

Testing of Heavy Brines

API RECOMMENDED PRACTICE 13J
SIXTH EDITION, JANUARY 2023

ERRATA 1, APRIL 2024



Special Notes

API publications necessarily address problems of a general nature. With respect to particular circumstances, local, state, and federal laws and regulations should be reviewed. The use of API publications is voluntary. In some cases, third parties or authorities having jurisdiction may choose to incorporate API standards by reference and may mandate compliance.

Neither API nor any of API's employees, subcontractors, consultants, committees, or other assignees make any warranty or representation, either express or implied, with respect to the accuracy, completeness, or usefulness of the information contained herein, or assume any liability or responsibility for any use, or the results of such use, of any information or process disclosed in this publication. Neither API nor any of API's employees, subcontractors, consultants, or other assignees represent that use of this publication would not infringe upon privately owned rights.

Users of this standard should not rely exclusively on the information contained in this document. Sound business, scientific, engineering, and safety judgment should be used in employing the information contained herein.

API is not undertaking to meet the duties of employers, manufacturers, or suppliers to warn and properly train and equip their employees, and others exposed, concerning health and safety risks and precautions, nor undertaking their obligations to comply with authorities having jurisdiction.

API publications may be used by anyone desiring to do so. Every effort has been made by the Institute to ensure the accuracy and reliability of the data contained in them; however, the Institute makes no representation, warranty, or guarantee in connection with this publication and hereby expressly disclaims any liability or responsibility for loss or damage resulting from its use or for the violation of any authorities having jurisdiction with which this publication may conflict.

API publications are published to facilitate the broad availability of proven, sound engineering and operating practices. These publications are not intended to obviate the need for applying sound engineering judgment regarding when and where these publications should be utilized. The formulation and publication of API publications is not intended in any way to inhibit anyone from using any other practices.

Any manufacturer marking equipment or materials in conformance with the marking requirements of an API standard is solely responsible for complying with all the applicable requirements of that standard. API does not represent, warrant, or guarantee that such products do in fact conform to the applicable API standard.

All rights reserved. No part of this work may be reproduced, translated, stored in a retrieval system, or transmitted by any means, electronic, mechanical, photocopying, recording, or otherwise, without prior written permission from the publisher. Contact the publisher, API Publishing Services, 200 Massachusetts Avenue, NW, Suite 1100, Washington, DC 20001.

Copyright © 2023 American Petroleum Institute

Foreword

Nothing contained in any API publication is to be construed as granting any right, by implication or otherwise, for the manufacture, sale, or use of any method, apparatus, or product covered by letters patent. Neither should anything contained in the publication be construed as insuring anyone against liability for infringement of letters patent.

The verbal forms used to express the provisions in this document are as follows.

Shall: As used in a standard, “shall” denotes a minimum requirement in order to conform to the standard.

Should: As used in a standard, “should” denotes a recommendation or that which is advised but not required in order to conform to the standard.

May: As used in a standard, “may” denotes a course of action permissible within the limits of a standard.

Can: As used in a standard, “can” denotes a statement of possibility or capability.

This document was produced under API standardization procedures that ensure appropriate notification and participation in the developmental process and is designated as an API standard. Questions concerning the interpretation of the content of this publication or comments and questions concerning the procedures under which this publication was developed should be directed in writing to the Director of Standards, American Petroleum Institute, 200 Massachusetts Avenue, NW, Suite 1100, Washington, DC 20001. Requests for permission to reproduce or translate all or any part of the material published herein should also be addressed to the director.

Generally, API standards are reviewed and revised, reaffirmed, or withdrawn at least every five years. A one-time extension of up to two years may be added to this review cycle. Status of the publication can be ascertained from the API Standards Department, telephone (202) 682-8000. A catalog of API publications and materials is published annually by API, 200 Massachusetts Avenue, NW, Suite 1100, Washington, DC 20001.

Suggested revisions are invited and should be submitted to the Standards Department, API, 200 Massachusetts Avenue, NW, Suite 1100, Washington, DC 20001, standards@api.org.

Contents

	Page
1 Scope.....	1
2 Normative References	1
3 Terms, Definitions, Acronyms, Abbreviations, and Symbols	1
3.1 Terms and Definitions.....	1
3.2 Acronyms, Abbreviations, and Symbols	3
4 Requirements	7
4.1 Quality Control Instructions.....	7
4.2 Records Retention.....	7
5 Calibration of Equipment	7
5.1 General Requirements	7
5.2 Reagents and Materials for Calibration and Verification	7
5.3 General Requirements for Calibration of Particular Apparatus	8
5.4 Frequency of Calibration/Verification	8
5.5 Calibration/Verification—Temperature-measuring Device	9
5.6 Calibration/Verification—Density-measuring Device	9
6 Density	11
6.1 General	11
6.2 Apparatus	12
6.3 Measurement of Relative Density or Density Using a Hydrometer	14
6.4 Density Corrections for Hydrometers and Brines	15
6.5 Calculation of Density in Units Other than g/mL or kg/m ³	22
6.6 Calculations for Pressure and Temperature Compensation	24
7 Crystallization Temperature.....	28
7.1 Principle	28
7.2 Apparatus	33
7.3 Determination of Crystallization Temperature of Halide Brines.....	35
8 Brine Clarity	35
8.1 Principle	35
8.2 Apparatus	36
8.3 Determination of Brine Clarity	36
9 Solids Evaluation by Gravimetric Procedure	37
9.1 Principle	37
9.2 Apparatus	37
9.3 Preparation of Glass-fiber Filter Disk.....	38
9.4 Selection of Sample Volume	39
9.5 Determination of Total Suspended Solids	39
9.6 Calculation of Total Suspended Solids.....	40
9.7 Calculation of Precision and Bias	40
9.8 Determination of Volatile and Non-volatile Solids	41
9.9 Calculation of Non-volatile and Volatile Solids	41

Contents

	Page
10 pH.....	41
10.1 Principle	41
10.2 Reagents and Materials	42
10.3 Apparatus	43
10.4 Measurement of pH of Halide Brines.....	44
10.5 Precision Statement.....	45
10.6 Care of the Electrode	45
11 Iron Contamination	45
11.1 Principle	45
11.2 Reagents and Materials	46
11.3 Apparatus	46
11.4 Preparation of Colorimetric Standards	47
11.5 Measurement of Iron Contamination.....	47
11.6 Precision Statement.....	48
12 Buffering Capacity of Brines.....	48
12.1 Principle	48
12.2 Equipment.....	49
12.3 Reagents and Materials	50
12.4 Procedure—Determination of Buffer Concentrations of Halide Brines.....	51
12.5 Calculation—First pH Endpoint	53
12.6 Calculation—Second pH Endpoint	55
13 Daily Completion Fluid Report.....	56
13.1 Principle	56
13.2 Daily Report Header	57
13.3 Wellbore Geometry, Pumps, and Zone Data	57
13.4 Completion Fluid Properties	58
13.5 Fluids and Products Accounting.....	59
13.6 Usage and/or Cost Accounting.....	59
13.7 Daily Operational Commentary	59
13.8 Vendor Representative Identification.....	59
13.9 Environmental and Safety Information	60
Annex A (informative) Example of Daily Completion Fluid Report	61
Annex B (informative) Gas Hydrates	62
Annex C (informative) Pressure Crystallization of Brines	64
Annex D (informative) Brine Viscosity.....	66
Annex E (informative) Principle of Corrosion Testing	67
Bibliography	80
Figures	
1 Hydrometer Reading at Bottom of Meniscus.....	15
2 Calcium Chloride Crystallization Temperature.....	29
3 Typical Crystallization Curve for Brine.....	33

Contents

	Page
4 Typical Crystallization Temperature Measurement Setup.....	34
5 Example of pH vs Volume of HCl Acid Added	52
6 Example of $\Delta\text{pH}/\Delta\text{VHCl}$ vs pH for More Accurate Determination of Titration Endpoint	53

Tables

1 Temperature Correction Factors for Hydrometers due to Glass Expansion and Contraction	17
2 Estimated Brine Thermal Expansion/Contraction Factors (Conversion Factors)	21
3 Pressure Compensation Factor in SI Units.....	25
4 Temperature Compensation Factor in SI Units	25
5 Pressure Compensation Factors in USC Units	27
6 Temperature Compensation Factors in USC Units	27
7 Calcium Chloride Solutions—Crystallization Temperature	30
8 Sodium Chloride Solutions—Crystallization Temperature	31
E.1 Mechanical Properties of Selected Oil Country Tubular Goods	70

Introduction

This standard is based on API Specification 13J, 5th Edition and covers the testing of heavy brines commonly used in petroleum and natural gas completion, fracturing, workover, and drill-in fluids. These brines can be purchased or rented from multiple sources and are available worldwide. No single source or limited source of supply is included, either by inference or reference.

Annexes A through E are given for information.

In this standard, quantities are expressed in the International System (SI) of units and are also, where practical, expressed in U.S. Customary (USC) units in parentheses.

NOTE The units do not necessarily represent a direct conversion of SI units to USC units, or of USC units to SI units.

Consideration has been given to the precision of the instrument making the measurement. For example, thermometers are typically marked in one-degree increments; therefore, temperature values have been rounded to the nearest degree. However, for certain critical measurements (such as brine crystallization), thermometers are typically calibrated and used to 0.05 °C (0.1 °F).

Calibrating an instrument refers to assuring the accuracy of the measurement. Accuracy is the degree of conformity of a measurement of a quantity to its actual or true value. Accuracy is related to precision, or reproducibility of a measurement. Precision is the degree to which further measurements or calculations will show the same or similar results. Precision is characterized in terms of the standard deviation of the measurement. The results of calculations or a measurement can be accurate but not precise; precise but not accurate; neither; or both. A result is valid if it is both accurate and precise.

This document uses a format for numbers that follows the examples given in the API Document Format and Style Manual, October 2020. In this document, the decimal mark is a period and separates the whole part from the fractional part of a number. No spaces are used in the numbering format. The thousands separator is a comma and is only used for numbers greater than 10,000 (i.e. 5000 items, 12,500 bags).

Testing of Heavy Brines

1 Scope

This standard covers the physical properties, potential contaminants, and test procedures for heavy brine fluids manufactured for use in oil and gas well drilling, completion, fracturing, and workover fluids.

This standard provides methods for assessing the performance and physical characteristics of heavy brines for use in field operations. It includes procedures for evaluating the density or specific gravity, the clarity or amount of particulate matter carried in the brines, the crystallization point or the temperature at which the brines make the transition between liquid and solid at atmospheric pressure (a discussion of crystallization temperature under pressure is provided Annex C), the pH, iron contamination, and buffering capacity. This standard also contains a discussion of gas hydrate formation and mitigation (Annex B), brine viscosity (Annex D), corrosion testing (Annex E), and a daily completion fluids report with example (Annex A).

NOTE Procedures for evaluating the crystallization point, pH, and buffer capacity of brines are not applicable to formate brines. Procedures applicable to formate brines are found in ISO 13503-3:2022 [4].

This standard is intended for the use of manufacturers, service companies, and end users of heavy brines.

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.

API Recommended Practice 13B-1, *Field Testing Water-based Drilling Fluids*

ASTM E77 ¹, *Standard Test Method for Inspection and Verification of Thermometers*

ASTM E617, *Standard Specification for Laboratory Weights and Precision Mass Standards*

NIST SRM 185h ², *Potassium Hydrogen Phthalate, pH Standard*

NIST SRM 186g, *Potassium Dihydrogen Phosphate, pH Standard*

NIST SRM 191C, *pH Standards*

NIST SRM 3126a, *Iron (Fe) Standard Solution*

3 Terms, Definitions, Acronyms, Abbreviations, and Symbols

3.1 Terms and Definitions

For the purposes of this standard, the following terms and definitions apply.

3.1.1

ACS reagent grade

Grade of chemical that meets purity standards as specified by the American Chemical Society (ACS).

¹ ASTM International, PO Box C700, 100 Barr Harbor Drive, West Conshohocken, PA 19428, www.astm.org.

² National Institute of Standards and Technology, 100 Bureau Drive, Gaithersburg, MD 20899, www.nist.gov.

3.1.2**calibration**

The verification of an instrument or to the adjustments made to the instrument if it is out of calibration.

NOTE The term “calibrate” also refers to instruments that cannot be adjusted if they are inaccurate and to determine their correction factors.

3.1.3**converted density**

Density of the brine at the reporting temperature, calculated from a brine density measured at a temperature other than the reporting temperature using a density–temperature conversion factor (conversion factor).

3.1.4**corrected density****corrected relative density**

Measured density or relative density of the fluid corrected for glass expansion/contraction (correction factor) when the measurement is made at a temperature other than the sample reference temperature.

3.1.5**density****mass density**

Mass of a specified material per volume of the specified material, at a specified temperature.

3.1.6**measured density****measured relative density**

Density or relative density of a fluid at its measured temperature.

3.1.7**relative density**

Dimensionless ratio of the mass of a volume of a particular substance to the mass of the same volume of a reference substance, i.e. the ratio of their respective mass densities.

NOTE 1 Generally speaking, the reference substance is pure water.

NOTE 2 Relative density is commonly known as specific gravity.

3.1.8**sample reference temperature**

The temperature at which measurements made do not require a correction factor.

3.1.9**specific gravity (SG) hydrometer****relative density hydrometer**

Common hydrometer measuring the relative density (specific gravity) of a liquid: the density of the liquid at a reference temperature (60 °F) to the density of distilled water at a reference temperature (60 °F) (i.e. relative density 60 °F/60 °F).

NOTE 1 The standard reference temperature can be taken at 15.56 °C.

NOTE 2 Density hydrometers provide a direct measurement of the density of a liquid at a reference temperature.

3.1.10**user**

Manufacturer, service company, end user, or operator applying the testing of this part of this standard.

3.2 Acronyms, Abbreviations, and Symbols

3.2.1 Acronyms and Abbreviations

ACS	American Chemical Society
AISI	American Iron and Steel Institute
BHP	bottomhole pressure
BHT	bottomhole temperature
CAS	Chemical Abstracts Service
CRA	corrosion-resistant alloy
CW	cold-worked
DSS	duplex stainless steel
FCTA	first crystal to appear
ISO	International Organization for Standardization
JSA	job safety assessments
LCTD	last crystal to dissolve
meq _{ACID}	milliequivalents of hydrochloric acid
MIC	microbiologically induced corrosion
mL _{BRINE}	milliliters of brine
MSS	martensitic stainless steel
MTALC	maximum temperature after last crystal
NACE	Formerly NACE International, now known as The Association for Materials Protection and Performance (AMPP)
NTU	nephelometric turbidity unit
PCT	pressure crystallization temperature
PPE	personal protective equipment
psi	pound-force per square inch
RTD	resistance temperature detector
SCC	stress corrosion cracking
SEM	scanning electron microscope
SG	relative density (specific gravity) hydrometer
SI	metric (unit)
SS	stainless steel
SSC	sulfide stress cracking
TCT	true crystallization temperature
TD	to deliver
TVD	true vertical depth
USC	U.S. customary (unit)

3.2.2 Symbols

B_c	density-measuring device-correction curve intercept, expressed in measuring-device density unit
C	brine density conversion factor, expressed in grams per milliliter and per degrees Celsius
$C_{P,SI}$	pressure compensation factor, expressed in (kilograms per cubic meter and per megapascal [(kg/m ³)/MPa]
$C_{P,USC}$	pressure compensation factor, expressed in pounds per gallon and per 1000 pounds-force per square inch [(lb/gal)/kpsi]
C_{SI}	brine density conversion factor, expressed in kilograms per cubic meter and per degrees Celsius
C_{USC}	brine density conversion factor, expressed in pounds per gallons and per degrees Fahrenheit
C_g	glass expansion/contraction correction factor, expressed in grams per milliliter or dimensionless
$C_{\theta,SI}$	temperature compensation factor, expressed in (kilograms per cubic meter and per 100 degrees Celsius [(kg/m ³)/100 °C]
$C_{\theta,USC}$	temperature compensation factor, expressed in pounds per gallon and per 100 degrees Fahrenheit [(lb/gal)/100 °F]
c_{B1}	first buffer concentration, expressed in milliequivalents of acid per milliliter of brine (meq _{ACID} /mL _{BRINE})
c_{B2}	second buffer concentration, expressed in milliequivalents of acid per milliliter of brine (meq _{ACID} /mL _{BRINE})
c_{KHCO_3}	concentration of titratable basic species, expressed in kilograms per cubic meter or in pounds per barrel of potassium bicarbonate
$c_{K_2CO_3}$	concentration of titratable basic species, expressed in kilograms per cubic meter or in pounds per barrel of potassium carbonate
$c_{Na_2CO_3}$	concentration of titratable basic species, expressed in kilograms per cubic meter or in pounds per barrel of sodium carbonate
c_{NaHCO_3}	concentration of titratable basic species, expressed in kilograms per cubic meter or in pounds per barrel of sodium bicarbonate
F_c	density-measuring device-correction factor, expressed in measuring-device density unit
$h_{TVD,SI}$	true vertical depth, expressed in meters
$h_{TVD,USC}$	true vertical depth, expressed in feet

M_{HCl}	molarity of the hydrochloric acid used, expressed in moles per liter
m_{S}	mass of total suspended solids, expressed in milligrams per liter
$m_{\text{S-nv}}$	mass of total non-volatile solids or residue, expressed in milligrams per liter
$m_{\text{S-v}}$	mass of total volatile solids, expressed in milligrams per liter
m_1	original mass of pan and glass-fiber filter, expressed in milligrams
m_2	final mass of pan, glass-fiber filter and residue, expressed in milligrams
m_3	mass of porcelain evaporating dish and filter medium, expressed in milligrams
m_4	mass of porcelain evaporating dish and filtered sample after drying at 105 °C (220 °F), expressed in milligrams
m_5	mass of porcelain evaporating dish and filtered sample after auto-ignition at 550 °C (1000 °F), expressed in milligrams
$P_{\text{hyd,SI}}$	hydrostatic pressure in the wellbore, expressed in kilopascals
$P_{\text{hyd,USC}}$	hydrostatic pressure, in the wellbore, expressed in pounds-force per square inch
R	density hydrometer corrected reading at measured temperature, expressed in grams per milliliter
R_{SG}	SG hydrometer corrected reading at measured temperature, dimensionless
R_1	average density reading at the lower bath temperature
R_2	average density reading at the higher bath temperature
$V_{\text{A-HCl}}$	volume of hydrochloric acid used to the first pH endpoint, expressed in milliliters
$V_{\text{B-HCl}}$	volume of hydrochloric acid used to reach the second pH endpoint, expressed in milliliters
V_{HCl}	volume of hydrochloric acid added, expressed in milliliters
V_{s}	volume of brine sample, expressed in milliliters
Z_{c}	density-measuring device-correction curve slope, expressed in measuring device unit per either degrees Celsius or per degrees Fahrenheit
$\Gamma_{\text{DFG,SI}}$	drilling fluid gradient expressed in kilopascals per meter
$\Gamma_{\text{DFG,USC}}$	drilling fluid gradient expressed in ponds-force per square inch and per foot (psi/ft) calculated from density expressed in pounds per gallon
$\Gamma_{\text{DFG,USC-2}}$	drilling fluid gradient, expressed in pounds per square foot, calculated from density in pounds per cubic foot
ΔpH	change in pH after addition of hydrochloric acid aliquot (dimensionless)

ΔV_{HCl}	volume of hydrochloric acid aliquot addition, expressed in milliliters
$\theta_{\text{BH,SI}}$	brine temperature measured at bottom hole, expressed in degrees Celsius
$\theta_{\text{BH,USC}}$	brine temperature, measured at bottom hole, expressed in degrees Fahrenheit
θ_{Ref}	sample reference temperature of hydrometer, expressed in degrees Celsius or Fahrenheit
$\theta_{\text{Surf,SI}}$	brine temperature measured at the surface or assumed to be 20 °C, expressed in degrees Celsius
$\theta_{\text{Surf,USC}}$	brine temperature measured at the surface or assumed to be 70 °F, expressed in degrees Fahrenheit
θ_{m}	measurement temperature, expressed in degrees Celsius or Fahrenheit
$\theta_{\text{m,SI}}$	measured temperature, expressed in degrees Celsius
$\theta_{\text{m,USC}}$	measured temperature, expressed in degrees Fahrenheit
θ_1	average temperature at the lower bath temperature, expressed in degrees Celsius or Fahrenheit
θ_2	average temperature at the higher bath temperature, expressed in degrees Celsius or Fahrenheit
$\theta_{1,\text{SI}}$	lower temperature, expressed in degrees Celsius
$\theta_{2,\text{SI}}$	higher temperature, expressed in degrees Celsius
ρ	corrected density, expressed in grams per milliliter
ρ_{SI}	density, expressed in kilograms per cubic meter
ρ_{USC}	density, expressed in pounds per gallon
$\rho_{\text{USC-2}}$	density, expressed in pounds per cubic foot
$\rho_{\text{av,SI}}$	average brine density in the wellbore, expressed in kilograms per cubic meter
$\rho_{\text{av,USC}}$	average brine density in the wellbore, expressed in pounds per gallon
$\rho_{\text{Surf,SI}}$	brine density at the surface, expressed in kilograms per cubic meter
$\rho_{\text{Surf,USC}}$	brine density at the surface, expressed in pounds per gallon
ρ_1	corrected density at lower temperature, expressed in grams per milliliter
ρ_2	corrected density at higher temperature, expressed in grams per milliliter
ρ_{20}	density at 20 °C, expressed in grams per milliliter
$\rho_{20,\text{SI}}$	converted density at 20 °C, expressed in kilograms per cubic meter



$\rho_{70,USC}$	converted density at 70 °F, expressed in pounds per gallon
ρ_{θ_m}	density at measurement temperature θ_m , expressed in grams per milliliter
$\rho_{\theta_m,SI}$	density at measurement temperature θ_m , expressed in kilograms per cubic meter
$\rho_{\theta_m,USC}$	density at measurement temperature θ_m , expressed in pounds per gallon

4 Requirements

4.1 Quality Control Instructions

Quality control work shall be controlled by documented instructions that include methodology and quantitative acceptance criteria.

4.2 Records Retention

Records specified in this standard shall be maintained for a minimum of one year from the date of preparation.

5 Calibration of Equipment

5.1 General Requirements

5.1.1 Laboratory equipment and reagents shall be calibrated at periodic intervals and by specified calibration procedures. For laboratory items not listed, the user shall develop procedures when deemed appropriate.

5.1.2 The user shall control, calibrate, verify, and maintain the laboratory equipment and reagents used in this standard for measuring product conformance.

5.1.3 The user shall maintain and use laboratory equipment and reagents that prevent measurement uncertainty and meet the required measurement accuracy.

5.1.4 The user shall document and maintain calibration procedures, including details of laboratory equipment and reagent type, identification number, frequency of checks, acceptance criteria, and corrective action to be taken when results are unsatisfactory.

5.1.5 The user shall establish and document responsibility for administration of the calibration program and responsibility for corrective action.

5.1.6 The user shall:

- a) document and maintain calibration records for laboratory equipment;
- b) periodically review these records for trends, sudden shifts, or other signals of approaching malfunction, and;
- c) identify each item with a suitable indicator or approved identification record to show calibration status.

5.2 Reagents and Materials for Calibration and Verification

5.2.1 Chemicals and Solutions

ACS reagent grade, or equivalent, shall be used. Shelf life shall not exceed the manufacturer's recommendation. If no recommendation is stated, then shelf life shall not exceed 6 months after first opening. The expiration date of standard reference material shall be shown on bottles used in the field. Bottles shall be kept tightly sealed.

5.2.2 Distilled or Deionized Water

The user shall develop, document, and implement a method to determine resistivity or conductivity of water. The water shall not be used if resistivity is less than 18.2 milliohms or conductivity is greater than 0.055 microsiemens.

5.3 General Requirements for Calibration of Particular Apparatus

5.3.1 Volumetric Glassware

Calibration of laboratory volumetric glassware used for testing, including flasks, graduated cylinders, and pipettes, is generally performed by the glassware manufacturer or supplier. Users of products in accordance with this standard shall document evidence of glassware calibration prior to use. Manufacturer or supplier certification of calibration shall be acceptable. In the absence of manufacturer or supplier certification, calibration shall be performed gravimetrically using a procedure based on API 13B-1 and meeting the product specification. Periodic recalibration shall not be required.

5.3.2 Laboratory Temperature-measuring Devices

The user shall calibrate all laboratory temperature-measuring devices used in measuring product conformance against a secondary reference temperature-measuring device. The secondary reference temperature-measuring device shall show evidence of calibration as performed against NIST, or international equivalent standard body or, certified master instrument in accordance with ASTM E77 or to equivalent national or international standard(s) such as ISO or equivalent body.

5.3.3 Laboratory Balances

The user shall calibrate laboratory balances periodically in the range of use with ASTM E617 Class 1, 4, or 6 or better weights, depending on the specifications for the balance accuracy. In accordance with good laboratory practices, good management practices, or ISO quality management standards, balances shall be serviced and adjusted whenever calibration indicates a problem.

If ASTM E617 cannot be obtained (i.e. international use of this standard), the secondary weights shall show evidence of calibration as performed against a certified and traceable master instrument to a national or international standard body, such as ISO or equivalent body.

5.3.4 Hydrometers

The user shall calibrate each hydrometer with fluids of known density referenced and traceable to a national or international standard and according to the equipment manufacturer's recommendations.

5.3.5 Density Meter

The user shall calibrate each density meter to a known national or international standard that is traceable and according to the equipment manufacturer's recommendations.

5.4 Frequency of Calibration/Verification

5.4.1 General

Any instrument subjected to movement that will affect its calibration shall be recalibrated prior to use.

5.4.2 Temperature-measuring Devices

Calibrate each temperature-measuring device before it is put into service. After calibration, mark each temperature-measuring device with an identifying number that ties it to its corresponding correction chart.

Check calibration as required and stated by manufacturer, against the secondary reference temperature-measuring device. Calibration periodicity should be user specified.

5.4.3 Laboratory Balances

Calibrate each balance prior to being put into service. Check calibration at least annually, or more frequently as stated by manufacturer. Calibration periodicity should be user specified.

5.4.4 Hydrometers

Calibrate each hydrometer prior to being put into service. After calibration, note and record each hydrometer identifying number that ties it to its correction chart. Before each use, inspect for damage, and if needed recalibrate or discard. Calibration periodicity should be user specified.

5.4.5 Density Meter

Calibrate each density meter prior to being put into service. After calibration, note and record each density meter identifying number that ties it to its correction chart. Before each use, inspect for damage, and if needed recalibrate or discard. Calibration periodicity should be at least according to manufacturer recommendation and user specified.

5.5 Calibration/Verification—Temperature-measuring Device

Calibration verification of temperature-measuring devices shall be performed as per the following.

- a) Place the temperature-measuring device to be calibrated side-by-side with a secondary reference temperature-measuring device in a constant-temperature water bath or suitable container of 4 L (1 gal) or more, filled with water, on a counter in a constant-temperature room. Allow to equilibrate for at least 1 h.
- b) Read and record the temperature indicated by each temperature-measuring device.
- c) Repeat the readings at 1 h intervals to obtain a minimum of four readings.
- d) Calculate the average and the range of readings for each temperature-measuring device. The difference between the ranges of readings for each temperature-measuring device shall not exceed 0.5 °C (1 °F) or the smallest scale division on the temperature-measuring device being calibrated.
- e) If the manufacturer of the temperature-measuring device recommends test calibration at multiple temperatures, repeat Item a) through Item b) in water baths at multiple temperatures.
- f) Calculate the average deviation of each temperature-measuring device reading from the secondary reference temperature-measuring device reading. Calculate and document correction for each temperature-measuring device. Discard the temperature-measuring device, if appropriate.

5.6 Calibration/Verification—Density-measuring Device

NOTE Calibration/verification procedure is applicable to density as well as to relative-density-measuring devices.

5.6.1 Calibration Procedure

Each density-measuring device to be used shall be calibrated against a national or international traceable standard density-measuring device. Calibration shall be performed using the same test solution in the anticipated density range at temperatures spanning the anticipated test temperatures.

Each density-measuring device shall be calibrated using the following method.

- a) Prepare 1 L of test solution of the relevant density.

- b) Place the test solution into a sedimentation cylinder. Then place the cylinder in a constant-temperature bath. Set bath temperature to the lowest expected temperature for any actual test. Allow to reach equilibrium $\pm 0.2^\circ\text{C}$ ($\pm 0.5^\circ\text{F}$). Insert the traceable standard density-measuring device and wait at least 5 min for the device and solution to reach the bath temperature, as measured by equilibrium of the solution temperature.
- c) Read and record the reading obtained by the density-measuring device. Read and record the reading obtained by the temperature-measuring device. Repeat readings at least 5 min apart to obtain a minimum of four readings.
- d) Repeat Item b) through Item c) using the density-measuring device to be calibrated.
- e) Calculate the average density-measuring device reading and designate this as R_1 . Calculate the average temperature reading and designate it as θ_1 .
- f) Repeat Item b) through Item c) with the bath temperature set to the highest expected test temperature. Calculate average density-measuring device and temperature readings and designate these readings as R_2 and θ_2 .

5.6.2 Correction Curve

The density-measuring device-correction curve should be defined by the curve slope and its intercept.

This curve should be generally designed with an ordinate value of 1 for the interception of the density reading axis by temperature axis.

- a) The density-measuring device-correction curve slope, Z_c , shall be calculated using Equation (1).

$$Z_c = \frac{R_1 - R_2}{\theta_2 - \theta_1} \quad (1)$$

where

Z_c is the density-measuring device-correction curve slope, expressed in measuring device density unit per either $^\circ\text{C}$ or $^\circ\text{F}$;

R_1 is the average density reading at the lower bath temperature;

R_2 is the average density reading at the higher bath temperature;

θ_1 is the average temperature at the lower bath temperature, either $^\circ\text{C}$ or $^\circ\text{F}$;

θ_2 is the average temperature at the higher bath temperature, either $^\circ\text{C}$ or $^\circ\text{F}$.

Temperature may be measured in either $^\circ\text{C}$ or $^\circ\text{F}$, and all measurements and calculations are consistent in units.

Density reading may be according to the measuring device in calibration/verification a density expressed in g/mL (g/cm^3) or any density units, or a relative density (dimensionless).

- b) The density-measuring device-correction curve intercept, B_c , shall be calculated using Equation (2).

$$B_c = (Z_c \times \theta_1) + (R_1 - 1) \quad (2)$$

where

B_c is the density-measuring device-correction curve intercept expressed in measuring-device density unit;

NOTE B_c is provided for reference in the permanent calibration record.

Z_c is the density-measuring device-correction curve slope, expressed in measuring device density unit per either °C or °F;

R_1 is the average density reading at the lower bath temperature;

θ_1 is the average temperature at the lower bath temperature, expressed in either °C or °F;

1 is the intercept density reading value by temperature axis [density expressed in g/mL (g/cm³) or as relative density].

c) Record Z_c , B_c , and density-measuring device serial number in a permanent calibration record.

5.6.3 Density Meter Temperature Correction Factor

Z_c and B_c can be used to calculate the appropriate temperature correction factor at a specific measurement temperature using Equation (3).

$$F_c = B_c - (Z_c \times \theta_m) \quad (3)$$

where

F_c is the density-measuring device-correction factor, expressed in density-measuring device unit;

Z_c is the density-measuring device-correction curve slope, expressed in measuring-device density unit per either °C or °F;

θ_m is the specific measurement temperature, expressed in either °C or °F;

B_c is the density-measuring device-correction curve intercept, expressed in measuring-device density unit.

Temperature correction factor F_c should be subtracted from density or relative density readings obtained at that specific measurement temperature.

6 Density

6.1 General

6.1.1 The density of brine is determined by its salt type and concentration. Moreover, the brine density decreases as the temperature increases. The amount of decrease depends on the brine composition. Conversely, the brine density increases as the pressure on the brine increases. Therefore, the brine density at ambient atmospheric conditions is not a reliable indicator of brine density downhole because the brine density changes with temperature, hydrostatic pressure, and applied pressure.

6.1.2 The density of brine is the mass of brine per unit of volume. In the SI system, density is expressed in kilograms per cubic meter (kg/m^3). The use of derived units, grams per cubic centimeter (g/cm^3) and grams per milliliter (g/mL), is acceptable. Density may also be expressed in terms of relative density (specific gravity) or pressure gradient. Relative density of brine is the density of the brine at a specified temperature relative to the density of the hydrometer reference material at its reference temperature. The density of a brine when measured at the reference temperature of the hydrometer can be calculated by multiplying the relative density by the density of the reference material at its reference temperature.

NOTE 1 In USC units, density is expressed in pounds per gallon (lb/gal) or pounds per cubic foot (lb/ft^3).

NOTE 2 It is considered that one milliliter is equal to one cubic centimeter.

NOTE 3 The reference material for hydrometers commonly used for heavy brine is air-free distilled water [density 999 kg/m^3 (8.337 lb/gal) at 15.56°C (60°F)].

Pressure gradient is the hydrostatic pressure exerted by the brine per unit depth. In SI system, pressure gradient is expressed in kilopascals per meter (kPa/m). In USC units, it is expressed in pounds-force per square inch, per foot [$(\text{lbf/in.}^2)/\text{ft}$ or commonly psi/ft].

6.1.3 The reference temperature for reporting brine density in SI units is 20°C . The reference temperature in USC units is 70°F . The reported/calculated density at 20°C or 70°F is not used to determine hydrostatic pressure. Instead, the actual measured density at surface temperature (measured density read or calculated from the hydrometer reading at surface temperature) is used to calculate an estimated hydrostatic pressure. A more accurate value can be obtained by integrating the density changes due to temperature and pressure increase along the brine column.

6.1.4 The measurement of the density of brines is affected by entrapped gases. If gas entrainment is a problem, the procedures outlined in API 13B-1 should be used to remove the entrained gas. These procedures use a pressurized fluid density (mud) balance and/or deaerator to aid in the density measurement.

6.1.5 The pressurized and atmospheric mud balances are useful for determining density trends (increases or decreases) in the field but are not sufficiently accurate for absolute determination of brine density. For purposes of absolute density determination, a set of calibrated hydrometers or calibrated density meters shall be used instead of a mud balance. The procedures specified in API 13B-1 shall be used when measuring density with mud balances.

6.1.6 Any instrument of sufficient precision to permit measurement to within $\pm 5 \text{ kg/m}^3$ ($\pm 0.005 \text{ g/mL}$; $\pm 0.05 \text{ lb/gal}$) and reportable to within $\pm 10 \text{ kg/m}^3$ ($\pm 0.01 \text{ g/mL}$; $\pm 0.1 \text{ lb/gal}$) may be used. Generally, this requires the use of hydrometers or density meters for fluid density measurements. An atmospheric or pressurized mud balance may be used but lacks sufficient precision to meet the requirements of this clause for reporting brine density (see 6.2.1 through 6.2.3).

6.2 Apparatus

6.2.1 Set of calibrated glass hydrometers, which cover the density or relative density range encountered in heavy brine applications with graduations not greater than 0.002 in density units expressed in grams per cubic centimeter (or grams per milliliter) or in relative density unit (dimensionless). Refer to 5.6 for hydrometer calibration verification method.

NOTE Hydrometers graduated in kg/m^3 or lb/gal are not common oilfield apparatuses.

The hydrometer is a weighted bulb with a graduated stem. Two types of hydrometers can be used: density hydrometers (density meter) and relative density hydrometers [specific gravity (SG) hydrometer]. The depth to which the hydrometer sinks in a fluid is determined by the density of the fluid and temperature (Archimedes' law); therefore, the brine temperature should be recorded to apply the temperature correction and/or conversion factors if required.

Each type of hydrometer is identified with:

- the reference temperature at which the measurement is made, called the sample reference temperature; and, in addition for SG hydrometers:
- the reference temperature at which the reference material is specified, called the reference material reference temperature.

These are typically displayed as, for example, 60 °F/60 °F, wherein the upper temperature is the sample reference temperature, and the lower temperature is the reference material reference temperature. Other SG hydrometer reference temperatures are 20 °C/4 °C and 20 °C/20 °C (often with one temperature written directly above the other).

NOTE 1 SG hydrometer reference temperatures are Sample Reference Temperature)/(Reference Material Reference Temperature.

NOTE 2 Most SG hydrometers used in the oilfield are 60 °F/60 °F hydrometers and the reference material is deaerated water. Therefore, the calculations reported herein are based on these 60 °F/60 °F SG hydrometers.

NOTE 3 For density hydrometers provided by suppliers where only one temperature, called the density meter calibration temperature, is marked on the apparatus, the user should verify that the temperature is both the reference temperature and the reference material temperature. Most density hydrometers are graduated with a reference temperature of 20 °C.

The following information shall be permanently and legibly marked on the hydrometer.

- 1) The basis of the scale [e.g. g/cm³, dimensionless relative density (SG hydrometer)].
- 2) The sample reference temperature for the SG hydrometer measurement (e.g. 20 °C, 60 °F) and the reference temperature for the reference standard (e.g. 15.56 °C, 60 °F). For density hydrometers, only one temperature called the apparatus reference or calibration temperature is recorded.
- 3) A particular surface tension expressed in millinewtons per meter (e.g. 75 mN/m), or a surface tension category (e.g. high or low surface tension), when known.
- 4) An identification number, the first two digits of which may indicate the year of manufacturing (e.g. 11xxxx).
- 5) The series identification (e.g. M50), related to accuracy of the hydrometer.

NOTE M50 hydrometers are providing an accuracy of ± 0.001 , at least series M100 and S50 are required.

6.2.1.1 Density Hydrometer

The scale shall indicate density (mass per unit of volume) with graduations in grams per milliliter (or grams per cubic centimeter) not greater than 0.002 g/mL (0.002 g/cm³). At the same time, brine temperature should be recorded to apply temperature correction and/or conversion factors if needed. The density of a brine when measured at the sample reference temperature of the density hydrometer is the density read directly from the density hydrometer. At temperatures other than the sample reference temperature, correction and conversion factors for temperature are required.

Since the hydrometer is constructed of glass, a correction factor due to the thermal volumetric expansion (or contraction) of glass shall be applied first to the measurement whenever the measurement is made at a temperature different from the sample reference temperature (see 6.4).

When converting the measured density of brine to a temperature different from the measured temperature, a conversion factor shall be applied based on the thermal volume expansion (or contraction) of the specific brine composition.

6.2.1.2 Relative Density Hydrometer (SG Hydrometer)

The sample reference temperature and the reference material reference temperature when using a SG hydrometer are typically 15.56 °C (60 °F). SG hydrometers are like density hydrometers and have a graduated stem with dimensionless graduations in relative density units not greater than 0.002. Brine temperature shall be recorded to apply temperature correction and/or conversion factors if needed.

Since the SG hydrometer is constructed of glass, a correction factor due to the thermal volumetric expansion (or contraction) of glass shall be applied first to the measurement whenever the measurement is made at a temperature different from the sample reference temperature.

The measurement is the relative density of a brine at the measurement temperature relative to the density of the reference material at its reference temperature. Then, the density of a brine at the measured temperature is calculated by multiplying the specific gravity at the measured temperature by the density of the reference material at the reference material reference temperature.

NOTE The density of the reference material deaerated distilled water for the most popular SG hydrometer (60 °F/60 °F) used for oilfield brine measurements is 0.999 g/mL (8.337 lb/gal) (see 6.4).

When converting the measured relative density of brine into density at a temperature different from the measured temperature, a conversion factor shall be applied based on the thermal volume expansion (or contraction) of the specific brine composition.

6.2.2 Cylindrical sample container, plastic, or glass. For convenience in pouring, the cylinder may have a lip on the rim. The inside diameter of the cylinder shall be at least 2.54 cm (1.0 in.) greater than the outside diameter of the hydrometer used. The height of the cylinder shall be such that the hydrometer floats in the sample fluid with at least 2.54 cm (1.0 in) clearance between the bottom of the hydrometer and the bottom of the cylinder.

6.2.3 Temperature-measuring device, range 0 °C to 105 °C (32 °F to 220 °F), with accuracy of ± 1 °C (± 2 °F).

6.2.4 Filter paper, qualitative hardened lint-free cotton linter filter paper designed for laboratory filtration.

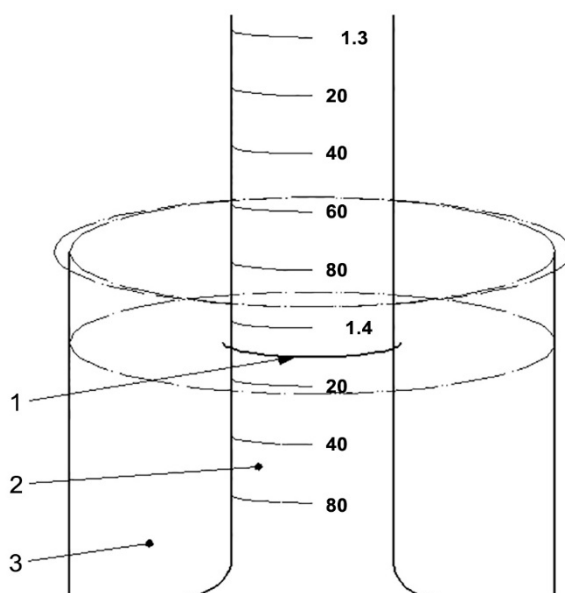
6.3 Measurement of Relative Density or Density Using a Hydrometer

This procedure is applicable for both density and SG hydrometers. Freshly filtered samples should be used.

NOTE Any oil present in the sample will interfere with the measurement.

Measurement shall be done as per the following procedure.

- a) Pour the sample fluid into the clean, dry cylinder without splashing. Splashing can entrain air bubbles in the fluid. Remove any air bubbles adhering to the surface by touching them with a piece of clean filter paper.
- b) Place the cylinder in a location that is free from air currents.
- c) Place the hydrometer vertically in the sample fluid and spin the hydrometer to center the device.
- d) After the hydrometer has come to rest and floats freely away from the walls of the cylinder, take the hydrometer reading as the point at which the surface of the sample fluid appears to cut the hydrometer scale (bottom of the meniscus) as shown in Figure 1.



Key

- 1 reading at bottom of meniscus
- 2 hydrometer
- 3 sample

Figure 1—Hydrometer Reading at Bottom of Meniscus

- e) Determine the temperature of the sample fluid immediately following reading the hydrometer.
- f) Ideally, the measurement temperature should be $20\text{ }^{\circ}\text{C} \pm 2\text{ }^{\circ}\text{C}$ for SI units reporting and $70\text{ }^{\circ}\text{F} \pm 5\text{ }^{\circ}\text{F}$ for USC units reporting to minimize measurement uncertainties and the application of correction and/or conversion factors. The following measurement scenarios exist.

- 1) When the measurement is made at the hydrometer sample reference temperature, no correction for glass thermal expansion/contraction or brine thermal expansion/contraction is required.

The brine thermal expansion/contraction factor (conversion factor) can then be used to obtain the density or relative density of the brine at some other temperature.

- 2) When the measured brine temperature is different from the hydrometer sample reference temperature, correction for glass expansion/contraction is required to obtain the density or relative density of the brine at the measured temperature, if significant (see 6.4).

The brine thermal expansion/contraction factor (conversion factor) can then be used to obtain the density or relative density of the brine at other temperatures.

6.4 Density Corrections for Hydrometers and Brines

6.4.1 Temperature Corrections for Hydrometer Readings

6.4.1.1 Density Hydrometer

If the hydrometer density reading is taken at a temperature reading other than the sample reference temperature for the hydrometer, then the reading will be in error because there is a change in volume of the hydrometer between the two temperatures due to the thermal expansion or contraction of the glass from which the hydrometer is made.

Appropriate corrections making allowance for the thermal glass expansion/contraction effect are given in Table 1. When positive in sign, the temperature correction is to be added to the hydrometer reading. Conversely when negative in sign, the temperature correction is to be subtracted from the hydrometer reading. The table is computed using a nominal coefficient of cubical thermal expansion for the glass of the hydrometer having a value of $25 \times 10^{-6} \text{ }^{\circ}\text{C}^{-1}$ ($13.9 \times 10^{-6} \text{ }^{\circ}\text{F}^{-1}$). In the worst cases for measuring temperatures dramatically different from the hydrometer sample reference temperature, the glass expansion/contraction factors affect only digits that are estimated from the hydrometer reading. Hydrometer readings corrected for glass expansion/contraction are labeled hydrometer corrected readings.

As generally density hydrometers are graduated in g/mL, corrected density of a brine, ρ_{θ_m} , at measurement temperature, θ_m , is given by the density hydrometer corrected reading, R , at measured temperature θ_m and can be calculated using Equations (4) to (6) according to the desired unit.

a) ρ_{θ_m} , expressed in g/mL is given as follows:

$$\rho_{\theta_m} = R \quad (4)$$

b) $\rho_{\theta_m, \text{SI}}$, expressed in kg/m^3 , is given as follows:

$$\rho_{\theta_m, \text{SI}} = 1000 \times R \quad (5)$$

c) $\rho_{\theta_m, \text{USC}}$, expressed in pounds per gallon, is given as follows:

$$\rho_{\theta_m, \text{USC}} = 8.345 \times \rho_{\theta_m} = 0.008345 \times \rho_{\theta_m, \text{SI}} \quad (6)$$

where

R is the density hydrometer corrected reading for thermal glass expansion/contraction at measured temperature (see Table 1).

6.4.1.2 Relative Density and Density by SG Hydrometer

If the SG hydrometer reading is taken at a temperature reading other than the sample reference temperature for the hydrometer, then the reading will be in error because there is a change in volume of the hydrometer between the two temperatures due to the thermal expansion or contraction of the glass from which the hydrometer is made.

As for density hydrometers, appropriate corrections making allowance for the thermal glass expansion/contraction effect are given in Table 1. When positive in sign, the temperature correction is to be added to the hydrometer reading. Conversely, when negative in sign, the temperature correction is to be subtracted from the hydrometer reading. The table is computed using a nominal coefficient of cubical thermal expansion for the glass of the hydrometer having a value of $25 \times 10^{-6} \text{ }^{\circ}\text{C}^{-1}$ ($13.9 \times 10^{-6} \text{ }^{\circ}\text{F}^{-1}$). In the worst cases for measuring temperatures dramatically different from the hydrometer sample reference temperature, the glass expansion/contraction factors affect only digits that are estimated from the hydrometer reading. Hydrometer readings corrected for glass expansion/contraction are labeled hydrometer corrected readings.

Table 1—Temperature Correction Factors for Hydrometers due to Glass Expansion and Contraction

Change in Measuring Temperature		Relative Density Reading (R_{SG}) or Density Reading (R) Dimensionless or expressed in g/mL (10^{-3} kg/m ³)						
°C	°F	1.0	1.2	1.4	1.6	1.8	2.0	2.2
-20	-36	0.0005	0.0006	0.0007	0.0008	0.0009	0.0010	0.0011
-15	-27	0.0004	0.0005	0.0005	0.0006	0.0007	0.0008	0.0008
-10	-18	0.0003	0.0003	0.0004	0.0004	0.0005	0.0005	0.0006
-5	-9	0.0001	0.0002	0.0002	0.0002	0.0002	0.0003	0.0003
Hydrometer Sample Reference Temperature		0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
5	+9	-0.0001	-0.0002	-0.0002	-0.0002	-0.0002	-0.0003	-0.0003
10	+18	-0.0003	-0.0003	-0.0004	-0.0004	-0.0005	-0.0005	-0.0006
15	+27	-0.0004	-0.0005	-0.0005	-0.0006	-0.0007	-0.0008	-0.0008
20	+36	-0.0005	-0.0006	-0.0007	-0.0008	-0.0009	-0.0010	-0.0011
25	+45	-0.0006	-0.0008	-0.0009	-0.0010	-0.0010	-0.0011	-0.0014

NOTE 1 These corrections when applied to the hydrometer reading at a measured temperature give relative density or the density (g/mL) at the measured temperature. They are based on the equation:

$$C_g = 25 \times 10^{-6} \times R_{SG} \times (\theta_{Ref} - \theta_m)$$

where

- C_g is the correction for glass expansion/contraction dimensionless for relative density or in g/mL for density;
- R_{SG} is the relative density hydrometer reading dimensionless or R density reading in g/mL;
- θ_m is the temperature of the liquid to be measured in °C or °F;
- θ_{Ref} is the sample reference temperature of the hydrometer in °C or °F.

NOTE 2 Cubical volume expansion factor for glass is 25×10^{-6} per °C, shall be replaced by (13.9×10^{-6}) per °F when temperature are expressed in °F.

Corrected density of a brine, ρ_{θ_m} , at measurement temperature, θ_m , based on the SG hydrometer corrected relative density reading, R_{SG} , at measured temperature θ_m can be calculated using Equations (7) to (9) according to the desired unit:

- a) ρ_{θ_m} , expressed in g/mL, using Equation (7), 0.999 is the density of deaerated distilled water at 15.56 °C (60 °F) expressed in g/mL:

$$\rho_{\theta_m} = 0.999 \times R_{SG} \quad (7)$$

- b) $\rho_{\theta_m, SI}$, expressed in kg/m³, using Equation (8), 999 is the density of deaerated water at 15.56 °C (60 °F) expressed in kg/m³:

$$\rho_{\theta_m, SI} = 999 \times R_{SG} \quad (8)$$

- c) $\rho_{\theta_m, USC}$, expressed in lb/gal, using Equation (9), 8.337 is the density of deaerated water at 15.56 °C (60 °F) expressed in lb/gal:

$$\rho_{\theta_m, USC} = 8.337 \times R_{SG} \quad (9)$$

where

R_{SG} is the SG hydrometer corrected reading for thermal glass expansion/contraction at measured temperature (see Table 1).

6.4.2 Temperature Corrections for Brine Density

The reported density of a brine sample shall be corrected to 20 °C for SI units reporting and to 70 °F for USC units reporting if the hydrometer measurement was taken at any other measurement temperature. This brine volume expansion/contraction factor is due to the change in volume of brine as the temperature of the brine changes. Therefore, brine density shall be corrected for brine volume changes when converting from one temperature to another using conversion factor, C (C_{SI} or C_{USC}), either an estimated factor read from Table 2 or calculated from Equations (10) through (14) according to the desired unit.

a) For SI derived units expressed in g/mL, C shall be calculated using Equation (10):

$$C = 10^{-3} \times \left[(-0.12868) + (1.4999 \times \rho_{\theta_m}) - (1.036 \times \rho_{\theta_m}^2) + (0.2727 \times \rho_{\theta_m}^3) \right] \quad (10)$$

where

C is the brine density conversion factor in g/mL per °C.

ρ_{θ_m} is the hydrometer corrected density reading at measured temperature expressed in g/mL.

b) For SI units expressed in kg/m³, C_{SI} shall be calculated using Equation (11):

$$C_{SI} = (-0.12868) + (1.4999 \times \rho_{\theta_m}) - (1.036 \times \rho_{\theta_m}^2) + (0.2727 \times \rho_{\theta_m}^3) \quad (11)$$

where

C_{SI} is the brine density conversion factor in kg/m³ per °C;

ρ_{θ_m} is the hydrometer corrected density reading at measured temperature expressed in g/mL;

or using Equation (12):

$$C_{SI} = \left[\begin{aligned} &(-0.12868) + (1.4999 \times 10^{-3} \times \rho_{\theta_m, SI}) - (1.036 \times 10^{-6} \times \rho_{\theta_m, SI}^2) \\ &+ (0.2727 \times 10^{-9} \times \rho_{\theta_m, SI}^3) \end{aligned} \right] \quad (12)$$

where

$\rho_{\theta_m, SI}$ is the hydrometer corrected density reading at measured temperature expressed in kg/m³;

C_{SI} is the brine density conversion factor in kg/m³ per °C.

c) For USC units, C_{USC} shall be calculated using Equation (13):

$$C_{\text{USC}} = 10^{-3} \times \left[\begin{aligned} &(-0.59659) + (0.83411 \times \rho_{\theta_m, \text{USC}}) - (0.06904 \times \rho_{\theta_m, \text{USC}}^2) \\ &+ (0.00218 \times \rho_{\theta_m, \text{USC}}^3) \end{aligned} \right] \quad (13)$$

where

C_{USC} is the brine density conversion factor in lb/gal per °F;

$\rho_{\theta_m, \text{USC}}$ is the hydrometer corrected density reading at measured temperature expressed in lb/gal;

or directly from corrected SG hydrometer relative density reading using Equation (14):

$$C_{\text{USC}} = 10^{-3} \times \left[(-0.59659) + (6.954 \times R_{\text{SG}}) - (4.799 \times R_{\text{SG}}^2) + (1.263 \times R_{\text{SG}}^3) \right] \quad (14)$$

where

C_{USC} is the brine density conversion factor in lb/gal per °F;

R_{SG} is the relative density corrected reading for a 60 °F/60 °F SG hydrometer (dimensionless).

6.4.3 Converted Brine Density at 20 °C or at 70 °F

Using the conversion factor from either Equations (10) to (14) or Table 2, the converted density shall be calculated at 20 °C for SI units or at 70 °F for USC units.

a) If temperature measurement is given in degrees Celsius, use Equation (15) to find the converted density in g/mL:

$$\rho_{20} = \rho_{\theta_m} + \left[(\theta_{m, \text{SI}} - 20) \times C \right] \quad (15)$$

where

ρ_{20} is the converted density at 20 °C, expressed in g/mL;

ρ_{θ_m} is the hydrometer corrected density reading at measured temperature expressed in g/mL;

NOTE ρ_{θ_m} can be calculated using Equation (4) or (7) and a corrected hydrometer reading.

$\theta_{m, \text{SI}}$ is the measured temperature, in °C;

C is the brine thermal expansion/contraction factor from Table 2 or Equation (10).

- b) If temperature measurement is given in degrees Celsius, use Equation (16) to find the converted density in kg/m³:

$$\rho_{20,SI} = \rho_{\theta_m,SI} + \left[(\theta_{m,SI} - 20) \times C_{SI} \right] \quad (16)$$

where

$\rho_{20,SI}$ is the converted density at 20 °C, expressed in kg/m³;

$\rho_{\theta_m,SI}$ is the hydrometer corrected density reading at measured temperature expressed in kg/m³;

NOTE $\rho_{\theta_m,SI}$ can be calculated using Equation (5) or (8) and a corrected hydrometer reading.

$\theta_{m,SI}$ is the measured temperature, in °C;

C_{SI} is the brine thermal expansion/contraction factor from Table 2 or Equation (11) or (12).

- c) If the temperature measurement is given in degrees Fahrenheit, use Equation (17) or Equation (18) to find the converted density in lb/gal. The coefficient of 8.337 is the deaerated distilled water density at 15.56 °C (60 °F) in lb/gal:

$$\rho_{70,USC} = (8.337 \times R_{SG}) + C_{USC} \times [(8.337 \times R_{SG}) - 70] \quad (17)$$

or, using $\rho_{\theta_m,USC}$ from Equation (6) or (9) to calculate the converted density:

$$\rho_{70,USC} = \rho_{\theta_m,USC} + \left[(\theta_{m,USC} - 70) \times C_{USC} \right] \quad (18)$$

where

$\rho_{70,USC}$ is the converted density at 70 °F, expressed in lb/gal;

R_{SG} is the SG hydrometer corrected reading, dimensionless;

$\rho_{\theta_m,USC}$ is the SG hydrometer corrected density reading at measured temperature expressed in lb/gal;

$\theta_{m,USC}$ is the measured temperature, expressed in °F;

C_{USC} is the brine thermal expansion/contraction factor from Table 2 or Equation (13) or (14).