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**Natural gas — Calculation of  
thermodynamic properties —**

**Part 5:  
Calculation of viscosity, Joule-  
Thomson coefficient, and isentropic  
exponent**

*Gaz naturel — Calcul des propriétés thermodynamiques —*

*Partie 5: Calcul de la viscosité, du coefficient de Joule-Thomson et de  
l'exposant isentropique*

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## Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see [www.iso.org/directives](http://www.iso.org/directives)).

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This document was prepared by Technical Committee ISO/TC 193, *Natural gas*, Subcommittee SC 1, *Analysis of natural gas*, in collaboration with the European Committee for Standardization (CEN) Technical Committee CEN/TC 238, *Test gases, test pressures and categories of appliances*, in accordance with the agreement on technical cooperation between ISO and CEN (Vienna Agreement).

A list of all parts in the ISO 20765 series can be found on the ISO website.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at [www.iso.org/members.html](http://www.iso.org/members.html).

## Introduction

This document gives simplified methods for the calculation of (dynamic) viscosity, Joule-Thomson coefficient, and isentropic exponent for use in natural gas calculations in the temperature range  $-20\text{ }^{\circ}\text{C}$  to  $40\text{ }^{\circ}\text{C}$ , with absolute pressures up to 10 MPa, and only within the gas phase. For the Joule-Thomson coefficient and isentropic exponent, the uncertainty of the formulae provided is greater than that obtained from a complete equation of state such as GERG-2008<sup>[1]</sup> (see ISO 20765-2) but is considered to be fit for purpose. The formulae given here are very simple.

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# Natural gas — Calculation of thermodynamic properties —

## Part 5:

# Calculation of viscosity, Joule-Thomson coefficient, and isentropic exponent

## 1 Scope

This document specifies methods to calculate (dynamic) viscosity, Joule-Thomson coefficient, isentropic exponent, and speed of sound, excluding density, for use in the metering of natural gas flow.

## 2 Normative references

There are no normative references in this document.

## 3 Terms and definitions

No terms and definitions are listed in this document.

## 4 Background

The main motivation for this document is to provide simplified methods for the calculations required, according to ISO 5167, to measure flow of high-pressure natural gas with an orifice plate meter.

Useful references for the work herein are given below:

- a) ISO 5167-1:1991, *Measurement of fluid flow in closed conduits — Part 1: Pressure differential devices*
- b) EN 5167-1:1997, *Measurement of fluid flow by means of pressure differential devices — Part 1: Orifice plates, nozzles and Venturi tubes inserted in circular cross-section conduits running full*
- c) ISO 5167-1:2003, *Measurement of fluid flow by means of pressure differential devices inserted in circular cross-section conduits running full — Part 1: General principles and requirements*
- d) ISO 5167-2:2003, *Measurement of fluid flow by means of pressure differential devices inserted in circular cross-section conduits running full — Part 2: Orifice plates*

The basic mass flowrate,  $q$ , formula is:

$$q = \frac{C}{\sqrt{1-\beta^4}} \varepsilon \frac{\pi}{4} d^2 \sqrt{2 \cdot \Delta P \cdot D} \quad (1)$$

where

$C$  is a function of  $\beta$ ,  $Re$ , and the type of orifice pressure tappings;

$\varepsilon$  is a function of  $\beta$ ,  $P$ ,  $\Delta P$ , and  $\kappa$ .

The symbols are defined in [Annex A](#). The standards above differ in the functions for  $C$  and  $\varepsilon$ . Although  $q$  is given by [Formula \(1\)](#), iteration is required since  $C$  is a function of  $Re$ , and  $Re$  is a function of  $q$ . Similarly, given  $q$  in [Formula \(1\)](#) does not directly give  $\Delta P$  since  $\varepsilon$  is a function of  $\Delta P$ .

The use of the formulae in ISO 5167 for calculating flowrate ( $q$ ) for an orifice plate meter, over a typical input range of temperature, pressure, differential pressure, and gas composition, gives the following formula for the standard uncertainty,  $u$ , (when the only source of uncertainties is considered to be in the calculation of the required gas thermophysical properties):

$$\begin{aligned}
 [u(q)/q]^2 &= [0,5 \pm 0,000\ 2]^2 \cdot [u(\rho)/\rho]^2 && \text{(molar or mass density)} \\
 &+ [0,000\ 6 \pm 0,000\ 2]^2 \cdot [u(\eta)/\eta]^2 && \text{(viscosity)} \\
 &+ [0,002 \pm 0,001\ 2]^2 \cdot [u(\kappa)/\kappa]^2 && \text{(isentropic exponent)} \\
 &+ [-0,000\ 4 \pm 0,000\ 2]^2 \cdot [u(\mu)/\mu]^2 && \text{(Joule-Thomson coefficient)}
 \end{aligned}
 \tag{2}$$

[Formula \(2\)](#) may be used to estimate the required uncertainty for the calculation of the properties that are part of this document.

For the mass flowrate expanded uncertainty ( $U$ ) (coverage factor  $k=2$ , with a 95 % confidence interval) to be less than 0,1 % it is required that

$$\begin{aligned}
 U(\rho)/\rho &< 0,1\ \% \\
 U(\eta)/\eta &< 85\ \% \\
 U(\kappa)/\kappa &< 25\ \% \\
 U(\mu)/\mu &< 125\ \%
 \end{aligned}
 \tag{3}$$

For the uncertainty contribution of these properties to the complete flowrate uncertainty to be less than 0,02 % requires that

$$\begin{aligned}
 U(\rho)/\rho &< 0,02\ \% \\
 U(\eta)/\eta &< 17\ \% \\
 U(\kappa)/\kappa &< 5\ \% \\
 U(\mu)/\mu &< 25\ \%
 \end{aligned}
 \tag{4}$$

Thus, density needs to be calculated as accurately as possible, while the uncertainty in the calculation of the other properties can be much higher, with a target uncertainty of less than about 25 % for a 0,1 % uncertainty in the flowrate ( $k = 2$ ). The use of the GERG-2008 equation of state<sup>[1]</sup> provides calculations of density that are generally within the required 0,1 % uncertainty.



## 5 Viscosity, $\eta$

### 5.1 Viscosity as a function of temperature, pressure, and composition

There are many methods for the calculation of gas phase (dynamic) viscosity, some of which that are based on theory are quite complicated (see Reference [10] for details). The Lohrenz-Bray-Clark method (LBC) is relatively simple, requires minimal component data, and is a method that is widely implemented, and is the method recommended here. One disadvantage is the sensitivity to the input density; but for the application considered here, accurate densities will be available.

This method requires that the gas composition is available. With inputs of temperature, pressure, and composition, the GERG-2008 equation of state (ISO 20765-2) may be used to obtain the molar density required in the formulae below. When the composition is not known, the method in 5.2 may be used.

The formulae needed to implement this method are outlined below (Annex B contains an example Visual Basic program), where the required parameters consist of the following component values for the  $N$  components:

— molar mass	$M_i$	[g/mol]
— critical temperature	$T_{c,i}$	[K]
— critical pressure	$P_{c,i}$	[MPa]
— critical density	$\rho_{c,i}$	[mol/dm <sup>3</sup> ]
— mole fraction	$x_i$	[mol/mol]

These mixture parameters may be estimated with the following formulae:

$$M_{\text{mix}} = \sum_{i=1}^N x_i M_i \quad (5)$$

$$T_{c,\text{mix}} = \sum_{i=1}^N x_i T_{c,i} \quad (6)$$

$$P_{c,\text{mix}} = \sum_{i=1}^N x_i P_{c,i} \quad (7)$$

$$V_{c,\text{mix}} = \sum_{i=1}^N \frac{x_i}{\rho_{c,i}} \quad (8)$$

The component values are obtained from any suitable source, e.g. ISO 20765-2:2015, Annex B.

The viscosity of a natural gas mixture is calculated as:

$$\eta = \eta_{\text{mix}} + \xi \cdot (\delta^4 - 1) \quad (9)$$

The generalized mixture viscosity, which is based on the pure fluid viscosities, is:

$$\eta_{\text{mix}} = \frac{\sum_{i=1}^N x_i \eta_i \sqrt{M_i}}{\sum_{i=1}^N x_i \sqrt{M_i}} \quad (10)$$

The parameter  $\xi$  is dependent only on the molar mass and the critical temperature and pressure, and is given as:

$$\xi = u_\eta \left( \frac{M_{\text{mix}}}{u_M} \right)^{1/2} \left( \frac{T_{c,\text{mix}}}{u_T} \right)^{-1/6} \left( \frac{P_{c,\text{mix}}}{u_P} \right)^{2/3} \quad (11)$$

This formula is made dimensionless with the use of the following constants:

$$\begin{aligned} u_\eta &= 0,000 \text{ 1 mPa}\cdot\text{s} \\ u_M &= 1 \text{ g / mol} \\ u_T &= 1 \text{ K} \\ u_P &= 0,101 \text{ 325 MPa} \end{aligned} \quad (12)$$

The parameter  $\delta$  in [Formula \(9\)](#) is density dependent, and given as:

$$\delta = 1,023 + 0,233 \, 64 \rho_r + 0,585 \, 33 \rho_r^2 - 0,407 \, 58 \rho_r^3 + 0,093 \, 324 \rho_r^4 \quad (13)$$

$$\rho_r = V_{c,\text{mix}} \cdot \rho \quad (14)$$

where  $\rho$  is the molar density at  $T$  and  $P$ , calculated from ISO 20765-2.

The pure fluid component viscosity is:

$$\eta_i = u_\eta \left( \frac{M_i}{u_M} \right)^{1/2} \left( \frac{T_{c,i}}{u_T} \right)^{-1/6} \left( \frac{P_{c,i}}{u_P} \right)^{2/3} \alpha \quad (15)$$

where  $\alpha$  is given as:

$$T_r \leq 1,5: \alpha = 3,4 \cdot T_r^{0,94} \quad (16)$$

$$T_r > 1,5: \alpha = 1,778 \cdot (4,58 \cdot T_r - 1,67)^{0,625} \quad (17)$$

The reduced temperature in these formulae is:

$$T_r = T / T_{c,i} \quad (18)$$

From the experimental data given in References [3] to [9] the estimated uncertainty of this method is about 4 % (95 % confidence interval). (Bias=-0,31 %, RMS=1,59 %). Note that using [Formula \(9\)](#) these are predicted calculations. The experimental data was not used in the development of the method.

The number of points and ranges are:

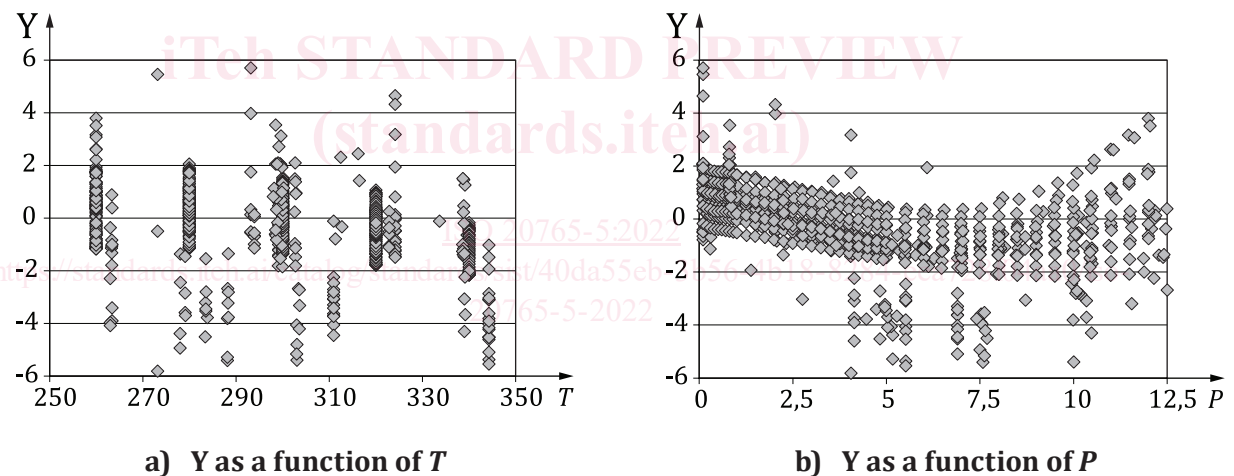
Total number of points 721

Temperature range 260 K to 344 K (–13 °C to 71 °C)

Pressure range 0,1 MPa to 12,7 MPa

[Figure 1](#) shows the distribution of the errors compared with the following experimental data:

1) Carr (1953) <sup>[3]</sup>	3 mixtures	55 points
2) Golubev (1959) <sup>[4]</sup>	1 mixture	17 points
3) Gonzalez et al. (1970) <sup>[5]</sup>	8 mixtures	35 points
4) Nabizadeh & Mayinger (1999) <sup>[6]</sup>	1 mixture	32 points
5) Assael et al. (2001) <sup>[7]</sup>	1 mixture	22 points
6) Schley et al. (2004) <sup>[8]</sup>	3 mixtures	521 points
7) Langelandsvik et al. (2007) <sup>[9]</sup>	2 mixtures	39 points



#### Key

$T$  temperature (K)

$Y$  viscosity error (%)

$P$  pressure (MPa)

**Figure 1 — Comparisons of viscosities calculated from the Lohrenz-Bray-Clark method ([Formula 9](#)) with experimental data**

If only bulk properties are available rather than a detailed composition, e.g. calorific value ( $CV$ ), relative density ( $RD$ ), and  $CO_2$  mole fraction ( $x(CO_2)$ ), then an equivalent  $N_2/CO_2/CH_4/C_3H_8$  mixture may be used in [Formula \(9\)](#) for viscosity. This equivalent four component mixture has two unknown mole fractions (for  $N_2$  and  $C_3H_8$ ), where the  $CO_2$  mole fraction is given and the  $CH_4$  mole fraction =  $1-x(N_2)-x(CO_2)-x(C_3H_8)$ . These two unknowns are determined from the provided input, e.g.  $CV$  and  $RD$ . The procedure assumes an initial compression factor,  $Z$  (e.g. 0,997 5) and solves the linearized  $CV$  and  $RD$  equations. An iterative routine updates  $Z$  until the method has converged, which is rapid since  $Z$  does not change much with natural gas composition.

An example of implementation to calculate the equivalent mixture is given in [Annex C](#). For an example of viscosity of methane, see [Annex D](#).