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

Part 1: Strapping method

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

Partie 1: Méthode par ceinturage

Reference number
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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.

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.

International Standard ISO 7507-1 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 7507-1:1993). It also cancels and replaces ISO 7507-6:1997, the subject of which is now included in this part of ISO 7507.

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*

— *Part 6: Recommendations for monitoring, checking and verification of tank calibration and capacity table*

Introduction

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

ISO 7507-2:1993, *Petroleum and liquid petroleum products — Calibration of vertical cylindrical tanks — Part 2: Optical-reference-line 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 7507-6:1997, *Recommendations for monitoring, checking and verification of tank calibration and capacity table*

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*

The strapping method for the calibration of vertical cylindrical tanks has been used for many years and is a recognized method of determining the capacity of storage tanks from measurements of the circumference of a tank at various heights. The strapping method is also often used to establish a reference circumference at a selected height to use as a datum in other methods of tank calibration.

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

Part 1: **Strapping method**

1 Scope

1.1 This part of ISO 7507 specifies a method for the calibration of substantially vertical cylindrical tanks by measuring the tank using a strapping tape.

1.2 This method is known as the “strapping method” and is suitable for use as a working method, a reference method or a referee method.

NOTE For the reference method, the number of strappings required will be specified in the standard which refers to this part of ISO 7507.

1.3 The operation of strapping, the corrections to be made and the calculations leading to the compilation of the tank capacity table are described.

1.4 This method does not apply to abnormally deformed, e.g. dented or non-circular, tanks.

1.5 This method is suitable for tilted tanks with a deviation of up to 3 % from the vertical, provided that a correction for the measured tilt is applied in the calculations.

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 91-1:1992, *Petroleum measurement tables — Part 1: Tables based on reference temperatures of 15 °C and 60 °F*

ISO 3675:1998, *Crude petroleum and liquid petroleum products — Laboratory determination of density — Hydrometer method*

ISO 4269:2001, *Petroleum and liquid petroleum products — Tank calibration by liquid measurement — Incremental method using volumetric meters*

3 Terms and definitions

For the purposes of this document and subsequent parts of ISO 7507, the following terms and definitions apply.

3.1
argument
independent variable of a function

NOTE A table is entered with value(s) of the independent variable(s), the value(s) extracted from the table being known as the dependent value(s).

3.2
bottom calibration
procedure to determine the quantity of liquid contained in a tank below the calibration datum-point

3.3
calibration
process of determining the capacity of a tank, or the partial capacities corresponding to different levels

3.4
capacity
total volume of a tank

3.5
capacity table
tank table
tank capacity table
table showing the capacities of, or volumes in, a tank corresponding to various liquid levels measured from a stable reference point

3.6
course
one circumferential ring of plates in a tank

3.7
calibration datum-point
point used as the datum in the preparation of a calibration table

NOTE Course heights and the effective levels of deadwood are measured from this point, to which the bottom calibration is also related.

3.8
deadwood
any tank fitting that affects the capacity of the tank

NOTE Deadwood is referred to as “positive deadwood” when the capacity of the fitting increases the effective capacity of the tank, or “negative deadwood” when the volume of the fitting displaces liquid and reduces the effective capacity.

3.9
dip
innage
depth of a liquid in a tank above the dipping datum-point

3.10
dip-hatch
gauge-hatch
opening in the top of a tank through which dipping and sampling operations are carried out

3.11
dip-point
point on the dip-plate which the dip-weight touches during gauging and from which the measurements of the oil and water depths are taken

NOTE The dip-point usually corresponds to the datum-point, but when this is not so, the difference in level between the datum-point and the dip-point has to be allowed for in the calibration table.

3.12
dip-plate
striking-plate positioned below the dip-hatch

NOTE The position of the dip-plate should not be affected by bottom or wall movements.

3.13
dip-tape
graduated steel tape used for measuring the depth of the oil or water in a tank, either directly by dipping or indirectly by ullage

3.14
dip-weight
weight attached to a steel dip-tape, of sufficient mass to keep the tape taut and of such shape as to facilitate the penetration of any sludge that might be present on the dip-point or the dip-plate

3.15
floating cover
screen
lightweight cover of either metal or plastics material designed to float on the surface of a liquid in a tank

NOTE The cover rests upon the liquid surface and is used to retard evaporation of volatile products in a tank.

3.16
floating-roof tank
tank in which the roof floats freely on the surface of the liquid contents, except at low levels when the weight of the roof is taken through its supports by the tank bottom

3.17
function
when two variable quantities are interrelated, one quantity is said to be a function of the other

NOTE In the context of tank calibration, the volume of liquid contained in a tank is said to be a function of the dip or of the ullage.

3.18
gauging
process of taking all the necessary measurements in a tank in order to determine the quantity of liquid that it contains

3.19
interpolation
process of obtaining the value of a function corresponding to a value of the argument intermediate between those given

3.20
Littlejohn grip
quick-release clamp that may be fitted around a strapping tape at any convenient position throughout its length

NOTE A handle is attached to the Littlejohn grip so that the strapping tape can be pulled to the correct tension.

3.21
open capacity
calculated capacity of a tank or part of a tank before any allowance has been made for deadwood

3.22
reference height
vertical distance between the dip-point and the upper reference point

3.23
overall height
total external height from the top of the shell to the base of the tank (plate)

3.24
referee method
application of the strapping method of tank calibration to give a calibration of a tank for custody transfer purposes or to provide a basis for assessing the accuracy of other methods of tank calibration

3.25
reference method
application of the strapping method of tank calibration to the measurement of a reference circumference for use in other methods of tank calibration

NOTE An example of such a method is the optical-reference-line method (see ISO 7507-2).

3.26
reference point
a point to which measurements in either calibration or gauging are related

3.27
step-over
device used in strapping for measuring the distance apart, along the arc, of two points on a tank shell where it is not possible to use a strapping tape directly because of an intervening obstruction, e.g. a protruding fitting

3.28
step-over constant
distance between the measuring points of a step-over as measured along the arc of the particular course of the tank concerned

3.29
step-over correction
difference between the apparent distance between two points on a tank shell as measured by a strapping tape passing over an obstruction and the true arc distance as measured by a step-over, i.e. the step-over constant

3.30
strapping tape
specially designed and calibrated steel measuring tape graduated in units of length and used for taking circumferential measurements in tank calibration

3.31
strapping method
method of tank calibration in which the capacities are calculated from the measurement of the external circumferences, due allowance being made for the thickness of the shell of the tank

3.32
tape positioner
guide sliding freely on the strapping tape, used to pull and hold it in the correct position for taking measurements

3.33
tensioning handles
handles fastened to the strapping tape, used for pulling it into the correct position and applying tension

3.34
ullage
outage
capacity of a tank not occupied by the liquid

3.35
upper reference point
point clearly defined on the dip-hatch directly above the dip-point to indicate the position at which dipping or ullaging shall be carried out

3.36
working method
application of the strapping method of tank calibration by a simplified procedure that may result in some loss of accuracy and is unsuitable for assessing other methods

4 Precautions

4.1 Introduction

This clause outlines the precautions that are applicable when tanks are being calibrated. The precautions necessary to ensure the safety of the operator are dealt with separately from those precautions which have to be taken to ensure the necessary precision required in the calibration of tanks.

4.2 General precautions

4.2.1 The utmost care and attention to detail shall be exercised when calibrating storage tanks.

4.2.2 All measurements shall be carefully observed and recorded as read, and any corrections which are required shall be recorded separately. If any unusual occurrences are noted during the operations, these occurrences shall be documented and the calibration shall be repeated, if necessary.

4.2.3 If the tank is only slightly distorted, sufficient additional measurements shall be taken to allow satisfactory calculation of its capacity table. If such additional measurements are required, the calibrator's notes shall include the reasons for the extra measurements.

It is also recommended that dimensioned sketches should be provided by the calibrator to show any abnormality of the tank or the fittings that affect calibration.

NOTE Seriously distorted tanks are best calibrated using liquid calibration methods similar to the method described in ISO 4269.

4.2.4 To ensure accuracy and repeatability of readings, lumps of paint, scale, etc., likely to interfere with measurement, shall be removed or the position of the measuring equipment adjusted accordingly.

4.2.5 If drawings for the tank are available, all relevant measurements shall be compared with the corresponding dimensions shown on the drawings. Any measurement which shows a significant discrepancy as a result of this comparison shall be reported and, if necessary, repeated.

4.2.6 If the calibration of a tank is interrupted, it may be resumed at a later date provided that:

a) if there is a change of equipment or personnel, sufficient check measurements shall be made to ensure that the results obtained prior to the change correspond within the tolerances given in this method;

b) all records of work done are complete and legible;

c) the liquid contents remain unchanged at substantially the same level;

d) the average liquid and atmospheric temperatures are within 10 °C of the average liquid and atmospheric temperatures recorded during the earlier working period.

4.3 Safety precautions

4.3.1 The safety precautions given in 4.3.2 to 4.3.6 constitute good practice, but the list is not necessarily comprehensive. It is recommended that the list should be read in conjunction with the appropriate sections of any applicable safety code. The precautions shall be taken whenever they do not conflict with legislative requirements, which shall always be followed.

4.3.2 All regulations covering entry into hazardous areas shall be rigorously observed.

4.3.3 If a tank being strapped contains a petroleum product, attention shall be paid to the normal safety precautions which apply to such tanks.

4.3.4 Before a tank which has been in use is entered, a safe-entry certificate issued in accordance with local or national regulations shall be obtained. All lines entering the tank shall be disconnected and blanked. The national or local regulations regarding the entry into tanks which have contained leaded fuels shall be meticulously observed.

4.3.5 Hand lamps shall be of a type approved for use in explosive atmospheres.

4.3.6 The safety of operating personnel shall be safeguarded by strict attention to the following.

a) Ladders shall be inspected before use, and extendable ladders used only within their safe operating range. The footing for each ladder shall be level and firm, and all ladders shall be securely lashed in position before being used.

b) When painters' cradles or bo'suns' chairs are used, blocks, falls, ropes, etc., shall be tested before erection, and any item of questionable strength or condition shall be replaced. Every care shall be paid to the securing of the equipment and its operational use.

c) If calibration cannot be carried out without the use of staging, properly constructed steel tube or timber scaffolding shall be erected. Loose bricks, drums, boxes, etc., shall not be used to form staging.

d) Where appropriate, safety harnesses shall be worn by personnel working above ground level.

5 Equipment

5.1 Strapping tape, conforming to A.1. The tape shall be well greased before use.

5.2 Spring balance, conforming to A.2, for measuring the tension applied to the tape.

5.3 Step-over, conforming to A.3.

5.4 Tape positioners and cords, conforming to A.4, fitted to the strapping tape, and supplied with plaited cords. Both upper and lower cords shall be long enough to cover the height of the tank.

5.5 Littlejohn grip, conforming to A.5, to hold the tape, without kinking, in order to facilitate application of the necessary tension.

5.6 Apparatus for thickness measurement, either a steel rule of convenient length graduated throughout its length in millimetres, with at least the first 10 mm subdivided into half-millimetres, and/or another device, such as an electronic thickness gauge.

5.7 Dip-tape conforming to A.6, long enough to reach from the dipping reference point at the tank roof to the dip-point on the tank bottom.

5.8 Dip-weight, conforming to A.7.

5.9 End-to-end rule, 1 m in length, with graduations in centimetres and millimetres, for measuring deadwood, etc. If a wooden rule is used, it shall be fitted with a brass ferrule at each end and shall be free from warp.

5.10 Ladders and staging: see 4.3.6 for safety precautions.

5.11 Density- and temperature-measuring apparatus, conforming to ISO 3675.

6 General requirements

NOTE If possible, measurements should be compared with the corresponding dimensions on the tank construction drawings and the roundness of the tank should be ascertained.

6.1 Fill the tank to its normal working capacity at least once and allow 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. However, if the temperature of the wall surface can differ by more than 10 °C between the empty part and the full part of the tank, the tank shall be either completely full or empty. Do not make transfers of liquid during the calibration.

The ambient temperature before and after calibration should be recorded.

Obtain the required number of external circumference measurements, together with the subsidiary measurements, where necessary, to correct for deviation of the strap due to obstructions, as described in 7.2.

NOTE Additional measurements required to enable a table of capacities to be prepared and the procedures to be used in obtaining them are described in Clauses 8 to 12.

6.2 It is necessary to refer all tank dips to the dip-point, which may be in a different position from the calibration datum-point, e.g. a point on the bottom angle, used for the purpose of tank calibration. Check that the dip-plate has been securely mounted in a stable position so that it is not affected by movement of the tank bottom or walls. Determine any difference in level between the dip-point and calibration datum-point, either by normal surveying methods or by other suitable means, and record it.

6.3 Measure the height of the upper reference point above the dip-point using the dip-tape and dip-weight. Record this reference height, to the nearest subdivision on the dip-tape, in the empty and the full conditions, as appropriate.

7 Circumference measurements

7.1 Levels strapped

7.1.1 If the calibration is for referee purposes, measure the circumference by three or more strappings per course, at approximately the following levels:

a) for riveted tanks:

   1) 100 mm to 150 mm above the level of the top of the bottom angle of the tank, and 100 mm to 150 mm above the upper edge of each horizontal overlap between courses;

2) at the middle position of each course;

3) 100 mm to 150 mm below the lower edge of each horizontal overlap between courses and 100 mm to 150 mm below the level of the lowest part of the top angle.

b) for welded tanks:

three or more levels as indicated in a), but the upper and lower levels shall be 270 mm to 330 mm from the bottom angle, top angle or horizontal seams.

7.1.2 If the calibration is for the working method, the circumference may be measured, if preferred, by only two strappings per course, taking one at each of the following levels:

— at about 1/5 to 1/4 of the course height or the ring height above the lower horizontal seam;

— at about 1/5 to 1/4 of the course height or the ring height below the upper horizontal seam.

7.1.3 If for any reason it is impracticable to take a strapping at the normal level, take a strapping as close to this level as practicable, but not nearer the bottom or top angle or any seam than is specified in 7.1.1 a) or b). Record in the strapper's notes the level at which this circumference has been measured, with the reason for abandoning the normal level.

If the tape is not in close contact with the surface of the tank throughout its whole path, apply a step-over as in 7.5, so that a correction may be calculated to adjust the gross circumference for this effect.

7.2 Strapping procedure

7.2.1 Strap the tank by either of the methods described in 7.2.2 and 7.2.3. The calibration tension specified on the strapping tape shall be applied to the tape using the tensioning handles and spring balance, and transmitted throughout the length of the tape.

NOTE A slight sawing motion imparted to the strapping tape will achieve this, or the strapping tape can be eased round the tank by pulling it away from the shell by the cords attached to the tape positioners, sliding these along the strapping tape as required.

Place the strapping tape on its correct path which shall be parallel to the horizontal seams of the tank.

7.2.2 If the strapping tape used is not long enough to encircle the tank completely, choose the level of the strapping tape path and then measure the circumference in sections. Draw scribed lines not nearer than about one-third of a plate length from a vertical seam at such distances apart as will enable measurements to be made conveniently. When the tension on the spring balance at the end of the strapping tape is as specified in 7.2.1 for each separate section, record the individual readings. The external circumference of the tank shall then be the sum of the separate measurements.

7.2.3 If the strapping tape used is long enough to encircle the tank completely, choose the level of the strapping tape path and then pass the tape around the circumference and hold it so that the zero graduation is not nearer than about one-third of a plate length from a vertical seam. Bring the other end of the strapping tape alongside. Then apply the tension to the spring balance and ensure that it is transmitted throughout the length of the strapping tape. Take the reading directly from the part of the strapping tape opposite the zero mark when the tension on the spring balance is as described in 7.2.1. Record the reading.

If a strapping tape subdivided only for the first metre is used, take care when recording the circumferential measurement to subtract the reading shown on the subdivided portion from the reading indicated by the main graduation (see Figure 1).

7.3 Repetition of measurement

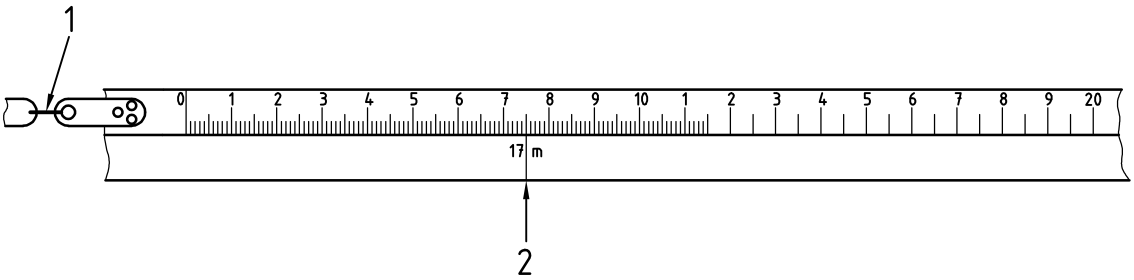
After a circumference has been measured as described in 7.2.2 or 7.2.3, release the tension and bring the strapping tape again to level and tension as in 7.2.1. Repeat and record the readings.

7.4 Tolerances

Measurements shall be read to the nearest 1 mm and shall be considered satisfactory if repetition as in 7.3 shows agreement within the following tolerances:

Circumferential measurement m	Tolerance mm
up to 25	2
above 25, up to 50	3
above 50, up to 100	5
above 100, up to 200	6
above 200	8

If agreement is not obtained, take and record further measurements until two consecutive readings do agree. Take the average of these two readings as the circumference. If consecutive measurements do not agree, determine the reasons for the disagreement and repeat the calibration procedure until agreement is obtained.



Key

1 spring balance and tension handle

2 reading shown would be 17 m minus 75 mm, or 16,925 m

Figure 1 — Reading of tape subdivided only for the first metre

7.5 Step-overs

7.5.1 Principle

If the tape path crosses obstructions such as projections, fittings, lapped joints, etc., which will cause it to deviate from a true circular path, an erroneous circumferential measurement will result. In order to avoid such an error, a step-over is used to measure the correction to be applied for such obstructions.

The constant for any one step-over will vary with the tank diameter and the course concerned, as it is determined on differently curved surfaces.

7.5.2 Use of step-overs

7.5.2.1 For each course, stretch the strapping tape as if in measurement of a circumference on the tank which is being calibrated (see 7.1). Apply the scribing points of the step-over to the tape near the middle of a plate where the tape is fully in contact with the tank surface.

Read the length between the points as measured on the tape to the nearest 1 mm.

Repeat the readings on four plates equally spaced around the course. Take the average of the results and record this as the step-over constant for the course concerned.

To assist in estimating fractions of a tape division, always take the reading from the same position on a graduation mark, e.g. from the right-hand edge.

7.5.2.2 With the tape still in position and under the tension used in strapping, apply the step-over to the tape on either side of each obstruction lying in the tape path. Take readings to the nearest 0,5 mm of the lengths of tape included between the scribing points (see last paragraph in 7.5.2.1). Record all step-over readings for subsequent use in the calculation.

7.5.2.3 The step-over correction for the obstruction concerned shall be the difference between the readings obtained as in 7.5.2.2 and the step-over constant obtained as in 7.5.2.1.

7.5.2.4 Include all obstructions for which a step-over correction is detectable. In the case of vertical seams, provided that the tape path is entirely clear of other obstructions, obtain a calculated step-over correction as described in 16.1.2.

7.5.2.5 Total the step-over corrections for all obstructions and vertical seams at the level concerned and deduct the result, rounded off to the nearest 1 mm, from the gross circumference measured in accordance with 7.2 to 7.4.

8 Other measurements on tank shell plates

8.1 Plate and paint thickness

Measure the thickness of the plate, paint and any internal coating for each course, whenever possible, except that, if tanks are of butt-welded construction, plate thicknesses may be taken from the drawings. Record the plate and paint thickness for each course to the nearest 0,5 mm.

8.2 Heights of courses

Measure course heights externally and record the vertical distances obtained to the nearest 5 mm. Make due allowance for the effect of any horizontal seam overlap in order to give the distance between successive edges of the course as exposed internally in the tank.

NOTE Seam overlaps may be obtained from the tank drawings or by difference between the measurement on successive courses.

Measure course heights at more than one position around the periphery. Average the results obtained and record them. The total of the separate course heights shall agree with the total height of the tank shell, which shall be measured separately at a position as near to the dip-point as practicable and recorded. If possible, also measure the bottom-course height internally to ensure that any repairs to, or renewals of, the tank bottom plating have not resulted in the internal height of the bottom course being reduced.

9 Deadwood

Measure the dimensions of the deadwood, whenever possible, and the heights of the lowest and highest points of such deadwood measured in relation to the datum-point of the tank. Record these measurements to the nearest 10 mm.

If physical measurements cannot be obtained, take details of deadwood from the tank drawings.

10 Tank bottoms

This clause should be read in conjunction with 17.2.

Calibrate the tank bottom by one of the following methods:

a) fill with measured quantities of a non-volatile liquid (preferably clean water), as specified in ISO 4269, to a minimum level that covers the bottom completely, immerse the dip-plate and eliminate the effect of bottom deformations; or

b) carry out a physical survey using a reference plane. Take care to ensure that the survey adequately describes the contours of the tank bottom. The recommended total number of survey points for the entire tank bottom is three times the tank diameter in metres.

NOTE Physical survey methods are used to determine the contents of the bottom by measuring down from a known truly horizontal plane across the tank bottom. Such a plane may be established by means of a dumpy level, a surveyor's level, a theodolite or water-filled tubes.

11 Measurement of tilt

Take measurements to determine the degree, if any, by which the tank is tilted.

NOTE This can conveniently be done during an internal bottom survey or by suspending a plumb line from the top angle and measuring at a sufficient number of points the maximum offset at the bottom angle [see 16.2 g)].

Bottom-course heights should also be checked to ensure that any tilt is genuine.

12 Floating-roof tanks

12.1 Carry out all calibration measurements exactly as for tanks with fixed roofs.

These measurements should preferably include liquid calibration of the tank bottom, which should be continued to a depth sufficient for the roof to become fully floating (see ISO 4269).

12.2 Carry out the following additional measurements.

a) The height of the lowest point of the roof above the datum-point when the roof is resting fully on its supports. If the roof is to be set at another working level, make the appropriate correction.

b) With the roof resting fully on its supports, paint four short horizontal white lines about 40 mm wide on the tank shell at approximately equidistant points and in such a position that, viewed from some definite point on the roof, their lower edges are just above four similar fixed reference points chosen along the periphery of the roof. Slowly pump liquid into the tank; when all roof reference points are seen to have moved equally upwards, regard the roof as fully floating. Read the dip reading of the liquid at this level and record it to the nearest 1 mm. Also measure and record the density and temperature of the liquid.

NOTE 1 The supporting legs can be utilized as a check of when the roof is fully floating. This has the advantage that reliance is not placed solely on movement of the roof periphery. There can be considerable flexing of the roof surface just before it becomes liquid-borne. As soon as the weight of the roof is removed from a leg by flotation of the adjacent roof surface, this leg can be freely shaken without removal of its supporting pin.

From the above data, it is possible to derive the mass of the roof if the quantity of displaced water is measured.

If facilities for liquid calibration are not available, measure the shape of the roof. Take sufficient measurements to enable the displacement of the roof to be calculated with reasonable accuracy and verified against the drawings.

c) If the mass of the roof and its attached appurtenances is given by the manufacturer or is indicated on a plate attached to the roof, record this value.

NOTE 2 The mass of the floating roof includes half of the mass of the ladder, and half the mass of accessories attached to the underside of, and partially supported by, the roof, e.g. flexible or articulated drain lines or floating suctions.

Check the recorded mass by calculation from the manufacturer's drawings.

d) If calibration of the tank is required over the range between the lowest level of the tank roof and the level of the liquid at which the roof becomes fully floating, use either of the following procedures (but preferably the first) [see note to 12.2 c)]:

   1) When liquid is pumped into the tank as in 12.2 b), carry this out in batches. Measure the quantity of each of the batches, which should be similar but not necessarily identical in volume, accurately using a meter calibrated for custody transfer or from measurements made in a storage tank provided with an accurate capacity table. Record the quantities to the nearest litre together with the corresponding liquid depths above the dip-point. Record dips to the smallest graduation on the dip-tape. Choose the batch size such that increments of approximately 50 mm are obtained. Record the density and temperature of the liquid.

From the above data it is possible to derive the mass of the roof.

   2) If facilities for liquid calibration are not available, measure the shape of the roof. Take sufficient measurements to enable the displacement of the roof, at various stages of immersion, to be calculated with reasonable accuracy and verified against the drawings.

NOTE 3 The calibration of this region of a tank by either procedure may not be accurate (see 17.3.6 and 17.3.11).

12.3 Measure fixed deadwood as described in Clause 9. Treat the drain line and other accessories attached to the underside of the roof as fixed deadwood in the position they occupy when the roof is at rest on its supports.

13 Recalibration

Tanks should be recalibrated as required by national regulations or if the calibration becomes suspect for any reason, e.g. deformation or movement of the tank foundations. If new equipment affecting deadwood volume is fitted, the deadwood volume should be calibrated and the tank capacity table recalculated. (see Annex B.)

14 Computation of tank capacity tables — General rules

14.1 All calculations shall be made in accordance with accepted mathematical principles.

NOTE 1 Errors in calculation are minimized and checking facilitated by the adoption of a standard form of calculation and data sheet. The use of the sheet illustrated in Annex C is therefore recommended.

NOTE 2 Calibration uncertainties may be computed as described in Annex D and a statement of these uncertainties may be added to the computed calibration table.

14.2 The calculation methods given below give minimum requirements for precision, but it is permissible to use alternative procedures which produce a final tank capacity table of similar or greater precision. Unless otherwise specified, volumes shall be expressed with an accuracy of five significant figures.

14.3 The standard temperature for which the tank capacity table has been calculated shall be recorded at the head of the table. In addition, the density of the liquid to be stored in the tank when in service and used in the computation of the tank capacity table shall be recorded.

To enable any necessary corrections to be made, the temperature of the tank shell should be calculated as described in Annex E.

14.4 As storage tanks expand under the head of liquid contained in them, a liquid head correction shall be applied in the development of the tank capacity table. Gauge temperature corrections shall be applied as described in Annex F.

NOTE 1 A suitable method of calculating the corrections for such expansion is given in Annex G.

NOTE 2 Storage tanks are also affected by thermal changes, as are any measuring tapes used, such as strapping and dip-tapes which are calibrated to be correct at the appropriate reference temperature, e.g. 20 °C. Tank capacity tables may be calculated to be correct at any required standard temperature, e.g. 15 °C, and therefore a correction is required when the temperature differs from the calibration temperature of the tapes.

NOTE 3 The subject is discussed in more detail in Annex H.

15 Form of tank capacity tables

15.1 Provided that tank capacity tables have been calculated in accordance with the principles given in this part of ISO 7507, the format adopted will not affect the mathematical correctness of the table. However, the principles given in this clause are recommended as they provide a table in a form most convenient for use. For each tank calibrated in accordance with this part of ISO 7507, a certificate of calibration, as specified in Annex I, shall be issued.

15.2 The intervals of dip at which the tables are set out shall be chosen to allow linear interpolation for intermediate dips without loss of accuracy.

15.3 Levels affected by bottom irregularities, floating-roof non-linearity range and deadwood shall not be included in the calculation of the average capacity per unit depth used for the proportional-parts table, and this table shall not be applied in interpolations in these ranges. These ranges shall be clearly marked on the tank capacity table.

15.4 The tables may be set out more fully; this can be justified in some cases where the greatest speed in calculation is desired. Nevertheless, a table set out on a single sheet of paper is often quicker in use than one which occupies several pages.

15.5 For certain products, e.g. heated bitumens, tables can be more conveniently set out in terms of ullage. However, if the gauging process is in terms of dip only, the corresponding form of table shall be employed.

16 Computation of open capacity

16.1 Corrections to measured circumferences

16.1.1 General

The corrections which have to be made to the measured circumferences are described in 16.1.2 to 16.1.4; the systematic incorporation of these corrections is described in 16.2.

16.1.2 Step-overs

For each obstruction, the reading of the tape measurement spanning the obstruction, less the step-over constant for the course concerned, shall be subtracted from the circumference figure obtained by strapping. The result shall be taken as the corrected circumference, free from error due to displacement of the tape from its proper path by the obstructions concerned (see 7.5.2).

The displacement of the tape by obstructions on the tank shell and the corresponding correction to the measured circumference shall normally be made by step-over.

NOTE In the case of normal vertical shell seams, the correction may be obtained by direct measurement as above or by calculation using formula (1) or formula (2) in 16.1.3 or 16.1.4, respectively. If the shell plates are thin, and the tape path is quite clear of any obstruction other than the seam, accurate measurement may be difficult and it is then preferable to use the formula.

Whenever a step-over is used, any correction shall be included (see 7.5.2.4), and it shall be permissible to determine an average step-over correction for each course from measurements taken on not less than three seams chosen at random on the particular course. The total correction for the course shall then be obtained by multiplying the average correction by the number of vertical seams on the course.

16.1.3 Double-sided obstructions

If the tape departs from the surface of the tank shell on each side of a small obstruction as shown in Figure 2b), the correction, in metres, to be deducted from the measured circumference shall be:

$$\frac{2Ntw}{d}+\left(\frac{8Nt}{3}\right)\sqrt{t/d} \qquad (1)$$

where

N is the number of butt straps or projections per course;

t is the amount of rise (thickness of straps or projections), in metres;

w is the width of the straps or projections, in metres;

d is the nominal diameter of the tank, in metres.

16.1.4 Single-sided obstructions

For vertical seams where the tape leaves the shell surface on one side of the seam only, as illustrated in Figure 2a), the correction, in metres, to be deducted from the measured circumference shall be:

$$\left(\frac{4Nt}{3}\right)\sqrt{t/2d} \qquad (2)$$

NOTE Formula (2) is derived from formula (1) as follows. In the case shown in Figure 2a), no deadwood correction for the seam needs to be made as the positive deadwood on one side of the seam is equivalent to and cancels the negative deadwood on the other side, as shown by the shaded areas in the figure. Formula (1) thus becomes:

$$\left(\frac{8N}{3}\times\frac{t}{2}\right)\sqrt{t/2d} =$$

$$=\left(\frac{4Nt}{3}\right)\sqrt{t/2d}$$

16.1.5 Plate and paint thickness

Plate thickness, measured in millimetres, shall be expressed in decimals of a metre to the nearest 0,000 5 m. The thickness of the paint shall similarly be converted and added to the corresponding plate thickness in subsequent calculations.

16.1.6 Temperature

Strapping tapes shall be calibrated at a reference temperature, normally 20 °C.

For practical purposes, the strapping measurements are assumed to be correct at the tape reference temperature. The tape is in close contact with the tank shell and thus can be considered to be at the same temperature as the tank shell. Normally, the coefficients of linear expansion of the tank shell metal and the tape metal are practically identical (i.e. they expand equally within the expected uncertainty bands). The measurements of the tank shell can then be considered correct at the tape calibration temperature irrespective of the temperature at which they were taken. If the capacity table is required at a temperature other than the reference temperature of the tape, the tabulated values shall be adjusted by a factor derived as described in Annex H.

If the coefficients of expansion of the tape and tank shell metals differ, i.e. the metals are different, the strapped circumference shall be multiplied by the following correction factor:

$$C_{\text{exp}} = [1 - (\alpha_{\text{st}} - \alpha_{\text{tk}}) \times (T_{\text{st}} - T_{\text{ref}})]$$

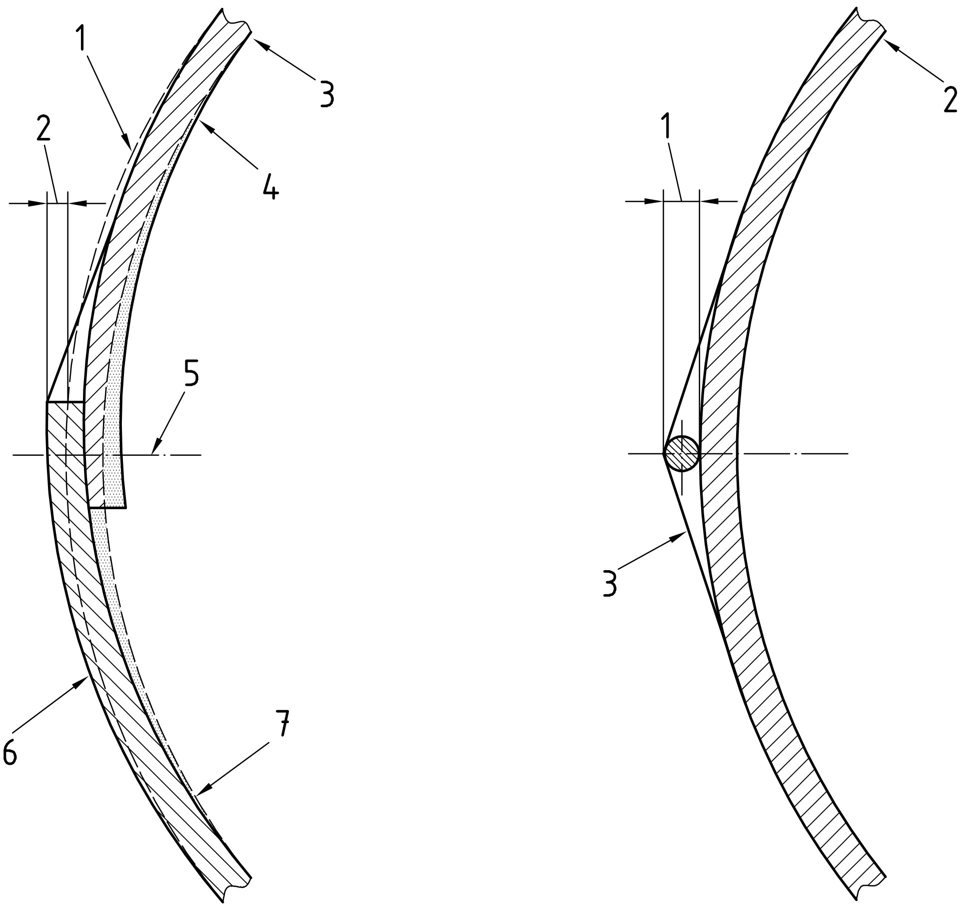
where

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}]

T_{ref} = reference temperature of the tank and strapping tape [°C]

T_{st} = temperature at strapping (same for tape and tank) [°C]



a) Tape departs from shell on one side of seam

b) Tape departs from shell on both sides of an obstruction

Key

1 dotted line represents corrected path of tape

2 tape rises one-half of plate thickness

3 radius of tank

4 point at which shell departs from nominal circle

5 centre-line of lap

6 actual tape path

7 point at which shell departs from scribed circle

Key

1 t = tape rise (equal to height of obstruction)

2 radius of tank

3 tape

Figure 2 — Correction of external strapping for vertical-seam overlaps

16.2 Systematic calculation

The calculation method below is arranged to be used in conjunction with, and follows the order of the columns of, the data and calculation sheet given in Annex C.

a) The mean external circumference at each level on each course shall first be calculated from the repeat measurements made at each particular level. Each mean circumference shall then be corrected for step-overs as specified in 16.1.2.

b) The mean corrected external circumference for each course shall be calculated from its three corrected mean circumferences calculated in a) above.

c) The mean internal circumference for each course shall be calculated from the corresponding mean external circumference for the course calculated as in b) above by deducting the correction for the sum of the plate and paint thicknesses (see 16.1.5), the correction being $2\pi t_n$ rounded to 0,000 1 m, where t_n is the sum of the plate and paint thicknesses in metres.

d) The correct mean internal circumference obtained in c) above for each course shall be squared and the result rounded off in each case to 0,001 m^2.

e) The open capacity per unit depth for each course shall be calculated as though the course were a right vertical cylinder, from the square of the corrected mean internal circumference (C^2) for each course obtained in d) above, by multiplying by the factor $1/(4\pi)$ (= 0,079 577 5); C being expressed in metres. The open capacity per unit depth shall be expressed in litres per millimetre.

f) The capacity per unit depth for each course as determined in e) shall be corrected for temperature by multiplying by the appropriate constant (see 16.1.4).

g) For tanks which are not substantially vertical, the open capacity per unit depth obtained in e) shall be multiplied by the following factor to determine the volume corrected for tilt:

$$C_{\text{tilt}} = \sqrt{1+b^2}$$

where b is the amount of tilt, in metres per metre of shell height.

NOTE This correction can be ignored for angles of tilt below 1 in 70 (14 mm/m) when the resulting error in volume will be less than 0,01 %.

h) Tank capacity (raw volume, V_r) at a level L within the n^{th} segment of the tank shall be determined from the formula

$$V_r = V_{\text{bot}} + [A_{1c} \times (h_1 - \Delta h)] + (A_{2c} \times h_2) + (A_{3c} \times h_3) + \ldots.. + [A_{nc} \times (L + \Delta h - h_1 - h_2 - \ldots - h_n)] \text{ [m}^3\text{]}$$

where

$h_1, A_{1c}, h_2, A_{2c}, \ldots$	are heights and cross-sectional areas (i.e. capacities per unit depth) of individual courses, measured on the inside of the tank;
L	is the level above dip-plate to which the volume is calculated;
Δh	is the offset between dipping reference point and the calibration datum point;
V_b	s the volume of tank bottom (under the calibration datum-point).

17 Construction of final tables

NOTE Specimen calculations as detailed in 17.1 to 17.3 are given in the data and calculation sheet in Annex C.

17.1 Deadwood

The open capacity of each course shall be adjusted for any deadwood it contains and, by proportion, the volume per unit depth at the appropriate levels.

a) The total volume of each piece of deadwood shall be calculated to the nearest litre.

NOTE 1 In this context, the term “pieces of deadwood” may include such items as rivet heads taken collectively as a single “piece” of deadwood in the particular course.

b) The effect of small pieces of deadwood may be omitted. However, the total effect of any such omission shall not lead to error in the tank capacity table exceeding 0,005 % of the total capacity of the course in which the deadwood occurs. Such deadwood shall be omitted only if it is located evenly, or substantially so, over the whole height of the course.

NOTE 2 In calculating the table, it is permissible to include the effect of any deadwood, however small. Deadwood calculations are facilitated and errors minimized by the use of the recommended standardized layout illustrated in Annex C.

c) In calculating deadwood allowances for any internal pipework in the tank, the total displacement, based on the external diameter, shall be taken when the pipe is closed off from the tank contents. When the pipe contains liquid, e.g. a swing-pipe or a floating suction, the displacement shall be calculated from the difference between the internal and external diameters, i.e. the volume of metal contained in the pipe.

d) The deadwood allowance for swing-pipes, floating suctions, flexible drains, etc., shall be deducted from the open capacity of the course at the appropriate levels which these accessories occupy at their lowest work position.

See also 17.3 for the additional adjustments required in the case of floating-roof tanks.

17.2 Tank bottoms

The procedure used to calibrate the tank bottom, chosen from those described in Clause 10, shall be reported in the certificate of calibration (see Annex I).

NOTE If the tank bottom is substantially horizontal, e.g. when the tank is carried on a level concrete raft or steel structure, bottom irregularities can be neglected.

If the tank bottom has been calibrated by measuring known volumes of liquid or by survey methods (see Clause 10), the tank capacity table for these levels shall be constructed from the measurements as in a) or b) below.

That portion of the tank capacity table calculated from strapping or internal diameters shall have no discontinuity with that portion calculated from the bottom calibration data, the former portion commencing at the highest level and corresponding capacity which are shown on the bottom calibration data sheet (see Annex C).

a) Tank bottoms, flat type

Correction for the effect of bottom characteristics shall be made, as necessary, in accordance with the following principles:

1) Tank bottoms that are essentially flat and regular in contour and which are stable under varying liquid head have no effect on tank capacity determined from geometric considerations.

2) The volume between the principal plane passing through the tank bottom and the plane passing through the dip-point shall be calculated as a right vertical cylinder.

3) If tank bottoms are of irregular slope or shape and/or instability exists, and if correct capacities cannot be determined conveniently from survey measurements, liquid calibration shall be used as described in ISO 4269.

4) The volume below the dip-point, whether calculated by survey or by liquid measurement, shall be included in the first increment of the tank capacity table.

5) If liquid calibration is used, as described in ISO 4269, it shall be continued to a depth in the tank sufficient to overcome all irregular shapes or unstable conditions.

6) A tank with a sloping or irregular bottom may be calibrated by the measurement and summation of incremental liquid volumes introduced into the tank, from the lowest point in the bottom to a point

above which computations can be made from dip and strapping measurements. The tank entries at the required intervals of dip shall be calculated by the method of divided differences or by other mathematical processes.

b) Tank bottoms, conical, hemispherical, semi-ellipsoidal and spherical-segment

Tank bottoms conforming to regular geometric shapes have volumes which may be either computed from survey measurements or, preferably, measured by liquid calibration through incremental filling. When volumes are to be computed from survey measurements, these shall be made at points shown on the applicable illustration in Figure 3. Any detailed differences in shape affecting the volume data, such as knuckle radii, shall be measured and recorded in sufficient detail to permit computation of the true volume.

17.3 Floating-roof tanks — Additional calculations to be applied

17.3.1 Two levels shall be defined, each an exact number of millimetres above the dip-point from which, in practice, dip readings will be taken. The first level, designated A, shall be not less than 40 mm and not more than 60 mm below the lowest point of the roof plates when the roof is at rest. The second level, designated B, shall be not less than 40 mm and not more than 60 mm above the free oil surface when the roof is just fully floating in the lowest-density liquid to be contained in the tank.

17.3.2 The allowance for the roof may be incorporated in a supplementary table, which shall be used in conjunction with the tank capacity table for all levels above B. Alternatively, the roof may be treated as deadwood and incorporated in the tank capacity table directly.

NOTE The partial displacement due to the roof between levels A and B may also be incorporated in the supplementary table or directly in the tank capacity table (see also 17.3.10).

17.3.3 The mass of the roof and accessories shall be checked against the manufacturer’s drawings [see note to 12.2 c)].

NOTE The displacement volume of the roof is calculated by dividing the mass of the roof by the average density of the product to be stored in the tank, as given in the appropriate table in ISO 91-1.

17.3.4 The drain line and other accessories attached to the underside of the roof shall be included as fixed deadwood in the positions they occupy when the roof is at rest on its supports.

17.3.5 Below level A, the allowance for deadwood shall be the algebraic sum of the fixed deadwood, calculated in accordance with 17.1, plus the volume of deadwood associated with the floating roof and calculated in accordance with 17.3.4. The total deadwood shall be allocated according to the relative heights which the separate components occupy up to level A.

17.3.6 Between levels A and B, the additional displacement of the floating roof itself has an increasing effect. It shall be treated in the same way as any other deadwood and shall be allocated proportionally to the relative volumes occupied by successive horizontal slices of appropriate depth.

NOTE The required volumes may be calculated from the dimensions of the floating roof. Alternatively, where measured quantities of liquid have been admitted to the tank [see Clause 10, 12.1 and 12.2 d)] and the corresponding levels of the free liquid surface have been determined by dipping, the necessary adjustments to the tank capacity within the range between levels A and B may be computed from this data.

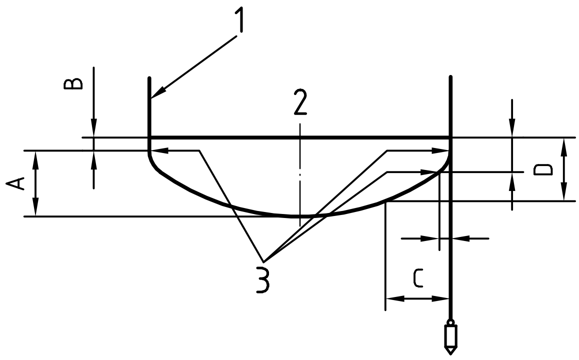
That part of the table between level A and level B shall be marked “not accurate”.

17.3.7 Above level B, at which the roof becomes fully floating, the volume of liquid displaced by the roof will be proportional to the density of the liquid on which it is floating, and shall be calculated as in 17.3.3.

17.3.8 The total displacement obtained from 17.3.6 includes the volume of the roof supports, and the displacement due to half the mass of the drain connection and swing-pipe. The roof supports have already been included in the deadwood calculation for the level below A, which also includes the total displacement of the swing-pipe and drain connection. When displacements are calculated from masses of the roof and deadwood measurements, the effect above level B of those portions of the deadwood which have previously been taken into consideration shall be removed by adding their total volumes at level B.

17.3.9 If the partial displacements of the roof have been included in the tank capacity table between levels A and B as in 17.3.2, the effect of the sum of the partial displacements shall be removed at level B before taking the total displacement of the roof into consideration as in 17.3.6.

17.3.10 The density of the liquid for which the roof displacement has been calculated shall be recorded in the tank capacity table. A table of corrections shall be appended giving quantities to be added to or subtracted from the oil volumes shown in the tank capacity table when the density of the oil differs from this fixed value. This table shall be calculated for a range of densities appropriate to the grade of oil which will be stored in the tank. If the total displacement of the roof has been taken into account directly in the preparation of the tank capacity table (see 17.3.2), this correction table shall only be used above level B. If the displacement of the roof has not been taken into account directly in the preparation of the tank capacity table, the appropriate correction shall be incorporated in the supplementary table which will apply at any level above level A.



Key

1 tank shell

2 head-to-shell joint

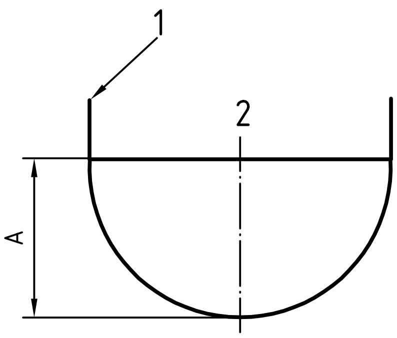
3 tangent points

Measurements shall be taken of A and B and offset measurements of C and D sufficient to describe the knuckle and contour of a spherical segment.

For convex tank bottoms of indefinite contour or with localized deformations, sufficient offset measurements such as C and D should be taken and recorded to establish the contours of the bottoms and extent of deformations. Sketches showing shapes of bottoms, deformations, if any, and locations of measurements should be included in the strapping record.

a) Spherical-segment (dished) tank bottoms, convex and accessible

Figure 3 — Calibration of bottoms of vertical cylindrical tanks

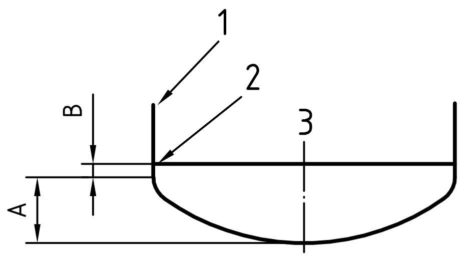


Key

1 tank shell

2 head-to-shell joint

Hemispherical bottom



Key

1 tank shell

2 tangent points

3 head-to-shell joint

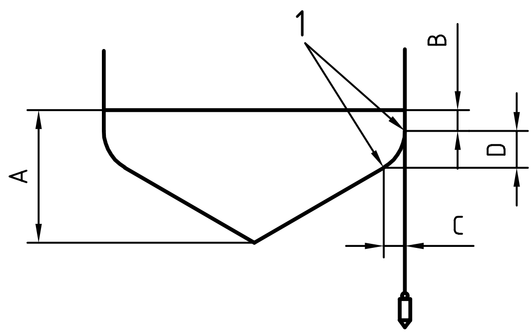
Semi-ellipsoidal bottom

Measurements shall be taken of A, or of A and B, for bottoms known to be hemispherical or semi-ellipsoidal in shape.

It is recommended that additional offset measurements of C and D, as shown in Figure 3a), for spherical-segment (dished) bottoms, be taken and recorded as supporting evidence.

Strapping records shall include the type of bottom and a sketch or sketches showing the locations of the measurements.

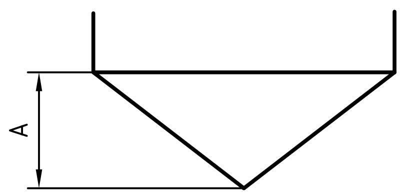
b) Hemispherical and semi-ellipsoidal tank bottoms, convex and accessible



Key

1 tangent points

With knuckle radius



Without knuckle radius

Measurements shall be taken of A and B and offset measurements of C and D sufficient to describe the knuckle and the cone.

c) Tank bottoms, coned downward and accessible

Figure 3 — Calibration of bottoms of vertical cylindrical tanks (*continued*)

17.3.11 It is considered impracticable to make allowances in the tank capacity table for the effects of extraneous matter retained by the roof, varying friction of the roof shoes, and any possible variation in immersion of the roof supports.

17.3.12 The effect on tank capacity tables of floating covers is similar to that of floating roofs. However, these covers are much lighter in construction and their displacement correspondingly less. If adjustment to the tank capacity table is required, it shall be calculated in a procedure similar to that in 17.3.1 to 17.3.11, from the mass of the cover components supplied by the manufacturer.

NOTE Variations in the temperature of the liquid on which the cover is floating are generally very small owing to the protection from thermal radiation afforded by the fixed tank roof and the cover itself. The corresponding variations in the density of the liquid immediately under the cover can therefore be neglected. The standard density for which the correction is calculated can be adjusted, if required, to the mean temperature of the tank at the time of gauging.

Annex A
(normative)

Specification for equipment used in strapping

A.1 Strapping tape

A.1.1 The tape shall be made of high-carbon steel having a carbon mass fraction of between 0,7 % and 1,0 %. The tape shall have a tensile strength of between $1,6 \times 10^{-3}$ Nm^{-2} and $1,85 \times 10^{-3}$ Nm^{-2} and a coefficient of thermal expansion of $(11 \pm 1) \times 10^{-6}$ °C^{-1}.

NOTE The tape may be provided with a suitable winding frame or case.

A.1.2 The tape shall have been calibrated at 20 °C and under an applied tension of 50 N. The calibration conditions shall be marked on the tape at or near the zero end of the tape.

A.1.3 The graduations shall be accurate to within 1,5 mm in each 30 m of length when the tape is fully supported on a flat surface at 20 °C and subjected to a tension of 50 N.

A.1.4 The tape shall be in one continuous length and graduated on one face only. The zero point of the tape shall be between 100 mm and 150 mm from the end tape. The tape shall be graduated at intervals of one metre and also at intervals of one decimetre, centimetre and millimetre.

The lengths of the graduations shall be as follows:

a) at each metre, across the full width of the tape;

b) at each decimetre, across the full width of the tape;

c) at each centimetre, across two-thirds of the full width of the tape;

d) at each fifth millimetre, across one-half of the full width of the tape;

e) at each millimetre, other than each fifth millimetre, across one-third of the full width of the tape.

The distance from the zero mark shall be marked at every metre, on a bright tablet, and at every centimetre and every decimetre. The size of the numbers used to denote the decimetre graduations shall be larger than those used to denote the centimetre graduations.

A.1.5 The figures and graduations shall be raised between 0,01 mm and 0,03 mm and be brightly coloured on a black background. The graduations shall be of uniform width, between 0,20 mm and 0,55 mm, and shall be normal to the edge of the tape.

A.2 Spring balance

A.2.1 The balance shall have a metal body and handle with a steel spring and hook.

A.2.2 The balance shall be of the barrel type with a loop handle at one end through which tension can be applied and, at the other end, a hook for attachment to the strapping tape. The hook shall be fitted with a self-closing latch to prevent the tape becoming detached from the balance if the tension is slackened.

A.2.3 The balance shall have a graduated scale marked from 0 to 100 N at intervals of 10 N and shall have an accuracy of ± 10 N.

A.3 Step-over

The step-over shall comprise a frame, rigidly holding two scribing points, of such a size that the points can be applied to the tape well clear of any obstruction without having any effect on the tape path and such that the frame itself does not touch either the obstruction or the tank shell. The step-over shall be of rigid construction.

NOTE The step-over may be of wood or metal.

A.4 Tape positioners and cords

A.4.1 The tape positioner shall comprise a metal guide bar, at least 120 mm long, with a metal bridge attached. The ends of the guide bar shall be bent to an angle of 45°, and holes shall be provided at each end for attaching a cord. The bridge shall be dimensioned so that the strapping tape can pass freely through it but cannot turn over when under it.

A.4.2 Cords shall be made of a material that will not produce or accumulate an electrostatic charge, e.g. cotton or another natural fibre.

Cords should preferably be of a plaited construction.

A.5 Littlejohn grip

NOTE A Littlejohn grip is a device used to attach a tensioning handle at intermediate positions on a strapping tape.

A.5.1 The grip shall be made of metal softer than that of the strapping tape.

A.5.2 The grip shall be constructed such that it can hold the strapping tape without slipping when a force of 100 N is applied to the tape.

A.5.3 The grip shall incorporate a quick-release mechanism.

A.6 Dip-tape

A.6.1 The dip-tape shall be made of high-carbon steel having a carbon mass fraction of between 0,7 % and 1,0 %. The tape shall have a tensile strength of between $1{,}6 \times 10^{-3}$ Nm^{-2} and $1{,}85 \times 10^{-3}$ Nm^{-2} and a coefficient of thermal expansion of $(11 \pm 1) \times 10^{-6}$ °C^{-1}.

A.6.2 The tape shall have been calibrated at 20 °C and under an applied tension of 15 N or at a tension equivalent to the weight of the bob. The calibration conditions shall be marked on the tape at or near the zero end of the tape.

A.6.3 The graduations shall be accurate to within 1,5 mm in each 30 m length when the tape is fully supported on a flat surface at 20 °C and subjected to a pull of 15 N.

A.6.4 The tape shall be in one continuous length and graduated on one face only. The tape shall be graduated at intervals of one metre and also at intervals of one decimetre, centimetre and millimetre.

The length of the graduations shall be as follows:

a) at each metre, across the full width of the tape;

b) at each decimetre, across the full width of the tape;

c) at each centimetre, across two-thirds of the full width of the tape;

d) at each fifth millimetre, across one-half of the full width of the tape;

e) at each millimetre, other than at each fifth millimetre, across one-third of the full width of the tape.

The distance from the zero mark shall be marked at every metre, on a bright tablet, at every centimetre and at every decimetre. The size of the numbers used to denote the decimetre graduations shall be larger than those used to denote the centimetre graduations.

A.6.5 A swivel hook shall be permanently secured (e.g. by means of riveting) to the front end of the tape to allow the attachment of a dip-weight. The hook shall be such that it will not distort in use and shall be equipped with a device to prevent accidental decoupling of the dip-weight.

NOTE Hooks made of brass are preferred.

A.6.6 The tape shall not be varnished or otherwise treated so that it becomes electrically insulated. The tape shall be wound onto a winding frame with a winding handle.

A.7 Dip-weight

NOTE The dip-weight is intended to be used in conjunction with, and form an integral part of, the dip-tape (A.6).

A.7.1 The dip-weight shall be made of brass or another non-spark-producing material of similar density.

A.7.2 The weight shall have a hole drilled into its top lug. The hole shall have a variable diameter dimensioned to accommodate the swivel hook (see A.6.5). When attached to the dip-tape, the weight and tape shall provide a continuous length-measuring device.

The bottom and top sections of the weight should preferably be chamfered. The bottom flat should preferably be approximately 13 mm in diameter.

A.7.3 If the weight is manufactured with a flat face on one side, and if this face is graduated at intervals of one centimetre and one millimetre, the graduation marks at each centimetre shall be longer than those at each millimetre and shall be numbered.

Annex B
(informative)

Recommendations for monitoring, checking and verification of tank calibration and capacity table

B.1 Introduction

Vertical cylindrical tanks are a type of tank in general use throughout the world for the storage of petroleum and petroleum products. Measurement of liquid levels and the use of the tank capacity table permit the assessment of volume of the liquid held in store or transferred. Vertical cylindrical tanks, in common with other measurement devices, are subject to alterations in their calibration. Previously, such alterations were considered insignificant and their magnitude had never been seriously assessed. This part of ISO 7507 is based on the results of an investigation carried out in the United States of America (see [1] in the Bibliography).

Data currently available indicates that tanks are subject to a primary settlement which generally occurs during the first five years to ten years of service. Secondary settlement can also occur but appears to spread over the next 10 years to 20 years of the tank’s life. Throughout their service life, tanks can undergo gradual changes in diameter, tank plate thickness and tilt. These factors affect the calibration of the tank and consequently the accuracy of any quantity assessments made using the tank capacity tables.

B.2 Scope

This annex gives guidance on monitoring the accuracy of the calibration and the tank capacity table of a vertical cylindrical tank.

B.3 Recalibration and recalculation

The assessment of the nature and extent of various factors which can influence changes in the capacity of the tank determine whether a tank should be recalibrated or its tank capacity table recalculated. It is not practicable to indicate definitively all those factors which would require either recalibration or recalculation.

Recalibration is the process of measuring the tank when it has been established that the original measurements no longer define the tank dimensions accurately. In these circumstances, the tank should be remeasured completely and a revised tank capacity table calculated from the new measurements.

Recalculation of the tank capacity table is required when operating variables, such as product density, average storage temperature, or reference height, are altered, or modification of the deadwood occurs. In these circumstances, the recalculation of the tank capacity table is based on previously measured tank dimensions.

B.4 Criteria for deciding significance of change

To establish acceptance limits for changes in the measurement and the operating variables which affect a tank’s capacity, it is necessary to decide the overall variation in tank volume that is considered to be significant. As a general rule, a variation in tank volume of 0,01 % or greater should be considered to be significant.

A range of 0,01 % to 0,05 % change in the tank capacity is given in Tables B.1 to B.5. Tables B.1, B.2 and B.3 provide criteria for recalibration, whilst Tables B.4 and B.5 provide criteria for recalculation.

In the case of tilt, the recommended criterion is a change of 10 mm/m of tank height.

Although this will affect the apparent tank capacity to only a relatively minor extent, the change in tilt is considered more important than the capacity effect. A significant degree of tilt can be an indication of serious structural problems in the tank's foundations and should be investigated.

B.5 Recalibration of the tank

B.5.1 Factors influencing the need for recalibration

Recalibration of a tank may be required if any of the dimensions or characteristics of the following are altered:

a) tank diameter;

b) tank plate thickness;

c) tank tilt;

d) deadwood;

e) tank reference height;

f) repairs undertaken to the tank structure which significantly alter its capacity.

B.5.2 Recommendations for assessment of the need for recalibration

The following recommendations are a basis for deciding whether recalibration is required.

a) Verification of the bottom course diameter, plate thickness and tank tilt should be carried out every five years. If the changes in measured dimensions exceed the minimum level of significance (see B.4), the recalibration should be undertaken.

b) A total recalibration should be undertaken every 15 years as a matter of routine, even if the five-yearly verification checks do not show any variation within the limits given in B.4.

B.5.3 Structural alterations to tanks

Recalibration may be required if structural alterations are made to the tank. Examples of such alterations are as follows:

a) extensive changes to the deadwood of the tank;

b) alterations to the reference height by alterations to the height of the dipping datum-point;

c) repair work to the bottom plating.

B.6 Recalculation of the tank capacity tables due to operational changes

B.6.1 Factors which generate a need for recalculation

There are several factors which, when altered, generate a need for recalculation of the tank capacity tables. The first two are operational factors, the others are mechanical changes:

a) changes in the average operating temperature of the tank shell;

b) changes in the density of the product stored in the tank;

c) alterations to the vertical position of the dipping datum-point;

NOTE This may require recalculation of the tank capacity tables (see B.6.5).

d) alterations to the mass of the floating roof;

e) simple changes to tank deadwood.

B.6.2 Tank shell temperature

Tank capacity tables are calculated at a standard temperature which is indicated on the printed tables.

Unless the tank capacity tables are included in a computerized oil volume calculation procedure which includes a routine to calculate the effect of temperature on the capacity of the tank, alterations in the average operating temperature of the tank shell may require that the tank capacity tables be recalculated. Such recalculations should be carried out in accordance with Annex E.

Table B.4 shows variations in tank capacity due to variations in the tank shell temperature, ambient air and liquid temperatures, to assist in determining whether a tank table requires recalculation.

B.6.3 Density changes

Tank capacity tables are calculated on the basis of either the tank in an unstressed condition, i.e. empty of liquid, or containing liquid of a stated liquid density. The basis is indicated in the printed tank capacity tables.

Unless the tables are included in a computerized volume calculation procedure which includes a routine to calculate the effect of varying density of the liquid contained in the tank, any alteration in the density of the liquid contained in the tank can require that the tank capacity tables be recalculated. Such recalculations should be carried out in accordance with this part of ISO 7507.

B.6.4 Floating-roof corrections

Floating-roof corrections are affected by the density of the product in which the roof is floating. If the floating-roof correction has been incorporated in the tank capacity tables, consideration should be given to recalculation if the density of the liquid stored in the tank is altered. In these circumstances, the effect of the variations in liquid density may be significant if the roof is grounded.

Recalculation should also be undertaken if there have been changes to the mass of the floating-roof.

B.6.5 Changes in dipping datum-point

Alterations to the vertical position of the dipping datum-point may require either a complete recalibration, or a complete recalculation.

If the datum-point has been moved downwards, unless the details of the bottom survey have been retained, it will be necessary to recalibrate the tank bottom so that the capacity below the datum-point can be recalculated.

If the datum-point has been moved upwards, the tank capacity tables may be recalculated by altering the vertical height between the calibration datum-point and the dipping datum-point.

B.6.6 Changes to tank deadwood

Corrections for minor changes in tank deadwood may be effected by recalculation of the tank capacity table. However, it may be preferable to allow for the effect of extensive changes in deadwood by recalibration of the tank.

Table B.1 — Variation in tank capacity (%) with change in diameter

Normal tank diameter	Approximate variation in capacity (%)					
	0,01	**0,02**	**0,03**	**0,04**	**0,05**	**0,06**
m	**Produced by change in tank diameter (mm)**					
5	—	—	1	1	1	1
10	—	1	1	2	2	3
15	(1)	1	2	3	4	4
20	(1)	2	3	4	5	6
25	(1)	2	4	5	6	7
30	(1)	3	4	6	7	9
35	(2)	3	5	7	9	10
40	(2)	4	6	8	10	12
45	(2)	4	7	9	11	13
50	(2)	5	7	10	12	15
55	(3)	5	8	11	14	16
60	(3)	6	9	12	15	18
65	(3)	6	10	13	16	19
70	(3)	7	10	14	17	21
75	(4)	7	11	15	19	22
80	(4)	8	12	16	20	24
85	(4)	8	13	17	21	25
90	(4)	9	13	18	22	27
95	(5)	9	14	19	24	28
100	(5)	10	15	20	25	30
105	(5)	10	16	21	26	31
110	(5)	11	16	22	27	33
115	(6)	11	17	23	29	34
120	(6)	12	18	24	30	36

NOTE Figures in parentheses are within the measurement tolerance for reference strapping. Caution should be exercised in using such data as indicators of the need for recalibration.

Table B.2 — Variation in capacity (%) due to alteration in thickness of bottom course plate of tank

Normal tank diameter m	Variation in capacity (%) of bottom course (nominal plate height: 2 m) for reductions in plate thickness of 1,5 mm to 3 mm			
	1,5 mm	**2,0 mm**	**2,5 mm**	**3,0 mm**
10	0,38	0,50	0,63	0,76
15	0,25	0,34	0,42	0,50
20	0,19	0,25	0,31	0,38
25	0,15	0,20	0,25	0,30
30	0,13	0,17	0,21	0,25
35	0,11	0,14	0,18	0,22
40	0,09	0,13	0,16	0,19
45	0,08	0,11	0,14	0,17
50	0,08	0,10	0,13	0,15
55	0,07	0,09	0,11	0,14
60	0,06	0,08	0,10	0,13
65	0,06	0,08	0,10	0,12
70	0,05	0,07	0,09	0,11
75	0,05	0,07	0,08	0,10
80	0,05	0,06	0,08	0,09
85	0,04	0,06	0,07	0,09
90	0,04	0,06	0,07	0,08
95	0,04	0,05	0,07	0,08
100	0,04	0,05	0,06	0,08
105	0,04	0,05	0,06	0,07
110	0,03	0,05	0,06	0,07
115	0,03	0,04	0,05	0,07
120	0,03	0,04	0,05	0,06

NOTE Plate thickness should be measured at eight points circumferentially on the bottom courses and averaged.

Table B.3 — Capacity correction for tank tilt

Tilt mm/m	**Capacity correction factor** %
14	0,010
16	0,013
18	0,016
20	0,020
22	0,024
24	0,029
26	0,034
28	0,039
30	0,045

Table B.4 — Effect on tank capacity variations in shell, ambient air and liquid temperatures

Variation in shell temperature, T_S °C	Variation in ambient air temperature, T_A °C	Variations in liquid temperature, T_L °C	Approximate variation in capacity %
5	10	10	0,01
10	20	20	0,03
15	30	30	0,04
20	45	45	0,05
NOTE A change in T_S, T_A or T_L will give rise to the variation in capacity shown.			

Table B.5 — Effect on tank capacity of change in liquid density

Variation in density %	Approximate variations in capacity %
10	0,008 to 0,015
20	0,015 to 0,030
30	0,030 to 0,040
40	0,040 to 0,050
50	0,050 to 0,065

Annex C
(informative)

Tank calibration data and calculation sheet

This annex gives an example of a tank calibration data and calculation sheet.

Company:
Installation:
Tank No.:
Type:

Column 1	Column 2	Column 3	Column 4	Column 5	Column 6	Column 7	Column 8	Column 9	Column 10	Column 11	Column 12	Column 13	Column 14			Column 15	Column 16
Internal height of course	Height of course above dip point	Plate thickness	External circum-ference	Correction for welds and other obstructions	Corrected external circum-ference	Mean external circum-ference	Correction for plate and paint thickness	Correction for liquid in tank at time of measure-ment	Correction for temperature	Corrected mean internal circum-ference	Open volume of course	Liquid head correction in service	Volume	Effective height dip-point		Net volume per unit depth	Net volume to top of course
mm	mm	mm	mm	mm	mm	mm	mm	mm	(Factor)	mm	l	t/mm	l/mm	from	to	l/mm	l
	11																
	(10)																
	(9)																
	11 952																
			143 426	8	143 418												
11 942	1 520 (8)	9	143 433	8	143 425	143 423	75	—	0,99 991	143 335	1 634,908 20	3,482 77	NIL			1 638,390 97	19 691 673
	10 431		143 433	8	143 425												
			143 433	8	143 425												
10 421	1 476 (7)	9	143 426	8	143 418	143 420	75	5	0,99 991	143 327	1 634,740 92	2,966 33	NIL			1 637,707 25	17 201 318
	8 955		143 426	8	143 418												
			143 420	8	143 412												
8 945	1 512 (6)	9	143 408	8	143 400	143 404	75	31	0,99 991	143 285	1 633,775 48	2,450 67	NIL			1 636,226 15	14 784 062
	7 443		143 408	8	143 400												
			143 408	8	143 400												
7 433	1 484 (5)	9	143 408	8	143 400	143 400	75	58	0,99 991	143 254	1 633,068 68	1,934 46	NIL			1 635,003 14	12 310 088
	5 959		143 408	8	143 400												
			143 408	8	143 400												

Column 1	Column 2	Column 3	Column 4	Column 5	Column 6	Column 7	Column 8	Column 9	Column 10	Column 11	Column 12	Column 13	Column 14			Column 15	Column 16
Internal height of course	Height of course above dip point	Plate thickness	External circum-ference	Correction for welds and other obstructions	Corrected external circum-ference	Mean external circum-ference	Correction for plate and paint thickness	Correction for liquid in tank at time of measure ment	Correction for temperature	Corrected mean internal circum-ference	Open volume of course	Liquid head correction in service	Volume	Effective height dip-point		Net volume per unit depth	Net volume to top of course
mm	mm	mm	mm	mm	mm	mm	mm	mm	(Factor)	mm	l	t/mm	l/mm	from	to	l/mm	l
5 949	1 502 (4)	9	143 414	8	143 406	143 404	75	85	0,99 991	143 231	1 632,544 37	1,420 29	NIL			1 633,964 66	9 883 744
	4 457		143 414	8	143 406												
			143 412	8	143 404												
4 447	1 494 (3)	10	143 413	8	143 405	143 404	82	100	0,99 991	143 209	1 632,042 95	0,929 98	NIL			1 632,972 93	7 429 529
	2 963		143 411	8	143 403												
			143 401	8	143 393												
2 953	1 482 (2)	11	143 395	8	143 387	143 390	88	113	0,99 991	143 176	1 631,290 95	0,489 37	NIL				4 989 867
	1 481		143 398	8	143 390								+ 0,195 08	550	1 010	1 720,875 85	
													+ 0,241 75	400	550	1 667,401 55	
			143 407	8	143 399								+	250	400	1 641,139 55	
1 471	1 471 (1)	13	143 405	8	143 397	143 397	101	114	0,99 991	143 169	1 631,139 05	0,140 31	+ 15 965	0	0	15 965,000 00	2 571 569
			143 404	8	143 396								+ 124 085	0	0	124 085,000 00	

Height of datum-point above dip-point: 10 mm
Paint thickness: 3 mm

Height of liquid in tank when measured: 9 950 mm
Liquid temperature: 15 °C
Density: 1 000,0 kg/m^3

Tilt: nil
Table to be standard at: 15 °C
Liquid head correction at a density of: 850,0 kg/m^3

Calibrator's notes: bottom calibrated with water, volumes corrected for temperature and meter factor.

Bottom calibration	
Dip mm	**Volume** litres
0	124 085
1	125 677
2	127 227
3	128 787
4	130 363
5	131 952
6	133 552
7	135 163
8	136 784
9	138 414
10	140 050

List of deadwood			
Item	**Volume** litres	**from** mm	**to** mm
610 mm	+ 119	400	1 010
1 inlet			
30 mm	+ 14	250	550
1 inlet			
150 mm	+ 3	250	400

Calibrated by: S.C Glennon
date: 2003-07-15

Calculations by: M. Williams
date: 2003-07-15

Annex D
(informative)

Tank calibration uncertainties

D.1 Introduction

This annex describes calculations used in estimation of uncertainties of tank calibration using the strapping method.

The calculations follow the guidelines set out in the Guide to the expression of uncertainty in measurement (GUM) [2].

D.2 Symbols

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

A_i	Corrected internal cross-sectional area of the tank at strapping height	m^2
A_{nc}	Area (internal) of tank for course n	m^2
C_{em}	Measured external circumference	m
C_{et}	External circumference corrected for temperature	m
C_i	Internal circumference of the tank	m
E	Young's modulus of elasticity of the tank wall material	N/m^3
$e\alpha_{st}$	Maximum error of estimate of the linear expansion coefficient of strapping tape	$°C^{-1}$
$e\alpha_{tk}$	Maximum error of estimate of the linear expansion coefficient of tank shell	$°C^{-1}$
eL_{ta}	Maximum error of alignment of a pair of strapping tapes	m
eT_{st}	Maximum error of estimate of strapping temperature	°C
g	Local acceleration due to gravity	m/s^2
h_n	Height (internal) of the tank for course n	m
L	Level (of liquid) in the tank	m
R_i	Internal radius of the tank	m
rL_{tr}	Resolution of strapping tape reading	m
tL_{tp}	Tolerance of strapping tape tension and position	m
t_{mp}	Metal and paint thickness of tank shell material	m
T_{ref}	Reference temperature of the tank and strapping tape	°C
T_{st}	Temperature of strapping tape and tank shell at strapping	°C
uA_i	Standard uncertainty of internal cross-sectional area of the tank at strapping height	m^2
uA_{nc}	Standard uncertainty of internal area of reservoir for course n	m^2
$u\alpha_{st}$	Standard uncertainty of coefficient of linear expansion of the strapping tape	$°C^{-1}$
$u\alpha_{tk}$	Standard uncertainty of coefficient of linear expansion of the tank shell material	$°C^{-1}$
uC_{em}	Standard uncertainty of measured external circumference	m
uC_{et}	Standard uncertainty of measured external circumference corrected for temperature	m
uC_i	Standard uncertainty of internal circumference of the tank	m
uE	Uncertainty of young's modulus of elasticity	N/m^3
ug	Uncertainty of local acceleration due to gravity	m/s^2
uh_n	Standard uncertainty of height (internal) of the tank for course n	m
uL	Standard uncertainty of level (of liquid) in the tank	m
uL_{st}	Standard uncertainty of strapping tape	m
UL_{st}	Expanded uncertainty of strapping tape length	m
uL_{ta}	Standard uncertainty of strapping tape alignment	m
uL_{tp}	Standard uncertainty of strapping tape tension and position	m
$u\rho$	Uncertainty on measurements of density of liquid	kg/m^3
$u\rho_{ref}$	Uncertainty of reference density	kg/m^3

uL_{tr}	Standard uncertainty of strapping tape reading	m
uR_i	Standard uncertainty of internal radius of the tank	m
ut_{mp}	Standard uncertainty of thickness of tank wall metal and paint	m
uT_{st}	Standard uncertainty of temperature at strapping (same for tape and tank)	°C
UV	Expanded uncertainty of volume in the tank table	m^3
UV_c	Expanded uncertainty of volume at calibration conditions	m^3
uV_{ad}	Standard uncertainty of volume caused by general additional factors	% vol
uV_b	Standard uncertainty of volume of the tank bottom	% vol
uV_{cal}	Standard uncertainty connected with the volume correction due to the hydrostatic head	m^3
uV_{dis}	Standard uncertainty of the volume displaced by floating roof/screen and deadwood	% vol
uV_h	Standard uncertainty of volume caused by factors related to hydrostatic expansion	% vol
uV_o	Standard uncertainty of volume caused by the deformation of the tank bottom due to hydrostatic heading	m^3
uV_r	Standard uncertainty of raw volume in the tank	m^3
uV_{sh}	Standard uncertainty of volume caused by tank shape	% vol
uV_t	Standard uncertainty of the correction for the volume of thermal expansion of tank	% vol
V	Volume contained in tank corresponding to the height for which the uncertainty is calculated	m^3
V_b	Volume in the tank bottom	m^3
V_{dis}	Volume displaced by floating roof/screen and deadwood	m^3
V_h	Expansion volume caused by hydrostratic head	m^3
V_r	Raw volume (of liquid) in the tank	m^3
V_t	Volume of thermal expansion of tank	m^3
wt_{mp}	Maximum uncertainty of thickness of the tank wall metal and paint	m
α_{st}	Coefficient of linear expansion of the strapping tape	$°C^{-1}$
α_{tk}	Coefficient of linear expansion of the tank shell material	$°C^{-1}$
ρ	Observed density of contained liquid at calibration	kg/m^3
ρ_{ref}	Reference density (density of ambient air)	kg/m^3

D.3 Calculations

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

— strapping and corrections for obstructions;

— external circumference;

— thermal corrections of strapping tape.

D.4 Source uncertainties

All components of uncertainties are assumed to be statistically independent.

D.4.1 Strapping tape length

The expanded uncertainty UL_{st} given by the calibration certificate for the whole tape, or an estimated uncertainty of the part of the tape that is being used for strapping, with a coverage factor k (usually $k = 2$, corresponding to a 95 % confidence level), yields the standard uncertainty:

$$uL_{st} = UL_{st}/k \text{ [m]}$$

D.4.2 Strapping tape reading

If rL_{tr} is the resolution of the tape (usually, $rL_{tr} = 1$ mm), the corresponding standard uncertainty is:

$$uL_{tr} = rL_{tr}/(2 \times 3^{1/2}) \text{ [m]}$$

NOTE 1 The factor $3^{1/2}$ corresponds to rectangular distribution.

NOTE 2 If multiple readings are performed, the value of uL_{tr} should be multiplied by the number of readings.

D.4.3 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 the 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.

$$uL_{tp} = tL_{tp}/(2 \times 3^{1/2}) \text{ [m]}$$

NOTE The factor $3^{1/2}$ corresponds to rectangular distribution.

tL_{tp} is the tolerance as measured (with rejection of obvious outliers) or read from Table D.1 (see 7.4), whichever is greater.

Table D.1 — Tank circumference tolerances

Tank circumference m	Tolerance tL_{tp} mm (m)
< 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)

D.4.4 Uncertainties of tape alignment

If several tapes are used to measure the tank circumference, the errors in their alignment result in additional uncertainty.

If eL_{ta} is the maximum error of the alignment of each pair of tapes (typically, eL_{ta} = 1 mm), the corresponding standard uncertainty of (n – 1) alignments between n tapes is:

$$uL_{ta} = (n - 1)^{1/2} \times eL_{ta}/(2 \times 3^{1/2}) \text{ [m]}$$

NOTE The factor $3^{1/2}$ corresponds to rectangular distribution.

D.4.5 Uncertainties of obstructions

Corrections of strapping tape length that runs over obstructions are subject to uncertainties (e.g. uncertainties of the dimensions of the obstructions) (see also 7.5).

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

D.5 Uncertainties of internal circumference at calibration conditions

All components of uncertainties are assumed to be statistically independent.

D.5.1 Measured external circumference

Since all measurement errors are additive, the uncertainty of the external circumference is obtained as the root-mean square (RMS) of all source uncertainties.

Standard uncertainty of measured external circumference:

$uC_{em} = [(uL_{st1}^2 + uL_{st2}^2 + \ldots + uL_{stn}^2 + uL_{tr}^2 + uL_{tp}^2 + uL_{ta}^2)/m]^{1/2}$ [m] if all the tapes are different

$uC_{em} = [(n^2 \times uL_{st}^2 + uL_{tr}^2 + uL_{tp}^2 + uL_{ta}^2)/m]^{1/2}$ [m] if one tape is used n times

where

n is the number of tape lengths used to measure the circumference;

m is the number of measured circumferences per tank course.

D.5.2 Uncertainties of volume at calibration conditions (extended raw volume)

D.5.2.1 Source uncertainties

All components of uncertainties are assumed to be statistically independent.

D.5.2.2 Uncertainty of course averaging

Uncertainties are due to the fact that an average circumference is ascribed to each tank course. If the course is not cylindrical, parts of it will differ from the average. Estimates of the averaging uncertainty can be obtained by evaluating deviations of the measured circumferences to their average.

Standard uncertainties of the tank circumferences due to course averaging are not calculated but are included in “additional uncertainties” (uV_{ad}).

D.5.2.3 Uncertainty of tank shape

Uncertainties are due to the fact that the tank may not be an ideal cylinder.

Typical standard uncertainty uV_{sh} = 0,05 % of volume, based on experimental data.

NOTE An additional factor of uV_{ad} (see D.5.2.4) applies to all calibration methods; strapping needs another addition as it does not yield an estimate of the tank deformation, whereas calibration methods based on a system of coordinates do.

D.5.2.4 Uncertainty of tank tilt

Standard uncertainty of tank tilt depends on the accuracy of measurements of distances. It is not calculated but is included in “additional uncertainties” (uV_{ad}).

D.5.2.5 Tank bottom

Standard uncertainty of tank bottom may be computed. A typical value may be estimated as:

uV_b = 0.25 % to 1.5 % [% of volume V_b of the bottom], depending on the size of the bottom, calibration method and the distortion of the shape of the bottom

NOTE 1 Smaller uncertainties usually apply to tanks with larger bottoms and vice versa.

NOTE 2 Deformation of the tank bottom due to hydrostatic forces is not included in the above value.

D.5.2.6 Uncertainty due to floating roof/screen and deadwood

The standard uncertainty uV_{dis}, based on experience is estimated as 1,5 % of displaced volume V_{dis}.

D.5.2.7 Additional uncertainties

The influences of the following corrections are included in the additional uncertainties:

- corrections for tank tilt;
- corrections related to tank deformations other than hydrostatic deformations;
- numerical approximations;
- other unquantifiable influences.

The additional standard uncertainty uV_{ad}, based on experience, is estimated, for vertical cylindrical tanks, as 0,02 % of volume.

D.5.2.8 Uncertainties of metal and paint thickness

With maximum uncertainty (width of rectangular distribution = wt_{mp}), the standard uncertainty of metal and paint thickness t_{mp} is:

$$ut_{mp} = wt_{mp}/(2 \times 3^{1/2}) \text{ [m]}$$

where, typically:

wt_{mp} = 0,000 5 m (= 0,5 mm), if taken from original manufacturer’s drawings, or

wt_{mp} = 0,001 m (= 1 mm), if taken from measurements

D.5.2.9 Internal circumference

Standard uncertainty of internal circumference (corrected for thickness of metal and paint) is:

$$uC_i = [uC_{et}2 + (2\pi \times ut_{mp})^2]^{1/2} \text{ [m]}$$

D.5.2.10 Internal radius

Standard uncertainty of internal radius is:

$$uR_i = uC_i/2\pi \text{ [m]}$$

D.5.2.11 Internal cross-sectional area

Standard uncertainty of internal cross-sectional area is:

$$uA_i = 2 \times uC_i \times A_i/C_i \text{ [m}^2\text{]}$$

D.5.2.12 Raw volume

The additional uncertainty in volume due to uncertainties in level measurements

a) at calibration,

b) in service,

are caused only where the cross-sectional area changes, e.g. at the boundaries between individual courses.

Calculated raw volume:

$$V_r = (A_{1c} \times h_1) + (A_{2c} \times h_2) + (A_{3c} \times h_3) + \ldots.. + [A_{nc} \times (L - h_1 - h_2 - \ldots - h_n)] \text{ [m}^3\text{]}$$

where

h_1, A_{1c}, h_2, A_{2c}, …., h_n, A_{nc} are dimensions of individual courses, measured on the inside of the tank;

L is the level above dip plate to which the volume is calculated;

h_1 is the (internal) height of the first course above the dip plate.

NOTE 1 The overlap between individual courses defines the heights of individual courses.

Raw volume standard uncertainty:

$$uV_r = \{(uA_{1c} \times h_1)^2 + (uA_{2c} \times h_2)^2 + \ldots.. + [uA_{nc} \times (L - h_1 - h_2 - \ldots - h_n)]^2\}^{1/2} \text{ [m}^3\text{]}$$

NOTE 2 There is no additional uncertainty due to tank tilt.

NOTE 3 The tank table gives volumes as a function of level. The uncertainties of the table volumes are only those of the cross-sectional area. Uncertainties of heights; uh_n, and levels, uL, are included in gauging.

D.5.2.13 Tank tables

Open tank tables are developed from the tank shell circumferences measured at selected heights.

Tank tables are developed from open tank tables by making the following corrections:

— adding capacity of the tank bottom;

— adding/removing the volumes of deadwood;

— incorporating floating roof parameters (if any).

Uncertainties of deadwood and floating roof are assumed to have been included in the additional uncertainties added to the raw volume.

D.5.2.14 Expanded uncertainty of volume at calibration conditions

The expanded uncertainty of volume at calibration conditions, including the uncertainties on the volume of the tank bottom, the uncertainties caused by its shape and by various additional factors is equal to

$$UV_r = k\{uV_r^2 + (uV_{sh} \times V_r)^2 + (uV_b \times V_b)^2 + (uV_{ad} \times V_r)^2 + (uV_{dis} \times V_{dis})^2\}^{1/2} \text{ [m}^3\text{]}$$

where k is the expansion coefficient, usually $k = 2$.

D.5.3 Uncertainties of volume at reference conditions

D.5.3.1 Source uncertainties

All components of uncertainties are assumed to be statistically independent.

D.5.3.2 Measurements and calculations

The following corrections are specified in this part of ISO 7507 to correct the open tank table dimensions at calibration for:

a) hydrostatic deformation due to liquid height, temperature and density (hydrostatic head); this correction gives a calibration table for an empty tank;

b) tank shell thermal expansion from calibration temperature to reference temperature.

D.5.3.3 Deformation due to hydrostatic head at reference conditions

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

R_i = internal radius; the uncertainty, uR_i, is calculated in D.5.2.10;

ρ = observed density of contained liquid at calibration; typical value of uncertainty of density measurements, $u\rho$, may be estimated as $5/3^{1/2}$ kg/m^3;

E = Young's modulus of elasticity of the tank wall material; typical value of uncertainty, uE, may be estimated as $5 \times 10^9/3^{1/2}$ N/m^2;

t_{mp} = thickness of tank wall metal and paint; the uncertainty, ut_{mp}, is calculated in D.5.2.8.

The uncertainties of the following variables are assumed to be zero and their effects are neglected:

uL = uncertainty of (fictive) level of liquid in the tank;

ug = uncertainty of local acceleration due to gravity;

$u\rho_{ref}$ = reference density (density of ambient air).

Standard uncertainty uV_h of the expansion volume caused by hydrostatic head is:

$$uV_h = V_h \times \{(3 \times uR_i/R_i)^2 + [u\rho/(\rho - \rho_{ref})]^2 + (uE/E)^2 + (ut_{mp}/t_{mp})^2\}^{1/2} \text{ [m}^3\text{]}$$

D.5.3.4 Correction for thermal expansion of tank and strapping tape at reference conditions

The standard uncertainty of the external circumference corrected for differential thermal expansion of the strapping tape and the tank shell includes:

a) standard uncertainty of the coefficients of expansion of the tape and the tank, and

b) standard uncertainty of the strapping temperatures (assumed to be the same for the tape and the tank shell).

Using

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}]

T_{ref} = reference temperature of the tank and strapping tape (zero uncertainty) [°C]

T_{st} = temperature at strapping (same for tape and tank) [°C]

Assuming rectangular distribution, the standard uncertainty of the strapping temperature is:

$uT_{st} = eT_{st} / (2 \times 3^{1/2})$ [°C]

where eT_{st} is the maximum error of estimate of the strapping temperature (for typical locations, eT_{st} = 5 °C).

Assuming rectangular distribution, the standard uncertainties of the coefficient of linear expansion of the stapping tape and the tank shell material are:

$u\alpha_{st} = e\alpha_{st}/(2 \times 3^{1/2})$ [°C^{-1}]

$u\alpha_{tk} = e\alpha_{tk}/(2 \times 3^{1/2})$ [°C^{-1}]

where $e\alpha_{st}$ and $e\alpha_{tk}$ are the maximum errors of the estimate of the linear expansion coefficients respectively (typically, $e\alpha_{st} = e\alpha_{tk} = 2 \times 10^{-6}$ °C^{-1}).

Standard uncertainty of corrected external circumference is:

$$uC_{et} = \{[uC_{em} \times (\alpha_{st} - \alpha_{tk}) \times (T_{st} - T_{ref})]^2 + [uT_{st} \times C_{em} \times (\alpha_{st} - \alpha_{tk})]^2 + (u\alpha_{st}^2 + u\alpha_{tk}^2) \times [C_{em} \times (T_{st} - T_{ref})]^2\}^{1/2} \text{ [m]}$$

Standard uncertainty of correction for thermal expansion of volume is:

$uV_t = 2 \times uC_{et}/C_{em} \times 100$ [% V]

D.5.3.5 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.

Standard uncertainty uV_o caused by the deformation of the tank bottom due to hydrostatic head depends on conditions like size or the state of the bottom.

It is not calculated, but a typical value may be estimated as:

$uV_o = 0{,}25/L$ [% V]

where L is the (fictive) filling height, in metres, with $1 \leqslant L$.

The standard uncertainty uV_{cal} connected with the volume correction due to the hydrostatic head is not calculated, but while reducing the error using a simplified mathematical model given in Annex G, the additional uncertainty of the calibrated volume may be estimated as $1{,}25 \times 10^{-4}$ of volume.

D.5.3.6 Expanded uncertainty of volume in the tank capacity table

Expanded uncertainty 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 and thermal expansion and the additional hydrostatic uncertainties, is therefore:

$$UV = 2 \times [uV_r^2 + uV_h^2 + uV_{cal}^2 + uV_t^2 \times V^2 + uV_o^2 \times V^2]^{1/2} \text{ [m}^3\text{]}$$

where V is the volume contained in the tank corresponding to the height *h* for which the uncertainty is calculated.

NOTE Due to variation of uV_r, UV will vary with varying volume of the liquid.

D.5.3.7 Examples

Tables D.2 and D.3 give, respectively, a example of the calculation of tank volume and of associated uncertainties.

Table D.2 — Calculation of tank volume

	Tank								Strap tape		Calibration conditions			
Parameters	Dip point > datum point Thickness of paint Average depth of bottom Volume of bottom			10 mm 1 mm 10 mm 15,88 m^3		$E = 2 \times 10^{11} N/m^2$ $\alpha_{tk} = 10^{-5}$ °C^{-1} Tilt = 3,0 % Reference temperature = 15 °C			Length = 20 m $\alpha_{st} = 2 \times 10^5$ °C^{-1} g = 9,806 65 m/s^2		Level of liquid L = 9 950 mm Density = 1 000 kg/m^3 Temperature of strapping T_{st} = −20 °C Density of air ρ_a = 1,21 kg/m^3			
	Height			Thickness	Circumference					Diameter	Area			Volume
No.	Course[a] (mm)	> Datum-point (mm)	> Dip-point (mm)	Thickness of metal (mm)	C_{em} (mm)	T-cor	C_{em} average (mm)	H-exp (mm)	Internal circumference[b] (mm)	Internal diameter[c] (mm)	Internal area (m^2)	T-comp (m^2)	Tilt-comp[d] (m^2)	(m^3)
8	1 549	12 173	12 183	9	141 385 141 392 141 392	0.999	141 290	0	141 228	44 954	1 587	1 589	1 590	19 327
7	1 505	10 624	10 634	9	141 392 141 385 141 385	0.999	141 288	14	141 211	44 949	1 587	1 589	1 589	16 864
6	1 541	9 119	9 129	9	141 379 141 367 141 367	0.999	141 272	41	141 168	44 935	1 586	1 588	1 588	14 472
5	1 513	7 578	7 588	9	141 367 141 367 141 367	0.999	141 268	67	141 138	44 926	1 585	1 587	1 588	12 024
4	1 531	6 065	6 075	9	141 367 141 373 141 373	0.999	141 272	93	141 116	44 918	1 585	1 587	1 587	9 622
3	1 523	4 534	4 544	10	141 371 141 372 141 370	0.999	141 272	108	141 095	44 912	1 584	1 586	1 587	7 192
2	1 511	3 011	3 021	11	141 360 141 354 141 357	0.999	141 258	119	141 063	44 902	1 583	1 585	1 586	4 776
1	1 500	1 500	1 510	13	141 366 141 372 141 372	0.999	141 271	119	141 064	44 902	1 584	1 585	1 586	2 379

a Average course height (m) = 1,522
b Nominal internal circumference (m) = 141
c Nominal internal diameter (m) = 45
d Nominal tilt compensation (m^2) = 1 588

Table D.3 — Uncertainty calculations

Source:				Value	u-type	Notes	At calibration										
No.	Course	Height	(mm)	5	1,443		Course	External circumference		Internal parameters			Volume				
		Thickness of metal + paint	(mm)	0,5	0,144		Averaging	uC_{em}	uC_{et}	uC_i	uR_i	A_i	Raw	Open table	Full table		
							(mm)	(mm)	(mm)	(mm)	(mm)	(m^2)	(m^3)	(m^3)	(m^3)	(%S)	(%R)
	Tank	temp.	(° C)	5	1,443												
8		bottom	(%R)	1			2,3	4,8	5,5	5,5	0,9	0,12	10,07	10,09	20,900	0,11	0,11
		t-exp.	(° C^{-1})	2×10^{-6}	6×10^{-7}												
7	Tape	length	(mm)	2	2	different tapes	4,7	5,4	5,9	6,0	1,0	0,13	8,81	8,82	18,285	0,09	0,11
		reading	(mm)	1	0,289												
		position	(mm)	6	1,732	(from table)											
6		alignment	(mm)	1	0,764	8 tapes	8,0	6,5	7,0		1,1	0,16	5,73	5,75	12,204	0,06	0 ,08
		temperature tape/tank	(° C)	5	1,443												
		tank-exp.	(° C^{-1})	2×10^{-6}	6×10^{-7}												
5							0,0	4,6	5,3	5,4	0,9	0,12	3,79	3,81	8,345	0,04	0,07
	Added	h-stat	(%R)	0,01 %													
		shape	(%R)	0,003 %													
4		others	(%R)	0,01 %			2,0	4,8	5,4	5,5	0,9	0,12	2,51	2,53	5,748	0,03	0,06
3							1,0	4,7	5,3	5,4	0,9	0,12		1,49	3,630	0,02	0,05
2							3,0	5,0	5,6	5,6	0,9	0,12	0,26	0,30	1,513	0,01	0,03
1							2,0	4,8	5,4	5,5	0,9	0,12	0,18	0,20	0,841	0,00	0,04
														Results - worst case:	21	0,108	0,108

Annex E
(informative)

Tank shell temperature determination

E.1 General

Criteria are given in E.2 and Table B.4 indicating a requirement to recalculate a tank calibration table if the average operating temperature of the tank shell alters from the original reference temperature printed on the tank capacity table.

Determination of the average operating temperature of the tank shell may be based on either

a) a temperature assumed to be the average operating temperature of the tank shell, or

b) several actual measurements of the parameters detailed in E.2 which determine that temperature and calculating an average of the temperatures.

E.2 Determination of the tank shell temperature

Determination of the tank shell temperature may be calculated using the following equation:

$$T_\mathrm{s} = \frac{T_\mathrm{l} + (K \times T_\mathrm{a})}{K + 1}$$

where

T_s is shell temperature, in degrees Celsius;

T_l is liquid temperature, in degrees Celsius, for $T_\mathrm{l} < 66$;

T_a is ambient temperature, in degrees Celsius;

$K = [(T_\mathrm{l} \times 7,2) + (324 \times V \times \mu^{0,5}) + (3121 \times \mu^{0,32}) - (222 + D \times 3,05)] \times 10^{-4}$

where

μ is viscosity, in pascal seconds, for $10^{-3} < \mu < 1$;

D is tank diameter, in metres, for $15 < D < 85$;

V is wind velocity, in kilometres per hour, for $0 < V < 19$.

E.3 Simplified equation for tank shell temperature

In practice, the determination of viscosity, wind velocity and tank shell temperature may prove difficult. However, the equation in E.2 involving these parameters may be simplified using the following equation:

$$T_\mathrm{s} = \frac{(7 \times T_\mathrm{l}) + T_\mathrm{a}}{8}$$

Annex F
(normative)

Gauge tape temperature correction

F.1 Introduction

The product temperature has an impact on the tank shell through expansion and contraction of the shell wall with associated changes to the tank volume. The gauge tape and the tank reference height also undergo thermal expansion resulting in changes to the volume. The gauge tape temperature effect is covered in detail in the Institute of Petroleum (IP) Petroleum Measurement Paper No. 11 [3].

This Annex describes simplified procedures for gauge tape correction, which are based on the Institute of Petroleum (IP) Petroleum Measurement Paper No. 11, and assume that the coefficient of expansion is the same for the shell as for the gauge tape. These simplified procedures are considered to be adequate for determining the effect of gauge tape temperature correction on tank volumes.

F.2 Calculation procedures

F.2.1 General

Tanks in custody and inventory service can be categorized broadly as follows:

a) tanks with no insulation;

b) tanks with external insulation; and

c) tanks that have non-contact and non-invasive automatic tank gauging (ATG) systems, namely radar gauges.

This Annex gives procedures for determining the necessary gauge tape corrections for each of these tank categories.

F.2.2 Tanks with no insulation

For tanks with no insulation, the basic assumption is that the section of the tank shell that is in contact with the liquid (innage level, L_I) is in thermal equilibrium with the liquid and that only this section of the tank shell will expand vertically. Also, the tank reference height (RH_C from the capacity table) will also increase but only the portion that is in contact with the liquid level (L_I), not the total height.

Based on the above assumptions, the following computations can be made.

— innage level: L_I

— reference height from the capacity table: RH_C

— coefficient of linear expansion: α

— liquid temperature: T

— capacity table reference temperature: T_C

— actual ullage level: L_U

Expansion of reference height $RH_E = L_I \times \alpha \times \Delta T$

where $\Delta T = T - T_C$

Total expanded reference height $RH_T = RH_C + RH_E$

$$RH_T = RH_C + (L_I \times \alpha \times \Delta T)$$

$$L_I = RH_T - L_U$$

$$= RH_C + (L_I \times \alpha \times \Delta T) - L_U$$

or, $L_I \times [1 - (\alpha \times \Delta T)] = RH_C - L_U$

but, $1 - (\alpha \times \Delta T) = 1/[1 + (\alpha \times \Delta T)]$ (approximately)

therefore, $L_I = (RH_C - L_U) \times [1 + (\alpha \times \Delta T)]$

This simply means that the innage is computed from the actual measured ullage using the reference height and multiplying by an expansion factor, which is equal to $[1 + (\alpha \times \Delta T)]$.

F.2.3 Tanks with insulation

For tanks with insulation, it is assumed that the vapour space and the liquid space are in thermal equilibrium and hence the tank reference height (RH_C from the capacity table) will expand fully and not partially as in the case of tanks with no insulation covered in F.2.2.

Also, the ullage, L_U, will expand with temperature. Assuming that this expanded ullage is L_{EU} and using the same notations used in F.2.2, the following computations can be made.

$$RH_T = RH_C \times [1 + (\alpha \times \Delta T)]$$

$$L_{EU} = L_U \times [1 + (\alpha \times \Delta T)]$$

computed innage $L_I = RH_T - L_{EU}$

$$= (RH_C - L_U) \times [1 + (\alpha \times \Delta T)]$$

This simply means that the innage is computed from the actual measured ullage using the reference height and multiplying by an expansion factor, which is equal to $[1 + (\alpha \times \Delta T)]$.

F.2.4 Tanks with non-contact and non-invasive automatic tank gauging (ATG) systems

For tanks with a non-contact and non-invasive automatic tank gauging (ATG) device, such as a radar gauge, the radar gauge is not affected by the temperature of the vapour space. Tanks with insulation and those without insulation have to be treated differently, as follows.

a) For tanks with no insulation but with a non-contact ATG, the correction factor will be the same as that given in F.2.2, i.e. equal to $[1 + (\alpha \times \Delta T)]$.

b) For tanks with insulation, the reference height will expand in full whereas the ullage, as measured by the radar gauge will not be impacted.

$$RH_T = RH_C \times [1 + (\alpha \times \Delta T)]$$

Computed innage $L_I = \{RH_C \times [1 + (\alpha \times \Delta T)]\} - L_U$

This simply means first correcting the reference height with the expansion factor and then subtracting the actual measured ullage.

Annex G
(informative)

Expansion due to liquid head

G.1 General

G.1.1 The effect of any liquid head should be introduced into tank capacity tables by means of a method which involves the calculation of expansion effects at progressively increasing liquid levels.

NOTE This correction may not be required if the tank calibration is to be used in computerized oil stock accounting systems which calculate expansion due to liquid head based on measured liquid level and density at the time of calculation.

G.1.2 The method of correction consists of two parts:

a) the removal of the effect, on each section, of the expansion due to the head of liquid in the tank at the time of strapping (in cases where the tank is empty during calibration, the necessity for this adjustment does not arise);

b) the adjustment for the effect on each course of the expansion due to the head of liquid to be contained in subsequent service.

G.2 Removal of the effect of expansion at time of strapping

G.2.1 The field measurements should be made with a depth of liquid in the tank, the level of which should be recorded in the calibrator's notes (see 6.1). The measurements should be tabulated, preferably using the standard form of calculation and data sheet illustrated in Annex C.

G.2.2 The circumference measurements should then be adjusted to the "empty tank", or unstressed, condition by means of the following equation, substituting in the equation the mean corrected circumference for each course (see 16.2) in turn.

$$\Delta C_i = \frac{g C_i^2 (\rho - 1{,}2) H_i}{2\pi E t_i \times 10^3}$$

where

ΔC_i is the circumference correction, in millimetres, to give the empty or unstressed condition for the particular circumference under consideration;

g is the acceleration due to gravity, in metres per second squared;

C_i is the particular mean circumference, in millimetres, corrected for plate and paint thickness;

ρ is the density at the observed temperature, in kilograms per cubic metre, of the liquid at the time of strapping;

NOTE A correction for air density of 1,2 kg/m^3 is included in the equation to correct for displacement of air by liquid.

H_i is the head of liquid, in millimetres, above the elevation of the particular strapped circumference, i, during strapping;

π is taken to be 3,141 593;

E is Young's modulus of elasticity, in newtons per square metre;

t_i is the plate thickness, in millimetres, of the course, i.

If

g = 9,806 65 m/s^2,

E = 200 × 10^9 N/m^2 and

π = 3,141 593

the above equation reduces to

$$\Delta C_i = \frac{0{,}780\ 39}{10^{14}}\ C_i^2\left(\rho - 1{,}2\right)\frac{H_i}{t_i}$$

G.2.3 The volume computation for the tank should then be made, subtracting the values obtained in G.2.2 from the mean corrected circumference of each section in turn.

NOTE An alternative method of removing the effect of expansion at the time of measurement is to adjust the calculated volumes to the unstressed condition by means of the formulae given in G.3 and applying the corrections negatively. However, this alternative method will require that an open "stressed" volume is calculated, the volume correction applied and an "unstressed" circumference calculated from the resultant volume.

G.3 Addition of effects of expansion in service

G.3.1 The capacities, corrected as described in G.2, if appropriate, should be adjusted to allow for the expansion which will occur due to the hydrostatic head pressure exerted by the liquid that the tank will contain in service. The adjustments should be made by means of the following equations:

First section:

$$V_1 = K\left(\frac{0{,}8\Delta h_1}{2t_1}\right)\Delta h_1$$

Second section:

$$V_2 = K\left(\frac{0{,}8\Delta h_1}{t_1} + \frac{\Delta h_2}{2t_2}\right)\ \Delta h_2$$

Third section:

$$V_3 = K\left(\frac{0{,}8\Delta h_1}{t_1} + \frac{\Delta h_2}{t_2} + \frac{\Delta h_3}{2t_3}\right)\ \Delta h_3$$

n^{th} section:

$$V_n = K\left(\frac{0{,}8\Delta h_1}{t_1} + \frac{\Delta h_2}{t_2} + \frac{\Delta h_3}{t_3} + \ \ldots\ + \frac{\Delta h_n}{2t_n}\right)\ \Delta h_n$$

where

$V_1, V_2, V_3, \ldots, V_n$	are the incremental increases in the capacity of the tank, in litres, of the first section, second section, third section and n^{th} section, caused by liquid head;
$\Delta h_1, \Delta h_2, \Delta h_3, \ldots, \Delta h_n$	are the heights, in millimetres, of the first section, second section, third section and n^{th} section; for the fully filled courses, the sections being equivalent to the tank courses; for the partly filled (top) course, the section is the height of the liquid above the base of the course.
$t_1, t_2, t_3, \ldots t_n$	are the thicknesses, in millimetres, of the plates of the first section, second section, third section and n^{th} section.

K is a constant for the entire tank, given by the following equation:

$$K = \frac{\pi g D^3 (\rho - 1{,}2)}{4E \times 10^9}$$

where

D is the nominal diameter of the tank, in millimetres (i.e. average of all C_i/π);

ρ is the density, in kilograms per cubic metre, of the liquid which the tank will contain in service;

π is taken to be 3,141 593;

E is Young's modulus of elasticity, in newtons per square metre;

g is the acceleration due to gravity, in metres per second squared.

NOTE A correction for air density of 1,2 kg/m^3 is included in the equation.

If

g = 9,806 65 m/s^2, and

$E = 200 \times 10^9$ N/m^2,

the above equation reduces to

$$K = \frac{3{,}851\ 1}{10^{20}} D^3 (\rho - 1{,}2)$$

G.3.2 Volumes calculated in the above formulae should be accumulated from the bottom section up to the liquid height and the result added to the volume calculated for the same liquid height in 16.2 and corrected in G.2 (see example in Table G.1)

G.3.3 An alternative method of calculating the effect of expansion due to the liquid which the tank will contain in service is given below. It is a non-linear method and gives the total expansion due to the liquid at any level L in the tank.

It may be used as an alternative to the method described in G.3.1 and is especially of use in computerized oil-accounting systems.

Level within first section ($0 < L \leqslant h_1$):

$$V_t = \frac{0{,}8KL^2}{t_1}$$

Level within second section ($h_1 < L \leqslant h_2$):

$$V_t = 0{,}8K\left[\frac{\Delta h_1^2}{t_1} + \frac{2\Delta h_1\left(L - h_1\right)}{t_1}\right] + K\left[\frac{\left(L - h_1\right)^2}{t_2}\right]$$

Level within third section ($h_2 < L \leqslant h_3$):

$$V_t = 0{,}8K\left[\frac{\Delta h_1^2}{t_1} + \frac{2\Delta h_1\left(L - h_1\right)}{t_1}\right] + K\left[\frac{\Delta h_2^2}{t_2} + \frac{2\Delta h_2\left(L - h_2\right)}{t_2}\right] + K\left[\frac{\left(L - h_2\right)^2}{t_3}\right]$$

Level within n^{th} section ($h_{n-1} < L \leqslant h_n$):

$$V_t = 0{,}8K\left[\frac{\Delta h_1^2}{t_1} + \frac{2\Delta h_1\left(L - h_1\right)}{t_1}\right] + K\left[\frac{\Delta h_2^2}{t_2} + \frac{2\Delta h_2\left(L - h_2\right)}{t_2}\right] + \quad \ldots \quad + K\left[\frac{\left(L - h_{n-1}\right)^2}{t_n}\right]$$

where

V_t	is the total increase in the capacity of the tank in litres, due to the liquid head pressure exerted by the liquid at level L;
$\Delta h_1, \Delta h_2, \Delta h_3, ..., \Delta h_n$	are the heights, in millimetres, of the first section, second section, third section and n^{th} tank course;
L	is the height of the liquid, in millimetres;
$t_1, t_2, t_3, ..., t_n$	are the thicknesses, in millimetres, of the plates in the first section, second section, third section and n^{th} section;
$h_1, h_2, h_3, ..., h_n$	are the cumulative heights, in millimetres, of the first section, second tank course, third section and n^{th} section;

whereas $h_j = \sum_{i=1}^{j} \Delta h_i$

K is a constant for any given tank, given by the following equation:

$$K = \frac{\pi g D^3\left(\rho - 1{,}2\right)}{8E \times 10^9}$$

where D is the nominal diameter of the tank, in millimetres (i.e. C_i/π).

if

g = 9,806 65 m/s^2,

E = 200 × 10^9 N/m^2 and

π = 3,141 593,

the above equation reduces to

$$K = \frac{1{,}925\,5}{10^{20}} D^3 \left(\rho - 1{,}2\right)$$

G.3.4 The capacity computations for the tank should then be made by adding the values obtained in G.3.3 to the “unstressed” capacities of the tank at level L calculated in 16.2 and corrected in G.2.

G.3.5 If a tank has been calibrated by internal measurement, it is necessary only to correct for the effect of expansion in service. The computation is then made as in the case of a tank calibrated by strapping (see G.4.3).

G.4 Example of computation of allowances for expansion under head of liquid

G.4.1 Calibration by strapping

In this example, it is assumed that a tank 45,6 m in diameter has been calibrated by strapping when containing water. The data required for substitution in the formulae given in G.2.2 and G.3.1 is as follows:

Height of water at time of strapping	= 9,950 mm
Density of air	= 1,2 kg/m^3
Density of the water at time of strapping	= 999,7 kg/m^3
Density of the oil to be contained in the tank in service	= 850 kg/m^3
Corrected tank circumference	= 143 397 mm

G.4.2 Removal of the effect of expansion at time of measurement

It can be seen that the number of levels at which correction to circumferences is made will depend upon the degree of accuracy required. Normal practice would be to calculate the correction for each level at which the circumference has been measured. For this example, however, it is considered simpler and clearer to take the liquid head (H) value at the midpoint of each section, the circumference correction then being applied to all strapping measurements within the same section.

ΔC_i is calculated from the following equation:

$$\Delta C_i = K \times \frac{H_i}{t_i}$$

where

$$K = \frac{0{,}780\,39}{10^{14}} \; C_i^2 \left(\rho - 1{,}2\right)$$

For the first section,

C_1 = 143 397 mm

ρ = 999,7 kg/m^3

Therefore

$$K = \frac{0{,}780\ 39}{10^{14}} \times 143\ \ 397^2 \times 998{,}5$$

$$= 0160\ 228$$

and

$$\Delta C_1 = 0{,}160\ 228 \times \frac{H_1}{t_1}$$

Subsequent calculations are given in Table G.1.

Table G.1 — Example of calculation routine for expansion during strapping

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Section No.	**Circum-ference**	**Section height**	**Distance between mid-heights of sections**	**Running totals of distances in column (4)**	**Difference between height of water and values in column (5)**	**Plate thickness**			**Correction to circum-ference**
	C_i	Δh_i	$\frac{\Delta h_i + \Delta h_{i-1}}{2}$		H_i	t_i	$\frac{H_i}{t_i}$	t_i	ΔC_i
	mm	mm	mm	mm	mm	mm		mm	mm
8	143 423	1 520	1 498,0	11 181,0	—	9	—	—	—
7	143 420	1 476	1 494,0	9 683,0	267,0	9	29,667	0,160 280	5
6	143 404	1 512	1 498,0	8 189,0	1 761,0	9	195,667	0,160 244	31
5	143 400	1 484	1 493,0	6 691,0	3 259,0	9	362,111	0,160 235	58
4	143 404	1 502	1 498,0	5 198,0	4 752,0	9	528,000	0,160 244	85
3	143 404	1 494	1 488,0	3 700,0	6 250,0	10	625,000	0,160 244	100
2	143 390	1 482	1 476,5	2 212,0	7 738,0	11	703,455	0,160 213	113
1	143 397	1 471	735,5	735,5	9 214,5	13	708,808	0,160 228	114
The figures in the final column should be subtracted from the corrected strapped circumferences, thereby giving the unstressed (tank empty) condition.									

G.4.3 Addition of the effects of expansion in service

The constant K for section 1 is given by

$$K = \frac{3{,}8511}{10^{20}} D^3 \left(\rho - 1{,}2\right)$$

where

D = 45 644,7 mm

ρ = 850,0 kg/m^3

therefore

$$K = \frac{3{,}8511}{10^{20}} \times 45\ \ 644{,}7^3 \times 848{,}8$$

$$= 0{,}003\ 108\ 6$$

Subsequent calculations are given in Table G.2.

Table G.2 — Example of calculation routine for expansion in service

Course No.	Course height, h mm	Plate thickness, t mm	1st course only $\frac{0,8h_1}{2t_1}$	Other courses $\frac{h}{2t}$	$\frac{0,8h_1}{t_1}$	$\frac{h_2}{t_2}$	$\frac{h_3}{t_3}$	$\frac{h_4}{t_4}$	$\frac{h_5}{t_5}$	$\frac{h_6}{t_6}$	$\frac{h_7}{t_7}$	$\Sigma\frac{h}{t}$	K	ΔV l/mm
8	1 520	9		84,444	90,523	134,727	149,400	166,889	164,889	168,000	164,000	1 122,873	0,003 101 7	3,482 77
7	1 476	9		82,000	90,523	134,727	149,400	166,889	164,889	168,000	—	956,428	0,003 101 5	2,966 33
6	1 512	9		84,000	90,523	134,727	149,400	166,889	164,889	—	—	790,428	0,003 100 4	2,450 67
5	1 484	9		82,444	90,523	134,727	149,400	166,889	—	—	—	623,984	0,003 100 2	1,934 46
4	1 502	9		83,444	90,523	134,727	149,400	—	—	—	—	458,095	0,003 100 4	1,420 29
3	1 494	10		74,700	90,523	134,727	—	—	—	—	—	299,950	0,003 100 4	0,929 98
2	1 482	11		67,364	90,523	—	—	—	—	—	—	157,887	0,003 099 5	0,489 37
1	1 471	13	45,262	—	—	—	—	—	—	—	—	45,262	0,003 100 0	0,140 31

The figures in the last column should then be added to the open capacity per unit depth obtained as in 16.2.

Annex H
(normative)

Expansion due to temperature

H.1 Introduction

This Annex gives the methods of calculation used to correct for expansion due to temperature.

The information given in this Annex is based on the Institute of Petroleum (IP) Petroleum Measurement Paper No.11.

H.2 General

H.2.1 The tank capacity tables, as computed in accordance with the method described in 16.2, have been corrected to give volumes for the following conditions:

a) tank shell at temperature T_{st};

b) depth of liquid measured with a dip-tape calibrated at T_{dt}, both liquid and tape being at a temperature T_l.

where

T_{dt} is the temperature at which the dip-tape is certified;

T_{st} is the temperature at which the strapping tape is certified;

T_l is the temperature of the liquid in the tank at the time of measurement.

H.2.2 The correction for expansion due to temperature can be dealt with in two parts:

a) The preparation of tank capacity tables at any standard temperature. This is carried out by the application of a multiplier or constant factor F_T (derived from a basic formula) to the "net volumes per unit depth" before these are accumulated to form the capacity table.

b) The computation of a specific volume at an observed temperature by the application of a factor F_o to the cumulative volume given in a tank capacity table which has been certified at a standard temperature.

H.3 Preparation of tank capacity tables at any standard temperature of certification

The factor F_T to be applied to the "net volume per unit depth" is obtained from the following equation:

$$F_T = 1 + 3\alpha(T - T_{st})$$

where

α is the coefficient of linear expansion of the tank shell metal;

NOTE The coefficient of linear expansion of mild steel is 0,000 011 °C^{-1}.

T is the required temperature of certification for the tank capacity table (other than T_{st});

T_{st} is the temperature of certification of the strapping tape used in calibrating the tank and, thus, the temperature of certification of the capacity table.

The tank capacity table is prepared by multiplying the “net volume per unit depth” by factor F_T and accumulating the result. The tank capacity table then gives correct volumes for the following conditions:

a) tank shell at temperature T_t °C;

b) depth of liquid measured with a dip-tape calibrated at T_{dt} °C, the liquid and the tape being assumed to be at T_t °C.

H.4 Correction to be applied to volumes obtained from tank capacity tables certified at a standard temperature T_s

H.4.1 Principle

The determination of a specific volume at an observed temperature T_t is effected by applying a factor F_o to the volume corresponding to a given depth of liquid as obtained from a tank capacity table certified at a standard temperature T_s.

H.4.2 Tanks with thermally insulated shells

For insulated tanks, the temperature of the liquid, the dip-tape and the tank shell are assumed to be the same.

For insulated tanks, the factor F_o is obtained from the following equation:

$$F_o = 1 + 3\alpha(T_l - T_s)$$

where

α is the coefficient of linear expansion of the tank shell metal;

T_s is the temperature of certification of the tank capacity table;

T_l is the observed temperature (average) of the liquid content, the dip-tape and the tank shell.

H.4.3 Tanks without thermal insulation

H.4.3.1 For tanks without thermal insulation, the factor F_o is obtained from the following equation:

$$F_o = [1 + \alpha(T_l - T_s)]\,[1 + 2\alpha(T_t - T_s)]$$

where

α is the coefficient of linear expansion of the tank shell metal;

T_s is the temperature of certification of the tank capacity table;

T_l is the observed temperature of the dip-tape (same as that of the liquid);

T_t is the temperature of the tank shell.

H.4.3.2 There are various formulae for the determination of the average temperature of the shell plates of a non-insulated tank which express T_t in terms of the liquid temperature and the ambient temperature (shade and sun). The accuracy of the evaluation of T_t may be dependent upon the following factors, amongst others:

a) the number and accuracy of thermometers on the outside skin of the tank shell and the effectiveness of their contact with the tank plates;

b) the difference between the temperature of the liquid contents in the tank and the ambient temperature.

It is recommended that the temperature T_t of the tank shell plates is calculated using the following equation for tanks with no insulation. For tanks with insulation, shell temperature is assumed to be the same as the liquid temperature.

$$T_s = (7T_l + T_a)/8$$

where

T_l is the liquid temperature;

T_a is the ambient temperature.

NOTE The above equation is based on API Chapter 2.2A[4].

Annex I
(normative)

Certificate of calibration

Each certificate of calibration shall include the following details:

a) the serial number of the certificate and the number of pages in the tank capacity table;

b) identification of the tank, including the site or installation tank number (which shall be unique to the site or installation);

c) the name of the owner or operator;

d) the name and address of the calibration authority or company that carried out the calibration;

e) the date of measurement;

f) the method of calibration used (making reference to this part of ISO 7507), with specific reference to the method adopted in calibrating the tank bottom;

g) the date of issue of the certificate;

h) the nominal height and diameter of the tank;

i) the overall height(s) at the dip-point(s) on which the table is based and also the position(s) of the point(s) referred to a reference fixed point on the tank top (the overall height(s) shall be given with the tank empty and, if possible, also with the tank filled with a liquid of approximately the same density as the liquid that the tank will contain in service);

j) the height(s) of the dip datum-point(s) with reference to the junction of the tank shell and bottom plating;

k) if an automatic gauging system is installed, the height of the gauge datum-point with reference to the junction of the tank shell and bottom plating;

l) for convenience of calculation and verification, the following data used in the calculation of the capacity table:

   1) Young's modulus of elasticity;

   2) the coefficient of linear expansion of the tank shell metal;

   3) the coefficient of linear expansion of the strapping tape metal;

   4) the temperature of certification of the strapping tape.

The contents of this list represent the minimum required information for inclusion in the certificate but the list is not exhaustive and any other information that may be of use should be included.

NOTE 1 Measured raw data, such as tank circumferences, deadwood dimensions, plate thicknesses, bottom dimensions, etc., may be required in the certificate.

NOTE 2 Uncertainties of the resulting tank table may be included.

Each page of the certificate shall be signed by the issuing calibration authority or company.

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