Main Index

North Sea
FLOW
Measurement Workshop

Paper ~~23~~: 4·3

EUROPEAN INTERCOMPARISON OF THE CALIBRATION OF GAS DENSITY METER AND AN INTRODUCTION TO A GUIDELINE TO THE DETERMINATION OF GAS DENSITY

Authors:
Marianne Tambo and Tove Søgaard, The FORCE Institute, Denmark

Organiser:
Norwegian Society of Chartered Engineers
Norwegian Society for Oil and Gas Measurement
Co-organiser:
National Engineering Laboratory, UK

EUROPEAN INTERCOMPARISON OF THE CALIBRATION OF GAS DENSITY METERS AND AN INTRODUCTION TO A GUIDELINE TO THE DETERMINATION OF GAS DENSITY

AUTHORS: Marianne Tambo and Tove Søgaard, The FORCE Institute, Denmark

SUMMARY

For more than 10 years Nordic countries have been producing, selling and/or buying natural gas. One of the major issues has been how to determine the amount of gas. Several of the methods involve the determination of gas density. Two laboratories in the Nordic countries perform calibration of vibrating element gas density meters and an intercomparison was performed as part of a NORDTEST* project between these two laboratories and three European calibration laboratories. The intercomparison was performed in 1996 at the laboratories listed in table 1. The calibration gas was nitrogen. The main conclusion of the intercomparison was that all the laboratories were well within an uncertainty of ± 0,1 % for the calibration of gas density meters with nitrogen, if the same source of nitrogen data was applied.

Table 1: Laboratories participating in the intercomparison

Country	Company
Denmark	The FORCE Institute
Germany	Ruhrgas AG
The Netherlands	NMI
Norway	FIMAS
United Kingdom	Solartron Instruments Ltd.

As another part of the NORDTEST project the applied methods for the determination of gas density on an industrial level in the Nordic countries were gathered and on the basis of this information a guideline for the determination of gas density was set up.

The determination of gas density in the Nordic countries is mainly performed in the natural gas industry and the two methods most commonly applied are 1) the application of a gas density meter with a vibrating element as sensor and 2) the application of the real gas equation. The guideline describes instrumentation, installation, maintenance for these two methods with an emphasis on the methods for the calculation of the uncertainty of the density determination.

---

* NORDTEST was founded in 1973 by the Nordic Council of Ministers to promote viable industrial development, the competetiveness of industry and to remove technical barriers to trade. NORDTEST finances joint research in testing technology and the development of test methods. NORDTEST also funds participation in European and other international standardization work. Each year NORDTEST funds around 200 projects in over 40 institutes and companies with up to 8 million FIM (~ 1 million £).

INTRODUCTION AND BACKGROUND

For over 10 years 4 out of 5 Nordic countries have been producing, selling and/or buying natural gas. One of the major issues has been how to determine the amount of gas. Several of the methods involve the determination of gas density. In the period 1995-1997 a NORDTEST project has been performed with the aim to gather existing applied methods for the determination of gas density in the Nordic countries and on the basis of this information to set up a guideline for the determination of gas density. At the same time an intercomparison on the calibration of vibrating element gas density meters with nitrogen has been carried out.

The project has resulted in three reports:

1) The determination of gas density - part 1 [1]
   State of the art in the Nordic countries

2) The determination of gas density - part 2 [2]
   Intercomparison: Calibration of gas density meters with nitrogen.

3) The determination of gas density - part 3 [3]
   A guideline to the determination of gas density

THE INTERCOMPARISON

The intercomparison was performed with 5 laboratories, see table 2, and on the subject calibration of vibrating element gas density meters. The calibration gas was nitrogen. The full address of the laboratories can be found in annex 1. All laboratories have a long history in calibrating gas density meters for the natural gas industry.

The intercomparison was performed with three Solartron 7812 vibrating element gas density meters as transfer standards. The meters were calibrated with pure nitrogen, 99,998 % or better, at 20 °C in the pressure range 1 MPa to 20 MPa.

Table 2: Laboratories participating in the intercomparison

Country	**Company**
Denmark	The FORCE Institute
Germany	Ruhrgas AG
The Netherlands	NMI
Norway	FIMAS
United Kingdom	Solartron Instruments Ltd.

The transfer standards of the intercomparison

A vibrating element gas density meter consists of a measuring unit and an amplifier unit.

The vibrating element is situated in the measuring unit and is activated at its natural frequency by the amplifier unit. The output signal is a frequency or a periodic time in the range 200 - 900 µseconds. Any change in the natural frequency will represent a density change in the gas that surrounds the vibrating element. As the output of the meter is periodic time the density meter must be calibrated before it can be applied in the industry to determine gas density.

The calibration of a gas density meter normally consists of a pure gas calibration at several points along the meters measuring range at one specific temperature. Following the pure gas calibration the density meters sensitivity to temperature and gas changes are determined. For some types of meters it is also necessary to determine the pressure sensitivity.

The pure gas calibration was the subject of the intercomparison. Information about the determination of the sensitivity of gas density meters to temperature, pressure and gas changes can be found in references [4],[5],[6],[7],[8].

Pure gases normally applied in the calibration of gas density meters are nitrogen, argon and methane. One of the reasons for choosing these gases is the number of aknowledged data on these gases, which have an uncertainty around ± 0,1 % - 0,2 % [9],[10],[11],[12],[13],[14],[15],[16]. The stated uncertainty today of the laboratories participating in this intercomparison is ± 0,10 - 0,15 %, so the above mentioned data sources are one of the main contributors to the uncertainty of the calibration of gas density meters.

The density meter, after calibration, is then furnished with calibration constants which are constants of regression curves that are approximations to the meters function. As an example the density of a Solartron 7812 gas density meter can be approximated with following regression curve:

$$\rho = \mathrm{A}\tau^2 + \mathrm{B}\tau + \mathrm{C} \qquad 1)$$

ρ:density of gas in kg/m^3

τ: periodic time in µseconds

A,B,C : calibration constants

The systematic error, when applying the calibration constants, see equation 1), is always set to be negligible compared to the uncertainty of the density measured in each measurement point of the calibration. This means that it is possible for one meter to have several sets of calibration constants to cover the whole measurement range of the meter.

Type of measurements of the intercomparison

Each laboratory was to perform a check of each meter upon receival of the meters and before shipping the meters to the next laboratory. The check consists of noting the signal of the meters at a vacuum below 1 mbar. The behaviour of the meters could with these checks be held under close surveillance throughout the intercomparison.

Each laboratory was then to perform a nitrogen calibration following their normal calibration procedures for all three meters. The calibrations were to be performed at 20 °C and at minimum 8 measurement points in the range 12 kg/m^3 to 220 kg/m^3.

It was optional whether the laboratories wished to calibrate with increasing pressure or with decreasing pressure or with both as the hysteresis of the gas density meter is known to be very small.

The results were to be sent to the pilot laboratory (the FORCE Institute).

The pilot laboratory was to perform the first and the last series of calibrations.

Data treatment

The data from all the laboratories were treated by the pilot laboratory. Full data treatment can be found in [2].

Several acknowledged data sources for the density of nitrogen exist. In table 3 the density, as predicted from 4 sources at 20 °C, can be seen. The prediction of density differs up to 0,18 %. Wagner & Span[11] was chosen as it was the most recent data source and had a stated uncertainty of ±0,02 % for the density range up to 12 MPa and ± 0,05 % over 12 MPa.

Table 3 Nitrogen density as predicted from different sources, 20 °C

Pressure MPa	L'Air Liquide[12] kg/m^3	IUPAC[10] kg/m^3	NIST[9] kg/m^3	Wagner & Span [11], kg/m^3
1	11,5320	11,5184	11,5191	11,5185
5	57,9056	57,8182	57,8185	57,8139
10	115,0640	114,8535	114,8538	114,8397
20	219,0181	218,6067	218,6054	218,5805
Stated uncert.	±0,1% - 0,2%	±0,1%-0,2%	±0,1%	±0,02%(≤12 MPa) ±0,05%(>12MPa)

The density predicted from each laboratory should be compared to the "true density". As it is not possible to achieve the "true density" it was chosen to compare each of the laboratories density with the density obtained as a mean of all the laboratories values for density. This could of course only be done because the mean deviation between all the measurements was less than 0,03 % and thereby comparable to the repeatability and the stability of the meter.

The results were divided into calibrations where increasing gas pressure(increasing density) was applied and where decreasing gas pressure(density) was applied. Therefore following laboratories are compared:

Increasing pressure: Laboratories: FIMAS, FORCE, NMI and SOLARTRON.

Decreasing pressure: Laboratories: FIMAS, FORCE, NMI and RUHRGAS.

As the results for all three meters showed the same tendencies, here will only be shown the results for one meter. Please refer to the report [2] for full data.

Increasing pressure

The result of the comparison with increasing pressure can be seen for meter No. 120930 in figure 1. The data basis for figure 1 can be seen in table 4. The results showed for all three meters, that all the laboratories have an absolute deviation less than 0,035 % from the mean value above 22 kg/m^3. Three of the laboratories deviate less than 0,035 % from the mean value in the range below 22 kg/m^3.

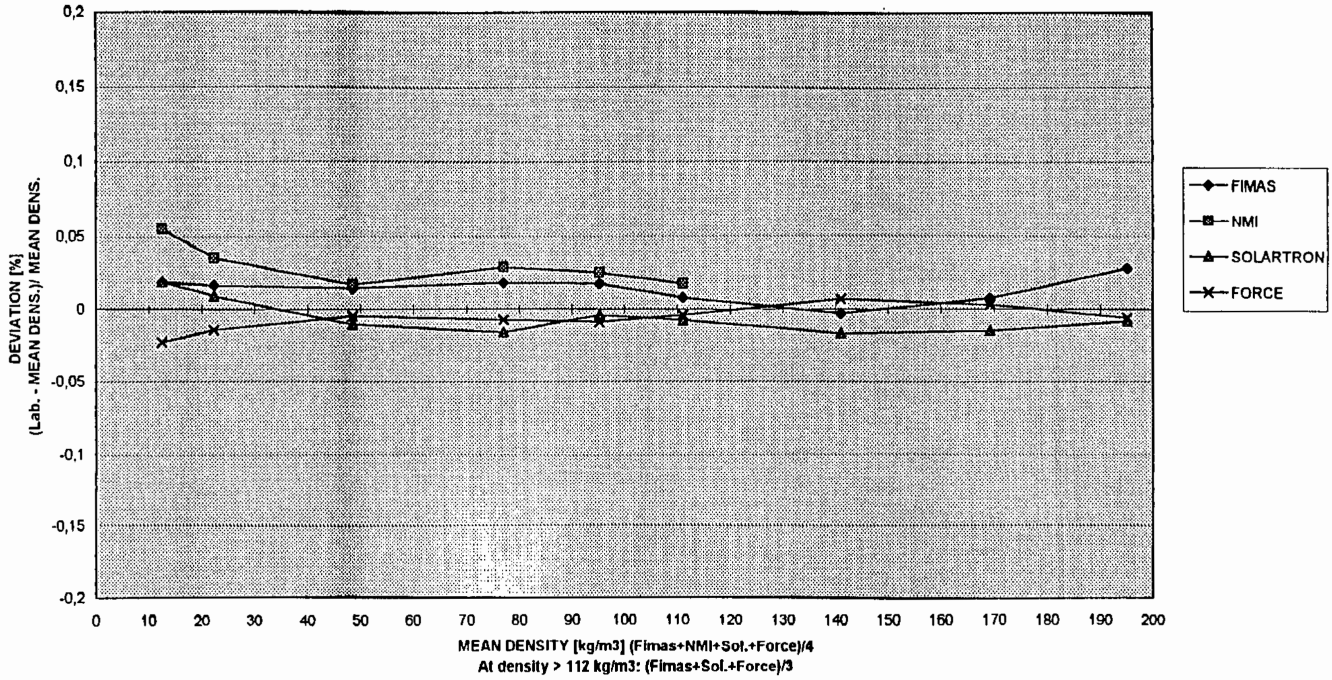

Figure 1: Comparison of the calibrations of the laboratories. Density Meter No. 120930 - Increasing pressure.

Table 4:

Comparison of the calibrations of the laboratories. Density Meter No. 120930 - Increasing pressure.

1 Period microsec.	2 FIMAS Density kg/m3	3 NMI Density kg/m3	4 SOLARTRON Density kg/m3	5 FORCE Density kg/m3	6 **MEAN VALUE** **Density** **kg/m3**	7 FIMAS COL. 2-6/6 Dev. %	8 NMI COL. 3-6/6 Dev. %	9 SOL. COL. 4-6/6 Dev. %	10 FORCE COL. 5-6/6 Dev. %	11 Mean of abs. val. of dev. %	12 s-L %	13 U-l %
530	12,4873	12,4919	12,4873	12,4850	**12,4879**	0,018	0,055	0,018	-0,023	0,029	0,023	0,032
550	22,3131	22,3172	22,3115	22,3096	**22,3128**	0,016	0,034	0,009	-0,015	0,018	0,015	0,021
600	48,5306	48,5320	48,5187	48,5239	**48,5263**	0,014	0,017	-0,011	-0,005	0,012	0,013	0,018
650	77,0476	77,0558	77,0216	77,0340	**77,0398**	0,018	0,028	-0,016	-0,007	0,017	0,019	0,028
680	95,2831	95,2905	95,2627	95,2669	**95,2758**	0,017	0,025	-0,004	-0,009	0,014	0,014	0,020
705	111,1148	111,1251	111,0976	111,1063	**111,1110**	0,008	0,017	-0,008	-0,004	0,009	0,010	0,015
750	141,0613		141,0419	141,0659	**141,0564**	-0,003		-0,017	0,007	0,009	0,009	0,013
790	169,2724		169,2345	169,2601	**169,2557**	0,007		-0,015	0,003	0,008	0,011	0,016
825	195,1901		195,1195	195,1362	**195,1486**	0,028		-0,009	-0,006	0,014	0,019	0,027

CONSTANTS FOR REGRESSSION CURVES (Density = Period*A*A +Period*B + C):

	Nom. Range micro sec.		A	B	C
FIMAS	525-565		-108,6503717	-0,02461343	0,0004776888
	565-654		-114,7926843	-0,00299635	0,0004586697
	654-718		-115,0226488	-0,00323459	0,0004595702
	718-834		-109,5679945	-0,01814185	0,0004697523
NMI	528-574		-110,5676202	-0,01747283	0,0004710576
	574-617		-117,1364620	0,00481016	0,0004521733
	617-656		-124,7530588	0,02821584	0,0004342452
	656-711		-116,6549303	0,00139393	0,0004563097
SOLARTRON	524-600		-110,7913963	-0,01660134	0,0004701937
	600-688		-108,3717026	-0,02335322	0,0004747287
	688-831		-113,0017110	-0,00883064	0,0004634072
FORCE	528-574		-109,4027523	-0,02177443	0,0004750025
	574-616		-115,8077855	0,00040992	0,0004557938
	616-710		-110,5563744	-0,01648012	0,0004693550
	710-855		-115,3312565	-0,00274967	0,0004594834

COL.: Column
s-L: Estimate for the between laboratory variance. See [17]
U-l: The uncertainty as evaluted from the inter-comparison results. U-l = Rep./2.
Rep.: reproducibility limit[17]

Fil : Table-4.nsf

Decreasing pressure
The result of the comparison with decreasing pressure can be seen in figure 2, see page 9. The data basis for figure 2 can be seen in table 5, see page 10. The results for all three meters showed that all the laboratories deviate less than 0,030 % from the mean value in the whole range.

Uncertainty of the calibration of gas density meters evaluated from the results of the intercomparison.

The major aim of the intercomparison was to evaluate, if possible, the level of uncertainty of the calibration of gas density meters with nitrogen for the laboratories participating.

The uncertainty is a combination of the uncertainty of the data source plus the uncertainty of all the measured parameters of the laboratories. When applying the same data source the deviations between the laboratories are solely an expression of the differences in the measured parameters (pressure, temperature and periodic time) and the quality of the calibration gas.

An estimate for the uncertainty, U_I, for the results (the uncertainty of the data source not included) can be set up in a number of ways. The estimation of the uncertainty is here based on the reproducibility limit, Rep., of a standard measurement method, as calculated from ISO standard 5725[17].

Although the intercomparison was not performed to determine the uncertainty of a standard measurement method, the overall principle of calibration of gas density meters can be regarded as a standard method.

We have for the uncertainty:

$$U_I \approx \frac{\text{Rep.}}{2} \qquad 2)$$

The total uncertainty can then be expressed as:

$$U_\rho = \sqrt{U_I^2 + U_T^2} \qquad 3)$$

where

Rep. = reproducibility limit [17]

U_ρ = the uncertainty of the gas density with a 95 % confidence level

U_I = the uncertainty as evaluted from the intercomparison results

U_T = the uncertainty of the source of data for nitrogen density

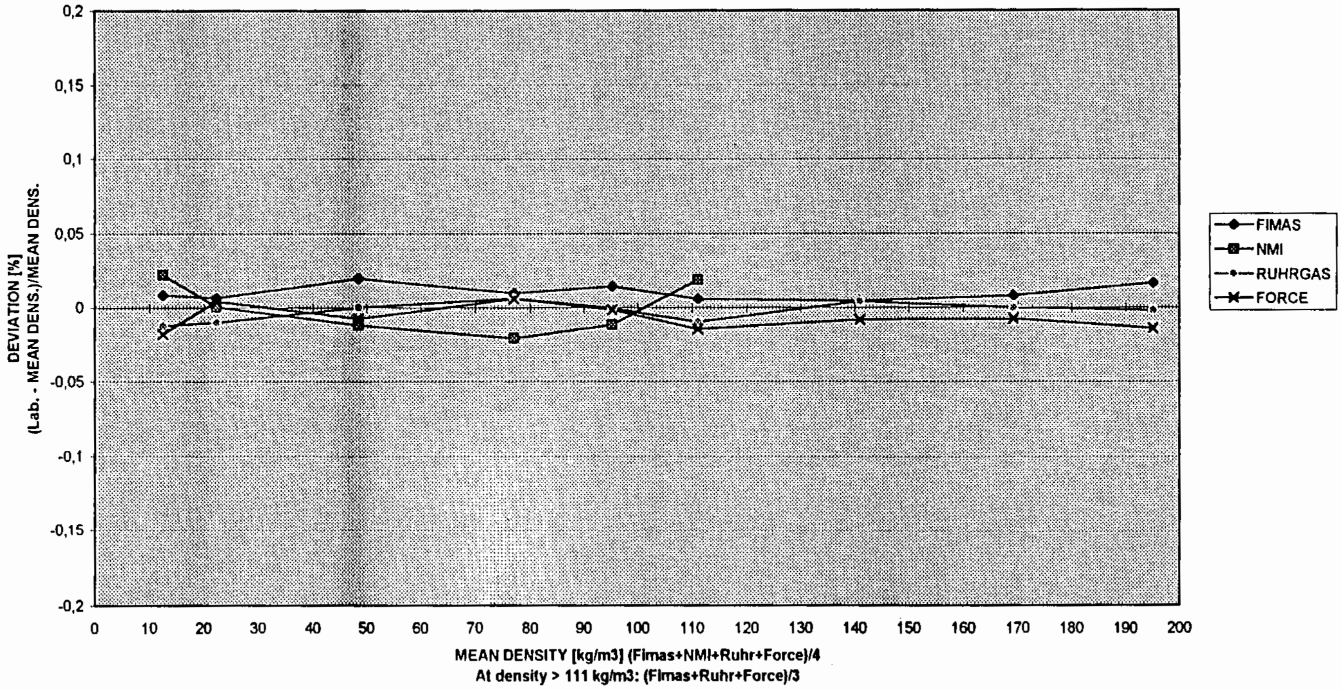

Figure 2: Comparison of the calibrations of the laboratories. Density Meter No. 120930 - Decreasing pressure.

Table 5:

Comparison of the calibrations of the laboratories. Density Meter No. 120930 - Decreasing pressure.

1	2	3	4	5	6	7	8	9	10	11	12	13
	FIMAS	NMI	RUHRGAS	FORCE	**MEAN VALUE**	FIMAS	NMI	RUHRGAS	FORCE	Mean of	s-L	U-I
Period	Density	Density	Density	Density	**Density**	COL. 2-6/6	COL. 3-6/6	COL. 4-6/6	COL. 5-6/6	abs. val.		
microsec.	kg/m3	kg/m3	kg/m3	kg/m3	**kg/m3**	Dev. %	Dev. %	Dev. %	Dev. %	of dev. %	%	%
530	12,4870	12,4887	12,4844	12,4837	**12,4860**	0,008	0,022	-0,012	-0,018	0,015	0,018	0,026
550	22,3113	22,3099	22,3076	22,3108	**22,3099**	0,006	0,000	-0,010	0,004	0,005	0,007	0,011
600	48,5256	48,5101	48,5160	48,5123	**48,5160**	0,020	-0,012	0,000	-0,008	0,010	0,014	0,020
650	77,0387	77,0154	77,0359	77,0356	**77,0314**	0,010	-0,021	0,006	0,005	0,010	0,014	0,020
680	95,2767	95,2520	95,2625	95,2614	**95,2631**	0,014	-0,012	-0,001	-0,002	0,007	0,010	0,015
705	111,1100	111,1246	111,0927	111,0875	**111,1037**	0,006	0,019	-0,010	-0,015	0,012	0,015	0,022
750	141,0541		141,0535	141,0360	**141,0479**	0,004		0,004	-0,008	0,006	0,007	0,011
790	169,2606		169,2458	169,2340	**169,2468**	0,008		-0,001	-0,008	0,005	0,008	0,011
825	195,1874		195,1503	195,1267	**195,1548**	0,017		-0,002	-0,014	0,011	0,016	0,022

	Nom. Range		CONSTANTS	FOR REGRESSSION CURVES (Density = Period*A*A + Period*B + C):	
	micro sec.		A	B	C
FIMAS	525-565		-108,657599	-0,02451566	0,0004775289
	565-654		-114,851556	-0,00275168	0,0004584115
	654-765		-115,602164	-0,00163850	0,0004584624
	688-833		-109,123322	-0,01951826	0,0004707633
NMI	527-573		-109,727263	-0,02039582	0,0004735699
	573-616		-117,786686	0,00745757	0,0004495063
	616-656		-121,911561	0,01941692	0,0004409608
	656-693		-94,982837	-0,06364729	0,0005050065
	693-711		-125,149859	0,02453721	0,0004405729
RUHRGAS	524-551		-107,137338	-0,03010463	0,0004826529
	551-616		-112,625682	-0,01026705	0,0004647274
	616-744		-111,681733	-0,01288908	0,0004664982
	744-831		-108,520102	-0,02044000	0,0004709398
FORCE	528-616		-111,863425	-0,01278293	0,0004667929
	616-789		-112,774780	-0,00957348	0,0004639838
	789-855		-126,308811	0,02393165	0,0004432572

COL.: Column
s-L: Estimate for the between laboratory variance. See [17]
U-l: The uncertainty as evaluted from the inter-comparison results. U-l = Rep./2
Rep.: reproducibility limit[17]

In table 6 can be seen the largest uncertainty, U_ρ, of all the measurement points for all three density meters.

Table 6 Uncertainty of the calibration of gas density meters with nitrogen (95% confidence level) as evaluated from the results of the intercomparison.

	increasing pressure		decreasing pressure	
	1 MPa < p ≤12 MPa	pressures above 12 MPa	1 MPa < p ≤12 MPa	pressures above 12 MPa
U_I	±0,038 %	±0,027 %	±0,030 %	±0,022 %
U_T	±0,020 %	±0,050 %	±0,020 %	±0,050 %
U_ρ	±0,043 %	±0,056 %	±0,036 %	±0,055 %

Conclusion on the intercomparison

From the results of the intercomparison following main conclusions can be made:

- The calibration laboratories have an uncertainty that is less than ± 0,10 % to ± 0,15 % for a pure gas calibration when applying Wagner and Span[11] as the data source. All the laboratories could actually state an uncertainty of ± 0,05 % in the range below 12 MPa and ± 0,06 % above 12 MPa.

- Great care should be taken when choosing the data source for the density of the calibration gas, as this still is one of the major contributors to the uncertainty of the calibration of gas density meters. For calibrations performed with nitrogen the Wagner & Span data source[11] will give the least uncertainty.

THE GUIDELINE

Background

The natural gas industry has been growing steadily and the number of countries applying natural gas is also increasing. There has been a great deal of focus on the uncertainty of the determination of the amount of gas and thereby on the uncertainty of the determination of gas density.

The determination of the density of gas in the Nordic countries is mainly applied in the natural gas industry and here mainly in connection with metering the amount of energy for the purpose of settling accounts.

Natural gas is distributed to and/or from the Nordic countries to Europe and to Russia and to some extent between the Nordic countries themselves.

The vibrating element gas density meter is applied in three of the Nordic countries on an industrial level.

Check-up systems and low pressure systems are based on the determination of gas density by applying the real gas equation.

On the basis of this information a NORDTEST guideline was set up on how to determine gas density on an industrial level with following two methods:

a) applying a gas density meter with a vibrating element as sensor
b) applying the real gas equation.

In the NORDTEST guideline examples of the instrumentation of measuring systems are set up and the uncertainty for these examples is estimated.

ISO (International Organization for Standardization)

During the last 5 years one of the working groups of ISO (The International Organization for Standardization), TC193/SC2/WG1, has been working on a document which covers installation and maintenance of some of the instruments applied in gas measurement, e.g. vibrating element gas density meters, pressure transducers and resistance thermometers. The ISO document is now on a working draft status, ISO/WD 11793[18]. Although it will be a few years before the document is an ISO standard, the document gives good guidelines on many of the issues treated in the NORDTEST guideline and is referred to as often as possible.

Uncertainty calculation

The uncertainty in the NORDTEST guideline is based on BIPM recommendation INC-1(1980) that has resulted in WECC doc. 19-1990: Guidelines for the expression of uncertainty of Measurements in calibrations[19] and Guide to expression of uncertainty of measurement (ISO/TAG4/WG3) [20]. The BIPM recommendation INC-1 can be found in [20] annex A. The calculation of the uncertainty will follow [19] and [20] in general. To avoid large statistical calculations, some assumptions will be made. It is necessary to check if the assumptions are valid for the actual measuring system. If this is not the case [19] and [20] can give guidelines in how to proceed.

Terms such as random and systematic error sources are replaced by terms such as type A and type B uncertainty parameters. Type A parameters kan be measured and thereafter treated statistically. Type B parameters do not have enough documentation to perform a statistical analysis and the uncertainty has to be evaluated from prior knowledge, for example maximum and minimum value.

The uncertainty contributions from the two types of parameters are combined into an expression for the total uncertainty as seen in equation 5). This equation is valid if the parameters, x, are independent (not correlated).

$$\rho = f(x_1, x_2, \ldots, x_N) \qquad 4)$$

$$u_\rho = \sqrt{\sum_{i=1}^{N} \left(\frac{\partial f}{\partial x_i} \right)^2 . \left(u_{\rho\text{-}A}{}^2(x_i) + u_{\rho\text{-}B}{}^2(x_i) \right)} \qquad 5)$$

$$U_\rho = k \cdot u_\rho \qquad 6)$$

U_ρ: expanded uncertainty of the density determination

u_ρ: combined standard uncertainty of the density determination

$u_{\rho\text{-}A}$: the standard uncertainty for parameters of type A

$u_{\rho\text{-}B}$: estimated approximations to the standard uncertainty for parameters of type B

k: coverage factor, for a 95 % confidence level: k=2

x_i: parameter

$\frac{\partial f}{\partial x_i}$: partial derivative here denoted sensitivity coefficient

Principles for determining gas density
The principles in how to determine gas density can be divided into following two groups:

a. on-line/in-line determination - continuous determination

  a.1 continuous measurement of one primary parameter
    - change in gascomposition a secondary effect

  a.2 continuous measurement of several primary parameters
    - change in gascomposition a primary effect

b. other determinations - non-continuous determination (often performed in laboratories).

The non continuous (laboratory) gas density determinations have an uncertainty that is less than the continuous density determinations, but the time and training necessary to apply the non-continuous methods do not render them practical for every day use for most industrial purposes. The non continuous methods are mainly applied to establish data from which equations of state can be derived for example for pure gases[21], [11]. Another application is check of continuous measuring systems [22].

Therefore the guideline deals only with the continuous determination.

Relation: $\rho = f(\tau, c, T, p)$
In the last 30 years a great deal of effort has been put into the development of a meter, from which the signal is primarily dependent upon density and only secondarily upon other parameters, such as pressure, temperature and gas composition. The meter is called a vibrating element gas density meter. The principle of this meter and its calibration can be seen on page 3.

In table 7 a list of the common instrumentation of measuring systems that apply gas density meters can be seen.

The guideline goes on to describe installation and maintenance and gives an example of the calculation of the uncertainty of the method.

Table 7: Commen instrumentation, $\rho = f(\tau, c, T, p)$

System	Instrumentation	Comments
a.1-a	density meter thermometer pressure transducer registration equipment	The pressure transducer is mainly included to be able to correct for the changes in gas composition through the determination of the velocity of sound.
a.1-b	density meter thermometer registration equipment	The gas composition is stable* and is measured at upstart.
a.1-c	density meter registration equipment	The gas composition and the temperature is stable* and are measured at upstart.

* The degree of stability that will result in a negligable influence on the density as determined by the density meter will differ depending on the type of density meter and even the density range. The gas composition and the gas temperature should regularily be checked to be sure that the system does remain stable.

The example chosen in the guideline corresponds to a.1-c and gives an uncertainty with a 95 % confidence level of ±0,20 %.

Relation: $\rho = p/(Z\,R_gT)$

The second method that is treated in the guideline is use of the gas density as determined from the real gas equation, equation 7).

$$\rho = \frac{p}{ZR_gT} \qquad 7)$$

ρ = density

p = pressure

T = temperature in Kelvin

Z = compression factor

R_g = gas consant; $R_g = \frac{R}{M}$

R = universal gas constant

M = molar mass

In table 8 can be seen the most common instrumentation when applying the real gas equation.

Table 8: Common Instrumentation, $\rho = p/(Z R_g T)$

System	Instrumentation	Comments
a.2-a	thermometer pressure transducer Z-meter gas analysis equipment-molar composition analysis registration equipment	Z is determined several times an hour. For more information about this meter see ISO WD 11793 [18].
a.2-b	thermometer pressure transducer gas analysis equipment-molar composition analysis registration equipment	The parameters, R_g and Z, can directly be calculated from the gas composition by applying recognized tables, e.g. ISO/DIS 12213 [23] part 2 for natural gas.
a.2-c	thermometer pressure transducer registration equipment	The gascomposition is stable and is measured by an external laboratory regularily. The parameters, R_g and Z, can directly be calculated from the gas composition by applying recognized tables, e.g. ISO/DIS 12213 [23] part 2 for natural gas.

The example chosen in the guideline corresponds to a.2-b and gives an uncertainty with a 95 % confidence level of ±0,23 %.

Acknowledgements
We would like to thank the laboratories for their participation in the intercomparison, especially following people: Mr. Jostein Eide and Mr. Atle Nordrehaug from FIMAS; Mr. Elskamp from NMI; Mr. Boeser and Mr. Boden from Ruhrgas and Mr.Norman Reed, Mr. Simon Wheeler and Mr. Andrew Matthews from Solartron.

We would also like to thank the NORDTEST project evaluation group listed in table 9, for giving support and guidance during the project.

Table 9: The project evaluation group

Country	Company	Name of participants
Denmark	Dangas A/S	Susanne Rasmussen
Denmark	Miljø- og Energiministeriet	Emil Sørensen
Finland	Gasum Oy	Jorma Rintamäki
Norway	Oljedirektoratet	Steinar Fosse
Norway	Statoil	Reidar Sakariassen
Sweden	Sydgas AB	Nils Widing

A special thanks to Dr. Manfred Jaeschke of Ruhrgas AG for commenting on the guideline at a short time notice.

References

1. M. Tambo, Tove Søgaard
   The Determination of gas density, part 1
   State of the art in the Nordic countries
   NORDTEST Technical report NT TECHN REPORT 353, NORDTEST,
   P.O.Box 116, FIN-02151

2. M. Tambo, Tove Søgaard
   The Determination of gas density, part 2
   Intercomparison: Calibration of gas density meters with nitrogen
   NORDTEST Technical report NT TECHN REPORT 354, NORDTEST,
   P.O.Box 116, FIN-02151

3. M. Tambo, Tove Søgaard
   The Determination of gas density, part 3
   A guideline to the determination of gas density
   NORDTEST Technical report NT TECHN REPORT 355, NORDTEST,
   P.O.Box 116, FIN-02151

4. P. Bates.
   Solartron 7812, Gas Density Transducer, Operating Manual.
   Solartron, Farnborough, October 1995.

5. Lars Rosenkilde and Marianne Tambo.
   Calibration and examination of gas density meters.
   1983-06-01, TR-projekt 133/360.81.368, UDC 531.75:662.767
   Dantest(now FORCE Institute).

6. Dr. M. Jaeschke, Dr.-Ing. X.Y. Guo, Dr. Ing.R. Kleinrahm,
   Prof. Dr.-Ing. W. Wagner
   A new accurate method for correcting the vos effect on vibrating gas density transducers
   Proceedings of the Int. Gas Research Conference in Cannes, 1995

7. J.W. Stansfeld.
   A new gas density meter with reduced velocity of sound effect.
   Schlumberger Industries(now Solartron), Transducer Division, Farnborough.

8. Dipl.-Ing- H. M. Hinze and Dr. M. Jaeshcke.
   Messung der dichte von erdgasen nach der wägemethode und mit betriebsdichteaufnehmern.
   VDI Reihe 6 Nr. 162, VDI-Verlag GmbH- Düsseldorf 1985

9. R.T. Jacobsen, et al
   Thermophysical properties of nitrogen from the fusion line to 3500 R (1944 K) for pressures to 150.000 psia (10342 x 10^5 N/m^3)
   NBS(now NIST) - National bureau of Standards, December 1973

10. International Union of Pure and Applied Chemistry, IUPAC.
Nitrogen, International thermodynamic tables of the fluid state-6.
Pergamon Press.

11 . Wagner and R. Span.
Special Equations of State for Methane, Argon and Nitrogen for the Temperature Range from 270 to 350 K at Pressures up to 30 MPa.
International Journal of Thermophysics, Vol. 14, No. 4, July 1993.

12. L'Air Liquide, Division Scientifique.
Encyclopedie des gaz - l'Air Liquide - Azote- N_2.
Elsevier, Amsterdam , 1976

13. R.D.Goodwin
The thermophysical properties of methane, from 90 to 500 K at pressures to 700 bar
NBS - National bureau of Standards (Now NIST), April 1974

14. International Union of Pure and Applied Chemistry, IUPAC.
Methane, International thermodynamic tables of the fluid state - 5.
Pergamon Press.

15. International Union of Pure and Applied Chemistry, IUPAC.
Argon, International thermodynamic tables of the fluid state - 1.
Pergamon Press.

16. A.L. Gosman, R.D. McCarty, J.G. Hust.
Thermodynamic properties of argon- From the triple point to 300 K - At pressures to 1000 Atmospheres.
National Bureau of Standards(now NIST), March 1969.

17. International standard ISO 5725 parts 1,2,3,4 and 6.
Accuracy (trueness and precision) of measurement methods and results.
First edition 1994-12-15, International Organization for Standardization, (Geneva,Switzerland).

18. ISO Working Draft WD 11793
Natural gas - measurement of properties
Density , pressure, temperature and compression factor
ISO/TC193/SC2/WG1

19. Guidelines for the Expression of the Uncertainty of Measurement in Calibrations.
WECC (Western European Calibration Cooperation) Doc. 19-1990

20. Guide to the Expression of Uncertainty in Measurement (TAG 4)
First edition 1993, International Organization for Standardization,
ISBN 92-67-10188-9 Switzerland.

21. N. Pieperbeck, R. Kleinrahm, W.Wagner, M. Jaeschke
Results of (pressure, density, temperature) measurements on methane and on nitrogen in the temperature range from 273.15 K to 323.15 K at pressures up to 12 MPa using a new apparatus for accurate gas-density measurements.
M-2572, J. Chem. Thermodynamics 1991, 23, 175-194.

22. Gerhard Olbricht, Reiner Kleinrahm, Hans-Wilhelm Lösch, Wolfgang Wagner and Manfred Jaeschke
Entwiklung einer Transportablen Prüfeinrichtung für Betriebsdichteaufnehmer in Erdgasmessstrecken
GWF Gas-Erdgas 136 (1995) Nr. 2

23. International standard ISO/DIS 12213, part 1,2 and 3.
Natural gas - Calculation of Compression factor.
1994, International Organization for Standardization, (Geneva,Switzerland).

Annex 1 Address list of the laboratories participating in the intercomparison

FIMAS Calibrationcenter
P. O. Box 23
N-5363 Ågotnes
Norway
Att.: Jostein Eide
Tlf: 47 56 33 54 54
Fax: 47 56 33 46 70

FORCE Institute
Park Allé 345
2605 Brøndby
Denmark
Att.: Marianne Tambo/Tove Søgaard
Tlf.: 45 43 26 70 00
Fax: 45 43 26 70 11

Nederlands Meetinstituut
Hugo de Grootplein 1
Postbus 394
3300 AJ Dordrecht
The Netherlands
Att.: H. Elskamp
Tlf.: 31 78 633 23 32
Fax: 31 78 633 23 09

Ruhrgas Aktiengesellschaft
Betriebsstelle Essen-Altenessen
Gladbecker Strasse 404
D-45326 Essen
Germany
Att.: Hr. Boesen / Mr. Boden
Tlf.: 49 201 1 84 82 72
Fax: 49 201 1 84 83 93

Solartron Transducers
Victoria Road, Farnborough
Hampshire
GU14 7PW England
Att.: Simon Wheeler / Norman Reed
Tlf.: 44 1252 544 433
Fax: 44 1252 547 384

nordtest report

NT TECHN REPORT 355

Approved 1997-06

THE DETERMINATION OF GAS DENSITY - PART 3

A guideline to the determination of gas density

Marianne Tambo
Tove Søgaard

GENERAL

Nordtest was founded in 1973 by the Nordic Council of Ministers and since then Nordtest has been an active member of the international testing community. From the beginning Nordtest's activities have been focused upon development of Nordic test methods and Nordic cooperation concerning testing. However, European aspects have become more and more important for Nordtest, especially after the creation of the European Economic Area and after three Nordic countries becoming members of the European Union. The main part of the work is performed in the five Nordic countries, but there are also projects that involve participation from outside the Nordic countries. The importance of this cooperation is going to increase even more during the coming years. Here the main task is to actively take part in the development of international test methods and standards and ensure that they can be used in Nordic conditions.

As a result of its projects Nordtest is able to offer competence and expertise in the field of technical testing, a large Nordic network of experts, 500 recommended Nordic testing methods and over 350 published technical reports.

OBJECTIVES

Nordtest endeavours

- as the joint Nordic organisation in the field of technical testing, to promote viable industrial development and the international competitiveness of Nordic industry by furthering relevant and cost effective testing and measurement activity in the Nordic countries and by advancing Nordic interests in an international context, particularly within European testing.
- to ensure that the end users receive products which satisfy the requirements concerning safety, resource economy and good environment, and that they can be used under Nordic conditions.
- to remove technical barriers to trade and to ensure that problems which arise due to these are solved effectively, and endeavours to bring about mutual acceptance of test results.

PRINCIPAL AREAS OF OPERATION

Nordtest

- directs and finances joint research in testing technology and the development and implementation of test methods.
- coordinates and promotes Nordic cooperation and division of work in testing and promotes Nordic cooperation in research, testing, certification and standardisation.
- endeavours to bring about Nordic participation in European cooperation.
- functions as an information centre in technical testing in the Nordic countries.

ORGANISATION

The organisation of Nordtest comprises a board, a secretariat and several strategy and expert groups. The task of the strategy groups is to decide the strategic direction within their areas of responsibility. The expert groups are working in specific fields within the areas of responsibility of the strategy groups. Development work in testing technology takes place in the form of projects. The principal tasks of the expert groups are to look for and assign priority to suitable project proposals in their areas, supervise the progression of funded projects and participate in international cooperation. Project work may be multidisciplinary or product specific. The multidisciplinary work is carried out in close cooperation between the strategy and expert groups concerned.

The areas of responsibility of the strategy groups are selected with regard to the existence in theseareas of pronounced development needs in testing technology in relation to industry, end users, European directives, special Nordic conditions or wishes, or Nordic testing infrastructure.

The organisation presently comprises of the strategy groups **Biotechnology and Chemistry, Civil Engineering, Environment, Information Technology and Electronics, Materials Technology** and **Quality Assurance and Metrology** and the expert groups **Building Materials and Construction, Fire, Mechanical Building Services, Safety Critical Systems, Solid Waste, Sound and Vibration** and **Use of Materials.**

NT TECHN REPORT 355

Approved 1997-06

Authors: Marianne Tambo Tove Søgaard	**NORDTEST project number:** 1254-95 **Institution:** FORCE Institute

Title (English): -

Title (Original): THE DETERMINATION OF GAS DENSITY - PART 3: A guideline to the determination of gas density

Abstract:

This guideline is part 3 of the NORDTEST project: The determination of gas density.

NT TECHN REPORT 353
The determination of gas density - part 1
State of the art in the Nordic countries

NT TECHN REPORT 354
The determination of gas density - part 2
Intercomparison: Calibration of gas density meters with nitrogen

NT TECHN REPORT 355
The determination of gas density - part 3
A guideline to the determination of gas density

The guideline describe two measuring systems that determine gas density on an industrial level.

System 1) a gas density meter with a vibrating element as sensor.
System 2) the real gas equation.

The instrumentation, installation and maintenance are described with references to the relevant standards. To enable a common approach to the calculation of the determination of gas density, the guideline explains in general how to determine the uncertainty based on some of the latest principles for uncertainty estimation and illustrates this with some examples on the industrial level.

Technical Group: Strategy Group on Quality and Metrology

ISSN: 0283-7234	**Language:** English	**Pages:** 29
Class (UDC): 53.088	**Key words:** Gas density, Determination, Guideline	
Distributed by: NORDTEST P.O.Box 116 FIN-02151 ESPOO Finland	**Publication code:**	

Table of Contents

1. Introduction

This guideline is part 3 of the NORDTEST project: The determination of gas density.

1) The determination of gas density - part 1
   State of the art in the Nordic countries

2) The determination of gas density - part 2
   Intercomparison: Calibration of gas density meters with nitrogen

3) The determination of gas density - part 3 (this report)
   A guideline to the determination of gas density

The guideline describes two measuring systems that determine gas density on an industrial level including installation and maintenance of the measuring systems. As the uncertainty of the density determination is an important factor when choosing a measuring system and when settling disputes between buyers and sellers, there is given guidelines on how to calculate the uncertainty.

2. Background and aim

Density is defined as the mass of gas divided by its volume at specified conditions of pressure and temperature [1] and is given in kg/m^3. It is a combined parameter that normally is applied to obtain another property for example the mass or the volume. Gas density determination in the natural gas industry can be taken as an example. The end result of measuring systems for natural gas is how much energy has been used by the customer. To achieve this goal the amount of natural gas being consumed must be determined and that is often done by determining the density and the volume flow of the gas and then calculating the mass or the standard volume of the natural gas.

Today there is a need for the determination of gas density at all levels of obtainable uncertainty which can be from 0,02 % to 0,5 % depending on the choise of principle and instrumentation.

As there is a great number of ways to determine gas density, the seller and buyer of the gas product often chooses to measure the gas density with two different methods. This will often result in two different values for the gas density creating a dispute as to the correctness of each value. Although it is common knowledge that each density value has an uncertainty it often causes contractual disputes. The many different approaches to calculating the uncertainty is also cause for confusion.

This guideline will give an overview of the different principles that exist today to determine gas density and will go into details with two of the measuring systems that are applied on an industrial level. To enable a common approach to the calculation of the uncertainty of the determination of gas density, the guideline will continue to explain in general how to determine the uncertainty based on some of the latest principles for uncertainty estimation[4],[5] and will illustrate this with some examples on the industrial level.

2.1 ISO (International Organization for Standardization)

The International Organization for Standardization has a technical committee, TC193, natural gas and in this committee there has been produced several documents that will be referred to in this guideline. The documents have the status of draft international standards(DIS) and working draft standards (WD). During the last 5 years one of the working groups TC193/SC2/WG1 has been working on a document which covers installation and maintenance of some of the instruments that are treated in this guideline, e.g. vibrating element gas density meters, pressure transducers and resistance thermometers. The ISO document is now on a working draft status. Although it will be a few years before the document is an ISO standard the document gives good guidelines on many of the issues in this guideline and is referred to as: ISO WD 11793 [2].

3. Uncertainty calculation

The uncertainty in this guideline will be based on BIPM recommendation INC-1(1980) that has resulted in WECC doc. 19-1990: Guidelines for the expression of uncertainty of Measurements in calibrations[4] and Guide to expression of uncertainty of measurement (ISO/TAG4/WG3) [5]. The BIPM recommendation INC-1 can be found in [5] annex A. The calculation of the uncertainty will follow [4] and [5] in general. To avoid large statistical calculations, some assumptions will be made. It is necessary to check if the assumptions are valid for the actual measuring system. If this is not the case [4] and [5] can give guidelines in how to proceed.

Terms such as random and systematic error sources are replaced by terms such as type A and type B uncertainty parameters. Type A parameters kan be measured and thereafter treated statistically. Type B parameters do not have enough documentation to perform a statistical analysis and the uncertainty has to be evaluated from prior knowledge, for example maximum and minimum value.

The uncertainty contributions from the two types of parameters are combined into an expression for the total uncertainty as seen in equation 2). This equation is valid if the parameters, x_i, are independent (not correlated).

$$\rho = f(x_1, x_2, \ldots, x_N) \qquad 1)$$

$$u_\rho = \sqrt{\sum_{i=1}^{N} \left(\frac{\partial f}{\partial x_i} \right)^2 \left(u_{\rho\text{-}A}{}^2(x_i) + u_{\rho\text{-}B}{}^2(x_i) \right)} \qquad 2)$$

$$U_\rho = k \cdot u_\rho \qquad 3)$$

U_ρ: expanded uncertainty of the density determination

u_ρ: combined standard uncertainty of the density determination

$u_{\rho\text{-}A}$: the standard uncertainty for parameters of type A

$u_{\rho\text{-}B}$: estimated approximations to the standard uncertainty for parameters of type B

k: coverage factor, for a 95 % confidence level: k=2

x_i: parameter

$\frac{\partial f}{\partial x_i}$: partial derivative here denoted sensitivity coefficient

4. Principles for determining gas density

The principles in how to determine gas density can be divided into following two groups:

a. on-line/in-line determination - continuous determination

a.1 continuous measurement of one primary parameter
  - change in gascomposition a secondary effect

a.2 continuous measurement of several primary parameters
  - change in gascomposition a primary effect

b. other determinations - non-continuous determination (often performed in laboratories).

In table 1 can be seen some of the relations that apply for the determination of gas density.

Table 1: Fundamental relations

No.	Relation	Group	Common uncertainty level, %
1	$\rho_{(p,T)} = f(\tau, c, T, p)$	a1	0,1 - 0,5
2	$\rho_{(p,T)} = \frac{p}{Z(p,T) R_g \ T}$	a2	0,1 - 0,5
3	$\rho_{(p,T)} = \frac{m}{V_{(p,T)}}$	b	0,05 - 0,1
4	$\rho_{(p,T)} = \frac{\Delta F / g}{V_{S(p,T)}}$	b	0,02-0,05

As to be expected the non continuous (laboratory) gas density determinations have an uncertainty that is less than the continuous density determinations, but the time and training necessary to apply the non-continuous methods do not render them practical for every day use for most industrial purposes. The non continuous methods are mainly applied to establish data from which equations of state can be derived for example for pure gases[6], [7]. Another appliance is check of continuous measuring systems [8].

Therefore this guideline will in the following deal only with the continuous determinations.

5. $\rho = f(\tau, c, T, p)$

In the last 30 years a great deal of effort has been put into the development of a meter, from which the signal is primarily dependent upon density and only secondarily upon other parameters, such as pressure, temperature and gas composition. The meter is called a vibrating element gas density meter.

A vibrating element gas density meter consists of a measuring unit and an amplifier unit. The vibrating element is situated in the measuring unit and is activated at its natural frequency by the amplifier unit. The output signal is a frequency or a periodic time in the range 200 - 900 µseconds. Any change in the natural frequency will represent a density change in the gas that surrounds the vibrating element.

The relation between the density and the periodic time of the meter is obtained through calibration of the meter with a pure gas at one temperature and at several points along the meters measuring range. The calibration results (τ,ρ) are then fitted with a regression curve. The form of the regression curve varies from manufacturer to manufacturer and in equation 4) can be seen one type of curve. Corrections can be necessary to compensate for the differences between calibration conditions and actual conditions (e.g. different temperature and variation in gas composition). The correction for gas composition can be estimated from the velocity of sound in the actual gas as compared to the calibration gas. The manufacturer and the calibration laboratories will be able to furnish certificates that have the corrections incorporated or equations that can calculate the size of the corrections.

$$\rho = A\tau^2+B\tau+C \qquad 4)$$

ρ: density of gas
τ: periodic time of the density meter
A,B,C: regression curve constants

5.1 Instrumentation and installation, $\rho = f(\tau,c,T,p)$

In principle the density meter is the only instrumentation necessary.

Often the pressure and temperature of a measuring site are regulated so that the deviations allowed only negligably influence the density as predicted by the density meter. The gas density can then be determined only with the gas density meter with a smaller addition to the uncertainty.

In other cases thermometers and pressure transducers are also included in the measuring system. The combinations of equipment listed in table 2 are the most commonly applied.

Table 2: Commen instrumentation, $\rho = f(\tau,c,T,p)$

System	Instrumentation	Comments
a.1-a	density meter thermometer pressure transducer registration equipment	The pressure transducer is mainly included to be able to correct for the changes in gas composition through the determination of the velocity of sound.
a.1-b	density meter thermometer registration equipment	The gas composition is stable* and is measured at upstart.
a.1-c	density meter registration equipment	The gas composition and the temperature is stable* and are measured at upstart.

* The degree of stability that will result in a negligable influence on the density as determined by the density meter will differ depending on the type of density meter and even the density range. The gas composition and the gas temperature should regularily be checked to be sure that the system does remain stable.

A flowcomputer is often applied as the registration equipment as the software in this equipment has been programmed with items such as the calibration constants of the meters. They are also built to register several parameters simultaneously. Some flowcomputers can calculate the velocity of sound based on the measurement of pressure and density and thereby determine the necessary correction to compensate for a variation in gas composition.

Before installation

The density meter must be calibrated before it can be applied to determine gas density. The calibration should be performed by a laboratory with traceability to international standards. The meter is calibrated with a reference gas such as pure nitrogen, argon or methane to obtain the relationsship between the signal of the instrument and the density of gas. The reason for applying these gases is the aknowledged data on these gases, e.g. [7]. The meter will have a characteristic temperature and gas composition offset (the latter is often called the velocity of sound offset). The size of these offsets are characteristic for each type of meter and normally the manufacturer of the meter has developed equations (empirically derived) to determine the size of the corrections. A number of the equations regarding the velocity of sound offset have been verified to be valid for a great number of gases, e.g. [9],[10],[11].

If the average composition of the actual gas is known, common practise is for the manufacturer of the gas density meters to issue an actual gas certificate where the calibration constants are valid for the actual gas. This is done by combining the density as determined by the pure gas calibration with the offset as determined empirically.

Pressure transducers and thermometers require calibration before installation. These sensors are so common that every country has laboratories that perform calibrations of these instruments with documented traceability to international standards.

The registration equipment should be chosen to suit the type of density meter and if relevant the type of pressure transducers and thermometers of the system and should also be checked/calibrated before installation.

Installation

The gas density meters should be installed according to the manufacturers guidelines. ISO WD 11793[2] and [12] gives more specific guidelines on installation, tests to be taken, calibration and verification. Here will be highlighted some of the areas where special care should be taken.

As the meters have to be demounted periodically for repair or recalibration, then the construction of the installation should take this into account.

Gas density meters are normally applied to measure gas density in pipelines and can be installed in several different manors with regard to the pipeline. These are treated in detail in ISO WD 11793[2]. The density meter receives a small sample of the gas continuously.

The flow through the density meter must be kept low enough to ensure that the pressure change from the main line is negligable but fast enough to represent the changes in gas composition.

Regardless of which form of installation is chosen, it is important to know what temperature and pressure the gas in the density meter will obtain. Even small differences from the actual temperature to the assumed temperature can cause large errors. For some natural gases ΔT of 3 K can correspond to an error in density of 1 %. Differences in pressure will have more influence on low pressure systems than high pressure systems

0,1 MPa in a 1 MPa system $\Rightarrow$ $\Delta\rho$ of appr. 10 %.

0,1 MPa in a 10 MPa system $\Rightarrow$ $\Delta\rho$ of appr. 1 %.

If the gas density meter is to be applied in connection with a volume flow meter to determine the amount of gas in kilograms, then great care must be taken to ensure that the gas density meter is installed, so the density at the same temperature and pressure as the volume flow meter can be determined. Often this will require either sufficient insulation of the density meter in connection with the pipeline or measurement of the temperature before and after the density meter. Some density meters have incorporated thermometers and these can be applied but care must be taken, as the thermometers are not directly in the gas but built into the foundation of the meter.

Regarding the pressure, it can be assumed that the pressure in the density meter is close to the pressure in the main pipeline, if the flow through the meter is small. On upstart of the measuring system the manufacturers gives guidelines on how to ensure a small pressure loss. The most efficient way would be to install flowmeters on the density meter outlet. In practise , though, this procedure is only applied to systems, that vent the gas to the atmosphere.

5.2 Maintenance, $\rho = f(\tau, c, T, p)$

The maintenance of a gas density meter is delt with in ISO WD 11793[2].

Shortly it can be said that if the density meter is operating on a gas that is free from dust and condensate and in temperature/pressure domains totally within the gaseous phase, then the meter has known to function well for several years. Even so it is recommended to calibrate the meter at least every 2 years. It is also recommended to set up an internal check (vacuum, air, or (p,T) measurements and the real gas equation) of the meter that can be performed several times a year, without demounting the meter, see [2].

If the meter is operating on gases that are not of above mentioned fine quality the vibrating element will slowly become contaminated and thereby show offsets from its calibration curve or instabilities. The meter will often return to normal after cleansing but it is recommended that a meter be recalibrated after having opened the meter and cleansed the vibrating element.

Taking apart the meter for cleansing should only be performed by welltrained personnel and in specially ventilated surroundings that ensure that no particle will settle on the vibrating element. Usually the laboratories that perform calibrations have rooms with special ventilation systems that ensure this. Manufacturers of the density meters of course also have these facilities.

By comparing the calibrations of the gas density meter (its history) the state of the meter can be determined. Comparisons can only be made if the meter has not been taken apart and cleansed before calibration. Shifts of around 0,10 % from calibration to calibration would indicate a need for demounting and cleansing the meter at least before the next calibration is performed.

Pressure and temperature sensors should be calibrated periodically, the interval depending on the type of instrument, and internal checks once a month are recommended.

The registration equipment should also be checked regularily. How often is dependent upon the type of equipment(6-12 months).

5.3Uncertainty, $\rho = f(\tau, c, T, p)$

In annex 3 the expanded uncertainty, U_ρ, is set up for one type of density meter system. The chosen density meter system has an uncertainty of ± 0,20 %. The uncertainty for other combinations of equipment can be set up by following the guidelines in annex 2 and 3.

6. $\rho = p/(Z R_g T)$

The second method that will be treated is gas density as determined from the real gas equation, equation 5).

$$\rho = \frac{p}{Z R_g T} \qquad 5)$$

ρ = density

p = pressure

T = temperature in Kelvin

Z = compression factor

R_g = gas consant; $R_g = \frac{R}{M}$

R = universal gas constant

M = molar mass

6.1 Instrumentation and installation, $\rho = p/(Z R_g T)$

The instrumentation for this method varies greatly depending upon the desired accuracy.

In table 3 the most common intrumentation combinations are given.

Table 3: Common Instrumentation, $\rho = p/(Z\,R_gT)$

System	Instrumentation	Comments
a.2-a	thermometer pressure transducer Z-meter gas analysis equipment-molar composition analysis registration equipment	Z is determined several times an hour. For more information about this meter see ISO WD 11793 [2].
a.2-b	thermometer pressure transducer gas analysis equipment-molar composition analysis registration equipment	The parameters, R_g and Z, can directly be calculated from the gas composition by applying recognized tables, e.g. ISO/DIS 12213 [1] part 2 for natural gas.
a.2-c	thermometer pressure transducer registration equipment	The gascomposition is stable and is measured by an external laboratory regularily. The parameters, R_g and Z, can directly be calculated from the gas composition by applying recognized tables, e.g. ISO/DIS 12213 [1] part 2 for natural gas.

A flowcomputer is often applied for this registration as the software in this equipment has been programmed with items such as the calibration constants of the meters. They are also built to register several parameters simultaneously.

Before installation

Pressure transducers and thermometers can be obtained for all uncertainty levels. Great care should be taken to purchase the instruments that give the required uncertainty.

Pressure transducers and thermometers require calibration before installation. These sensors are so common that every country has laboratories that perform calibrations of these instruments with documented traceability to international standards.

The registration equipment should be chosen to suit the type of pressure transducers and thermometers of the system and should also be checked/calibrated before installation.

Installation

The equipment should be installed according to the manufacturers guidelines. ISO WD 11793 [2] gives more specific guidelines on pressure transducers of several types and of resistance thermometers. Here will shortly be listed some of the major items.

As the meters have to be demounted periodically for repair or recalibration, then the ease of demounting should be considered when building the installation.

It is important that the temperature and pressure are measured at the point where the density is to be determined. Regarding the temperature measurement the sensor is often placed in a pocket in the system. It is important that the temperature in the pocket actually represents the temperature in the gas line. This can be improved by having speciel thermoconductive oils in the pocket.

The gas analysis equipment usually measures on samples taken from the line and can therefore be placed at a different location than the other equipment. The sampling point should be the spot where the density is wished to be determined. The surroundings should correspond to the manufacturers guidelines. For more details on sampling please refer to ISO/DIS 10715 [13] and for more details on molar composition gas analysis please refer til ISO/DIS 6974 [14]. Most gas analysis equipment has to be calibrated with one or more reference gases [14] but this should be performed after installation of the equipment.

6.2 Maintenance, $\rho = p/(Z\ R_g\ T)$

Pressure and temperature sensors should be calibrated periodically, the interval depending upon the type of instrument, and internal checks once a month are recommended.

The registration equipment should also be checked regularily. How often is dependent upon the type of equipment(6-12 months).

The gas analysis equipment is normally calibrated and adjusted with the reference gas in connection with the daily use and large shifts in the setting of the analysis equipment would indicate a need for more extensive checks.

6.3 Uncertainty, $\rho = p/(Z\ R_g\ T)$

In annex 4 an example of a measuring system is set up. The the expanded uncertainty, U_ρ, has been calculated. The chosen system has an uncertainty of ± 0,23 %. The uncertainty for other combinations of equipment can be set up by following the guidelines in annex 2 and annex 4.

Aknowledgements

The authors would like to thank the NORDTEST project evaluation group listed in table 4, for giving support and guidance during the production of this document.

Table 4: The project evaluation group

Country	Company	Name of participants
Denmark	Dangas A/S	Susanne Rasmussen
Denmark	Miljø- og Energiministeriet	Emil Sørensen
Finland	Gasum Oy	Jorma Rintamäki
Norway	Oljedirektoratet	Steinar Fosse
Norway	Statoil	Reidar Sakariassen
Sweden	Sydgas AB	Nils Widing

We would also like to thank Dr. Manfred Jaeschke of Ruhrgas AG for commenting the document at a short time notice.

References

[1] International standard ISO/DIS 12213, part 1,2 and 3.
Natural gas - Calculation of Compression factor.
1994, International Organization for Standardization, (Geneva,Switzerland).

[2] ISO Working Draft WD 11793
Natural gas - measurement of properties
Density , pressure, temperature and compression factor
ISO/TC193/SC2/WG1.

[3] International vocabulary of basic and general terms in metrology (VIM).
Second edition 1993, International Organization for Standardization,
(Geneva,Switzerland).

[4] Guidelines for the Expression of the Uncertainty of Measurement in Calibrations.
WECC (Western European Calibration Cooperation) Doc. 19-1990.

[5] Guide to the Expression of Uncertainty in Measurement (TAG 4)
First edition 1993, International Organization for Standardization,
ISBN 92-67-10188-9 Switzerland.

[6] N. Pieperbeck, R. Kleinrahm, W.Wagner, M. Jaeschke
Results of (pressure, density, temperature) measurements on methane and on nitrogen in the temperature range from 273.15 K to 323.15 K at pressures up to 12 MPa using a new apparatus for accurate gas-density measurements.
M-2572, J. Chem. Thermodynamics 1991, 23, 175-194.

[7] W. Wagner and R. Span.
Special Equations of State for Methane, Argon and Nitrogen for the Temperature Range from 270 to 350 K at Pressures up to 30 MPa.
International Journal of Thermophysics, Vol. 14, No. 4, July 1993.

[8] Gerhard Olbricht, Reiner Kleinrahm, Hans-Wilhelm Lösch, Wolfgang Wagner and Manfred Jaeschke
Entwiklung einer Transportablen Prüfeinrichtung für Betriebsdichteaufnehmer in Erdgasmessstrecken
GWF Gas-Erdgas 136 (1995) Nr. 2

[9] Dipl.-Ing- H. M. Hinze and Dr. M. Jaeshcke.
Messung der dichte von erdgasen nach der wägemethode und mit betriebsdichte-aufnehmern.
VDI Reihe 6 Nr. 162, VDI-Verlag GmbH- Düsseldorf 1985

[10] Dr. M. Jaeschke, Dr.-Ing. X.Y. Guo, Dr. Ing.R. Kleinrahm, Prof. Dr.-Ing. W. Wagner
A new accurate method for correcting the vos effect on vibrating gas density transducers.
Proceedings of the Int. Gas Research Conference in Cannes, 1995

[11] Lars Rosenkilde and Marianne Tambo.
Calibration and examination of gas density meters.
1983-06-01, TR-projekt 133/360.81.368, UDC 531.75:662.767
Dantest(now FORCE Institute).

[12] Petroleum Measurement Manual, Part VII, Density, section 2, Continuous Density Measurement.
The Institute of Petroleum, London, nov. 1983.

[13] International standard ISO/DIS 10715
Natural gas - Sampling guideline
1994, International Organization for Standardization, (Geneva,Switzerland).

[14] International standard ISO/DIS 6974 part V.
Natural gas - Determination of composition with defined uncertainty by gas chromatography - Part 5: Determination of nitrogen, carbon dioxide and hydrogen carbons (C_1 up to C_5 and C_{6+}) for a laboratory and on-line process application.
1995, International Organization for Standardization, (Geneva,Switzerland).

Annex 1
Definitions, symbols and units

For the purpose of this technical report following defintions apply. Whenever possible the reference from where the definition is taken is given.

Related to gas density

Symbol	Name	Definition	Unit
ρ:	density of gas	The mass of gas divided by its volume at specified conditions of pressure and temperature [1].	kg/m^3
τ:	periodic time	The signal of the density meter [2].	µseconds
Δ:	Deviation	Deviation between two results.	result unit
B:	The barometric pressure	The pressure at atmosfæric conditions	Pa
c:	Velocity of sound	Sound velocity in a gas	m/s
m:	Mass	Mass of gas	kg
F:	Buoyant-force	Force exerted on a sinker[6],[7],[8]	kg m/s
f:	Function	f(x,z)	
g:	acceleration of free fall	Applied in the sinker method[6],[7],[8]	m/s
M:	Molar mass	The mass of one mole of gas	kg/mole
p:	Pressure	The absolute gas pressure	Pa
R:	Universal gas constant	R= 8,314510 J Mol^{-1} K^{-1}[1]	J Mol^{-1} K^{-1}
R_g:	Gas constant	The universal gas constant divided by the molar mass R/M	J kg^{-1} K^{-1}
Z:	Compression factor	$Z_{(p,T)} = Vm_{(p,T)}(\text{real}) / Vm_{(p,T)}(\text{ideal})$, see ref. [1]	-
T:	Temperature	Thermodynamic temperature of the gas[1]	Kelvin
V:	Volume of gas	-	m^3
Vm:	Volume of gas pr. mole	-	m^3
V_S:	Volume of a sinker	The volume of the sinker applied in the sinker-method [6],[7],[8]	m^3

Definitions, symbols and units(continued)

Related to uncertainty

Symbol	Name	Definition	Unit
a_j:	upper/lower bound	[5] half-width of a rectangular distribution of possible values of input quantity x_i	input quantity
c_j:	constant	based on the probablity distribution	-
$\frac{\partial f}{\partial x}$:	sensitivity coefficient	partial derivative[5]	varies
k:	coverage factor	For a 95 % confidence level: k=2	-
s:	standard deviation	$\sqrt{\left(\sum_{i=1}^{n}\left(x_i-\bar{x}\right)^2/(n-1)\right)}$	unit of property
u:	combined standard uncertainty	an estimated standard deviation that characterizes the dispersion of the values that could reasonably be attributed to the measurand[5]	unit of property
u_A:	standard uncertainty	the standard uncertainty for parameters of type A	unit of property
u_B:	standard uncertainty	estimated approximations to the standard uncertainty for parameters of type B	unit of property
U:	expanded uncertainty	the uncertainty of a property with a 95 % confidence level , see also [5] U=2u	unit of property
x:	parameter	-	varies
z:	parameter	-	varies

Annex 2 Combined standard uncertainty for the output of an instrument

When determining gas density several instruments can be applied.

- pressure transducers
- thermometers
- density meters
- gaschromatographs
- Z-meters

and also various registration equipment such as

- flow computers
- multimeters
- counters

To determine the expanded uncertainty of a measuring system one of the first steps is to estimate the contribution to the uncertainty from each of the instruments applied in the system.

This is done by estimating the combined standard uncertainty for the output, z_i, of each of the possible instruments. The combined standard uncertainty for each of the instruments will consist of uncertainty contributions from type A and type B components. Type A components can be measured and thereafter treated statistically. Type B components do not have enough documentation to perform a statistical analysis and the uncertainty has to be evaluated from prior knowledge, for example maximum and minimum value.

The standard uncertainty of type A components relevant for the output of an instrument are based upon repeated measurements and can be approximated by the experimental standard deviation of the mean output [5] as seen in equation 2.1.

$$u_{Z-A} \approx s(\bar{z}) \qquad 2.1)$$

$$s^2(\bar{z}) = \frac{s^2(z_i)}{n} \qquad 2.2)$$

The standard uncertainty of type B components relevant for the output of an instrument are listed in table 2.1.

Table 2.1 Type B components

No.	Component description	a_j	c_j	$a_j \cdot c_j$
1	Calibration of the instrument			
2	Reading error during calibration			
3	Shift between calibrations			
4	Reading error during measurement			
5	Hysteresis effect			
6	Deviation from calibration conditions			
7	Installation effects.			

a_j: Half-width of a rectangular distribution of possible values of input quantity.
$a = (a_+ - a_-)/2$[5]. Here the input quantity is each component. The component in row 1 is assumed to have a normal distribution but is for simplicity included in the table. The components in row 2-7 are assumed to have a rectangular distribution.

c_j: a constant based on the probability distribution of the value a. [5]
normal distribution: $c_j = 1$.
rectangular distribution: $c_j = 1/\sqrt{3}$

re 1: a_j from the calibration of the instrument is ½ of the uncertainty stated by the calibration laboratory, if the laboratory has stated an uncertainty at a 95 % confidence level.

re 2: a_j from the reading error when working with digital display instruments (registration equipment) can be set to 1/2 of the resolution.
For example: Pressure = 1,0005 MPa; resolution = 0,0001 MPa; a_j = 0,00005 MPa.

re 3: a_j for the shift between calibrations is based upon the knowledge of the history of the instrument. For every calibration (without repairs or adjustments) the new calibration results are compared to the former calibration results. The deviation between the two calibrations represents the shift. If the shift is too large the length of the recalibration period can be shortened and vice versa.
Example: calibration of a Pt-100 resistance thermometer at 20,00 °C

calibration date	1996-03-05	1997-03-05	shift, $2 * a_j$
temperature as determined by the Pt-100.	20,05 °C	20,10 °C	0,05 °C

re 4: see re 2.

re 5: a_j for the hysteresis effect can be determined by the calibration laboratory. The laboratory will perform a calibration in steps from 0 to full span of the instrument and a second calibration from full span to 0 of the instrument. Any difference in the output of the instrument at the same calibration point for the 2 calibrations is an expression for the hysteresis effect and is equal to 2 a_j.

re 6: a_j for the deviation from the calibration conditions can be evaluated by the calibration laboratory or can in some cases be obtained as manufacturer information. In some cases corrections are made and then a_j will be the interval in which the correction might lay. For example: a gas density meter is calibrated at 20 °C with nitrogen and applied in natural gas at 5 °C. The reading of the density meter is corrected with the estimated offsets, resulting from the temperature and gas composition differences. a_j is then the error in the determination of the size of the offsets.

re 7: Installation can in itself cause errors and a_j must in each case be estimated. For example a thermometer placed in a pocket, will never completely obtain the temperature of the gas surrounding the pocket. The installation can though be made so that the error is negligable.

The standard uncertainty of type B components can then be estimated by equation 2.3).

$$u_{Z-B} = \sqrt{\sum\left(a_j \cdot c_j\right)^2} \qquad 2.3)$$

For the instrument the combined standard uncertainty can then be calculated from equation 2.4).

$$u_Z = \sqrt{\left(u_{Z-A}\right)^2 + \left(u_{Z-B}\right)^2} \qquad 2.4)$$

Annex 3 Calculation of the uncertainty of a gas density meter system ρ=f(τ, c,T,p)

The density is here determined using a vibrating element gas density meter.

$$\rho = \rho_{\text{density meter}} \qquad 3.1)$$

$$u_\rho = u_{\rho_{\text{density meter}}} \qquad 3.2)$$

Example

The gas is natural gas at following conditions:
(the natural gas data is taken from an example in [1])

p = 6 MPa

T = 290 K (t = 16,85 °C)

Z = 0,88006

R_g = 0,00049481 MJ/kmol K

ρ = 47,512 kg/m³

The gas composition is as listed in table 3.1

Table 3.1 Gascomposition

Component	Mole fraction	Uncertainty, mole fraction
CH_4	0,965	0,001
C2H6	0,018	0,001
C3H8	0,0045	0,0005
C4H10-i	0,001	0,0003
C4H10-n	0,001	0,0003
C5H12-i	0,0005	0,0001
C5H12-n	0,0003	0,0001
C6+	0,0007	0,0001
N2	0,003	0,001
CO2	0,006	0,001
Total	1	

The measuring system consists of the density meter and its registration equipment (table 2, system a.1-c). To simplify the example the density meter is calibrated with the registration equipment (a flowcomputer). In practise the instruments are calibrated separately and then the influence of the uncertainty of the input/output of the flowcomputer on the gas density should be included in this estimation. This can be done in the same manner as the combined standard uncertainty of the output of each instrument is estimated.

The combined standard uncertainty

$$u_\rho = u_{\rho_{\text{density meter}}} = \sqrt{\left(u_{\rho_{\text{density meter}-A}}\right)^2 + \left(u_{\rho_{\text{density meter}-B}}\right)^2}$$

$$u_\rho = \sqrt{(0,001)^2 + (0,0479)^2} = 0,048\ \text{kg}/\text{m}^3$$

The expanded uncertainty

$U_\rho = 2 \cdot u_\rho = 0,096\ \text{kg}/\text{m}^3$ **at 47,512 kg/m3 (290 K and 6 MPa)**

$U_\rho/\rho \quad = \quad 0,20\ \%$

In the following U_ρ is derived step by step.

The standard uncertainty of type A component is obtained by determining the density (at stable conditions) at the density of 47 kg/m^3 at least 10 times and deriving the standard deviation of the mean.

$$u_{\rho_{\text{density meter}-A}} \approx s\left(\overline{\rho_{\text{density meter}}}\right) = 0,001\ \text{kg}/\text{m}^3$$

The standard uncertainty of type B components

The type B components are listed in table 3.2. Each component is treated as in annex 2.

Table 3.2 Type B components

No.	Component description	a_j kg/m^3	c_j	$a_j \cdot c_j$ kg/m^3
1	Calibration of the instrument	0,047	1	0,047
2	Reading error during calibration	0,0005	$1/\sqrt{3}$	0,00029
3	Shift between calibrations	0,012	$1/\sqrt{3}$	0,0069
4	Reading error during measurement	0,0005	$1/\sqrt{3}$	0,00029
5	Hysteresis effect	0,0047	$1/\sqrt{3}$	0,0027
6	Deviation from calibration conditions	0,0047	$1/\sqrt{3}$	0,0027
7	Installation effects	0,008	$1/\sqrt{3}$	0,0046
$u_{\rho_{\text{density meter}}\text{-B}} = \sqrt{\sum\left(a_j \cdot c_j\right)^2}$				0,0479

re 1 calibration result is given with ± 0,2% with a 95% level of uncertainty ⇒ a = 0,047 kg/m^3. The calibration is performed with nitrogen and an actual gas certificate is issued based on the above listed gas composition and 290 K. The density meter and the flowcomputer is calibrated as a unit. The flowcomputer has been checked/calibrated immediately before the calibration of the meter.

re 2 resolution: 0,001 kg/m^3 ⇒ a = 0,0005 kg/m^3

re 3 the shift between calibrations is in "clean" gases less than 0,05 % ⇒ a = 0,025 % ⇒ a = 0,012 kg/m^3.

re 4 resolution: 0,001 kg/m^3 ⇒ a = 0,0005 kg/m^3

re 5 the density meter has a hysteresis less than 0,02 % ⇒ a = 0,01 % ⇒ a= 0,0047 kg/m^3.

re 6 The density meter has a certificate for 290 K and the gas to be measured upon is at 290 K ± 2 K. The temperature sensitivity of the density meter is less than 0,01%/K⇒ a=0,0047 kg/m^3. Because the gas composition varies very little the influence on the gas density is in this example negligable.

re 7 The difference in the temperature of the gas in the density meter and the gas in the pipeline is 0,1 K which corresponds to a density change of 0,016 kg/m^3 ⇒ a = 0,008 kg/m^3.

Annex 4 Calculation of the uncertainty of a real gas equation system ρ=p/(ZR$_g$T)

The density is here calculated from several measured parameters, see equation 4.1). The uncertainty can be calculated as seen in equation 4.2. This equation is the equation for noncorrelated parameters. It can be applied because the compression factor in most practicle situations can be assumed to be so constant, that the covariances of (p,Z), (T,Z) and (R$_g$,Z) are insignificant, see [5] section F 1.2.1. If the gascomposition, temperature or pressure of a measuring system should vary greatly then the estimation of the uncertainty should include the covariances and in [5] guidance is given on the estimation of these. Equations 4.3 to 4.4 give the sensitivity coefficients and when inserting these into equation 4.2 and dividing on both sides with ρ^2, then the relative uncertainty can be derived as in equation 4.5.

$$\rho = p/(ZR_gT) \qquad 4.1)$$

$$u_\rho^2 = \left(\left(\frac{\partial\rho}{\partial p}\right)^2 u_p^2 + \left(\frac{\partial\rho}{\partial T}\right)^2 u_T^2 + \left(\frac{\partial\rho}{\partial Z}\right)^2 u_Z^2 + \left(\frac{\partial\rho}{\partial R_g}\right)^2 u_{R_g}^2 \right) \qquad 4.2)$$

$$\frac{\partial\rho}{\partial p} = \frac{1}{ZR_gT} \qquad \frac{\partial\rho}{\partial T} = -\frac{p}{ZR_gT^2} \qquad 4.3)$$

$$\frac{\partial\rho}{\partial R_g} = -\frac{p}{ZR_g^2T} \qquad \frac{\partial\rho}{\partial Z} = -\frac{p}{Z^2R_gT} \qquad 4.4)$$

$$\frac{u_\rho^2}{\rho^2} = \left(\left(\frac{u_p}{p}\right)^2 + \left(\frac{u_T}{T}\right)^2 + \left(\frac{u_Z}{Z}\right)^2 + \left(\frac{u_{R_g}}{R_g}\right)^2 \right) \qquad 4.5)$$

Example

The gas is natural gas at following conditions:
(the natural gas data is taken from an example in [1])

$p = 6$ MPa
$T = 290$ K ($t = 16{,}85$ °C)

$Z = 0{,}88006$

$R_g = 0{,}00049481$ MJ/kmol K

$\rho = 47{,}512$ kg/m^3

The gas composition is as listed in table 4.1

Table 4.1 Gas composition

Component	Mole fraction	Uncertainty, mole fraction
CH_4	0,965	0,001
C2H6	0,018	0,001
C3H8	0,0045	0,0005
C4H10-i	0,001	0,0003
C4H10-n	0,001	0,0003
C5H12-i	0,0005	0,0001
C5H12-n	0,0003	0,0001
C6+	0,0007	0,0001
N2	0,003	0,001
CO2	0,006	0,001
Total	1	

The measuring system consists of the instruments seen in table 4.2

Table 4.2 Measuring system

Instruments
Absolute pressure transducer
Pt-100 resistance thermometer
Flowcomputer
Gas chromatograph

To simplify the example the instruments are calibrated with the registration equipment (a flowcomputer). In practise the instruments are calibrated separately and then the influence of the uncertainty of the input/output of the flowcomputer on the output of each instrument should be estimated. This can be done in the same manner as the uncertainty of the output of each instrument is estimated.

The combined standard uncertainty

$$\frac{u_\rho^2}{\rho^2} = \left(\left(\frac{u_p}{p}\right)^2 + \left(\frac{u_T}{T}\right)^2 + \left(\frac{u_Z}{Z}\right)^2 + \left(\frac{u_{R_g}}{R_g}\right)^2 \right)$$

$$\frac{u_\rho}{\rho} = \sqrt{\left(2{,}7\cdot 10^{-4}\right)^2 + \left(3{,}2\cdot 10^{-4}\right)^2 + \left(7{,}6\cdot 10^{-4}\right)^2 + \left(7{,}5\cdot 10^{-4}\right)^2} = 11{,}5\cdot 10^{-4}$$

(the relative uncertainties of the parameters are derived in the following)

$$u_\rho = 47{,}512\cdot 11{,}5\cdot 10^{-4} = 0{,}055\ \mathrm{kg/m^3}$$

The expanded uncertainty

$U_\rho = 2\cdot u_\rho = 0{,}11\ \mathrm{kg/m^3}$ **at 47,512 kg/m3 (290 K and 6 MPa)**

$U_\rho/\rho \quad = \quad 0{,}23\ \%$

In the following the relative combined standard uncertainties of the parameters are derived step by step.

u_p/p

$$u_p = \sqrt{\left(u_{p-A}\right)^2 + \left(u_{p-B}\right)^2}$$

The standard uncertainty of type A component is obtained by determining the pressure (at stable conditions) at the pressure of 6 MPa at least 10 times and deriving the standard deviation of the mean.

$$u_{p-A} \approx s(\bar{p}) = 1{,}0\ \mathrm{kPa}$$

The standard uncertainty of type B components

Table 4.3 **Type B components u_p**

No.	Component description	a_j kPa	c_j	$a_j \cdot c_j$ kPa
1	Calibration of the instrument	1	1	1
2	Reading error during calibration	0,5	$1/\sqrt{3}$	0,29
3	Shift between calibrations	1,0	$1/\sqrt{3}$	0,58
4	Reading error during measurement	0,5	$1/\sqrt{3}$	0,29
5	Hysteresis effect	0,5	$1/\sqrt{3}$	0,29
6	Deviation from calibration conditions	0,05	$1/\sqrt{3}$	0,03
7	Installation effects	≈ 0	$1/\sqrt{3}$	0
	$u_{p\text{-}B} = \sqrt{\sum \left(a_j \cdot c_j\right)^2}$			1,26

re 1 calibration result is given with the uncertainty of ± 2 kPa at a 95 % confidence level in the range 5-6 MPa ⇒ a= 1 kPa. The transducer and the flowcomputer is calibrated as a unit. The flowcomputer has been checked/calibrated immediately before the calibration of the transducer.

re 2 resolution 1 kPa (0,01 bar) ⇒ a = 0,5 kPa.

re 3 the shift between calibrations is less than 2 kPa ⇒ a = 1 kPa.

re 4 resolution 1 kPa (0,01 bar) ⇒ a = 0,5 kPa.

re 5 the hysteresis is less than 1 kPa ⇒ a = 0,5 kPa.

re 6 the temperature dependency of the transducer is given by the manufacturer to be less than 0,03 kPa / K. The transducer is calibrated at 293,15 K and the gas to be measured upon is at 290 K ⇒ a = 0,05 kPa.

re 7 The installation effects are estimated to be negligable (less than 0,01 kPa).

$$u_p = \sqrt{\left(u_{p\text{-}A}\right)^2 + \left(u_{p\text{-}B}\right)^2}$$

$$u_p = \sqrt{(1,0)^2 + (1,26)^2} = 1,61 \text{ kPa}$$

$$\frac{u_p}{p} = 1,61/6000 = 0,00027$$

u_T/T

$$u_T = \sqrt{(u_{T-A})^2 + (u_{T-B})^2}$$

The standard uncertainty of type A component is obtained by determining the temperature (at around 290 K) at least 10 times and deriving the standard deviation of the mean.

$$u_{T-A} \approx s(\overline{T}) = 0{,}02 \text{ K}$$

The standard uncertainty of type B components

Table 4.4 Type B component; u_T

No.	Component description	a_j K	c_j	$a_j \cdot c_j$ K
1	Calibration of the instrument	0,05	1	0,05
2	Reading error during calibration	0,05	$1/\sqrt{3}$	0,029
3	Shift between calibrations	0,1	$1/\sqrt{3}$	0,058
4	Reading error during measurement	0,05	$1/\sqrt{3}$	0,029
5	Hysteresis effect	≈0	$1/\sqrt{3}$	0
6	Deviation from calibration conditions	≈0	$1/\sqrt{3}$	0
7	Installation effects.	0,05	$1/\sqrt{3}$	0,029
	$u_{T\text{-}B} = \sqrt{\sum (a_j \cdot c_j)^2}$			0,092

re 1	calibration result is given with the uncertainty of ±0,1 K at a 95 % confidence level ⇒ a= 0,05 K. The thermometer and the flowcomputer are calibrated as a unit. The flowcomputer has been checked/calibrated immediately before the calibration of the thermometer.
re 2	resolution 0,1 K ⇒ a= 0,05 K.
re 3	the shift between calibrations is less than 0,2 K ⇒ a= 0,1 K.
re 4	resolution 0,1 K⇒ a= 0,05 K.
re 5	the hysteresis is negligable.
re 6	the thermometer is calibrated at ambient pressure and will be applied in 6 MPa, but the effect of this on the temperature measurement will be negligable.
re 7	the thermometer is situated in a pocket and even with thermal insulation of and thermal conductive oil in the pocket the difference between the temperature of the gas to the temperature measured has prior to upstart been determined to be around 0,1 K ⇒ a= 0,05 K.

$$u_T = \sqrt{(u_{T-A})^2 + (u_{T-B})^2}$$

$$u_T = \sqrt{(0,02)^2 + (0,092)^2} = 0,094\ \text{K}$$

$$\frac{u_T}{T} = 0,094/290 = 0,00032$$

u_Z/Z

Z is calculated from ISO/DIS 12213[1], part 2, applying the molar compositional analysis in table 4.1 obtained with a gaschromatographic analysis that has been performed at the upstart of the measuring system. The variations in gascomposition are very small.

The expanded uncertainty of Z is given in ISO/DIS 12213[1] as being a combination of the expanded uncertainty of the use of the calculation method and of the expanded uncertainty of the gas analysis. Use of the calculation method in this pressure, temperature range gives an uncertainty of ± 0,1 % at a 95 % confidence level. If the expanded uncertainty of the gasanalysis is as given in table 4.1 then according to ISO/DIS 12213[1] the influence of this on the compression factor is less than ± 0,1 %.

$$u_Z = \sqrt{(a_{\text{cal. method}}\ c_{\text{cal. method}})^2 + (a_{\text{analysis}}\ c_{\text{analysis}})^2}$$

$$a_{\text{cal. method}} = 0,05\ \%\ 0,88006 = 0,00044$$

$$c_{\text{cal. method}} = 1$$

$$a_{\text{analysis}} = 0,1\ \%\ 0,88006 = 0,00088$$

$$c_{\text{analysis}} = \frac{1}{\sqrt{3}}$$

$$u_Z = \sqrt{(0,00044)^2 + (0,00051)^2} = 6,7 \cdot 10^{-4}$$

$$\frac{u_Z}{Z} = \frac{6,7 \cdot 10^{-4}}{0,88006} = 7,6 \cdot 10^{-4}$$

u_{Rg}/R_g

R_g is calculated by applying the molar compositional analysis obtained from the gaschromatographic analysis, see table 4.1, that has been performed at the upstart of the measuring system. The expanded uncertainty of the determination is estimated to be ± 0, 13 % and as the variations in gascomposition are very small, no further contribution to the uncertainty of R_g is expected.

$$u_{R_g} = a_{R_g} \cdot c_{R_g}$$

$$a_{R_g} = 0{,}0013 \cdot 0{,}000495 = 6{,}435 \cdot 10^{-7}$$

$$c_{R_g} = \frac{1}{\sqrt{3}}$$

$$u_{R_g} = 3{,}72 \cdot 10^{-7}$$

$$\frac{u_{R_g}}{R_g} = \frac{3{,}72 \cdot 10^{-7}}{0{,}00049481} = 7{,}5 \cdot 10^{-4}$$

TECHNICAL REPORTS FROM THE STRATEGY GROUP ON QUALITY AND METROLOGY

48 Ohlon, R. Comments to the EUROLAB working document on quality systems. Espoo 1994. Nordtest, NT Techn Report 248. 66 p.

51 Steffen, B., Kallio, H. & Þorsteinsson, Freygarður, Editors, Traceable calibration and uncertainty of measurements and tests. Espoo 1994. Nordtest, NT Techn Report 251. 164 p.

52 Guðmundsson, Halldór & Rúnarsson, Tómas P., Traceable calibration and uncertainty of measurements in scanning electron microscopy. Espoo 1994. Nordtest, NT Techn Report 252. 48 p.

53 Lau, P., Pre-study for establishing a facility for calibration of liquid density meters. Borås 1994. Swedish National Testing and Research Institute, Report SP AR 1994:18. 26 p. (in Swedish)

84 Jensen, H. & Nielsen, L., Uncertainty of pH measurements. Espoo 1995. Nordtest, NT Techn Report 284. 22 p.

5 Calibration, Traceability and Uncertainty, Seminar in Espoo 1-2 November 1995. Espoo 1995. Nordtest, NT Techn Report 305. 154 p.

7 Ohlon, R., Schemes related to peer evaluation. Espoo 1995. Nordtest, NT Techn Report 307. 41 p.

8 Thun, R., Aunela-Tapola, L. & Tulenheimo, V., Quality assurance of industrial environmental performance. Espoo 1995. Nordtest, NT Techn Report 308. 71 p.

2 Ohlon, R., Preparation of contributions to development of harmonized standards. Borås 1996. Swedish National Testing and Research Institute, Report SP AR 1996:17. 39 p.

3 Elo, N., Kujala, S., Lindroos, V. & Tiittanen, K., Report format and signing of docments. Espoo 1996. Nordtest, NT Techn Report 323. 21 p.

4 Svensson, T., Digital filtering of data from measurements. Espoo 1996. Nordtest, NT Techn Report 324. 17 p.

2 Forstén, J., The different roles of organizations performing testing. Espoo 1996. Nordtest, NT Techn Report 332. 17 p.

1 Guðmundsson, H., Calibration and uncertainty of XRF measurements in the SEM. Espoo 1997. Nordtest, NT Techn Report 351. 42 p. NT Project No. 1280-96.

2 Rydler, K.-E. & Nilsson, H.,Transparency of national evaluation methods of accreditation in the field of electrical measurements. Espoo 1997. Nordtest, NT Techn Report 352. 61p. NT Project No. 1255-95.

3 Tambo, M. & Søgaard, T., The determination of gas density - part 1: State of the art in the Nordic countries. Espoo 1997. Nordtest, NT Techn Report 353. 19p. NT Project No. 1254-95.

4 Tambo, M. & Søgaard, T., The determination of gas density - part 2: Intercomparison — Calibration of gas density meters with nitrogen. Espoo 1997. Nordtest, NT Techn Report 354. 91 p. NT Project No. 1254-95.

5 Tambo, M. & Søgaard, T., The determination of gas density - part 3: A guideline to determination of gas density. Espoo 1997. Nordtest, NT Techn Report 355. 29 p. NT Project No. 1254-95.

References

[1] Paper presented at the North Sea Flow Measurement Workshop, a workshop arranged by NFOGM & TUV-NEL

Note that this reference was not part of the original paper, but has been added subsequently to make the paper searchable in Google Scholar.