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

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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 °C to 40 °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[1] (see ISO 20765-2) but is considered to be fit for purpose. The formulae given here are very simple.

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:

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

where

C is a function of β, Re, and the type of orifice pressure tappings;

ε is a function of β, P, ΔP, and κ.

The symbols are defined in Annex A. The standards above differ in the functions for C and ε. 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 ΔP since ε is a function of ΔP.

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):

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

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[1] provides calculations of density that are generally within the required 0,1 % uncertainty.

5 Viscosity, η

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	$T_{\mathrm{c},i}$	[K]
— critical pressure	$P_{\mathrm{c},i}$	[MPa]
— critical density	$\rho_{\mathrm{c},i}$	[mol/dm^3]
— mole fraction	x_i	[mol/mol]

These mixture parameters may be estimated with the following formulae:

$$M_{\mathrm{mix}} = \sum_{i=1}^{N} x_i M_i \tag{5}$$

$$T_{\mathrm{c,mix}} = \sum_{i=1}^{N} x_i T_{\mathrm{c},i} \tag{6}$$

$$P_{\mathrm{c,mix}} = \sum_{i=1}^{N} x_i P_{\mathrm{c},i} \tag{7}$$

$$V_{\mathrm{c,mix}} = \sum_{i=1}^{N} \frac{x_i}{\rho_{\mathrm{c},i}} \tag{8}$$

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:

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

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

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

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

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

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

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

The parameter δ in Formula (9) is density dependent, and given as:

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

$$\rho_r = V_{\text{c,mix}} \cdot \rho \tag{14}$$

where ρ is the molar density at T and P calculated from ISO 20765-2.

The pure fluid component viscosity is:

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

where α is given as:

$$T_r \le 1{,}5 : \alpha = 3{,}4 \cdot T_r{}^{0{,}94} \tag{16}$$

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

The reduced temperature in these formulae is:

$$T_r = T / T_{\text{c},i} \tag{18}$$

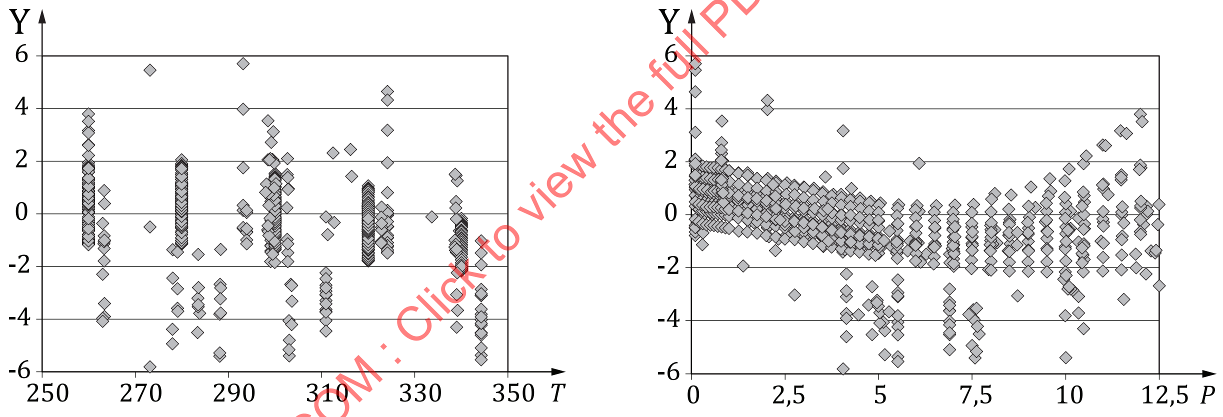
From the experimental data given in References [3] to [9] the estimated uncertainty of this method is about 4 % (95 % confidence interval). (Bias=-0,31 %, RMS=1,59 %). Note that using Formula (9) these are predicted calculations. The experimental data was not used in the development of the method.

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



a) Y as a function of *T*

b) Y as a function of *P*

Key

T temperature (K)

P pressure (MPa)

Y viscosity error (%)

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 = $1\text{-}x(N_2)\text{-}x(CO_2)\text{-}x(C_3H_8)$. 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.

5.2 Viscosity as a function of temperature and mass density

When only temperature and mass density are known (i.e. the gas composition is not known), the following simple formula may be used:

$$\eta = 0{,}010\,36 + 0{,}000\,033 \cdot t + 0{,}000\,021 \cdot D + 0{,}000\,000\,17 \cdot D^2 \tag{19}$$

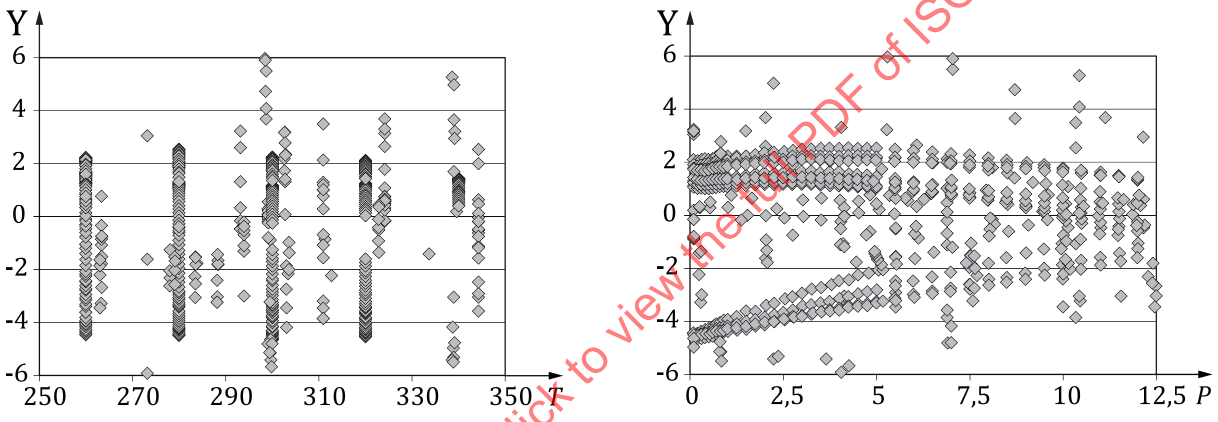
where

t is given in °C

D is given in kg/m^3

η is given in mPa·s

The estimated uncertainty of this method is about 5 % (95 % confidence interval) (Bias = 0,08 %, RMS = 2,57 %). Note that Formula 19 was fitted to the experimental data, so the true uncertainty is actually likely to be greater than 5 %. Figure 2 shows the distribution of the errors for the 721 data points.



a) Y as a function of *T*

b) Y as a function of *P*

Key

T	temperature (K)
P	pressure (MPa)
Y	viscosity equation error (%)

Figure 2 — Comparisons of viscosity calculated from Formula 19 with experimental data

6 Other properties

6.1 Preamble

Other properties, including those listed in this section, are accurately calculated with the GERG-2008 equation of state[1] (as detailed in ISO 20765-2). There are no existing widely used simple methods for these properties (unlike the case above for viscosity), so new formulae were derived. To determine the optimal formulae, a range of simulated natural gases (5 000 compositions) was generated based on the limits, given in Table 1.

Table 1 — Component or property limits

Component or property	Mole fraction %	
	Lower limit	Upper limit
N_2	0,05	7
CO_2	0,01	4
CH_4	80	98
C_2H_6	0,25	9
C_3H_8	0,01	3,5
n-C_4H_{10}	0,001	1
n-C_5H_{12}	0,001	0,2
n-C_6H_{14}	0,001	0,2
i-C_4H_{10}/n-C_4H_{10}	0,45	0,83
i-C_5H_{12}/n-C_5H_{12}	0,83	1,33
neo-C_5H_{12}/n-C_5H_{12}	0,01	0,015
$C_n/C_{n\text{-}1}$	0,2	0,4
Gross CV (MJ/m^3)	35	45

Composition values were generated uniformly for N_2, CO_2, and C_2H_6 within this range; C_3H_8 values were obtained from the ratio limits ($C_n/C_{n\text{-}1}$) with the C_2H_6 value, and likewise for n-C_4H_{10}, n-C_5H_{12}, and n-C_6H_{14} (with ratio limits of C_3H_8, n-C_4H_{10}, or n-C_5H_{12}, respectively). Composition values were then obtained for i-C_4H_{10}, i-C_5H_{12}, and neo-C_5H_{12} from the ratio limits. The CH_4 composition is the remainder, and the mixture was rejected if the CH_4 and CV values (as well as those for C_3H_8, n-C_4H_{10}, n-C_5H_{12}, and n-C_6H_{14} values) were not within their ranges.

The GERG-2008 equation of state[1] was then used to calculate the properties for all the mixtures in a grid of temperatures and pressures over the range of interest. From these calculations it was observed that the compositional variation was less than the temperature and pressure variation, and was within the target uncertainty outlined in the introduction. Therefore, formulae only as a function of T and P were sought (the compositional variation is accounted for in the final overall uncertainty.)

To determine the optimal formula, a bank of terms with powers of T and P (including fractional powers, and positive and negative values) was used with a selection and fitting routine in an Excel Add-In. The final formulae that achieved the desired requirements are very straightforward.

The recommended formulae are given in the following sections, along with a table of values (from the formula), a table of bias errors, and a table of RMS errors (as absolute values and as percent). The RMS may be interpreted as a standard uncertainty (coverage factor k=1).

The bias and RMS (root-mean-squared) errors with respect to the calculation of ISO 20765-2 (GERG-2008 equation of state[1]) are (for any property Y):

$$\text{Bias} = \frac{1}{\text{K}} \sum_{k=1}^{\text{K}} \left(Y_k^{\text{formula}} - Y_k^{\text{gerg}} \right) \tag{20}$$

$$\text{RMS} = \sqrt{\frac{1}{\text{K}} \sum_{k=1}^{\text{K}} \left(Y_k^{\text{formula}} - Y_k^{\text{gerg}} \right)^2} \qquad \text{RMS\%} = 100 \sqrt{\frac{1}{\text{K}} \sum_{k=1}^{\text{K}} \left(\frac{Y_k^{\text{formula}} - Y_k^{\text{gerg}}}{Y_k^{\text{gerg}}} \right)^2} \tag{21}$$

where K is the number of test points (in this case 5 000).

The major contribution to the RMS comes from the compositional variation rather than from the simplicity of the formula.

6.2 Joule-Thomson coefficient, μ

Definition:

$$\mu = \left(\frac{\partial T}{\partial P}\right)_H \tag{22}$$

Formula:

$$\mu = (\ 5{,}94 - 0{,}042 \cdot t) + (-0{,}0177 + 0{,}000\,21 \cdot t) \cdot P^2 \tag{23}$$

where

t is given in $^\circ$C

P is absolute pressure given in MPa

μ is given in K/MPa

The data were fitted in the range 0 °C to 30 °C with absolute pressures to 10 MPa, but as shown in the table below, the extrapolation outside of this range is acceptable.

Table 2 — Joule-Thomson coefficient values and bias errors

P MPa	**Joule-Thomson coefficient value** ***μ*** K/MPa							***P*** MPa	**Bias** K/MPa						
10	4,59	4,38	4,17	3,96	3,75	3,54	3,33	**10**	0,43	0,19	0,08	0,04	0,03	0,03	0,02
8	5,38	5,09	4,81	4,52	4,24	3,95	3,66	**8**	0,06	0,04	0,05	0,07	0,07	0,06	0,03
6	5,99	5,65	5,30	4,96	4,61	4,27	3,93	**6**	-0,18	−0,05	0,03	0,08	0,09	0,07	0,02
4	6,43	6,04	5,66	5,27	4,88	4,50	4,11	**4**	-0,20	−0,04	0,06	0,10	0,10	0,06	−0,01
2	6,69	6,28	5,87	5,46	5,05	4,63	4,22	**2**	-0,12	0,01	0,09	0,11	0,09	0,03	−0,05
***T* (°C)**	**-20**	**−10**	**0**	**10**	**20**	**30**	**40**	***T* (°C)**	**-20**	**−10**	**0**	**10**	**20**	**30**	**40**

Table 3 — Joule-Thomson coefficient RMS and RMS% errors

P MPa	***RMS*** K/MPa							***P*** MPa	**RMS %**						
10	0,44	0,21	0,18	0,19	0,19	0,19	0,19	**10**	10,6	5,2	4,5	5,0	5,4	5,6	5,8
8	0,24	0,28	0,28	0,28	0,27	0,25	0,23	**8**	4,7	5,6	6,1	6,5	6,7	6,6	6,4
6	0,47	0,40	0,37	0,34	0,31	0,28	0,25	**6**	7,2	7,0	7,1	7,2	7,2	7,0	6,5
4	0,54	0,45	0,40	0,37	0,34	0,30	0,26	**4**	7,8	7,3	7,3	7,4	7,3	6,9	6,4
2	0,51	0,44	0,40	0,37	0,33	0,29	0,27	**2**	7,2	7,0	7,1	7,2	6,9	6,4	6,1
***T* (°C)**	**-20**	**−10**	**0**	**10**	**20**	**30**	**40**	***T* (°C)**	**-20**	**−10**	**0**	**10**	**20**	**30**	**40**

6.3 Isentropic exponent, κ

Definition:

$$\kappa = -\frac{V}{P}\left(\frac{\partial P}{\partial V}\right)_S \tag{24}$$

Formula:

$$\kappa = (1{,}302\,8 - 0{,}000\,579\,4 \cdot t) + (-0{,}008\,437 + 0{,}000\,265\,8 \cdot t) \cdot P + (0{,}003\,267 - 0{,}000\,055\,17 \cdot t) \cdot P^2$$
(25)

where

t is given in °C

P is absolute pressure given in MPa

κ is dimensionless

The data were fitted in the range 0 °C to 20 °C with absolute pressures to 7,5 MPa, but as shown in the table below, the extrapolation outside of this range is acceptable.

Table 4 — Isentropic exponent values and bias errors

P MPa	Isentropic exponent value							Bias						
10	1,614	1,580	1,545	1,511	1,476	1,442	1,408	−0,224	−0,107	−0,055	−0,033	−0,027	−0,032	−0,042
8	1,484	1,464	1,444	1,425	1,405	1,385	1,365	−,058	−0,024	−0,010	−0,005	−0,007	−0,011	−0,018
6	1,389	1,379	1,370	1,360	1,350	1,341	1,331	−,003	0,001	0,002	0,002	0,000	−0,003	−0,005
4	1,329	1,325	1,321	1,317	1,313	1,309	1,305	0,002	0,001	0,000	−0,001	−0,001	−0,001	0,000
2	1,304	1,302	1,299	1,296	1,294	1,291	1,288	−,001	−0,002	−0,002	−0,002	−0,002	−0,001	0,000
***T* (°C)**	**-20**	**−10**	**0**	**10**	**20**	**30**	**40**	**-20**	**−10**	**0**	**10**	**20**	**30**	**40**

Table 5 — Isentropic exponent RMS and RMS% errors

P MPa	RMS							RMS %						
10	0,250	0,119	0,060	0,034	0,027	0,032	0,043	12,9	6,9	3,7	2,2	1,8	2,2	2,9
8	0,062	0,025	0,010	0,009	0,012	0,016	0,022	4,0	1,7	0,7	0,6	0,8	1,1	1,6
6	0,010	0,012	0,013	0,014	0,014	0,014	0,015	0,7	0,9	1,0	1,0	1,0	1,1	1,1
4	0,015	0,015	0,015	0,015	0,014	0,014	0,014	1,1	1,1	1,1	1,1	1,1	1,1	1,1
2	0,013	0,013	0,013	0,013	0,013	0,013	0,013	1,0	1,0	1,0	1,0	1,0	1,0	1,0
***T* (°C)**	**-20**	**−10**	**0**	**10**	**20**	**30**	**40**	**-20**	**−10**	**0**	**10**	**20**	**30**	**40**

6.4 Speed of sound, W

Definition:

$$W = \sqrt{\frac{1}{M}\left(\frac{\partial P}{\partial \rho}\right)_S} \tag{26}$$

Formula:

$$W = \sqrt{\frac{\kappa \cdot P \cdot 10^6}{D}} \tag{27}$$

where

P is absolute pressure given in MPa

D is mass density given in kg/m^3

W is speed of sound given in m/s

In Formula (27), κ is calculated from Formula 25 and D is calculated using the GERG-2008 equation of state[1] (see ISO 20765-2).

The RMS values shown below were obtained from comparisons between values calculated with Formula (27) and the input data described at the beginning of this clause.

Table 6 — Speed of Sound RMS% errors

P MPa	RMS %						
10	6,75	3,51	1,86	1,11	0,91	1,09	1,48
8	2,02	0,84	0,36	0,32	0,42	0,57	0,79
6	0,34	0,43	0,48	0,51	0,52	0,54	0,57
4	0,57	0,56	0,56	0,55	0,55	0,54	0,54
2	0,50	0,50	0,50	0,50	0,49	0,49	0,49
T (°C)	**-20**	**−10**	**0**	**10**	**20**	**30**	**40**

7 Example calculations

As an aid in computer implementation, calculated values of properties from the formulae given here, and for the density calculated with the GERG-2008 equation of state[1], are given below. The number of digits displayed does not indicate the accuracy in the values but are given for validation of computer code.

The following natural gas mixture (with component mole fractions in percent, given below) was selected for those properties requiring density, and thus a composition for calculation:

Table 7 — Example natural gas composition

CH_4	N_2	CO_2	C_2H_6	C_3H_8	n-C_4H_{10}	i-C_4H_{10}	n-C_5H_{12}	i-C_5H_{12}	n-C_6H_{14}
89,21	1,69	1,43	5,67	1,43	0,25	0,18	0,04	0,05	0,05

With this gas as the input, calculated values of the density from the GERG-2008 equation of state and from the formulae presented in this standard are given below:

Table 8 — Example calculations inputs and results

T K	P MPa	D kg/m^3	ρ mol/dm^3	η mPa·s	η mPa·s	μ K/MPa	κ -	W m/s
		GERG-2008	GERG-2008	Formula 9	Formula 19	Formula 23	Formula 25	Formula 27
280	5	44,810 41	2,474 665	0,011 596	0,011 868	5,245 763	1,337 977	386,384 6
280	10	103,162 8	5,697 187	0,014 384	0,014 562	4,026 150	1,521 577	384,047 9
320	5	36,894 7	2,037 518	0,012 596	0,012 912	3,775 763	1,312 791	421,794 4
320	10	79,026 48	4,364 254	0,014 253	0,014 627	3,186 150	1,384 041	418,493 0

Values shown for the speed of sound are not typical values for any gas composition, but only for that specified here.

8 Conclusions

Formulae are given that are simple to implement, but accurate enough to be useful in certain applications (especially for high pressure orifice plate metering) for natural gas in the temperature range −20 °C to 40 °C, with pressures up to 10 MPa. The formulae should be easy to implement in a flow computer.

9 Reporting of results

Results for the thermodynamic properties shall be given with the number of significant figures that are appropriate for the uncertainties.

Annex A
(informative)

Symbols and units

Symbol	Meaning	Units	
C	discharge coefficient	[-]	
d	orifice diameter	[m]	
d_P	pipe (inside) diameter	[m]	(used in *Re* and β formulae only)
D	mass density	[kg/m^3]	
H	enthalpy	[kJ/kg]	
M	molar mass	[g/mol]	
P	pressure	[MPa]	(absolute pressure)
q	mass flowrate	[kg/s]	
Re	Reynolds number $(4 \cdot q)/(\pi \cdot \eta \cdot d_P)$	[-]	
S	entropy	[kJ/(kg-K)]	
T	temperature	[K]	(absolute temperature)
t	temperature	[˚C]	
V	molar specific volume $(=1/\rho)$	[dm^3/mol]	
W	speed of sound	[m/s]	
x	mole fraction	[mol/mol]	
β	diameter ratio $(=d/d_P)$	[-]	
Δp	differential pressure	[Pa]	
ε	expansibility factor	[-]	
η	dynamic viscosity	[mPa·s]	
κ	isentropic exponent	[-]	
μ	Joule-Thomson coefficient	[K/MPa]	
π	$= 3{,}141\,592\,654$		
ρ	molar density	[mol/dm^3]	

Annex B
(informative)

Example LBC viscosity function

```
    Function VisLBC(x() As Single, T As Single, d As Single) As Single
'Inputs:  x - Array with 22 components for the fluids listed below, molar amounts
'         T - Temperature in K
'         d - Density in mol/dm3
'Output:  VisLBC - Viscosity from the Lohrenz-Bray-Clark method, in mPa.s (= cP)
  Dim i As Integer
  Dim sum As Single, Mmix As Single, Tcmix As Single, Pcmix As Single, Vcmix As Single
  Dim Vis As Single, Vis1 As Single, Vis2 As Single, Vismix As Single
  Dim Tr As Single, Dr As Single, alpha As Single, delta As Single, xi As Single
  Dim Dc(22) As Single, Tc(22) As Single, M(22) As Single, Pc(22) As Single
'   Dc (mol/dm3)             Tc (K)            M (g/mol)          Pc (MPa)
  Dc(1) = 10.139342719:  Tc(1) = 190.564:  M(1) = 16.04246:   Pc(1) = 4.5992   'CH4
  Dc(2) = 11.1839:       Tc(2) = 126.192:  M(2) = 28.0134:    Pc(2) = 3.3958   'N2
  Dc(3) = 10.624978698:  Tc(3) = 304.1282: M(3) = 44.0095:    Pc(3) = 7.3773   'CO2
  Dc(4) = 6.87085454:    Tc(4) = 305.322:  M(4) = 30.06904:   Pc(4) = 4.8718   'C2H6
  Dc(5) = 5.000043088:   Tc(5) = 369.825:  M(5) = 44.09562:   Pc(5) = 4.24661  'C3H8
  Dc(6) = 3.920016792:   Tc(6) = 425.125:  M(6) = 58.1222:    Pc(6) = 3.79053  'nC4
  Dc(7) = 3.86014294:    Tc(7) = 407.817:  M(7) = 58.1222:    Pc(7) = 3.63729  'iC4
  Dc(8) = 3.215577588:   Tc(8) = 469.7:    M(8) = 72.14878:   Pc(8) = 3.37098  'nC5
  Dc(9) = 3.271:         Tc(9) = 460.35:   M(9) = 72.14878:   Pc(9) = 3.37823  'iC5
  Dc(10) = 2.705877875:  Tc(10) = 507.82:  M(10) = 86.17536:  Pc(10) = 3.04293 'nC6
  Dc(11) = 2.315324434:  Tc(11) = 540.13:  M(11) = 100.20194: Pc(11) = 2.73107 'nC7
  Dc(12) = 2.056404127:  Tc(12) = 569.32:  M(12) = 114.22852: Pc(12) = 2.49781 'nC8
  Dc(13) = 1.81:         Tc(13) = 594.55:  M(13) = 128.2551:  Pc(13) = 2.28198 'nC9
  Dc(14) = 1.64:         Tc(14) = 617.7:   M(14) = 142.28168: Pc(14) = 2.10137 'nC10
  Dc(15) = 14.94:        Tc(15) = 33.19:   M(15) = 2.01588:   Pc(15) = 1.315   'H2
  Dc(16) = 13.63:        Tc(16) = 154.595: M(16) = 31.9988:   Pc(16) = 5.03895 'O2
  Dc(17) = 10.85:        Tc(17) = 132.86:  M(17) = 28.0101:   Pc(17) = 3.49821 'CO
  Dc(18) = 17.87371609:  Tc(18) = 647.096: M(18) = 18.01528:  Pc(18) = 22.064  'H2O
  Dc(19) = 10.19:        Tc(19) = 373.1:   M(19) = 34.08088:  Pc(19) = 8.99873 'H2S
  Dc(20) = 17.399:       Tc(20) = 5.1953:  M(20) = 4.002602:  Pc(20) = 0.22746 'He
  Dc(21) = 13.407429659: Tc(21) = 150.687: M(21) = 39.948:    Pc(21) = 4.85963 'Ar
  Dc(22) = 3.24397:      Tc(22) = 433.75:  M(22) = 72.14878:  Pc(22) = 3.194   'neoC5
  sum = 0: For i = 1 To 22: sum = sum + x(i): Next i
  For i = 1 To 22: x(i) = x(i) / sum: Next i
  Mmix = 0: Tcmix = 0: Pcmix = 0: Vcmix = 0: Vis1 = 0: Vis2 = 0
  For i = 1 To 22
    Mmix = Mmix + x(i) * M(i)                                                  'formula 5
    Tcmix = Tcmix + x(i) * Tc(i)                                               'formula 6
    Pcmix = Pcmix + x(i) * Pc(i)                                               'formula 7
    Vcmix = Vcmix + x(i) / Dc(i)                                               'formula 8
    Tr = T / Tc(i)                                                             'formula 18
    If (Tc(i) < 40) Then
      alpha = (7.08 * Tr + 2.26) ^ 0.72                                        'H2 & He
    Else
      If Tr <= 1.5 Then
        alpha = 3.4 * Tr ^ 0.94                                                'formula 16
      Else
        alpha = 1.778 * (4.58 * Tr - 1.67) ^ 0.625                             'formula 17
      End If
    End If
    Vis = 0.0001 * Sqr(M(i)) * Tc(i) ^ (-1 / 6) * (Pc(i) / 0.101325) ^ (2 / 3) * alpha
'formula 15
    Vis1 = Vis1 + x(i) * Sqr(M(i))                                             'formula 10
    Vis2 = Vis2 + x(i) * Vis * Sqr(M(i))                                       'formula 10
  Next i
  Vismix = Vis2 / Vis1                                                         'formula 10
  xi = 0.0001 * Sqr(Mmix) * Tcmix ^ (-1 / 6) * (Pcmix / 0.101325) ^ (2 / 3)    'formula 11
  Dr = Vcmix * d                                                               'formula 14
  delta = 1.023 + 0.23364 * Dr + 0.58533 * Dr ^ 2 - 0.40758 * Dr ^ 3 + 0.093324 * Dr ^ 4
```