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

Part 2:
Optical-reference-line method

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

Partie 2: Méthode par ligne de référence optique

Reference number
ISO 7507-2:2005(E)

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Foreword

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International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

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.

ISO 7507-2 was prepared by Technical Committee ISO/TC 28, *Petroleum products and lubricants*, Subcommittee SC 3, *Static petroleum measurement*.

This second edition cancels and replaces the first edition (ISO 7507-2:1993), which has been technically revised.

ISO 7507 consists of the following parts, under the general title *Petroleum and liquid petroleum products — Calibration of vertical cylindrical tanks*:

— *Part 1: Strapping method*

— *Part 2: Optical-reference-line method*

— *Part 3: Optical-triangulation method*

— *Part 4: Internal electro-optical distance-ranging method*

— *Part 5: External electro-optical distance-ranging method*

Introduction

This part of ISO 7507 forms part of a series on tank calibration, including the following:

ISO 4269:2001, *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 7507-3:1993, *Petroleum and liquid petroleum products — Calibration of vertical cylindrical tanks — Part 3: Optical-triangulation method*

ISO 7507-4:1995, *Petroleum and liquid petroleum products — Calibration of vertical cylindrical tanks — Part 4: Internal electro-optical distance-ranging method*

ISO 7507-5:2000, *Petroleum and liquid petroleum products — Calibration of vertical cylindrical tanks — Part 5: External electro-optical distance-ranging method*

ISO 8311:1989, *Refrigerated light hydrocarbon fluids — Calibration of membrane tanks and independent prismatic tanks in ships — Physical measurement*

ISO 9091-1:1991, *Refrigerated light hydrocarbon fluids — Calibration of spherical tanks in ships — Part 1: Stereo-photogrammetry*

ISO 9091-2:1992, *Refrigerated light hydrocarbon fluids — Calibration of spherical tanks in ships — Part 2: Triangulation measurement*

ISO 12917-1:2002, *Petroleum and liquid petroleum products — Calibration of horizontal cylindrical tanks — Part 1: Manual methods*

ISO 12917-2: 2002, *Petroleum and liquid petroleum products — Calibration of horizontal cylindrical tanks — Part 2: Internal electro-optical distance-ranging method*

This part of ISO 7507 describes a method for the calibration of vertical cylindrical tanks by measurement of one reference circumference by strapping and then determining the remaining circumferences at different levels from measurements of radial offsets from vertical optical-reference-lines. These circumferences are corrected to give the true internal circumferences.

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

Part 2:
Optical-reference-line method

1 Scope

This part of ISO 7507 specifies a method for the calibration of tanks above eight metres in diameter with cylindrical courses that are substantially vertical. It provides a method for determining the volumetric quantity contained within a tank at gauged liquid levels.

NOTE The optical (offset) measurements required to determine the circumferences can be taken internally or externally.

The method specified in this part of ISO 7507 is 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.

This method is an alternative to other methods such as strapping (ISO 7507-1) and the optical-triangulation method (ISO 7507-3).

2 Normative references

The following referenced documents are indispensable for the application 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 4269:2001, *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*

3 Terms and definitions

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

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 using a horizontal scale that is mounted on the trolley

3.3
station
location where the optical device and the magnetic trolley 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 measured at the bottom course where the reference circumference is measured

4 Precautions

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

5 Equipment

5.1 Equipment for tank strapping, as follows, as specified in ISO 7507-1:

— strapping tapes;

— spring balance;

— step-over;

— littlejohn grip;

— dip-tape and dip-weight.

5.2 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 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.

5.3 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 have 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) A cord or wire cable shall be attached to enable it to be raised or lowered from the tank roof or, via a pulley system, from ground level.

d) A graduated scale 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.

5.4 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 using standard methods and standard reference devices.

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 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, optical-reference-lines 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 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, therefore, shall 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

6.4.1 Set up the optical-reference-line device (5.2), magnetic trolley (5.3) and graduated scale (5.4) 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.

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

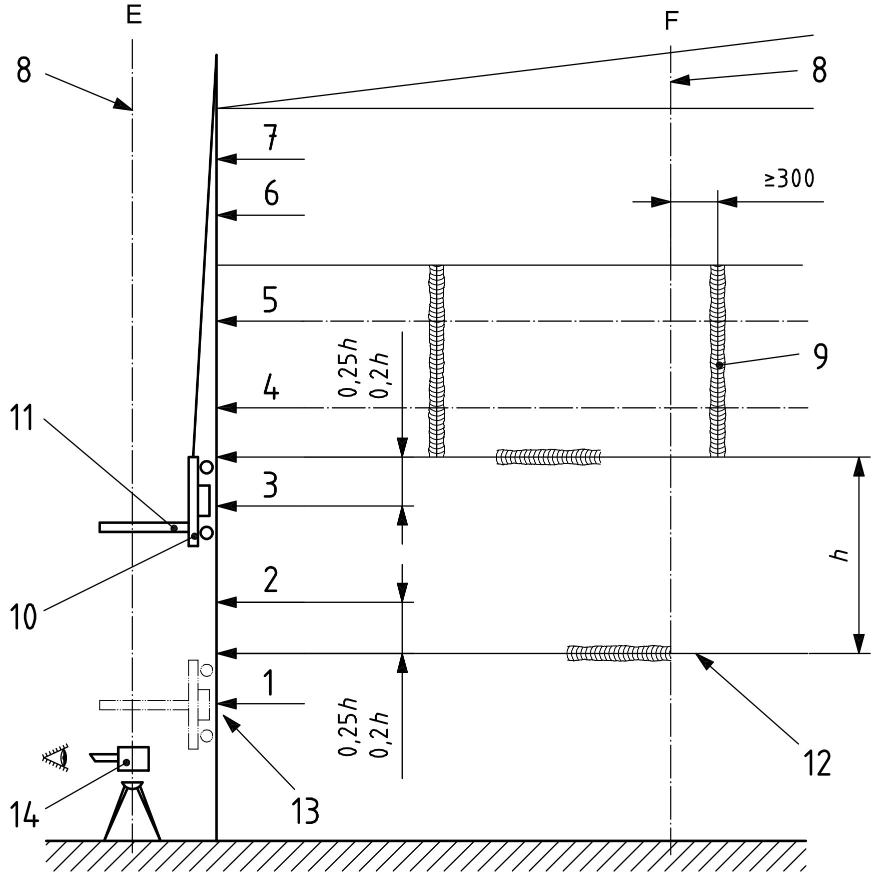
Table 1 — Minimum number of horizontal stations

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

NOTE 1 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.

NOTE 2 Using the minimum number of horizontal stations, especially for smaller tanks, can lead to larger-than-acceptable uncertainties.

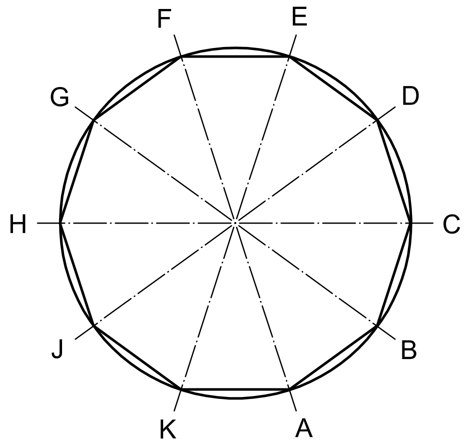
Dimensions in millimetres



Key

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

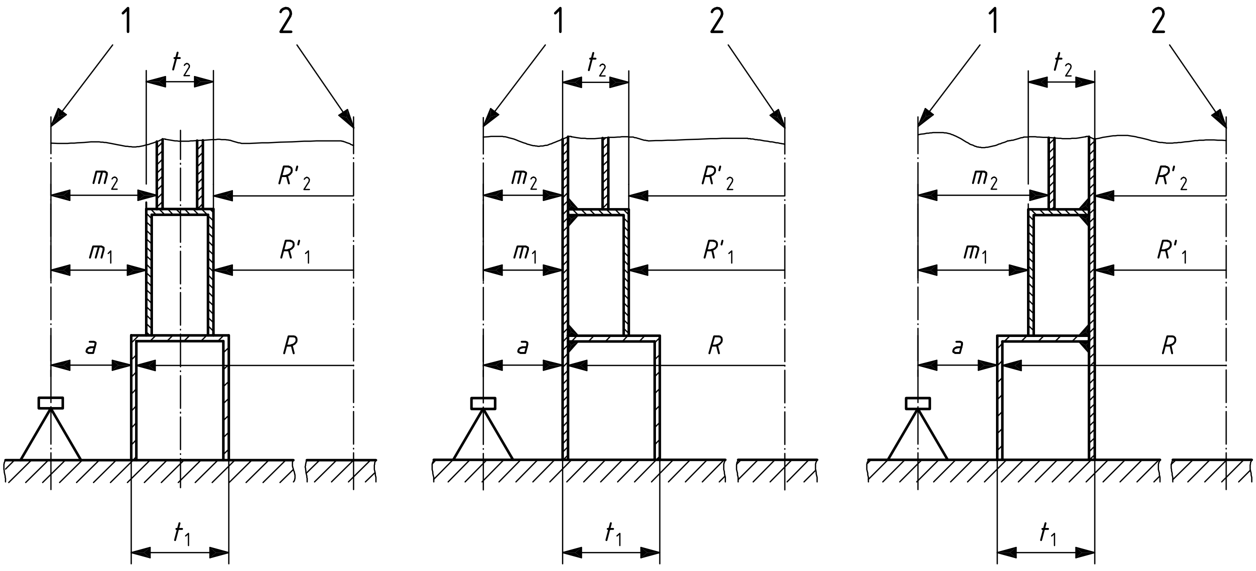
a) Tank elevation



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**

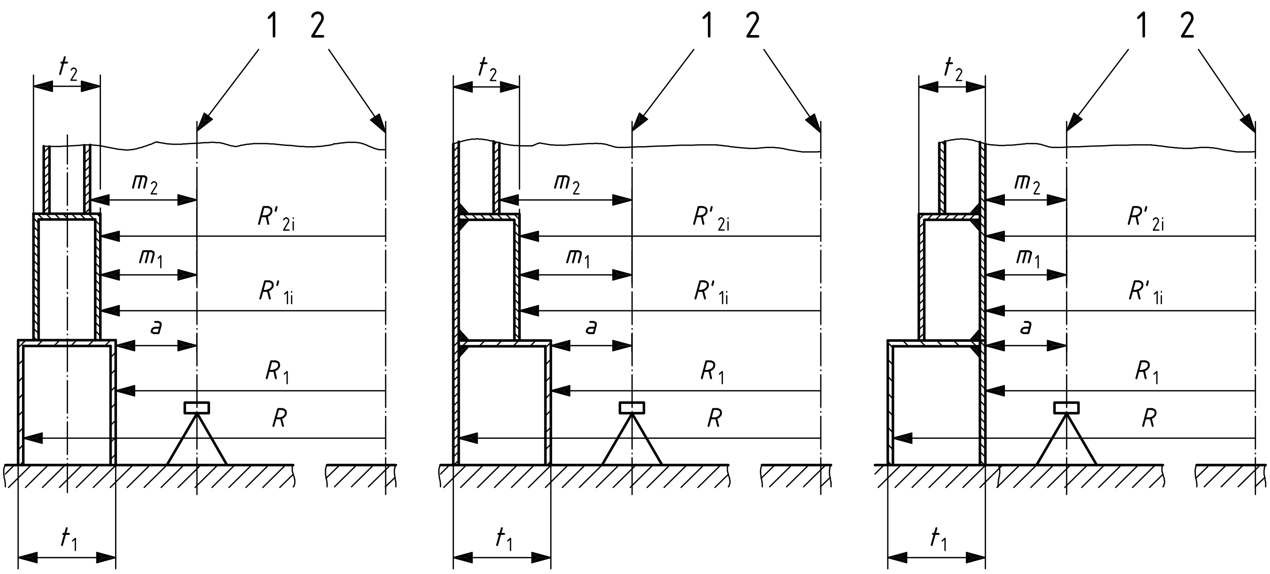
Key

1 optical-reference-line

2 tank centreline

External reference circumference	$= C_{em}$
External reference radius (bottom course)	$= C_{em}/2\pi = R$
Outer radius of second course	$= R'_1, R'_2,$
Course thicknesses	$= t_1, t_2,$ etc.
Reference offset	$= a$
Reference radius	$= R$
Individual course offsets	$= m_1, m_2,$ etc.
Internal reference radius	$= R - t_1 = C_{em}/2\pi - t_1 = R_1$
Internal radius, second course, bottom	$= R'_{1i}$
Internal radius, second course, top	$= R'_{2i}$

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

External reference circumference	$= C_{em}$
External reference radius (bottom course)	$= C_{em}/2\pi = R$
Outer radius of second course	$= R'_1, R'_2,$
Course thicknesses	$= t_1, t_2$, etc.
Reference offset	$= a$
Reference radius	$= R$
Individual course offsets	$= m_1, m_2$, etc.
Internal reference radius	$= R - t_1 = C_{em}/2\pi - t_1 = R_1$
Internal radius, second course, bottom	$= R'_{1i}$
Internal radius, second course, top	$= R'_{2i}$

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 Tank bottom calibration

Calibrate the tank bottom, preferably by filling with measured quantities of a non-volatile liquid (preferably clean water), as illustrated in 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.

6.6 Other measurements and data

6.6.1 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).

6.6.2 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.

6.6.3 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.

6.6.4 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
$\leqslant 25$	2
> 25, $\leqslant 50$	3
> 50, $\leqslant 100$	5
> 100, $\leqslant 200$	6
> 200	8

8 Tank capacity table calculation procedure

8.1 Outside circumference

Calculate the outside circumference from offset readings and the reference circumference by using Equations (1) to (3):

$$R = \frac{C_{\text{em}}}{2\pi} \tag{1}$$

$$R + a = R' + m \tag{2}$$

$$R' = R + (a - m) \tag{3}$$

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, expressed in metres, from the reference circumference to the reference line;

m is the offset, 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 Equation (4):

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

and for internal measurements by Equations (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.

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

A.1 Introduction

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
Δh_j	Height of the jth section	m
h_j	Cumulative height of the jth section	m
uh_j	Standard uncertainty of height (internal) of the tank for section j	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
$u\delta R_{\text{h}}$	Standard uncertainty of radius correction for deformation due to hydrostatic head	m

Symbol	Description	Unit
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
$uma_{j\text{i}}$	Standard uncertainty of the difference of offsets measured at height $H_{j\text{i}}$ 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
ut_{m}	Standard uncertainty of thickness of tank wall metal	m
R_{i}	Average of the internal radii of the jth section	m
uR_{ia}	Standard uncertainty of internal radius averaged for one course in the tank	m
K_{sh}	Empirical factor that covers uncertainties due to tank shell deformation in horizontal plane	—
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}
$e\alpha_{\text{tp}}$	Maximum error of coefficient of linear expansion of the strapping or dip tape material	°C^{-1}
$u\alpha_{\text{tp}}$	Standard uncertainty of coefficient of linear expansion of the strapping tape material	°C^{-1}
$e\alpha_{\text{tk}}$	Maximum error of estimate of the linear expansion coefficient of tank shell	°C^{-1}
$u\alpha_{\text{tk}}$	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
eT_{tp}	Maximum error of estimate of strapping temperature	K
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

Symbol	Description	Unit
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_{o}	Tank bottom volume (measured)	m^3
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_{o}	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	
wt_{mp}	Maximum uncertainty equal to the width of rectangular distribution	
N_{hs}	Number of horizontal stations around the tank	
N_{mc}	Number of measured radii in each course	
V_{raw}	Raw volume	
eT_{ts}	Maximum error of estimate of the service temperature	
uT_{ts}	Standard uncertainty of the service temperature	
V_{ts}	Specific volume corrected for expansion due to temperature in service	
V_{hc}	Volume given in the tank capacity table;	

A.3 Calculations overview

Methods for the following calculations are given in this part of ISO 7507:

— 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 Equation (A.1):

$$uL_{\text{st}} = \frac{UL_{\text{st}}}{k} \tag{A.1}$$

A.4.1.2 Strapping tape reading

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

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

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

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 Equation (A.4):

$$uL_{tp} = \frac{tL_{tp}}{12^{1/2}} \tag{A.4}$$

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	Tolerance tL_{tp}	
m	mm	m
$\leqslant$ 25	2	0,002
$>$ 25, $\leqslant$ 50	3	0,003
$>$ 50, $\leqslant$ 100	5	0,005
$>$ 100, $\leqslant$ 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 Equation (A.1) is given in Equation (A.5):

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

NOTE The factor 1/12½ 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 is different from ISO 7507-1 in that in this part of ISO 7507 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 Equation (A.6) and (A.7) where N_{m} is the number of measurements of the reference circumference. Equation (A.6) should be used if one tape is used repeatedly, N_{m} times. Equation (A.7) should be used in N_{m} different tapes are used to measure the reference circumference:

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

$$uC_{\mathrm{em}} = \left(\frac{uL_{\mathrm{tr}}^2 + uL_{\mathrm{tp}}^2 + uL_{\mathrm{ta}}^2}{N_{\mathrm{m}}} + uL_{\mathrm{st1}}^2 + uL_{\mathrm{st2}}^2 + \ldots + uL_{\mathrm{st}n}^2 + uL_{\mathrm{m}}^2 \right)^{1/2} \tag{A.7}$$

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 Equation (A.8):

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

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 Equation (A.9):

$$ut_{\mathrm{mp}} = \frac{wt_{\mathrm{mp}}}{12^{1/2}} \tag{A.9}$$

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 Equation (A.10):

$$uma_j = \frac{\left\{\left[\left(H_j - H_{\mathrm{ref}}\right) \times ut_{\mathrm{v}}\right]^2 + \left(2 \times ut_{\mathrm{r}}^2\right)\right\}^{1/2}}{12^{1/2}} \qquad \text{(A.10)}$$

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 $2 \times ut_{\mathrm{r}}$ corresponds to two independent measurements of the offsets that are performed (one for the reference offset, a, and one for $N_{m_{\mathrm{i}}}$).

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 Equation (A.11):

$$uR_{\mathrm{i}} = \left[uR_{\mathrm{ext}}^2 + \frac{\sum\left(uma_i\right)^2}{N_{\mathrm{hs}}^2} + ut_{\mathrm{mp}}^2 + K_{\mathrm{sh}}\right]^{1/2} \qquad \text{(A.11)}$$

where

K_{sh} is the factor 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 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 Equation (A.12):

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

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 $K_{\mathrm{sv}} > 1$ (typically $K_{\mathrm{sv}} = 3$).

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 Equation (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 Equation (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_o 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.7.2.1.1 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.7.2.1.2 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 Equation (A.15):

$$uV_{\text{o}} = 0{,}25 \text{ to } 1{,}5 \quad \text{(A.15)}$$

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.7.2.1.3 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 Equation (A.16):

$$uV_{\text{dis}} = \frac{tV_{\text{dis}} \times V_{\text{dis}}}{12^{1/2}} \quad \text{(A.16)}$$

A.7.2.1.4 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 Equation (A.17):

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

NOTE The above equation assumes statistical independence of measurements in all tank courses.

A.7.4 Volume at reference conditions

A.7.4.1 Source uncertainties

A.7.4.1.1 General

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 Equation (A.18):

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

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

The maximum error of Young's modulus of elasticity of the tank wall material is eE, a typical value of which is 5×10^9 N/m^2). Assuming rectangular distribution, the standard uncertainty, uE, expressed in newtons per square metre, is given by Equation (A.19):

$$uE = \frac{eE}{12^{1/2}} \quad \text{(A.19)}$$

The maximum error for the estimate of the strapping temperature is eT_{tp} (eT_{tp} is 5 °C for typical locations). Assuming rectangular distribution, the standard uncertainty, uT_{tp}, is given by Equation (A.20):

$$uT_{tp} = \frac{eT_{tp}}{12^{1/2}} \quad \text{(A.20)}$$

The maximum error for the estimate of the linear expansion coefficients are $e\alpha_{tp}$ and $e\alpha_{tk}$, respectively (typical values of which are $e\alpha_{tp} = e\alpha_{tk} = 2 \times 10^{-6}$ °C^{-1}). Assuming rectangular distribution, the standard uncertainties, $u\alpha_{tp}$ and $u\alpha_{tk}$, expressed in reciprocal degrees Celsius, are given by Equations (A.21) and (A.22):

$$u\alpha_{tp} = \frac{e\alpha_{tp}}{12^{1/2}} \quad \text{(A.21)}$$

$$u\alpha_{tk} = \frac{e\alpha_{tk}}{12^{1/2}} \quad \text{(A.22)}$$

The uncertainties of the following variables are assumed to be negligible:

— uL, which is the uncertainty of level of liquid in the tank at calibration (if any);

— ug, which is the uncertainty of local acceleration due to gravity;

— $u\rho_{ref}$, which is the uncertainty of density of ambient air.

A.7.4.1.2 Correction for deformation due to hydrostatic head at reference conditions

This uncertainty is a combination of contributions of uncertainties of the following parameters involved in hydrostatic correction:

- internal radius;
- density of the liquid at calibration;
- Young's modulus of elasticity;
- thickness of the tank wall material.

The standard uncertainty uV_h of the expansion volume caused by hydrostatic head is given by Equation (A.23):

$$uV_h = V_h \times \left[\left(3 \times \frac{uR_i}{R_i} \right)^2 + \left(\frac{u\rho}{\rho - \rho_{ref}} \right)^2 + \left(\frac{uE}{E} \right)^2 + \left(\frac{ut_m}{t_m} \right)^2 \right]^{1/2} \quad \text{(A.23)}$$

where ρ_{ref} is the density of ambient air.

A.7.4.1.3 Correction for thermal expansion of tank and strapping tape at reference conditions

The standard uncertainty, expressed in metres, for the correction of the internal radius for differential thermal expansion of the strapping tape and the tank shell, $u\delta R_{it}$, includes

- standard uncertainty of the coefficients of expansion of the tape and the tank,
- standard uncertainty of the strapping temperatures (assumed to be the same for the tape and the tank shell),

and is given by Equation (A.24):

$$u\delta R_{it} = \left\{ \left[uR_i \times \left(\alpha_{tp} - \alpha_{tk} \right) \times \left(T_{tk} - T_{ref} \right) \right]^2 + \left[uT_{tk} \times R_i \times \left(\alpha_{tp} - \alpha_{tk} \right) \right]^2 + \left(u\alpha_{tp}^2 + u\alpha_{tk}^2 \right) \times \left[R_i \times \left(T_{tk} - T_{ref} \right) \right]^2 \right\}^{1/2} \quad \text{(A.24)}$$

The volume, expressed in cubic metres, at reference conditions corrected for thermal expansion can be calculated by the Equation (A.25):

$$V_{tr} = V \times \left[\alpha_{tp} \times \left(T_{tp} - T_{ref} \right) + 2 \times \alpha_{tk} \times \left(T_{tp} - T_{ref} \right) \right] \quad \text{(A.25)}$$

where

α_{tp} is the coefficient, expressed in reciprocal degrees Celsius, of linear expansion of the strapping tape;

α_{tk} is the coefficient, expressed in reciprocal degrees Celsius, of linear expansion of the tank shell material;

T_{ref} is the reference temperature, expressed in degrees Celsius, of the tank and strapping tape (zero uncertainty);

T_{tp} is the temperature, expressed in degrees Celsius, at strapping (same for tape and tank).

The standard uncertainty, expressed in volume percent, for the correction for thermal expansion of volume uV_t, which is given by Equation (A.26):

$$uV_t = \frac{2 \times u\delta R_{it}}{R_i} \times 100 \quad \text{(A.26)}$$

A.7.4.1.4 Additional hydrostatic uncertainties

The influence of the following quantities are included in the additional hydrostatic uncertainties:

— hydrostatic deformation of tank bottom at reference conditions;

— uncertainty of the model of hydrostatic head correction.

NOTE The standard uncertainty, uV_b, of the tank bottom depends on conditions such as the size and the state of the tank bottom. A typical value may be empirically estimated as $0{,}25/L$, expressed as a percentage of the volume, % V, where L is the height of the liquid (if any) in metres for $L \geqslant 1$. For $L < 1$, uV_b is estimated to be 0,25 % of the measured volume.

The standard uncertainty, uV_{Cal}, of the model of hydrostatic head correction is not calculated; but in accordance with the mathematical model given in ISO 7507-1:1993, Annex A, the additional uncertainty, expressed in cubic metres, can be as given in Equation (A.27):

$$uV_{Cal} = 1{,}25 \times 10^{-4} \times V \quad \text{(A.27)}$$

A.8 Tank table in service

A.8.1 Calculations

Corrections to the tank-table dimensions at reference conditions are specified for the following:

— deformation due to hydrostatic head from calibration density to density in service;

— thermal expansion of the tank shell from calibration temperature to temperature in service.

The expanded uncertainty, UV, of the values given in the tank capacity table (with coverage factor $k = 2$), including the uncertainties of the corrections of the extended raw volume-like deformation due to hydrostatic head, thermal expansion and the additional hydrostatic uncertainties is given by Equation (A.28):

$$UV = 2 \times \left[uV_r^2 + uV_h^2 + uV_{Cal}^2 + \left(uV_t^2 \times V^2 \right) + uV_b^2 \right]^{1/2} \quad \text{(A.28)}$$

NOTE Due to variations of uV_r, uV_t and uV_b, UV varies with varying volume of the liquid.

A.8.2 Uncertainties in service

A.8.2.1 Source uncertainties

The uncertainties in the following list have already been accounted for in the calculations of uncertainties at reference conditions (see A.7.4):

— uR_i, internal radius;

— uE, Young's modulus of elasticity of the tank wall material;

— ut_m, thickness of tank wall metal;

— $u\alpha_{tk}$, linear expansion coefficient of the tank shell material;

— uL, liquid level in the tank (= 0);

— ug, local acceleration due to gravity (= 0);

— $u\rho_{ref}$, reference density (= 0).

The following source uncertainties are different in the service conditions:

— The maximum error of estimate of the service temperature is eT_{ts} (which is 5 °C for typical locations). Assuming rectangular distribution, the standard uncertainty, uT_{ts}, expressed in degrees Celsius, is given by Equation (A.29):

$$uT_{ts} = \frac{eT_{ts}}{12^{1/2}} \quad \text{(A.29)}$$

— The extended uncertainty of observed liquid density of the liquid contained in the tank in service is $U\rho_s$ (which has a typical value of 5 kg/m^3). The standard uncertainty, $u\rho_s$, is given by Equation (A.30):

$$u\rho_s = \frac{U\rho_s}{k} \quad \text{(A.30)}$$

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

A.8.2.2 Correction for deformation due to hydrostatic head in service

The uncertainty is a combination of contributions of uncertainties of the following parameters involved in hydrostatic correction:

Standard uncertainty, uV_h, expressed in cubic metres, of the expansion volume caused by hydrostatic head in service is given by Equation (A.31):

$$uV_{hs} = \left\{ uV_h^2 + \left[V_{hs} \times \frac{u\rho}{\left(\rho_{ref} - \rho\right)} \right]^2 \right\}^{1/2} \quad \text{(A.31)}$$

A.8.2.3 Correction for thermal expansion in service

The correction of a specific volume for expansion due to temperature in service, yielding a temperature-corrected volume, V_{ts}, expressed in cubic metres, can be calculated from Equation (A.32):

$$V_{ts} = V_{hc} \times \left[\alpha_{tp} \times \left(T_{tp} - T_{ref}\right) + 2 \times \alpha_{tk} \times \left(T_{tk} - T_{ref}\right) \right] \quad \text{(A.32)}$$

where

V_{hc} is the volume given in the tank capacity table;

α_{tk} is the coefficient, expressed in reciprocal degrees Celsius, of linear expansion of the tank shell material;

α_{tp} is the coefficient, expressed in reciprocal degrees Celsius, of linear expansion of the dip-tape;

T_{ref} is the reference temperature, expressed in degrees Celsius, of the tank (zero uncertainty);

T_{tk} is the temperature, expressed in degrees Celsius, of the tank (in service);

T_{tp} is the temperature, expressed in degrees Celsius, of dip-tape (in service);

The standard uncertainty, uV_{ts}, expressed in volume percent, of correction of volume for thermal expansion is given by Equation (A.33):

$$uV_{ts} = 100 \times \left\{ \left(uV_{hc} / V_{hc} \right)^2 + \left[\alpha_{tp} \times \left(T_{tp} - T_{ref} \right) \right]^2 + \left(uT_{tp} \times \alpha_{tp} \right)^2 + \left[2 \times u\alpha_{tk}^2 \times \left(T_{tk} - T_{ref} \right) \right]^2 + \left(uT_{tk} \times 2 \times \alpha_{tk} \right)^2 \right\}^{1/2} \quad \text{(A.33)}$$

A.8.2.4 Model of hydrostatic head correction

The calculation of a correction for the deformation due to hydrostatic head in service using a mathematical model leads to an additional uncertainty uV_{Cal} (see A.7.4.4).

NOTE This uncertainty correlates strictly with that of the calculation of the correction for the deformation due to hydrostatic head at reference conditions if the mathematical model given in ISO 7507-1:1993, Annex A, is used in both cases.

A.8.2.5 Dipping

The standard uncertainty of dipping includes the following:

- the standard uncertainty of measurement of the distance between the surface of the liquid and the dipping point,
- the standard uncertainty of the dip-tape reading.

The maximum error, ed_m, expressed in millimetres, of estimate of measurement of the distance between the surface of the liquid and the dipping point is equal to $\pm (1{,}3 + 0{,}2 \times L_{tape})$, where L_{tape} is the dip tape length expressed in metres.

The measuring device used in dipping is normally a dip-tape. If an ullage-based gauging system is used, the maximum error, ed_m, expressed in millimetres, of estimate of measurement is equal to $[(3 + 0{,}4 \times L) + \delta H]$.

Assuming rectangular distribution, the standard uncertainty, ud_m, expressed in metres, is given by Equation (A.34):

$$ud_m = \frac{ed_m}{3^{1/2}} \quad \text{(A.34)}$$

The error of estimate of measurement of the liquid level caused by a reduction in height, δH, expressed in metres, of the tank is given by Equation (A.35):

$$\delta H = \frac{R_i \times L^2 \times \rho \times g}{4 \times \mu \times E \times t_1} \quad \text{(A.35)}$$

where μ is the Poisson ratio of the material of the tank shell (e.g. for steel $\mu \approx 3{,}3$).

If rL_{td} is the resolution of the dip-tape or of the gauging system (usually, rL_{td} = 1 mm), the corresponding standard uncertainty, uL_{td}, is given by Equation (A.36):

$$uL_{td} = \frac{rL_{td}}{12^{1/2}} \tag{A.36}$$

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

The standard uncertainty of dipping, uD_{dip}, is given by Equation (A.37):

$$uD_{dip} = \left(ud_m^2 + uL_{td}^2 + \delta H^2 \right)^{1/2} \tag{A.37}$$

A.8.3 Volume in service

The standard uncertainty of volume, uV_{Ls}, for a liquid level, L, in service, is given by Equation (A.38):

$$uV_{ls} = 2 \times \left\{ \left[\left(\frac{UV}{k} \right)^2 + uV_{bs}^2 + \left(uV_{ts}^2 \times V_L^2 \right) + \left(uD_{dip} \times R_i^2 \times \pi \right)^2 \right]^{1/2} + uV_{Cal} \right\} \tag{A.38}$$

where

V_L is the volume given in the tank capacity table at a liquid level, L;

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

NOTE The uncertainty uV_{Cal} of the mathematical model for correction for deformation due to hydrostatic head in service can be positive or negative.

Bibliography

[1] GUM:1995, *Guide to the expression of uncertainty in measurement*, first edition BIPM/IEC/IFCC/ISO/IUPAC/IUPAP/OIML

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