SOP 31

Standard Operating Procedure for
Scale Plate Calibration for Volumetric Field Standards

1   Introduction

  1.1   Purpose

    This procedure is used for conformity assessment to verify the accuracy and linearity of scale plates used on volumetric field standards per NIST Handbook 105-3: Specifications and Tolerances for Graduated Neck Type Volumetric Field Standards (2010) and NIST Handbook 105-4: Specifications and Tolerances for Liquefied Petroleum Gas and Anhydrous Ammonia Liquid Volumetric Provers (2016). Neck scale plate calibrations are generally conducted only for new or damaged volumetric measures or those that have not been calibrated by the laboratory in the past.

  1.2   Prerequisites

    Verify that prerequisites listed in SOP 18, SOP 19, or SOP 21 (as applicable) are met prior to the scale plate calibration.

2   Methodology

  2.1   Scope, Precision, Accuracy

    This procedure is applicable for the calibration of scale plates on field standard test measures and provers. The scale plate is evaluated according to requirements published in Handbook 105-3 or Handbook 105-4 (as applicable) where the uncertainty of the calibration process is considered as a part of the compliance assessment.

  2.2   Summary

    The neck volume of the test measure or prover is evaluated across the range of the scale plate graduations using calibrated volumetric standards to assess accuracy and linearity of the scale plate for 4 to 6 calibration intervals. Temperature measurements and volumetric corrections are not performed during the neck calibration.

2.3 Required Standards and Equipment

2.3.1 The test measure or prover being evaluated.

2.3.2 A funnel to aid in transferring water from calibrated volumetric standards into the unknown prover.

2.3.3 Calibrated volumetric standards of suitable sizes to fill the prover body and neck to the nominal volume.

2.3.4 Calibrated volumetric standards of suitable sizes to verify the scale plate for the test measure or prover. Volumetric standards used for this purpose must be calibrated to or corrected for the appropriate reference temperature. An ideal standard is approximately one-fourth of the volume of the scale plate on the test measure or prover (or reasonable sub-multiples).

Note: For example, per NIST Handbook 105-3, the *minimum* neck volume on the scale of a 100 gal prover is 1.5 gal (347 in^3). For the sake of simplicity in an example, if the neck volume noted on the scale plate is 2.0 gal, four calibration points of 0.5 gal (115.5 in^3) provides good calibration points with the nominal volume mid-range in the calibration process.

2.3.5 Meniscus reading devices (See GMP 3).

2.4 Procedure

2.4.1 Preliminary Operations

2.4.1.1 Prepare and level the test measure or prover according to the applicable calibration procedure.

2.4.1.2 Fill the unknown prover with water from the laboratory working standard that will be used to perform the calibration of the prover to nominal volume. The neck scale calibration is conducted during this prover wet-down run.

2.4.1.3 Check the prover level condition in the same way in which it will be used by placing a precision spirit or electronic digital level vertically on the neck on at least two locations, 90 degrees apart around the circumference of the neck and adjust the orientation of the unknown prover until the neck is as close to vertical (plumb or perpendicular to the horizontal plane) as possible. Adjust the prover orientation as necessary.

2.4.1.4 Check the prover system for leaks.

2.4.2   Cleanliness check

The standard(s) and the unknown prover must be internally clean and should have been verified during preliminary operations. The gauge tube and scale plate must be clean and clear to enable proper scale plate readings.

2.4.3   Scale plate calibration

2.4.3.1 The number of calibration points used is determined by the neck volume and the size of the standard from which water will be delivered to conduct the calibration. Typically, 4 to 6 calibration points are distributed across the range of the volume on the neck scale plate. Select the number of neck scale calibration points and the bottom scale reading, sr_i, so that one of the neck scale calibration points is near the prover nominal volume line. This is most easily accomplished by using an even number of neck scale calibration points.

Note: A higher number of calibration points increases the time required for the calibration, increases the uncertainty due to the number of meniscus reading components, and provides limited value.

2.4.3.2 Select the volume of the standard, V_{Sn}, to use for the neck calibration intervals by dividing the total volume of the neck scale plate that will be calibrated by the number of calibration points, keeping in mind that the value of V_{Sn} may be the sum of multiple deliveries from the actual standard used (see Eqn. 1).

Note: For example, a prover with scale plate volume of 2 gal and 4 calibration points will result in the V_{Sn} of 0.5 gal, but each interval may be measured with two deliveries of a 0.25 gal calibrated standard.

$$V_{Sn} = \frac{\text{Total neck scale plate volume}}{\#\,\text{calibration points}}$$

Eqn. (1)

2.4.3.3 The best starting point for the initial scale reading, sr_i, for a prover having the nominal volume graduation near the midpoint of the neck can be calculated using Eqn. 2:

$$sr_i = Nom_{prover} - \frac{\#\,\text{calibration points}}{2} V_{Sn}$$

Eqn. (2)

2.4.3.4 Offsetting from the nominal value is permitted for older provers where the nominal volume is offset from the middle of the neck scale. In those cases, the value of sr_i may be calculated and set based on a full multiple of V_{Sn}, but offset, where the number of neck scale calibration points is not centered around the nominal prover volume graduation.

2.4.3.5 Decrease the liquid level to an easily read graduation mark near the value calculated for sr_i above. "Rock" the prover to "bounce" the liquid level, momentarily, to ensure that it has reached an equilibrium level. Read and record this setting to be used as the initial scale reading, sr_i.

2.4.3.6 Remove any fill hoses or pipes obstructing the top opening and insert a wetted funnel, if needed.

2.4.3.7 Verify the sr_i scale reading, then add water in a quantity equal to the volume of the first calibration point from a suitable calibrated standard. Record the scale reading as sr_1.

2.4.3.8 Continue verifying each interval by successive additions from the calibrated standard until the selected number of calibration points have been recorded.

2.4.3.9 Record scale readings after each addition. The last reading is the final scale reading, sr_f. Be aware that as the water level approaches the top of the neck, it will become harder to "bounce" the liquid in the gauge.

2.4.3.10 A plot of scale readings with respect to the total volume of water added to reach that reading should be linear and is a gross check of the validity of this calibration. Calculate and assess the accuracy (Deviation between volume added and observed scale plate reading) of the neck scale for each interval using Eqn. 3:

$$\Delta sr_x = sr_x - \left(sr_i + xV_{Sn} \right)$$

Eqn. (3)

2.4.3.11 A neck scale correction factor may be calculated using Eqn. 4:

$$NSCF = \frac{V_w}{\left(sr_f - sr_i \right)}$$

Eqn. (4)

Note: When a neck scale correction factor is provided to a user, a description of how they should use the neck scale correction factor to correct their measurements must also be provided. The *NSCF* is a multiplier by which the indicated deviation from the prover nominal volume must be multiplied to calculate the actual volume indicated by the reading and applies *only* to that portion of the prover volume indicated by the scale deviation from the prover nominal. *The NSCF is NOT multiplied by the total prover volume and is only a correction factor for the volume deviation from nominal for the scale plate readings!*

Table 1. Variables for neck scale calibration and Neck Scale Correction Factor equation.

Variable	Description
$NSCF$	Neck scale correction factor
# calibration points	Total number of intervals making up the neck scale calibration
V_{Sn}	'To Deliver' volume of water added for each interval of the neck scale calibration, may be multiples of actual volume of standard used. The calibrated volume at the prover reference temperature must be used (typically 60 °F for test measures and provers used for petroleum products). If glassware is used, an additional calibration value for the flask is needed as they are normally calibrated to 20 °C.
V_w	Total volume of water added to neck to increase the water level from sr_i to sr_f
x	number assigned to each increasing neck scale calibration point; $x = f$ for final calibration point
sr_i	Initial scale reading
$sr_x \dots sr_f$	Scale reading for each interval of the neck scale calibration (1 through f) 'f '= # calibration points
Δsr_x	Deviation between volume added and observed scale plate reading

3   Measurement Assurance

The process for scale plate calibration does not need to be duplicated unless the data, accuracy, and linearity appear questionable or fail to comply with the published requirements. In the case where questionable data are observed or a scale plate calibration fails compliance, a replicate calibration should be conducted for confirmation. Typically, the process standard deviation, s_p, will be dominated by the operator's ability to read the meniscus and thus the component(s) for the meniscus reading are deemed sufficient to cover the process standard deviation.

4   Assignment of Uncertainties

4.1   Uncertainties associated with the neck scale calibration include the setting of the meniscus on the standard used (with each delivery), the reading of the meniscus on the unknown prover (at each volume reading), and the calibration uncertainty of the standard used and are used in compliance assessments and are included in the test measure or prover calibration uncertainty. The uncertainty for the standard, u_s, used will be treated as a dependent uncertainty and combined in summation prior to the root sum square combination of the meniscus reading uncertainties for the standard, u_{mS}, and meniscus reading uncertainties for the field standard, u_{mX}, in question. Follow the guidance provided in NISTIR 7383, GMP 3 for methods to estimate the uncertainty of the meniscus readings in each prover. The calibration uncertainty for four neck scale calibration intervals comprised of one delivery from the standard per interval, with a meniscus reading on both the standard and unknown measure might look like the following equation:

$$u_n = \sqrt{(u_S \times 4)^2 + 4 \times (u_{mS}^2) + 4 \times (u_{mX}^2)}$$

Eqn. (5)

The calibration uncertainty for four neck scale calibration intervals comprised of two deliveries from the standard for each interval with a meniscus reading on both the standard and unknown measure might look like the following equation:

$$u_n = \sqrt{(u_S \times 8)^2 + 8 \times (u_{mS}^2) + 4 \times (u_{mX}^2)}$$

Eqn. (6)

4.2   Uncorrected systematic errors, included in the uncertainty budget for a test measure or prover, must be less than the compliance limits specified in the published requirements, must be less than limits published in NISTIR 6969, SOP 29 (i.e., less than the expanded uncertainty when all other components are combined) and may be included as a rectangular distribution in the test measure or prover calibration uncertainties. The mean (average) deviation of all calibration points may be calculated from the deviation for each calibration point and used as the value for an uncorrected systematic error.

Table 2. Example Uncertainty Budget Table.

Uncertainty Component Description	Symbol	Source	Typical Distribution
Uncertainty of the standard	u_s	Calibration certificate; may be multiplied or added based on dependencies	Expanded divided by coverage factor
Ability to read the Meniscus in S	u_m	None if using a slicker-plate type standard; GMP 3	Triangular
Ability to read the Meniscus in X	u_m	GMP 3	Triangular

5   Compliance Assessments

5.1   The maximum capacity tolerance between the nominal volume line and any other line on the scale must be less than the published specifications or the scale plate should be replaced. Alternatively, if the scale readings are determined to be in error but proportional to the calibration points, a Neck Scale Correction Factor (*NSCF*) may be issued with instructions to the user for its use if it is anticipated that this correction factor will be used. For use of the *NSCF* to be valid, all corrected scale plate readings must fall within the applicable tolerance after the *NSCF* is applied to the actual scale plate reading. If the linearity and proportionality errors are sufficiently large that the *NSCF* does not bring all corrected neck scale readings within the tolerance limits, use of the *NSCF* correction is not appropriate.

5.2   Neck scale errors less than the limits provided in published requirements should be included in the uncertainty estimate associated with the prover calibration as uncorrected errors.

5.3   Uncertainties must be considered when evaluating the acceptability of the neck scale plate. If uncertainties for the scale plate calibration exceed the published compliance limits, the laboratory may not reject the scale plate. The application of scale plate tolerances must allow for the uncertainty of the neck scale calibration measurements. The neck scale capacity error must exceed the value of one division

plus the uncertainty of the neck scale calibration to be rejected by the weights and measures enforcement agency.

5.3.1   Per NIST Handbook 105-3 for field standard test measures and provers:

Capacity Tolerances also apply to the scale intervals marked on both sides of the scale mark corresponding to the nominal capacity of a volumetric field standard (test measure or prover). This means that the volume represented by each scale mark over the entire range of the scale plate must be accurate within the maximum permissible error of 0.05 % of the nominal capacity.

The maximum capacity error between the nominal volume line and any other line on the scale must be less than one (1) maximum subdivision as defined in the handbook. If smaller subdivisions are used, the maximum allowed subdivision is the tolerance applied to the neck uniformity.

5.3.2   Per NIST Handbook 105-4 for field standard LPG and anhydrous provers:

Capacity Tolerances apply to the scale intervals marked on both sides of the scale mark corresponding to the nominal capacity of a volumetric field standard (test measure or prover). This means that the volume represented by each scale mark over the entire range of the scale plate must be accurate within the maximum permissible error of 0.2 % of the nominal capacity.

The maximum capacity tolerance between the nominal volume line and any other line on the scale must be less than two (2) major scale divisions as defined in the handbook. If smaller divisions or subdivisions are used, two (2) times the maximum allowed division listed in the handbook is the tolerance applied to the neck uniformity.

6   Calibration Certificate

A supplemental statement on the test measure or prover calibration certificate may be generated and include supporting measurement calibration results or may include the neck scale correction factor along with instructions as to its use.

6.1   Conformity Statement

Evaluate and report compliance to applicable tolerances as needed or required by the customer or by legal metrology requirements as described in Section 5. Compliance assessments must note the applicable documentary standard and which portions of the standard were or were not evaluated.

Appendix A

Scale Plate Calibration Data Form
(One needed for each scale plate calibrated)

Laboratory data and conditions:

Laboratory		Date Calibrated	
Location		Temperature	
		Barometric Pressure	
Date Received		Relative Humidity	

Unknown Standard Description:

Owner		Neck Scale calibrated (Right or Left)	
Unique Identifier		Neck Inside Diameter	
Model/Type		Gauge Tube Inside Diameter	
Material		Neck scale graduations	
Nominal Volume		Maximum allowed subdivision	
Cubical Coefficient of Expansion (β)		Applicable scale plate accuracy limit	
Total Neck Scale Plate volume		Applicable scale plate linearity limit	
Reference temperature		Reason for Neck Scale Calibration	

Volume standard(s) data:

ID (Note ID of Standards)	Nom. Vol.	Ref. Temp.	Cal. Vol. V_{Sn}	Exp. Unc.	Unc. k factor	# Del. per interval	Cubical Coef. of Exp. (α)
S							
S							
S							

Volumes delivered from the standards into the neck:

Interval #	Vol. Added _____ units	Scale Plate Reading sr_x _____ units	Dev. between volume added and observed scale plate reading Δsr_x	Passes Scale Plate Accuracy Limit? (Yes/No)
Initial Scale Reading, sr_i				
1				
2				
3				
4				
5				
6				
Average (absolute) deviation for uncorrected systematic uncertainty:				
Neck Scale Correction Factor (NSCF) if appropriate				