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# "Z/Z-METER", ON-LINE MEASUREMENT OF COMPRESSIBILITY-RATIOS FOR REFERENCE VALUES OF VOLUME AT OPERATIONAL CONDITIONS

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## ABSTRACT

One of the methods to realize reference values for Volume of e.g. Natural Gas at increased pressures is via a calibration under a pressure difference (i.e. with expansion). In such a process, applied since the sixties in the Netherlands [1, 2], the 'un-known' meter or Meter-under-Test (MuT) is compared through expansion with the 'known' meter or Reference Meter (RM) at low-pressure.
In a 'normal' calibration-process the difference in pressure between the two compared meters is relative small and the resulting difference between the compressibility at the Reference Meter $Z_{RM}$ and the compressibility at the Meter-under-Test $Z_{MuT}$ has hardly any effect on the ratio $Z_{RM}/Z_{MuT}$ and can be neglected (the ratio is thus considered to have a value of 1). However, in a calibration under expansion a comparison is made of a gas-flow under significant differential pressure-conditions and one of the most important contributions of uncertainty stems from the real gas constant Z.
So, the ratio $Z_{RM}/Z_{MuT}$ is of importance, rather than the absolute values of the compressibility factor.
The Z/Z-meter is one of the current technical developments at NMi VSL-Flow [3, 4].
The uncertainty contribution in the conventional method of calculation, described e.g. in M-GERG [5, 6] of 1991, is rather high (0,1% for the compressibility factor) and the resulting uncertainty of the $Z_{RM}/Z_{MuT}$ ratio is 0,14%.

Therefore, a method leading to a lower contribution to this source of uncertainty offers advantages.
In the presented approach is the ratio $Z_{RM}/Z_{MuT}$ is considered to be the measurand. The ratio should then be measured more accurately than the one resulting from calculation of the absolute values of the compressibility factor.
As a consequence, the impact of this source of uncertainty is reduced. NMi has developed a device that is able to measure the ratio $Z_{RM}/Z_{MuT}$ directly.

In this paper, the development of a new measuring instrument is described that measures the $Z_1/Z_2$ ratio of gases (at pressures $P_1$ and $P_2$ between 1 and 70 bar) with a maximum uncertainty of 0,03%.
The measuring principle of the Z/Z ratio meter is based upon the accurate measurement of a piston-displacement. The piston is displaced by a controlled gas expansion from high-pressure to a low-pressure condition (or for compression, vice versa) in a measurement cell. The measurement cell with an adjustable volume is mounted inside a high-pressure vessel for an adequate control of temperature and pressure. The cell is constructed as a cylinder-piston combination together with small ball-valve actuators that can be opened and closed to connect or disconnect the chamber of the cell to the surrounding vessel and to fill or empty the system.

During its operation, measurements are taken of the piston-displacement, together with measurements of pressures and temperatures. For the calculation of the ratio $Z_1/Z_2$ basically only the ratio of the cell volumes at pressures $P_1$ and $P_2$ needs to be established.

## INTRODUCTION

Reference values of gas-flow measurements under operational conditions are established in the Netherlands for 30 years now. The initial reference values for the unit of volume of Natural Gas are realized and validated in a System of Basic Verification. After 30 years and many modifications the primary Device of Dynamic Displacement (DDD) is still in operation in Dordrecht. In 2000, a new DDD was built with extended ranges in flow and pressure. After the realization of the "Unit of Volume" a series of boot-strap processes follow that realize higher flow-rates. In expansion-steps flow-rates at higher pressures are realized.

The traceability-chain of high-pressure gas-flow measurements, construed and in operation at NMi VSL covers pressures ranging from atmospheric conditions up to 60 bar, and flow-rates range from 0,1 ml/h (Air) till 2,4 $*10^6$ $m_0^3/h$ (Natural Gas); the unit $m_0^3$ relates to the volume at standard conditions of $0^0$ C and 1,01325 bar.
Disadvantages of the long traceability chain are the increase of uncertainty as the chain is built and the scatter (variations) of the produced reference values. The long chain of realizations offers at the same time calibration-conditions for most situations as encountered in practical measuring applications.
Both effects cannot be avoided in the system, as it exists today.
NMi VSL has started several developments in search of lower uncertainties.
During the realization of reference values in expansion steps, the ratio of the real gas constant $Z_{RM}$ at the Reference Meter (RM) and the value of $Z_{MuT}$ at the Meter-under-Test (MuT) are important.
In this paper NMi VSL presents the development of a new measuring instrument that directly measures the $Z_1/Z_2$ ratio of Natural Gas at pressures between 1 and 75 bar with a maximum relative uncertainty of 0,03%. By simply measuring the displacement of a piston in a vessel in an expansion step, the ratio of $Z_1/Z_2$ can be calculated. During the operation, pressures and temperatures are measured.
The design of the measuring instrument has been based on a careful assessment of uncertainty occurring at the expansion step in the measuring instrument.

In this paper the results of the uncertainty calculations are shown and the working principle of the measuring instrument is explained.

## MATHEMATICAL MODEL OF CALIBRATION WITH AN EXPANSION STEP

### Compressibility factor

The equation of state of an ideal gas is expressed as : $p * V = n * R * T$ (1)
where :

| | |
|---|---|
| n = quantity of matter | [mol] |
| R = universal gas constant | [8,3145 J/mol.K] |
| P = pressure of the gas | [Pa] |
| T = temperature of the gas | [K] |

Real gases do not behave exactly as described by this law. To take this non-ideal behaviour into account, the equation of state of real gases (either as mixture or pure) becomes :

$$p * V = Z * n * R * T \tag{2}$$

The factor Z is called the 'real gas factor', 'super compressibility' or 'compressibility factor'. Its value is represents the non-ideal behaviour of a real gas. As all gases become ideal at zero pressure, Z tends towards unity when the pressure nears zero. Typical values for the compressibility of 'Groningen Natural Gas' at different pressures and temperatures are given.

| | | |
|---|---|---|
| P = 60 bar | T = 313,15 K | Z = 0,916 |
| P = 10 bar | T = 293,15 K | Z = 0,982 |
| P = 1 bar | T = 283,15 K | Z = 0,998 |

This example of calculation shows a deviation from an ideal gas to be :

$$\frac{1 - 0,916}{1} * 100\% = 8,4\%$$

## Mathematical model of calibration with expansion

In Figure 1, the basic scheme is presented for the calibration of a flow-meter over a pressure-difference [7]. The 'un-known' meter or Meter-under-Test (MuT) at high-pressure, is compared via expansion with the 'known' meter or Reference Meter (RM) at low-pressure. A heat exchange unit (H-E) is located between the Meter-under-Test and the Reference Meter in order to keep the temperature constant during the process of calibration.

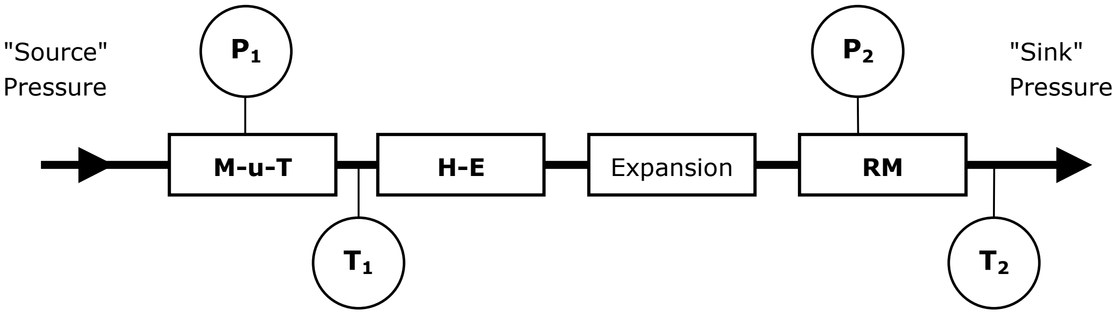

Figure 1, Basic scheme for the calibration process with expansion

It is assumed that calibration takes place under quasi-stationary conditions. This implies that the mass-flow through the system remains constant.
So a mass balance equation can be written.

$$\rho_1 * Q_1 = \rho_2 * Q_2 \tag{3}$$

ρ is the density of gas [kg/m$^3$] and Q the volume flow-rate [m$^3$/s]. The indices 1 and 2 refer to the Meter-under-Test and the Reference Meter, respectively.

The densities are obtained using the state of equation of a real gas.

$$P_i = Z_i * \rho_i * R * T_i \quad (i = 1, 2) \tag{4}$$

Note, that the universal gas constant is expressed in [J/kg.K].
In the calibration with expansion a pressure difference ΔP is created between the Meter-under-Test and the Reference Meter.

$$\Delta P = P_1 - P_2 = P_{MuT} - P_{RM} > 0 \tag{5}$$

The quantity determined in the calibration process, is the relative deviation of the gas-flow meter $e_{MuT}$. The relative deviation $e_{RM}$ of the Reference Meter (or Standard) is determined through calibration of the Standard. Both quantities are defined as a relative difference of the flow-rate indicated by the instrument and the actual flow-rate at the instrument as indicated by the Standard.

$$e_{MuT} = \frac{Q_{MuT}}{Q_1} - 1 \quad \text{and} \quad e_{RM} = \frac{Q_{RM}}{Q_2} - 1 \tag{6}$$

Q is obtained from the number of pulses N collected in the measuring time t and the impulse factor of the meter I [pulses/m$^3$]

$$Q_{MuT} = \frac{N_{MuT}}{I_{MuT} * t_{MuT}} \quad \text{and} \quad Q_{RM} = \frac{N_{RM}}{I_{RM} * t_{RM}} \tag{7}$$

Successive substitutions of the equations (4) till (7) into the mass balance equation leads to the following general expression for the deviation of the Meter-under-Test

$$e_{MuT} = \frac{P_{RM} + \Delta P}{P_{RM}} * \frac{Z_{RM}}{Z_{MuT}} * \frac{N_{MuT}}{N_{RM}} * \frac{I_{RM}}{I_{MuT}} * \frac{t_{RM}}{t_{MuT}} * \frac{T_{RM}}{T_{MuT}} * (1 + e_{RM}) - 1 \tag{8}$$

$\Delta P$ = pressure difference between MuT and RM [Pa] (>0)

The real gas constant or super compressibility factor Z is an important source of uncertainty.
In the traceability chain from Dordrecht to Westerbork three large pressure-steps can be distinguished. As the chain is construed the accumulation of uncertainty is mainly attributed to the real gas constant as a source and contribution of uncertainty.
In the conventional method, the absolute value of the real gas constant is calculated with the M-GERG algorithm [5]. The uncertainty of this algorithm is rather high : 0,1% for the absolute factor of compressibility. Therefore a method leading to a lower contribution to this source of uncertainty is desirable.
The presented equation (8) shows that the compressibility ratio $Z_{RM} / Z_{MuT}$ is of importance. In the followed approach the compressibility ratio is measured directly with a low uncertainty. This is accomplished by controlled expansion of a gas volume from a high-pressure to a low-pressure condition. A closed gas-volume $V_1$ having an initial pressure $P_1$ and an initial temperature $T_1$ expands to a gas-volume $V_2$ with a pressure $P_2$ and a temperature $T_2$. The equation of state of a real gas in both situations is described.

$$P_1\ V_1 = n\ Z_1\ R\ T_1 \tag{9}$$

$$P_2\ V_2 = n\ Z_2\ R\ T_2 \tag{10}$$

The amount (mass) of molecules n remains constant during the expansion-step.

$$\frac{Z_2}{Z_1} = \frac{P_2\ V_2\ T_1}{P_1\ V_1\ T_2} \tag{11}$$

For the calculation of the ratio $Z_2 / Z_1$ basically only the ratio of the cell volumes $V_2$ and $V_1$ at pressures $P_2$ and $P_1$ and temperatures $T_2$ and $T_1$ need to be established.
The basic design of the measuring instrument, the "Z/Z-meter", is a cylinder-piston combination. During the expansion of a gas-volume the piston moves upwards in the cylindrical vessel. The ratio of the cell volumes equals the ratio of the piston heights (h, displacement) in the vessel. Thus the ratio of $Z_2 / Z_1$ is determined by measuring the displacement ($\Delta h$) of the piston with a high-resolution transmitter.

## WORKING PRINCIPLE OF THE Z/Z-METER

### Design criteria of the Z/Z-meter

The design of the Z/Z-meter is being based on the following criteria :

1. The measuring instrument is suitable for Natural Gas;
2. The working range of pressures is between 1 and 70 bar;
3. The operational temperature-range lies between 5 $^0$C and 50 $^0$C.
4. During the expansion the temperature should remain constant, i.e. isothermal expansion;
5. The relative uncertainty of measurement of the compressibility ratio should be lower than 0,03% for all pressure steps within the desired working range of pressures.

The dimensions of the measuring cell, e.g. diameter and length of the cell influence the absolute value of the compressibility ratio and the uncertainty of measurement of this ratio. In order to determine the optimal dimensions a careful uncertainty assessment of the Z/Z measurement should be carried out.

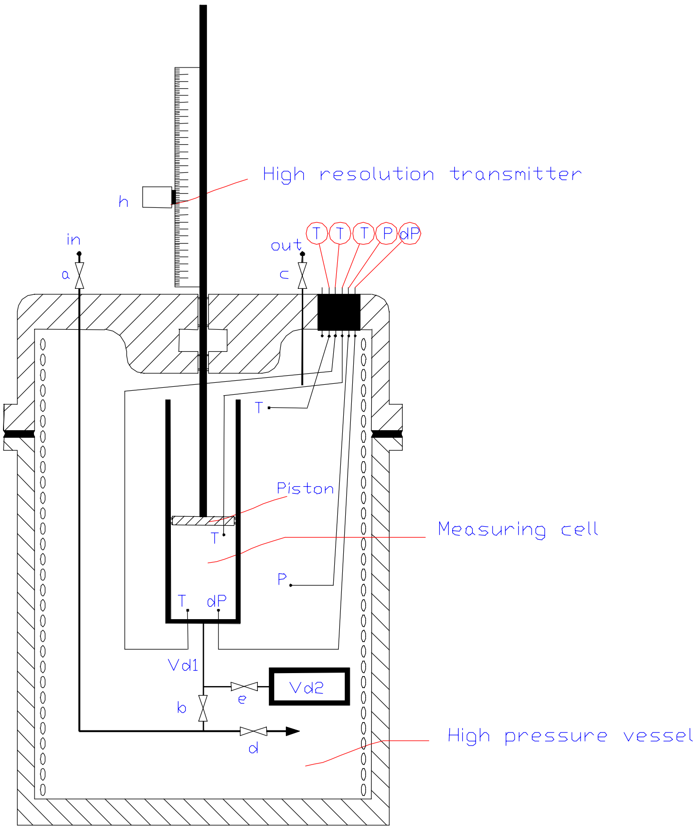

Figure 2, Schematic drawing of the Z/Z-meter

**Working principle of the Z/Z-meter**

A schematic drawing of the Z/Z-meter is presented in Figure 2. The cylinder-piston combination is mounted inside a high-pressure tank for better temperature and pressure control. Small ball-valve actuators are connected to the cylinder that can be opened and closed to fill or empty the system. The high-pressure tank is provided with a heat-exchange unit to ensure temperature equilibrium during the expansion and to test at different temperatures.

Operational sequences

1. Filling of the high-pressure vessel and open measuring cell with gas to the high-pressure condition $P_1$. During the filling process no pressure difference exists over the cell wall. In this way distortion of the cylinder is prevented.
2. Positioning of the piston in the measuring cell. The measuring cell is closed. If temperature equilibrium has been reached, readings of pressure $P_1$ and temperature $T_1$ will be taken.
3. Expansion. Gas is released from the vessel until it reaches the final pressure at lower $P_2$. The measuring cell volume will expand until $P = P_2$ and the piston moves upwards to the final height $h_2$.

The piston in the measuring cell is controlled by a servo system. The prototype control system has already been tested.

Because the pressure difference between both sides of the piston is controlled to zero, the leakage along the piston tends to be zero.

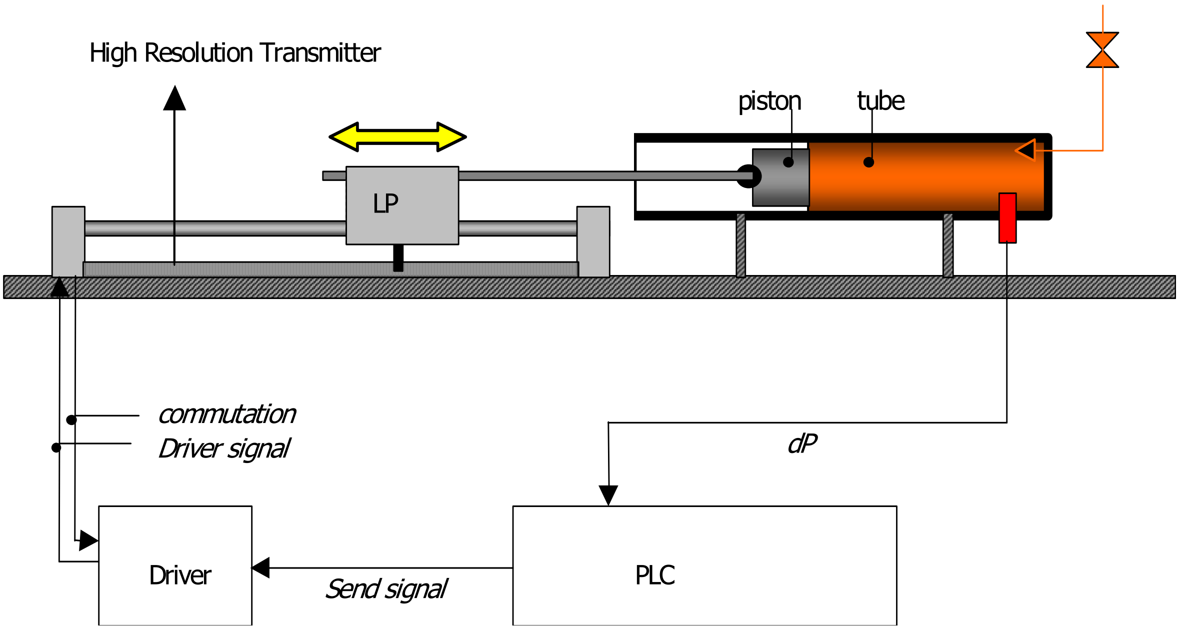

Figure 3, Prototype setup of the control system
PLC = Programmable Logic Controller, LP = Linear Positioning unit

The low differential pressure gauge measures the pressure difference dP between both sides of the piston, which is between the outside area and inside the measuring cell. The desired value of dP is set to zero. Simplified, the system can be illustrated as in Figure 4.

"Hr" represents the servo-position system that moves the piston in the measuring cell to a certain height "h". "Hs" symbolizes the physical process that causes the relation between the piston height (h) and the pressure in the cell. The pressure difference (dP) over the piston is measured with a low differential pressure sensor and dP is the feedback to the input for comparison with the set value. The system controls the process until the set value (input) equals the output signal from the differential pressure sensor. When input and output are equal, the motor will stop and the piston will be at its final height.

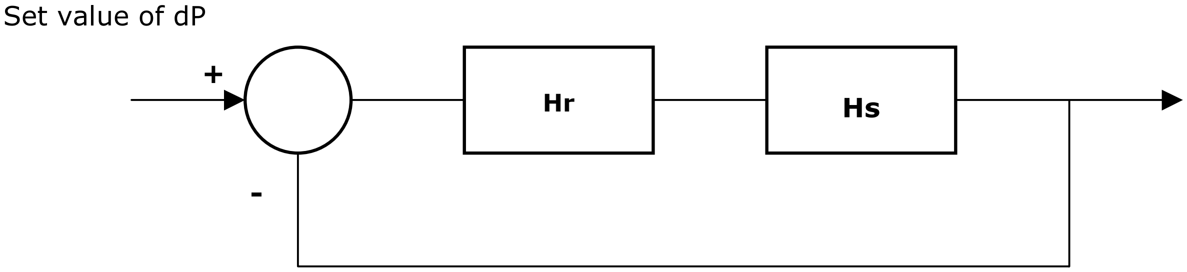

Figure 4, Schematic drawing of the control system

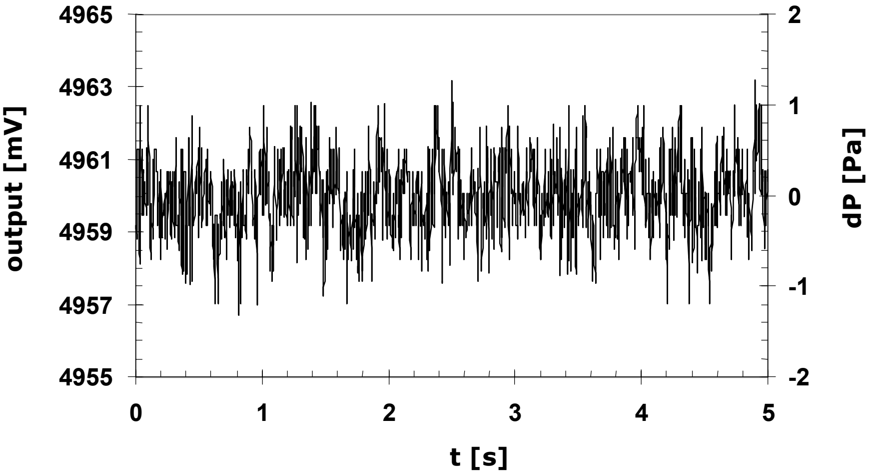

Figure 5, Output signal (in mV) and pressure noise dP as function of time

In Figure 5 the noise signal is plotted in the case of a zero-flow. Both the output signal Up and the pressure noise are plotted during 5 seconds. The standard deviation of the pressure noise is 0,4 Pa. This means that the uncertainty of the pressure noise is less than 1 Pa, which is a satisfying signal for the servo-controlled system.

The control system was tested at a flow-rate of 20 l/h. The results are shown in Figure 6a and 6b. The pressure difference is plotted as a function of time.

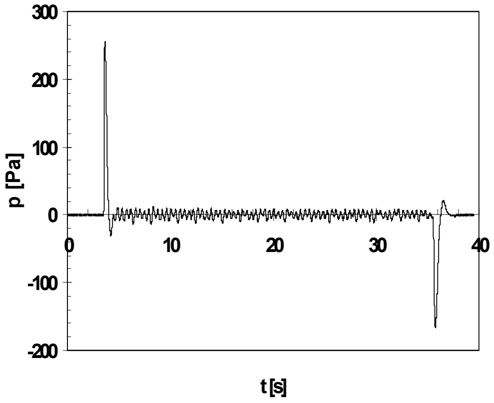

Figure 6a

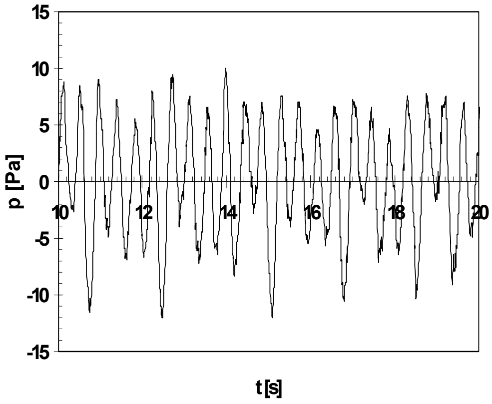

Figure 6b

Keep in mind that the first transient is due to a sudden connection of the measuring cell to a gas flow of 20 l/h (step function). The second transient is due to a sudden disconnection of the flow. When this control system is used for the Z/Z meter, these spikes will not show up, while the process will be controlled by smooth pressure expansion and temperature variations. The uncertainty of the pressure difference is smaller than 10 Pa, which is within the design specifications of the Z/Z-meter.

4. After temperature equilibrium, measurements are taken of the displacement of the piston, and readings of $P_2$ and $T_2$. The displacement of the piston is measured with a commercially available high-resolution transmitter. The transmitter is positioned **outside** the high-pressure tank.
   In the high-pressure environment the transmitter could possibly be damaged. Moreover, safety aspects play an important role.
5. Calculation of the ratio of the cell volumes at pressures $P_1$ and $P_2$ is executed and together with some corrections the ratio of $Z_2/Z_1$ is determined.

The gas volumes $V_1$ and $V_2$ are both the sum of the gas volume in the measuring cell and a fixed Start volume $V_s$, called the "Start volume" (in the figures referred to as "dead volume") and "d" is the diameter of the measuring cell.

$$V_1 = V_s + \frac{\pi}{4} d^2 h_1 \quad \text{and} \quad V_2 = V_s + \frac{\pi}{4} d^2 h_2 \tag{12}$$

'Open' Volumes of pressure transmitters, stopcocks, and seals will contribute to the total "Start volume" $V_s$ of the system. This Start volume is abbreviated as $V_{s1}$. Moreover an additional Start volume $V_{s2}$ could be present.

Taking the Start volume $V_s$ of the system into account, the equation for the compressibility ratio reads :

$$\frac{Z_2}{Z_1} = \frac{P_2 (V_s + \frac{\pi}{4} d^2 h_2) T_1}{P_1 (V_s + \frac{\pi}{4} d^2 h_1) T_2} \tag{13}$$

**Uncertainty assessment of the compressibility ratio**

A careful uncertainty assessment of the measurement of the compressibility ratio has been carried out to determine the optimal dimensions of the measuring cell, e.g. cell diameter, cell length, stroke length, and Start volumes.

Equation 13 is the basis of the uncertainty calculations. The basic criterion for selecting the dimensions of the cell is a design uncertainty of the Z/Z ratio lower than 0,03% for every expansion step within the working range of pressures. Other design criteria are a realistic Start volume of the system and a maximum stroke length $h_2$-$h_1$ of the piston of 30 cm.
The uncertainty calculations are based on an ISO Standard, commonly known as GUM [8].
The type of gas used in the calculations is 'Groningen Natural Gas' [9] with its typical gas composition expressed in mole percentages : 14,320% $N_2$, 0,890% $CO_2$, 0,050% n-Hexane, 0,040% n-Pentane, 0,150% n-Butane, 0,380% Propane, 2,870% Ethane and 81,290% Methane.
The influence of start pressure $P_1$, final pressure $P_2$, diameter of the cell $d_{cel}$, start height of piston $h_1$, and Start volume $V_s$ on the uncertainty of the compressibility ratio has been studied. Another result of the calculations is the final height $h_2$ of the piston.

In this paragraph we will present the results of the calculations. The next parameters have been established as a result of the calculations.

- Temperatures $T_1 = T_2 = 290$ K
- Uncertainty in temperature measurement $u(T_1) = u(T_2) = 0{,}05$ K
- Uncertainty in measurement of pressures larger than 10 bar, $u(P_1) = u(P_2) = 0{,}001$ bar
- Uncertainty in measurement of pressures smaller than 10 bar, $u(P_1) = u(P_2) = 0{,}0001$ bar
- Uncertainty in measurement length $u(h_1) = u(h_2) = 2.10^{-6}$ m
- Uncertainty in cell diameter measurement $u(d_{cel}) = 5.10^{-6}$ m

The uncertainties in measurements of temperature, pressure, and length are typical specifications of the devices and of the measurement conditions.

**Results of uncertainty calculations**

As mentioned in the introduction, the design specifications of the measurement instrument are based on the uncertainty assessment. The start height of the piston $h_1$, the cell diameter $d_{cel}$, the (fixed) Start volume $V_s$, the uncertainty of the Start volume measurement u(Vs) and the uncertainty of the piston position $u(h_1, h_2)$ determine the uncertainty of the Z/Z ratio u(y) and the final piston height $h_2$.
In a simulation program, uncertainty calculations are made with the above stated input values.
The calculations have given the most suitable input values to be.

- Start Height of the piston $h_1 = 0{,}000 \pm 0{,}001$ mm
- Cell Diameter $d_{cel} = 150{,}000 \pm 0{,}005$ mm
- Start Volume $V_s = 500{,}00 \pm 0{,}05$ ml

These values lead to a suitable construction with reference to the practical pressure steps as needed for the 'conventional' Dutch traceability chain.

| Start Pressure $P_1$ [bara] | Final Pressure $P_2$ [bara] |
|---|---|
| 9 | 1 |
| 51 | 9 |
| 41 | 9 |
| 61 | 9 |

For pressure ratios higher than 8, the fixed Start volume has to decrease to 66,700±0,005 ml and the piston starts with a height of $h_1 = 0{,}000 \pm 0{,}001$ mm. It means that the piston rests on the bottom of the cylinder and the position of the piston is 100% certain.
We will distinguish two different expansion processes.

1. Pressure ratios $P_1/P_2$ smaller than 8.
2. Pressure ratios $P_1/P_2$ larger than 8.

**Expansion with a pressure ratio smaller than 8**
If pressure ratios are smaller than 8, uncertainty calculations result in optimum dimensions of the measuring cell with :
Diameter of the cell = 150,000±0,005 mm;
Total Start volume = 500,00±0,05 ml;
Start height = 0,000±0,001 mm.
The total Start volume of 500,00 ml is the sum of the Start volume $V_{s1}$ of pressure transmitters, stopcocks and seals equalling to 66,700 ml and the additional volume $V_{s2}$ of 433,30 ml.
The total Start volume of 500,00 ml can be selected by opening valve "e".

In Figures 7 and 9 the relative uncertainty of the compressibility ratio is presented for the various pressure steps. Results of calculations show that for all expansion steps the relative uncertainty of the compressibility ratio is smaller than the specified 0,03%.

In Figures 8 and 10 the final height is presented for the various pressure steps. Both the final height and the stroke length never exceed 30 cm.
The sensitivity of the parameters is presented in Figures 11 a-e. In the captions of Figure 11 the criteria for the selected parameters are explained.

The calculated dimensions of the measuring cell meet the required design specifications.

However, for pressure ratios larger than 8, the design specifications are not met. This is illustrated in Figure 8 when focusing on the 70-bar line. When the gas has a final pressure lower than 9 bar, the final height will surpass 30 cm, the stroke length. The optimum pressure ratio is therefore set to 70/9 = 8.
It remains possible to measure at low pressures as shown in Figure 9 and 10.

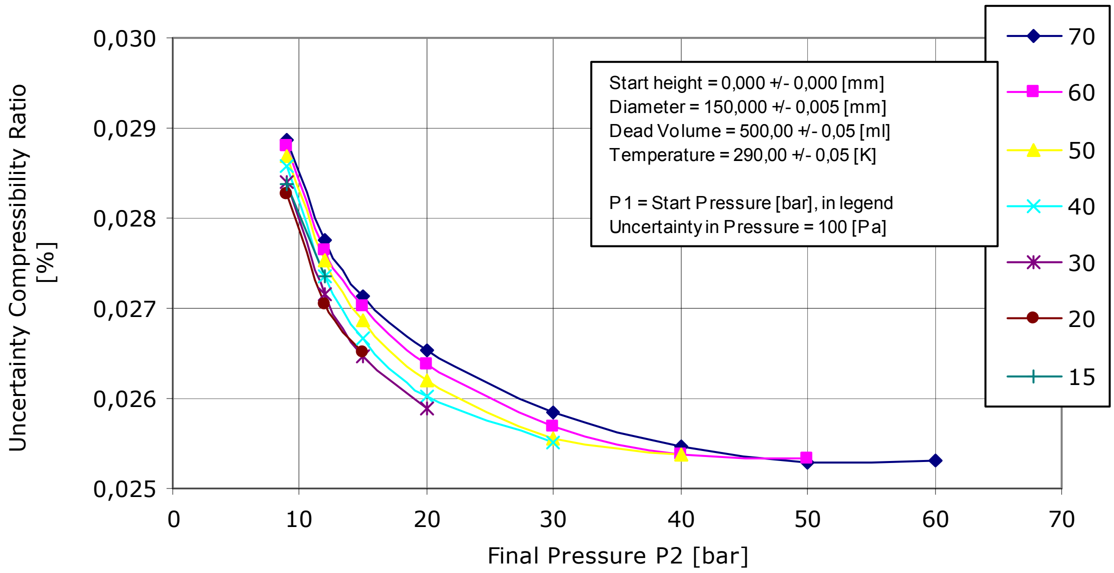

Figure 7, Uncertainty of the compressibility ratio for different expansion steps
Final pressure larger than 9 bara

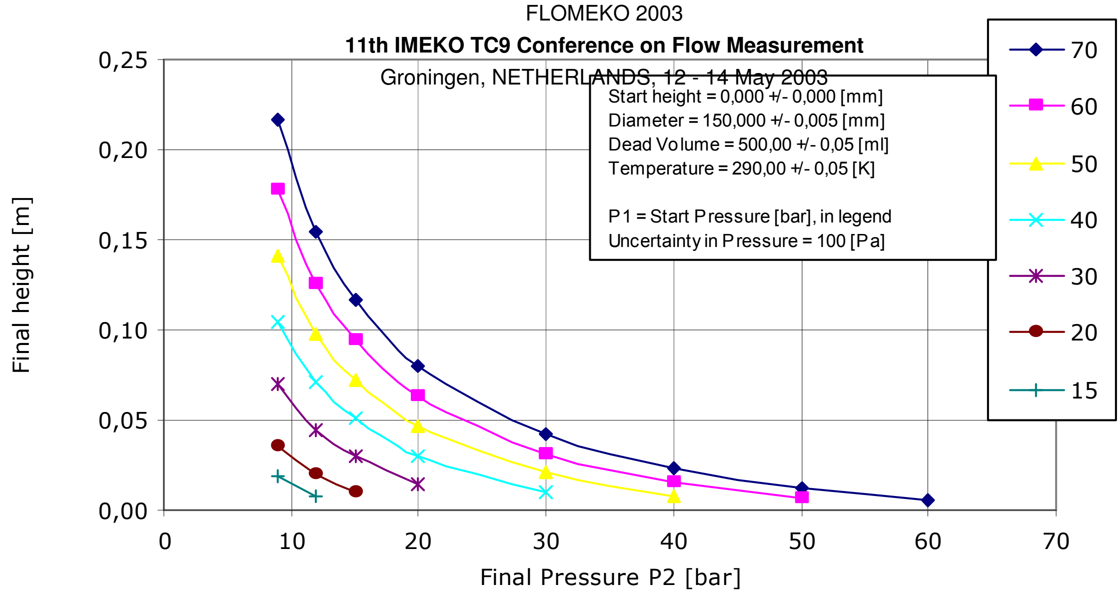

Figure 8, Final height of piston for different expansion steps
Final Pressure larger than 9 bara

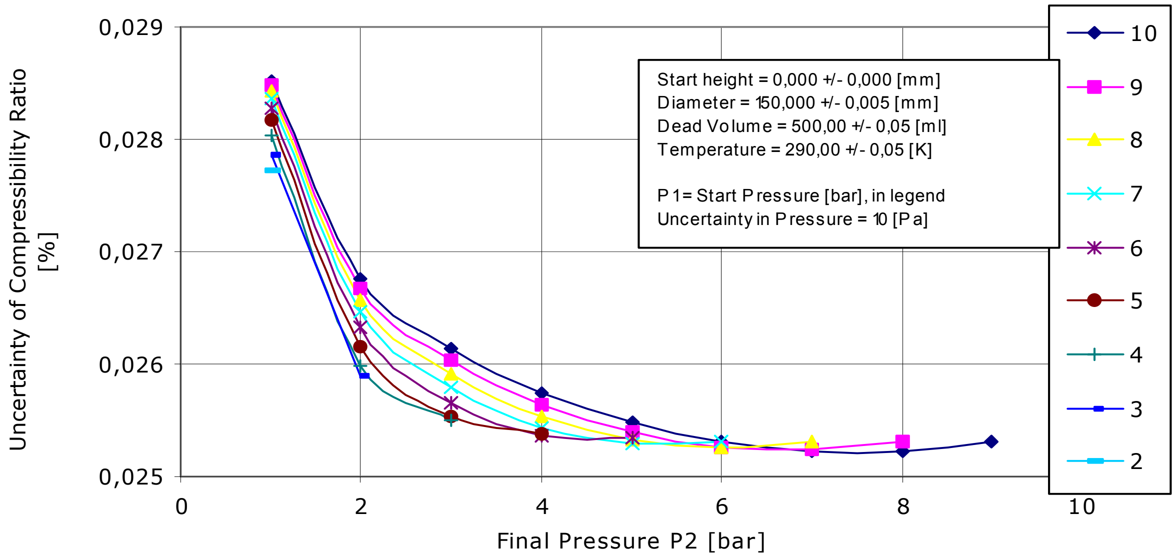

Figure 9, Uncertainty of the compressibility ratio for different expansion steps
Final Pressure smaller than 9 bara

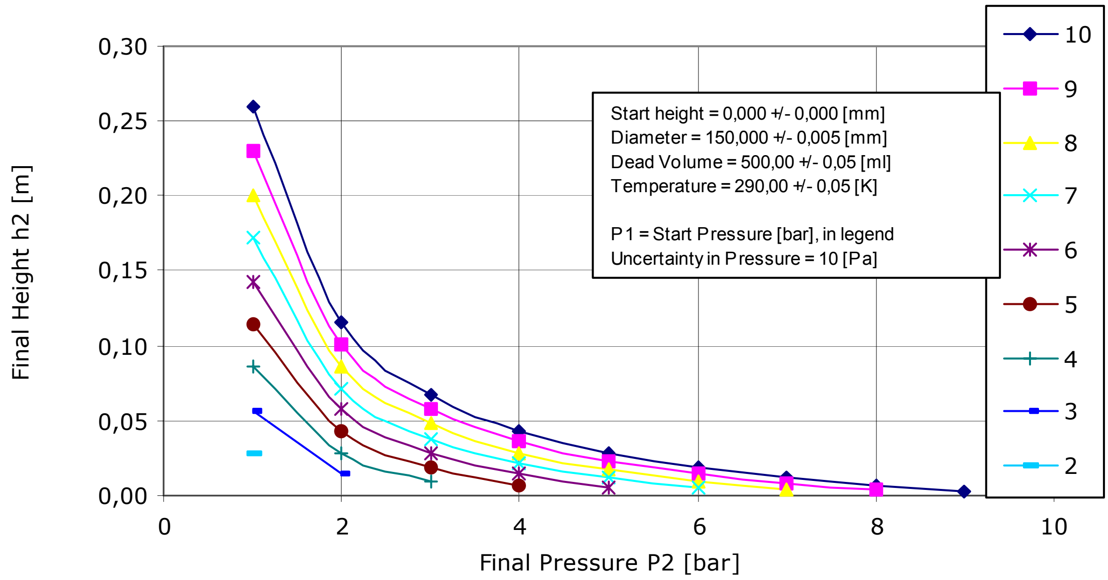

Figure 10, Final height of piston for different expansion steps
Final Pressure smaller than 9 bara

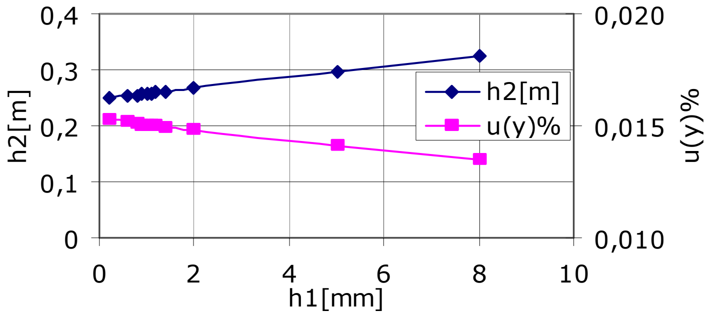

Figure 11a
The start height (h1) of the piston must be below 5 mm in order to keep the final height h2 of the piston below 30 cm. With a start height of 0 mm accurate measurements of the Z/Z ratio are possible.

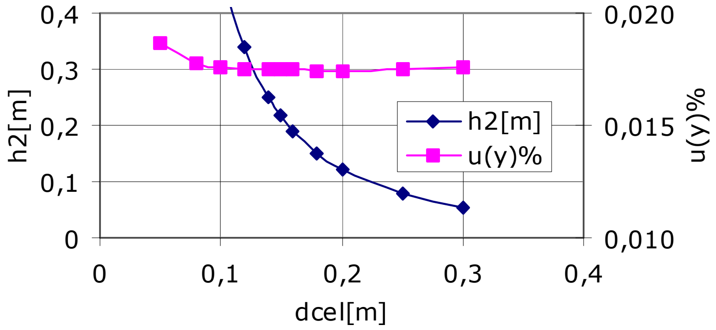

Figure 11b
The cell diameter ($d_{cel}$) must be larger than 14 cm in order to keep the final height (h2) of the piston below 30 cm. The most accurate measurement of ZZ-ratio is achieved with a cell diameter of ca. 15 cm. It is important that the diameter is not too large, because of temperature stability.

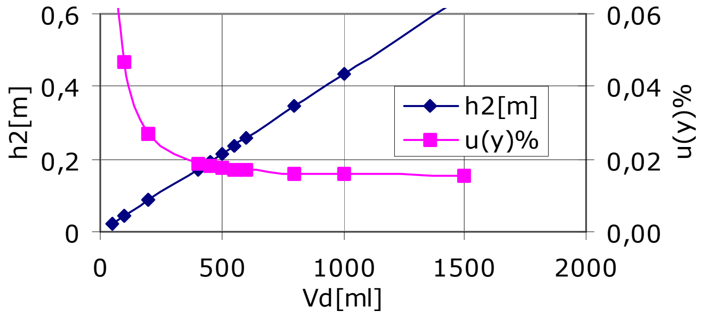

Figure 11c
An optimum Start volume of 500 ml is concluded from the calculations.
For Start volumes smaller than 500 ml, the final height h2 becomes too large.

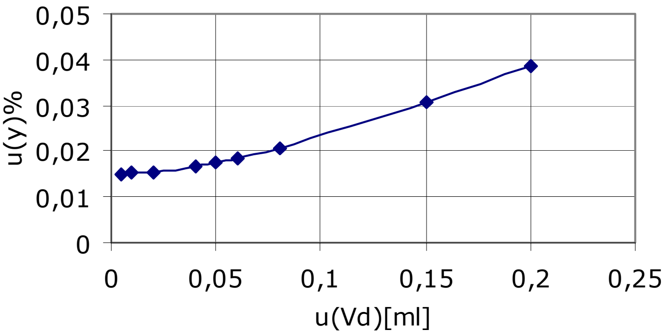

Figure 11d
The uncertainty of the Start volume u(Vs) has a great influence on the uncertainty of the ZZ-ratio u(y).
A practical and acceptable value of the uncertainty of the Start volume is 0,05 ml.

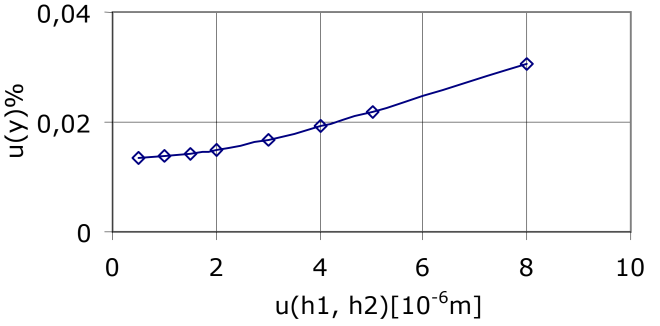

Figure 11e
The uncertainty of the piston heights u(h1,h2) influences the uncertainty of the ZZ-ratio u(y). The uncertainty of the displacement measurement should be below 2 µm in order to reach design specifications.

**Expansion with pressure ratios larger than 8**

The uncertainty calculations lead to optimum dimensions of the measuring cell for expansion of Natural Gas with pressure ratios larger than 8 with :
Diameter cell = 150,000±0,005 mm;
Total Start volume = 66,700±0,005 ml;
Start height = 0,000 ± 0,001 mm.
The Start volume of 66,700 ml is selected by closing valve "e".
At these small volumes measurements with an uncertainty of only 0,005 ml are realistic.
Note that in case the piston rests on the bottom of the cylinder and the start height will be 0,000 mm with an uncertainty of 0,001 mm.
In Figures 12 and 13 some typical results of uncertainty calculations are presented.

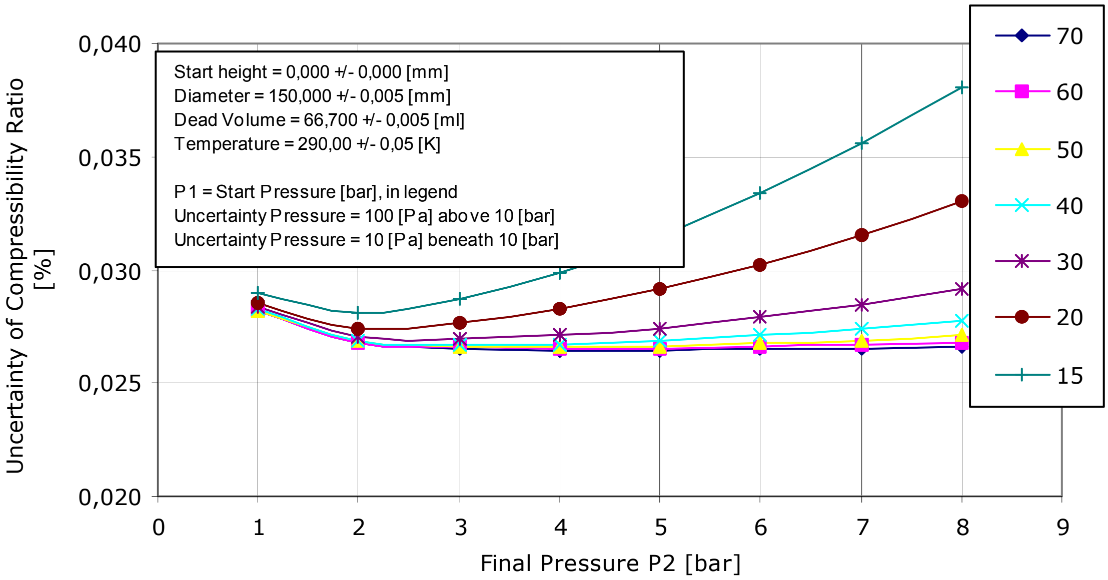

Figure 12, Uncertainty of compressibility ratio for different expansion steps
Expansion ratio larger than 8

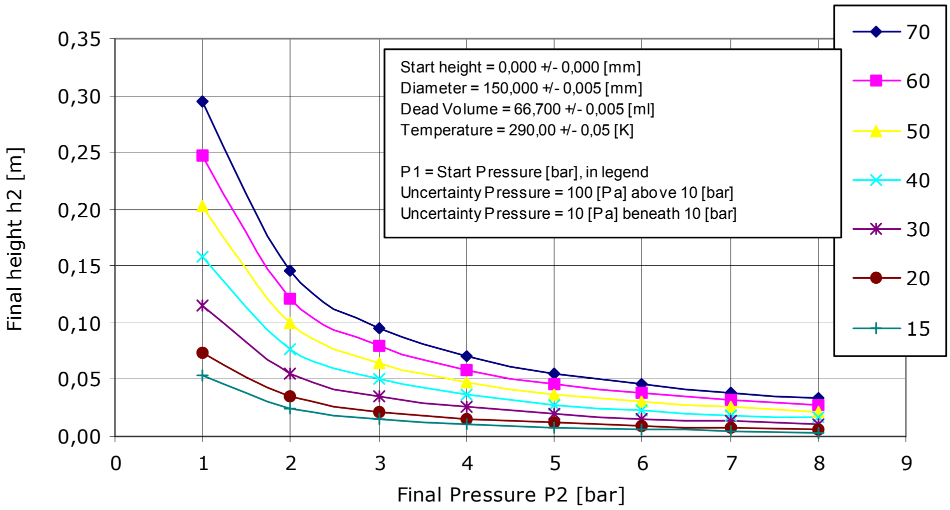

Figure 13, Final height of piston for different expansion steps
Expansion ratio larger than 8

## CONCLUSION

The optimum geometry of the measuring cell is a cylinder with a diameter of 0,15 m, a maximum stroke length of 0,30 m and a total available Start volume of 500,00 ml.
The total Start volume of the system is the sum of the Start volumes present in pressure transmitters, stopcocks and seals of $V_{s1}$ (= 66,700 ml) and an additional Start volume of 433,30 ml. The Start volume can be selected either as $V_{s1}$ or as the total volume $V_s$ (= 500,00 ml) by opening/closing of valve "e".
The optimum start height is 0,001 m.
Of course, the cell length is larger than the stroke length. The start height $h_1$ of the piston is adjustable.

## Post-Scriptum

**As a National institute for Standards in Measurement, NMi VSL has a function to provide industry and society with applicable expertise and knowledge in Metrology, usually delivered as "Traceability Services". A prerequisite to this function for the Metrology of Flow is e.g., the capability to generate reliable reference values for high-pressure gas-flow measurements. Extending its capabilities NMi VSL keeps its dedication on track to reduce uncertainties in high-pressure gas-flow measurements [10-13].**
**The anticipated small uncertainty of the Dutch traceability-chain will contribute to even smaller uncertainties via the Harmonization process [14-18].**

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