

Hydrocarbon management

HM 8

Continuous density measurement

2nd edition

HM 8
CONTINUOUS DENSITY MEASUREMENT

Second edition

March 2019

Published by
Energy Institute, London

The Energy Institute is a professional membership body incorporated by Royal Charter 2003
Registered charity number 1097899

The Energy Institute (EI) is the chartered professional membership body for the energy industry, supporting over 20 000 individuals working in or studying energy and 250 energy companies worldwide. The EI provides learning and networking opportunities to support professional development, as well as professional recognition and technical and scientific knowledge resources on energy in all its forms and applications.

The EI's purpose is to develop and disseminate knowledge, skills and good practice towards a safe, secure and sustainable energy system. In fulfilling this mission, the EI addresses the depth and breadth of the energy sector, from fuels and fuels distribution to health and safety, sustainability and the environment. It also informs policy by providing a platform for debate and scientifically-sound information on energy issues.

The EI is licensed by:

- the Engineering Council to award Chartered, Incorporated and Engineering Technician status, and
- the Society for the Environment to award Chartered Environmentalist status.

It also offers its own Chartered Energy Engineer, Chartered Petroleum Engineer, and Chartered Energy Manager titles.

A registered charity, the EI serves society with independence, professionalism and a wealth of expertise in all energy matters.

This publication has been produced as a result of work carried out within the Technical Team of the EI, funded by the EI's Technical Partners. The EI's Technical Work Programme provides industry with cost-effective, value-adding knowledge on key current and future issues affecting those operating in the energy sector, both in the UK and internationally.

For further information, please visit <http://www.energyinst.org>

The EI gratefully acknowledges the financial contributions towards the scientific and technical programme from the following companies

BP Exploration Operating Co Ltd	Qatar Petroleum
BP Oil UK Ltd	Repsol Sinopec
Centrica	RWE npower
Chevron North Sea Ltd	Saudi Aramco
Chevron Products Company	Scottish Power
Chrysaor	SGS
CLH	Shell UK Oil Products Limited
ConocoPhillips Ltd	Shell U.K. Exploration and Production Ltd
DCC Energy	SSE
EDF Energy	TAQA Bratani
ENI	Total E&P UK Limited
E. ON UK	Total UK Limited
Equinor	Tullow Oil
ExxonMobil International Ltd	Uniper
Innogy	Valero
Kuwait Petroleum International Ltd	Vattenfall
Nexen CNOOC	Vitol Energy
Ørsted	Woodside
Perenco	World Fuel Services
Phillips 66	

However, it should be noted that the above organisations have not all been directly involved in the development of this publication, nor do they necessarily endorse its content.

Copyright © 2019 by the Energy Institute, London.

The Energy Institute is a professional membership body incorporated by Royal Charter 2003.

Registered charity number 1097899, England

All rights reserved

No part of this book may be reproduced by any means, or transmitted or translated into a machine language without the written permission of the publisher.

ISBN 978 1 78725 058 1

Published by the Energy Institute

The information contained in this publication is provided for general information purposes only. Whilst the Energy Institute and the contributors have applied reasonable care in developing this publication, no representations or warranties, express or implied, are made by the Energy Institute or any of the contributors concerning the applicability, suitability, accuracy or completeness of the information contained herein and the Energy Institute and the contributors accept no responsibility whatsoever for the use of this information. Neither the Energy Institute nor any of the contributors shall be liable in any way for any liability, loss, cost or damage incurred as a result of the receipt or use of the information contained herein.

Hard copy and electronic access to EI and IP publications is available via our website, <https://publishing.energyinst.org>.

Documents can be purchased online as downloadable pdfs or on an annual subscription for single users and companies.

For more information, contact the EI Publications Team.

e: pubs@energyinst.org

CONTENTS

	Page
Foreword	11
Acknowledgements	12
Introduction	13
1 Scope	14
2 Terms and definitions	15
2.1 Definitions	15
2.1.1 Approved laboratory	15
2.1.2 Competent person	15
2.1.3 Density	15
2.1.4 Density meter	15
2.1.5 Density meter, continuous	15
2.1.6 Density meter, in-the-line	15
2.1.7 Density meter, off-line, laboratory or benchtop	15
2.1.8 Density meter, on-line	16
2.1.9 Density sensor	16
2.1.10 Density transducer	16
2.1.11 Error	16
2.1.12 Meter bank	16
2.1.13 Meter run	16
2.1.14 Observed value	16
2.1.15 Observed density	16
2.1.16 Reference conditions	16
2.1.17 Relative density (of gas)	16
2.1.18 Relative density (of liquid)	17
2.1.19 Standard conditions	17
2.1.20 Sampling system	17
2.1.21 Uncertainty	17
2.2 Symbols	17
2.2.1 Symbols	18
2.2.2 Subscripts	18
3 Normative references	19
4 Safety precautions	20
4.1 General	20
4.2 Precautions	20
4.2.1 Equipment installation and operation	20
4.2.2 Leaded fuels	21
4.2.3 Volatile liquids	21
4.2.4 Pyknometers	21

Contents continued

	Page
5 Instrument types	22
5.1 General	22
5.1.1 Application	22
5.1.2 Meter components	22
5.1.3 Selection	23
5.2 Density meters	23
5.2.1 Continuous weighing technique	23
5.2.2 Vibrating element (fixed frequency) technique	23
5.2.3 Vibrating element (natural resonance) technique	24
5.2.4 Constant head techniques	25
5.2.5 Centrifugal technique	25
5.2.6 Acoustic technique	26
5.2.7 Nucleonic technique	26
5.3 Choice of instrument type	27
5.3.1 Liquid density instruments	27
5.3.2 Gas density instruments	27
6 Liquid density measurement applications	28
6.1 General	28
6.2 Applications	28
6.3 Basic measuring system	28
6.3.1 Component parts	28
6.3.2 Interconnection	28
6.3.3 Measurement conditions	29
6.3.4 Conversion requirements	29
6.3.5 Density-temperature relationship	29
6.3.6 Fluid thermal expansion	30
6.3.7 Density-pressure relationship	30
6.3.8 Fluid compressibility	31
6.4 Manual methods for conversion of density to reference conditions	31
6.4.1 Historical standards and tabulated conversion factors	31
6.4.3 Conversion of density from line to standard conditions	32
6.4.4 Volume weighting	32
6.5 Automatic continuous conversion to standard conditions	33
6.5.1 General	33
6.5.2 On-line computation	33
6.6 Compensation for effects of conditions at the transducer	34
6.6.1 Improvement in accuracy	34
6.6.2 Magnitude of effects	35
6.6.3 Implementation	35
6.7 Quality determination or monitoring	35
6.7.1 Applications	35
6.7.2 Requirements	35
6.8 Mass flow measurement	35
6.8.1 Applications	35
6.8.2 Mass rate calculation	36
6.8.3 Mass throughput	36

Contents continued

	Page
6.9 Manual mass computation	36
6.9.1 Volume flow	36
6.9.2 Density data and computation method	36
6.9.3 Conditions	37
6.10 Automatic continuous mass computation	37
6.10.1 Equipment	37
6.10.2 Calculation method	38
6.11 High accuracy systems	38
6.11.1 General	38
6.12 Standby facilities	38
6.12.1 Use of one density meter	38
6.12.2 Use of two or more density meters	39
6.12.3 Comprehensive systems	40
6.13 The effect of sediment and water (S&W)	41
6.13.1 Measurement of wet oil	41
6.13.2 Calculation of dry oil	41
6.13.3 Measurement of water content	42
6.14 Air buoyancy	43
6.14.1 Applicability	43
6.14.2 Calculation	43
7 Installation of liquid density meters	44
7.1 General installation considerations	44
7.1.1 In-the-line and external loop installations	44
7.1.2 General design	44
7.1.3 Condition of the liquid at the sampling density and measurement points	44
7.1.3.1 Representativeness	44
7.1.3.2 Homogeneity	45
7.1.3.3 Deposits	45
7.1.3.4 Mixing	45
7.1.3.5 Vapour pressure	45
7.2 Installation design for density at reference conditions	45
7.3 Installation design for mass flow measurement	45
7.3.1 Flow element imposed limitations	45
7.3.2 Pressure effects	46
7.3.3 Temperature effects	46
7.3.4 Examples of required pressure and temperature equalisation	46
7.3.5 Unregistered flow	47
7.4 Practical installation considerations	47
7.4.1 Suitability of specification	47
7.4.2 Rating	47
7.4.3 Temperature equilibrium	47
7.4.4 Non-homogeneous liquids	48
7.4.5 Phase separation	48
7.4.6 Piggable lines	48
7.4.7 Representativeness of flow	48
7.4.8 Flow velocity	48

Contents continued

	Page
8 Verifying the calibration of liquid density meters	49
8.1 General	49
8.1.1 <i>In situ</i> calibration	49
8.1.2 Representativeness	49
8.1.3 Laboratory method	49
8.1.4 Uncertainties	49
8.2 Laboratory measurement procedures	50
8.2.1 Homogeneity	50
8.2.2 Hydrometer method	50
8.2.3 Oscillating U-Tube density meter method	50
8.2.4 Capillary pycnometer methods	50
8.3 Pressure pycnometer procedure	51
8.3.1 Application	51
8.3.2 Technique	51
8.4 Transfer standard procedure	51
8.4.1 Advantages	51
8.4.2 Precautions	51
8.5 Substitution method	52
8.5.1 Technique	52
8.5.2 Application considerations	52
8.5.3 Failure to meet comparison limits	53
9 Gas density measurement applications	54
9.1 General	54
9.2 Applications and systems	54
9.2.1 Applications	54
9.2.2 Effect of line conditions on density	54
9.3 Mass flow measurement	55
9.3.1 Differential pressure primary elements	55
9.3.2 Volumetric meters	55
9.4 Measurement of density at reference conditions	55
9.4.1 Relative density	55
9.4.2 Principles of measurement	56
9.4.3 Instrument types	56
9.4.4 Installation considerations	56
9.5 Calculation of volume at standard conditions	57
9.6 High accuracy gas density measurement	57
9.7 Standby facilities	57
9.7.1 Redundancy	57
9.7.2 Comparison monitoring	58
9.7.3 Computational redundancy	58
10 Installation of gas density meters	59
10.1 General	59
10.2 Installation considerations	59
10.2.1 Initial data requirements	59
10.2.2 Safety	59
10.2.3 Location	59
10.2.4 Effect of density error on the flow computation	60
10.2.5 Temperature equalisation	60
10.2.6 Compensation for process condition differences	60

Contents continued

	Page
10.3 Error sources and their effects on installation design	60
10.3.1 Flow element imposed limitations	60
10.3.2 Pressure effects (main stream)	61
10.3.3 Pressure effects (sample flow)	62
10.3.4 Temperature effects (main stream)	62
10.3.5 Temperature effects (sample flow)	63
10.3.6 Unregistered gas	63
10.4 Installation arrangements	63
10.4.1 Basic installation types	63
10.4.2 External loop, bypass method.	65
10.4.3 External loop, pressure recovery method	67
10.4.4 Direct insertion method	67
11 Verifying the calibration of gas density meters.	68
11.1 General.	68
11.2 Mass flow metering systems	68
11.2.1 Calibration.	68
11.2.2 Installation checking.	68
11.3 Density meter calibration checks	68
11.3.1 Atmospheric pressure check.	69
11.3.2 Operating density check.	69
11.3.3 Vacuum check	69
11.3.4 Continuous calculation.	69
11.3.5 Transfer standard proving	69
11.3.6 Precautions necessary in transfer standard proving.	70
11.4 Checking density measured at reference conditions.	70
11.4.1 Basic method	70
11.4.2 Secondary effect considerations	70
11.4.3 Other methods.	70
 Annexes	
Annex A Density correction using petroleum measurement tables	71
Annex B Calculation of volume weighted average temperature	73
Annex C Density units and conversion factors	74
Annex D Calibration of on-line density meters by pressure pycnometry.	75
D.1 Introduction	75
D.2 Scope.	75
D.3 Normative references	76
D.4 Terms and definitions	76
D.4.1 Density	76
D.4.2 Weighing	76
D.4.3 Mass.	76

Contents continued

		Page
	D.4.4 Conventional mass	76
	D.4.5 Air buoyancy	77
	D.4.6 Competent person	77
D.5	Equipment	77
	D.5.1 Pycnometer	77
	D.5.2 Temperature measurement	78
	D.5.3 Pressure measurement	79
	D.5.4 Flow indicator	79
	D.5.5 Carrying case	79
	D.5.6 Hoses	79
	D.5.7 Balance	79
	D.5.8 Weights	79
	D.5.9 Air density	80
D.6	Procedure	80
	D.6.1 Metering system checks	80
	D.6.2 Pycnometer preparation	81
	D.6.3 Sampling	81
	D.6.4 Cleaning	82
D.7	Weighing	83
	D.7.1 Weighing environment	83
	D.7.2 Setting up balance	83
	D.7.3 Weighing pycnometers	84
D.8	Calculations	85
	D.8.1 Calculate the pycnometer volume	85
	D.8.2 Calculation of air density	85
	D.8.3 Calculation of oil weight	85
	D.8.4 Calculation of oil mass	86
	D.8.5 Calculation of oil density	86
	D.8.6 Oil density acceptance criteria	86
D.9	Test report	86
Annex E	Reference conditions for measurement of petroleum liquids and gases.	90
	E.1 International standard conditions	90
Annex F	Correlation equations	92
	F.1 Density-temperature relationship of hydrocarbon fluids	92
	F.2 Density-pressure relationship of hydrocarbon fluids	93
	F.3 Use of correlation equations	94
Annex G	Calibration of pycnometer volume	95
	G.1 Scope and field of application	95
	G.2 Definitions	95
	G.3 Principle	96
	G.4 Apparatus	96
	G.4.1 Constant temperature bath	96
	G.4.2 Thermometry	96
	G.4.3 Pressure generation and measurement	97
	G.4.4 Balance and weights	97
	G.4.5 Drying	97

Contents continued

	Page
G.5 Reagents	97
G.5.1 Water	97
G.5.2 Cleaning solvents	97
G.5.3 Drying solvent	97
G.6 Preparation of the pycnometer	98
G.7 Calibration procedure	98
G.8 Calculations	100
G.8.1 Air density	100
G.8.2 Water density	100
G.8.3 Calculation of pycnometer volume	100
G.8.4 Sample calculation	100
G.9 Expression of results	101
G.10 Precision	102
G.10.1	102
G.10.2 Uncertainty budget – use of poise weights	103
G.11 References	103
Annex H Transfer standard calibration	105
H.1 Type of instrument	105
H.2 Installation	105
H.2.1 Piping arrangement	105
H.2.2 Vents and drains	105
H.3 Similarity of process conditions	105
H.3.1 Temperature and pressure conditions	105
H.3.2 Insulation	106
H.3.3 Flow indication	106
H.4 Homogeneity of sample	106
H.5 Readout considerations	106
H.6 Operation	106
H.6.1 Preparation	106
H.6.2 Purging and stabilisation	106
H.6.3 Data collection	107
H.7 Error calculation	107
H.7.1 Method	107
H.7.2 Acceptance criteria	107
H.8 Decommissioning	107
H.9 Calibration frequency	108
H.10 Common mode errors	108
Annex I Abbreviations and acronyms	109
Annex J References	110

LIST OF FIGURES AND TABLES

	Page
Figures	
Figure 1	Basic measuring system for liquid density at line conditions 29
Figure 2	Measuring system for liquid density at standard conditions 33
Figure 3	Measuring system for compensated liquid density 34
Figure 4	Measuring system for compensated and corrected liquid density 34
Figure 5	Basic liquid mass measuring system 37
Figure 6a–d	Possible arrangements for two or more density meters 40
Figure 7	Typical liquid fiscal metering system with duplicate density meters (mass and standard volume measurement) 41
Figure 8a–g	Various methods of density meter installation 64
Figure 8a–g (cont'd)	Various methods of density meter installation 66
Figure D.1	Example of pyknometer 87
Figure D.2	Example of pyknometer installation 88
Tables	
Table 1	Typical temperature correction tables SI standard conditions 31
Table 2	Differences in pressure and temperature that will each cause a change in liquid density of 0,03 % 47
Table A.1	Correction values to convert observed density to equivalent hydrometer reading at t °C. 72
Table C.1	Density units and conversion factors 74
Table E.1	Property and density of air at various internationally used reference conditions . . . 90
Table F.1	K_0 , K_1 and K_2 values to calculate tangent coefficient 92
Table G.10.1	Uncertainty budget example 102
Table G.10.2	Items on the comparator for the empty and full weighings. 103

FOREWORD

Measurement accuracy is essential in the sale, purchase and handling of petroleum products. It avoids disputes between buyer and seller and provides control over losses. Accurate measurement involves the use of standard equipment and procedures that are traceable to national reference standards.

The Energy Institute (EI) Hydrocarbon Management Committee is responsible for the production and maintenance of standards and guidelines covering various aspects of static and dynamic measurement of petroleum. The EI maintains liaison with parallel working groups of the American Petroleum Institute's (API) Committee on Petroleum Measurement, and other organisations concerned with quantitative measurement in other countries and in other industries.

The EI Hydrocarbon Management Guidelines (formerly Petroleum Measurement Manual and Petroleum Measurement Papers) are widely used by the petroleum industry and have received recognition in many countries by consumers and the authorities. To promote international good practice, the EI works via the British Standards Institute (BSI) to develop standards through the International Standards Organization's technical committee TC-28 Petroleum Products and related products of synthetic or biological origin and its sub-committee TC28/SC2 Measurement of petroleum and related products.

A full list of Hydrocarbon Management publications is available on request from the EI.

The EI Hydrocarbon Management publications are recommended for general adoption but should be read and interpreted in conjunction with safety, environmental, weights and measures, customs and excise and other regulations in force in the country in which they are to be applied. Such regulatory requirements have precedence over corresponding clauses in the EI document except where the requirements of the latter are more rigorous, when its use is recommended. Users should also consider contractual constraints imposed by any other interested party.

Although it is believed that adoption of the recommendations of this publication will assist the user, the EI cannot accept any responsibility, of whatsoever kind, for damage or alleged damage arising or otherwise occurring where this document has been applied.

Attention is also drawn to the fact that some of the equipment mentioned in the publication is protected by patents throughout the world. The mention of any proprietary information in this publication does not imply its endorsement by the EI for any particular application; neither does omission imply rejection.

Users of these publication are invited to send comments, suggestions, or details of relevant experience to:

Technical Department
Hydrocarbon Management
Energy Institute
61 New Cavendish Street
London
W1G7AR
United Kingdom
www.energyinst.org