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Advances in Gas Flow Measurement using Weighing Method

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Preliminary note

The transfer gas flow standard ROMBACH NB2 was calibrated in the Zagreb Gasworks using two different balances incorporated into the basic calibration system. The basic difference between these balances was in their resolution, i.e. 1 g for the SARTORIUS IS64FG and 0,1 g for the SARTORIUS LA64001. Before measurements with the SARTORIUS IS64FG balance, absolute pressure sensors HBM P3MBA were calibrated using the digital barometer VAISALA PTB 220. The deadweight tester PRESSUREMENTS 6100-1L was employed for HBM P3MBA calibration before tests with the SARTORIUS LA64001 balance. In all tests, experiments were carried out for flow rates from 0,02 m^3/s to 1,4 m^3/s. Experimental results compare well with experiments previously performed in the Baden-Württemberg Office of Legal Metrology, Germany. The spread of obtained experimental values was within 0,25% for the total range of flow rates. The measurement repeatability was within 0,1%. The highest contributions to measurement uncertainty result from the air temperature and humidity in the tested gas flow meter and in the container. The measurement uncertainty in tests with the SARTORIUS LA64001 was smaller than in tests with the SARTORIUS IS64FG. Total measurement uncertainty was reduced when absolute pressure sensors HBM P3MBA were calibrated using the deadweight tester PRESSUREMENTS 6100-1L compared to results obtained with the VAISALA PTB 220 digital barometer.

Poboljšanja kod mjerenja protoka plina uz primjenu metode vaganja

Prethodno priopćenje

U Gradskoj plinari Zagreb provedeno je umjeravanje prijenosnog etalona protoka plina ROMBACH NB2 uz korištenje dviju različitih vaga. Temeljna razlika između ovih vaga je u njihovoj rezoluciji, tj. 1 g za SARTORIUS IS64FG i 0,1 g za SARTORIUS LA64001. Prije mjerenja s vagom SARTORIUS IS64FG, osjetnici apsolutnog tlaka HBM P3MBA su umjeravani uz korištenje digitalnog barometra VAISALA PTB 220. Tlačna vaga PRESSUREMENTS 6100-1L je korištena za umjeravanje HBM P3MBA prije mjerenja s vagom SARTORIUS LA64001. Kod svih ispitivanja eksperimenti su provedeni za protoke od 0,02 m^3/s do 1,4 m^3/s. Eksperimentalni rezultati se dobro podudaraju s prethodnim ispitivanjima provedenim u Uredu za zakonsko mjeriteljstvo savezne države Baden-Württemberg u Njemačkoj. Rasipanje dobivenih rezultata u cjelokupnom području protoka je unutar 0,25 %. Ponovljivost mjerenja je unutar 0,1 %. Najveći doprinos mjernoj nesigurnosti proizlazi iz mjerenja temperature i vlage zraka u ispitivanom mjerilu protoka plina i u zatvorenom spremniku. Mjerna nesigurnost je manja kod ispitivanja s vagom SARTORIUS LA64001 u odnosu na rezultate zabilježene kod mjerenja s vagom SARTORIUS IS64FG. Ukupna mjerna nesigurnost je manja kada su osjetnici apsolutnog tlaka HBM P3MBA umjeravani uz korištenje tlačne vage PRESSUREMENTS 6100-1L u odnosu na rezultate dobivene upotrebom digitalnog barometra VAISALA PTB 220.

Keywords
Calibration
Gas flow meter
Measurement uncertainty
Weighing method

Ključne riječi
Metoda vaganja
Mjerilo protoka plina
Mjerna nesigurnost
Umjeravanje

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Symbols/Oznake

a_0, a_1, a_2, a_3	- constants obtained by the least square method - konstante izračunate metodom najmanjih kvadrata
C	- ratio of number of pulses per unit of volume, imp./m^3 - broj impulsa po jediničnom volumenu
e	- relative deviation, % - relativno odstupanje
h_a	- humidity of surrounding air, % - vlažnost zraka u okolišu
h_i	- humidity of air in the tested gas flow meter, % - vlažnost zraka u ispitivanom mjerilu protoka plina
h_K	- humidity of air in the container, % - vlažnost zraka u spremniku
h_z	- humidity of air in the bell prover, % - vlažnost zraka u ispitnom zvonu
Δm	- reading of mass on the balance, kg - očitana vrijednost mase na vagi
N_{NB2}	- number of pulses registered at the tested gas flow meter during measurement - broj impulsa registriran na ispitivanom mjerilu protoka plina tijekom mjerenja
p_a	- atmospheric pressure, Pa - atmosferski tlak
p_i	- absolute pressure in the tested gas flow meter, Pa - apsolutni tlak u ispitivanom mjerilu protoka plina
p_k	- absolute pressure of air in the container, Pa - apsolutni tlak zraka u spremniku
P_z	- absolute pressure of air in the bell prover, Pa - apsolutni tlak zraka u ispitnom zvonu
R	- function - funkcija
Q	- volume flow, m^3/s - volumenski protok
ϑ_a	- temperature of surrounding air, °C - temperatura zraka u okolišu
ϑ_i	- temperature of air in the tested gas flow meter, °C - temperatura zraka u ispitivanom mjerilu protoka plina
ϑ_u	- temperature of oil, °C - temperature ulja
ϑ_z	- temperature of air in the bell prover, °C - temperatura zraka u ispitnom zvonu
ϑ_{ZK}	- temperature of air in the container, °C - temperatura zraka u spremniku
u	- absolute uncertainty of ΔV_i - apsolutna nesigurnost od ΔV_i
$u(x_i)$	- absolute uncertainty of the quantities x_i - apsolutna nesigurnost veličina x_i
u_R	- relative uncertainty of ΔV_i - relativna nesigurnost od ΔV_i
ΔV_i	- volume of air which flowed through the tested gas flow meter, m^3 - volumen zraka koji je protekao kroz ispitivano mjerilo protoka plina
ΔV_{NB2}	- volume of air registered at the tested gas flow meter, m^3 - volumen zraka registriran na ispitivanom mjerilu protoka plina
x_i	- variables - varijable
y	- measured quantity - mjerena veličina
ρ	- fluid density, kg/m^3 - gustoća fluida
ρ_{ZK1}	- density of air in the container, kg/m^3 - gustoća fluida u spremniku
ρ_i	- density of air in the tested gas flow meter, kg/m^3 - gustoća fluida u ispitivanom mjerilu protoka plina
ρ_u	- density of oil, kg/m^3 - gustoća ulja
ρ_a	- density of atmospheric air, kg/m^3 - gustoća zraka u okolišu

1. Introduction

The gas flow measurement is an important subject in gas transport and distribution systems. It became even more important over the past few years, as oil and gas prices increased dramatically. Therefore, there was demand to improve precision of gas flow measurements and reduce measurement uncertainty. Among other methods applied in gas flow meters calibration, the weighing method found large acceptance in the engineering community. More details on this method including the calibration technology, characterization and maintenance to measure low gas mass flow can be found in Bair [1]. Although this method is very time-consuming and technique-dependent, it provides a valuable tool in calibration of gas flow meters. However, it is usually not applied for routine calibrations on process instruments or large numbers of transfer standards. Therefore, the laboratory equipment is directly traceable to the fundamental units of mass and time with very low uncertainties.

Recently, significant efforts have been made in the Zagreb Gasworks to improve a gas flow measurement technique and procedures to reduce the measurement uncertainty. In general, approximately 10000 G4 and G6 meters and about 150 G10 to G250 meters have been tested and verified annually. Using the weighing method a calibration of the bell prover and flow meters in a range to 1,4 m^3/h is carried out. Calibration of transfer gas flow standards in a range to 135 m^3/h is performed using the bell prover. Transfer standards are used for calibration of sonic nozzles as well as G10 and G250 standards directly in range to 135 m^3/h. In a range to 400 m^3/h calibration is performed using the “bootstrapping” method, as reported in Pavlović and Kozmar [2, 3]. In Ref. [4] Pavlović reported the calibration of transfer of gas flow standards using the liquid displacement method, where the obtained measurement uncertainty was less than 0,1%. Calibration results for rotary displacement gas meters G16 and G250 were presented in Pavlović and Kozmar [5] and Pavlović et al. [6]. These results suggest the gas flow working standards can be satisfactorily calibrated for flow rates to 400 m^3/h with significantly lower measurement uncertainty compared to previous measurements.

In the Zagreb Gasworks, an existing technique for gas flow meter calibration using the weighing method was improved and measurements were carried out to test its characteristics. Implemented improvements are expected to increase the accuracy and reliability of flow measurements devices. In this study, calibration results for gas flow meter NB2 were presented. In these measurements, the basic calibration system was employed and the characteristics of balances SARTORIUS IS64FG and SARTORIUS LA64001 were compared. The experimental setup and obtained measurement results are presented in the following sections.

Figure 1. System for calibrating gas flow standards in the Zagreb Gasworks

Slika 1. Sustav za umjeravanje etalona protoka plina u Gradskoj plinari Zagreb

2. Laboratory description and experimental procedures

A system for calibration of gas flow working standards in the Zagreb Gasworks is shown in Figure 1.

Using the weighing method, a calibration of the bell prover and gas flow meters for flow rates to 1,4 m^3/h can be performed. Calibration of transfer gas flow standards for flow rates to 135 m^3/h can be performed using the bell prover. Transfer standards are used for calibration of sonic nozzles as well as G16 and G250 standards directly for flow rates to 135 m^3/h. In a range up to 400 m^3/h calibration is performed using the "bootstrapping" method. Traceability chain for experimental procedures presented in the following sections is shown in Figure 2.

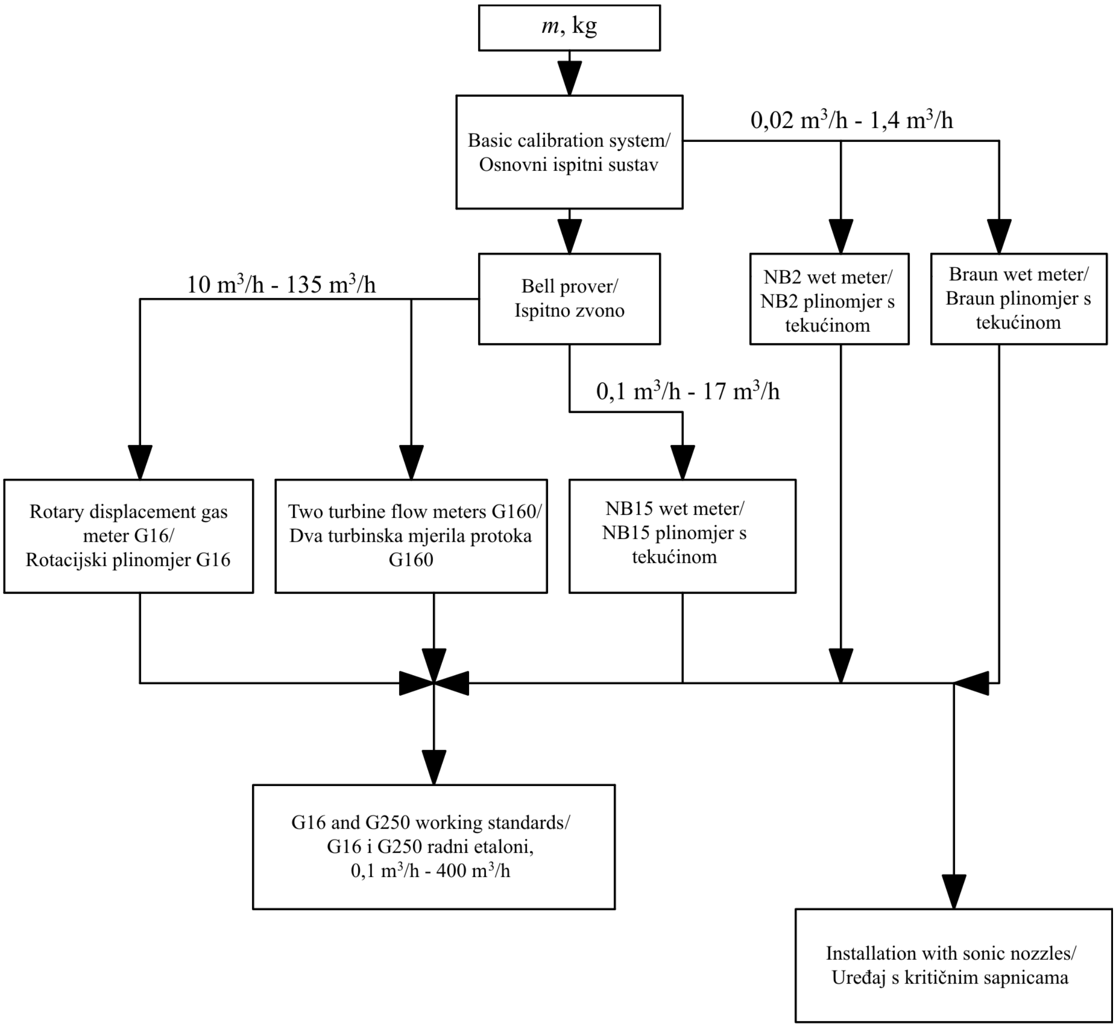

Figure 2. Traceability chain in calibration of gas flow working standards, Laboratory for Gas Flow Measurement in the Zagreb Gasworks

Slika 2. Sljedivost pri umjeravanju radnih etalona protoka plina, Laboratorij za mjerenje protoka plina u Gradskoj plinari Zagreb

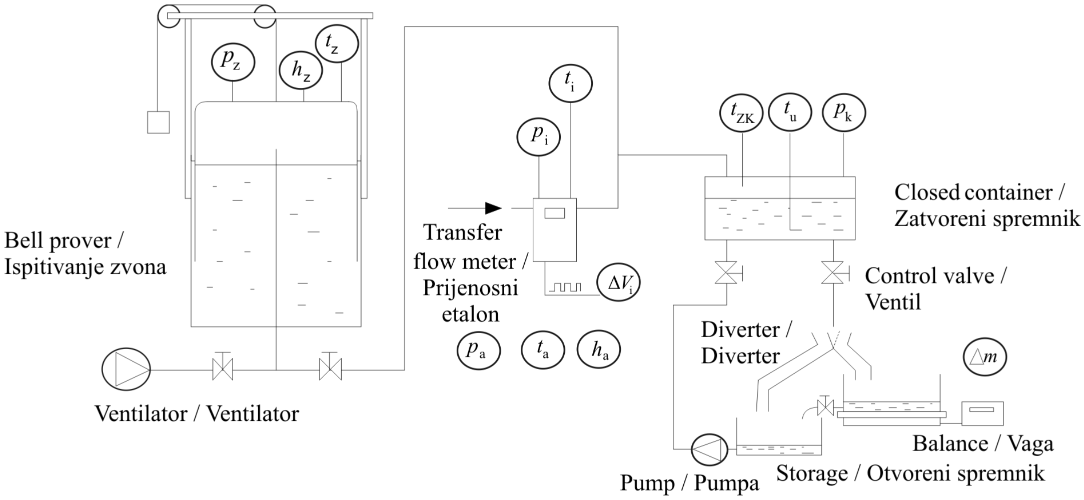

Figure 3. Basic system for calibration of the bell prover and transfer gas flow meters

Slika 3. Osnovni sustav za umjeravanje ispitnog zvona i prijenosnih mjerila protoka plina

2.1. Basic calibration system

The basic calibration system shown in Figure 3 was used to calibrate transfer gas flow standards and the bell prover for flow rates to 1,4 m^3/h. The oil leaves the container being collected in an open tank placed on an electronic balance. The volume of oil flowing out of the container is replaced by an equal volume of air. Since the oil density was known, the volume of oil in an open tank was obtained by weighing. Corrections of buoyancy force and temperature gradients in oil and air were carried out. Temperature variations in the lab were not larger than 0,5 ^{0}C. Main components of this system are a bell prover, transfer wet gas meter, container and an open tank on the balance, which is shown in Figure 3.

The balance SARTORIUS IS64FG with the resolution 1 g was applied for measurements before 2005, while the new balance SARTORIUS LA64001 with resolution 0,1 g was used after 2005. Both balances work in a range up to 64 kg. In this study, they were calibrated using six 10 kg weights of F1 accuracy class, which are traceable to Physikalisch-Technische Bundesanstalt (PTB), Germany. The 70 dm^3 container was placed 2 m above the floor and connected to the outlet of transfer gas flow meter and outlet of the bell prover. The oil leaving the container flows through a control valve and to the diverter. The diverter directs the flow into the open tank on the balance or into the storage. Recorded flow rates were from 0,07 m^3/h to 1,1 m^3/h. Two different measurement procedures can be performed using the basic calibration system; i.e. the calibration of the bell prover and the calibration of the transfer gas flow meter. The measurement process is practically the same for both measurements.

The oil flow from the container to the storage or the balance is regulated using the control valve and a diverter. The manometric pressure in the bell prover is approximately 12 mbar. Before each measurement the balance was tared. Data taken during the measurement were: absolute pressure in the bell prover and gas flow meter, absolute pressure in the container, temperature and humidity of air in the bell prover and gas flow meter, temperature and humidity of air in the container, temperature of oil in the container, flow rates, mass at the balance, atmospheric pressure, temperature and humidity of ambient air.

In measurements with the SARTORIUS IS64FG balance, absolute pressure sensors HBM P3MBA were calibrated using the digital barometer VAISALA PTB 220 traceable to UKAS. Deadweight tester PRESSUREMENTS 6100-1L traceable to NIST was employed for HBM P3MBA calibration in tests with the SARTORIUS LA64001 balance.

Special attention was given to selection of optimal data acquisition parameters, which is very important in performing a satisfactory measurement, as reported in Boršić [7].

2.2. Calibration of transfer gas flow standard

For flow rates larger than 1,4 m^3/h calibration is performed using the measuring system with the bell prover shown in Figure 4, which consists of the bell prover, piping, valves and a tested gas flow meter.

The flow rate can be adjusted with control valves from 0,04 m^3/h to 135 m^3/h. The volume of the bell prover is 1000 dm^3. Tested gas flow meters were the wet meter NB15, the rotary displacement meter G16 and turbine meters G65, G160 and G250.

The basic measurement principle is to compare the volume of air recorded at the meter under test with the volume of air in the bell prover using pressure and temperature corrections.

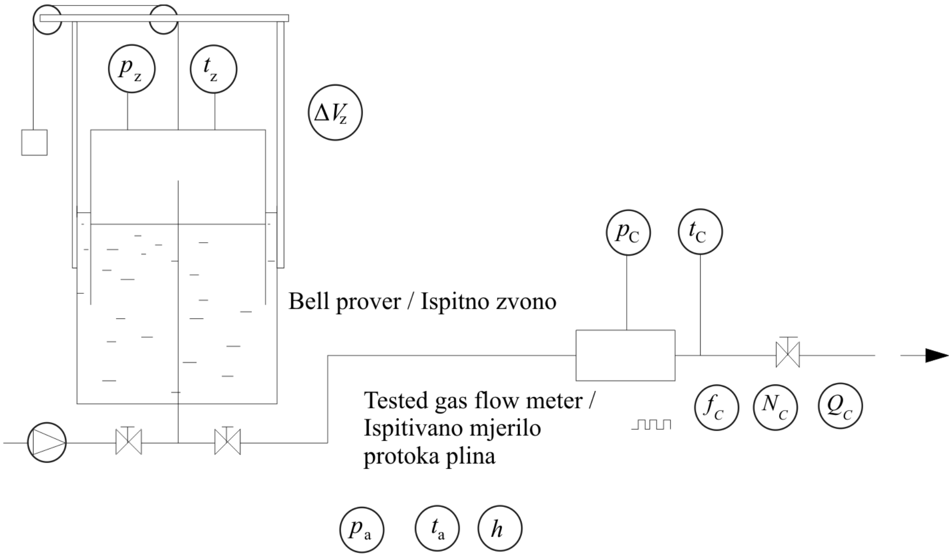

Figure 4. Calibration of transfer gas flow standards using the bell prover

Slika 4. Umjeravanje prijenosnih etalona protoka plina uz korištenje ispitnog zvona

2.3. Calibration of sonic nozzles

Sonic nozzles were calibrated using transfer standards NB2, NB15 and G16. The nominal flow rates for each nozzle were 0,02 m^3/h; 0,04 m^3/h; 0,1 m^3/h; 0,2 m^3/h; 1,0 m^3/h; 2,0 m^3/h; 3,5 m^3/h; 4,5 m^3/h and 6,0 m^3/h. Testing installation shown in Figure 5 consists of a vacuum pump, two blocks of nozzles, connecting pipes, valves, pressure, temperature and humidity sensors.

During calibration, the air flows through a transfer gas flow standard, filter, nozzle and a vacuum pump. Measured physical quantities were the flow rate in transfer gas flow standard, temperature, pressure and humidity.

2.4. Calibration of G16 and G250 working standards

Calibration of G16 working standard was performed using the NB15 transfer standard and another G16 transfer standard. The G250 working standard was calibrated using the NB15 transfer standard and the G16 transfer standard for flow rates to 25 m^3/h. For flow rates from 25 m^3/h to 135 m^3/h the G250 working standard was calibrated using turbine flow meters. In range above 135 m^3/h, the G250 working standard was calibrated using two turbine meters, as shown in Figure 6.

Thereafter, measurements were performed using the turbine meter G160 and the G250 working standard. Now, the G250 was used as a reference, and the G160 was calibrated for flow rates from 135 m^3/h to 210 m^3/h. Finally, the G250 was calibrated for flow rates to 400 m^3/h using two turbine flow meters G160 installed in parallel together with the working standard.

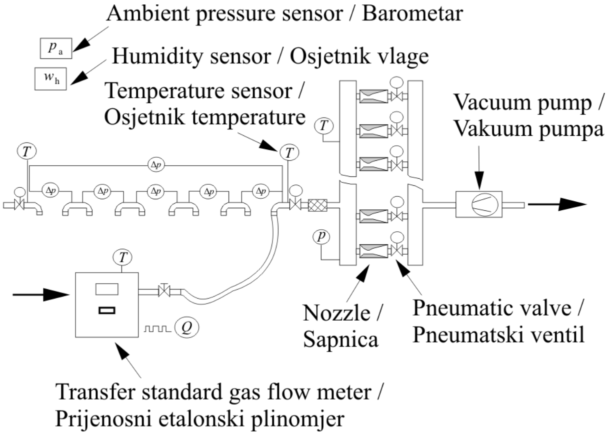

Figure 5. Calibration of sonic nozzles using transfer gas flow standard

Slika 5. Umjeravanje kritičnih sapnica uz korištenje prijenosnog etalona protoka plina

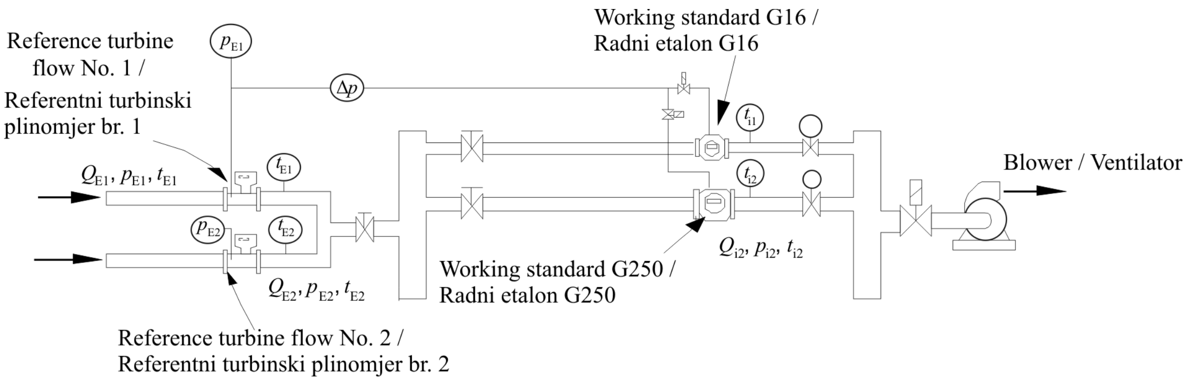

Figure 6. Testing installation for calibration of the G16 and G250 working standards
Slika 6. Ispitna instalacija za umjeravanje radnih etalona G16 i G250

3. Mathematical model and measurement uncertainty

The following assumptions were taken into account in mathematical modelling of the measurement process:

- Variations in pressure and temperature during measurement can be neglected,
- The fluid flow is steady and one-dimensional,
- There is no water-hummer effect at the start and the end of measurements.

The continuity equation in the form suggested by Fancev [8] was applied,

$$\rho Q = \text{const.} \tag{1}$$

The volume of air through the tested gas flow meter is defined as

$$\Delta V_{\mathrm{i}} = \frac{\rho_{\mathrm{ZK1}}}{\rho_{\mathrm{i}}} \frac{1}{\rho_{\mathrm{u}} - \rho_{\mathrm{a}}} \Delta m \,. \tag{2}$$

The oil density was calculated as

$$\rho_{\mathrm{u}} = a_0 + a_1 t_{\mathrm{u}} + a_2 t_{\mathrm{u}}^{\,2} + a_3 t_{\mathrm{u}}^{\,3} \,. \tag{3}$$

The air density in the container, in the tested gas flow meter and in ambient was calculated as suggested in Davis [9].

The air volume in the tested gas flow meter was calculated as

$$\Delta V_{\mathrm{NB2}} = \frac{N_{\mathrm{NB2}}}{C} \,. \tag{4}$$

The relative deviation of the tested gas flow meter was given in the form

$$e = \left(\frac{\Delta V_{\mathrm{NB2}}}{\Delta V_{\mathrm{i}}} - 1 \right) \times 100\% \,. \tag{5}$$

The measurement uncertainty analysis was based on the GUIDE [10] and Figliola and Beasley [11]. It was assumed the measured quantity y was a function of n different variables x_{i} (i = 1, . . . n). This variable y was defined as

$$y = R\,(x_1, x_2, \ldots, x_n). \tag{6}$$

The absolute uncertainty in each of the quantities x_{i} was $u(x_{\mathrm{i}})$. The uncertainty of y is described as

$$u = \sqrt{\sum_{\mathrm{i}=1}^{\mathrm{n}} \left(\frac{\partial R}{\partial x_{\mathrm{i}}} \right)^2 u^2 \left(x_{\mathrm{i}} \right)} \,. \tag{7}$$

The partial derivation $\partial R/\partial x_{\mathrm{i}}$ represents the sensitivity coefficient. $u_{\mathrm{i}}(y)$ is the uncertainty contribution in y due to the individual quantity x_{i}. It can be expressed as:

$$u_{\mathrm{i}} \left(y \right) = \frac{\partial R}{\partial x_{\mathrm{i}}} u \left(x_{\mathrm{i}} \right) . \tag{8}$$

The measurement uncertainty u is the root sum square of the uncertainty contributions $u_{\mathrm{i}}(y)$. In this study, the measurement uncertainty analysis includes:

a) Sensors readouts,
b) Environmental conditions,
c) Variations in measurement conditions.

Some aspects of the rounding of measurement results are presented in Godec [12].

4. Results

Obtained relative deviations for tested gas flow meter NB2 using the weighing method, which was described in section 2.1, are shown in Figure 7.

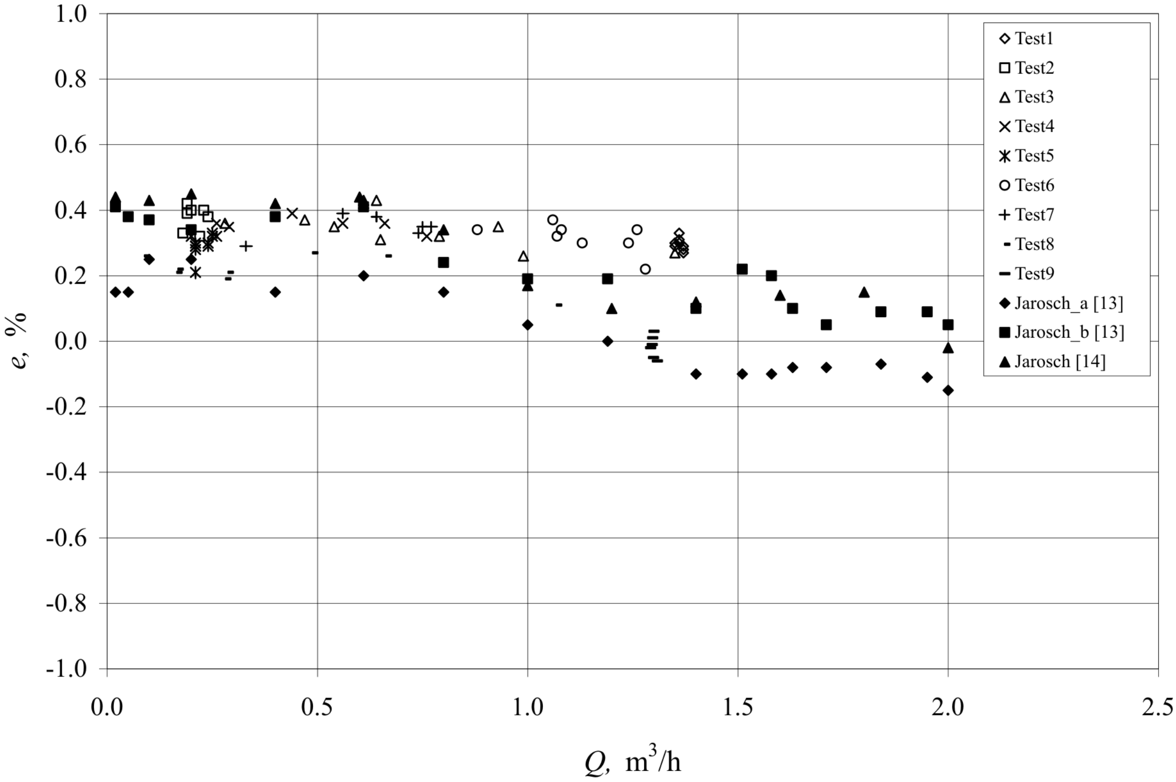

Figure 7. Relative deviations of the tested gas flow meter NB2

Figure 7. Relativno odstupanje ispitivanog mjerila protoka plina NB2

The measurements Test 1 to Test 7 were taken in the Laboratory for Gas Flow Measurements, the Zagreb Gasworks, in 2005 using the balance SARTORIUS IS64FG. Test 8 and Test 9 were carried out in 2008 with the SARTORIUS LA64001 balance. Results were compared with measurements reported in Jarosch [13, 14], as participating in comparison measurements gives an opportunity to validate own experimental results [15]. Relative deviation was calculated as shown in Eq. 5. In general, the obtained results agree well with Jarosch [13, 14], who calibrated the same wet gas flow meter NB2 in the Office of Legal Metrology of the State of Baden-Württemberg, Germany. The spread of own values is within the band of 0,25 % for the overall range of flow rates. Test1 and Test9 were carried out to study the measurement repeatability. Results for each of these tests are within 0,1 %; where the spread for Test9 is slightly larger than in Test 1.

The analysis of measurement uncertainty in tests carried out using the balance SARTORIUS IS64FG (Test 1 to Test 7) was performed for flow rates from 0,02 m^3/s to 1,4 m^3/s. Measurement uncertainties calculated for Test5 at a flow rate of 0,25 m^3/h are presented in Table 1, as representative values for tests with the SARTORIUS IS64FG. It needs to be said that the obtained results differed insignificantly in all these tests for all flow rates.

Table 1. Measurement uncertainties in Test5 for a flow rate of 0,25 m^3/h

Tablica 1. Mjerne nesigurnosti za Test5 pri vrijednosti protoka 0,25 m^3/h

x_i	$\partial(\Delta V_i)/\partial x_i$	$u(x_i)$	$u_i(\Delta V_i)$
p_i, Pa	$5{,}661 \cdot 10^{-7}$	15,000	$8{,}492 \cdot 10^{-6}$
ϑ_i, ^0C	$1{,}668 \cdot 10^{-4}$	$1{,}087 \cdot 10^{-1}$	$1{,}813 \cdot 10^{-5}$
h_i, %	$-5{,}739 \cdot 10^{-4}$	$3{,}007 \cdot 10^{-2}$	$-1{,}726 \cdot 10^{-5}$
p_k, Pa	$-5{,}922 \cdot 10^{-7}$	15,000	$-8{,}883 \cdot 10^{-6}$
ϑ_{ZK}, ^0C	$-1{,}920 \cdot 10^{-4}$	$1{,}000 \cdot 10^{-1}$	$-2{,}460 \cdot 10^{-5}$
ϑ_u, ^0C	$6{,}801 \cdot 10^{-5}$	$1{,}000 \cdot 10^{-1}$	$6{,}801 \cdot 10^{-6}$
h_K, %	$-5{,}874 \cdot 10^{-4}$	$3{,}007 \cdot 10^{-2}$	$-1{,}766 \cdot 10^{-5}$
p_a, Pa	$-6{,}842 \cdot 10^{-10}$	10,20	$-6{,}977 \cdot 10^{-9}$
ϑ_a, ^0C	$-2{,}631 \cdot 10^{-7}$	$1{,}414 \cdot 10^{-1}$	$-3{,}721 \cdot 10^{-8}$
h_a, %	$-7{,}395 \cdot 10^{-7}$	$3{,}007 \cdot 10^{-2}$	$-2{,}224 \cdot 10^{-8}$
Δm, kg	$1{,}175 \cdot 10^{-3}$	$3{,}000 \cdot 10^{-3}$	$3{,}524 \cdot 10^{-6}$
ρ_{ZK1}, kg/m^3	$4{,}324 \cdot 10^{-2}$	$1{,}000 \cdot 10^{-5}$	$4{,}324 \cdot 10^{-7}$
ρ_i, kg/m^3	$-4{,}317 \cdot 10^{-2}$	$1{,}000 \cdot 10^{-5}$	$-4{,}317 \cdot 10^{-7}$
ρ_a, kg/m^3	$5{,}928 \cdot 10^{-5}$	$1{,}000 \cdot 10^{-5}$	$5{,}928 \cdot 10^{-10}$
u, m^3			$4{,}269 \cdot 10^{-5}$
u_R, %			0,085

Table 2 shows measurement uncertainties calculated in Test 8 at the flow rate 0,26 m^3/h. This data was representative for all experiments in Test 8 and Test 9, which were carried out using the SARTORIUS LA64001.

The presented results clearly indicate that the measurement uncertainty in tests with the SARTORIUS LA64001 was smaller than in tests with the SARTORIUS IS64FG. Largest differences in performance of these two balances can be seen in $u_{\Delta m}(\Delta V_{\Delta m})$, which is due to better resolution of the SARTORIUS LA64001 balance. Total measurement uncertainty was reduced when absolute pressure sensors HBM P3MBA were calibrated using the PRESSUREMENTS 6100-1L compared to results obtained with the VAISALA PTB 220. This was due to smaller uncertainty of the PRESSUREMENTS 6100-1L (0,008% of reading) device compared to the VAISALA PTB 220 (0,012%).

Table 2. Measurement uncertainties in Test8 for a flow rate of 0,26 m^3/h

Tablica 2. Mjerne nesigurnosti za Test8 pri vrijednosti protoka 0,26 m^3/h

x_i	$\partial(\Delta V_i)/\partial x_i$	$u(x_i)$	$u_i(\Delta V_i)$
p_i, Pa	$-7,128\cdot 10^{-8}$	13,000	$-9,266\cdot 10^{-7}$
ϑ_i, ${}^0C$	$1.178\cdot 10^{-4}$	$7.287\cdot 10^{-2}$	$8,587\cdot 10^{-6}$
h_i, %	$-3.496\cdot 10^{-4}$	$3,080\cdot 10^{-2}$	$-1,080\cdot 10^{-5}$
p_k, Pa	$5,685\cdot 10^{-8}$	14,000	$7,959\cdot 10^{-7}$
ϑ_{ZK}, ${}^0C$	$-1,246\cdot 10^{-4}$	$7.303\cdot 10^{-2}$	$-9,098\cdot 10^{-6}$
ϑ_u, ${}^0C$	$3.694\cdot 10^{-5}$	$6.468\cdot 10^{-2}$	$2,389\cdot 10^{-6}$
h_K, %	$-3.676\cdot 10^{-4}$	$3,080\cdot 10^{-2}$	$-1,132\cdot 10^{-5}$
p_a, Pa	$9.586\cdot 10^{-11}$	10,05	$9,633\cdot 10^{-10}$
ϑ_a, ${}^0C$	$-1.720\cdot 10^{-7}$	$1,414\cdot 10^{-1}$	$-2,432\cdot 10^{-8}$
h_a, %	$-4.866\cdot 10^{-7}$	$3,080\cdot 10^{-2}$	$-1,499\cdot 10^{-8}$
Δm, kg	$1,170\cdot 10^{-3}$	$3,000\cdot 10^{-4}$	$3,510\cdot 10^{-7}$
ρ_{ZK1}, kg/m^3	$2.969\cdot 10^{-2}$	$1,000\cdot 10^{-5}$	$2,969\cdot 10^{-7}$
ρ_i, kg/m^3	$-2.961\cdot 10^{-2}$	$1,000\cdot 10^{-5}$	$-2,961\cdot 10^{-7}$
ρ_a, kg/m^3	$4.097\cdot 10^{-5}$	$1,000\cdot 10^{-5}$	$4,097\cdot 10^{-10}$
u, m^3			$2,020\cdot 10^{-5}$
u_R, %			0,058

5. Conclusions

The transfer gas flow standard ROMBACH NB2 was calibrated using two different balances, SARTORIUS IS64FG and SARTORIUS LA64001, which were incorporated into the basic calibration system. The basic difference between these two balances is in their resolution, i.e. 1 g for the SARTORIUS IS64FG and 0,1 g for the SARTORIUS LA64001. Before measurements with the SARTORIUS IS64FG balance, absolute pressure sensors HBM P3MBA were calibrated using the digital barometer VAISALA PTB 220. The deadweight tester PRESSUREMENTS 6100-1L was employed for HBM P3MBA calibration before tests with the SARTORIUS LA64001 balance. Tests were carried out for flow rates from 0,02 m^3/s to 1,4 m^3/s.

The results of this study agree well with Jarosch [13, 14], who previously calibrated the same wet gas flow meter NB2. The spread of obtained experimental values is within 0,25 % for the total range of flow rates. The measurement repeatability was within 0,1%. The highest contributions to measurement uncertainty result from the air temperature and humidity in the tested gas flow meter and in the container.

The measurement uncertainty in tests with the SARTORIUS LA64001 was smaller than in tests with the SARTORIUS IS64FG. Total measurement uncertainty was reduced when absolute pressure sensors HBM P3MBA were calibrated using the deadweight tester PRESSUREMENTS 6100-1L compared to results obtained using the VAISALA PTB 220 digital barometer.

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