INVESTIGATION OF TEMPERATURE INFLUENCES ON GAS METERS

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Abstract: As basically known for each kind of measuring instrument, the measurement deviation of gas meters depends from a list of influence values. In the last 2 decades input perturbations as well as the gas pressure (which leads to different gas densities and hence *Re* - numbers) were major subjects of interest. The gas temperature have to be investigated as an important influence figure because the application of gas meters may differ much from the calibration temperature. The impact of the temperature depends from the technique used for the flow or volume measurement in the meter.

The investigation of temperature effects on gas meters is needed increasingly for type testing of meters used for custody transfer, the estimation of temperature influences on the measurement uncertainties especially if used as flow standard and the evaluation of performance figures claimed by the manufacturers.

The European regulations on Measuring Instruments (MID) require the investigation of all influences and hence of the gas and the environment temperature on the behavior of gas meter as part of the conformity assessment. PTB as a notified body for MID assessments wants to carry out the metrological key tests itself, other tests will be accepted, if they are done by accredited test laboratories for instance.

In order to follow this policy PTB developed and realised a test rig for temperature tests in a range between -45 ºC up to 80 ºC. The main features of the test facility as well as the chosen technical solutions will be described in the paper.

The facility was designed to investigate all kind of gas meters as well as flow standards like critical nozzles up to a flow rate of 300 m^3/h at standard conditions. The rig is able to stabilise the temperature in a test chamber in which the MUT is installed as well as the temperature of the test gas separately. For this the test gas flows through a heat exchanger which is equipped with an own it temperature control system. In order to avoid ice creation especially in the heat exchanger, the test gas is dried down to a dew point of - 60 °C. The design uses preferably critical nozzles as flow standards which are installed under ambient condition in the test hall. By this approach a total uncertainty of U = 0,2 % (k=2) is reached for the flow rate at the conditions of the MUT (Q > 0,1 m^3/h, -25 ºC up to 60 ºC).

First results of the investigation of laminar flow elements, wet gas meters (drum type) and mass flow elements based on a thermal principle are described.

The results show considerable influences, which may be eliminated by appropriate correction approaches.

1. INTRODUCTION

The European regulation on measuring instruments (Measuring Instrument Directive) applies on gas meters besides other kind of instruments used for legal metrology applications. MID is about general requirements and special requirements (minimum flow rate ranges, MPE, requirements on battery and power supply etc.).The MID requires an assessment of all influences which may have an impact on the meter error (meter deviation) in order to guarantee the conformity. Hence the harmonized European standard for diaphragm gas meters, EN 1359, describes a large number of influence tests. Also in the OIML recommendation R137 for gas meters a set of influence tests is listed. Such influences are input perturbation, the gas composition, gas pressure and also gas temperature. Depending on the regulation the meter shall respect the MPE or the shift is limited in respect to the error curve determined by atmospheric air under reference conditions is.

The MID requires explicitly the assessment of meters in the whole range of rated operating conditions. The meter shall respect the MPE for all flow rates and temperatures independent of the error curve at reference conditions. This requirement have an impact on the technical solutions and the flow rate ranges which a manufacturer is allowed to claim for a product.

The influence of temperature may have considerable impact on meter deviation caused by the change of dimensions, the behavior of bearings and lubricants, stiffness of diaphragms, the viscosity, the temperature distribution inside electronic devices and so on.

For instance domestic gas meters using often bi-metal build in temperature conversion devices, which change the cyclic volume as a function of temperature. The correct work need to be tested by different flow rates and temperatures. Because of the large time consumption of such tests the manufacturer shall check the meter statistically in the temperature range, i.e. some percent of a production batch shall be tested at least.

On the other hand, the application of flow standards like turbines or rotary piston meters may happen at temperatures which are more or less different from the calibration temperature. Especially changes of the mechanical dimensions, the gas viscosity or different cooling conditions of electronic components may lead to deviations The temperature based changes of the error curves need to be considered in MU budget, taking into account the temperature range in which the flow standard shall be used. A qualified estimation of the uncertainty is only possible if the meter is investigated by experiments.

Because of the increasing importance of temperature investigation at PTB a rig for temperature tests in a range between -45 ºC up to 80 ºC was realized. This test facility shall enable PTB as a notified body for module B,D and H1 of MID to investigate gas meters up to DN 100 (4“). The test rig shall be used also for calibration of flow standards, mainly for uncertainty investigations and scientific projects.

2. EXPERIMENTAL SETUP

2.1. General Arrangement

The test facility is a part of the test infrastructure at PTB which uses compressed air delivered by a net. Figure 1 shows the general arrangement of the rig.

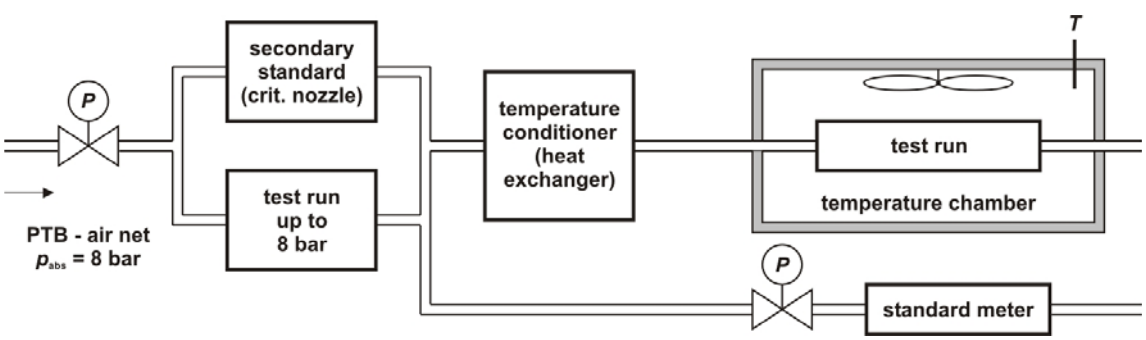

Fig. 1 Test capabilities of PTB for the investigation of temperature influences and calibration of flow meters/ critical nozzles in a range between ϑ_{min} = -45 ºC and ϑ_{max} = 80 ºC and up to p_{abs} = 8bar

The gas meter section of PTB is able to use the compressed air net to calibrate gas meters up to a standard flow rate of Q_N = 650 m^3/h and a maximum pressure of p_{abs} = 8 bar limited by the capacity of the air supply line.

The facility allows the calibration of secondary flow standards under increased pressure. In this case downstream to a pressure control valve the MUT is installed inside the test run. The flow standard used for the calibration is then located downstream to a flow or pressure control valve. As standards turbines or rotary gas meters are available which were calibrated by the PTB test facilities for atmospheric air [2].

The pipes of the compressed air net are installed mainly in the soil and contain a relatively large storage volume. Further several locally distributed compressors are available in the net. This leads to a good pressure stability which is little depending on the used flow rate. During a measuring time of 5 minutes the pressure (downstream to the pressure control valve) does not drift more the 2 mbar. In order to cover the whole flow rate range different sizes of pressure regulators are in use. All regulators, also if spring loaded, allow the application of an control pressure on the control diaphragm in order to allow a fine adjustment of the outlet pressure.

For flow rates up to Q_N = 250 m^3/h the temperature of the air is determined by ambient conditions in the building. Above this value the temperature drifts to the soil temperature (in which the net is installed). In addition the Joule Thompson effect becomes more important which leads to decreasing temperatures too. In order to reduce the uncertainty of temperature determination an electric heater was introduced downstream to the first pressure control valve. By adjusting the supply voltage of the heater the drifts described above may be compensated very well.

Currently this kind of calibrations are mainly applied for the determination of the discharge coefficient of critical nozzles. The reached *Re* numbers for toroidal nozzles are still in the laminar range (see figure 2) which is important, if the nozzles shall be used as upstream flow standards [1].

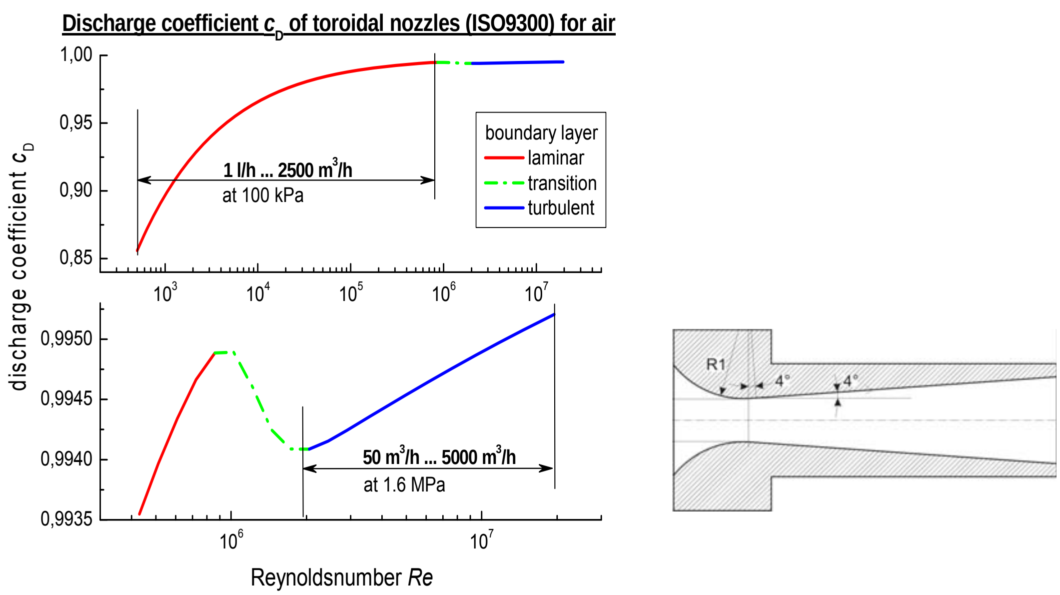

Fig. 2 Discharge coefficient of toroidal nozzles as a function of Re-Number and outline of such nozzles in accordance to ISO 9300 [1]

The humidity in the compressed air net is around ϑ_{dew} = -15 ºC. This value is measured by a dew point sensor. The humidity has an influence on the critical flow function as well as on the gas constant as shown in equation (1).

$$Q_m = \frac{\pi}{4} d^2 \cdot c_D \cdot c^* \frac{p_1}{\sqrt{R \cdot T_1}} \qquad (1)$$

As shown in Fig. 1 the facility allows to use flow standards by an input pressure of up to 8 bar and then to calibrate a MUT downstream.

This is advantageous for some application, for instance if it is not sure that the gas meter is free of dirt or dust which may hurdle the flow standard if located downstream. Especially if the gas flow must be treated (cooled or heated) this arrangement guarantee stable temperatures at the standard.

2.2. Test facility for temperature investigation of gas meters

As shown in Fig. 3 the temperature test rig consists of a flow standard, a temperature controlled chamber and a heat exchanger installed between the flow standard and the meter under test.

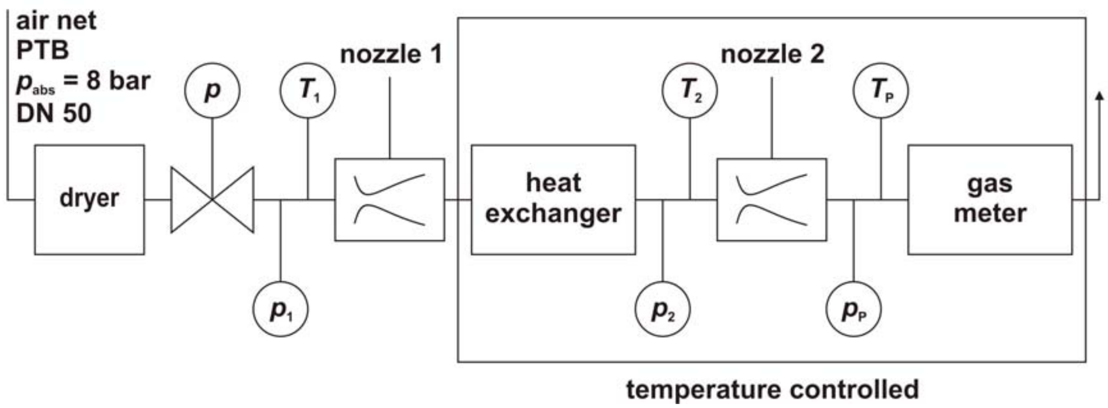

Fig. 3 Schema of the test facility for the investigation of temperature influences on gas meters

The aim of the heat exchanger is to cool or heat the gas flow, which was determined by the flow standard to the test temperature. In order to avoid water condensation or ice creation in the heat exchanger upstream to the flow standards an air dryer is part of the arrangement.

Fig. 4 shows a photography of this device. Beside the two vessels containing the adsorption material the input filters and output filters are to recognize. In the right bottom corner the dome type pressure control valve is to be seen which is used for the large flow rates up to up to Q_N = 650 m^3/h (for investigation at ambient temperature only , see Fig. 1).

Fig. 4 Photography of the adsorption air dryer

The adsorption air dryer is able to deliver a maximum standard flow rate of $Q_{N,max}$ = 300 m^3/h. The reached dew point is below ϑ_{dew} ≤ - 50 ºC. The adsorption air dryer uses the decreased dew point of air after an decompression in order to refresh the adsorption material. That means that one vessel of the adsorption dryer is used for drying the test air at operation pressure (p_{abs} = 8 bar) meanwhile the other vessel is in refreshment cycle (p_{abs} = 1 bar). The cycle time depends from the input dew point and the delivered flow rate. The shortest cycle is 2 minutes. Upstream as well as downstream to the dryer different filters are in use. The downstream filter shall avoid that small particles of the adsorption material will enter the downstream located parts of the facility.

Because of the low uncertainty and the very good long term stability critical nozzles are used as flow standards. Further the nozzles allow the generation of the wished flow rates by the control of input pressure.

The input pressure of a nozzle downstream to the pressure regulator may be chosen between p_1 = 3,5 bar up to p_1 = 8 bar which it allow to cover a flow rate range of 2:1 by one nozzle at least. In order to deliver the whole flow rate range between Q_{min}=8 l/h and Q_{max} = 300m^3/h, 12 different sizes of nozzles are needed. Taking into account the extensive time consumption of temperature tests it is advantageous to use a nozzle exchange unit in stead of a nozzle bench. Fig. 5 shows the exchange unit and the nozzle holders.

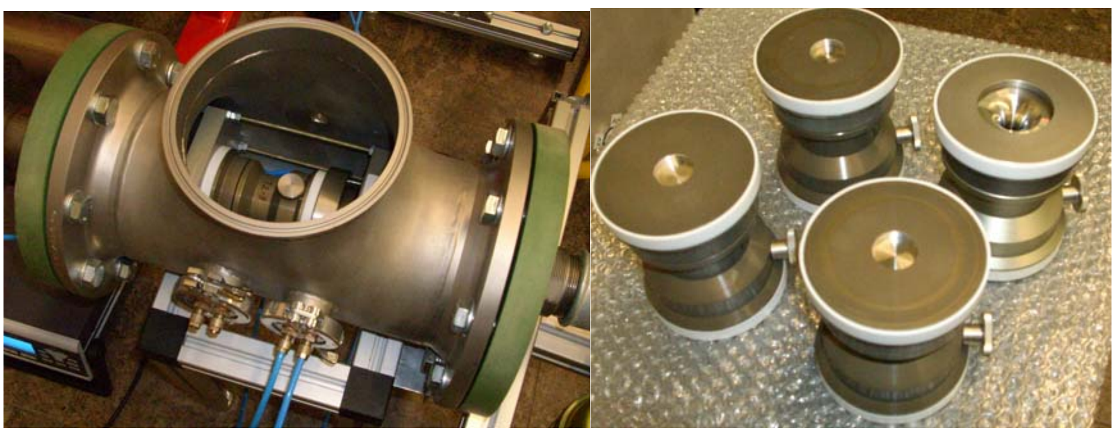

Fig.5 Photography of nozzle exchange unit (left) and the holders in which the nozzle are mounted (right).

The exchange unit is opened and closed by an cylinder/piston drive which uses compressed air to generate the needed forces. The design of the exchange unit includes on both sides double rubber seals in order to allow a fast check of leak tightness after a nozzle was replaced. The nozzles are mounted in holders to reach an uniform size of the units which have to be exchanged. The exchange unit itself is mounted inside a vacuum tight housing. This feature allows a heat isolation if used for temperatures other then ambient temperature.

In order to control the temperature around the MUT as well as the temperature of the test gas the "temperature device" of the facility was designed to have to technically separated sets of cooling machines and electrical heaters respectively. One set is for the chamber in which the MUT is installed, the other is for a heat exchanger which allows the treatment of the test gas. For cooling each set consists of a cascade of 2 water cooled heat machines with a power consumption of 8 kW for the temperature controlled chamber and 16 kW for the heat exchanger of the test gas. The temperature controlled chamber is equipped by an recirculation ventilation based on two fans in order to adapt and stabilize the temperature of the meter body by the circulating air around the meter under test (MUT) as fast as possible and also to avoid temperature layers in the chamber. Fig. 6 shows a photography of the chamber. On the left and right side of the chamber 2 wholes are available to install input and output pipes. In the bottom of chamber special supports are integrated in order to allow the arrangement of heavy MUT. The size of the chamber is designed to investigate meters up to an nominal Diameter of DN 100. The maximum flow rate is limited by Q_{max} = 300 m^3/h (under standard conditions: p_N =1013,25 mbar; ϑ_N = 0 ºC) determined by the capacity of the air dryer as well as the heat exchanger.

The main features of the temperature device are summarized in Table 1.

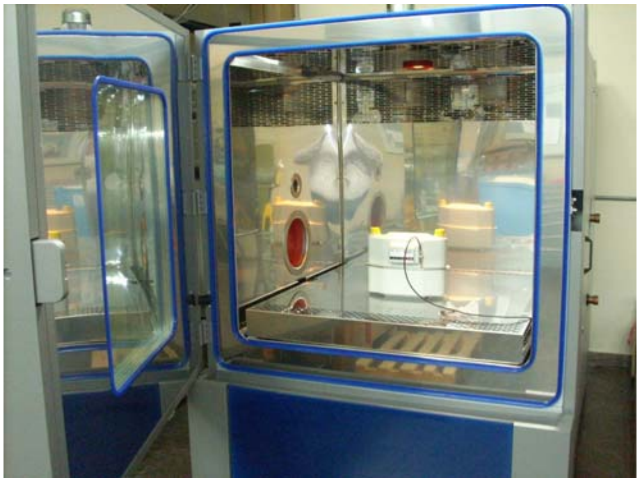

Fig. 6 Photography of the temperature controlled chamber

Table 1: Main characteristics temperature test facility

Parameter	**Value**
volume of test chamber (depth, height, width)	800 x 800 x 1000 mm^3
maximum weight of MUT	m_{max} = 120 kg
Maximum nominal diameter of MUT	DN 100
temperature range	ϑ_{max} = +80 °C ϑ_{min} = -45 °C
temperature change rate: heating cooling (down to -40 °C)	1 K/min 1 K/min
temperature deviation	±0,3 K after 1 h ±0,1 K after 2 h
dew point of test air	ϑ_{dew} ≤ - 50 C
maximum pressure resistance of heat exchanger	p_{max} = 10 bar
maximum flow rate (standard conditions)	$Q_{N,max}$ = 300 m^3/h
total uncertainty of the flow rate at the conditions on the MUT	U = 0,2 % (k=2) $\vartheta_{MUT} \geq$ -20 °C; Q > 0,1 m^3/h U = 0,3 % (k=2) ϑ_{MUT} < -20 °C
dead volume of heat exchanger	V_{he} = 8 dm^3
pressure drop of heat exchanger	$\Delta p_{he,max}$ = 2 bar (Q_N = 300 m^3/h)
Total power consumption of the heat machines	P_{el} = 28 kW

The heat exchanger for treating the test gas was carried out as an plate heat exchanger. This has the advantage that the volume between the flow standard and the MUT is as low as possible. The heat exchanger is able to stabilize the test gas at the maximum flow rate if the input pressure is at least $p_{he,input,abs}$ = 4 bar. In order to reach this, it is necessary to insert behind the heat exchanger a flow control valve with an appropriate pressure loss or a second critical nozzle as shown in Figure 2.

The diameter and hence throat area A_2 of the second nozzle must be chosen appropriate to the throat area A_1 of the first nozzle in order to reach critical condition for both nozzles. If done, then it is possible to use the stability of pressure p_2 as an indication for reached temperature stability behind the heat exchanger as given by equation (2).

$$p_2 = p_1 \cdot \frac{A_1}{A_2}\sqrt{\frac{T_2}{T_1}} \qquad (2)$$

In order to use the nozzle exchange unit also for the second nozzle as just described the vacuum heat isolation was designed.

The separate controlled heat exchanger allows to change the temperature of the gas flow independent to the temperature inside temperature controlled test chamber. The experiences show that this feature may be used to compensate heat losses between the heat exchanger and the MUT which are caused by the limited isolation ability of the currently used isolation material. Especially for flow rates below Q = 1 m^3/h an additional pipe loop will be installed in the test chamber in order to test the meter with a gas temperature which is nearly equal to the temperature of the meter body.
In principle the facility allows to carry out tests with tempered gas with has a different temperature then the maintained temperature in the test chamber. This is only reasonable if the temperature compensation is part of tested meter. Otherwise the results will be influenced strongly by the choice of the location and technical realisation of the reference temperature determination.
As indication of a MUT pulses or other kind of electric interfaces may be used. If only an mechanical or alpha numerical indication is available then a CCD camera in combination with proper lenses are usable to read the meter. The used camera system is able to memorise pictures which are shot synchronised by an electrical signal. This allows to determine the measuring time and the progress of the indication with the lowest possible uncertainty.

3. INVESTIGATION OF DIFFERENT METER TYPES

3.1. Investigation of a wet gas meter with oil as sealing liquid

Wet gas meters were used in the past very often for the verification of gas meters under legal control. In this field of application nowadays critical nozzle are mainly in use [2].
But wet gas meters have some advantages which make them interesting for a lot of application:

- large flow rate range Q_{max} to Q_{min} of 100:1
- low pressure loss
- volume counting also below Q_{min}
- independency from the kind of gas (if the dilution in the sealing liquid is negligible)
- low uncertainty (if the vaporisation is negligible and if a sufficient number or full rotations of the drum are used for data acquisition)
- very good long term stability

There some disadvantage like

- large volume in comparison to other meters with similar Q_{max}
- sensitivity to temperature changes
- difficult to handle, especially the adjustment of the filling level of the sealing liquid
- transport usually without filled in sealing liquid is needed

At PTB wet gas meters are applied as transfer standards which are mainly used for the calibration of critical nozzles. During a calibration the temperature is kept constant after the adjustment of the level of the sealing liquid.

There are several level indicator types on the market. Fig. 7 shows the front of the wet gas meter (left) and the indicator (right) with which the wet gas meters of PTB are mainly equipped. In order to come to repeatable results it necessary to adjust the meter horizontally, keep the drum wetted by some rotations, to position the drum at a special position prescribed for level adjustment and after a determined time, the level adjustment itself is to carry out The photographed level indicator uses a needle, which shall touch the oil surface. Because of the surface tension the flatness of the oil surface near to the needle is disturbed if the level is not correct adjusted. By some experience the procedure allows a reproducibility of 0,1% in respect to the meter deviation which is one of the largest uncertainty influences.

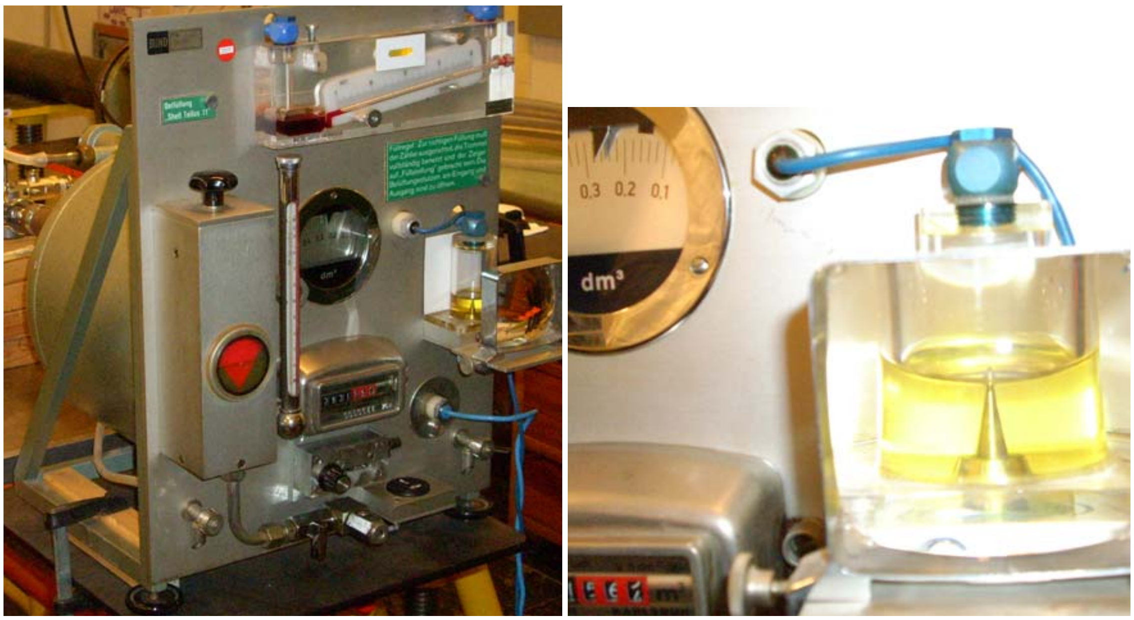

Fig. 7 Photography of the front of a oil filled wet gas flow standard and the sealing liquid indicator (right side) in particular.

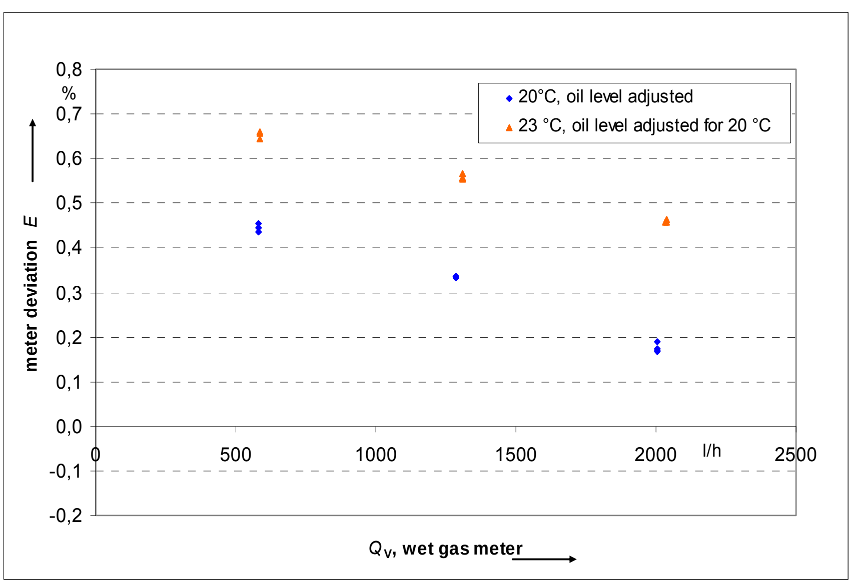

Fig. 8 Meter deviation of a wet gas meter for an ambient and oil temperature of 20 ºC and 23 ºC respectively, the oil level was only adjusted by a temperature of 20 ºC

Because of the density changes of the oil caused by temperature changes, the meter deviation and hence the uncertainty of the results is increased. In order to quantify this influence an oil filled wet gas meter was investigated in the temperature rig. The results show that a temperature change of 3 K lead to a shift of around ΔE = 0,25 % in the error curve nearly independent from the flow rate as shown in Figure 8.
If the oil level will be adjusted for the actual oil temperature, then the error curve is independent from the oil temperature itself as shown in Fig. 9. The diagram shows the results of several calibrations, for each test and temperature the oil level was adjusted new. The results show that the error curves deviate by an uncertainty of U = 0,1 % which is the uncertainty belonging to the level adjustment procedure itself. The error curves show no additional systematic influences (for instance because of the large viscosity changes of sealing liquid) by the temperature. It is to conclude, that the meter should be adjusted at the temperature at which the application takes place in order to reach the lowest uncertainty possible.

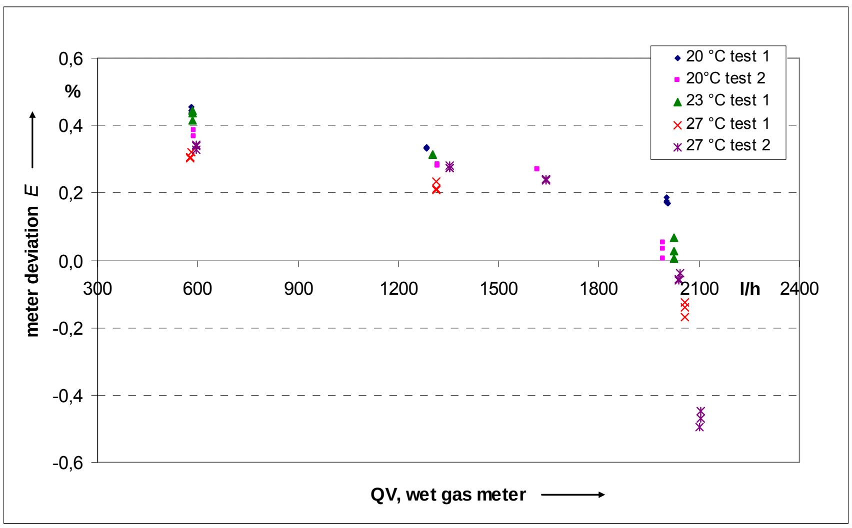

Fig. 9 Meter deviation of a wet gas meter for 20 ºC, 23 ºC and 27 ºC if oil level was adjusted for each temperature separately

If wet gas meters are applied for long lasting measurements then the level of the sealing liquid may be influenced by the vaporisation. This will lead to decreasing liquid levels and hence to error curves which a shifted to minus. This should be taken into account for the choice of the kind of sealing liquid an the frequency of level checks during the application respectively.

3.2. Investigation of Laminar Flow Elements

Laminar flow elements are used for different applications, mostly for small and medium size flow rates (up to Q = 2000 m^3/h). The flow rate is determined by the differential pressure Δp along small channels. If the flow is laminar inside the channels then the flow rate Q is proportional to the differential pressure Δp and the dynamic viscosity η

$$Q_{\mathrm{V}} = k_{LFE} \cdot \frac{\Delta p}{\eta} \tag{3}$$

The constant k_{LFE} depends from the dimensions, namely the size and length of the channels. The cinematic viscosity η follows from the kind of fluid and the temperature. Up to pressures of 5 bar the influence of pressure on the viscosity in to neglect.

In the literature different viscosity models are available. A model which was described for air in a temperature range between 0 °C and 50 °C was developed by Kestin & Whitelaw (4).

$$\eta_{KW,dry}(T) = \left[((k_3 \cdot T + k_2) \cdot T + k_1) \cdot T + k_0\right] \cdot 10^{-6} \quad (4)$$

($\eta_{\mathrm{KW,dry}}$ in Pa s, T in K). The used constants for the viscosity model described by Kestin & Whitelaw are given in the following table.

Table 2 Constants for the viscosity model described by Kestin & Whitelaw

k_0	-1,951657
k_1	9,635324 E-2
k_2	-1,197338 E-4
k_3	8,790226 E-08

Fig. 10 shows the design of a new kind of LFE, a slit type LFE which was described by Koppenwallner [6]. The channels which are used for the generation of laminar flow conditions are manufactured as slits in a rod.

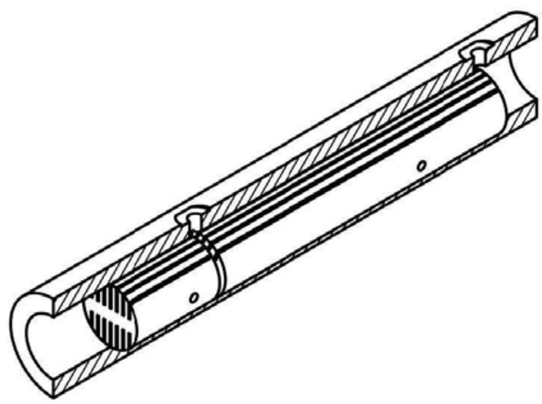

Fig. 10 Laminar flow element in slit design

In order to measure the pressure difference only over a developed laminar flow, the first pressure tape is located downstream to the beginning of slits.

In order to reach laminar flow conditions inside the channels the *Re* - number must be sufficient small, that means considerable below the transition *Re* - number for a turbulent pipe flow (5). The characteristic length *d* follows for the slit type LFE from width of the slits i.e. the smaller dimension perpendicular to flow direction. By an arrangement of a sufficient slit area the manufacturer is able to realize the intended flow rate range.

$$\mathrm{Re} = \frac{\bar{u}\, d\, \rho}{\eta} = 5 \ldots 900 \quad (5)$$

(η dynamic viscosity, *d* slit width as characteristic length, *u* gas velocity, ρ density). In order to calculate the flow rate at the MUT the reference temperature and reference pressure have to be defined. Several approaches are possible, in the described measurements the pressure at the upstream tape was used as reference pressure. Hence this pressure was also used for the calculation of the density.

If equation (4) is used for the calculation of the flow rate, then relatively large deviations of the calculated flow rate may occur over the flow rate range because only a fixed constant k_{LFE} is used do characterize the LFE. The more complex behavior of a LFE is caused by different influences like the limited input length for the development of the laminar flow in the channels and the changing density along the channels etc. [2].

In order to reduce the measurement error the calibration curve may be approximated by a so called “Uni Flow approach” described by Todd [5].

The Uni flow equation (6) uses 3 constants B, C and D to characterize the behavior of the an LFE.

These constants may be determined by a regression analysis.

$$\left(\frac{Q_V \cdot \rho}{\eta}\right) = B \cdot \left(\frac{\Delta p \cdot \rho}{\eta^2}\right) + C \cdot \left(\frac{\Delta p \cdot \rho}{\eta^2}\right)^2 + D \cdot \left(\frac{\Delta p \cdot \rho}{\eta^2}\right)^3 \qquad (6)$$

(η dynamic viscosity, ρ density). By using the uni flow constants the application of a LFE for conditions different to the calibration is possible. At PTB several types of LFE where investigated by air an methane.

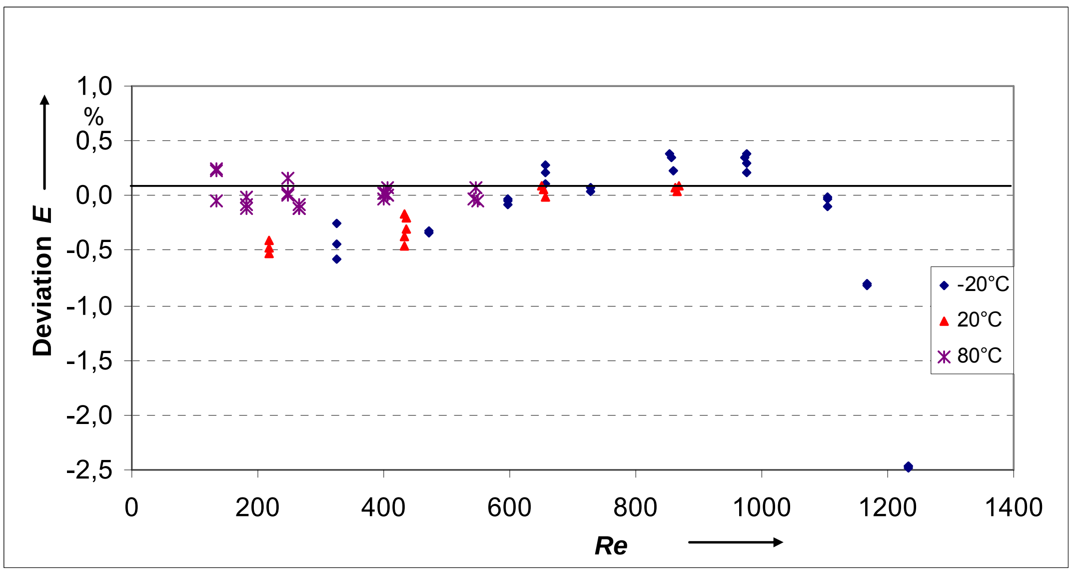

Fig. 11 Deviation of a slit type LFE measured with methane for 3 different temperatures. The calibration uses the constants determined in respect to the "Uni Flow approach" applied only for results measured with dry air at 20 °C.

Fig. 11 shows the deviations of a slit type LFE if the constants in respect to the Uni Flow approach (6) were determined only with dry air at 20 °C. In order to calculate the viscosity of methane the equations described by Daniel [3] were used. The results show a good agreement for all temperatures except the -20 °C for high flow rates and *Re* - numbers respectively. The reason for this behavior follows from the already to high *Re*-Numbers in this case.

The results show the potential of the test rig to come to reasonable uncertainty values for different conditions at the application.

3.3. Investigation of a mass flow controller

Especially for industrial application, process measurement and control mass flow controller (MFC) and mass flow meter (MFM) are used in large numbers. The technique is based on thermal properties namely the heat conductivity and the specific heat of gas. As shown in Fig. 12 often a flow divider is used to generate a defined by pass flow through a small pipe. This is equipped with a heater (R_H) and to temperature sensors R_{T1} and R_{T2}.

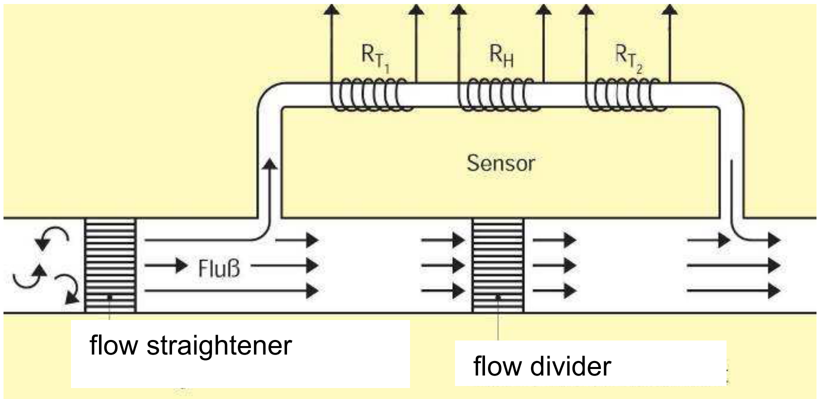

Fig. 12 Principle of thermal gas flow meter

The needed energy to heat up the heater R_H to a certain constant over temperature as well as the measured temperatures upstream and downstream to the heater by the temperature sensors R_{T1} and R_{T2} are usable for the determination flow rate and flow direction.

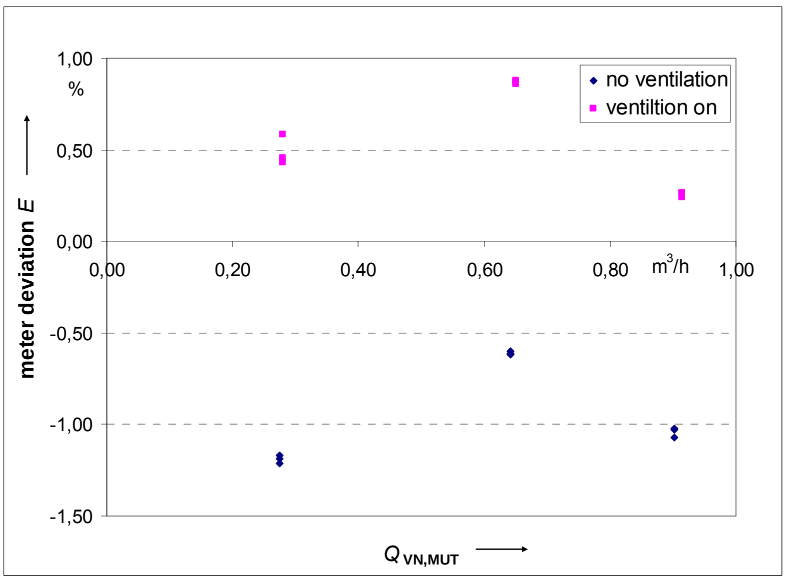

Fig. 13 Error curve of a mass flow meter based on a thermal flow sensor for 20 °C with running ventilation inside the temperature chamber and 23 °C (no ventilation).

Fig. 13 shows the meter deviation of a mass flow meter measured at 20 °C with running ventilation inside the temperature chamber and 23 °C without temperature control and ventilation. The error curve shoes a shift of more then $\Delta E \geq 1{,}5$ % independently from the flow rate. For both calibration conditions the zero point (indication without flow) was checked but no significant deviation were displayed.

The influence on the MFE may be caused by the ventilation which influences the temperature distribution in the electronics or by the influence on the viscosity of the gas.

It is not to conclude that all meters of this type or all brands of such instruments react so strongly on the relative low change of the temperature. It is up to further research to come to general results. Nevertheless the manufacturers claim of an accuracy of 1 % was not confirmed by the results.

4. SOURCES OF UNCERTAINTY

Basically the uncertainty of a test facility shall be appropriate for the purpose of a test. The requirements given in OIML R137 distinguish between type testing and verification tests. In the latter case 1/3 of the MPE are acceptable, for type testing during approvals 1/5 of the MPE are required. The test rig was designed to reach this figures, that means *U* = 0,2% (*k* =2) for flow rates above Q = 0,1 m3/h and *U* = 0,3% (*k* =2) below. This figures have to be evaluated for each test partly new, because the piping and hence the dead volume is changed. Also the measuring time and the uncertainties related to the read out of indicated volume or mass may differ.

In general the calibration uncertainty of the flow rate follows firstly from the uncertainty of the flow standard. By using the flow standard at ambient conditions of the test hall mainly the calibration uncertainty is to consider, as well as the uncertainties of the pressure and temperature measurements during a calibration. The uncertainty related to humidity and gas composition are very small because of the very low dew points. The nozzles will be calibrated by using the same equipment as during the application, hence installation influences are to neglect.

Further main sources of uncertainties are given by uncertainty of the used sensors for pressure and temperature. In order to analyze the calibration results the following sensor indications have to be considered:

- the pressure *p* and the temperature *T* at the flow standard and at the MUT,
- the dew point of test air
- the flow rate indication of the meter under test Q_{MUT},
- the measuring time

The mathematical model for mass flow rate determined by a nozzle is given in (7), the volume flow at the MUT follows by (8) under usage of the density determined by the temperature and pressure at the MUT.

$$Q_{m,nozzle} = \frac{\pi}{4} d^2 \cdot c_{\mathrm{D}} \cdot c^* \frac{p_1}{\sqrt{R \cdot T_1}} \qquad (7)$$

$$Q_{V,MuT} = \frac{Q_{m,MuT}}{\rho_{MuT}} \qquad (8)$$

In addition to the uncertainty of the sensor signals also the uncertainty of density equation have to be considered. For test rig the formula of Giacomo [4] is in use.

The flow rate at the MUT follows from equation (9) considering

- the line pack effect (10) and
- the leakage flow Q_{leak} to the environment (11).

$$Q_{m,MuT} = Q_{m,nozzle} - Q_{Leak} - Q_{linepack} \qquad (9)$$

$$Q_{m,linepack} = \frac{V_{line}\ \rho}{t_{meas}} \left(\frac{\Delta p}{p} - \frac{\Delta T}{T} \right) \qquad (10)$$

$$Q_{\mathrm{m,leak}} = \frac{\Delta p \cdot V_{line} \cdot \rho}{t_{\mathrm{test}} \cdot p_{\mathrm{abs}}} \text{ (if } T = \text{constant)} \qquad (11)$$

The leakage have to tested in front and of each new test temperature. The detected leakage shall be lower then 1/3 of claimed uncertainty for the lowest flow rate. The line pack effect is related to the drift of temperature and pressure during the measuring time and the pipe volume between the flow standard and the MUT. Because of the volume saving design of the heat exchanger the total volume between the flow standard and the MUT is relatively small.

The sources uncertainty are summarized in Table 2.

Table 3 Summary of uncertainty influences

Value	Symbol	standard uncertainty (k = 1)
Effective throat erea (including the discharge coefficient of a nozzle) as function of p_1	$\frac{\pi}{4} d^2 \cdot c_D$	u = 0,06 % Q ≥ 0,1 m^3/h u = 0,1 % Q < 0,1 m^3/h
critical flow function	C^*	u = 0,03 %
gas constant	R	u = 0,02 %
dew point	ϑ_{dew}	u = 4 K (ϑ_{dew} < -30 °C)
density equation	$\rho = f(x_1, \quad , x_n)$	u = 0,02 %
input pressure of nozzle 1	p_1	u = 0,05 mbar
input temperature of nozzle 1	ϑ_1	u = 30 mK
temperature at the MUT	ϑ_{MUT}	u = 80 mK ($\vartheta \geq$ 0 °C; $\vartheta \leq$ 40 °C) u = 200 mK (ϑ < 0 °C)
absolute pressure at the MUT	p_{MUT}	u = 2 Pa
temperature at the outlet of the heat exchanger	ϑ_2	u = 100 mK ($\vartheta \geq$ 0 °C; $\vartheta \leq$ 40 °C) u = 300 mK (ϑ <0 °C; ϑ > 40 °C)
measuring time	t	u = 0,05 s
Dead volume	V_{line}	u = 10%
leakage	Q_{leak}	u < 0,05 % (depending on flow rate)
Line pack	$Q_{linepack}$	u < 0,05 % (depending on flow rate)

The uncertainties of C* and the gas constant R are to neglect because of the nearly identical conditions during calibration and application of the nozzles (if dry air is used as test gas).

The total uncertainty have to be estimated individually for each calibration after the evaluation of the separate influences. Especially for low temperatures the determination of leakage become more difficult. In order to evaluate the influence of the dead volume the temperature and pressure is memorised every 5 s during the complete measuring time. This allows to calculate average values for pressure and temperature as well as the value for the line pack effect. Because of the long measuring times (t_{meas} > 5 min) the line pack effect contribute usually minor to the total uncertainty.

5. CONCLUSIONS

The test facility for temperature influences was successfully constructed an evaluated. It was used for several investigations in the intended temperature range and the proper work could be demonstrated. Besides the conformity assessment of gas meters the test rig shall be used for the calibration of flow standards and the investigation of flow meters for product certification and process control application. First results show that the impact of temperature influence depends on the used technique. If the physical impacts like the change of the viscosity or the density on the meter principle are known, then the influence may be corrected if an appropriate model is available.

Based on critical nozzles as flow standards, low pressure and temperature drift during a measurements and other design features it was possible to reach low uncertainties which fulfill the requirements of the OIML recommendation R137.

The current experiences made evident that it is necessary to spend further efforts to improve the heat isolation of the lines between the heat exchanger and MUT inside the test chamber.

The results demonstrated the necessity of future temperature influence investigation for instance of ultrasonic meters.

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