment shall be calibrated by applicable industry standards.

8.6.1 Strapping procedure using Internal Electro-optical Distance-ranging Method:

An alternative method to measure the internal diameters is the internal electro-optical distance-ranging method as described in API *MPMS* Chapter 2.2F. The equipment used is an electro-optical distance-ranging instrument (total station), a mounting device (tripod or similar), and a stadia rod. The specification of the equipment is described in API *MPMS* Chapter 2.2D. The instrument shall be set up in a stable position inside the tank. After the instrument is switched on and brought to operating temperature, measurements will be made to target points on the tank surface as described. No target points shall be positioned within twelve inches of a welded seam or stiffener.

8.6.1.1 On each cylindrical course, a minimum of sixteen target points are required on tank cars less than ten feet in diameter. A minimum of twenty four target points are required on the tank cars equal to or larger than ten feet in diameter. The target points are selected at random locations but distributed over the entire surface. The uncertainty of the calibration will be reduced if a greater number of target points is used.

8.6.1.2 On each head, a minimum of fifty target points, randomly but evenly distributed over the surface, shall be sighted. The uncertainty of the calibration will be reduced if a greater number of target points is used.

8.6.1.3 On the knuckle dished end, or straight portion of the heads where the head connects to the cylinder, a minimum of sixteen target points, randomly but evenly distributed over the surface, shall be sighted. The uncertainty of the calibration will be reduced if a greater number of target points is used.

8.6.1.4 At each random target point, sight the point with the total station, then measure and record the horizontal angle, the vertical angle, and the slope distance. Two successive readings, at each point, shall be taken until each angle repeats within 32 seconds of a degree (0.01 gon) and each length repeats within 0.006 feet (2 mm).

8.6.1.5 If more than one measurement station is required, move the instrument from station to station, taking sufficient measurements at each station to ensure a proper traverse.

Continue measurements on all points on the cylinder, the heads, and the knuckle dished end, without interruption.

8.7 Field equipment verification

To verify the accuracy of the total station, place the stadia rod inside the tank between ten and twenty feet from the total station in a position that is perpendicular to the instrument. Measure the slope distance to the mark on the left side of the rod. Rotate the scope of the instrument to the mark on the right side of the rod, measuring the horizontal angle. Measure the slope distance to the right side mark. Using these three measurements, calculate the length of the stadia rod using the equation:

$$a = SQRT\,[b^2 + c^2 - 2bc\cos(A)]$$

Where:

a = length of stadia rod

b = slope distance to left mark

c = slope distance to right mark

A = horizontal angle between marks

The calculated length of the rod should agree to within 0.010 feet (3 mm) of the known length of the stadia rod.

Move the rod to a different distance from the instrument and repeat the process.

8.7.1 Calculation of Internal Radii (per API *MPMS* Chapter 2.2D Appendix B)

The dimensional coordinates of each target point shall be converted to cartesian coordinates using the following equations:

$$X = (D)(\cos\theta)(\cos\phi)$$

$$Y = (D)(\sin\theta)(\sin\phi)$$

$$Z = (D)(\sin\phi)$$

Where:

D is the measured slope distance

Θ is the measured horizontal angle

Φ is the measured vertical angle

Reduction of the values of the X and Y coordinates to the internal radius at each course shall be carried out by established mathematical techniques.

9 Capacity Tables

9.1 Certification of Capacity Tables

The capacity table should be prepared on the basis of gauging from the striking point upward to the liquid level in the gauge hatch. The preparation of the gauge table is related to the method used for obtaining field data in the zone of partial displacement, that is, whether liquid calibrated or linear measured.

Sound engineering and mathematical principles should be used in all calculations for development of capacity tables. These principles should include those given herein for application to this particular type of work. Certification of a capacity table ensures that all measurements and computations are performed in accordance with API *MPMS* Chapter 2.2A. In the process of certification, it is the responsibility of the contractor and/or individual and tank owners to clearly document and specify any deviations from the standard. Any deviations from the standard that result in nonconformity with the standard renders the capacity table unsuitable for custody transfer usage.

9.2 Structure of the Capacity table

The results shall be presented either as an innage table or as an outage table listing the distance from a specific datum in ascending order in inches with the corresponding volume at that level. The table shall be prepared with maximum increments of 1/8-inch. The volume shall be expressed in whole gallons to one decimal point.

The innage table shall use the lowest point on the inside bottom of the tank underneath the gauging point as the zero innage. The zero innage point may have an associated volume if the lowest shell point is not underneath the gauging point.

An outage table shall present each increment as the distance from the shell-full point. The outage table is formatted such that an outage of 0-0-0 inches is the shell-full volume, with the outage increasing as the volume decreases. Since calibration methods generally are performed from the bottom of the tank to the top of the tank, preparation of an outage table in specified increments may require interpolation of the calibration results to correspond to the specified increment.

A subsidiary table may be included that assists with interpolation of the increments but is not required.

Deadwood allowance shall be made for any fittings or appurtenances inside the tank. Such volume shall be deducted in its proper relation to the bottom of the tank.

9.3 Required Elements

9.3.1 General

The capacity table as published shall include all the elements identified in this standard, and API *MPMS* Chapter 2.2A.

The table shall be identified as either an innage or outage capacity table and indicate the volumes for the liquid.

The point at which the measurements of liquid level are being referenced (i.e., the zero point of the capacity table) shall be identified in writing on the capacity table such that a gauger, with no knowledge of the internal structure of the tank or the procedure for designating shell-full capacity, can correctly measure the contents.

Capacity table shall state the reference gauge height and reference gauge point location.

The car for which the table is applicable shall be identified by the tank car reporting mark and number.

Capacity tables not in compliance with this standard shall include a reference stating they are not to be used for custody transfer purposes.

9.3.2 Development of a Capacity Table

The following parameters shall be considered for the development of capacity tables:

a) Expansion and contraction of steel tank shell due to liquid head

b) Expansion and contraction of steel tank shell with temperature; recommended to be applied independent of capacity table computations

c) Tilt from a vertical position

d) Tank bottoms that are irregular in shape

e) Effective inside tank height

f) Deductions for Circumference Tape Rises.

9.3.3 Final Capacity Table

The final capacity table shall contain the following information:

a) Product name and gravity at 60 °F (or 15 °C)

b) Whether recomputed or recalibrated

c) If recomputed, basis for recomputing

d) Unit of measure for volume (gallons @ 60 °F)

e) Unit of measure for increments (feet and inches)

f) Reference gauge height, maximum fill height, and maximum safe height

g) Description/location of reference gauge point

h) It should be noted on the capacity table that the volume below the striking point, whether determined by linear or liquid calibration, is included in the first increment

i) Nominal cylinder length, diameter, and head shape

j) Temperature at which the capacity table is computed if integral to the table. It is recommended the capacity table be computed at 60 °F (or 15 °C)

k) Contractor company's name

l) Date of calibration/recalibration/re-computation

m) Standard on which calibration is based.

9.4 Rounding of Volumes

The only rounding that is permitted in this standard is in the preparation of the published capacity table.

Liquid heights shall be listed in the increments chosen. As independent variables, they are not rounded; they are as printed.

Volumes shall be listed in whole liters or in whole gallons. Incremental volumes, if included, shall be listed rounded to 4 decimal places.

Annex A
(Informative)
Data Forms

Straight Length	A-End			B-End			Average Half Tank Straight Length
	Head Straight Flange Length	Head to Mid Seam Length	A Half Tank Straight Length	Head Straight Flange Length	Head to Mid Seam Length	B Half Tank Straight Length	
Top Dead Center							
Bottom Dead Center							
Quarter 90°							
Quarter 270°							
Average Half Tank Straight Length							

Head Depth	A End Dimensions			B End Dimensions			Average Head Depth
	Head Depth	Head Thickness	Inside Head Depth	Head Depth	Head Thickness	Inside Head Depth	
Top Dead Center							
Bottom Dead Center							
Thickness Point 1							
Thickness Point 2							
Thickness Point 3							
Thickness Point 4							
Average							

Determine Radius of Each Tank Head

From AAR 4-2	A Head	B Head	Average
Radius			

Determine slope of the tank car, s

Elevation from Datum	A End	B End	Average
Bottom Dead Center			X
Car Center Bottom			X
Slope			

Bibliography

[1] API *MPMS* Chapter 3.2, *Gauging Petroleum and Petroleum Products in Tank Cars*
[2] API *MPMS* Chapter 4.8, *Operation of Proving Meters*
[3] API *MPMS* Chapter 6.2A, *Truck and Rail Loading and Unloading Measurement Systems*
[4] API *MPMS* Chapter 7 (all sections), *Temperature Determination*
[5] API *MPMS* Chapter 9.4, *Continuous Density Measurement under Dynamic (Flowing) Conditions*
[6] API *MPMS* Chapter 12.1.2, *Calculation Procedures for Tank Cars*
[7] API *MPMS* Chapter 12.2, *Calculation of Petroleum Quantities Using Dynamic Measurement Methods & Volumetric Correction Factors*