INTERNATIONAL STANDARD

ISO 7507-2

Third edition
2022-03

Petroleum and liquid petroleum products — Calibration of vertical cylindrical tanks —

Part 2: Optical-reference-line method or electro-optical distance-ranging method

Pétrole et produits pétroliers liquides — Jaugeage des réservoirs cylindriques verticaux —

Partie 2: Mesurage par ligne de référence optique ou mesurage électro-optique de la distance

Reference number
ISO 7507-2:2022(E)

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Published in Switzerland

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 28, *Petroleum and related products, fuels and lubricants from natural or synthetic sources*, Subcommittee SC 2, *Measurement of petroleum and related products*.

This third edition cancels and replaces the second edition (ISO 7507-2:2005), which has been technically revised.

The main changes are as follows:

— offsets between reference circumference and specified levels are measured by electro-optical distance-ranging method.

A list of all parts in the ISO 7507 series can be found on the ISO website.

Any feedback or questions on this document should be directed to the user’s national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

This document forms part of a family of documents on tank calibration listed in the Bibliography as References [2] to [6], as well as ISO 7507-1 and ISO 7507-4 which are listed in Clause 2.

Petroleum and liquid petroleum products — Calibration of vertical cylindrical tanks —

Part 2: Optical-reference-line method or electro-optical distance-ranging method

1 Scope

This document specifies methods for the calibration of tanks above eight metres in diameter with cylindrical courses that are vertical. It provides two methods for determining the volumetric quantity of the liquid contained within a tank at gauged liquid levels.

NOTE For optical-reference-line method, the optical (offset) measurements required to determine the circumferences can be taken internally or externally, provided that insulation is removed if tank is insulated.

The methods are suitable for tilted tanks with up to 3 % deviation from the vertical provided that a correction is applied for the measurement tilt, as described in ISO 7507-1.

These methods are alternatives to other methods such as strapping (ISO 7507-1) and the optical-triangulation method (ISO 7507-3).

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 undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 4269, *Petroleum and liquid petroleum products — Tank calibration by liquid measurement — Incremental method using volumetric meters*

ISO 7507-1:2003, *Petroleum and liquid petroleum products — Calibration of vertical cylindrical tanks — Part 1: Strapping method*

ISO 7507-4, *Petroleum and liquid petroleum products — Calibration of vertical cylindrical tanks — Part 4: Internal electro-optical distance-ranging method*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 7507-1, ISO 7507-4 and the following apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

3.1
optical-reference-line
vertical optical ray (virtual) that is established using the optical device at a given location

3.2
magnetic trolley
mechanical device that can be traversed up or down the tank shell wall to measure deviations in the tank shell relative to the *optical-reference-line* (3.1) using a horizontal scale that is mounted on the trolley

3.3
station
location where the optical device and the *magnetic trolley* (3.2) are placed for optical measurements

3.4
horizontal station
station where the optical device is located as it is moved around the tank circumference

3.5
vertical station
station where the magnetic trolley is located along the tank shell wall

3.6
reference circumference
circumference measured at the bottom course that forms the basis for subsequent computations

3.7
reference offset
distance of the shell wall (at each horizontal station) from the *optical-reference-line* (3.1) measured at the bottom course where the *reference circumference* (3.6) is measured

4 Precautions

The general precautions and safety precautions specified in ISO 7507-1 shall apply to this document.

5 Equipment

5.1 Equipment for tank strapping

Equipment consists of the following, as specified in ISO 7507-1:

— strapping tapes;

— spring balance;

— step-over;

— littlejohn grip;

— dip-tape and dip-weight.

5.2 Optical-reference-line method

5.2.1 Optical-reference-line device, such as a precision optical plummet, a precision engineer's level with a pentaprism attachment, or a precision engineer's theodolite with a pentaprism attachment.

NOTE 1 These are optical instruments with a means of attachment to either a tripod, magnetic bracket or other stable means of support.

The instrument, when set on its support and levelled, either manually using bubble vials or automatically if an automatic levelling device is fitted, shall be capable of giving a vertical line of sight.

The instrument should preferably be of short focal length so that, when set up at a practical working height, it can be focused on the scale at the reference strapping level.

The instrument including digital device with laser beam element shall have a resolution of at least 1:20 000 and be equipped with a telescope with a magnification of not less than 20. The pentaprism attachment for use with an engineer's level or engineer's theodolite shall not introduce any significant collimation errors.

NOTE 2 Optical plummets can be fitted with a single optical train, i.e. a zenith plummet, a double optical train or a single superimposed optical train giving both upward and downward lines of sight, i.e. a nadir/zenith plummet. It is preferable that the plummet does not have any movable elements in its optical train, such as mirrors or pentaprisms, to ensure stability of the line of sight.

5.2.2 Magnetic trolley, of robust construction. Its design shall include the following features.

a) The magnet(s) shall be of sufficient power to ensure that the trolley does not lose contact with the tank shell in conditions of high wind or when ring joints need to be negotiated or when there are heavy layers of paint or scale.

b) The magnet(s) shall be adjustable for height so that the clearance between the magnet faces and the tank may be varied to suit the tank construction and condition.

c) Manual magnetic trolley shall have a cord or wire cable attached to enable it to be raised or lowered from the tank roof or via a pulley system, from ground level. Automatic magnetic trolley can be moved up and down by electronic motor built in and controlled by remote control.

d) A graduated scale or laser receiving element to indicate the actual offset measurement shall be attached securely to the trolley at its centreline. When the trolley is in its operational mode, the scale shall be either perpendicular to the tank shell or horizontal.

e) The scale shall be attached to the trolley as closely as possible to the centreline of an axis in order to reduce errors caused by deformations in the tank.

NOTE Trolleys that are not magnetic can be used to maintain contact with the tank shell.

5.2.3 Graduated scale, made of steel and marked in millimetre increments. The length of the scale shall be as short as is practicable and shall be determined by the distance at which the optical equipment can be set up from the tank side. The scale shall be calibrated to a resolution of 1 mm or better using standard methods and standard reference devices.

5.3 Electro-optical distance-ranging (EODR) method

Equipment to use shall comply with description made in ISO 7507-4.

6 Procedure

6.1 Principle

This calibration method is based on the accurate measurement of a reference circumference using a calibrated measuring tape at one level on an accessible, non-obstructed course. Repeat measurements agreeing within specified tolerances are made to avoid any systematic error in the derived circumferences. The derived circumferences are calculated from the measured reference circumference, and measurements of offsets taken at the specified levels and at the reference circumference. These offsets are a measure of the deviation of the tank wall. They are measured at a specified number of vertical stations, spaced equally around the tank.

NOTE For examples see Figures 1 to 3.

6.2 Preparation of the tank

For new tanks or for tanks after repair, fill the tank to its normal working capacity with water or liquid intended to be filled during normal operation at least once and allow it to stand for at least 24 h prior to calibration.

If the tank is calibrated with liquid in it, record the depth, temperature and density of the liquid at the time of calibration. Do not make transfers of liquid during the calibration.

For floating-roof tanks where offset measurements may be taken internally, the roof shall be in its lowest position, resting on the legs.

6.3 Reference circumference

Reference circumference has a direct impact on the calibrated volume of entire tank. It shall therefore be measured as accurately as possible.

Determine the reference circumference using the reference method described in ISO 7507-1 and the following.

a) Take multiple measurements of the reference circumference either prior to the commencement or after the completion of the optical readings. If the first three consecutive measurements agree within the tolerances specified in Clause 7, take their mean average as the reference circumference and their standard deviation as the standard uncertainty. If they do not agree within the tolerances specified in Clause 7, repeat the measurements until two standard deviations of the mean of all measurements is less than the half of the tolerances specified in Clause 7. Use the mean as the measured reference circumference and the standard deviation as the standard uncertainty. Use standard procedures to eliminate obvious outliers.

b) Take the measurement of the reference circumference at a position where work conditions allow reliable measurements, and which is within the focal range of the optical instrument. Strap the tank, aiming at one of the following levels:

   1) 1/4 of the course height above the lower horizontal seam,

   2) 1/4 of the course height below the upper horizontal seam;

and repeat the measurement to achieve measurements agreeing within the tolerances specified in Clause 7.

6.4 Offset readings by optical reference line method

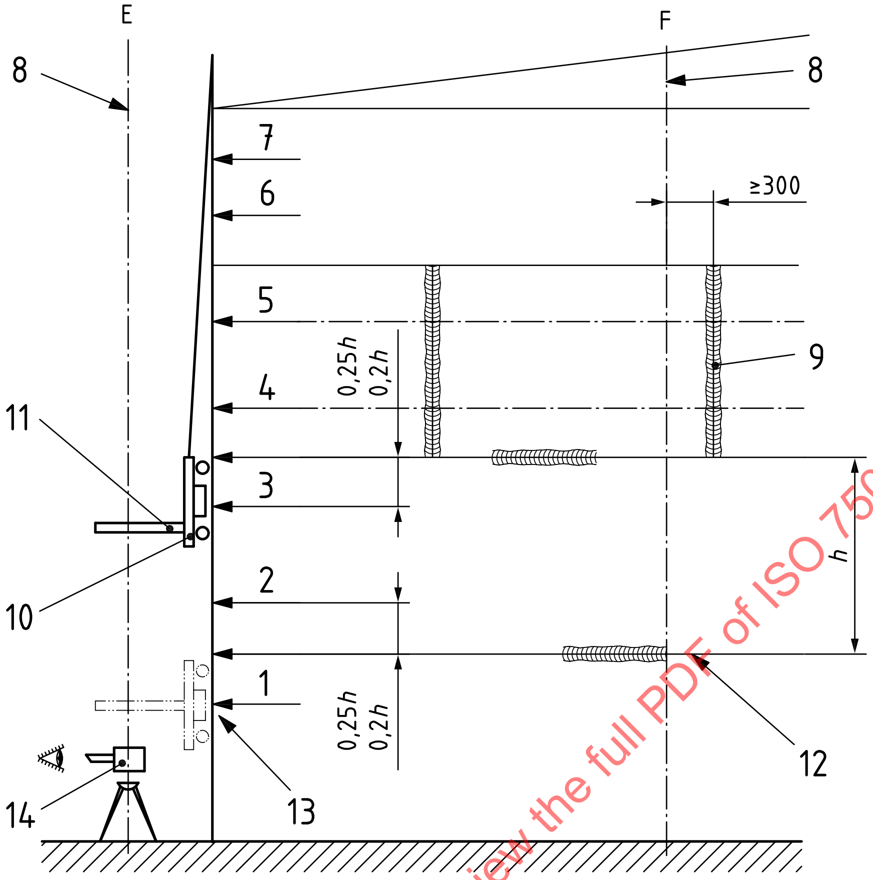
6.4.1 Set up the optical-reference-line device (5.2.1), magnetic trolley (5.2.2) and graduated scale (5.2.3) successively at the horizontal stations (see 6.4.2) that are equally spaced around the tank, as close as possible to the tank wall. Reference lines shall be chosen such that the trolley does not run over a vertical seam or its weld. The graduated scale board should be attached to the trolley with the zero reading closest to the tank shell for both external and internal offset measurements.

6.4.2 The minimum number of horizontal stations shall be as given in Table 1.

Table 1 — Minimum number of horizontal stations

Circumference m	Minimum number of horizontal stations
≤ 50	10
> 50, ≤ 100	12
> 100, ≤ 150	16
> 150, ≤ 200	20
> 200, ≤ 250	24
> 250, ≤ 300	30
> 300	36
The number of horizontal stations divided by the number of plates in tank segments should not be equal to an integer (e.g. 1, 2, 3, etc.) in order to avoid systematic errors. Using the minimum number of horizontal stations, especially for smaller tanks, can lead to larger-than-acceptable uncertainties.	

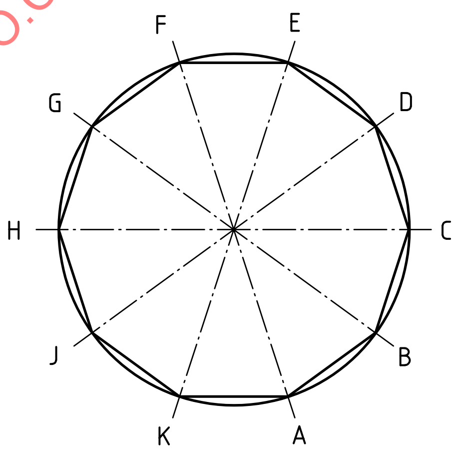
Dimensions in millimetres



Key

1 to 7	horizontal levels
8	optical-reference-line
9	weld seam (vertical)
10	magnetic trolley
11	graduated scale
12	weld seam (horizontal)
13	reference circumference taken close to location 1
14	optical equipment

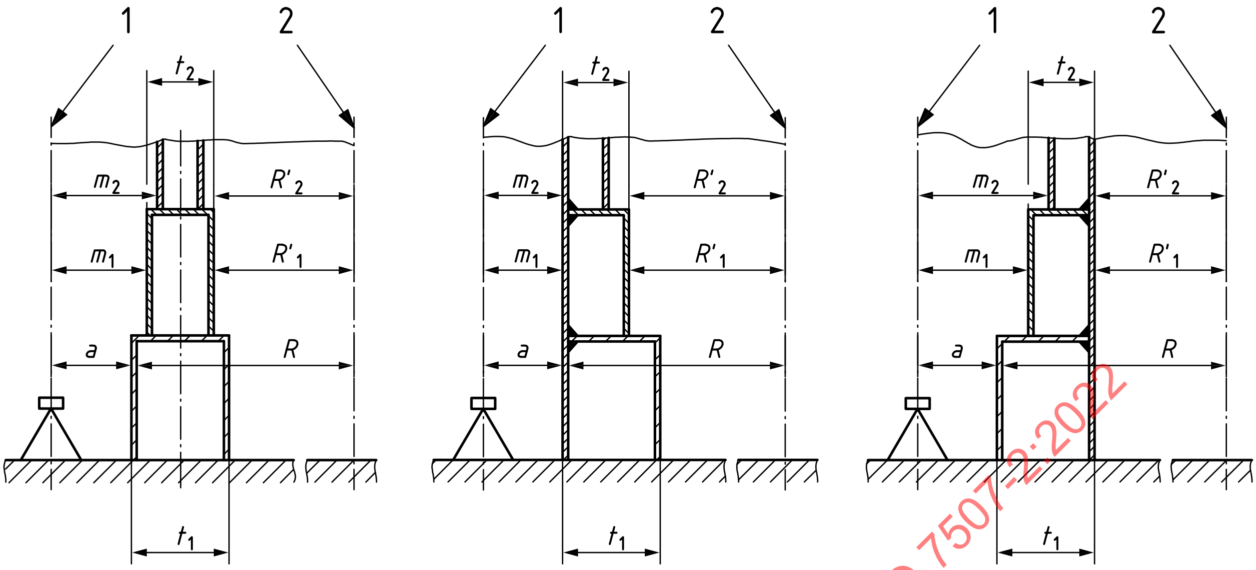
a) Tank elevation



b) Plan of horizontal stations

NOTE The horizontal stations are designated A to K in the plan view (see also 6.4.2). Of these, only E and F are shown in the elevation.

Figure 1 — Optical measurement of offsets from tank wall (typical case)

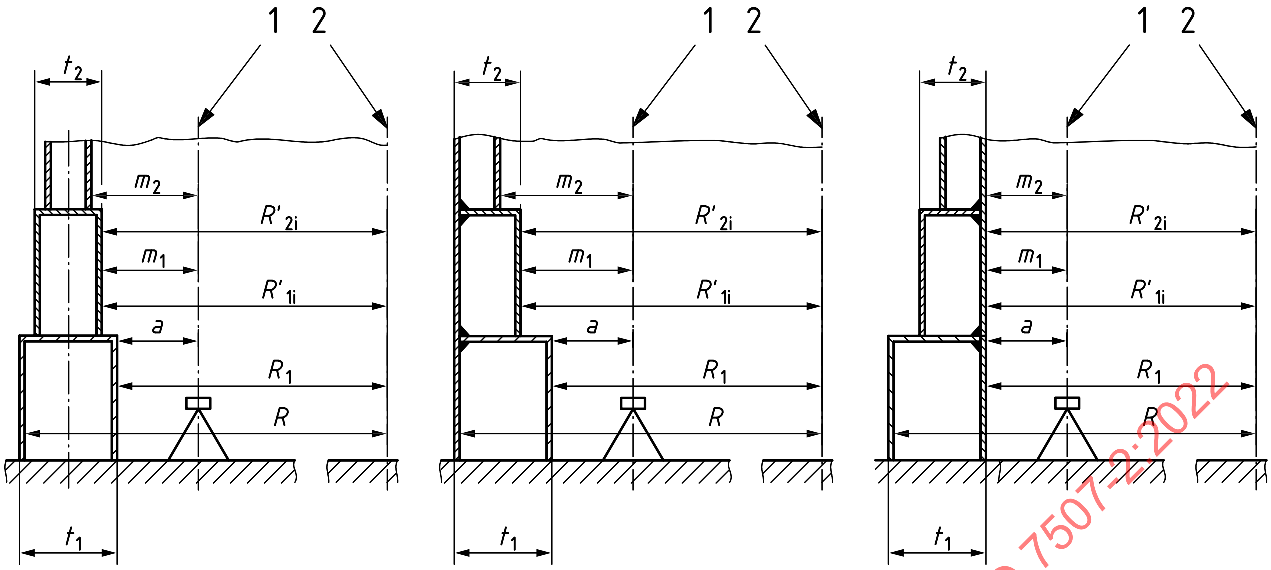


a) Centreline flush   b) Outside flush   c) Inside flush

Key

1	optical-reference-line
2	tank centreline
$R = C_{em} / 2\pi$	external reference radius (bottom course)
C_{em}	external reference circumference
R'_1, R'_2,	outer radius of second course
t_1, t_2, etc.	course thicknesses
a	reference offset
R	reference radius
m_1, m_2, etc.	individual course offsets
$R_1 = C_{em} / 2\pi - t_1 = R - t_1$	internal reference radius
R'_{1i}	internal radius, second course, bottom
R'_{2i}	internal radius, second course, top

Figure 2 — Determination of internal radius from offsets to external optical-reference-line



a) **Centreline flush** b) **Outside flush** c) **Inside flush**

Key

1	optical-reference-line
2	tank centreline
$R = C_{em} / 2\pi$	external reference radius (bottom course)
C_{em}	external reference circumference
R'_1, R'_2,	outer radius of second course
t_1, t_2, etc.	course thicknesses
a	reference offset
R	reference radius
m_1, m_2, etc.	individual course offsets
$R_1 = C_{em} / 2\pi - t_1 = R - t_1$	internal reference radius
R'_{1i}	internal radius, second course, bottom
R'_{2i}	internal radius, second course, top

Figure 3 — Determination of internal radius from offsets to internal optical-reference-line

6.4.3 Verify the verticality of the optical-reference-line prior to the commencement of readings by turning the optical instrument at the first horizontal station through 180°, whereby the difference between the two readings of the diametrically opposite positions shall be within 1 in 20 000. Also, verify the verticality of the optical-reference-line at each station at the completion of the readings. If verticality has not been maintained, repeat the calibration procedure at this station.

6.4.4 Take a minimum of two measurements of offsets from vertical per course at each horizontal station, aiming at 1/4 of course height above the lower horizontal seam and at 1/4 of course height below the upper horizontal seam. Read the graduated scale to the nearest millimetre.

6.4.5 At all horizontal stations, measure the reference offset and then take offset measurements progressively at vertical stations on each course as the trolley is raised up the tank wall. After the last offset measurement has been taken on the top course, lower the trolley to the bottom course and repeat the reference offset. The initial and final reference offset readings shall agree to within two millimetres. In further calculations, use the mean average of the initial and the final offset readings.

If agreement is not obtained, repeat vertical offset measurements at this horizontal station.

6.5 Offsets measured by electro-optical distance-ranging method

6.5.1 EODR instrument set-up

6.5.1.1 The instrument shall be set up with care, in accordance with the procedure and instructions given by the manufacturer.

6.5.1.2 Set up the instrument so as to be stable. Drive the legs of the tripod fully home into the ground.

6.5.1.3 Set the bed plate of the instrument as near as possible to the horizontal.

NOTE This ensures verticality of the swivel axis of the theodolite or total station.

6.5.1.4 The sighting lines from the instrument to the tank shell wall shall not be obstructed.

6.5.1.5 At least the minimum settling time recommended by the manufacturer should be allowed before the instrument is used.

6.5.1.6 The instrument shall be set horizontal, thus ensuring that the vertical axis (standing axis) is vertical.

6.5.2 EODR calibration procedure

6.5.2.1 All measurements should be carried out without interruption and as quickly as possible.

6.5.2.2 Set up the theodolite or total station outside the tank, as shown in Figure 4 for 10 theodolite stations and as described in 6.5.1.

The minimum number of stations (T1, T2, etc.) per circumference shall be as given in Table 1.

The theodolite positions should be such that the target points are at least 300 mm from any vertical welded seam and the tank shell wall not be obstructed.

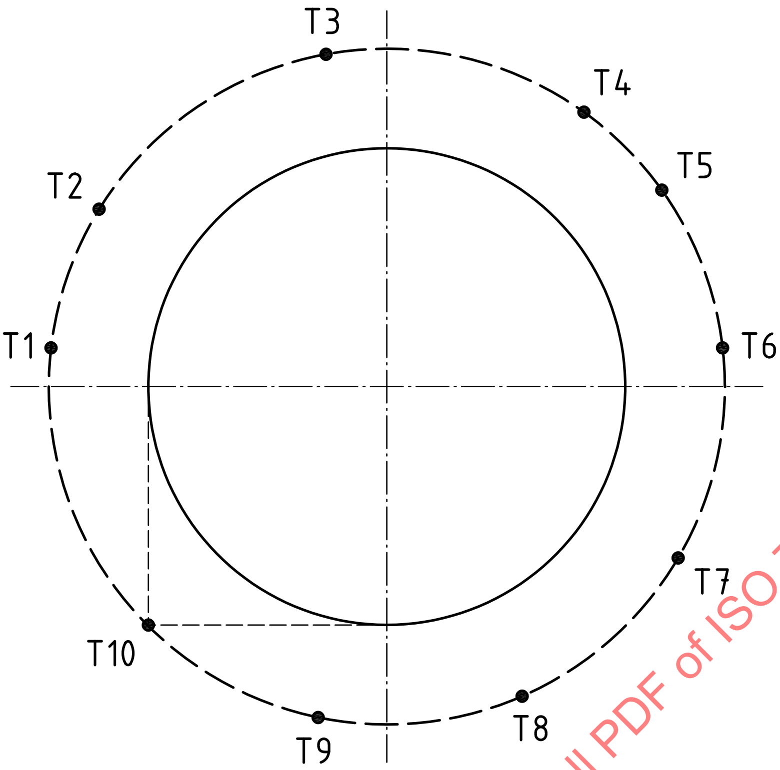
Care should be taken, especially for smaller tanks, that the stations are evenly distributed around the tank.

6.5.2.3 From each station and at the height at which the reference circumference was measured (see 6.3), make a sighting tangentially to the tank on either side of the theodolite as shown in Figure 4. Maintain the same vertical angle of the theodolite in both sightings.

NOTE 1 This ensures that the intended targets on the tank are at the same level.

Record the horizontal angles subtended by the tangents at the theodolite and calculate the average horizontal angle θ_{avg}.

NOTE 2 Using the horizontal angle θ_{avg} to sight target points will ensure that the line passing through the theodolite station and the target points intersects the vertical axis of the tank.



Key

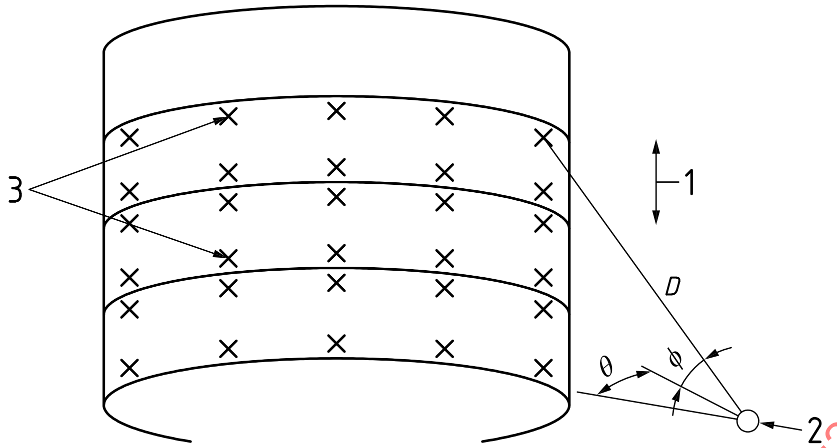
T1, T2, T3, etc. theodolite stations

Figure 4 — Example of theodolite station locations

6.5.2.4 Select and clearly mark one reference target point on the tank wall as near to the average horizontal angle, Θ_{avg}, and to the reference circumference. Measure and record the slope distance, horizontal and vertical angles or, if possible, the horizontal distance of this reference target point.

6.5.2.5 For each theodolite station (e.g. T1) and as near to the average horizontal angle, Θ_{avg}, sight two target points per course, one at about 1/4 of the course height above the lower horizontal seam, the other at about 1/4 of the course height below the upper horizontal seam. Measure and record the slope distance, horizontal and vertical angles or, if possible, the horizontal distance of each target point. The calibration procedure is shown in Figure 5.

NOTE horizontal distance = slope distance $D \times \cos(\Phi)$.



Key

1 course height
2 EODR instrument
3 target points on tank wall
θ horizontal angle
Φ vertical angle
D slope distance

Figure 5 — Illustration of calibration procedure

6.5.2.6 After all measurements have been completed, repeat the measurements to the reference target point. If the repeated slope (or if possible horizontal) distance to the reference target point do not agree with in 2 mm, repeat the procedure given in 6.5.2.1 to 6.5.2.5

6.5.2.7 Move the theodolite from station T1 to T2 to T3, etc., until the whole circumference is covered. Repeat all the above steps at each station (i.e. T1, T2, etc.), for each level. Record the slope distance, horizontal and vertical angles or, if possible, the horizontal distance for each of the points sighted.

6.6 Tank bottom calibration

Calibrate the tank bottom, preferably by filling with measured quantities of a non-volatile liquid (preferably clean water), in conformity with ISO 4269, to a minimum level that covers the bottom completely, immersing the dip-plate and eliminating the effect of bottom deformations. Transfer further measured quantities of liquid into the tank until the highest point of the tank bottom is covered and the liquid level is higher than the lowest point on the tank that will be calibrated by strapping (for example the offset measurement location or the reference circumference location as appropriate). Alternatively, calibrate the tank bottom by a physical survey using a reference plane to determine the shape of the bottom as specified in ISO 7507-1.

6.7 Other measurements and data

6.7.1 Determine, using calibrated equipment, and process the following data as described in ISO 7507-1:

a) plate and paint thickness;

b) height of the courses;

c) density and working temperature of the liquid to be stored in the tank;

d) ambient temperature and the temperature of the liquid at the time of measurement;

e) maximum filling height;

f) deadwood;

g) number, width and thickness of any vertical welds or overlaps;

h) tilt of the tank as shown by the plumb line deviations;

i) shape, landing height and apparent mass in air of any floating roof or cover.

NOTE Average mean value and a range of tank shell temperatures are required for uncertainty analysis (see Annex A).

6.7.2 It is necessary to refer each tank dip to the dip-point, which may be in a different position from the datum-point used for the purpose of tank calibration (e.g. a point on the bottom angle). Determine any difference in level between the datum-point and dip-point, either by normal surveying methods or by other means, and record it.

6.7.3 Measure the overall height of the reference point on each dip-hatch (upper reference point) above the dip-point using the dip-tape and dip-weight as specified in ISO 7507-1. Record this overall height, to the nearest millimetre and permanently mark it on the tank adjacent to that dip-hatch.

6.7.4 If possible, compare measurements with corresponding dimensions shown in the drawings and verify any measurement that shows a significant discrepancy.

7 Tolerances

Reference circumference measurements shall agree within the absolute tolerances given in Table 2.

Table 2 — Absolute tolerances on circumferential measurements

Circumferential measurement m	Absolute tolerance mm
≤ 25	2
> 25, ≤ 50	3
> 50, ≤ 100	5
> 100, ≤ 200	6
> 200	8

8 Tank capacity table calculation procedure

8.1 Outside circumference

Calculate the outside circumference from offset readings (see 6.4) or offset measurements (see 6.5) and the reference circumference by using Formulae (1) to (3):

$$R=\frac{C_{\mathrm{em}}}{2\pi} \quad (1)$$

$$R+a=R'+m \quad (2)$$

$$R'=R+(a-m) \quad (3)$$

where

C_{em} is the reference circumference, expressed in metres;

R is the radius, expressed in metres, of the reference circumference;

R' is the radius, expressed in metres, of the tank circumference at any measuring level;

a is the reference offset or reference horizontal distance, expressed in metres, from the reference circumference to the reference line;

m is the offset or horizontal distance, expressed in metres, at the same measuring level as R'.

The tank radius, expressed in metres, at any measuring level, based on all of the horizontal stations is given, for external measurements, by Formula (4):

$$R' = R + \frac{\sum (a - m)}{n} - t' \tag{4}$$

and for internal measurements by Formulae (5) and (6):

$$R' = R - t + \frac{\sum (m - a)}{n} \tag{5}$$

$$C' = 2\pi \times R' \tag{6}$$

where

n is the number of horizontal stations;

t' is the thickness, expressed in metres, of the plate and paint at any measured level;

t is the thickness, expressed in metres, of the plate and paint at the reference level;

C' is the internal circumference, expressed in metres, at any measured level.

NOTE It is assumed that the a and m readings in these calculations have the scale board zero reading attached to the trolley closest to the shell, in both external and internal measurements.

8.2 Corrections

Assuming that the capacity table has been calculated from internal radii (circumferences), corrections for the following as described in ISO 7507-1, shall be applied to it:

a) vertical seams, if lap-welded;

b) hydrostatic-head effect;

c) expansion or contraction of the tank shell due to temperature effects;

d) tilt of the tank;

e) mass of any floating roof or cover;

f) deadwood.

8.3 Tank capacity table

Calculate and prepare the tank capacity table as described in ISO 7507-1. Calculations may be undertaken in radii (in ISO 7507-1 the calculations are based on circumferences).

Annex A
(informative)

Tank calibration uncertainties for optical-reference-line method

A.1 General

This annex describes calculations that are used in the estimation of uncertainties of tank calibration when using optical-reference-line method.

The calculations follow the guidelines set out in the Guide for the expression of uncertainties in measurement (GUM)[1].

A.2 Symbols

The following terms and their units have been used in this annex.

Symbol	Description	Unit
k	Coverage factor (defined in GUM)[1]	
H_j	Height at which calibration is performed	m
H_{max}	Height of the top measured circumference (tank height)	m
H_{ref}	Height at which the reference circumference is strapped	m
uL_{st}	Standard uncertainty of strapping tape	m
UL_{st}	Expanded uncertainty of strapping tape length	m
rL_{tr}	Resolution of strapping tape reading	m
uL_{tr}	Standard uncertainty of strapping tape reading	m
tL_{tp}	Tolerance of strapping tape tension and position	m
uL_{tp}	Standard uncertainty of strapping tape tension and position	m
eL_{ta}	Maximum error of alignment	m
uL_{ta}	Standard uncertainty of strapping tape alignment	m
uL_{m}	Standard deviation of mean of multiple strapping measurements	m
C_{em}	Measured external reference circumference	m
uC_{em}	Standard uncertainty of measured external reference circumference	m
uR_{ext}	Standard uncertainty of external (strapped) reference radius the tank	m
uR_{int}	Standard uncertainty of internal reference radius the tank	m
uR_{it}	Standard uncertainty of any internal radius of the tank corrected for temperature	m
$u\delta R_{h}$	Standard uncertainty of radius correction for deformation due to hydrostatic head	m
uR_{i}	Standard uncertainty of any internal radius of the tank	m
t_{v}	Maximum deviation from vertical of the reference line	%
t_{r}	Maximum error of reading of the scale on the magnetic trolley	m
uma_{ji}	Standard uncertainty of the difference of offsets measured at height H_{ji} and H_{ref} respectively	m
wt_{mp}	Maximum uncertainty of thickness of the tank wall metal and paint	m
ut_{mp}	Standard uncertainty of thickness of tank wall metal and paint	m

Symbol	Description	Unit
ut_m	Standard uncertainty of thickness of tank wall metal	m
R_j	Average of the internal radii of the section *j*	m
uR_{ia}	Standard uncertainty of internal radius averaged for one course in the tank	m
u_{sh}	Standard uncertainty due to tank shell deformation in horizontal plane	m
K_{sv}	Empirical factor that covers uncertainties due to course deformation in vertical plane	
α_{st}	Coefficient of linear expansion of the strapping tape	°C^{-1}
α_{tk}	Coefficient of linear expansion of the tank shell material	°C^{-1}
$e\alpha_{tp}$	Maximum error of coefficient of linear expansion of the strapping or dip tape material	°C^{-1}
$u\alpha_{tp}$	Standard uncertainty of coefficient of linear expansion of the strapping tape material	°C^{-1}
$e\alpha_{tk}$	Maximum error of estimate of the linear expansion coefficient of tank shell	°C^{-1}
$u\alpha_{tk}$	Standard uncertainty of coefficient of linear expansion of the tank shell material	°C^{-1}
T_{ref}	Reference temperature of the tank and strapping tape	°C
T_{tk}	Temperature of tank shell in service	°C
T_{tp}	Temperature of (strapping or dip) tape	°C
uT_{tp}	Standard uncertainty of temperature of (strapping or dip) tape	°C
L	Level of liquid in the tank at dipping	m
uL	Standard uncertainty of level of liquid in the tank	m
L_{tape}	Dip tape length	m
ed_m	Maximum error of ullage dipping	m
ud_m	Standard uncertainty of dipped level	m
rL_{td}	Resolution of dip tape reading	m
uL_{td}	Standard uncertainty of dip tape reading	m
eT_{tp}	Maximum error of temperature of (strapping or dip) tape	°C
uT_{sp}	Standard uncertainty of temperature at strapping (same for tape and tank)	°C
uD_{dip}	Total standard uncertainty of dipping	m
ρ	Liquid density in service	kg/m^3
ρ_{ref}	Liquid density at reference conditions	kg/m^3
$u\rho$	Standard uncertainty of liquid density	kg/m^3
$U\rho$	Extended uncertainty of liquid density	kg/m^3
eE	Maximum error of Young's modulus of elasticity of the tank wall material	N/m^2
uE	Standard uncertainty of Young's modulus of elasticity of the tank wall material	N/m^2
b	Tank tilt	m/m
φ	Tank tilt angle	rad
V_{dead}	Volumes of deadwood	m^3
V_{dis}	Displacement volume of floating roof	m^3
V_h	Expansion of tank volume caused by hydrostatic head	m^3
V_L	Volume of the tank at level L	m^3
V_0	Tank bottom volume (measured)	m^3

Symbol	Description	Unit
V_r	Volume at calibration conditions (raw volume) of the tank	m^3
V_{ref}	Volume of the tank under reference conditions	m^3
uV_r	Standard uncertainty of raw volume in the tank	m^3
uV_b	Standard uncertainty of tank bottom volume at calibration	m^3
uV_0	Standard uncertainty of tank bottom volume at reference conditions	m^3
tV_{dis}	Tolerance (worst case) limit of displacement volume of floating roof	%
uV_{dis}	Standard uncertainty of displacement volume of floating roof	m^3
uV_{ad}	Standard uncertainty of volume caused by general additional factors	%
uV_{Cal}	Standard uncertainty of the model of hydrostatic head correction	m^3
uV_h	Standard uncertainty of expansion volume caused by hydrostatic head	m^3
uV_{ref}	Standard uncertainty of volume of the tank under reference conditions	m^3
uV_t	Standard uncertainty of correction for thermal expansion volume	%
UV	Expanded uncertainty of volume in the tank table	m^3
n	Number of sections into which the circumference is divided	
N_A	Number of alignments	
N_m	Number of measurements	
N_{hs}	Number of horizontal stations around the tank	
N_{mc}	Number of measured radii in each course	
eT_{ts}	Maximum error of estimate of the service temperature	°C
uT_{ts}	Standard uncertainty of the service temperature	°C
V_{ts}	Specific volume corrected for expansion due to temperature in service	m^3
V_{hc}	Volume given in the tank capacity table;	m^3

A.3 Calculations overview

This document gives the methods for the following calculations:

— strapping and corrections for obstructions (see also ISO 7507-1);

— reference circumference (see also ISO 7507-1);

— differences between individual section offsets and the corresponding reference offset;

— circumferences from the reference circumference and the offset readings.

A.4 Strapping

NOTE All components of uncertainties are assumed to be statistically independent.

A.4.1 Source uncertainties

A.4.1.1 Strapping tape length

The expanded uncertainty, UL_{st}, given by the calibration certificate, with a coverage factor, k, (usually, $k = 2$, corresponding to a 95 % confidence level), yields the standard uncertainty, expressed in metres, as given in Formula (A.1):

$$uL_{st} = \frac{UL_{st}}{k} \quad \text{(A.1)}$$

A.4.1.2 Strapping tape reading

If rL_{tr} is the resolution of the tape (usually, rL_{tr} = 1 mm), the corresponding standard uncertainty, expressed in metres, is as given in Formula (A.2) if two readings are taken for each section and as given in Formula (A.3) if one reading is taken for each section (with the tapes read from zero):

$$uL_{tr} = \left(\frac{2 \times n \times rL_{tr}^2}{12} \right)^{1/2} \quad \text{(A.2)}$$

$$uL_{tr} = \left(\frac{n \times rL_{tr}^2}{12} \right)^{1/2} \quad \text{(A.3)}$$

where n is the number of sections, into which the circumference is divided.

NOTE The factor $1/12^{1/2}$ corresponds to rectangular distribution.

A.4.1.3 Strapping tape tension and position

Strapping tape tension and position uncertainty includes the following components:

— uncertainty of the tension on the device measuring the length (tape);

— uncertainty of the distribution of this tension along the tape, due to friction against the tank;

— uncertainty due to the tape not being in one plane;

— uncertainty due to the tape plane not being perpendicular to the tank axis.

The standard uncertainty, expressed in metres, of strapping tape tension and position is given in Formula (A.4):

$$uL_{tp} = \frac{tL_{tp}}{12^{1/2}} \quad \text{(A.4)}$$

NOTE The factor $1/12^{1/2}$ corresponds to rectangular distribution.

Typical values for tL_{tp} are given in Table A.1.

Table A.1 — Tolerances on tank circumferences

Tank circumference m	Tolerance tL_{tp} mm	 m
≤ 25	2	0,002
> 25, ≤ 50	3	0,003
> 50, ≤ 100	5	0,005
> 100, ≤ 200	6	0,006
> 200	8	0,008

A.4.1.4 Tape alignment

If the tape used is not long enough to encircle the tank completely, it is necessary to measure the circumference in sections. This procedure gives rise to errors if the adjacent tapes are not correctly aligned with each other.

This error in the alignment results in additional uncertainty. If eL_{ta} is the maximum error of the alignment of each section's measurement (typically, eL_{ta} = 1 mm), the corresponding standard uncertainty of N_A alignments given in Formula (A.1) is given in Formula (A.5):

$$uL_{ta} = \left(\frac{N_A \times eL_{ta}^2}{12} \right)^{1/2} \tag{A.5}$$

NOTE The factor $1/12^{1/2}$ corresponds to rectangular distribution.

A.4.1.5 Obstructions

Corrections for the strapping tape length that runs over obstructions are subject to uncertainties (e.g. uncertainties of the dimensions of the obstructions).

The formulae for individual corrections are given in ISO 7507-1.

Standard uncertainty of the tape length due to obstructions is not calculated but is included in "additional uncertainties" (uV_{ad}).

A.4.1.6 Multiple measurements

This document differs from ISO 7507-1 in that the reference circumference is measured a number of times (three or more) and the resulting circumference is the measurement mean average, with added standard uncertainty equal to the standard deviation of the mean average of all measurements, uL_m.

A.4.2 External reference circumference

Since all measurement errors are additive, the uncertainty, expressed in metres, of the external reference circumference is obtained as the root-mean square (RMS) of all source uncertainties as given in Formula (A.6) and (A.7) where N_m is the number of measurements of the reference circumference. Formula (A.6) should be used if one tape is used repeatedly, N_m times. Formula (A.7) should be used in N_m different tapes are used to measure the reference circumference:

$$uC_{em} = \left[\frac{uL_{tr}^2 + uL_{tp}^2 + uL_{ta}^2}{N_m} + \left(N_m^2 \times uL_{st}^2 \right) + uL_m^2 \right]^{1/2} \tag{A.6}$$

$$uC_{em} = \left(\frac{uL_{tr}^2 + uL_{tp}^2 + uL_{ta}^2}{N_m} + uL_{st1}^2 + uL_{st2}^2 + \ldots + uL_{stn}^2 + uL_m^2 \right)^{1/2} \tag{A.7}$$

where N_m is the number of measurements of the reference circumference.

A.4.3 External reference radius

The standard uncertainty, expressed in metres, of the external reference radius is given by Formula (A.8):

$$uR_{ext} = \frac{uC_{em}}{2\pi} \tag{A.8}$$

A.4.4 Thickness of metal of tank shell and paint

With maximum uncertainty (equal to the width of rectangular distribution) represented by wt_{mp}, the standard uncertainty, expressed in metres, is given by Formula (A.9):

$$ut_{mp} = \frac{wt_{mp}}{12^{1/2}} \quad (A.9)$$

where wt_{mp} is typically 0,001 m (1 mm) if taken from original manufacturer's drawings.

NOTE The factor $1/12^{1/2}$ corresponds to rectangular distribution.

Measurements should be taken if at all possible in order to verify the tank wall thickness.

A.5 Optical measurements

A.5.1 Source uncertainties

The following uncertainties should be considered:

— ut_v, which is the maximum deviation from vertical of the reference line (typically 0,02 % of H);

— ut_r, which is the maximum error of reading in metres (worst-case error including error of the scale, its resolution and the human error) and is the same for all readings (typically, t_r = 0,001 m);

— ut_{mp} which is the uncertainty, expressed in metres, of the thickness of the plate and paint.

A.5.2 Uncertainties of offsets from reference offset

The standard uncertainty, expressed in metres, of the difference of offsets measured at height H_j and H_{ref} is given in Formula (A.10):

$$uma_j = \frac{\left\{\left[\left(H_j - H_{ref}\right) \times ut_v\right]^2 + \left(2 \times ut_r^2\right)\right\}^{1/2}}{12^{1/2}} \quad (A.10)$$

where

H_j is the height, expressed in metres, at which the offsets from vertical line are measured;

H_{ref} is the height, expressed in metres, at which the reference circumference is strapped.

NOTE 1 The factor $1/12^{1/2}$ corresponds to rectangular distribution.

NOTE 2 The factor 2 × ut_r corresponds to two independent measurements of the offsets that are performed (one for the reference offset, a, and one for N_{mi}).

A.5.3 Uncertainties of internal radii

The standard uncertainty, expressed in metres, of any internal radius (which is equal to the estimate of uncertainty of the average of the radii of a section) is given by Formula (A.11):

$$uR_i = \left[uR_{ext}^2 + \frac{\sum (uma_i)^2}{N_{hs}^2} + ut_{mp}^2 + u_{sh}^2\right]^{1/2} \quad (A.11)$$

where

u_{sh} is the standard uncertainty, expressed in meter, related to tank shape in the horizontal plane at the given height. It may be estimated as the standard deviation of measured offsets corrected for tank tilt;

uR_{ext} is the standard uncertainty, expressed in metres, of the external reference radius;

N_{hs} is the number of horizontal stations around the tank.

NOTE The effect of tank tilt can be the major contribution to the uncertainty of the radius. There are several methods of correcting for it that can remove more or less of the uncertainty of the radius.

A.5.4 Uncertainties of internal radii of tank course

The standard uncertainty, expressed in metres, of the averaged mean radius for each course of the tank is given by Formula (A.12):

$$uR_{ia} = \left[\frac{\sum (uR_i)^2}{N_{mc}} \times K_{sv} \right]^{1/2} \tag{A.12}$$

where

N_{mc} is the number of measured radii in each course;

K_{sv} is the empirical factor that covers the uncertainty due to the difference of the mean average (tank shape in the vertical plane) based on a limited number of measurements where $K_{sv} > 1$ (typically $K_{sv} = 3$).

NOTE The factor K_{sv} cannot be easily calculated but can be estimated by experiment.

A.6 Open tank table

Tank tables are developed from the tank radii at selected heights.

The raw volume, expressed in cubic metres, of an open tank table is given by Formula (A.13):

$$V_{raw} = \pi \times \sum \left(R_j^2 \times \Delta h_j \right) \tag{A.13}$$

A.7 Tank table at calibration

A.7.1 Calculations

Tank tables are developed from open tank tables by:

— adding a correction for tank tilt;

— adding the volumes of deadwood;

— incorporating floating roof parameters (if any).

The correction for tank tilt, bottom volume, volumes of deadwood and displacement volume of the floating roof are included in the extended raw volume, expressed in cubic metres, which is given by Formula (A.14):

$$V_r = \frac{V_{raw}}{\cos\varphi} + V_0 + V_{dead} - V_{dis} \tag{A.14}$$

where

φ is arctan b;

b is the tank tilt, expressed in metres per metre;

V_0 is the volume, expressed in cubic metres, of the tank bottom;

V_{dead} is the volume, expressed in cubic metres, of deadwood;

V_{dis} is the volume, expressed in cubic metres, of product displaced by the floating roof (if any).

A.7.2 Uncertainties

A.7.2.1 Source uncertainties

All components of uncertainties are assumed to be statistically independent.

A.7.2.2 Tank tilt

The standard uncertainty of the tank tilt depends on the accuracy of the measurements of distances.

It is not calculated but is included in “additional uncertainties,” (uV_{ad}).

A.7.2.3 Volume of tank bottom

The standard uncertainty of the tank bottom can be calculated. A typical value, expressed as a volume percent, can be estimated as given in Formula (A.15):

$$uV_0 = 0{,}25 \text{ to } 1{,}5 \tag{A.15}$$

depending on the size of the bottom, calibration method and the deformation of the tank bottom.

NOTE Smaller uncertainties usually apply to tanks with larger bottoms and vice versa.

A.7.2.4 Floating roof or blanket

The tolerance (worst-case limit), tV_{dis} has a typical value of 5 % of V_{dis}.

The standard uncertainty, expressed in cubic metres, is given by Formula (A.16):

$$uV_{dis} = \frac{tV_{dis} \times V_{dis}}{12^{1/2}} \tag{A.16}$$

A.7.2.5 Additional uncertainties

The influence of the following corrections are included in the additional uncertainty, uV_{ad}:

— corrections for tank tilt;

— corrections for internal or external deadwood;

— numerical approximations.

The additional standard uncertainty, uV_{ad}, may be estimated, based on experience, as 0,005 % of V_r.

A.7.3 Volume at calibration conditions

A.7.3.1 Calculations

The following corrections are specified in ISO 7507-1 to correct the open tank table dimensions at calibration for:

— deformation due to hydrostatic head from calibration density to reference density;

— tank shell thermal expansion from calibration temperature to reference temperature.

A.7.3.2 Uncertainties

The standard uncertainty, expressed in cubic metres, of volume at calibration conditions (extended raw volume) is given by Formula (A.17):

$$uV_r = \left\{ \left[2 \times \pi \times \Sigma \left(R_{ia} \times uR_{ia} \times \Delta h_j \right) \right]^2 + \left(uV_0^2 \times V_0^2 \right) + \left(uV_{ad}^2 \times V_r^2 \right) + \left(uV_{dis}^2 \times V_{dis}^2 \right) \right\}^{1/2} \quad (A.17)$$

NOTE Formula (A.17) assumes statistical independence of measurements in all tank courses.

A.7.4 Volume at reference conditions

A.7.4.1 Source uncertainties

The following uncertainties affect the uncertainty of volume at reference conditions.

Uncertainties calculated previously include:

— uR_i which is the uncertainty of the internal radius; calculated in A.5.3;

— ut_m is the uncertainty of the thickness of tank wall metal; calculated in A.4.4.

The extended uncertainty of the observed liquid density of the liquid contained in the tank at calibration is $U\rho$ (a typical value of which is 5 kg/m^3). The standard uncertainty, $u\rho$, expressed in kilograms per cubic metre, is given by Formula (A.18):

$$u\rho = \frac{U\rho}{k} \quad (A.18)$$

where k is the coverage factor (typically $k = 2$).

