

# Orifice Metering of Natural Gas and Other Related Hydrocarbon Fluids— Concentric, Square-edged Orifice Meters

## Part 1: General Equations and Uncertainty Guidelines



**American Gas Association**

AGA Report No. 3  
Part 1



AMERICAN PETROLEUM INSTITUTE

Manual of Petroleum  
Measurement Standards  
Chapter 14.3.1

**American Gas Association**  
400 North Capitol Street, NW  
Washington, DC 20001

**American Petroleum Institute**  
1220 L Street, NW  
Washington, DC 20005

FOURTH EDITION, SEPTEMBER 2012  
ERRATA, JULY 2013

An American National Standard  
ANSI/API MPMS Ch. 14.3.1/AGA Report No. 3, Part 1



## Special Notes

This AGA/API publication necessarily addresses problems of a general nature. With respect to particular circumstances, local, state, and federal laws and regulations should be reviewed.

Neither AGA and API nor any of AGA's or 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 AGA and API nor any of AGA's or API's employees, subcontractors, consultants, or other assignees represent that use of this publication would not infringe upon privately owned rights.

This AGA/API publication may be used by anyone desiring to do so. Every effort has been made by AGA/API to assure the accuracy and reliability of the data contained in it; however, AGA/API 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.

This AGA/API publication is published to facilitate the broad availability of proven, sound engineering and operating practices. It is not intended to obviate the need for applying sound engineering judgment regarding when and where this publication should be utilized. The formulation and publication of this AGA/API publication 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 either the American Gas Association, 400 N. Capitol St., NW, Washington, DC 20001 or API Publishing Services, 1220 L Street, NW, Washington, DC 20005.



## Foreword

Nothing contained in this AGA/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.

This document was produced under API standardization procedures that ensure appropriate notification and participation in the developmental process and is designated as API *Manual of Petroleum Measurement Standard (MPMS)* Chapter 14.3.1 and AGA Report No. 3, Part 1. 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. Questions concerning the interpretation of the content of this publication should be directed to the Director of Standards, American Petroleum Institute, 1220 L Street, NW, Washington, DC 20005 and to the Vice President, Operations and Engineering, American Gas Association, 400 N. Capitol Street, NW, Washington, DC 20001, and shall be handled in accordance with API's *Procedures for Standards Development*. Requests for permission to reproduce or translate all or any part of the material published herein should also be addressed to the Director of Standards, American Petroleum Institute (as above) or the Vice President, Operations and Engineering, American Gas Association (as above).

This AGA/API publication is 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, 1220 L Street, NW, Washington, DC 20005.

A catalog of AGA Operations and Engineering publications, which is published and updated as needed and can be obtained by contacting AGA Operations and Engineering Department, phone (202) 824-7000 or web site [http://www.aga.org/Pages/contact\\_us.aspx](http://www.aga.org/Pages/contact_us.aspx).

Suggested revisions are invited and should be submitted to the Standards Department, API, 1220 L Street, NW, Washington, DC 20005, [standards@api.org](mailto:standards@api.org) or Operations and Engineering Department, American Gas Association, 400 North Capitol Street, NW, Washington, DC 20001, [http://www.aga.org/Pages/contact\\_us.aspx](http://www.aga.org/Pages/contact_us.aspx).



# Contents

|             | Page  |
|-------------|---|
| <b>1</b>    | <b>Introduction</b> . . . . . <b>1</b>  |
| <b>1.1</b>  | <b>Scope</b> . . . . . <b>1</b>   |
| <b>1.2</b>  | <b>Organization of Standard</b> . . . . . <b>1</b>  |
| <b>2</b>    | <b>Normative References</b> . . . . . <b>2</b>  |
| <b>3</b>    | <b>Terms, Definitions, and Symbols</b> . . . . . <b>3</b>   |
| <b>3.1</b>  | <b>Terms and Definitions</b> . . . . . <b>3</b>   |
| <b>3.2</b>  | <b>Symbols</b> . . . . . <b>7</b>   |
| <b>4</b>    | <b>Field of Application</b> . . . . . <b>8</b>  |
| <b>4.1</b>  | <b>Applicable Fluids</b> . . . . . <b>8</b>   |
| <b>4.2</b>  | <b>Types of Meters</b> . . . . . <b>9</b>   |
| <b>4.3</b>  | <b>Uncertainty of Measurement</b> . . . . . <b>10</b>   |
| <b>5</b>    | <b>Method of Calculation</b> . . . . . <b>10</b>  |
| <b>6</b>    | <b>Orifice Flow Equation</b> . . . . . <b>10</b>  |
| <b>6.1</b>  | <b>Velocity of Approach Factor (<math>E_v</math>)</b> . . . . . <b>12</b>                               |
| <b>6.2</b>  | <b>Orifice Plate Bore Diameter (<math>d</math>)</b> . . . . . <b>12</b>                                 |
| <b>6.3</b>  | <b>Meter Tube Internal Diameter (<math>D</math>)</b> . . . . . <b>12</b>                                |
| <b>7</b>    | <b>Empirical Coefficient of Discharge</b> . . . . . <b>13</b>   |
| <b>7.1</b>  | <b>Regression Database</b> . . . . . <b>14</b>  |
| <b>7.2</b>  | <b>Empirical Coefficient of Discharge Equation for Flange-tapped Orifice Meters</b> . . . . . <b>15</b> |
| <b>7.3</b>  | <b>Reynolds Number (<math>Re_D</math>)</b> . . . . . <b>16</b>  |
| <b>7.4</b>  | <b>Flow Conditions</b> . . . . . <b>16</b>  |
| <b>7.5</b>  | <b>Pulsating Flow</b> . . . . . <b>17</b>   |
| <b>8</b>    | <b>Empirical Expansion Factor (<math>Y</math>) for Flange-tapped Orifice Meters</b> . . . . . <b>19</b> |
| <b>8.1</b>  | <b>Upstream Expansion Factor (<math>Y_1</math>)</b> . . . . . <b>20</b>                                 |
| <b>8.2</b>  | <b>Downstream Expansion Factor (<math>Y_2</math>)</b> . . . . . <b>21</b>                               |
| <b>9</b>    | <b>In-situ Calibration</b> . . . . . <b>22</b>  |
| <b>9.1</b>  | <b>General</b> . . . . . <b>22</b>  |
| <b>9.2</b>  | <b>Meter Factor (<math>MF</math>)</b> . . . . . <b>22</b>   |
| <b>10</b>   | <b>Fluid Physical Properties</b> . . . . . <b>23</b>  |
| <b>10.1</b> | <b>Viscosity (<math>\mu</math>)</b> . . . . . <b>23</b>   |
| <b>10.2</b> | <b>Density (<math>\rho_{l,p}</math>, <math>\rho_b</math>)</b> . . . . . <b>23</b>                       |
| <b>10.3</b> | <b>Isentropic Exponent (<math>\kappa</math>)</b> . . . . . <b>24</b>                                    |
| <b>11</b>   | <b>Unit Conversion Factors</b> . . . . . <b>24</b>  |
| <b>11.1</b> | <b>Orifice Flow Equation</b> . . . . . <b>24</b>  |
| <b>11.2</b> | <b>Reynolds Number Equation</b> . . . . . <b>25</b>   |
| <b>11.3</b> | <b>Expansion Factor Equation</b> . . . . . <b>25</b>  |
| <b>11.4</b> | <b>Flow Rate per Unit of Time Conversion</b> . . . . . <b>25</b>  |
| <b>12</b>   | <b>Practical Uncertainty Guidelines</b> . . . . . <b>28</b>   |
| <b>12.1</b> | <b>General</b> . . . . . <b>28</b>  |
| <b>12.2</b> | <b>Uncertainty Over a Flow Range</b> . . . . . <b>28</b>  |
| <b>12.3</b> | <b>Uncertainty of Flow Rate</b> . . . . . <b>28</b>   |
| <b>12.4</b> | <b>Typical Uncertainties</b> . . . . . <b>31</b>  |
| <b>12.5</b> | <b>Example Uncertainty Calculations</b> . . . . . <b>37</b>   |

## Contents

Page

|   |           |
|---|-----------|
| <b>Annex A (informative) Discharge Coefficients for Flange-tapped Orifice Meters</b> .....  | <b>40</b> |
| <b>Annex B (informative) Adjustments for Instrument Calibration and Use</b> .....   | <b>51</b> |
| <b>Annex C (informative) Buckingham and Bean Empirical Expansion Factor (<math>Y</math>) for Flange-tapped Orifice Meters</b> ..... | <b>52</b> |
| <b>Bibliography</b> .....   | <b>56</b> |

### Figures

|  |           |
|--|-----------|
| <b>1 Orifice Tapping Location</b> .....  | <b>5</b>  |
| <b>2 Orifice Meter Elements</b> .....  | <b>9</b>  |
| <b>3 Contribution to Flow Error Due to Differential Pressure Instrumentation</b> .....     | <b>29</b> |
| <b>4 Empirical Coefficient of Discharge: Uncertainty at Infinite Reynolds Number</b> ..... | <b>32</b> |
| <b>5 Relative Change in Uncertainty: Dependence on Reynolds Number</b> .....               | <b>32</b> |
| <b>6 Practical Uncertainty Levels.</b> .....   | <b>34</b> |

### Tables

|  |           |
|--|-----------|
| <b>1 Linear Coefficient of Thermal Expansion</b> .....   | <b>13</b> |
| <b>2 Orifice Flow Rate Equation: Unit Conversion Factor (<math>N_1</math>)</b> .....   | <b>26</b> |
| <b>3 Reynolds Number Equation: Unit Conversion Factor (<math>N_2</math>)</b> .....   | <b>27</b> |
| <b>4 Empirical Expansion Factor Equation: Unit Conversion Factor (<math>N_3</math>)</b> .....  | <b>27</b> |
| <b>5 Uncertainty Statement for Empirical Expansion Factor</b> .....  | <b>33</b> |
| <b>6 Example Uncertainty Estimate for Liquid Flow Calculation</b> .....  | <b>38</b> |
| <b>7 Example Uncertainty Estimate for Natural Gas Flow Calculation</b> .....   | <b>39</b> |
| <b>A.1 Discharge Coefficients for Flange-tapped Orifice Meters: Nominal 2-in. (50-mm) Meter</b><br><b>[<math>D = 1.939</math> in. (49.25 mm)]</b> .....      | <b>40</b> |
| <b>A.2 Discharge Coefficients for Flange-tapped Orifice Meters: Nominal 3-in. (75-mm) Meter</b><br><b>[<math>D = 2.900</math> in. (73.66 mm)]</b> .....      | <b>41</b> |
| <b>A.3 Discharge Coefficients for Flange-tapped Orifice Meters: Nominal 4-in. (100-mm) Meter</b><br><b>[<math>D = 3.826</math> in. (97.18 mm)]</b> .....     | <b>42</b> |
| <b>A.4 Discharge Coefficients for Flange-tapped Orifice Meters: Nominal 6-in. (150-mm) Meter</b><br><b>[<math>D = 5.761</math> in. (146.33 mm)]</b> .....    | <b>43</b> |
| <b>A.5 Discharge Coefficients for Flange-tapped Orifice Meters: Nominal 8-in. (200-mm) Meter</b><br><b>[<math>D = 7.625</math> in. (193.68 mm)]</b> .....    | <b>44</b> |
| <b>A.6 Discharge Coefficients for Flange-tapped Orifice Meters: Nominal 10-in. (250-mm) Meter</b><br><b>[<math>D = 9.562</math> in. (242.87 mm)]</b> .....   | <b>45</b> |
| <b>A.7 Discharge Coefficients for Flange-tapped Orifice Meters: Nominal 12-in. (300 mm) Meter</b><br><b>[<math>D = 11.374</math> in. (288.90 mm)]</b> .....  | <b>46</b> |
| <b>A.8 Discharge Coefficients for Flange-tapped Orifice Meters: Nominal 16-in. (400-mm) Meter</b><br><b>[<math>D = 14.688</math> in. (373.08 mm)]</b> .....  | <b>47</b> |
| <b>A.9 Discharge Coefficients for Flange-tapped Orifice Meters: Nominal 20-in. (500-mm) Meter</b><br><b>[<math>D = 19.000</math> in. (482.60 mm)]</b> .....  | <b>48</b> |
| <b>A.10 Discharge Coefficients for Flange-tapped Orifice Meters: Nominal 24-in. (600-mm) Meter</b><br><b>[<math>D = 23.000</math> in. (584.20 mm)]</b> ..... | <b>49</b> |
| <b>A.11 Discharge Coefficients for Flange-tapped Orifice Meters: Nominal 30-in. (750-mm) Meter</b><br><b>[<math>D = 29.000</math> in. (736.60 mm)]</b> ..... | <b>50</b> |



# Orifice Metering of Natural Gas and Other Related Hydrocarbon Fluids— Concentric, Square-edged Orifice Meters Part 1: General Equations and Uncertainty Guidelines

## 1 Introduction

### 1.1 Scope

This standard provides a single reference for engineering equations, uncertainty estimations, construction and installation requirements, and standardized implementation recommendations for the calculation of flow rate through concentric, square-edged, flange-tapped orifice meters. Both U.S. customary (USC), and international system of units (SI) units are included.

### 1.2 Organization of Standard

The standard is organized into four parts. Parts 1, 2, and 4 apply to the measurement of any Newtonian fluid in the petroleum and chemical industries. Part 3 focuses on the application of Parts 1, 2, and 4 to the measurement of natural gas.

#### 1.2.1 Part 1—General Equations and Uncertainty Guidelines

The mass flow rate and base (or standard) volumetric flow rate equations are discussed, along with the terms required for solution of the flow equation.

The empirical equations for the coefficient of discharge and expansion factor are presented. However, the basis for the empirical equations are contained in other sections of this standard or the appropriate reference document.

In several sections of this revision of Part 1, identified errata have been changed relative to previous editions. In addition, this revision includes a change to the empirical expansion factor ( $Y$ ) calculation for the flange-tapped orifice meters.

For all existing installations, the decision as to which expansion factor equation to use shall be at the discretion of the parties involved. However, the parties should be cognizant of the following:

- 1) If the calculated difference between previous revision (1990) Buckingham and Bean expansion factor equation (Annex C or API *MPMS* Ch. 14.3.3/AGA Report No. 3, Part 3, Annex G) and the new revised expansion factor equation is less than or equal to 0.25 %, then the expansion factor values produced by either expansion factor equation will be within the uncertainty of the new expansion factor database and the existence of any flow bias will be uncertain.
- 2) However, if the calculated difference between expansion factor equations exceeds 0.25 %, then a variable flow bias, which is a function of diameter ratio ( $\beta$ ), isentropic exponent ( $\kappa$ ), and  $\Delta P/P_{f1}$  ratio ( $x_1$ ), will be experienced unless the new expansion factor equation is utilized.

For the proper use of this standard, a discussion is presented on the prediction (or determination) of the fluid's properties at flowing conditions. The fluid's physical properties shall be determined by direct measurements, appropriate technical standards, or equations of state.

Uncertainty guidelines are presented for determining the possible error associated with the use of this standard for any fluid application. User-defined uncertainties for the fluid's physical properties and auxiliary (secondary) devices are required to solve the practical working formula for the estimated uncertainty.