

**Manual of Petroleum
Measurement Standards
Chapter 9.4—Continuous Density
Measurement Under Dynamic
(Flowing) Conditions**

FIRST EDITION, JANUARY 2018



AMERICAN PETROLEUM INSTITUTE

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.

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.

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.

Copyright © 2018 American Petroleum Institute. 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, 1220 L Street, NW, Washington, DC 20005.

Foreword

This standard, API MPMS Chapter 9.4, *Continuous Density Measurement Under Dynamic (Flowing) Conditions*, First Edition, supersedes API MPMS Chapter 14.6, *Continuous Density Measurement*, Second Edition, which is withdrawn.

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, 1220 L Street, NW, Washington, DC 20005. 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) 682-2000. A catalog of API publications and materials is published annually by API, 1220 L Street, NW, Washington, DC 20005.

Suggested revisions are invited and should be submitted to the Standards Department, API, 1220 L Street, NW, Washington, DC 20005, standards@api.org.

Contents

	Page
1 Scope	1
2 Field of Application	1
3 Normative References	1
3.1 API Manual of Petroleum Measurement Standards (MPMS)	1
3.2 ASTM	2
3.3 GPA	3
3.4 OIML	3
4 Terms, Definitions, and Symbols	3
4.1 Terms and Definitions	3
4.2 Symbols, Acronyms, and Abbreviations	8
5 Safety Precautions	12
5.1 Overview	12
5.2 Equipment Design	12
5.3 Operation	13
6 Density Determination Methods	13
7 Equipment	14
7.1 General	14
7.2 Vibrating Element (Natural Resonance)	15
7.3 Vibrating Element (Fixed Frequency)	16
7.4 Acoustic	16
7.5 Nuclear	16
7.6 Continuous Weighing	17
7.7 Buoyancy	17
7.8 Hydrostatic Pressure	17
7.9 Gas Chromatograph (GC)	18
8 Applications of Continuous Density Measurement	18
8.1 Overview	18
8.2 Quantity Applications	18
8.3 Quality Determination	20
8.4 Interface Detection	20
8.5 Inventory Control/Process Control	20
9 Performance Requirements- System and Density Meter	20
9.1 General	20
9.2 Inferred Mass Flow Measurement	21
9.3 Volumetric Measurement	21
9.4 Volume from Direct Mass	22
9.5 Other Density Measurement Applications	22
10 Design of Density Measurement System	23
10.1 General	23
10.2 Application Considerations	23
10.3 Fluid Properties	24
10.4 Process Conditions	25
10.5 Density Meter and Method Selection	27
10.6 Sample System	29

Contents

	Page
10.7 Sample Conditioning	31
10.8 Density Meter Signals	32
10.9 Mechanical Considerations	33
10.10 Installation Configurations	34
10.11 Verification and Proving Design Considerations	42
11 Proving, Verification, or Calibration of Liquid Density Meters	42
11.1 General	42
11.2 Representativeness	43
11.3 In-situ Proving	44
11.4 Methods for Proving, Verification, and Calibration (In-situ)	46
12 Calculations	48
12.1 Overview	48
12.2 Volume Correction Factor (VCF) Determination and Density	49
12.3 Density Conditions	50
12.4 Fluid Compressibility	51
12.5 Fluid Expansion/Contraction Due to Temperature	51
12.6 Density Computation Methods	51
12.7 Flow-weighting	52
12.8 Density Unit of Measure Conversions	52
Annex A (informative) Density Sensitivity—Light Hydrocarbon Liquids	53
Annex B (normative) Test Equipment—Pycnometer Calibration and Proving	68
Annex C (normative) Pycnometer Calibration—Laboratory Method	72
Annex D (normative) Density Meter Proving—Pycnometer Method	84
Annex E (informative) Derivation of Air Buoyancy Equation	99
Annex F (informative) Reference Fluids (Air and Water)	107
Annex G (informative) Conversion Factors	110
Annex H (normative) Offline Density Meter Factor Determination for Crude Oils and Viscous Fluids	118
Annex I (normative) Density Used in Volume Calculation	122
Annex J (informative) Concepts of Mass and Weight	123
Bibliography	127
Figures	
1 Density Determination Methods	14
2 Variable Element Density Meters	15
3 Inserting Element (Insertion) Density Meters	16
4 Nuclear Density Meters	17
5 Volume Measurement	34
6 Inferred Mass Flow Measurement	35
7 Multiple Meter Runs with Individual Density Meters	36
8 Typical Multiple Meter Run with Common Density Meter on Inlet	37
9 Slipstream-type Sampling System: Velocity Head Devices	38
10 Slipstream-type Sampling System: Valve Restriction Devices	38

Contents

	Page	
11	Slipstream-type Sampling System: Orifice Restriction Devices	39
12	Slipstream-type Continuous Density Sampling Systems: Pump Devices (for Light Hydrocarbons and Refined Products)	40
13	Insertion-type Sampling System—Pumped Density Prover Loop	40
14	In-line-type Sampling System with Pumped Density Prover Loop	40
15	Parallel Density Prover Loop	41
16	Parallel Pumped Density Prover Loop	41
17	Double-wall Vacuum Sphere Pycnometer	45
18	Density Meter Calculation Sequence	49
C.1	Vacuum Filling the Water Reservoir (Laboratory Calibration) (optional procedure)	76
C.2	Deaerating the Water Reservoir (Laboratory Calibration)	76
C.3	Vacuum Emptying the Pycnometer	77
C.4	Pycnometer Calibration Test Apparatus	78
C.5	Reinstallation of Test Tubing	80
C.6	Optional E_t Test Apparatus	83
E.1	Net Forces on Pycnometer	99
F.1	Buoyancy Illustration	107
J.1	Report of Mass Values	125

Tables

1	Typical Density Meter Performance Expectations at 0.25 % Total Measurement System Uncertainty	21
A.1	Density Sensitivity for 0.2 °F Difference for Fluid Temperatures Between 40 °F and 100 °F and Pressures Between 400 psig and 1200 psig	53
A.2	Density Sensitivity for 1 psi Difference For Fluid Pressures Between 400 psig and 1200 psig and Temperatures Between 40 °F and 100 °F	60
A.3	Composition Matrix	67
C.1	Test Equipment for Laboratory Calibration of a Pycnometer	74
C.2	Pycnometer Certificate Heading	81
C.3	Pycnometer Weights and Volume	82
C.4	Pycnometer Report Calibration Devices	82
C.5	Pycnometer Report Test Result Data	83
D.1	Proving Report Heading	96
D.2	Proving Report Density Meter Data	96
D.3	Proving Report Field Calibration Data	96
D.4	Proving Report Pycnometer Identification Data	97
D.5	Proving Report Proving Data and Calculations	98
G.1	Density Conversion Factors (SI units to SI units)	111
G.2	Density Conversion Factors (SI units to USC units)	112
G.3	Density Conversion Factors (USC units to SI Units)	112
G.4	Density Conversion Factors (USC Units to USC Units—lb/gal and RD)	112
G.5	Density Conversion Factors (USC Units to USC Units – lb/gal, RD and °API)	113
G.6	Temperature Conversion Units (SI and USC)	114
G.7	Pressure Conversion Units (SI and USC)	115
G.8	Dynamic (Absolute) Viscosity Conversion Units (SI and USC)	117
G.9	Kinematic Viscosity Conversion Units (SI and USC)	117

Continuous Density Measurement Under Dynamic (Flowing) Conditions

1 Scope

This standard covers the continuous on-line determination and application of flowing liquid densities for custody transfer. This standard covers liquid and dense phase fluids, including: natural gas liquids, refined products, chemicals, crude oil, and other liquid products commonly encountered in the petroleum industry. This document does not apply to the density measurement of natural gas, LNG, multiphase mixtures, semi-solid liquids such as asphalt, and solids such as coke and slurries.

This standard also provides criteria and procedures for designing, installing, operating, and proving continuous on-line density measurement systems for custody transfer. This standard also discusses the different levels and requirements of accuracy for various applications.

2 Field of Application

The application of this standard provides a minimum set of requirements for density measurement applications, including custody transfer. In all cases, the measured density has to accurately represent the density of the flowing stream. Accurate density measurements are essential for custody transfer and for many quantitative purposes. For allocation measurement and process control applications, this standard can be used as a guide.

Common technologies utilized in continuous density measurement include vibrating element, buoyancy, and nuclear devices. The most widely utilized device in custody transfer applications is the vibrating element.

This standard also includes analytical systems that work in conjunction with equations of state or empirically derived calculations to determine the flowing density.

3 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.

3.1 API Manual of Petroleum Measurement Standards (MPMS)

API MPMS Chapter 8.1, *Standard Practice for Manual Sampling Petroleum and Petroleum Products*

API MPMS Chapter 8.2, *Standard Practice for Automatic Sampling of Petroleum and Petroleum Products*

API MPMS Chapter 8.5, *Standard Practice for Manual Piston Cylinder Sampling for Volatile Crude Oils, Condensates, and Liquid Petroleum Products*

API MPMS Chapter 9.1, *Standard Test Method for Density, Relative Density or API Gravity of Crude Petroleum and Liquid Petroleum Products by Hydrometer Method*

API MPMS Chapter 9.2, *Standard Test Method for Density or Relative Density of Light Hydrocarbons by Pressure Hydrometer*

API MPMS Chapter 9.3, *Standard Test Method for Density, Relative Density, and API Gravity of Crude Petroleum and Liquid Petroleum Products by Thermohydrometer Method*