PROJECT 1125

Evaluation of cross-float measurements with pressure balances

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[1] For full address see Table 1

[2] This protocol is a draft.

1. Context

The calibration of a pressure balance involves determining the values of A_0 and the pressure distortion coefficient λ that define the effective area A_p of the piston-cylinder assembly as a function of pressure. There exist various approaches to determine and estimate the uncertainties of these parameters, with results that may differ significantly. The purpose of this project was to verify numerically the performance of different methods used by the NMI's by applying simulated data sets.

In this first loop, the values of the effective areas and the effective area parameters calculated by each participant - the evaluation of their uncertainties included - are compared. The results is then used to evaluate the appropriateness of the different methods and to make recommendations. As the calculation methods of the NMIs are not the same, some significant deviations can occur between their the calculations of the effective area from the simulated data sets, a second loop that gives the mean value and the uncertainty of the effective areas directly was done in order to ensure the validity of the recommendations.

2. Participants

15 laboratories listed in Table 1 have been included to participate in this comparison. They are listed in alphabetic order along with coordinators for contact.

Table 1. List of participants

Laboratory	Contact Person	Phone Fax	E-mail
Bundesamt für Eich und Vemessungswesen (BEV) Arltgasse 35 A-1160 Wien Austria	Dr. Dietmar Steindl	+43 1 211 10 6362 +43 1 211 10 6000	dietmar.steindl@bev.gv.at
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Institute of Metals and Technology (IMT) Lepi pot 11 SI-1000 Ljubljana Slovenia	Dr. Janez Setina	Tel: +386 1 4701 976 Fax: +386 1 4701 939	janez.setina@imt.si
Istituto Nazionale di Ricerca Metrologica (INRIM) Strada delle Cacce 73 10135 Torino Italy	Dr. Mercede Bergoglio	+39-011-3919-920 +39-011-3919-926	m.bergoglio@inrim.it

Laboratory	Contact Person	Phone Fax	E-mail
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3. Data provided for the comparison

3.1. Description of the given data

Calibration data sets have been simulated: two for a gas calibration in 10 MPa and two for an oil calibration in 500 MPa. All data which are usually recorded during a cross-float and their associated uncertainties are given. The data are the following:

Reference piston-cylinder assembly (PCA)

- piston mass and its uncertainty
- piston density and its uncertainty
- Effective area at null pressure and its uncertainty
- Distorsion coefficient and its uncertainty
- PCA's thermal expansion coefficient and its uncertainty.

Mass set of the reference balance

- list of mass pieces
- their masses and their uncertainties
- their densities and their uncertainties

Calibrated PCA

- piston mass and its uncertainty
- piston density and its uncertainty
- PCA's thermal expansion coefficient and its uncertainty.

Mass set of the calibrated balance

- list of mass pieces
- their masses and their uncertainties
- their densities and their uncertainties

Environmental conditions

- height difference between the reference levels with ist uncertainty;
- uncertainties of: PCAs temperatures, room temperature, air temperature, pressure and humidity.

3.2. Reference data

First of all, arbitrary theoretical values have been defined and considered as true values (with no uncertainty): the effective area at null pressure A_{0c_th} and the distorsion coefficient λ_{c_th} of the calibrated PCAs. These values were fixed considering the experience of the pilot laboratory .

Fluid	**Case**	A_{0c_th} / mm^2	λ_{c_th} /Pa^{-1}
Gas (Nitrogen)	Case 1	49,0189	$-2{,}40 \cdot 10^{-12}$
	Case 2	49,0192	$-2{,}38 \cdot 10^{-12}$
Oil (Sebacate)	Case 1	1,90290	$7{,}79 \cdot 10^{-13}$
	Case 2	1,90292	$7{,}80 \cdot 10^{-13}$

3.3. Data generation procedure

Once the theoretical values were fixed, the calibration data have been generated using the Analysis Toolpak (generation of pseudo-random numbers).

3.3.1. Mass pieces and balance parameters

Concerning the following quantities - the mass pieces, the mass and section of the pistons and of the bells (for both balances) - the distribution law is the normal distribution with

- a given average value of the quantity which is the nominal value
- its standard deviation which corresponds to the uncertainty of the quantity measurement.

For each quantity, systematic errors have been also generated using a normal distribution with an average value of zero and a standard deviation equal to the standard uncertainty of the quantity measurement. Each value is the sum of its related generated value and of the associated systematic error.

Concerning the calibration of the gas balance, the mass pieces are composed of:

- the bell mass

- the piston mass
- the mass of 4 kg
- 9 masses of 5 kg (mass 1 to mass 9).

The application of the mass pieces on the piston is described in Table 2.

Table 2. Appliance of the mass pieces : case of the gas balance calibrations

Nominal pressure */kPa*	**Nominal total masses** */kg*	**Used masses**
200	1,0	Bell mass + Piston mass
1 000	5,0	Bell mass + Piston mass + mass of 4 kg
2 000	10,0	Bell mass + Piston mass + mass of 4 kg + mass 1
3 000	15,0	Bell mass + Piston mass + mass of 4 kg + mass 1 + mass 2
4 000	20,0	Bell mass + Piston mass + mass of 4 kg + mass 1 + mass 2 + mass 3
5 000	25,0	Bell mass + Piston mass + mass of 4 kg + mass 1 + mass 2 + mass 3 + mass 4
6 000	30,0	Bell mass + Piston mass + mass of 4 kg + mass 1 + mass 2 + mass 3 + mass 4 + mass 5
7 000	35,0	Bell mass + Piston mass + mass of 4 kg + mass 1 + mass 2 + mass 3 + mass 4 + mass 5 + mass 6
8 000	40,0	Bell mass + Piston mass + mass of 4 kg + mass 1 + mass 2 + mass 3 + mass 4 + mass 5 + mass 6 + mass 7
10 000	50,0	Bell mass + Piston mass + mass of 4 kg + mass 1 + mass 2 + mass 3 + mass 4 + mass 5 + mass 6 + mass 7 + mass 8 + mass 9

Concerning the calibrations of the oil balances, the mass pieces are composed of:

- the bell mass
- the piston mass
- the mass of 4 kg
- 19 masses of 5 kg (mass 1 to mass 19).

For each cycle, the application of the mass pieces on the piston is described in Table 3.

Table 3. Appliance of the mass pieces : case of the oil balance calibrations

Nominal pressure */MPa*	**Nominal total masses** */kg*	**Used masses**
5	1,0	Bell mass + Piston mass
50	10,0	Bell mass + Piston mass + mass of 4 kg + mass 1
100	20,0	Bell mass + Piston mass + mass of 4 kg + mass 1 + mass 2 + mass 3
150	30,0	Bell mass + Piston mass + mass of 4 kg + mass 1 + mass 2 + mass 3 + mass 4 + mass 5
200	40,0	Bell mass + Piston mass + mass of 4 kg + mass 1 + mass 2 + mass 3 + mass 4 + mass 5 + mass 6 + mass 7
250	50,0	Bell mass + Piston mass + mass of 4 kg + mass 1 + mass 2 + mass 3 + mass 4 + mass 5 + mass 6 + mass 7 + mass 8 + mass 9
300	60,0	Bell mass + Piston mass + mass of 4 kg + mass 1 + mass 2 + mass 3 + mass 4 + mass 5 + mass 6 + mass 7 + mass 8 + mass 9 + mass 10 + mass 11
350	70,0	Bell mass + Piston mass + mass of 4 kg + mass 1 + mass 2 + mass 3 + mass 4 + mass 5 + mass 6 + mass 7 + mass 8 + mass 9 + mass 10 + mass 11 + mass 12 + mass 13
400	80,0	Bell mass + Piston mass + mass of 4 kg + mass 1 + mass 2 + mass 3 + mass 4 + mass 5 + mass 6 + mass 7 + mass 8 + mass 9 + mass 10 + mass 11 + mass 12 + mass 13 + mass 14 + mass 15
500	100,0	Bell mass + Piston mass + mass of 4 kg + mass 1 + mass 2 + mass 3 + mass 4 + mass 5 + mass 6 + mass 7 + mass 8 + mass 9 + mass 10 + mass 11 + mass 12 + mass 13 + mass 14 + mass 15 + mass 16 + mass 17 + mass 18 + mass 19

3.3.2. Environmental conditions

The calibration room is a temperature controlled room. All the calculations have been done considering that the room temperature is T = 20 °C and the hygrometry is H = 50 %HR.

The atmospheric pressure and the PCAs temperatures for each cycle are generated. The atmospheric pressure for each cycle follows a normal law distribution with an average of 1013.25 hPa and a standard deviation of 0.30 hPa. The PCAs temperatures $T_1(cycle\ j)$ at the beginning of each calibration cycle (first pressure point) are generated considering a distribution following the normal law with an average of 20 °C and a standard deviation of 2 °C. At the other pressure points, the PCAs temperatures follow a normal law distribution with an average of $T_1(cycle\ j)$ and a standard deviation of 0.1 °C.

The PCAs height values and their systematic errors have been chosen arbitrarily. However, they are not equal and the systematic error does not exceed the expanded uncertainty which is 3 mm. The PCAs height is the sum of its value and its systematic error.

3.3.3. Determination of the additional masses

The additional masses are then the difference between the sum of the masses pieces applied – that are known without systematic errors – and the sum of the masses that must be applied to establish equilibrium between the pressure balances. As an operator cannot do the equilibrium perfectly, a resolution on the application of these additional masses is applied. See the detailed procedure in annex A.

3.3.4. List of data: general parameters

Quantity	**Value**	**Standard uncertainty**
Room temperature	20,0 °C	The uncertainties of these quantities have not been considered.
Hygrometry	50 %HR	
Local gravity	$9{,}809273\ \text{m.s}^{-2}$	
Tilt of the piston	-	
Linear thermal expansion coefficients (reference or calibrated PCA)	$9{,}0 \cdot 10^{-6}\ °\text{C}^{-1}$	

Two type of balances are considered in this comparison:

A. a gas balance in the range of 0,2 MPa -10 MPa

B. oil balance in the range of 5 MPa -500 MPa.

For each balance, two series of data are generated. They will be treated as two different calibrations.

In case A, the operating gas is nitrogen characterized by its density $\rho_0(N_2)$ at 1013,25 hPa and at 0°C: $\rho_0(N_2) = 1{,}25046\ \text{kg.m}^3$. All calculations should be performed considering the dependence of the nitrogen density on pressure and temperature.

In case B, the operating oil is sebacate, characterized by the following parameters:

Density at 20 °C	$\rho_0(\text{liq})$	$= 912{,}5\ \text{kg.m}^{-3}$
Expansion coefficient	$\beta(\text{liq})$	$= 0{,}714\ \text{kg}\cdot\text{m}^{-3}\cdot°\text{C}^{-1}$
Compressibility coefficient	$z(\text{liq})$	$= 4{,}0 \cdot 10^{-7}\ \text{kg.m}^{-3}.\text{Pa}^{-1}$
Surface tension of the oil	Γ	$= 0{,}0311\ \text{N.m}^{-1}$

All calculations should be performed considering the dependence of the oil density on pressure and temperature. The uncertainty of the medium densities is not considered.

3.3.5. List of data: calibration of gas balance in the range of 0,2 MPa -10 MPa

Case 1

Table 4. Mass pieces given to the participants

Designation	**Nominal value**	**Density** /kg.m^{-3}	**Conventional values associated to the balance under test**	**Conventional values associated to the reference balance**	**Standard uncertainty**
Bell	0,8 kg	5 058	0,800009 9 kg	0,800012 8 kg	2,5 mg
Piston	0,2 kg	8 030	0,200001 6 kg	0,200002 4 kg	1,3 mg
Mass 4 kg	4 kg	7 920	4,000019 6 kg	4,000020 6 kg	3,6 mg
Mass 1 (5 kg)	5 kg	7 920	4,999972 7 kg	4,999995 8 kg	4,6 mg
Mass 2 (5 kg)	5 kg	7 920	4,999971 8 kg	5,000021 4 kg	4,6 mg
Mass 3 (5 kg)	5 kg	7 920	5,000024 2 kg	5,000000 8 kg	4,6 mg
Mass 4 (5 kg)	5 kg	7 920	5,000019 3 kg	5,000011 6 kg	4,6 mg
Mass 5 (5 kg)	5 kg	7 920	4,999954 9 kg	5,000018 0 kg	4,6 mg
Mass 6 (5 kg)	5 kg	7 920	4,999995 6 kg	5,000009 6 kg	4,6 mg
Mass 7 (5 kg)	5 kg	7 920	4,999976 1 kg	4,999979 2 kg	4,6 mg
Mass 8 (5 kg)	5 kg	7 920	4,999972 8 kg	5,000040 7 kg	4,6 mg
Mass 9 (5 kg)	5 kg	7 920	5,000001 6 kg	4,999978 9 kg	4,6 mg

Table 5. Theoretical mass pieces whose values were use as the mean to generates the data (cf. Table 4)

Designation	**Nominal value**	**Density** /kg.m^{-3}	**Conventional values associated to the balance under test**	**Conventional values associated to the reference balance**
Bell	0,8 kg	5 058	0.799992 4 kg	0.800010 8 kg
Piston	0,2 kg	8 030	0.200002 4 kg	0.199999 1 kg
Mass 4 kg	4 kg	7 920	4.000003 4 kg	4.000014 8 kg
Mass 1 (5 kg)	5 kg	7 920	4.999979 6 kg	4.999978 6 kg
Mass 2 (5 kg)	5 kg	7 920	4.999978 6 kg	5.000004 0 kg
Mass 3 (5 kg)	5 kg	7 920	5.000019 2 kg	4.999999 9 kg
Mass 4 (5 kg)	5 kg	7 920	5.000018 5 kg	5.000005 6 kg
Mass 5 (5 kg)	5 kg	7 920	4.999966 7 kg	5.000006 9 kg
Mass 6 (5 kg)	5 kg	7 920	5.000008 4 kg	4.999991 0 kg
Mass 7 (5 kg)	5 kg	7 920	4.999966 7 kg	4.999994 9 kg
Mass 8 (5 kg)	5 kg	7 920	4.999989 4 kg	5.000028 3 kg
Mass 9 (5 kg)	5 kg	7 920	5.000001 4 kg	4.999990 2 kg

Table 6. Additional masses applied on the reference pressure balance to establish equilibrum

Nominal pressure	**$m_{\text{Cycle 1}}$**	**$m_{\text{Cycle 2}}$**	**$m_{\text{Cycle 3}}$**	**$m_{\text{Cycle 4}}$**	**$m_{\text{Cycle 5}}$**
/ kPa	*/ mg*	*/ mg*	*/ mg*	*/ mg*	*/ mg*
200	20	30	0	20	0
1 000	200	240	70	160	40
2 000	420	540	130	340	110
3 000	610	810	180	530	140
4 000	830	1 110	320	710	240
5 000	1 040	1 400	380	920	300
6 000	1 280	1 630	430	1 060	320
7 000	1 440	1 920	540	1 240	370
8 000	1 660	2 140	630	1 420	400
10 000	2 160	2 720	760	1 800	520

Density of the additional masses: 7920 kg/m^3.

Table 7. Description of the reference PCA

Designation	**Nominal value**	**Theoretical value**	**Values associated to the reference balance**	**Standard uncertainty**
A_0	49 mm^2	49,02000 mm^2	49,02005 mm^2	$8{,}0 \cdot 10^{-6} \cdot A_0$
λ	$-2{,}5 \cdot 10^{-12}$ Pa^{-1}	$-2{,}42 \cdot 10^{-12}$ Pa^{-1}	$-2{,}44 \cdot 10^{-12}$ Pa^{-1}	5 %
Calibrated PCA's height		120.2 mm	120 mm	1 mm
Reference PCA's height		35 mm	35 mm	1 mm

Table 8. Environmental pressure

	$P_{\text{Cycle 1}}$	**$P_{\text{Cycle 2}}$**	**$P_{\text{Cycle 3}}$**	**$P_{\text{Cycle 4}}$**	**$P_{\text{Cycle 5}}$**	**Standard uncertainty**
Atmospheric pressure / hPa	1000,64	994,43	1005,53	1000,66	998,45	0,30

Table 9. Reference PCA's temperature in °C

Nominal pressure	**$T_{\text{Cycle 1}}$**	**$T_{\text{Cycle 2}}$**	**$T_{\text{Cycle 3}}$**	**$T_{\text{Cycle 4}}$**	**$T_{\text{Cycle 5}}$**	**Standard uncertainty**
/ kPa	*/ °C*	*/ °C*	*/ °C*	*/ °C*	*/ °C*	*/ °C*
200	21,08	23,20	21,02	22,77	19,46	0,10
1 000	21,05	23,22	21,03	22,76	19,45	0,10
2 000	21,01	23,27	20,98	22,71	19,46	0,10
3 000	21,04	23,18	20,95	22,85	19,45	0,10
4 000	21,01	23,22	21,10	22,72	19,42	0,10
5 000	21,07	23,22	20,97	22,84	19,38	0,10
6 000	21,06	23,22	21,02	22,80	19,47	0,10
7 000	21,03	23,20	21,06	22,72	19,38	0,10
8 000	21,15	23,19	21,03	22,78	19,45	0,10
10 000	21,16	23,25	21,05	22,78	19,44	0,10

Table 10. Calibrated PCA’s temperature in °C

Nominal pressure	$T_{\text{Cycle 1}}$	$T_{\text{Cycle 2}}$	$T_{\text{Cycle 3}}$	$T_{\text{Cycle 4}}$	$T_{\text{Cycle 5}}$	**Standard uncertainty**
/ kPa	*/ °C*	*/ °C*	*/ °C*	*/ °C*	*/ °C*	*/ °C*
200	19,79	20,53	22,67	22,16	21,62	0,10
1 000	19,86	20,57	22,58	22,20	21,64	0,10
2 000	19,66	20,53	22,71	22,23	21,60	0,10
3 000	19,76	20,52	22,66	22,17	21,67	0,10
4 000	19,78	20,49	22,69	22,17	21,49	0,10
5 000	19,88	20,52	22,72	22,17	21,58	0,10
6 000	19,69	20,47	22,69	22,13	21,68	0,10
7 000	19,82	20,54	22,68	22,16	21,65	0,10
8 000	19,83	20,54	22,56	22,14	21,63	0,10
10 000	19,74	20,55	22,72	22,08	21,67	0,10

Case 2

Table 11. Mass pieces given to the participants

Designation	**Nominal value**	**Density** /kg,m^{-3}	**Conventional values associated to the balance under test**	**Conventional values associated to the reference balance**	**Standard uncertainty**
Bell	0,8 kg	5 058	0,8000099 kg	0,8000128 kg	2,5 mg
Piston	0,2 kg	8 030	0,2000016 kg	0,2000024 kg	1,3 mg
Mass 4 kg	4 kg	7 920	4,0000196 kg	4,0000206 kg	3,6 mg
Mass 1 (5 kg)	5 kg	7 920	4,9999727 kg	4,9999958 kg	4,6 mg
Mass 2 (5 kg)	5 kg	7 920	4,9999718 kg	5,0000214 kg	4,6 mg
Mass 3 (5 kg)	5 kg	7 920	5,0000242 kg	5,0000008 kg	4,6 mg
Mass 4 (5 kg)	5 kg	7 920	5,0000193 kg	5,0000116 kg	4,6 mg
Mass 5 (5 kg)	5 kg	7 920	4,9999549 kg	5,0000180 kg	4,6 mg
Mass 6 (5 kg)	5 kg	7 920	4,9999956 kg	5,0000096 kg	4,6 mg
Mass 7 (5 kg)	5 kg	7 920	4,9999761 kg	4,9999792 kg	4,6 mg
Mass 8 (5 kg)	5 kg	7 920	4,9999728 kg	5,0000407 kg	4,6 mg
Mass 9 (5 kg)	5 kg	7 920	5,0000016 kg	4,9999789 kg	4,6 mg

Table 12. Theoretical mass pieces whose values were use as the mean to generates the data (cf. Table 11)

Designation	**Nominal value**	**Density** /kg.m^{-3}	**Conventional values associated to the balance under test**	**Conventional values associated to the reference balance**
Bell	0,8 kg	5 058	0.799992 4 kg	0.800010 8 kg
Piston	0,2 kg	8 030	0.200002 4 kg	0.199999 1 kg
Mass 4 kg	4 kg	7 920	4.000003 4 kg	4.000014 8 kg
Mass 1 (5 kg)	5 kg	7 920	4.999979 6 kg	4.999978 6 kg
Mass 2 (5 kg)	5 kg	7 920	4.999978 6 kg	5.000004 0 kg
Mass 3 (5 kg)	5 kg	7 920	5.000019 2 kg	4.999999 9 kg
Mass 4 (5 kg)	5 kg	7 920	5.000018 5 kg	5.000005 6 kg
Mass 5 (5 kg)	5 kg	7 920	4.999966 7 kg	5.000006 9 kg
Mass 6 (5 kg)	5 kg	7 920	5.000008 4 kg	4.999991 0 kg
Mass 7 (5 kg)	5 kg	7 920	4.999966 7 kg	4.999994 9 kg
Mass 8 (5 kg)	5 kg	7 920	4.999989 4 kg	5.000028 3 kg
Mass 9 (5 kg)	5 kg	7 920	5.000001 4 kg	4.999990 2 kg

Table 13. Additional masses applied on the reference pressure balance to establish equilibrium

Nominal pressure	$m_{\text{Cycle 1}}$	$m_{\text{Cycle 2}}$	$m_{\text{Cycle 3}}$	$m_{\text{Cycle 4}}$	$m_{\text{Cycle 5}}$
/ kPa	*/ mg*	*/ mg*	*/ mg*	*/ mg*	*/ mg*
200	70	50	50	70	50
1 000	410	340	350	360	340
2 000	820	740	770	760	710
3 000	1 210	1 100	1 100	1 090	1 040
4 000	1 640	1 480	1 530	1 500	1 410
5 000	2 060	1 890	1 900	1 920	1 830
6 000	2 420	2 260	2 340	2 220	2 140
7 000	2 910	2 570	2 700	2 640	2 520
8 000	3 280	3 010	3 040	2 950	2 860
10 000	4 020	3 700	3 800	3 700	3 520

Density of the additional masses: 7920 kg/m^3.

Table 14. Description of the reference PCA

Designation	**Nominal value**	**Theoretical value**	**Values associated to the reference balance**	**Standard uncertainty**
A_0	49 mm²	49,02200 mm²	49,02200 mm²	$8{,}0 \cdot 10^{-6} \cdot A_0$
λ	$-2{,}5 \cdot 10^{-12}$ Pa^{-1}	$-2{,}50 \cdot 10^{-12}$ Pa^{-1}	$-2{,}47 \cdot 10^{-12}$ Pa^{-1}	5 %
Calibrated PCA’s height		153 mm	150 mm	1 mm
Reference PCA’s height		31 mm	29 mm	1 mm

Table 15. Environmental conditions

	$P_{Cycle\ 1}$	**$P_{Cycle\ 2}$**	**$P_{Cycle\ 3}$**	**$P_{Cycle\ 4}$**	**$P_{Cycle\ 5}$**	**Standard uncertainty**
Atmospheric pressure / hPa	1005,06	1004,13	1003,59	1002,49	999,91	0,30

Table 16. Reference PCA's temperature in °C

Nominal pressure	**$T_{Cycle\ 1}$**	**$T_{Cycle\ 2}$**	**$T_{Cycle\ 3}$**	**$T_{Cycle\ 4}$**	**$T_{Cycle\ 5}$**	**Standard uncertainty**
/ kPa	*/ °C*	*/ °C*	*/ °C*	*/ °C*	*/ °C*	*/ °C*
200	21,86	21,78	22,31	22,19	21,44	0,10
1 000	21,93	21,75	22,33	22,16	21,38	0,10
2 000	21,95	21,72	22,30	22,19	21,42	0,10
3 000	21,84	21,80	22,29	22,14	21,43	0,10
4 000	21,91	21,74	22,21	22,15	21,46	0,10
5 000	21,87	21,85	22,26	22,26	21,48	0,10
6 000	21,85	21,90	22,37	22,18	21,43	0,10
7 000	21,91	21,70	22,24	22,21	21,39	0,10
8 000	21,90	21,81	22,32	22,13	21,42	0,10
10 000	21,87	21,75	22,35	22,20	21,37	0,10

Table 17. Calibrated PCA's temperature in °C

Nominal pressure	**$T_{Cycle\ 1}$**	**$T_{Cycle\ 2}$**	**$T_{Cycle\ 3}$**	**$T_{Cycle\ 4}$**	**$T_{Cycle\ 5}$**	**Standard uncertainty**
/ kPa	*/ °C*	*/ °C*	*/ °C*	*/ °C*	*/ °C*	*/ °C*
200	20,39	21,13	21,40	21,50	21,12	0,10
1 000	20,39	21,18	21,51	21,49	21,09	0,10
2 000	20,44	21,15	21,28	21,50	21,19	0,10
3 000	20,43	21,07	21,43	21,54	21,13	0,10
4 000	20,44	21,11	21,39	21,57	21,18	0,10
5 000	20,41	21,08	21,42	21,51	21,14	0,10
6 000	20,41	21,04	21,33	21,44	21,12	0,10
7 000	20,40	21,21	21,33	21,44	21,07	0,10
8 000	20,39	21,08	21,37	21,55	21,09	0,10
10 000	20,43	21,10	21,44	21,47	21,02	0,10

3.3.6. List of data: calibration of oil balance in the range of 5 MPa -500 Mpa

Case 1

Table 18. Mass pieces given to the participants

Designation	**Nominal value**	**Density** /kg,m^{-3}	**Conventional values associated to the balance under test**	**Conventional values associated to the reference balance**	**Standard uncertainty**
Bell	0,8 kg	5 058	0,7999962 kg	0,8000007 kg	2,5 mg
Piston	0,2 kg	8 030	0,1999960 kg	0,2000038 kg	1,3 mg
Mass 4 kg	4 kg	7 920	3,9999608 kg	3,9999960 kg	3,6 mg
Mass 1 (5 kg)	5 kg	7 920	4,9999890 kg	4,9999857 kg	4,6 mg
Mass 2 (5 kg)	5 kg	7 920	4,9999886 kg	4,9999928 kg	4,6 mg
Mass 3 (5 kg)	5 kg	7 920	4,9999928 kg	4,9999939 kg	4,6 mg
Mass 4 (5 kg)	5 kg	7 920	5,0000110 kg	4,9999891 kg	4,6 mg
Mass 5 (5 kg)	5 kg	7 920	4,9999891 kg	4,9999784 kg	4,6 mg
Mass 6 (5 kg)	5 kg	7 920	5,0000041 kg	4,9999553 kg	4,6 mg
Mass 7 (5 kg)	5 kg	7 920	4,9999951 kg	4,9999918 kg	4,6 mg
Mass 8 (5 kg)	5 kg	7 920	4,9999994 kg	5,0000338 kg	4,6 mg
Mass 9 (5 kg)	5 kg	7 920	4,9999799 kg	4,9999584 kg	4,6 mg
Mass 10 (5 kg)	5 kg	7 920	4,9999928 kg	4,9999770 kg	4,6 mg
Mass 11 (5 kg)	5 kg	7 920	4,9999828 kg	4,9999539 kg	4,6 mg
Mass 12 (5 kg)	5 kg	7 920	5,0000071 kg	4,9999980 kg	4,6 mg
Mass 13 (5 kg)	5 kg	7 920	4,9999945 kg	4,9999988 kg	4,6 mg
Mass 14 (5 kg)	5 kg	7 920	5,0000285 kg	4,9999651 kg	4,6 mg
Mass 15 (5 kg)	5 kg	7 920	4,9999689 kg	5,0000032 kg	4,6 mg
Mass 16 (5 kg)	5 kg	7 920	5,0000110 kg	5,0000310 kg	4,6 mg
Mass 17 (5 kg)	5 kg	7 920	5,0000012 kg	4,9999956 kg	4,6 mg
Mass 18 (5 kg)	5 kg	7 920	5,0000068 kg	4,9999824 kg	4,6 mg
Mass 19 (5 kg)	5 kg	7 920	4,9999776 kg	4,9999921 kg	4,6 mg

Table 19. Theoretical mass pieces whose values were use as the mean to generates the data (cf. Table 18)

Designation	**Nominal value**	**Density** /kg,m^{-3}	**Conventional values associated to the balance under test**	**Conventional values associated to the reference balance**
Bell	0,8 kg	5 058	0.799992 3 kg	0.800001 4 kg
Piston	0,2 kg	8 030	0.199996 2 kg	0.200001 6 kg
Mass 4 kg	4 kg	7 920	3.999968 2 kg	4.000003 4 kg
Mass 1 (5 kg)	5 kg	7 920	4.999996 8 kg	4.999993 3 kg
Mass 2 (5 kg)	5 kg	7 920	4.999996 3 kg	5.000000 8 kg
Mass 3 (5 kg)	5 kg	7 920	5.000000 7 kg	5.000001 9 kg
Mass 4 (5 kg)	5 kg	7 920	5.000018 7 kg	4.999996 9 kg
Mass 5 (5 kg)	5 kg	7 920	4.999997 1 kg	4.999986 1 kg
Mass 6 (5 kg)	5 kg	7 920	5.000012 1 kg	4.999962 9 kg
Mass 7 (5 kg)	5 kg	7 920	5.000002 8 kg	4.999999 7 kg
Mass 8 (5 kg)	5 kg	7 920	5.000007 4 kg	5.000041 6 kg
Mass 9 (5 kg)	5 kg	7 920	4.999988 0 kg	4.999966 4 kg
Mass 10 (5 kg)	5 kg	7 920	5.000000 6 kg	4.999985 0 kg
Mass 11 (5 kg)	5 kg	7 920	4.999990 8 kg	4.999961 8 kg
Mass 12 (5 kg)	5 kg	7 920	5.000014 9 kg	5.000005 8 kg
Mass 13 (5 kg)	5 kg	7 920	5.000002 4 kg	5.000006 5 kg
Mass 14 (5 kg)	5 kg	7 920	5.000036 7 kg	4.999973 0 kg
Mass 15 (5 kg)	5 kg	7 920	4.999976 8 kg	5.000011 0 kg
Mass 16 (5 kg)	5 kg	7 920	5.000018 9 kg	5.000038 7 kg
Mass 17 (5 kg)	5 kg	7 920	5.000009 2 kg	5.000003 4 kg
Mass 18 (5 kg)	5 kg	7 920	5.000014 5 kg	4.999990 3 kg
Mass 19 (5 kg)	5 kg	7 920	4.999985 3 kg	4.999999 9 kg

Table 20. Additional masses applied on the reference pressure balance to establish equilibrium

Nominal pressure	$m_{\text{Cycle 1}}$	$m_{\text{Cycle 2}}$	$m_{\text{Cycle 3}}$	$m_{\text{Cycle 4}}$	$m_{\text{Cycle 5}}$
/ MPa	*/ mg*	*/ mg*	*/ mg*	*/ mg*	*/ mg*
5	220	160	160	220	160
50	1 100	1 100	1 100	1 400	1 100
100	1 950	2 100	2 250	2 700	2 250
150	3 200	2 800	3 000	3 800	2 800
200	4 000	3 750	4 250	5 500	3 750
250	4 500	4 500	5 100	6 600	5 400
300	5 600	5 250	7 000	7 350	6 650
350	7 200	6 800	7 600	8 800	7 200
400	7 650	8 100	8 100	10 800	8 550
500	9 350	9 900	11 000	12 650	9 900

Density of the additional masses: 7920 kg/m^3.

Table 21. Description of the reference PCA

Designation	**Nominal value**	**Theoretical value**	**Values associated to the reference balance**	**Standard uncertainty**
A_0	1,9 mm^2	1,903100 mm^2	1,903118 mm^2	$1,0 \cdot 10^{-5} \cdot A_0$
λ	$7,8 \cdot 10^{-13}$ Pa^{-1}	$7,81 \cdot 10^{-13}$ Pa^{-1}	$7,43 \cdot 10^{-13}$ Pa^{-1}	5 %
Calibrated PCA’s height		129 mm	129 mm	1 mm
Reference PCA’s height		58 mm	56 mm	1 mm

Table 22. Environmental conditions

	$P_{Cycle\ 1}$	**$P_{Cycle\ 2}$**	**$P_{Cycle\ 3}$**	**$P_{Cycle\ 4}$**	**$P_{Cycle\ 5}$**	**Standard uncertainty**
Atmospheric pressure / hPa	1006,27	1004,28	1002,86	994,55	986,75	0,30

Table 23. Reference PCA's temperature in °C

Nominal pressure	**$T_{Cycle\ 1}$**	**$T_{Cycle\ 2}$**	**$T_{Cycle\ 3}$**	**$T_{Cycle\ 4}$**	**$T_{Cycle\ 5}$**	**Standard uncertainty**
/ MPa	*/ °C*	*/ °C*	*/ °C*	*/ °C*	*/ °C*	*/ °C*
5	19,22	20,27	20,65	22,78	20,46	0,10
50	19,28	20,14	20,60	22,80	20,49	0,10
100	19,21	20,36	20,68	22,81	20,53	0,10
150	19,17	20,21	20,75	22,89	20,47	0,10
200	19,21	20,26	20,57	22,82	20,42	0,10
250	19,18	20,31	20,68	22,75	20,49	0,10
300	19,29	20,32	20,66	22,78	20,45	0,10
350	19,20	20,34	20,66	22,75	20,43	0,10
400	19,23	20,24	20,69	22,81	20,48	0,10
500	19,15	20,22	20,61	22,90	20,53	0,10

Table 24. Calibrated PCA's temperature in °C

Nominal pressure	$T_{\text{Cycle 1}}$	$T_{\text{Cycle 2}}$	$T_{\text{Cycle 3}}$	$T_{\text{Cycle 4}}$	$T_{\text{Cycle 5}}$	**Standard uncertainty**
/ MPa	*/ °C*	*/ °C*	*/ °C*	*/ °C*	*/ °C*	*/ °C*
5	20,46	21,81	20,67	20,44	21,21	0,10
50	20,52	21,78	20,68	20,41	21,26	0,10
100	20,41	21,93	20,64	20,42	21,18	0,10
150	20,46	21,77	20,70	20,45	21,20	0,10
200	20,41	21,79	20,67	20,46	21,19	0,10
250	20,47	21,80	20,78	20,52	21,28	0,10
300	20,46	21,91	20,67	20,48	21,13	0,10
350	20,39	21,87	20,67	20,47	21,20	0,10
400	20,45	21,81	20,68	20,41	21,20	0,10
500	20,42	21,73	20,59	20,40	21,26	0,10

Case 2

Table 25. Mass pieces

Designation	**Nominal value**	**Density** /kg,,m^{-3}	**Conventional values associated to the balance under test**	**Conventional values associated to the reference balance**	**Standard uncertainty**
Bell	0,8 kg	5 058	0,8000009 kg	0,7999840 kg	2,5 mg
Piston	0,2 kg	8 030	0,1999987 kg	0,1999997 kg	1,3 mg
Mass 4 kg	4 kg	7 920	3,9999804 kg	4,0000172 kg	3,6 mg
Mass 1 (5 kg)	5 kg	7 920	5,0000143 kg	5,0000231 kg	4,6 mg
Mass 2 (5 kg)	5 kg	7 920	5,0000241 kg	5,0000130 kg	4,6 mg
Mass 3 (5 kg)	5 kg	7 920	5,0000130 kg	5,0000113 kg	4,6 mg
Mass 4 (5 kg)	5 kg	7 920	4,9999792 kg	4,9999924 kg	4,6 mg
Mass 5 (5 kg)	5 kg	7 920	4,9999826 kg	5,0000119 kg	4,6 mg
Mass 6 (5 kg)	5 kg	7 920	5,0000131 kg	5,0000272 kg	4,6 mg
Mass 7 (5 kg)	5 kg	7 920	4,9999930 kg	5,0000045 kg	4,6 mg
Mass 8 (5 kg)	5 kg	7 920	4,9999438 kg	5,0000381 kg	4,6 mg
Mass 9 (5 kg)	5 kg	7 920	4,9999809 kg	5,0000537 kg	4,6 mg
Mass 10 (5 kg)	5 kg	7 920	4,9999802 kg	5,0000294 kg	4,6 mg
Mass 11 (5 kg)	5 kg	7 920	4,9999921 kg	4,9999732 kg	4,6 mg
Mass 12 (5 kg)	5 kg	7 920	5,0000076 kg	5,0000081 kg	4,6 mg
Mass 13 (5 kg)	5 kg	7 920	4,9999913 kg	5,0000207 kg	4,6 mg
Mass 14 (5 kg)	5 kg	7 920	5,0000023 kg	5,0000707 kg	4,6 mg
Mass 15 (5 kg)	5 kg	7 920	5,0000007 kg	4,9999862 kg	4,6 mg
Mass 16 (5 kg)	5 kg	7 920	4,9999884 kg	5,0000025 kg	4,6 mg
Mass 17 (5 kg)	5 kg	7 920	4,9999819 kg	5,0000007 kg	4,6 mg
Mass 18 (5 kg)	5 kg	7 920	5,0000087 kg	4,9999995 kg	4,6 mg
Mass 19 (5 kg)	5 kg	7 920	5,0000023 kg	5,0000081 kg	4,6 mg

Table 26. Theoretical mass pieces whose values were use as the mean to generates the data (cf. Table 25)

Designation	**Nominal value**	**Density** /kg,m^{-3}	**Conventional values associated to the balance under test**	**Conventional values associated to the reference balance**
Bell	0,8 kg	5 058	0.800001 6 kg	0.799986 0 kg
Piston	0,2 kg	8 030	0.199999 5 kg	0.199999 2 kg
Mass 4 kg	4 kg	7 920	3.999985 1 kg	4.000010 4 kg
Mass 1 (5 kg)	5 kg	7 920	5.000021 8 kg	5.000021 8 kg
Mass 2 (5 kg)	5 kg	7 920	5.000031 0 kg	5.000012 7 kg
Mass 3 (5 kg)	5 kg	7 920	5.000019 7 kg	5.000010 0 kg
Mass 4 (5 kg)	5 kg	7 920	4.999987 1 kg	4.999991 3 kg
Mass 5 (5 kg)	5 kg	7 920	4.999989 6 kg	5.000011 8 kg
Mass 6 (5 kg)	5 kg	7 920	5.000020 6 kg	5.000026 1 kg
Mass 7 (5 kg)	5 kg	7 920	5.000000 3 kg	5.000003 3 kg
Mass 8 (5 kg)	5 kg	7 920	4.999950 4 kg	5.000036 8 kg
Mass 9 (5 kg)	5 kg	7 920	4.999989 1 kg	5.000051 5 kg
Mass 10 (5 kg)	5 kg	7 920	4.999988 0 kg	5.000028 5 kg
Mass 11 (5 kg)	5 kg	7 920	4.999999 7 kg	4.999972 4 kg
Mass 12 (5 kg)	5 kg	7 920	5.000015 6 kg	5.000005 9 kg
Mass 13 (5 kg)	5 kg	7 920	4.999999 2 kg	5.000019 3 kg
Mass 14 (5 kg)	5 kg	7 920	5.000009 9 kg	5.000069 3 kg
Mass 15 (5 kg)	5 kg	7 920	5.000006 7 kg	4.999984 8 kg
Mass 16 (5 kg)	5 kg	7 920	4.999995 8 kg	5.000001 0 kg
Mass 17 (5 kg)	5 kg	7 920	4.999989 2 kg	4.999996 6 kg
Mass 18 (5 kg)	5 kg	7 920	5.000016 1 kg	4.999998 0 kg
Mass 19 (5 kg)	5 kg	7 920	5.000010 4 kg	5.000006 9 kg

Table 27. Additional masses applied on the reference pressure balance to establish equilibrium

Nominal pressure	$m_{\text{Cycle 1}}$	$m_{\text{Cycle 2}}$	$m_{\text{Cycle 3}}$	$m_{\text{Cycle 4}}$	$m_{\text{Cycle 5}}$
/ MPa	*/ mg*	*/ mg*	*/ mg*	*/ mg*	*/ mg*
5	220	220	220	220	160
50	1 100	1 100	1 200	1 000	1 100
100	1 800	2 400	2 400	1 950	1 950
150	2 800	3 600	3 200	2 400	3 200
200	4 250	4 750	4 750	3 250	4 250
250	4 500	5 700	5 400	4 500	4 800
300	5 950	6 650	5 950	5 250	5 950
350	6 400	8 400	8 000	5 600	6 800
400	8 100	9 000	8 550	6 750	7 200
500	10 450	11 000	10 450	8 800	9 350

Density of the additional masses: 7920 kg/m^3.

Table 28. Description of the reference PCA

Designation	**Nominal value**	**Theoretical value**	**Values associated to the reference balance**	**Standard uncertainty**
A_0	1,9 mm^2	1,903100 mm^2	1,903100 mm^2	$1{,}0 \cdot 10^{-5} \cdot A_0$
λ	$7{,}8 \cdot 10^{-13}$ Pa^{-1}	$7{,}81 \cdot 10^{-13}$ Pa^{-1}	$7{,}81 \cdot 10^{-13}$ Pa^{-1}	5 %
Calibrated PCA’s height		48 mm	50 mm	1 mm
Reference PCA’s height		32 mm	29 mm	1 mm

Table 29. Environmental conditions

	$P_{Cycle\ 1}$	**$P_{Cycle\ 2}$**	**$P_{Cycle\ 3}$**	**$P_{Cycle\ 4}$**	**$P_{Cycle\ 5}$**	**Standard uncertainty**
Atmospheric pressure / hPa	1003,45	1001,79	999,39	1001,18	988,41	0,30

Table 30. Reference PCA’s temperature in °C

Nominal pressure	**$T_{Cycle\ 1}$**	**$T_{Cycle\ 2}$**	**$T_{Cycle\ 3}$**	**$T_{Cycle\ 4}$**	**$T_{Cycle\ 5}$**	**Standard uncertainty**
/ MPa	*/ °C*	*/ °C*	*/ °C*	*/ °C*	*/ °C*	*/ °C*
5	21,53	22,79	22,31	21,55	21,94	0,10
50	21,53	22,77	22,28	21,51	21,88	0,10
100	21,52	22,85	22,28	21,51	21,98	0,10
150	21,52	22,82	22,34	21,57	21,87	0,10
200	21,50	22,82	22,33	21,56	21,92	0,10
250	21,48	22,79	22,35	21,53	21,85	0,10
300	21,50	22,83	22,29	21,61	21,97	0,10
350	21,36	22,72	22,33	21,61	21,94	0,10
400	21,51	22,76	22,37	21,50	21,89	0,10
500	21,60	22,78	22,31	21,61	21,96	0,10

Table 31. Calibrated PCA's temperature in °C

Nominal pressure	$T_{\text{Cycle 1}}$	$T_{\text{Cycle 2}}$	$T_{\text{Cycle 3}}$	$T_{\text{Cycle 4}}$	$T_{\text{Cycle 5}}$	**Standard uncertainty**
/ MPa	*/ °C*	*/ °C*	*/ °C*	*/ °C*	*/ °C*	*/ °C*
5	21,12	20,08	20,74	22,53	21,45	0,10
50	21,08	20,09	20,78	22,57	21,51	0,10
100	21,10	20,01	20,75	22,56	21,47	0,10
150	21,10	20,13	20,69	22,54	21,40	0,10
200	21,10	20,15	20,68	22,45	21,57	0,10
250	21,09	20,09	20,80	22,59	21,42	0,10
300	21,19	20,10	20,78	22,57	21,46	0,10
350	21,13	20,09	20,76	22,60	21,46	0,10
400	21,11	20,00	20,71	22,49	21,50	0,10
500	21,17	20,15	20,68	22,51	21,37	0,10

3.4. Calculation methods of the participants

3.4.1. Description of the reported results

Results had to be reported to the pilot lab before the week 38 (20/09/2010 – 24/09/2010). All information that had to be sent to the pilot lab is listed below:

1. The effective area A_p of the calibrated piston-cylinder assemblies as a function of pressure (calculated from the simulated data provided in the tables 4-27)
2. The uncertainty of the effective area A_p: $u(A_p)$,
3. The estimate $\hat{A}_p$ of A_p: $\hat{A}_p = A_0\cdot(1+\lambda\cdot P) = A_0+\beta\cdot P$,
4. The standard uncertainties of the estimate: $u(\hat{A}_p)$.

Besides, the effective area parameters of the calibrated piston cylinder assemblies must be provided. It includes the calculated effective area at null pressure A_0 and the calculated pressure distortion coefficient λ including their uncertainties. If it is relevant in their calculations, the covariance between both parameters A_0 and β must be provided.

3.4.2. Calculation of A_p according to the EM/cg/03.01/p March 2010

The effective area Ap was calculated by using the equation (1).

$$p_\mathrm{j} = \frac{\sum_i m_{ci}\cdot \varPhi \cdot g + \varGamma \cdot C}{A_\mathrm{pj}\cdot\left[1+(\alpha_\mathrm{p}+\alpha_\mathrm{c})(t_j - t_0)\right]} + (\rho_\mathrm{f\_j} - \rho_\mathrm{a})\cdot g \cdot \varDelta h \tag{1}$$

Where

Γ	is the surface tension of the fluid (for gas: $\Gamma = 0$)
C	is the circumference of the piston or its extension in the level where it emerges from oil
g	is the local gravity
p_j	is the gauge pressure measured at the reference level of the piston (pressure point j)
m_{ci}	is the individual conventional mass value of each weight applied on the piston, including all floating elements
ρ_0a	is the conventional value of the air density, $\rho_\mathrm{0a} = 1.2$ kg/m^3
ρ_0	is the conventional value of the mass density, $\rho_0 = 8000$ kg/m^3
ρ_a	is the density of air
ρ_{mi}	is the density of each weight
$\rho_\mathrm{f\_j}$	is the density of the measuring fluid at the pressure point p_j
α_p	is the linear thermal expansion coefficient of the piston
α_c	is the linear thermal expansion coefficient of the cylinder
t_j	is the measured temperature of the piston-cylinder assembly during its use for the pressure point j in °C
t_0	is the reference temperature of the piston-cylinder assembly (20 °C)
A_pj	is the effective area of the piston-cylinder assembly at a reference temperature t_0 and at pressure p_j
Δh	is the difference between the altitude h1 of the balance reference level and the altitude h2 of the point where the pressure has to be measured: $\Delta h = h_1 - h_2$
Φ	is a correction factor which compensate the difference between the actual density of the weights material ρ_m and the conventional density of 8000 kg/m3

The dependence of the effective area with the measured pressure is given by the following equation:

$$A_p = A_0 + \beta \cdot p = A_0 \cdot (1 + \lambda \cdot p) \qquad (2)$$

3.4.3. Methods applied by BEV

The Calculation was done by calculating each value of A(p) of the test PC according to the realized pressure of the reference pressure balance using the equation (1). The values for pressure were corrected for the height differences between the reference balance and the balance under test. The density was corrected on pressure and temperature. The results of each value of $A_p(p)$ were linearized (linear Function, regression) by the ordinary least square fit method. The A_0 was calculated according to the linear function.

3.4.4. Methods applied by CEM

Our calculation method is based on JCGM 100:2008 “Evaluation of measurement data — Guide to the expression of uncertainty in measurement” (September 2008) (see example H.3.1):

The effective area $A_p(p)$ is a linear function of pressure. This can be considered the case when the deviations of $A_p(p)$ from the best fit straight line of $(A_{pj};p_j)$ are comparable with the standard deviations of $A_{pj}(p)$ calculated at each nominal reference pressure. Then noting A_0 the effective area at null pressure and λ - the pressure distortion coefficient of the piston-cylinder assembly $A_p(p)$ can be presented by equation:

$$A_p = A_0 \cdot (1 + \lambda \cdot p)$$

where A_0 and λ are defined by expressions:

$$A_0 = \frac{\sum p_j^2 \sum A_{pj} - \sum p_j \sum p_j A_{pj}}{N \sum p_j^2 - \left(\sum p_j\right)^2} \text{ and } \lambda = \theta_1 / A_0$$

With θ_1 being the slope of the linear fit:

$$\theta_1 = \frac{N\sum p_j A_{\mathrm{p}j} - \sum p_j \sum A_{\mathrm{p}j}}{N\sum p_j^2 - \left(\sum p_j\right)^2}.$$

The type A standard uncertainties of A_0, λ and A_{p} corresponding to the distribution of $A_{\mathrm{p}j}$ around the fit function $A_{\mathrm{p}}(p)$ are calculated from the variances and the covariance of A_0 and θ_1, $V(A_0)$, $V(\theta_1)$ and $\mathrm{cov}(A_0, \theta_1)$:

$$u_{\mathrm{A}}(A_0) = \left[V(A_0)\right]^{0.5}$$

$$u_{\mathrm{A}}(\lambda) = \left[\left(V(\theta_1)/A_0{}^2\right) + \left(V(A_0)\cdot\theta_1^2/A_0^4\right) - 2\cdot\mathrm{cov}(A_0,\theta_1)\cdot\theta_1/A_0^3\right]^{0.5}$$

$$u_{\mathrm{A}}(A_{\mathrm{p}}) = \left[V(A_0) + V(\theta_1)\cdot p^2 + 2\,\mathrm{cov}(A_0,\theta_1)\cdot p\right]^{0.5}$$

with

$$V(A_0) = \frac{\sum p_j^2}{N\sum p_j^2 - \left(\sum p_j\right)^2}\cdot\frac{\sum\left(A_{\mathrm{p}j} - A_0 - \theta_1\cdot p_j\right)^2}{N-2}$$

$$V(\theta_1) = \frac{N}{N\sum p_j^2 - \left(\sum p_j\right)^2}\cdot\frac{\sum\left(A_{\mathrm{p}j} - A_0 - \theta_1\cdot p_j\right)^2}{N-2}$$

$$\mathrm{cov}(A_0,\theta_1) = \frac{-\sum p_j}{N\sum p_j^2 - \left(\sum p_j\right)^2}\cdot\frac{\sum\left(A_{\mathrm{p}j} - A_0 - \theta_1\cdot p_j\right)^2}{N-2}$$

For type B uncertainty the maximum (among all pressure values) type B combined uncertainty has been calculated and used as Type B uncertainty for A_0. The uncertainty has been obtained from the previous loop results.

The reference piston cylinder assembly λ standard relative uncertainty (5 %) has been used as Type B uncertainty for λ.

3.4.5. Methods applied by EIM

Calculation of A_p and its uncertainty

The effective area Ap was calculated by using equation (1). For the gas cases, density of nitrogen was estimated according to the expression :

$\rho(N_2)|$ T,P $= \rho_0(N_2)\ (P/P_0)\ (T_0/T)$

where :

$\rho(N_2)|$ T,P	: density at pressure P and temperature T
ρ_0(N2)	: 1,25046 kg.m^{-3}
P_0	: 1013,25 hPa
T_0	: 273,15 K

The uncertainty from using the above formula was taken to be 5% (rectangular distribution) - for pressures up to 100 bar, based on RUSKA recommendation of 3% uncertainty for pressures up to 70 bar – to be combined with uncertainties in fluid temperature and pressure, through the use of the law of propagation of uncertainties. The equation used for oil density was ρ(P,T) = 912,5 + ß(20-T) + z(Pgauge), with T in 0C and Pgauge in Pa, with no uncertainty, as proposed in the protocol.

The formula used for estimating air density is

$$\rho_a = \frac{0{,}34848\, P_{bar} - 0{,}009024\,(\mathrm{RH})\,\exp(0{,}0612\,\mathrm{T}_{air})}{273{,}15 + T_{air}}$$

as proposed by OIML R 111-1 (2004) , appendix E, par. E.3, with relative error u(ρa)/ρa < 2.E-4 (for 900 mbar≤ Pbar ≤ 1100 mbar, RH≤ 80% και 10 oC ≤ Tair ≤ 30 oC), combined with uncertainty in barometric pressure (no uncertainties for temperature & relative humidity) through the use of the law of propagation of uncertainties. No uncertainties were considered for quantities for which there was no provision for an explicit uncertainty figure.

Due to the relatively big differences (in the oil cases) between the nominal and the Final Calculated Reference Pressure Value (FCRPV), the effective area was not calculated at the nominal pressure, but at the FCRPV. To do this, calculations with the nominal value were carried out as a first "estimate" to calculated an effective area and a reference pressure value. The latter is then used as a better "estimate" to recalculate a new effective are and subsequently a better (and final) FCRPV. "Convergence" was very quick and no more "iterations" were necessary.

Estimation of A_p and its uncertainty

The non-weighted least squares method was used to obtain the best straight line fit of Ap vs P, as proposed in [5]. The FCRPV (not the nominal pressure values) were used to obtain the best straight line fit in all cases (gas & oil). According to EIM, there are small differences in the final results (Ao & λ), even by varying P (x-axis) a lot. Ao in particular, was very insensitive.

Âp was provided for both the nominal pressures, as well as for FCRPV. Apparently there are small differences and the latter will be the considered data in this report.

Besides cov(Ao, θ), the term cov(Ao, λ) is also provided according to GUM, par. F.1.2.3. Considering Ao=Ao & λ = θ/Ao:

$$\mathrm{cov}(\mathrm{Ao},\lambda) = \frac{\partial \mathrm{Ao}}{\partial Ao}\frac{\partial \lambda}{\partial Ao}u^2(Ao) + \frac{\partial Ao}{\partial \theta}\frac{\partial \lambda}{\partial \theta}u^2(\theta) = -\frac{\theta}{Ao^2}u^2(Ao)$$

where u(Ao) is estimated as $u_A(A_0) = [N \cdot V(A_0)]^{0.5}$ by using equation (A.8) of [5], type A contributions and u(λ) is estimated as $u_A(\lambda) = [N \cdot V(\theta_1)]^{0.5}/A_0$ by using equation (A.9) of [5], type A contributions.

3.4.6. Methods applied by DANIAmet – Force

The effective area Ap was calculated by using equation (1). The calculation of the air density was calculated according to [8]. C is expressed by:

$$c = 2 \cdot \sqrt{\pi \cdot A_{0,nom} \cdot \left(1 + (\alpha_p + \alpha_c) \cdot (T - 20)\right)} \tag{4}$$

The dependence of the effective area with the measured pressure is given by the equations (2) and (3). A_0, λ are calculated from the weighed least-squares straight line (WLS).

3.4.7. Methods applied by FSB-LPM

<u>*Calculation of A_p and its uncertainty*</u>

LPM Computing method used to determine the effective area with the associated uncertainty of the piston-cylinder assembly of a pressure balance is mostly based on EURAMET Calibration Guide (draft) with some simplifications. Simplifications are mostly related to determination of uncertainty of effective area at null pressure $u(A_0)$.

The effective area Ap was calculated by using equation (1). A_p is calculated as mean effective area (n=5) at each reference pressure. $u(A_p)$ is calculated as combination of Type A, u_{ApA} and Type B, u_{ApB} uncertainties at each reference pressure:

$$u(A_p) = \sqrt{u_{ApA}{}^2 + u_{ApB}{}^2}$$

$$u_{ApA} = \sqrt{\frac{1}{n-1} \cdot \sum_{i=1}^{n} \left(Ap - \overline{Ap}\right)^2}$$

$$u_{ApB} = \sqrt{\left(\frac{\partial A}{\partial p_e} \cdot u_{pe}\right)^2 + \left(\frac{\partial A}{\partial M} \cdot u_M\right)^2 + \left(\frac{\partial A}{\partial t} \cdot u_t\right)^2 + \left(\frac{\partial A}{\partial 2\alpha} \cdot u_{2\alpha}\right)^2 + \left(\frac{\partial A}{\partial \rho_m} \cdot u_{\rho m}\right)^2}$$

$$= \sqrt{\left(\left(\frac{u_{pe}}{p_e}\right)^2 + \left(\frac{u_M}{M}\right)^2 + (2\alpha \cdot u_t)^2 + (\Delta t \cdot u_{2\alpha})^2 + \left(\frac{\rho_a}{\rho_m{}^2} \cdot u_{\rho m}\right)^2\right) \cdot A_e{}^2}$$

Where u_{pe} is uncertainty of reference pressure (index E pertains to reference balance):

$$
\begin{aligned}
\left(u_{pe}\right)^2 = {} & u^2(\lambda)_E \cdot p^4 + \\
& \left(\begin{array}{l}
\left(\dfrac{u(m)_E}{m_E}\right)^2 + \left(\dfrac{u(\rho_a)_E}{\rho_{mE}}\right)^2 + \left(\dfrac{u(A_e)_E}{A_{eE}}\right)^2 + \\
+\left(2\alpha \cdot u\left(\Delta t\right)_E\right)^2 + \left(\Delta t \cdot u\left(2\alpha\right)_E\right)^2 \\
+\left(\dfrac{\rho_a}{\rho_{m_E}{}^2} \cdot u\left(\rho_{mE}\right)\right)^2
\end{array}\right) \cdot p_e{}^2 \\
& +\left(g \cdot \left(\rho_{fl} - \rho_a\right) \cdot u(\Delta h)\right)^2
\end{aligned}
$$

The dependence of the effective area with the measured pressure is given by the equation (2). A_0, λ are calculated from the ordinary least-squares straight line.

Estimation of A_p and its uncertainty

It is assumed that effective area is a linear function of pressure (see Section 3.4.1) and the fitting parameters will be calculated by applying the ordinary least square method (OLS).

The uncertainty of effective area at null pressure $u(A_0)$ is determined as average value of all $u(Ap)$ values. The uncertainty of pressure distortion coefficient λ is the same as uncertainty of reference balance distortion coefficient. The uncertainty of the estimation of A_p is considered equal to the uncertainty of A_0.

3.4.8. Methods applied by IMBiH

All the calculations were done according to [5]. Their procedures were developed in the framework of educations and knowledge transfer from Institute of metals and technology (IMT) in Slovenia. Therefore, the applied methods are similar to the methods presented in Section 3.4.9.

3.4.9. Methods applied by IMT

All the calculations were done according to [5]. A_0 and λ are calculated applying the ordinary least square method as presented in [5]. The reported uncertainties of Ao and lambda coefficient are only Type A contribution as were obtained according to Appendix A of the Guide. IMT don’t usually give a combined uncertainty (type A + type B) separately for Ao and lambda but IMT gives a formula to calculate uncertainty of Ap according to Appendix B (section B.5 of [5]).

3.4.10. Methods applied by INRIM [6]

Calculation of A_p and its uncertainty

The effective area *Ap* was calculated by using equation (1).

Estimation of A_p and its uncertainty

The trend of *Ae* versus pressure shows an acceptable linearity and a polynomial function of *m=1* degree is enough to describe it:

$$Ae = A_0 (1+\lambda p) = \beta_0 + \beta_1 p.$$

where β and β_1 are the polynomial coefficients $\beta_0 = Ao$ and $\beta_1 = A_0 \lambda$

The *Ae* data versus pressure were fitted by using generalized least square method. The correlations between the measurements of different pressure points are due to the common components of uncertainty arising from systematic effects. The results, obtained minimizing the χ^2 of the fit, allow to derive *A*o, λ, their uncertainty and covariance.

The multivariate measurement model specifies a relationship between the output quantity $\mathbf{p}=(p_1,\ldots p_{10})^T$ and input quantity $\mathbf{X} = (Mi, Ao, \lambda, \Delta t_i, \rho_a, \rho_m, \rho_f, \Delta h, g)^T$ and its form is:

$$\mathbf{h_j(Y,X)} = (p-g\,\rho_f\,\Delta h)\,Ao\,(1+\lambda\,p)(1+\alpha\,\Delta t_j) - M_i\,g\,(1-(\rho_a/\rho_m)) = 0 \qquad (5)$$

The estimate of p_i is obtained by solving equation (5) where the estimates of the quantities Mi, Ao, λ, Δt_i, ρ_a, ρ_m, ρ_f, Δh are known. The quantities g, α are also know and their uncertainty are considered equal to zero. The covariance matrix $\boldsymbol{U}_y$ of dimension 10x10 associated with $\boldsymbol{y}=(\boldsymbol{p}_1\ldots\boldsymbol{p}_{10})^T$ is evaluated from

$$\boldsymbol{C}_y \boldsymbol{U}_y \boldsymbol{C}_y^T = \boldsymbol{C}_x \boldsymbol{U}_x \boldsymbol{C}_x^T$$

Where: $\boldsymbol{C}_y$ is the sensitivity matrix of dimension 10x10 containing the partial derivatives $\frac{\partial h_l}{\partial p_j}$ $l = 1,..\ 10$; $j=1,..10$; $\boldsymbol{C}_x$ is the matrix of dimension 10x18 containing the partial derivatives $\frac{\partial h_l}{\partial X_i}$ $l=1,..\ 10$; $i=1,..18$; evaluated at X=x; $\boldsymbol{U}_x$ is the covariance matrix of dimension 18x18 associated with **x.** he uncertainty matrices $\boldsymbol{U}_x$ and $\boldsymbol{U}_y$ are related by:

$$U_p = U_y = C\, U_x C^T$$

where $C = C^{-1}_y\, C_x$

The same approach has been used to calculate $\boldsymbol{U}_{Ae}$ covariance matrix of Ae. The multivariate measurement model:

$$Ae = \frac{\Sigma Mi' \cdot \Phi' \cdot \left(1 - \frac{\rho_a}{\rho_m}\right) \cdot g + \sigma C'}{p \cdot (1 + \alpha'(t' - 20))}$$

specifies the relationship between the output quantity $\boldsymbol{Y}= \boldsymbol{A_e} = (A_{e1},\ldots A_{e10})^T$ and input quantity $Z = (M'_i,\ \phi',\ p,\ \alpha,\ \Delta t_i',\ \rho_a,\ \rho_m,\ g,\ \sigma,\ C')^T$ and its form is:

$$h_j(A_e, Z) = A_e\ p\ (1+\alpha\, \Delta t_i') - M'_i\, g\ (1 - (\rho_a / \rho_m)) - \sigma C' = 0$$

$\boldsymbol{U}_x$, covariance matrix associated with x, was built by using the input quantities M_i, Δt, ρ_a, ρ_m, g, σ, C' uncertainties and the covariance matrix $\boldsymbol{U}_p$ obtained as previously described. Finally the covariance matrix of Ae is given by:

$$U_{Ae} = C\ U_x\, C^T$$

where $C = C^{-1}_y\, C_x$

The measurements were repeated 5 times, the repeatability is given by the standard deviations of the mean of this measurements and used to build a diagonal matrix. The type A matrix was add to U_{Ae} to obtain the combined uncertainty matrix of Ae.

The polynomial function that fits the data, taking care of the uncertainty of the Ae by means of the covariance matrix U_{Ae}, has been computed. The vectors p_{rif} and Ae of n elements are known and the interpolation matrix P becomes: $P = [\ 1\ prif\ ]$. To find the polynomial functions, the vertical vector of m+1 elements is identified $\beta = [\beta_0,\ \beta_1]^T$ which solve the equation: $P\ \beta = A_e$. A solution is estimated applying the generalized least square method. If the probability distribution of the random variables is normal the X^2□ of the problem is expected to be close to the number of degrees of freedom ν =□$n - m$. X^2 will be found from:

$$X^2 = (Ae - P\,\beta)^T\, U^{-1}{}_{Ae}\ □(Ae - P\,\beta)$$

Under this assumption □β□ is $\beta = (P^T U^{-1}{}_{Ae} P□)^{-1} P^T U^{-1}{}_{Ae} A_e$ and the covariance matrix of the coefficients β is $\psi_\beta = (P^T U^{-1}{}_{Ae} P)^{-1}$. From the square roots of the main diagonal elements in ψ_β□□ the standard combined uncertainty of each coefficient β_i is calculated: $u(\beta_i) = \sqrt{\psi_{\beta_i}}$. To calculated the Ae values the following formula is used $Ae_{\text{calculated}} = P$ x β. The Ae standard uncertainty is given by the square root of the main diagonal elements in ψ_u:

$$u(Ae_{calculated}) = \sqrt{\psi_{u_i}}$$

where ψ_u is $\psi_u = \mathrm{P}\ \psi^{-1}{}_\beta\, \mathrm{P}^T$

3.4.11. Methods applied by IPQ

Calculation of Ap

Each value of the effective area Ap was calculated by using first the equation (1), to obtain the reference pressure and then using equation (1), in order of Ap with the data for the calibrated balance. The fluid densities were calculated by applying the following equations:

$$\rho_{f\_j} = \frac{(p_j + 101325)\cdot M}{R\cdot(273{,}15 + t_j)}$$ for the gas

$$\rho_{f\_j} = \rho_0 \cdot \left[1 + 0{,}00078\cdot(t_j - t_0)\right] + 0{,}752097\cdot p_j - 1{,}64485\cdot 10^{-3}\cdot p_j^2 + 1{,}45625\cdot 10^{-6}\cdot p_j^3$$

for a liquid

With R=8,314471 Jmol^{-1}K^{-1}.

The air density was obtained by the equation of the simplified version of the CIPM-formula, (exponential version) described in Appendix A of the Euramet guide/cg-18/v.02.

Estimation of A_p and its uncertainty

The dependence of the effective area with the measured pressure for the four cases is given by the equation (2).

In the first loop it was only calculated the type A uncertainty of Ap, using the equation A.10 from the draft of the guide of pressure balances. The values of A_0, u(A_0), λ, u(λ) and covariance (A_0,λ) were obtained from eq. (A6, A8, A9,A13 from the same guide), only type A uncertainties were calculated,

In the second loop this values and uncertainties were calculated by using the linest function of Excel. The uncertainty of $\hat{A}_p$ is then obtained by the quadratic sum of the uncertainty u(Ap) provided by the pilot laboratory and the value of the standard deviation of the fitting obtained by the linest function.

3.4.12. Methods applied by LNE

Calculation of Ap and its uncertainty

The effective area Ap was calculated by using the following equations (expressed from (1)):

$$A_{\mathrm{pj,ca}} = \frac{\sum_i m_{\mathrm{ci},ca} \cdot g \cdot \left(1 - \frac{\rho_{0\mathrm{a}}}{\rho_0} + \frac{\rho_{0\mathrm{a}} - \rho_{\mathrm{a}}}{\rho_{m_{i,ca}}}\right) + \Gamma \cdot C_{ca}}{\left(p_{\mathrm{j,ref}} + (\rho_{\mathrm{f\_j}} - \rho_{\mathrm{a}}) \cdot g \cdot (h_{ref} - h_{ca})\right) \cdot \left[1 + (\alpha_{\mathrm{p}} + \alpha_{\mathrm{c}})_{ca} \cdot (t_{j,ca} - t_0)\right]}$$

$$P_{j,ref} = \frac{\sum_i m_{ci,ref} \cdot g \cdot \left(1 - \frac{\rho_{0a}}{\rho_0} + \frac{\rho_{0a} - \rho_a}{\rho_{m_{i,ref}}}\right) + \Gamma \cdot C_{ref}}{A_{0,ref} \cdot \left(1 + \lambda_{ref} \cdot p_{nom}\right) \cdot \left[1 + (\alpha_p + \alpha_c)_{ref} (t_{j,ref} - t_0)\right]}$$

$$P_{nom} = \frac{\sum_i m_{ci,ref} \cdot g \cdot \left(1 - \frac{\rho_{0a}}{\rho_0} + \frac{\rho_{0a} - \rho_a}{\rho_{m_{i,ref}}}\right) + \Gamma \cdot C_{ref}}{A_{0,ref}}$$

$$\rho_{f\_j} = \rho_0 \cdot \left(\frac{p_j + p_{atm}}{101325}\right) \cdot \left(\frac{273{,}15}{273{,}15 + t}\right) \text{ for a gas}$$

$$\rho_{f\_j} = \rho_0 + \beta \cdot \left(t_j - t_0\right) + Z \cdot \left(p_j + p_{atm}\right) \text{ for a liquid}$$

Index “ref” is referring to the data relative to the reference piston-cylinder assembly and index “ca” to the data relative to the calibrated one. Index “nom” refers to nominal value. C is expressed by:

$$C = 2\sqrt{\pi \cdot A_{0,nom}}$$

The uncertainty of each A_{pj} was calculated by applying the propagation law of the following uncertainty components:

- Uncertainty of the sum of the applied mass pieces
- Uncertainty of the reference effective area at null pressure
- Uncertainty of the reference distortion coefficient
- Uncertainty of the temperature
- Uncertainty of the difference between the reference piston-cylinder assembly and the calibrated one.

Other uncertainties have been neglected, like the surface tension of the oil, the circumference of the piston, the uncertainty on the density of air used for the buoyancy and the density of the fluid. Besides, the covariance between the reference effective area at null pressure and the reference distortion coefficient was not considered.

Estimation of A_p and its uncertainty

The dependence of the effective area with the measured pressure is given by the equation (2). Their values and uncertainties were calculated by using the generalized least square method (GLS). Indeed, if we consider V as the variance-covariance matrix, X as the matrix defined by:

$$\begin{pmatrix} 1 & P_1 \\ 1 & P_2 \\ 1 & P_3 \\ 1 & P_4 \\ 1 & P_5 \\ 1 & P_6 \\ 1 & P_7 \\ 1 & P_8 \\ 1 & P_9 \\ 1 & P_{10} \end{pmatrix}$$

, X' it transposition and Y the vector

$$\begin{pmatrix} Ap_1 \\ Ap_2 \\ Ap_3 \\ Ap_4 \\ Ap_5 \\ Ap_6 \\ Ap_7 \\ Ap_8 \\ Ap_9 \\ Ap_{10} \end{pmatrix}$$

, the vector of the parameters $Coef = \begin{pmatrix} A_0 \\ b \end{pmatrix}$ is calculated by the equation:

.

$$Coef = \left(X' \cdot V^{-1} \cdot X\right)^{-1} \cdot \left(X' \cdot V^{-1} \cdot Y\right) \qquad (6)$$

Besides, the variance-covariance matrix of the parameters is calculated by the following equation:

$$V_{Coef} = \begin{pmatrix} u_{A_0}^2 & cov(A_0, b) \\ cov(A_0, b) & u_{\beta}^2 \end{pmatrix} = \left(X' \cdot V^{-1} \cdot X\right)^{-1} \qquad (7)$$

Then the distorsion coefficient λ is calculated by the expression : $\lambda = \frac{b}{A_0}$ and its uncertainty is the combination of the uncertainties of b and A_0 (see GUM [2]).

The difficulty of the method is then to determine the matrix V which has the following form:

$$V = \begin{pmatrix} u^2_{Ap_1} & u(Ap_1, Ap_2) & \dots & u(Ap_1, Ap_j) & \dots & u(Ap_1, Ap_{10}) \\ u(Ap_1, Ap_2) & u^2_{Ap_2} & \dots & u(Ap_2, Ap_j) & \dots & u(Ap_2, Ap_{10}) \\ \dots & \dots & \dots & \dots & \dots & \dots \\ u(Ap_1, Ap_j) & u(Ap_2, Ap_j) & \dots & u^2_{Ap_j} & \dots & u(Ap_j, Ap_{10}) \\ \dots & \dots & \dots & \dots & \dots & \dots \\ u(Ap_1, Ap_{10}) & u(Ap_2, Ap_{10}) & \dots & u(Ap_j, Ap_{10}) & \dots & u^2_{Ap_{10}} \end{pmatrix} \tag{8}$$

The calculation of u^2_{Ap} was explained above. The covariance between the effective area at pressure p_i and the effective area at pressure p_j $u(A_{pi};A_{pj})$ with $i \neq j$ is calculated considering the following equation:

$$u(Ap_i; Ap_j) = u_B(Ap_i) \cdot u_B(Ap_j) \tag{9}$$

with

$u_B(A_p)$ the type B uncertainty of A_p.

3.4.13. Methods applied by METAS

Calculation of Ap and its uncertainty

The effective area Ap was calculated by using the equation (1). The calculation of the pressure generated made by METAS include the usual influence factors:

- Buoyancy of the mass in the air.
- Calculation of the air density with the revised formula for moist air (Picard and al.).
- Force generated by the tension surface in the case of oil as fluid.
- Thermal expansion of the piston-cylinder.
- Deformation of the piston-cylinder
- Correction of the pressure due to the difference of height.

Some of these influence factors could easily be neglected as they are similar on the reference and the device under test.

The calculation of the uncertainty on the average value of the effective area for a given pressure could be divided in type B uncertainties that are mostly due to the generation of pressure by the reference piston and to the generation of force on the piston under test. Type A uncertainty are estimated on the base of the standard deviation on the effective area determined at each of the five successive runs. The final uncertainty is given by the incoherent sum of type A and type B uncertainty. The value that have been considered to contribute to the type B uncertainty are:

- Effective area of the reference piston
- Deformation coefficient of the reference piston
- Temperature of the reference piston
- Temperature of the piston under test
- Mass on the reference piston
- Mass on the piston under test
- Density of the mass
- Height of the column of fluid

The uncertainty on the surface tension of the oil, on the circumference of the piston and the uncertainty on the density of air used for the buoyancy has been neglected as these uncertainties are correlated on the two pressure balances and cancel mutually.

The uncertainty on the mass has been considered as highly correlated and the uncertainty of the total mass is the sum of the uncertainty on each individual mass loaded on the piston.

Estimation of A_p and its uncertainty

All the measured points are taken into account for the determination of the linear regression. When there is a large difference of the effective area at a given pressure and that this is easily explained because at that pressure the piston-cylinder is not working properly then the measurements at this pressure are not taken into account. In this project, the measurements of the oil pressure balance at 5 MPa are not taken for the linear regression as it is at 1% of the full range of the balance and the measured effective area is too large.

The values of the parameters (the effective area at zero pressure A_0 and distortion coefficient λ on the piston under test) is obtained by applying the ordinary least square method. The uncertainty on A_0 is given by the typical type A uncertainty of the effective area plus the uncertainty of the linear regression. The uncertainty on λ is given by the incoherent summation of the uncertainty on the deformation coefficient of the reference piston and the uncertainty on the dependence of the area with the pressure as given by the linear regression.

The uncertainty on the estimate $\hat{A}_p$ is given by the incoherent summation of the uncertainty on the average value of the effective area for the corresponding pressure and the estimated uncertainty of a value given by the regression line. In the case that the measurement at that specific pressure is not taken in account for the determination of the linear regression, then the latter term is replaced by the difference between the regression and the average measured value is taken into account.

3.4.14. Methods applied by MIKES

The pressure laboratory of MIKES is a secondary level one, and it has a conservative approach on the data obtained for its standards from outside. An allowance for instability is applied on both the effective areas and pressure distortion coefficients in calculating the uncertainty of its reference standards. Further, the treatment of some uncertainty components is simplified by rounding up to the worst case. The same methods are applied on the data of the reference standards of this project.

The expanded uncertainty for the range 5 MPa to 16 MPa gas medium is 12 Pa $+4*10^{-5}*p$ and for the range 200 MPa to 500 MPa oil medium $1.2 * 10^{-4} * p$ in the MIKES CMC tables, accepted in October 2005. A reduction of the uncertainties is in planning.

For Euramet 1125, MIKES' result set was calculated using the method described in the new EURAMET guide on calibrating pressure balances (linear fit and co-variances), and based on all the given data of the 50 cross-floatings. The proposal of MIKES' reduced CMC uncertainties will be based on this method.

3.4.15. Methods applied by MKEH

<u>Calculation of Ap and its uncertainty</u>

The effective area A_{pi} was calculated by using the equation (1), with i the index representing the associated cycle. The average value of the effective area $\overline{A}_p$ is calculated in each pressure point from n = 5 observations:

$$A_p = \frac{\sum_{i=1}^{n} A_{pi}}{n}.$$

The estimation of the combined standard uncertainty of the effective area has been determined in two steps in accordance with the GUM [2].

In the first step the combined standard uncertainty u_{Pe} (type B) of the generated pressure is estimated in each calibration point by the calculation of the complete uncertainty budget according to the equation (1). The uncertainty components are the uncertainty of the:

- masses of the reference pressure balance (the uncertainty of the total mass applied on the piston is calculated as sum of the individual standard uncertainties of the used masses because of the correlation).

- effective area of the reference PCA at reference temperature t_r and at null pressure
- distortion coefficient of the reference PCA
- air density
- temperature of the reference PCA
- height difference between the reference levels
- air temperature
- air humidity
- local gravity
- linear thermal expansion coefficient of the reference PCA
- density of the pressurized fluid (gas or oil)
- density of the weights

In the second step the type A and type B uncertainty of the calculated effective area of the calibrated PCA are estimated at each nominal pressure point.

The type A uncertainty component of the calculated effective area at each pressure point is estimated as the experimental standard deviation of the mean area.

$$u_{Ap,A} = \sqrt{\frac{\sum_{i=1}^{n}\left(A_{p,i} - \overline{A_p}\right)^2}{n \cdot (n-1)}} \text{ with n the number of cycles (n=5)} \qquad (10)$$

This uncertainty component represents the repeatability of the calibrated pressure balance including the uncertainty component from the resolution of the adjustment (cross floating sensitivity).

The type B uncertainty $u_{\mathrm{Ap,B}}$ of the calculated effective area is estimated in each calibration point by the calculation of the complete uncertainty budget according to the equation (1). The uncertainty components are the uncertainty of the:

- masses of the calibrated pressure balance
- reference pressure generated by the reference pressure balance (estimated in the first step)
- air density
- temperature of the calibrated PCA
- air temperature
- air humidity
- local gravity
- linear thermal expansion coefficient of the calibrated PCA
- density of the weights

The combined standard uncertainty u_{Ap} of the effective area A_{p} is derived from the root-sum-of-squares summation of the type A and type B uncertainties.

$$u_{Ap} = \sqrt{u_{Ap,A}^{2} + u_{Ap,B}^{2}} \tag{11}$$

Estimation of A_p and its uncertainty

The dependence of the effective area with the measured pressure is given by the equation (2).

A_0, b and their uncertainties (type A uncertainties: $u_{A0,A}$ and $u_{b,A}$) and the covariance between A_0 and b are estimated by applying the ordinary least mean squares method. The uncertainty of the estimate value of the effective area $\hat{A}_{\mathrm{p}}$ is determined by the equation (12).

$$u_{\hat{A}p} = \sqrt{u_{\hat{A}p,A}^{2} + u_{Ap,B}^{2}} \tag{12}$$

Where

$$u_{\hat{A}p,A} = \sqrt{\left(\frac{\partial \hat{A}_p}{\partial A_0}\right)^2 \cdot u_{A_0,A}^2 + \left(\frac{\partial \hat{A}_p}{\partial b}\right)^2 \cdot u_{b,A}^2 + 2 \cdot \left(\frac{\partial \hat{A}_p}{\partial A_0}\right) \cdot \left(\frac{\partial \hat{A}_p}{\partial b}\right) \cdot \mathrm{cov}(A_0, b)}$$

and $u_{Ap,B}$ is the type B uncertainty of A_p.

The uncertainty u_{Ao} is estimated by the root-sum-of-squares summation of the standard uncertainty $u_{A0,A}$ and the maximum of the individually determined type B standard uncertainties $u_{\mathrm{Ap,B}}$.

$$u_{A_0} = \sqrt{u_{A_0,A}^{2} + u_{Ap,B,\max}^{2}} \tag{13}$$

The pressure distortion coefficient is:

$$\lambda = \frac{b}{A_0} \tag{14}$$

and the uncertainty of the λ is estimated according to the following equation:

$$u_{\lambda} = \sqrt{\left(-\frac{b}{A_0^2}\right)^2 \cdot u_{A_0}^2 + \left(\frac{1}{A_0}\right)^2 \cdot u_b^2 - 2 \cdot \left(\frac{b}{A_0^2}\right) \cdot \left(\frac{1}{A_0}\right) \cdot \mathrm{cov}(A_0, b)} \tag{15}$$

3.4.16. Methods applied by PTB

The PTB evaluation method includes several steps.

First, for each cross-float measurement in gauge mode, the pressure at the reference level of the calibrated pressure balance (p) and its effective area (A) are determined using equations (1) and (2). The air density is calculated from the temperature, pressure and humidity using the so called BIPM equation.

Applying equations (1, 2) to every cross-float point, a set of data (p_j, A_j) is generated where j is number a cross-float point, $j = 1,\ldots,N$, N being the total number of points. This data set is analysed by 4 model equations describing the dependence of the effective area on pressure:

A_0-model: $$A(p) = A_0, \tag{16}$$

A_0,λ-model: $$A(p) = A_0 + A_0\lambda \cdot p, \tag{17}$$

A_0,F-model: $$A(p) = A_0 + F/p, \tag{18}$$

A_0,λ,F-model: $$A(p) = A_0 + A_0\lambda \cdot p + F/p. \tag{19}$$

Physically, A_0-model corresponds to the case of pressure independent effective area.

A_0,λ-model implies linear dependence of the effective area on pressure usually dealing with unknown/incorrect pressure distortion coefficient in (2).

A_0,F-model assumes existence of an additional unknown force acting on piston of the reference standard or the standard under test, which is constant in all pressure points and can be associated with unknown/erroneous mass of pistons and weight carriers, height difference, fluid density, surface tension, etc.

Finally, A_0,λ,F -model supposes existence of errors in both force and pressure distortion coefficient.

The data for two cases of a gas and two cases of an oil pressure balance's cross-float calibration included in the technical protocol of this project were evaluated by the method described above. For all four data sets the A_0,λ,F-model led to the best results: it leads to the smallest uncertainty for A_p in the biggest part of the calibration pressure range. Parameters of the model equations are found by the least-squares method minimising the sum of squared deviations χ^2:

$$\chi^2 = \sum\left[A_j - A\left(p_j\right)\right]^2 \rightarrow \min \tag{20}$$

Here and in all following equations Σ assumes summing over *j* from 1 to *N* if not specified differently. All uncertainties in this section 3.4.18. are standard ones. All type A uncertainties are calculated corresponding to the uncertainty of data distribution, not of their mean value.

A_0,λ,F-model: calculation of the parameters

A_0, λ and F are calculated by:

$$A_0 = \frac{X \cdot XY \cdot X^{-2} - N \cdot X \cdot YX^{-1} - X^{-1} \cdot X^2 \cdot YX^{-1} - N \cdot X^{-1} \cdot XY + N^2 \cdot Y - Y \cdot X^2 \cdot X^{-2}}{N^3 - N \cdot X^2 \cdot X^{-2} - 2N \cdot X \cdot X^{-1} + \left(X\right)^2 \cdot X^{-2} + \left(X\right)^{-2} \cdot X^2} \qquad (21)$$

$$\lambda = \frac{A_0 \cdot \left(N \cdot X^{-1} - X^{-2} \cdot X\right) + X^{-2} \cdot XY - N \cdot YX^{-1}}{A_0 \cdot \left(N^2 - X^2 \cdot X^{-2}\right)} \qquad (22)$$

$$F = \frac{A_0 \cdot \left(N \cdot X - X^{-1} \cdot X^2\right) + X^2 \cdot YX^{-1} - N \cdot XY}{N^2 - X^2 \cdot X^{-2}}$$

with designations

$$X = \sum p_j\,,\; X^2 = \sum p_j^2\,,\; \left(X\right)^2 = \left(\sum p_j\right)^2,\; X^{-1} = \sum p_j^{-1}\,,\; X^{-2} = \sum p_j^{-2}\,,\; \left(X\right)^{-2} = \left(\sum p_j^{-1}\right)^2,$$

$$Y = \sum A_j\,,\; Y^2 = \sum A_j^2\,,\; \left(Y\right)^2 = \left(\sum A_j\right)^2,\; XY = \sum p_j \cdot A_j\,,\; YX^{-1} = \sum A_j / p_j\,.$$

A_0,λ,F-model: calculation of the uncertainty of the parameters

Variances and covariances of A_0, $A_0\lambda$ and F, $V(A_0)$, $V(A_0\lambda)$, $V(F)$, $\mathrm{cov}(A_0,A_0\lambda)$, $\mathrm{cov}(A_0,F)$ and $\mathrm{cov}(A_0\lambda,F)$, are given by:

$$V\left(A_0\right) = \frac{X^2 \cdot X^{-2} - N^2}{D} \cdot \frac{\chi^2}{N-3} \qquad (23)$$

$$V\left(A_0\lambda\right) = \frac{N \cdot X^{-2} - \left(X\right)^{-2}}{D} \cdot \frac{\chi^2}{N-3} \qquad (24)$$

$$V\left(F\right) = \frac{N \cdot X^2 - \left(X\right)^2}{D} \cdot \frac{\chi^2}{N-3}$$

$$\mathrm{cov}\left(A_0, A_0\lambda\right) = -\frac{X \cdot X^{-2} - N \cdot X^{-1}}{D} \cdot \frac{\chi^2}{N-3} \qquad (25)$$

$$\mathrm{cov}\left(A_0, F\right) = -\frac{X^{-1} \cdot X^2 - N \cdot X}{D} \cdot \frac{\chi^2}{N-3}$$

$$\mathrm{cov}(A_0\lambda, F) = -\frac{N^2 - X \cdot X^{-1}}{D} \cdot \frac{\chi^2}{N-3}$$

With $\chi^2 = \sum \left(A_j - A_0 - A_0\lambda \cdot p_j - F/p_j\right)^2$

and $D = N \cdot X^2 \cdot X^{-2} - N^3 - (X)^2 \cdot X^{-2} + 2N \cdot X \cdot X^{-1} - X^2 \cdot (X)^{-2}$.

Type A uncertainties A_0, λ, F and of A_p are calculated with:

$$u_\mathrm{A}(A_0) = \left[N \cdot V(A_0)\right]^{0.5} \tag{26}$$

$$u_\mathrm{A}(\lambda) = \left[N \cdot V(A_0\lambda)\right]^{0.5} / A_0 \tag{27}$$

$$u_\mathrm{A}(F) = \left[N \cdot V(F)\right]^{0.5}$$

$$\begin{aligned} u_\mathrm{A}(A_\mathrm{p}) = N^{0.5} \cdot \big[& V(A_0) + V(A_0\lambda) \cdot p^2 + V(F)/p^2 \\ & + 2\,\mathrm{cov}(A_0, A_0\lambda) \cdot p + 2\,\mathrm{cov}(A_0, F)/p + 2\,\mathrm{cov}(A_0\lambda, F)\big]^{0.5} \end{aligned}$$

The type B uncertainty of the model parameters is calculated numerically in the following way. First, A_0, λ and F as furnished by the four models above are calculated. Then every of the n input quantities (q_l) in equations (1, 2) is consecutively changed by the value of its uncertainty ($u(q_l)$) and, every time, A_0, λ and F are recalculated. The changes in A_0, λ and F observed when changing an input quantity present its contribution to the uncertainty of A_0, λ and F. The total type B combined uncertainty is the root-sum-squares of all the type B uncertainty contributions.

Combined standard uncertainties of the model parameters, $u_\mathrm{AB}(A_0)$, $u_\mathrm{AB}(\lambda)$ and $u_\mathrm{AB}(F)$, are calculated by:

$$u_\mathrm{AB}(A_0) = \left[u_\mathrm{A}^2(A_0) + u_\mathrm{B}^2(A_0)\right]^{0.5} \tag{28}$$

$$u_\mathrm{AB}(\lambda) = \left[u_\mathrm{A}^2(\lambda) + u_\mathrm{B}^2(\lambda)\right]^{0.5} \tag{29}$$

$$u_\mathrm{AB}(F) = \left[u_\mathrm{A}^2(F) + u_\mathrm{B}^2(F)\right]^{0.5}$$

A_0,λ,F-model: $u_\mathrm{AB}(A_\mathrm{p}) = \left[u_\mathrm{A}^2(A_\mathrm{p}) + u_\mathrm{B}^2(A_0) + u_\mathrm{B}^2(\lambda) \cdot A_0^2 \cdot p^2 + u_\mathrm{B}^2(F)/p^2\right]^{0.5}$, (30)

Calculation of the uncertainty of the mean experimental effective area

The mean experimental effective area ($\bar{A}_\mathrm{p}$) at the same nominal pressure p, its type A uncertainty $u_\mathrm{A}(\bar{A}_\mathrm{p})$ and the combined uncertainty $u_\mathrm{AB}(\bar{A}_\mathrm{p})$ are calculated by:

$$\bar{A}_\mathrm{p} = \sum_{i=1}^{N_p} A_i(p) / N_p \qquad (31)$$

$$u_\mathrm{A}\left(\bar{A}_\mathrm{p}\right) = \left[\sum_{i=1}^{N_p} \left(A_i(p) - \bar{A}_\mathrm{p}\right)^2 / \left(N_p - 1\right)\right]^{0.5}$$

$$u_\mathrm{AB}\left(\bar{A}_\mathrm{p}\right) = \left[u_\mathrm{A}^2\left(\bar{A}_\mathrm{p}\right) + u_\mathrm{B}^2\left(\bar{A}_\mathrm{p}\right)\right]^{0.5} \qquad (32)$$

where N_p is the number of points at pressure p.

In practice, the additional force (F) furnished by the A_0,F and A_0,λ,F models is not reported in the calibration certificate because it cannot not be ascribed to a certain experimental parameter (piston and weight carrier mass, height difference, fluid density, surface tension, etc.) and, in particular, because it cannot be decided whether this additional force is an intrinsic property of the calibrated pressure balance or results only from the conditions of the performed calibration. For this reason this additional force is used in first line to analyse whether all the data recorded during the calibration are correct. If the value of the additional force is approximately equal to one or several uncertainties of piston and weight carrier mass, height difference, fluid density, surface tension, etc., this force does not need further consideration because its contribution to the model is of the order of the uncertainty of the input quantities. In opposite case, the additional force is used as an additional uncertainty contribution to the uncertainty of A_p. Then the final uncertainty of the effective area is calculated as:

$$u_{\mathrm{AB},F}\left(A_\mathrm{p}\right) = \left[u_\mathrm{AB}^2\left(A_\mathrm{p}\right) + \left(F/3\right)^2 / p^2\right]^{0.5} \qquad (33)$$

in which the factor 3, corresponding to a rectangular distribution, takes into account the fact that F is the maximum difference between the F-containing, correct model and the simplified F-free model, based only on A_0 and λ, used in the calibration certificate.

Reporting results

It is necessary to mention that not all input uncertainties which usually considered in the PTB calibration practise were included in the technical protocol and thus they were set to zero.

The values reported were calculated with the following equations:

A_p - Equation (31)

U(A_p)	- Equation (32)
$\hat{A}_p$	- Equation (17)
U($\hat{A}_p$)	- Equation (33) with $u_{AB}(A_p)$ from (30)
Effective area at null pressure (A_0)	- Equation (21)
u(A_0)	- Equation (28) with $u_A(A_0)$ from (26) and (23)
Pressure distortion (λ)	- Equation (22)
u(λ)	- Equation (29) with $u_A(\lambda)$ from (27) and (24)
Covariance (A0 , λ)	– as $\mathrm{cov}(A_0,A_0\lambda)/A_0$ with (25)

As the A_0,λ,F-model was applied, covariance $\mathrm{cov}(A_0,A_0\lambda)/A_0$ calculated and reported in the table differs from resulting from the A_0,λ-model.

3.4.17. Methods applied by UME

Calculation of Ap and its uncertainty

The values of the effective area and the pressure distortion coefficient were calculated by evaluating the input data of pressure balances. It was determined the uncertainty budget for each nominal pressure point and the values of standard uncertainty. The effective area A_p was calculated according to [5]. Weighted least square method was used to calculate the effective area at null pressure.

$$A'_0 = \frac{\sum_{i=1}^{N} g_i p^2{}_i \sum_{i=1}^{N} g_i A_{pi} - \sum_{i=1}^{N} g_i p_i \sum_{i=1}^{N} g_i p_i A_{pi}}{\sum_{i=1}^{N} g_i \sum_{i=1}^{N} g_i p^2{}_i - \left[\sum_{i=1}^{N} g_i p_i \right]^2}$$

The air density was calculated via the following equation:

$$\rho_{air}(kg/m^3) = 3{,}48353 \cdot 10^{-3} \cdot \frac{p(Pa)}{Z \cdot T(^oK)} \cdot (1 - 0{,}3780 \cdot x_U)$$

the density of nitrogen was calculated from this equation:

$$\rho_{nitrogen} = \frac{p \cdot M}{R \cdot T}$$

With

R is idea gas constant: R = 8,314510 $\mathrm{Jmol^{-1}K^{-1}}$

M Is the molar mass of Nitrogen: M = 28,0135.10^{-3} kg $\mathrm{mol^{-1}}$

The density of oil was calculated from the equation below:

$$\rho_{sebacate} = 912{,}7 + 0{,}772 \cdot p - 0{,}001645 \cdot p^2 + 0{,}000001456 \cdot p^3$$

Variance and covariance values are calculated according to [5].

$$V(\theta_1) = \frac{\sum_{i=1}^{N} g_i}{\sum_{i=1}^{N} g_i \sum_{i=1}^{N} g_i p^2{}_i - \left[\sum_{i=1}^{N} g_i p_i\right]^2}$$

$$\mathrm{cov}(A_0, \theta_1) = \frac{-\sum_{i=1}^{N} g_i p_i}{\sum_{i=1}^{N} g_i \sum_{i=1}^{N} g_i p^2{}_i - \left[\sum_{i=1}^{N} g_i p_i\right]^2}$$

where

$$g_j = \frac{1}{\sum_i u_i^2\left(A_{pj}\right)}$$

Estimation of A_p and its uncertainty

The weighted least squares method was used to obtain the best straight line fit of Ap vs P, as proposed in [5]. The uncertainty is then the combination of the uncertainty on Ap and the uncertainty due to the fitting.

4. Results of the first loop

4.1. Calculation of the mean effective areas by NMIs

4.1.1. Gas – case n°1

Nominal pressure kPa	BEV mm^2	CEM mm^2	EIM mm^2	DANIAmet mm^2	FSB-LPM mm^2	IMBiH mm^2	IMT mm^2	INRIM mm^2	IPQ mm^2
200	49.01946	49.01968	49.01969	49.01969	49.01968	49.01982	49.01982	49.01968	49.01969
1 000	49.01860	49.01902	49.01902	49.01902	49.01902	49.01906	49.01906	49.01902	49.01902
2 000	49.01825	49.01869	49.01869	49.01869	49.01869	49.01894	49.01894	49.01869	49.01869
3 000	49.01803	49.01848	49.01848	49.01848	49.01848	49.01897	49.01897	49.01848	49.01848
4 000	49.01795	49.01841	49.01841	49.01841	49.01841	49.01866	49.01866	49.01841	49.01841
5 000	49.01784	49.01830	49.01830	49.01830	49.01830	49.01847	49.01847	49.01830	49.01830
6 000	49.01770	49.01816	49.01816	49.01816	49.01816	49.01851	49.01851	49.01816	49.01816
7 000	49.01755	49.01801	49.01801	49.01801	49.01801	49.01835	49.01835	49.01801	49.01801
8 000	49.01749	49.01795	49.01795	49.01795	49.01795	49.01826	49.01826	49.01795	49.01795
10 000	49.01721	49.01767	49.01767	49.01767	49.01767	49.01801	49.01801	49.01767	49.01767

Nominal pressure kPa	LNE mm^2	METAS mm^2	MIKES mm^2	MKEH mm^2	PTB mm^2	UME mm^2
200	49.01969	49.01971	49.01970	49.01969	49.01969	49.01969
1 000	49.01902	49.01903	49.01902	49.01902	49.01902	49.01902
2 000	49.01870	49.01871	49.01870	49.01870	49.01870	49.01869
3 000	49.01848	49.01850	49.01849	49.01849	49.01849	49.01848
4 000	49.01841	49.01842	49.01841	49.01841	49.01841	49.01841
5 000	49.01830	49.01831	49.01830	49.01830	49.01830	49.01830
6 000	49.01816	49.01817	49.01817	49.01816	49.01816	49.01816
7 000	49.01801	49.01803	49.01802	49.01801	49.01801	49.01801
8 000	49.01795	49.01797	49.01796	49.01796	49.01796	49.01795
10 000	49.01768	49.01769	49.01768	49.01768	49.01767	49.01767

4.1.2. Gas – case n°2

Nominal pressure kPa	**BEV** mm²	**CEM** mm²	**EIM** mm²	**DANIAmet** mm²	**FSB-LPM** mm²	**IMBiH** mm²	**IMT** mm²	**INRIM** mm²	**IPQ** mm²
200	49.01956	49.01996	49.01996	49.01996	49.01996	49.01999	49.01999	49.01996	49.01997
1 000	49.01869	49.01931	49.01931	49.01931	49.01931	49.01934	49.01934	49.01931	49.01931
2 000	49.01829	49.01891	49.01891	49.01891	49.01891	49.01916	49.01916	49.01891	49.01892
3 000	49.01813	49.01877	49.01877	49.01877	49.01877	49.01926	49.01926	49.01877	49.01877
4 000	49.01802	49.01867	49.01868	49.01868	49.01868	49.01893	49.01893	49.01867	49.01868
5 000	49.01791	49.01857	49.01857	49.01857	49.01857	49.01874	49.01874	49.01857	49.01857
6 000	49.01777	49.01843	49.01843	49.01843	49.01843	49.01878	49.01878	49.01843	49.01843
7 000	49.01761	49.01826	49.01826	49.01826	49.01826	49.01860	49.01860	49.01826	49.01826
8 000	49.01754	49.01819	49.01819	49.01819	49.01819	49.01850	49.01850	49.01819	49.01819
10 000	49.01732	49.01797	49.01797	49.01797	49.01797	49.01830	49.01830	49.01797	49.01797

Nominal pressure kPa	**LNE** mm²	**METAS** mm²	**MIKES** mm²	**MKEH** mm²	**PTB** mm²	**UME** mm²
200	49.01997	49.01997	49.01998	49.01997	49.01996	49.01996
1 000	49.01931	49.01931	49.01932	49.01931	49.01931	49.01931
2 000	49.01892	49.01891	49.01892	49.01892	49.01892	49.01891
3 000	49.01878	49.01877	49.01878	49.01878	49.01878	49.01877
4 000	49.01868	49.01867	49.01869	49.01868	49.01868	49.01867
5 000	49.01857	49.01857	49.01858	49.01857	49.01858	49.01857
6 000	49.01843	49.01842	49.01844	49.01843	49.01843	49.01843
7 000	49.01826	49.01826	49.01827	49.01826	49.01826	49.01826
8 000	49.01820	49.01819	49.01820	49.01820	49.01820	49.01819
10 000	49.01797	49.01797	49.01798	49.01798	49.01797	49.01797

4.1.3. Oil – case n°1

Nominal pressure	**BEV**	**CEM**	**EIM**	**DANIAmet**	**FSB-LPM**	**IMBiH**	**IMT**	**INRIM**	**IPQ**
kPa	mm²	mm²	mm²	mm²	mm²	mm²	mm²	mm²	mm²
5 155	1.902989	1.902989	1.902989	1.902989	1.902632	1.903006	1.902989	1.902989	1.902989
51 548	1.902982	1.902982	1.902982	1.902982	1.902941	1.902996	1.902982	1.902982	1.902982
103 096	1.903054	1.903054	1.903054	1.903054	1.903028	1.903062	1.903054	1.903054	1.903054
154 645	1.903142	1.903142	1.903142	1.903143	1.903119	1.903144	1.903142	1.903142	1.903143
206192	1.903211	1.903211	1.903211	1.903211	1.903194	1.903207	1.903211	1.903211	1.903211
257 738	1.903285	1.903285	1.903285	1.903285	1.903260	1.903283	1.903285	1.903285	1.903285
309286	1.903356	1.903356	1.903356	1.903356	1.903329	1.903351	1.903356	1.903356	1.903356
360 838	1.903425	1.903425	1.903425	1.903426	1.903396	1.903421	1.903425	1.903425	1.903425
412 383	1.903497	1.903497	1.903497	1.903498	1.903465	1.903492	1.903498	1.903498	1.903497
515 478	1.903647	1.903647	1.903647	1.903649	1.903609	1.903643	1.903647	1.903647	1.903647

Nominal pressure	**LNE**	**METAS**	**MIKES**	**MKEH**	**PTB**	**UME**
kPa	mm²	mm²	mm²	mm²	mm²	mm²
5 155	1.902989	1.902989	1.902989	1.902989	1.902990	1.902989
51 548	1.902982	1.902982	1.902982	1.902982	1.902982	1.902982
103 096	1.903054	1.903054	1.903054	1.903054	1.903054	1.903054
154 645	1.903142	1.903142	1.903143	1.903142	1.903143	1.903142
206192	1.903211	1.903211	1.903211	1.903211	1.903211	1.903211
257 738	1.903285	1.903285	1.903285	1.903285	1.903285	1.903285
309286	1.903356	1.903356	1.903355	1.903356	1.903356	1.903356
360 838	1.903425	1.903425	1.903425	1.903425	1.903425	1.903425
412 383	1.903498	1.903498	1.903497	1.903498	1.903497	1.903498
515 478	1.903647	1.903647	1.903646	1.903647	1.903647	1.903647

4.1.4. Oil: case n°2

Nominal pressure	**BEV**	**CEM**	**EIM**	**DANIAmet**	**FSB-LPM**	**IMBiH**	**IMT**	**INRIM**	**IPQ**
kPa	mm²	mm²	mm²	mm²	mm²	mm²	mm²	mm²	mm²
5 155	1.902826	1.902826	1.902826	1.902826	1.902804	1.902736	1.902736	1.902826	1.902826
51 550	1.902982	1.902982	1.902982	1.902982	1.902977	1.902991	1.902991	1.902982	1.902982
103 097	1.903070	1.903070	1.903070	1.903070	1.903063	1.903072	1.903072	1.903070	1.903070
154 646	1.903150	1.903150	1.903150	1.903150	1.903142	1.903157	1.903157	1.903150	1.903150
206 197	1.903216	1.903216	1.903216	1.903216	1.903212	1.903224	1.903224	1.903216	1.903216
257 742	1.903299	1.903299	1.903299	1.903299	1.903286	1.903318	1.903318	1.903299	1.903299
309 294	1.903377	1.903377	1.903377	1.903377	1.903362	1.903395	1.903395	1.903377	1.903377
360 840	1.903451	1.903451	1.903451	1.903451	1.903433	1.903467	1.903467	1.903451	1.903451
412 392	1.903531	1.903531	1.903531	1.903531	1.903511	1.903548	1.903548	1.903531	1.903531
515 492	1.903684	1.903684	1.903684	1.903683	1.903660	1.903699	1.903699	1.903684	1.903683

Nominal pressure kPa	LNE mm^2	METAS mm^2	MIKES mm^2	MKEH mm^2	PTB mm^2	UME mm^2
5 155	1.902826	1.902826	1.902826	1.902826	1.902826	1.902826
51 550	1.902982	1.902982	1.902983	1.902982	1.902982	1.902982
103 097	1.903070	1.903070	1.903070	1.903070	1.903070	1.903070
154 646	1.903150	1.903150	1.903151	1.903150	1.903150	1.903150
206 197	1.903216	1.903216	1.903216	1.903216	1.903216	1.903216
257 742	1.903299	1.903299	1.903299	1.903299	1.903299	1.903299
309 294	1.903377	1.903377	1.903377	1.903377	1.903377	1.903377
360 840	1.903451	1.903451	1.903451	1.903451	1.903451	1.903451
412 392	1.903531	1.903531	1.903531	1.903531	1.903531	1.903531
515 492	1.903684	1.903684	1.903683	1.903684	1.903683	1.903684

4.2. Uncertainties of the mean effective areas by NMIs

4.2.1. Gas – case n°1

Nominal pressure kPa	BEV mm^2	CEM mm^2	EIM mm^2	DANIAmet mm^2	FSB-LPM mm^2	IMBiH mm^2	IMT mm^2	INRIM mm^2	IPQ mm^2
200	0.00051	0.00049	0.00055	0.000 50	0.00049	0.00061	0.00054	0.00055	0.000120
1 000	0.00044	0.00041	0.00042	0.000 44	0.00042	0.00044	0.00042	0.00043	0.000042
2 000	0.00043	0.00040	0.00041	0.000 43	0.00041	0.00043	0.00041	0.00042	0.000014
3 000	0.00043	0.00040	0.00041	0.000 43	0.00041	0.00043	0.00041	0.00042	0.000021
4 000	0.00043	0.00040	0.00041	0.000 43	0.00041	0.00044	0.00041	0.00041	0.0000048
5 000	0.00043	0.00040	0.00041	0.000 43	0.00041	0.00044	0.00041	0.00041	0.000011
6 000	0.00043	0.00040	0.00041	0.000 43	0.00041	0.00045	0.00041	0.00041	0.000012
7 000	0.00043	0.00040	0.00041	0.000 43	0.00041	0.00045	0.00041	0.00041	0.0000092
8 000	0.00043	0.00040	0.00041	0.000 43	0.00041	0.00046	0.00041	0.00042	0.0000018
10 000	0.00043	0.00040	0.00041	0.000 43	0.00041	0.00047	0.00041	0.00042	0.0000065

Nominal pressure kPa	LNE mm^2	METAS mm^2	MIKES mm^2	MKEH mm^2	PTB mm^2	UME mm^2
200	0.00052	0.00053	0.0011	0.00049	0.00058	0.00052
1 000	0.00041	0.00043	0.00051	0.00041	0.00043	0.00042
2 000	0.00040	0.00042	0.00048	0.00041	0.00041	0.00041
3 000	0.00040	0.00042	0.00047	0.00041	0.00041	0.00041
4 000	0.00040	0.00042	0.00047	0.00040	0.00040	0.00041
5 000	0.00040	0.00042	0.00047	0.00041	0.00041	0.00041
6 000	0.00040	0.00042	0.00047	0.00041	0.00041	0.00041
7 000	0.00040	0.00042	0.00047	0.00041	0.00041	0.00041
8 000	0.00040	0.00042	0.00047	0.00041	0.00041	0.00041
10 000	0.00040	0.00042	0.00048	0.00041	0.00041	0.00041

4.2.2. Gas – case n°2

Nominal pressure kPa	**BEV** mm²	**CEM** mm²	**EIM** mm²	**DANIAmet** mm²	**FSB-LPM** mm²	**IMBiH** mm²	**IMT** mm²	**INRIM** mm²	**IPQ** mm²
200	0.00065	0.00052	0.00066	0.000 62	0.00062	0.00071	0.00063	0.00066	0.00020
1 000	0.00047	0.00041	0.00043	0.000 44	0.00042	0.00044	0.00043	0.00043	0.000050
2 000	0.00046	0.00040	0.00041	0.000 43	0.00041	0.00043	0.00041	0.00042	0.000016
3 000	0.00046	0.00040	0.00041	0.000 43	0.00041	0.00043	0.00041	0.00042	0.000019
4 000	0.00046	0.00040	0.00041	0.000 43	0.00041	0.00044	0.00041	0.00042	0.000016
5 000	0.00046	0.00040	0.00041	0.000 43	0.00041	0.00044	0.00041	0.00042	0.000017
6 000	0.00046	0.00040	0.00041	0.000 43	0.00041	0.00045	0.00041	0.00042	0.000013
7 000	0.00046	0.00040	0.00041	0.000 43	0.00041	0.00045	0.00041	0.00041	0.0000079
8 000	0.00046	0.00040	0.00041	0.000 43	0.00041	0.00046	0.00041	0.00042	0.000011
10 000	0.00046	0.00040	0.00041	0.000 43	0.00041	0.00047	0.00041	0.00042	0.0000080

Nominal pressure kPa	**LNE** mm²	**METAS** mm²	**MIKES** mm²	**MKEH** mm²	**PTB** mm²	**UME** mm²
200	0.00063	0.00066	0.0011	0.00052	0.00077	0.00048
1 000	0.00042	0.00043	0.00051	0.00041	0.00044	0.00042
2 000	0.00040	0.00042	0.00048	0.00041	0.00041	0.00041
3 000	0.00040	0.00042	0.00047	0.00041	0.00041	0.00041
4 000	0.00040	0.00042	0.00047	0.00041	0.00041	0.00041
5 000	0.00040	0.00042	0.00047	0.00041	0.00041	0.00041
6 000	0.00040	0.00042	0.00047	0.00041	0.00041	0.00041
7 000	0.00040	0.00041	0.00047	0.00041	0.00041	0.00041
8 000	0.00040	0.00042	0.00047	0.00041	0.00041	0.00041
10 000	0.00040	0.00042	0.00048	0.00041	0.00041	0.00041

4.2.3. Oil – case n°1

Nominal pressure kPa	**BEV** mm²	**CEM** mm²	**EIM** mm²	**DANIAmet** mm²	**FSB-LPM** mm²	**IMBiH** mm²	**IMT** mm²	**INRIM** mm²	**IPQ** mm²
5 155	0.000064	0.000033	0.000060	0.0015	0.000071	0.000077	0.000054	0.000060	0.000025
51 548	0.000034	0.000020	0.000022	0.00015	0.000026	0.000026	0.000022	0.000023	0.0000044
103 096	0.000033	0.000020	0.000022	0.000077	0.000026	0.000028	0.000022	0.000023	0.0000038
154 645	0.000035	0.000021	0.000027	0.000055	0.000036	0.000034	0.000026	0.000025	0.0000065
206192	0.000034	0.000022	0.000027	0.000043	0.000038	0.000036	0.000026	0.000026	0.0000048
257 738	0.000034	0.000023	0.000029	0.000038	0.000036	0.000039	0.000029	0.000029	0.0000052
309286	0.000036	0.000024	0.000033	0.000035	0.000042	0.000044	0.000032	0.000033	0.0000067
360 838	0.000033	0.000024	0.000033	0.000030	0.000041	0.000045	0.000032	0.000034	0.0000026
412 383	0.000034	0.000026	0.000037	0.000030	0.000042	0.000050	0.000036	0.000037	0.0000051
515 478	0.000033	0.000029	0.000042	0.000026	0.000049	0.000056	0.000042	0.000042	0.0000031

Nominal pressure kPa	**LNE** mm²	**METAS** mm²	**MIKES** mm²	**MKEH** mm²	**PTB** mm²	**UME** mm²
5 155	0.000059	0.000060	0.000067	0.000033	0.000080	0.000060
51 548	0.000022	0.000022	0.000026	0.000020	0.000024	0.000022
103 096	0.000022	0.000023	0.000028	0.000021	0.000024	0.000022
154 645	0.000026	0.000027	0.000035	0.000023	0.000030	0.000027
206192	0.000026	0.000026	0.000038	0.000025	0.000029	0.000027
257 738	0.000029	0.000029	0.000044	0.000027	0.000031	0.000027
309286	0.000033	0.000033	0.000051	0.000030	0.000036	0.000029
360 838	0.000032	0.000032	0.000055	0.000032	0.000033	0.000033
412 383	0.000037	0.000036	0.000062	0.000035	0.000038	0.000037
515 478	0.000042	0.000041	0.000075	0.000041	0.000042	0.000042

4.2.4. Oil: case n°2

Nominal pressure kPa	**BEV** mm²	**CEM** mm²	**EIM** mm²	**DANIAmet** mm²	**FSB-LPM** mm²	**IMBiH** mm²	**IMT** mm²	**INRIM** mm²	**IPQ** mm²
5 155	0.000060	0.000032	0.000058	0.0015	0.000058	0.000075	0.000053	0.000059	0.000024
51 550	0.000033	0.000021	0.000027	0.00015	0.000029	0.000030	0.000026	0.000026	0.0000082
103 097	0.000032	0.000021	0.000027	0.000078	0.000037	0.000032	0.000026	0.000028	0.0000076
154 646	0.000030	0.000021	0.000025	0.000054	0.000043	0.000033	0.000025	0.000028	0.0000048
206 197	0.000030	0.000022	0.000028	0.000044	0.000046	0.000037	0.000027	0.000030	0.0000055
257 742	0.000029	0.000023	0.000029	0.000037	0.000041	0.000040	0.000029	0.000032	0.0000042
309 294	0.000029	0.000024	0.000032	0.000033	0.000043	0.000044	0.000031	0.000032	0.0000046
360 840	0.000029	0.000025	0.000034	0.000031	0.000056	0.000047	0.000034	0.000037	0.0000041
412 392	0.000029	0.000026	0.000037	0.000029	0.000054	0.000051	0.000037	0.000039	0.0000038
515 492	0.000030	0.000030	0.000044	0.000028	0.000060	0.000059	0.000044	0.000044	0.0000051

Nominal pressure kPa	**LNE** mm²	**METAS** mm²	**MIKES** mm²	**MKEH** mm²	**PTB** mm²	**UME** mm²
5 155	0.000057	0.000058	0.000065	0.000032	0.000077	0.000058
51 550	0.000027	0.000027	0.000030	0.000021	0.000032	0.000027
103 097	0.000027	0.000027	0.000032	0.000022	0.000032	0.000027
154 646	0.000025	0.000025	0.000034	0.000023	0.000027	0.000025
206 197	0.000027	0.000028	0.000040	0.000025	0.000030	0.000025
257 742	0.000029	0.000029	0.000045	0.000027	0.000030	0.000028
309 294	0.000032	0.000031	0.000051	0.000030	0.000033	0.000029
360 840	0.000034	0.000034	0.000058	0.000032	0.000035	0.000034
412 392	0.000037	0.000037	0.000064	0.000035	0.000038	0.000037
515 492	0.000044	0.000044	0.000079	0.000042	0.000046	0.000044

4.3. Analysis of the calculation of the effective areas

4.3.1. Gas – case n°1

The relative deviations of the calculated effective areas (from the simulated data and not from the fitted parameters) between the NMIs have been reported in the table 32 for the respective nominal pressure point 4 000 kPa. From this table, it can be noticed that for three NMIs, the results show deviations higher than 10^{-6} with the results of the 12 other NMIs.

For this reason, the values of this 3 NMIs (BEV, IMBiH and IMT) were not considered to calculate the **reference value** at each nominal pressure points, which is the average of the values of the considered participants.

Table 33 reports the deviations of the NMIs' results from the calculated mean value. It can be seen that the deviations are not significant ($< 5 \cdot 10^{-7}$) between the NMIs values, without considering the results of BEV, IMBiH and IMT. Therefore, without considering this 3 exceptions, the calculation of the theoretical parameters (values and uncertainties of the effective area at null pressure A_0 and the distortion coefficient λ) are done based on the same initial values.

Concerning the uncertainties estimated by the NMIs, we can say that the estimations are almost the same. Indeed, only IPQ has very different uncertainties. Indeed only the Type A uncertainties have been reported. In reality, the combined uncertainty is similar to the other NMIs and this uncertainty have been reported only in the second loop. The difference between the NMIs' method is seen only in low pressure. In low pressure, the uncertainty values (excepted the ones estimated by IPQ and MIKES) vary from 0.00049 mm² to 0.00058 mm². The highest given uncertainty was estimated by MIKES as 0.0011 mm² for the first pressure point, which significantly different and between 0.00047 mm² and 0.00051 mm² for the other pressure points, which does not really differ from the uncertainties of the other NMIs.

Table 32. Relative deviations between the calculated effective areas for the gas case n°1 (nominal pressure point : 4000 kPa)

NMIs	BEV	CEM	EIM	DANIAmet	FSB-LPM	IMBiH	IMT	INRIM	IPQ
BEV	-	9.3E-06	9.3E-06	9.3E-06	9.3E-06	1.4E-05	1.4E-05	9.3E-06	9.3E-06
CEM	-9.3E-06	-	2.9E-09	2.8E-09	-2.2E-09	5.2E-06	5.2E-06	-2.7E-09	6.7E-09
EIM	-9.3E-06	-2.9E-09	-	-3.6E-11	-5.1E-09	5.2E-06	5.2E-06	-5.5E-09	3.8E-09
DANIAmet	-9.3E-06	-2.8E-09	3.6E-11	-	-5.0E-09	5.2E-06	5.2E-06	-5.5E-09	3.9E-09
FSB-LPM	-9.3E-06	2.2E-09	5.1E-09	5.0E-09	-	5.2E-06	5.2E-06	-4.6E-10	8.9E-09
IMBiH	-1.4E-05	-5.2E-06	-5.2E-06	-5.2E-06	-5.2E-06	-	-1.7E-09	-5.2E-06	-5.2E-06
IMT	-1.4E-05	-5.2E-06	-5.2E-06	-5.2E-06	-5.2E-06	1.7E-09	-	-5.2E-06	-5.2E-06
INRIM	-9.3E-06	2.7E-09	5.5E-09	5.5E-09	4.6E-10	5.2E-06	5.2E-06	-	9.4E-09
IPQ	-9.3E-06	-6.7E-09	-3.8E-09	-3.9E-09	-8.9E-09	5.2E-06	5.2E-06	-9.4E-09	-
LNE	-9.3E-06	-4.7E-08	-4.4E-08	-4.4E-08	-4.9E-08	5.2E-06	5.2E-06	-5.0E-08	-4.0E-08
METAS	-9.6E-06	-3.2E-07	-3.2E-07	-3.2E-07	-3.3E-07	4.9E-06	4.9E-06	-3.3E-07	-3.2E-07
MIKES (guide)	-9.3E-06	-4.9E-08	-4.6E-08	-4.6E-08	-5.1E-08	5.2E-06	5.2E-06	-5.1E-08	-4.2E-08
MKEH	-9.3E-06	-4.9E-08	-4.6E-08	-4.6E-08	-5.1E-08	5.2E-06	5.2E-06	-5.1E-08	-4.2E-08
PTB	-9.4E-06	-7.7E-08	-7.5E-08	-7.5E-08	-8.0E-08	5.1E-06	5.1E-06	-8.0E-08	-7.1E-08
UME	-9.3E-06	-3.1E-09	-2.0E-10	-2.3E-10	-5.3E-09	5.2E-06	5.2E-06	-5.7E-09	3.6E-09

NMIs	LNE	METAS	MIKES	MKEH	PTB	UME
BEV	9.3E-06	9.6E-06	9.3E-06	9.3E-06	9.4E-06	9.3E-06
CEM	4.7E-08	3.2E-07	4.9E-08	4.9E-08	7.7E-08	3.1E-09
EIM	4.4E-08	3.2E-07	4.6E-08	4.6E-08	7.5E-08	2.0E-10
DANIAmet	4.4E-08	3.2E-07	4.6E-08	4.6E-08	7.5E-08	2.3E-10
FSB-LPM	4.9E-08	3.3E-07	5.1E-08	5.1E-08	8.0E-08	5.3E-09
IMBiH	-5.2E-06	-4.9E-06	-5.2E-06	-5.2E-06	-5.1E-06	-5.2E-06
IMT	-5.2E-06	-4.9E-06	-5.2E-06	-5.2E-06	-5.1E-06	-5.2E-06
INRIM	5.0E-08	3.3E-07	5.1E-08	5.1E-08	8.0E-08	5.7E-09
IPQ	4.0E-08	3.2E-07	4.2E-08	4.2E-08	7.1E-08	-3.6E-09
LNE	-	2.8E-07	1.8E-09	1.8E-09	3.0E-08	-4.4E-08
METAS	-2.8E-07	-	-2.7E-07	-2.7E-07	-2.5E-07	-3.2E-07
MIKES	-1.8E-09	2.7E-07	-	0.0E+00	2.9E-08	-4.6E-08
MKEH	-1.8E-09	2.7E-07	0.0E+00	-	2.9E-08	-4.6E-08
PTB	-3.0E-08	2.5E-07	-2.9E-08	-2.9E-08	-	-7.4E-08
UME	4.4E-08	3.2E-07	4.6E-08	4.6E-08	7.4E-08	-

Table 33. Relative deviations between the calculated effective areas and the reference values for the gas case n°1

Nominal pressure kPa	**Mean value** mm²	BEV	CEM	EIM	DANIAmet	FSB-LPM	IMBiH	IMT	INRIM
200	49.019689	-4.6E-06	-9.1E-08	-8.6E-08	-8.6E-08	-1.2E-07	2.6E-06	2.6E-06	-9.7E-08
1 000	49.019019	-8.6E-06	-4.9E-08	-4.6E-08	-4.6E-08	-5.2E-08	9.3E-07	9.3E-07	-5.4E-08
2 000	49.018696	-9.1E-06	-5.6E-08	-5.3E-08	-5.3E-08	-7.2E-08	5.1E-06	5.1E-06	-6.0E-08
3 000	49.018485	-9.3E-06	-5.9E-08	-5.6E-08	-5.6E-08	-6.7E-08	1.0E-05	1.0E-05	-6.3E-08
4 000	49.018410	-9.3E-06	-4.3E-08	-4.0E-08	-4.0E-08	-4.5E-08	5.2E-06	5.2E-06	-4.6E-08
5 000	49.018300	-9.4E-06	-4.3E-08	-4.0E-08	-4.0E-08	-4.4E-08	3.5E-06	3.5E-06	-4.5E-08
6 000	49.018161	-9.4E-06	-5.7E-08	-5.4E-08	-5.4E-08	-5.3E-08	7.1E-06	7.1E-06	-5.8E-08
7 000	49.018013	-9.4E-06	-4.7E-08	-4.4E-08	-4.4E-08	-4.3E-08	6.9E-06	6.9E-06	-4.7E-08
8 000	49.017955	-9.5E-06	-5.8E-08	-5.5E-08	-5.5E-08	-5.0E-08	6.2E-06	6.2E-06	-5.7E-08
10 000	49.017675	-9.5E-06	-5.5E-08	-5.2E-08	-5.2E-08	-4.4E-08	6.8E-06	6.8E-06	-5.3E-08

Nominal pressure kPa	IPQ	LNE	METAS	MIKES	MKEH	PTB	UME
200	-2.7E-08	-1.7E-08	5.0E-07	2.2E-07	1.5E-08	-4.2E-08	-8.1E-08
1 000	-3.7E-08	3.4E-09	3.1E-07	2.8E-08	2.8E-08	-4.2E-10	-4.5E-08
2 000	-4.9E-08	-7.3E-09	2.8E-07	8.5E-08	8.5E-08	7.3E-09	-5.3E-08
3 000	-5.3E-08	-1.1E-08	2.7E-07	9.8E-08	9.8E-08	1.2E-08	-5.6E-08
4 000	-3.6E-08	4.0E-09	2.8E-07	5.8E-09	5.8E-09	3.4E-08	-4.0E-08
5 000	-3.7E-08	3.5E-09	2.8E-07	5.3E-09	5.3E-09	3.6E-08	-4.0E-08
6 000	-4.9E-08	-1.0E-08	2.6E-07	1.8E-07	-2.3E-08	1.8E-08	-5.4E-08
7 000	-4.1E-08	-2.0E-09	2.7E-07	1.3E-07	-7.0E-08	1.8E-08	-4.4E-08
8 000	-4.8E-08	-1.2E-08	2.6E-07	9.4E-08	9.4E-08	-7.6E-09	-5.5E-08
10 000	-4.4E-08	-9.6E-09	2.7E-07	9.2E-08	9.2E-08	-4.8E-08	-4.7E-08

4.3.2. Gas – case n°2

The relative deviations of the calculated effective areas (from the simulated data and not from the fitted parameters) between the NMIs have been reported in the table 34 for the respective nominal pressure point 4 000 kPa. From this table, it can be noticed that the same NMIs show deviations higher than 10^{-6} with the results of the 12 other NMIs.

The **reference value** at each nominal pressure points is still defined as the average of the values of the 12 other NMIs.

Table 35 reports the deviations of the NMIs' results from the calculated mean value. It can be seen that the deviations are not significant ($< 5 \cdot 10^{-7}$) between the NMIs values, without considering the results of BEV, IMBiH and IMT. Therefore, without considering this 3 exceptions, the calculation of the theoretical parameters (values and uncertainties of the effective area at null pressure A_0 and the distortion coefficient λ) are done based on the same initial values.

Concerning the uncertainties estimated by the NMIs, we can say that the estimations are almost the same. Indeed, only IPQ has very different uncertainties. Indeed only the Type A uncertainties have been reported. In reality, the combined uncertainty is similar to the other NMIs and this uncertainty have been reported only in the second loop. The difference between the NMIs' method is seen only in low pressure. In low pressure, the uncertainty values (excepted the ones estimated by IPQ and MIKES) vary from 0.00048 mm² to 0.00071 mm². The highest given uncertainty was estimated by MIKES as 0.0011 mm² for the first pressure point, which significantly different and between 0.00047 mm² and 0.00051 mm² for the other pressure points, which does not really differ from the uncertainties of the other NMIs.

Table 34. Relative deviations between the calculated effective areas for the gas case n°2 (nominal pressure point : 4000 kPa)

NMIs	BEV	CEM	EIM	DANIAmet	FSB-LPM	IMBiH	IMT	INRIM	IPQ	LNE	METAS	MIKES	MKEH	PTB	UME
BEV	-	1.3E-05	1.3E-05	1.3E-05	1.3E-05	1.8E-05	1.8E-05	1.3E-05	1.3E-05	1.3E-05	1.3E-05	1.4E-05	1.3E-05	1.3E-05	1.3E-05
CEM	-1.3E-05	-	4.8E-09	4.8E-09	2.4E-08	5.1E-06	5.1E-06	-1.0E-08	3.5E-08	8.7E-08	-5.5E-08	3.1E-07	1.1E-07	1.2E-07	3.7E-09
EIM	-1.3E-05	-4.8E-09	-	7.8E-12	1.9E-08	5.1E-06	5.1E-06	-1.5E-08	3.1E-08	8.3E-08	-6.0E-08	3.1E-07	1.0E-07	1.2E-07	-1.1E-09
DANIAmet	-1.3E-05	-4.8E-09	-7.8E-12	-	1.9E-08	5.1E-06	5.1E-06	-1.5E-08	3.1E-08	8.3E-08	-6.0E-08	3.1E-07	1.0E-07	1.2E-07	-1.1E-09
FSB-LPM	-1.3E-05	-2.4E-08	-1.9E-08	-1.9E-08	-	5.1E-06	5.1E-06	-3.5E-08	1.1E-08	6.3E-08	-7.9E-08	2.9E-07	8.2E-08	9.6E-08	-2.1E-08
IMBiH	-1.8E-05	-5.1E-06	-5.1E-06	-5.1E-06	-5.1E-06	-	-6.8E-09	-5.2E-06	-5.1E-06	-5.1E-06	-5.2E-06	-4.8E-06	-5.0E-06	-5.0E-06	-5.1E-06
IMT	-1.8E-05	-5.1E-06	-5.1E-06	-5.1E-06	-5.1E-06	6.8E-09	-	-5.2E-06	-5.1E-06	-5.1E-06	-5.2E-06	-4.8E-06	-5.0E-06	-5.0E-06	-5.1E-06
INRIM	-1.3E-05	1.0E-08	1.5E-08	1.5E-08	3.5E-08	5.2E-06	5.2E-06	-	4.6E-08	9.8E-08	-4.5E-08	3.2E-07	1.2E-07	1.3E-07	1.4E-08
IPQ	-1.3E-05	-3.5E-08	-3.1E-08	-3.1E-08	-1.1E-08	5.1E-06	5.1E-06	-4.6E-08	-	5.2E-08	-9.0E-08	2.7E-07	7.1E-08	8.5E-08	-3.2E-08
LNE	-1.3E-05	-8.7E-08	-8.3E-08	-8.3E-08	-6.3E-08	5.1E-06	5.1E-06	-9.8E-08	-5.2E-08	-	-1.4E-07	2.2E-07	1.9E-08	3.3E-08	-8.4E-08
METAS	-1.3E-05	5.5E-08	6.0E-08	6.0E-08	7.9E-08	5.2E-06	5.2E-06	4.5E-08	9.0E-08	1.4E-07	-	3.7E-07	1.6E-07	1.8E-07	5.9E-08
MIKES	-1.4E-05	-3.1E-07	-3.1E-07	-3.1E-07	-2.9E-07	4.8E-06	4.8E-06	-3.2E-07	-2.7E-07	-2.2E-07	-3.7E-07	-	-2.0E-07	-1.9E-07	-3.1E-07
MKEH	-1.3E-05	-1.1E-07	-1.0E-07	-1.0E-07	-8.2E-08	5.0E-06	5.0E-06	-1.2E-07	-7.1E-08	-1.9E-08	-1.6E-07	2.0E-07	-	1.4E-08	-1.0E-07
PTB	-1.3E-05	-1.2E-07	-1.2E-07	-1.2E-07	-9.6E-08	5.0E-06	5.0E-06	-1.3E-07	-8.5E-08	-3.3E-08	-1.8E-07	1.9E-07	-1.4E-08	-	-1.2E-07
UME	-1.3E-05	-3.7E-09	1.1E-09	1.1E-09	2.1E-08	5.1E-06	5.1E-06	-1.4E-08	3.2E-08	8.4E-08	-5.9E-08	3.1E-07	1.0E-07	1.2E-07	-

Table 35. Relative deviations between the calculated effective areas and the reference values for the gas case n°2

Nominal pressure kPa	**Mean value** mm²	**BEV**	**CEM**	**EIM**	**DANIAmet**	**FSB-LPM**	**IMBiH**	**IMT**	**INRIM**
200	49.019964	-8.2E-06	-9.2E-08	-7.1E-08	-6.9E-08	-5.5E-08	6.2E-07	6.1E-07	-1.1E-07
1 000	49.019311	-1.3E-05	-3.8E-08	-3.1E-08	-3.1E-08	-6.8E-09	5.7E-07	5.7E-07	-5.3E-08
2 000	49.018916	-1.3E-05	-3.5E-08	-2.9E-08	-2.9E-08	-1.9E-08	4.9E-06	4.9E-06	-4.7E-08
3 000	49.018773	-1.3E-05	-4.6E-08	-4.1E-08	-4.1E-08	-2.4E-08	9.9E-06	9.9E-06	-5.7E-08
4 000	49.018677	-1.3E-05	-4.9E-08	-4.4E-08	-4.4E-08	-2.5E-08	5.1E-06	5.1E-06	-5.9E-08
5 000	49.018572	-1.3E-05	-3.4E-08	-2.9E-08	-2.9E-08	-3.3E-09	3.5E-06	3.5E-06	-4.3E-08
6 000	49.018429	-1.3E-05	-4.3E-08	-3.9E-08	-3.9E-08	-8.2E-09	7.1E-06	7.1E-06	-5.1E-08
7 000	49.018261	-1.3E-05	-3.2E-08	-2.8E-08	-2.8E-08	8.1E-10	6.9E-06	6.9E-06	-3.9E-08
8 000	49.018193	-1.3E-05	-4.3E-08	-3.8E-08	-3.8E-08	-6.9E-09	6.2E-06	6.2E-06	-4.9E-08
10 000	49.017972	-1.3E-05	-4.2E-08	-3.7E-08	-3.7E-08	-2.7E-09	6.8E-06	6.8E-06	-4.5E-08

Nominal pressure kPa	**IPQ**	**LNE**	**METAS**	**MIKES**	**MKEH**	**PTB**	**UME**
200	3.9E-08	5.7E-08	3.0E-08	3.3E-07	1.2E-07	4.3E-09	-9.1E-08
1 000	1.0E-08	6.0E-08	-6.7E-08	1.9E-07	-1.1E-08	4.4E-08	-3.5E-08
2 000	5.8E-09	5.7E-08	-8.1E-08	8.7E-08	8.7E-08	6.5E-08	-3.1E-08
3 000	-8.7E-09	4.3E-08	-9.9E-08	1.4E-07	1.4E-07	6.7E-08	-4.2E-08
4 000	-1.4E-08	3.8E-08	-1.0E-07	2.6E-07	5.7E-08	7.2E-08	-4.5E-08
5 000	5.1E-09	5.5E-08	-8.7E-08	1.7E-07	-3.3E-08	8.7E-08	-3.0E-08
6 000	-1.7E-09	4.5E-08	-9.7E-08	2.2E-07	1.9E-08	7.2E-08	-3.9E-08
7 000	6.0E-09	5.2E-08	-8.8E-08	1.8E-07	-2.9E-08	6.7E-08	-2.9E-08
8 000	-2.7E-09	4.3E-08	-9.7E-08	1.4E-07	1.4E-07	3.7E-08	-3.9E-08
10 000	-1.0E-10	4.2E-08	-9.5E-08	1.6E-07	1.6E-07	-2.4E-08	-3.8E-08

4.3.3. Oil – case n°1

The relative deviations of the calculated effective areas (from the simulated data and not from the fitted parameters) between the NMIs have been reported in the table 36 for the respective nominal pressure point 200 MPa. From this table, it can be noticed that the same NMIs show deviations higher than 10^{-6} with the results of the 12 other NMIs.

For this reason, the values of this 3 NMIs (FSB-LPM, IMBiH and IMT) were not considered to calculate the **reference value** at each nominal pressure points, which is the average of the values of the considered participants.

Table 37 reports the deviations of the NMIs' results from the calculated mean value. It can be seen that the deviations are not significant ($< 5 \cdot 10^{-7}$) between the NMIs values, without considering the results of FSB-LPM, IMBiH and IMT. Therefore, without considering this 3 exceptions, the calculation of the theoretical parameters (values and uncertainties of the effective area at null pressure A_0 and the distortion coefficient λ) are done based on the same initial values.

Concerning the uncertainties estimated by the NMIs, we can say that the estimations are different. The uncertainties are very low for IPQ. Indeed only the Type A uncertainties have been reported. In reality, the combined uncertainty is similar to the other NMIs and this uncertainty have been reported only in the second loop. But for the other NMIS, it can vary from 0.000033 mm² (by CEM and MKEH) to 0.000080 mm² (by PTB) at 5 MPa and from 0.000029 mm² (by CEM) at 5 Mpa to 0.000075 mm² (by MIKES) at 500 MPa.

Table 36. Relative deviations between the calculated effective areas for the oil case n°1 (nominal pressure point : 200 MPa)

NMIs	BEV	CEM	EIM	DANIAmet	FSB-LPM	IMBiH	IMT	INRIM	IPQ	LNE	METAS	MIKES	MKEH	PTB	UME
BEV	-	4.0E-09	3.2E-09	7.0E-08	-8.9E-06	-2.1E-06	-2.1E-06	1.6E-07	5.1E-08	4.2E-08	3.3E-08	-1.3E-07	-1.3E-07	5.6E-08	2.7E-08
CEM	-4.0E-09	-	-7.9E-10	6.6E-08	-8.9E-06	-2.1E-06	-2.1E-06	1.5E-07	4.7E-08	3.8E-08	2.9E-08	-1.3E-07	-1.3E-07	5.2E-08	2.3E-08
EIM	-3.2E-09	7.9E-10	-	6.6E-08	-8.9E-06	-2.1E-06	-2.1E-06	1.5E-07	4.8E-08	3.8E-08	3.0E-08	-1.3E-07	-1.3E-07	5.2E-08	2.3E-08
DANIAmet	-7.0E-08	-6.6E-08	-6.6E-08	-	-9.0E-06	-2.2E-06	-2.2E-06	-7.0E-07	-1.8E-08	-2.8E-08	-3.6E-08	-2.0E-07	-2.0E-07	-1.4E-08	-4.3E-08
FSB-LPM	8.9E-06	8.9E-06	8.9E-06	9.0E-06	-	6.8E-06	6.8E-06	2.0E-05	9.0E-06	9.0E-06	9.0E-06	8.8E-06	8.8E-06	9.0E-06	8.9E-06
IMBiH	2.1E-06	2.1E-06	2.1E-06	2.2E-06	-6.8E-06	-	-8.6E-09	2.1E-06	2.2E-06	2.2E-06	2.2E-06	2.0E-06	2.0E-06	2.2E-06	2.1E-06
IMT	2.1E-06	2.1E-06	2.1E-06	2.2E-06	-6.8E-06	8.6E-09	-	2.1E-06	2.2E-06	2.2E-06	2.2E-06	2.0E-06	2.0E-06	2.2E-06	2.2E-06
INRIM	-1.6E-07	-1.5E-07	-1.5E-07	7.0E-07	-2.0E-05	-2.1E-06	-2.1E-06	-	-2.3E-07	4.6E-08	4.5E-10	-6.2E-07	-9.1E-08	-2.3E-07	-6.6E-09
IPQ	-5.1E-08	-4.7E-08	-4.8E-08	1.8E-08	-9.0E-06	-2.2E-06	-2.2E-06	2.3E-07	-	-9.8E-09	-1.8E-08	-1.8E-07	-1.8E-07	4.2E-09	-2.5E-08
LNE	-4.2E-08	-3.8E-08	-3.8E-08	2.8E-08	-9.0E-06	-2.2E-06	-2.2E-06	-4.6E-08	9.8E-09	-	-8.2E-09	-1.7E-07	-1.7E-07	1.4E-08	-1.5E-08
METAS	-3.3E-08	-2.9E-08	-3.0E-08	3.6E-08	-9.0E-06	-2.2E-06	-2.2E-06	-4.5E-10	1.8E-08	8.2E-09	-	-1.6E-07	-1.6E-07	2.2E-08	-6.8E-09
MIKES	1.3E-07	1.3E-07	1.3E-07	2.0E-07	-8.8E-06	-2.0E-06	-2.0E-06	6.2E-07	1.8E-07	1.7E-07	1.6E-07	-	0.0E+00	1.8E-07	1.5E-07
MKEH	1.3E-07	1.3E-07	1.3E-07	2.0E-07	-8.8E-06	-2.0E-06	-2.0E-06	9.1E-08	1.8E-07	1.7E-07	1.6E-07	0.0E+00	-	1.8E-07	1.5E-07
PTB	-5.6E-08	-5.2E-08	-5.2E-08	1.4E-08	-9.0E-06	-2.2E-06	-2.2E-06	2.3E-07	-4.2E-09	-1.4E-08	-2.2E-08	-1.8E-07	-1.8E-07	-	-2.9E-08
UME	-2.7E-08	-2.3E-08	-2.3E-08	4.3E-08	-8.9E-06	-2.1E-06	-2.2E-06	6.6E-09	2.5E-08	1.5E-08	6.8E-09	-1.5E-07	-1.5E-07	2.9E-08	-

Table 37. Relative deviations between the calculated effective areas and the reference values for the oil case n°1

Nominal pressure MPa	Mean value mm²	BEV	CEM	EIM	DANIAmet	FSB-LPM	IMBiH	IMT	INRIM
5	1.902989	7.9E-08	-1.0E-07	-1.3E-07	4.0E-08	-1.9E-04	9.1E-06	9.3E-06	6.2E-08
50	1.902982	-4.9E-08	-6.0E-08	-6.2E-08	-2.3E-08	-2.1E-05	7.2E-06	7.2E-06	-4.2E-08
100	1.903054	-1.8E-08	-1.8E-08	-1.9E-08	2.3E-08	-1.4E-05	4.2E-06	4.2E-06	-3.6E-09
150	1.903143	-3.1E-08	-3.0E-08	-3.1E-08	2.1E-08	-1.2E-05	5.9E-07	5.9E-07	-1.1E-08
200	1.903211	-5.1E-09	-1.1E-09	-1.9E-09	6.5E-08	-8.9E-06	-2.1E-06	-2.1E-06	2.7E-08
250	1.903285	-3.8E-08	-3.2E-08	-3.3E-08	5.2E-08	-1.3E-05	-1.2E-06	-1.2E-06	8.2E-09
300	1.903356	-5.9E-09	1.3E-09	7.1E-10	1.5E-07	-1.4E-05	-2.4E-06	-2.4E-06	5.7E-08
350	1.903425	-3.2E-08	-2.7E-08	-2.7E-08	3.7E-07	-1.6E-05	-2.2E-06	-2.2E-06	4.7E-08
400	1.903498	-7.8E-08	-6.9E-08	-7.0E-08	4.5E-07	-1.7E-05	-2.7E-06	-2.7E-06	2.6E-08
500	1.903647	-8.3E-08	-7.4E-08	-7.5E-08	7.7E-07	-2.0E-05	-2.0E-06	-2.0E-06	7.3E-08

Nominal pressure MPa	IPQ	LNE	METAS	MIKES	MKEH	PTB	UME
5	1.0E-07	-1.2E-07	1.3E-07	-9.1E-08	-9.1E-08	2.1E-07	-9.8E-08
50	1.2E-07	-6.2E-08	-3.5E-08	6.7E-08	6.7E-08	1.4E-07	-5.8E-08
100	1.1E-07	-9.3E-09	1.0E-10	-9.2E-08	-9.2E-08	1.3E-07	-1.3E-08
150	5.7E-08	-8.0E-09	-8.4E-09	2.6E-07	-2.7E-07	6.8E-08	-1.6E-08
200	4.6E-08	3.7E-08	2.8E-08	-1.3E-07	-1.3E-07	5.1E-08	2.2E-08
250	-1.9E-08	2.5E-08	9.6E-09	1.9E-08	1.9E-08	-1.3E-08	2.1E-09
300	-1.5E-08	7.9E-08	5.8E-08	-4.5E-07	8.0E-08	-1.5E-08	5.1E-08
350	-6.7E-08	7.6E-08	4.8E-08	-1.8E-07	-1.8E-07	-6.3E-08	4.3E-08
400	-1.3E-07	6.0E-08	2.6E-08	-3.2E-07	2.1E-07	-1.3E-07	2.0E-08
500	-1.6E-07	1.2E-07	7.3E-08	-5.4E-07	-1.8E-08	-1.5E-07	6.6E-08

4.3.4. Oil – case n°2

The relative deviations of the calculated effective areas (from the simulated data and not from the fitted parameters) between the NMIs have been reported in the table 38 for the respective nominal pressure point 200 MPa. From this table, it can be noticed that the same NMIs show deviations higher than 10^{-6} with the results of the 12 other NMIs.

The **reference value** at each nominal pressure points is still defined as the average of the values of the 12 other NMIs.

Table 39 reports the deviations of the NMIs' results from the calculated mean value. It can be seen that the deviations are not significant ($< 5 \cdot 10^{-7}$) between the NMIs values, without considering the results of FSB-LPM, IMBiH and IMT. Therefore, without considering this 3 exceptions, the calculation of the theoretical parameters (values and uncertainties of the effective area at null pressure A_0 and the distortion coefficient λ) are done based on the same initial values.

Concerning the uncertainties estimated by the NMIs, we can say that the estimations are different. The uncertainties are very low for IPQ. Indeed only the Type A uncertainties have been reported. In reality, the combined uncertainty is similar to the other NMIs and this uncertainty have been reported only in the second loop. IPQ and DANIAmet excluded, the uncertainties reported by NMIs can vary from 0.000032 mm² (by MKEH) to 0.000077 mm² (by PTB) at 5 MPa. For DANIAmet, the value is the highest with 0.0015 mm². IPQ excluded, the uncertainties reported by NMIs can vary from 0.000028 mm² (by DANIAmet) at 5 MPa to 0.000079 mm² (by MIKES) at 500 MPa. For DANIAmet, the value.

Table 38. Relative deviations between the calculated effective areas for the oil case n°2 (nominal pressure point : 200 MPa)

NMIs	BEV	CEM	EIM	DANIAmet	FSB-LPM	IMBiH	IMT	INRIM	IPQ
BEV	-	2.3E-09	1.6E-09	3.3E-08	-2.2E-06	3.9E-06	3.9E-06	1.7E-07	1.7E-08
CEM	-2.3E-09	-	-7.3E-10	3.1E-08	-2.2E-06	3.9E-06	3.9E-06	1.7E-07	1.4E-08
EIM	-1.6E-09	7.3E-10	-	3.2E-08	-2.2E-06	3.9E-06	3.9E-06	1.7E-07	1.5E-08
DANIAmet	-3.3E-08	-3.1E-08	-3.2E-08	-	-2.2E-06	3.9E-06	3.8E-06	5.4E-07	-1.7E-08
FSB-LPM	2.2E-06	2.2E-06	2.2E-06	2.2E-06	-	6.0E-06	6.0E-06	1.3E-05	2.2E-06
IMBiH	-3.9E-06	-3.9E-06	-3.9E-06	-3.9E-06	-6.0E-06	-	-1.1E-08	-7.7E-06	-3.9E-06
IMT	-3.9E-06	-3.9E-06	-3.9E-06	-3.8E-06	-6.0E-06	1.1E-08	-	-7.7E-06	-3.9E-06
INRIM	-1.7E-07	-1.7E-07	-1.7E-07	-5.4E-07	-1.3E-05	7.7E-06	7.7E-06	-	-1.9E-07
IPQ	-1.7E-08	-1.4E-08	-1.5E-08	1.7E-08	-2.2E-06	3.9E-06	3.9E-06	1.9E-07	-
LNE	-5.2E-08	-4.9E-08	-5.0E-08	-1.8E-08	-2.2E-06	3.8E-06	3.8E-06	-5.7E-08	-3.5E-08
METAS	-3.3E-08	-3.1E-08	-3.2E-08	2.0E-10	-2.2E-06	3.9E-06	3.8E-06	-5.2E-10	-1.6E-08
MIKES (guide)	1.7E-07	1.7E-07	1.7E-07	2.0E-07	-2.0E-06	4.1E-06	4.0E-06	4.4E-07	1.8E-07
MKEH	1.7E-07	1.7E-07	1.7E-07	2.0E-07	-2.0E-06	4.1E-06	4.0E-06	-8.5E-08	1.8E-07
PTB	-1.6E-08	-1.4E-08	-1.4E-08	1.7E-08	-2.2E-06	3.9E-06	3.9E-06	1.9E-07	8.6E-10
UME	-3.0E-08	-2.8E-08	-2.9E-08	2.9E-09	-2.2E-06	3.9E-06	3.8E-06	-1.1E-09	-1.4E-08

NMIs	LNE	METAS	MIKES	MKEH	PTB	UME
BEV	5.2E-08	3.3E-08	-1.7E-07	-1.7E-07	1.6E-08	3.0E-08
CEM	4.9E-08	3.1E-08	-1.7E-07	-1.7E-07	1.4E-08	2.8E-08
EIM	5.0E-08	3.2E-08	-1.7E-07	-1.7E-07	1.4E-08	2.9E-08
DANIAmet	1.8E-08	-2.0E-10	-2.0E-07	-2.0E-07	-1.7E-08	-2.9E-09
FSB-LPM	2.2E-06	2.2E-06	2.0E-06	2.0E-06	2.2E-06	2.2E-06
IMBiH	-3.8E-06	-3.9E-06	-4.1E-06	-4.1E-06	-3.9E-06	-3.9E-06
IMT	-3.8E-06	-3.8E-06	-4.0E-06	-4.0E-06	-3.9E-06	-3.8E-06
INRIM	5.7E-08	5.2E-10	-4.4E-07	8.5E-08	-1.9E-07	1.1E-09
IPQ	3.5E-08	1.6E-08	-1.8E-07	-1.8E-07	-8.6E-10	1.4E-08
LNE	-	-1.8E-08	-2.2E-07	-2.2E-07	-3.6E-08	-2.1E-08
METAS	1.8E-08	-	-2.0E-07	-2.0E-07	-1.7E-08	-2.7E-09
MIKES	2.2E-07	2.0E-07	-	0.0E+00	1.8E-07	2.0E-07
MKEH	2.2E-07	2.0E-07	0.0E+00	-	1.8E-07	2.0E-07
PTB	3.6E-08	1.7E-08	-1.8E-07	-1.8E-07	-	1.4E-08
UME	2.1E-08	2.7E-09	-2.0E-07	-2.0E-07	-1.4E-08	-

Table 39. Relative deviations between the calculated effective areas and the reference values for the oil case n°2

Nominal pressure MPa	Mean value	BEV	CEM	EIM	DANIAmet	FSB-LPM	IMBiH	IMT	INRIM
5	1.902826	2.6E-08	-5.5E-08	-5.6E-08	5.9E-08	-1.1E-05	-4.7E-05	-4.7E-05	-7.5E-09
50	1.902982	-3.4E-08	-4.0E-08	-4.0E-08	-2.6E-08	-2.9E-06	4.4E-06	4.3E-06	-3.3E-08
100	1.903070	-1.7E-08	-1.6E-08	-1.7E-08	-2.9E-09	-3.5E-06	9.1E-07	9.0E-07	-6.3E-09
150	1.903150	-3.9E-08	-3.7E-08	-3.7E-08	-1.7E-08	-4.6E-06	3.4E-06	3.4E-06	-1.9E-08
200	1.903216	9.9E-09	1.2E-08	1.2E-08	4.3E-08	-2.1E-06	3.9E-06	3.9E-06	4.2E-08
250	1.903299	-4.9E-09	2.9E-10	-8.7E-10	4.6E-08	-6.8E-06	9.8E-06	9.8E-06	-1.4E-07
300	1.903377	-1.6E-08	-1.2E-08	-1.4E-08	5.1E-08	-7.9E-06	9.2E-06	9.2E-06	5.0E-08
350	1.903451	-6.5E-08	-5.8E-08	-6.1E-08	4.3E-08	-9.2E-06	8.7E-06	8.7E-06	2.4E-08
400	1.903531	-5.2E-08	-4.7E-08	-5.0E-08	6.1E-08	-1.0E-05	9.0E-06	9.0E-06	6.0E-08
500	1.903684	-2.7E-08	-2.1E-08	-2.6E-08	-4.0E-07	-1.3E-05	7.9E-06	7.9E-06	1.4E-07

Nominal pressure MPa	IPQ	LNE	METAS	MIKES	MKEH	PTB	UME
5	3.6E-08	-6.8E-08	5.1E-08	6.7E-09	6.7E-09	5.4E-08	-5.3E-08
50	1.5E-08	-3.5E-08	-2.7E-08	3.8E-07	-1.4E-07	1.9E-08	-3.7E-08
100	2.3E-08	2.8E-10	-3.2E-09	1.1E-08	1.1E-08	2.7E-08	-9.8E-09
150	-1.1E-08	-5.3E-09	-1.7E-08	3.7E-07	-1.6E-07	-9.6E-09	-2.1E-08
200	2.7E-08	6.1E-08	4.3E-08	-1.6E-07	-1.6E-07	2.6E-08	4.0E-08
250	4.7E-09	7.0E-08	4.5E-08	-3.6E-08	-3.6E-08	6.1E-09	4.1E-08
300	-1.6E-08	8.2E-08	5.1E-08	-1.0E-07	-1.0E-07	-1.9E-08	4.9E-08
350	-6.9E-08	6.3E-08	2.5E-08	7.5E-08	7.5E-08	-7.2E-08	2.1E-08
400	-6.4E-08	1.0E-07	6.0E-08	-3.3E-08	-3.3E-08	-6.5E-08	6.0E-08
500	-4.5E-08	2.0E-07	1.4E-07	-3.0E-07	2.3E-07	-5.0E-08	1.4E-07

5. Results of the second loop: gas balances

5.1. Provided data

As some NMIs' effective areas get by calculations from the given data were significantly deviated from most of NMIs, it was decided to give each effective area at pressure p and its standard uncertainty in order to compare the calculation methods of the fitting parameters.

The initial data were the one presented in table 40. These data are considered as experimental areas calculated from the calibration data given in Section 3.

The uncertainty of the effective areas are similar between the NMIs. Therefore, the uncertainties reported are the one calculated by LNE. However, by comparing the theoretical value of the effective areas and the calculated ones, it can be noticed that the effective area relative to the first pressure point is not coherent with the theoretical value. It is mainly due to the generation of the additional data where a resolution has been considered. In practise, this parameter is not always considered by NMIs, as the repeatability of the first point often reflects this parameter. However, there are some cases when the repeatability is indeed underestimated for this first point. That’s one of the main issues of the fitting determination and that’s why this uncertainty component has not been added in the data.

Table 40. Provided data: cases of gas balances

	Case n°1		**Case n°2**	
Nominal pressure kPa	**A_p** mm²	**$u(A_p)$** mm²	**A_p** mm²	**$u(A_p)$** mm²
200	49.01969	0.00052	49.01997	0.00062
1 000	49.01902	0.00042	49.01931	0.00042
2 000	49.01870	0.00041	49.01892	0.00041
3 000	49.01849	0.00041	49.01877	0.00041
4 000	49.01841	0.00041	49.01868	0.00041
5 000	49.01830	0.00041	49.01857	0.00041
6 000	49.01816	0.00041	49.01843	0.00041
7 000	49.01801	0.00041	49.01826	0.00041
8 000	49.01796	0.00041	49.01819	0.00041
10 000	49.01768	0.00041	49.01797	0.00041

5.2. Effective area at null pressure A_0 and distortion coefficient λ

5.2.1. Case n°1

Table 41. Case n°1: calculation of A_0 and λ by NMIs

NMIs	**A_0** mm²	**u_{A0}** mm²	**λ** Pa^{-1}	**u_λ** Pa^{-1}	**u_λ/λ**	**$u(A_0,\beta)$** $mm^4 \cdot Pa^{-1}$
BEV	49.01923	0.00044	-3.50E-12	3.5E-13	10%	-
CEM	49.01923	0.00048	-3.50E-12	2.7E-13	7.8%	-4.9E-16
EIM	49.01923	0.00037	-3.50E-12	1.4E-12	39%	-4.2E-16
DANIAmet	49.01914	0.00003	-2.44E-12	7.6E-14	3.1%	-9.5E-17
FSB-LPM	49.01923	0.00042	-3.49E-12	1.7E-13	5.0%	-
IMBiH	49.01923	0.00041	-3.50E-12	1.5E-12	43%	-2.5E-15
IMT	49.01923	0.00041	-3.50E-12	1.5E-12	43%	-2.5E-14
INRIM	49.01897	0.00059	-2.68E-12	2.4E-13	8.9%	-5.9E-16
IPQ	49.01923	0.00041	-3.50E-12	4.8E-13	14%	-5.7E-17
LNE	49.01897	0.00040	-2.71E-12	2.0E-13	7.4%	-5.3E-16
METAS	49.01901	0.00042	-2.79E-12	1.5E-13	5.6%	-
MIKES	49.01923	0.00041	-3.50E-12	1.5E-12	43%	-2.5E-15
MKEH	49.01923	0.00052	-3.50E-12	4.8E-13	14%	-2.5E-15
PTB	49.01887	0.00042	-2.50E-12	4.4E-13	18%	-5.4E-17
UME	49.01916	0.00047	-2.79E-12	9.3E-13	33%	-9.8E-15

The results are reported in Table 41 and illustrated in Fig. 1 and Fig. 2. BEV, CEM, EIM, FSB-LPM, IMBiH, IMT, IPQ, MIKES and MKEH have calculated the same value of the effective area at null pressure 49.01923 mm² and the same value of the coefficient distortion –

$3.50 \cdot 10^{-12}$ Pa^{-1}. Indeed, all these NMIs have used the same calculation method: the ordinary least square method. IPQ has estimated the uncertainty of A_0 with a value lower than the other NMIs quoted above: their uncertainties is evaluated between 0.0004 mm² and 0.0005 mm² while IPQ has estimated it about 0.00013 mm². Besides, although they obtained the same value for the distortion coefficient and although most of these NMIs used the same methods, it seems that their method to estimate the uncertainty of the distortion coefficient are different from one to another. The relative uncertainty is estimated less than 10% by BEV, CEM, FSB-LPM. It is estimated about 14% by IPQ and MKEH, 39% by EIM and 43% by IMBiH, IMT and MIKES.

DANIAmet, INRIM, LNE, METAS, PTB and UME have used different methods and their results are different. Their deviations and their estimations of the uncertainties will be discussed later. It can just be said that DANIAmet gives the lowest uncertainty. However, it is not really relevant because only the Type A uncertainty is given.

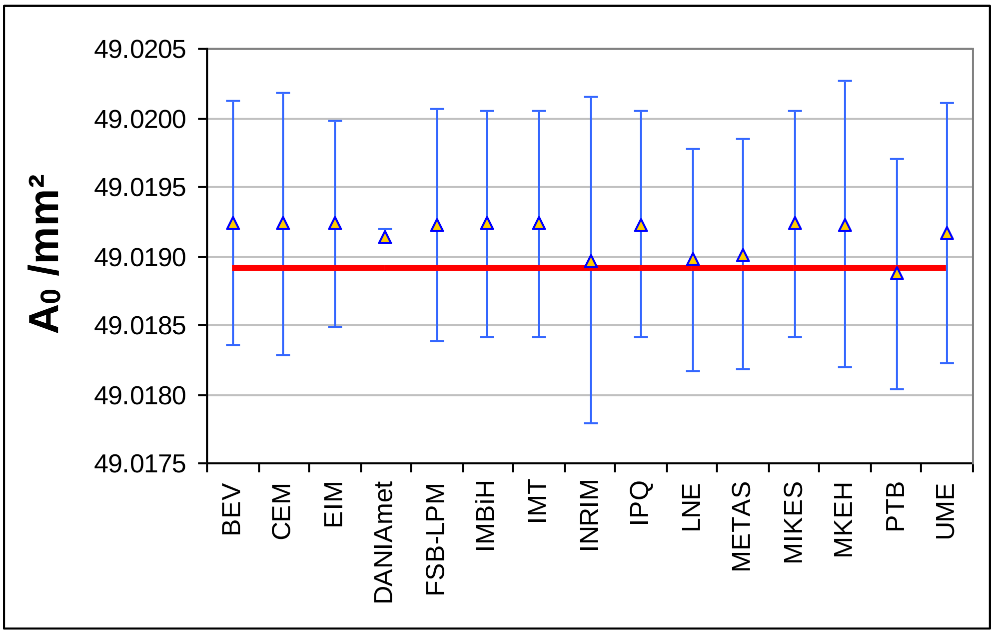

Fig. 1. Effective area at null pressure A_0 of a gas balance (case n°1) calculated by every NMIs, compared with the theoretical value of A_0 (straight line). The vertical lines represents the expanded uncertainty of A_0 given by the NMIs (twice the values reported in Table 41).

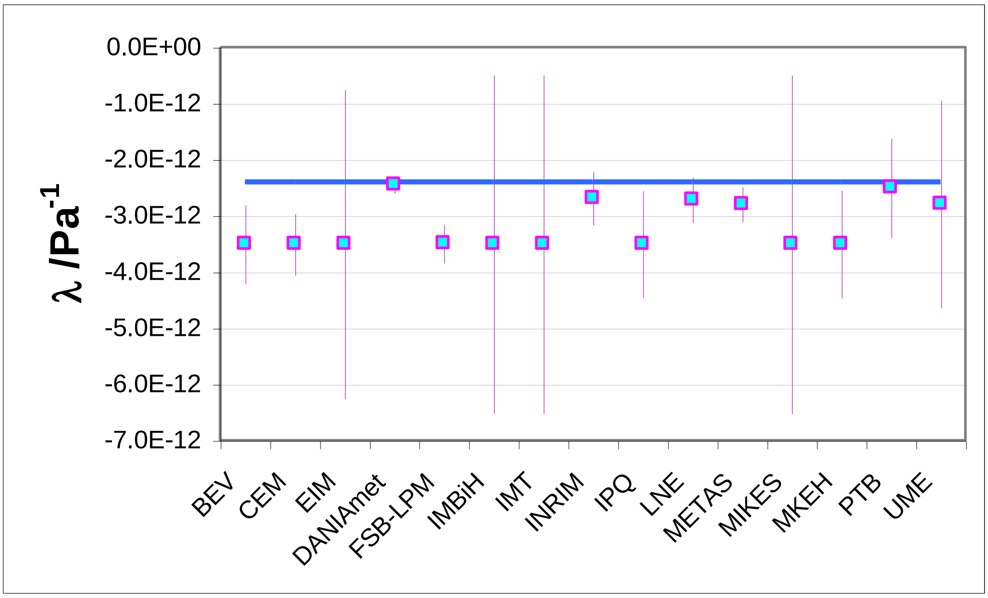

Fig. 2. Distortion coefficient λ of a gas balance (case n°1) calculated by every NMIs, compared with the theoretical value of λ (straight line). The vertical lines represents the expanded uncertainty of λ given by the NMIs (twice the values reported in Table 41).

5.2.2. Case n°2

Table 42. Case n°2: calculation of A_0 and λ by NMIs

NMIs	**A_0** mm^2	**u_{A0}** mm^2	**λ** Pa^{-1}	**uλ** Pa^{-1}	**u_λ/λ**	**u(A_0,β)** mm^4·Pa^{-1}
BEV	49.01950	0.00050	-3.50E-12	4.0E-13	11%	-
CEM	49.01950	0.00048	-3.51E-12	3.0E-13	8.5%	-6.4E-16
EIM	49.01950	0.00038	-3.50E-12	1.4E-12	40%	-4.4E-16
DANIAmet	49.01914	0.00003	-2.44E-12	7.6E-14	3.1%	-9.5E-17
FSB-LPM	49.01950	0.00043	-3.50E-12	1.8E-13	5.0%	-
IMBiH	49.01950	0.00042	-3.50E-12	1.6E-12	44%	-2.7E-15
IMT	49.01950	0.00042	-3.50E-12	1.6E-12	44%	-2.7E-14
INRIM	49.01920	0.00059	-2.60E-12	2.5E-13	9.4%	-6.4E-16
IPQ	49.01950	0.00042	-3.51E-12	4.9E-13	14%	-6.1E-17
LNE	49.01921	0.00040	-2.62E-12	2.1E-13	7.9%	-5.6E-16
METAS	49.01926	0.00042	-2.78E-12	1.6E-13	5.7%	-
MIKES	49.01950	0.00042	-3.50E-12	1.6E-12	44%	-2.7E-09
MKEH	49.01950	0.00060	-3.52E-12	4.9E-13	14%	-2.7E-15
PTB	49.01913	0.00041	-2.48E-12	5.3E-13	21%	-7.5E-17
UME	49.01939	0.00048	-3.15E-12	9.4E-13	30%	-1.0E-14

The results are reported in Table 42 and illustrated in Fig. 3 and Fig. 4.The observations of the results can be made like the case n°1. BEV, CEM, EIM, FSB-LPM, IMBiH, IMT, IPQ, MIKES and MKEH have calculated the same value of the effective area at null pressure 49.01950 mm² and almost the same values of the coefficient distortion about $-3.50\cdot10^{-12}$ Pa^{-1}. Indeed, all these NMIs have used the same calculation method: the ordinary least square method. IPQ has estimated the uncertainty of A_0 with a value lower than the other NMIs quoted above: their uncertainties is evaluated between 0.0004 mm² and 0.0005 mm² while

IPQ has estimated it about 0.00013 mm². Besides, although they obtained the same value for the distortion coefficient and although most of these NMIs used the same methods, it seems that their method to estimate the uncertainty of the distortion coefficient are different from one to another. The relative uncertainty is estimated less than 11% by BEV, CEM, FSB-LPM. It is estimated about 14% by IPQ and MKEH, 40% by EIM and 44% by IMBiH, IMT and MIKES.

DANIAmet, INRIM, LNE, METAS, PTB and UME have still used different methods and their results are different. Their deviations and their estimations of the uncertainties will be discussed later. It can just be said that DANIAmet gives the lowest uncertainty. However, it is not really relevant because only the Type A uncertainty is given.

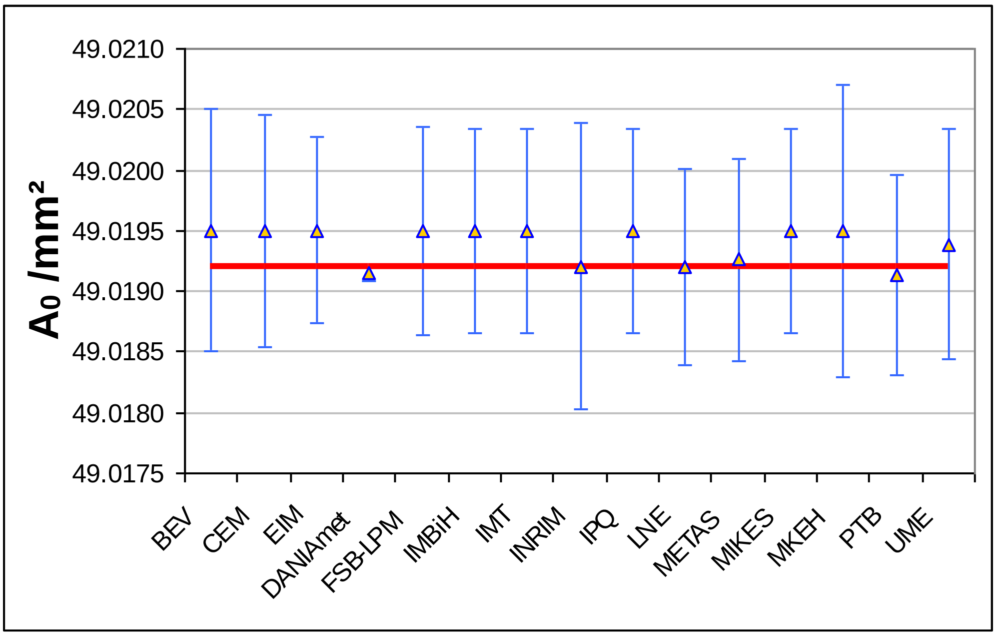

Fig. 3. Effective area at null pressure A_0 of a gas balance (case n°2) calculated by every NMIs, compared with the theoretical value of A_0 (straight line). The vertical lines represents the expanded uncertainty of A_0 given by the NMIs (twice the values reported in Table 42).

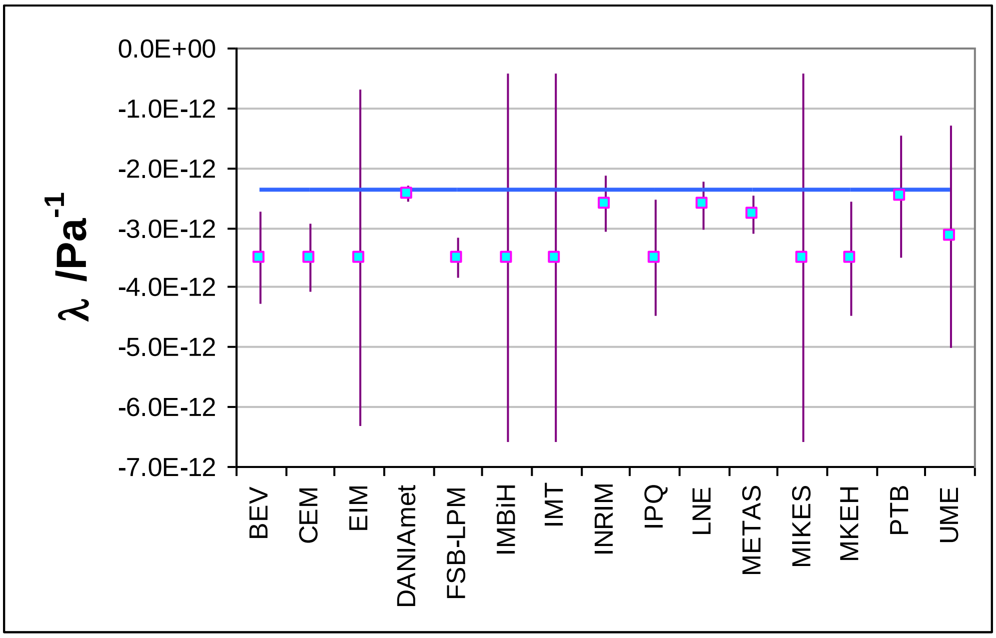

Fig. 4. Distortion coefficient λ of a gas balance (case n°2) calculated by every NMIs, compared with the theoretical value of λ (straight line). The vertical lines represents the expanded uncertainty of λ given by the NMIs (twice the values reported in Table 42).

5.3. Calculation of the fitted effective areas by NMIs

The fitted effective area at a pressure point p, Âp, is defined by the equation (2).

6. Results of the second loop: oil balances

6.1. Provided data

As some NMIs' effective areas get by calculations from the given data were significantly deviated from most of NMIs, it was decided to give each effective area at pressure p and its standard uncertainty in order to compare the calculation methods of the fitting parameters.

The initial data were the one presented in table 43. these data are considered as possible areas calculated from the calibration data given in Section 3.

Table 43. Provided data: cases of gas balances

Case n°1			Case n°2		
Nominal pressure MPa	**A_p** mm^2	**$u(A_p)$** mm^2	**Nominal pressure** MPa	**A_p** mm^2	**$u(A_p)$** mm^2
5.16	1.902989	0.000065	5.16	1.902826	0.000063
51.55	1.902982	0.000025	51.55	1.902982	0.000029
103.10	1.903054	0.000026	103.10	1.903070	0.000030
154.65	1.903143	0.000030	154.65	1.903150	0.000028
206.19	1.903211	0.000030	206.20	1.903216	0.000030
257.74	1.903285	0.000033	257.74	1.903299	0.000032
309.29	1.903356	0.000037	309.29	1.903377	0.000035
360.84	1.903425	0.000036	360.84	1.903451	0.000037
412.38	1.903498	0.000041	412.39	1.903531	0.000040
515.48	1.903647	0.000046	515.49	1.903684	0.000048

6.2. Effective area at null pressure A_0 and distortion coefficient λ

The fitted effective area at a pressure point p, $\hat{A}p$, is defined by the equation (2).

6.2.1. Case n°1

Table 44. Case n°1: calculation of A_0 and λ by NMIs

NMIs	A_0 mm^2	u_{A0} mm^2	λ Pa^{-1}	$u\lambda$ Pa^{-1}	u_λ/λ	$u(A_0,\beta)$ $\mathrm{mm}^4\cdot\mathrm{Pa}^{-1}$
BEV	1.902936	0.000039	7.15E-13	7.0E-14	10%	-
CEM	1.902936	0.000029	7.15E-13	3.8E-14	5.3%	-1.4E-19
EIM	1.902936	0.000034	7.14E-13	6.3E-14	8.8%	-6.8E-20
DANIAmet	1.902912	0.0000069	7.51E-13	1.1E-14	1.5%	-1.3E-19
FSB-LPM	1.902966	0.000041	7.14E-13	3.6E-14	5.0%	-
IMBiH	1.902936	0.000037	7.14E-13	6.9E-14	10%	-4.1E-19
IMT	1.902936	0.000037	7.14E-13	6.9E-14	10%	-4.1E-18
INRIM	1.902915	0.000020	7.46E-13	3.9E-14	5.2%	-1.5E-19
IPQ	1.902936	0.000037	7.36E-13	3.7E-14	5.0%	4.3E-19
LNE	1.902906	0.000022	7.62E-13	2.3E-14	3.1%	7.5E-19
METAS	1.902913	0.000028	7.49E-13	3.8E-14	5.0%	-
MIKES	1.902936	0.000038	7.15E-13	7.0E-14	10%	-4.2E-19
MKEH	1.902936	0.000061	7.15E-13	2.2E-14	3.1%	-4.1E-19
PTB	1.902909	0.000024	7.54E-13	3.7E-14	4.9%	-3.3E-19
UME	1.902917	0.000026	7.44E-13	5.2E-14	7.0%	-9.9E-19

The results are reported in Table 44 and illustrated in Fig. 5 and Fig. 6. BEV, CEM, EIM, IMBiH, IMT, IPQ, MIKES and MKEH have calculated the same value of the effective area at null pressure 1.902936 mm^2 and the same value of the coefficient distortion about $7.15\cdot10^{-12}$ Pa^{-1}. Indeed, all these NMIs have used the same calculation method: the ordinary least square method. IPQ has estimated the uncertainty of A_0 with a value lower than the other NMIs quoted above: their uncertainties is evaluated between 0.000029 mm² and 0.000039 mm² while IPQ has estimated it about 0.000012 mm². Besides, although they obtained the same value for the distortion coefficient and although most of these NMIs used the same methods, it seems that their method to estimate the uncertainty of the distortion coefficient are different from one to another. The relative uncertainty is estimated less than 10% by all the participants. Contrary to the gas balance cases, although FSB-LPM uses the same method, it seems that the results are different from the other NMIs.

DANIAmet, INRIM, LNE, METAS, PTB and UME have used different methods and their results are different. Their deviations and their estimations of the uncertainties will be discussed later. It can just be said that DANIAmet gives the lowest uncertainty. However, it is not really relevant because only the Type A uncertainty is given.

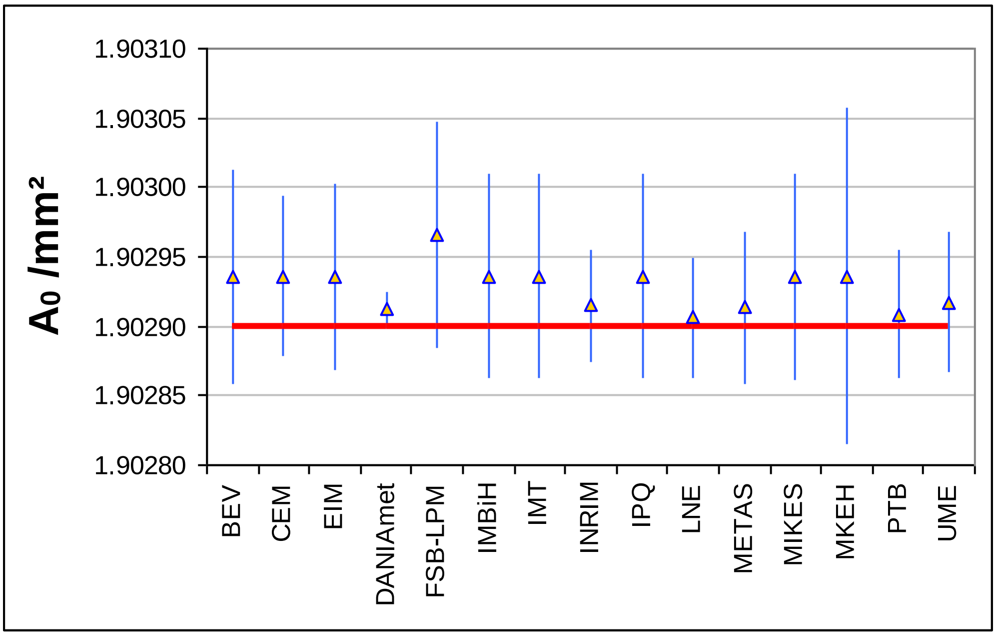

Fig. 5. Effective area at null pressure A_0 of a oil balance (case n°1) calculated by every NMIs, compared with the theoretical value of A_0 (straight line). The vertical lines represents the expanded uncertainty of A_0 given by the NMIs (twice the values reported in Table 44).

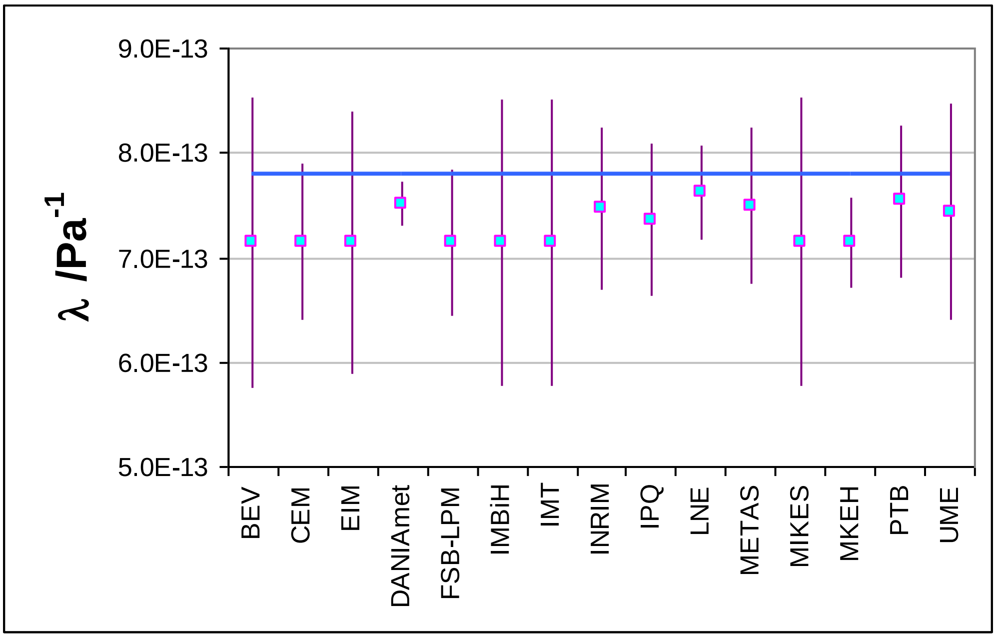

Fig. 6. Distortion coefficient λ of a oil balance (case n°1) calculated by every NMIs, compared with the theoretical value of λ (straight line). The vertical lines represents the expanded uncertainty of λ given by the NMIs (twice the values reported in Table 44).

6.2.2. Case n°2

Table 45. Case n°2: calculation of A_0 and λ by NMIs

NMIs	**A_0** mm²	**u_{A0}** mm²	**λ** Pa^{-1}	**uλ** Pa^{-1}	**u_λ/λ**	**$u(A_0,\beta)$** $mm^4 \cdot Pa^{-1}$
BEV	1.902881	0.000033	8.36E-13	8.0E-14	10%	-
CEM	1.902881	0.000030	8.36E-13	4.4E-14	5.3%	-1.9E-19
EIM	1.902881	0.000046	8.35E-13	8.4E-14	10%	-1.2E-19
DANIAmet	1.902911	0.000010	7.90E-13	1.6E-14	2.0%	-2.6E-19
FSB-LPM	1.902920	0.000047	8.36E-13	4.2E-13	50.0%	-
IMBiH	1.902881	0.000050	8.35E-13	9.3E-14	11%	-7.4E-19
IMT	1.902881	0.000050	8.35E-13	9.3E-14	11%	-7.4E-18
INRIM	1.902911	0.000021	7.90E-13	4.2E-14	5.3%	-2.6E-19
IPQ	1.902881	0.000050	8.61E-13	4.3E-14	5.0%	6.8E-19
LNE	1.902952	0.000019	7.33E-13	2.1E-14	2.8%	1.1E-18
METAS	1.902911	0.000029	7.89E-13	4.0E-14	5.0%	-
MIKES	1.902881	0.000050	8.36E-13	9.2E-14	11%	-7.2E-19
MKEH	1.902881	0.000060	8.36E-13	2.9E-14	3.5%	-7.3E-19
PTB	1.902919	0.000022	7.80E-13	2.9E-14	3.7%	-1.1E-19
UME	1.902901	0.000029	8.07E-13	5.7E-14	7.1%	-1.5E-18

The results are reported in Table 45 and illustrated in Fig. 7 and Fig. 8. BEV, CEM, EIM, IMBiH, IMT, IPQ, MIKES and MKEH have calculated the same value of the effective area at null pressure 1.902881 mm² and the same value of the coefficient distortion about $8.36 \cdot 10^{-13}$ Pa^{-1}. Indeed, all these NMIs have used the same calculation method: the ordinary least square method. Besides they obtained the same value for the distortion coefficient. However, it seems that the calculation of the uncertainties are not harmonized between these NMIs. Besides, the relative uncertainty of the distortion coefficient given by FSB-LPM is significant (about 50%) if it is compared to the uncertainty given by the other NMIs (< 11%).

DANIAmet, LNE, METAS and PTB have used different methods and their results are different. Their deviations and their estimations of the uncertainties will be discussed later. It can just be said that DANIAmet gives the lowest uncertainty. However, it is not really relevant because only the Type A uncertainty is given.

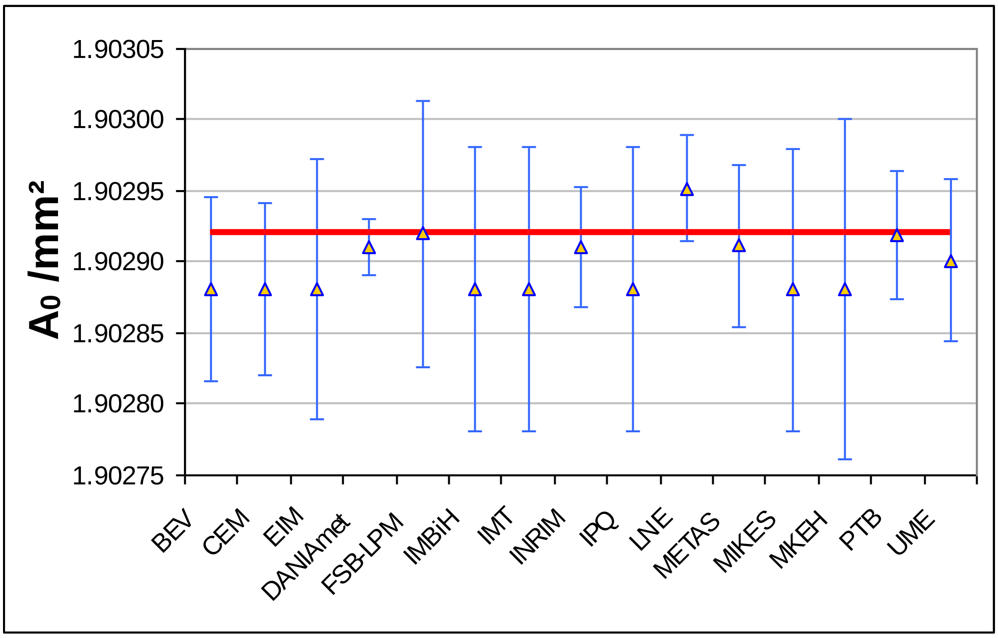

Fig. 7. Effective area at null pressure A_0 of a oil balance (case n°2) calculated by every NMIs, compared with the theoretical value of A_0 (straight line). The vertical lines represents the expanded uncertainty of A_0 given by the NMIs (twice the values reported in Table 45).

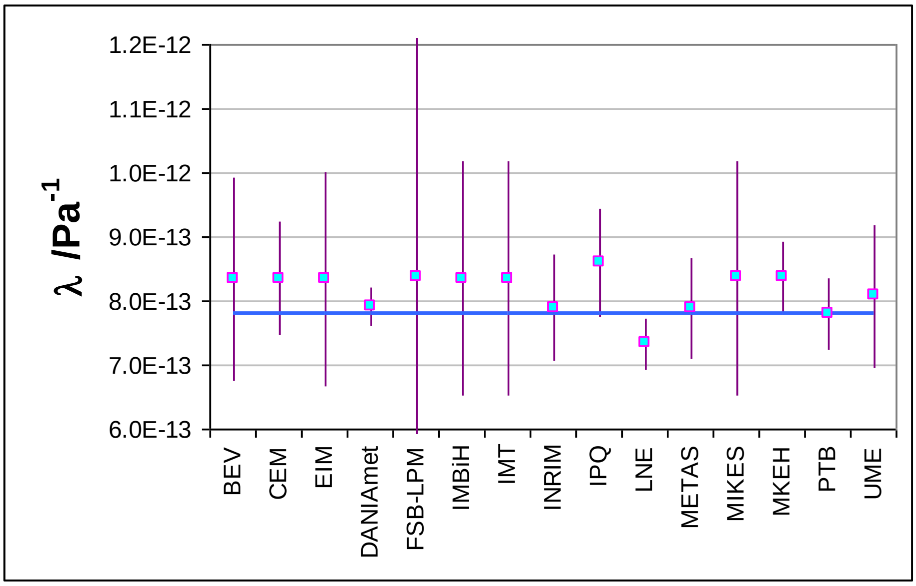

Fig. 8. Distortion coefficient λ of a oil balance (case n°6) calculated by every NMIs, compared with the theoretical value of λ (straight line). The vertical lines represents the expanded uncertainty of λ given by the NMIs (twice the values reported in Table 45).

7. Analysis of the results

The fitted effective area at a pressure point *p*, $\hat{A}p$, is defined by the equation (2). In this section the degree of equivalence will be quoted *D*.

$D_{i,j}$ is the degree of equivalence of the fitted effective area A_{pi} at the pressure point p_i calculated from the NMI j to the reference effective area at the same pressure point. It is calculated from the following equation:

$$D_{i,j} = \frac{\hat{A}_{p_i,j} - \hat{A}_{p_i,th}}{2 \cdot u_{\hat{A}_{p_i,j}}} \qquad (34)$$

$$D_{A_0} = \frac{A_0 - A_{0,th}}{2 \cdot u_{A_0}}$$

$$D_\lambda = \frac{\lambda - \lambda_{th}}{2 \cdot u_\lambda}$$

7.1. Gas balances

The results of the oil balances cases are reported in Table 46 and 47.

Table 46. Results given by NMIs, relative deviation from the reference data and degree of equivalence: gas balance, case n°1 (red if |D|>1 ; blue if the relative deviation is the minimum value considering all the participants results; magenta if the relative deviation is the maximum value considering all the participants results)

Nominal pressure	**Theoretical value of A_p**	**BEV**				**CEM**			
	$\hat{A}_{p,th}$	$\hat{A}_p$	u $\hat{A}_p$	Relative deviation	D	$\hat{A}_p$	u $\hat{A}_p$	Relative deviation	D
kPa		mm²	mm²			mm²	mm²		
200	**49.018876**	49.01920	0.00044	6.6E-06	0.37	49.01920	0.00048	6.6E-06	0.34
1 000	**49.018782**	49.01906	0.00044	5.7E-06	0.32	49.01906	0.00048	5.7E-06	0.29
2 000	**49.018665**	49.01889	0.00044	4.6E-06	0.26	49.01889	0.00048	4.6E-06	0.24
3 000	**49.018547**	49.01872	0.00043	3.5E-06	0.20	49.01872	0.00048	3.5E-06	0.18
4 000	**49.018429**	49.01855	0.00043	2.4E-06	0.14	49.01855	0.00048	2.4E-06	0.12
5 000	**49.018312**	49.01838	0.00043	1.3E-06	0.07	49.01837	0.00048	1.3E-06	0.07
6 000	**49.018194**	49.01820	0.00043	2.1E-07	0.01	49.01820	0.00048	1.9E-07	0.01
7 000	**49.018076**	49.01803	0.00043	-8.9E-07	-0.05	49.01803	0.00048	-9.1E-07	-0.05
8 000	**49.017959**	49.01786	0.00043	-2.0E-06	-0.11	49.01786	0.00048	-2.0E-06	-0.10
10 000	**49.017724**	49.01752	0.00043	-4.2E-06	-0.24	49.01752	0.00049	-4.2E-06	-0.21
A_0 /mm²	**49.018900**	49.01923	0.00044	6.8E-06	0.38	49.01923	0.00048	6.8E-06	0.35
λ /Pa^{-1}	**-2.40E-12**	-3.50E-12	3.5E-13	45.8%	-1.6	-3.50E-12	2.7E-13	45.9%	-2.0

Nominal pressure	**Theoretical value of A_p**	EIM				DANIAmet			
kPa	**$\hat{A}_{p,th}$**	$\hat{A}_p$ mm²	u $\hat{A}_p$ mm²	Relative deviation	D	$\hat{A}_p$ mm²	u $\hat{A}_p$ mm²	Relative deviation	D
200	**49.018876**	49.01920	0.00060	6.6E-06	0.27	49.01888	0.00053	1.4E-07	0.01
1 000	**49.018782**	49.01906	0.00052	5.7E-06	0.27	49.01879	0.00046	9.3E-08	0.00
2 000	**49.018665**	49.01889	0.00049	4.6E-06	0.23	49.01867	0.00046	2.9E-08	0.00
3 000	**49.018547**	49.01872	0.00047	3.5E-06	0.18	49.01855	0.00046	-3.5E-08	0.00
4 000	**49.018429**	49.01855	0.00046	2.4E-06	0.13	49.01842	0.00045	-1.0E-07	-0.01
5 000	**49.018312**	49.01838	0.00045	1.3E-06	0.07	49.01830	0.00045	-1.6E-07	-0.01
6 000	**49.018194**	49.01820	0.00046	2.1E-07	0.01	49.01818	0.00045	-2.3E-07	-0.01
7 000	**49.018076**	49.01803	0.00048	-8.9E-07	-0.05	49.01806	0.00045	-2.9E-07	-0.02
8 000	**49.017959**	49.01786	0.00051	-2.0E-06	-0.10	49.01794	0.00045	-3.6E-07	-0.02
10 000	**49.017724**	49.01752	0.00058	-4.2E-06	-0.18	49.01770	0.00045	-4.9E-07	-0.03
A_0 /mm²	**49.018900**	49.01923	0.00037	6.8E-06	0.45	49.019144	0.000027	5.0E-06	4.5
λ /Pa^{-1}	**-2.40E-12**	-3.50E-12	1.4E-12	46%	-0.40	-2.44E-12	7.6E-14	1.8%	-0.28

Nominal pressure		FSB-LPM				IMBiH			
kPa	**Theoretical value of A_p**	$\hat{A}_p$ mm²	u $\hat{A}_p$ mm²	Relative deviation	D	$\hat{A}_p$ mm²	u $\hat{A}_p$ mm²	Relative deviation	D
200	**49.018876**	49.01920	0.00042	6.5E-06	0.38	49.01920	0.00066	6.5E-06	0.38
1 000	**49.018782**	49.01906	0.00042	5.6E-06	0.33	49.01906	0.00054	5.6E-06	0.33
2 000	**49.018665**	49.01889	0.00042	4.5E-06	0.27	49.01889	0.00050	4.5E-06	0.27
3 000	**49.018547**	49.01872	0.00042	3.4E-06	0.20	49.01872	0.00048	3.4E-06	0.20
4 000	**49.018429**	49.01854	0.00042	2.3E-06	0.14	49.01855	0.00046	2.3E-06	0.14
5 000	**49.018312**	49.01837	0.00042	1.3E-06	0.07	49.01838	0.00046	1.3E-06	0.07
6 000	**49.018194**	49.01820	0.00042	1.6E-07	0.01	49.01820	0.00047	1.6E-07	0.01
7 000	**49.018076**	49.01803	0.00042	-9.4E-07	-0.05	49.01803	0.00050	-9.4E-07	-0.05
8 000	**49.017959**	49.01786	0.00042	-2.0E-06	-0.12	49.01786	0.00053	-2.0E-06	-0.12
10 000	**49.017724**	49.01752	0.00042	-4.2E-06	-0.25	49.01752	0.00061	-4.2E-06	-0.25
A_0 /mm²	**49.018900**	49.01923	0.00042	6.7E-06	0.39	49.01923	0.00041	6.7E-06	0.39
λ /Pa^{-1}	**-2.40E-12**	-3.49E-12	1.7E-13	45%	-3.2	-3.5E-12	1.5E-12	45%	-3.2

Nominal pressure	**Theoretical value of A_p**	IMT				INRIM			
kPa	**$\hat{A}_{p,th}$**	$\hat{A}_p$ mm²	u $\hat{A}_p$ mm²	Relative deviation	D	$\hat{A}_p$ mm²	u $\hat{A}_p$ mm²	Relative deviation	D
200	**49.018876**	49.01920	0.00062	6.6E-06	0.26	49.01894	0.00065	1.3E-06	0.05
1 000	**49.018782**	49.01906	0.00054	5.7E-06	0.26	49.01884	0.00060	1.1E-06	0.05
2 000	**49.018665**	49.01889	0.00050	4.6E-06	0.22	49.01870	0.00059	8.2E-07	0.03
3 000	**49.018547**	49.01872	0.00048	3.5E-06	0.18	49.01857	0.00059	5.3E-07	0.02
4 000	**49.018429**	49.01855	0.00047	2.4E-06	0.13	49.01844	0.00059	2.5E-07	0.01
5 000	**49.018312**	49.01838	0.00047	1.3E-06	0.07	49.01831	0.00059	-3.5E-08	0.00
6 000	**49.018194**	49.01820	0.00048	2.1E-07	0.01	49.01818	0.00059	-3.2E-07	-0.01
7 000	**49.018076**	49.01803	0.00050	-8.9E-07	-0.04	49.01805	0.00059	-6.0E-07	-0.03
8 000	**49.017959**	49.01786	0.00053	-2.0E-06	-0.09	49.01792	0.00059	-8.9E-07	-0.04
10 000	**49.017724**	49.01752	0.00061	-4.2E-06	-0.17	49.01765	0.00059	-1.5E-06	-0.06
A_0 /mm²	**49.018900**	49.01923	0.00041	6.8E-06	0.41	49.01897	0.00059	1.4E-06	0.06
λ /Pa^{-1}	**-2.40E-12**	-3.5E-12	1.5E-12	45.9%	-0.37	-2.68E-12	2.4E-13	12%	-0.6

Nominal pressure	**Theoretical value of A_p**	**IPQ**				**LNE**			
kPa	**$\hat{A}_{p,th}$**	$\hat{A}_p$ mm²	u $\hat{A}_p$ mm²	Relative deviation	D	$\hat{A}_p$ mm²	u $\hat{A}_p$ mm²	Relative deviation	D
200	**49.018876**	49.01920	0.00057	6.5E-06	0.28	49.01895	0.00040	1.4E-06	0.09
1 000	**49.018782**	49.01906	0.00047	5.7E-06	0.29	49.01884	0.00040	1.2E-06	0.07
2 000	**49.018665**	49.01889	0.00046	4.6E-06	0.24	49.01871	0.00040	8.7E-07	0.05
3 000	**49.018547**	49.01872	0.00046	3.5E-06	0.18	49.01857	0.00040	5.6E-07	0.03
4 000	**49.018429**	49.01854	0.00046	2.4E-06	0.12	49.01844	0.00040	2.5E-07	0.02
5 000	**49.018312**	49.01837	0.00046	1.3E-06	0.07	49.01831	0.00040	-5.9E-08	0.00
6 000	**49.018194**	49.01820	0.00046	1.5E-07	0.01	49.01818	0.00040	-3.7E-07	-0.02
7 000	**49.018076**	49.01803	0.00046	-9.5E-07	-0.05	49.01804	0.00040	-6.8E-07	-0.04
8 000	**49.017959**	49.01786	0.00046	-2.1E-06	-0.11	49.01791	0.00040	-9.9E-07	-0.06
10 000	**49.017724**	49.01751	0.00046	-4.3E-06	-0.22	49.01764	0.00040	-1.6E-06	-0.10
A_0 /mm²	**49.018900**	49.01923	0.00013	6.7E-06	1.3	49.01897	0.00040	1.5E-06	0.09
λ /Pa^{-1}	**-2.40E-12**	-3.50E-12	4.8E-13	46%	-1.2	-2.71E-12	2.0E-13	13%	-0.77

Nominal pressure	**Theoretical value of A_p**	**METAS**				**MIKES**			
kPa	**$\hat{A}_{p,th}$**	$\hat{A}_p$ mm²	u $\hat{A}_p$ mm²	Relative deviation	D	$\hat{A}_p$ mm²	u $\hat{A}_p$ mm²	Relative deviation	D
200	**49.018876**	49.01899	0.00087	2.3E-06	0.06	49.01920	0.0011	6.6E-06	0.15
1 000	**49.018782**	49.01888	0.00046	1.9E-06	0.10	49.01906	0.00060	5.7E-06	0.23
2 000	**49.018665**	49.01874	0.00043	1.6E-06	0.09	49.01889	0.00056	4.6E-06	0.20
3 000	**49.018547**	49.01860	0.00044	1.2E-06	0.06	49.01872	0.00053	3.5E-06	0.16
4 000	**49.018429**	49.01847	0.00043	7.7E-07	0.04	49.01855	0.00052	2.4E-06	0.11
5 000	**49.018312**	49.01833	0.00043	3.9E-07	0.02	49.01838	0.00052	1.3E-06	0.06
6 000	**49.018194**	49.01819	0.00043	-4.3E-09	0.00	49.01820	0.00053	2.1E-07	0.01
7 000	**49.018076**	49.01806	0.00043	-3.9E-07	-0.02	49.01803	0.00055	-8.9E-07	-0.04
8 000	**49.017959**	49.01792	0.00043	-7.8E-07	-0.04	49.01786	0.00058	-2.0E-06	-0.08
10 000	**49.017724**	49.01765	0.00043	-1.6E-06	-0.09	49.01752	0.00066	-4.2E-06	-0.16
A_0 /mm²	**49.018900**	49.01901	0.00042	2.3E-06	0.14	49.01923	0.00041	6.8E-06	0.41
λ /Pa^{-1}	**-2.40E-12**	-2.79E-12	1.6E-13	16%	-1.3	-3.5E-12	1.5E-12	46%	-0.37

Nominal pressure	**Theoretical value of A_p**	**MKEH**				**PTB**			
	$\hat{A}_{p,th}$	$\hat{A}_p$	u $\hat{A}_p$	Relative deviation	D	$\hat{A}_p$	u $\hat{A}_p$	Relative deviation	D
kPa		mm^2	mm^2			mm^2	mm^2		
200	**49.018876**	49.01920	0.00052	6.6E-06	0.31	49.01885	0.00065	-5.8E-07	-0.02
1 000	**49.018782**	49.01906	0.00043	5.7E-06	0.32	49.01875	0.00042	-6.5E-07	-0.04
2 000	**49.018665**	49.01889	0.00042	4.6E-06	0.27	49.01863	0.00041	-7.5E-07	-0.05
3 000	**49.018547**	49.01872	0.00042	3.5E-06	0.21	49.01851	0.00041	-8.4E-07	-0.05
4 000	**49.018429**	49.01855	0.00042	2.5E-06	0.14	49.01838	0.00040	-9.4E-07	-0.06
5 000	**49.018312**	49.01838	0.00042	1.4E-06	0.08	49.01826	0.00040	-1.0E-06	-0.06
6 000	**49.018194**	49.01821	0.00042	3.2E-07	0.02	49.01814	0.00041	-1.1E-06	-0.07
7 000	**49.018076**	49.01803	0.00042	-9.5E-07	-0.06	49.01802	0.00041	-1.2E-06	-0.07
8 000	**49.017959**	49.01786	0.00042	-2.0E-06	-0.12	49.01789	0.00041	-1.3E-06	-0.08
10 000	**49.017724**	49.01752	0.00043	-4.2E-06	-0.24	49.01765	0.00042	-1.5E-06	-0.09
A_0 /mm^2	**49.018900**	49.01923	0.00052	6.7E-06	0.32	49.01887	0.00042	-5.6E-07	-0.03
λ /Pa^{-1}	**-2.40E-12**	-3.50E-12	4.8E-13	45.8%	-1.1	-2.50E-12	4.4E-13	4.0%	-0.11

Nominal pressure	**Theoretical value of A_p**	**UME**			
	$\hat{A}_{p,th}$	$\hat{A}_p$	u $\hat{A}_p$	Relative deviation	D
kPa		mm^2	mm^2		
200	**49.018876**	49.01913	0.00058	5.3E-06	0.22
1 000	**49.018782**	49.01903	0.00047	5.0E-06	0.26
2 000	**49.018665**	49.01889	0.00045	4.6E-06	0.25
3 000	**49.018547**	49.01875	0.00044	4.2E-06	0.23
4 000	**49.018429**	49.01862	0.00043	3.8E-06	0.22
5 000	**49.018312**	49.01848	0.00043	3.4E-06	0.20
6 000	**49.018194**	49.01834	0.00043	3.0E-06	0.17
7 000	**49.018076**	49.01821	0.00044	2.6E-06	0.15
8 000	**49.017959**	49.01807	0.00045	2.2E-06	0.12
10 000	**49.017724**	49.01780	0.00049	1.5E-06	0.07
A_0 /mm^2	**49.018900**	49.01916	0.00047	5.3E-06	0.28
λ /Pa^{-1}	**-2.40E-12**	-2.79E-12	9.3E-13	16.1%	-0.21

Table 47. Results given by NMIs, relative deviation from the reference data and degree of equivalence: gas balance, case n°2 (red if |D|>1 ; blue if the relative deviation is the minimum value considering all the participants results; magenta if the relative deviation is the maximum value considering all the participants results)

Nominal pressure	**Theoretical value of A_p**	**BEV**				**CEM**			
kPa	**$\hat{A}_{p,th}$**	$\hat{A}_p$ mm²	u $\hat{A}_p$ mm²	Relative deviation	D	$\hat{A}_p$ mm²	u $\hat{A}_p$ mm²	Relative deviation	D
200	**49.019177**	49.01947	0.00050	5.9E-06	0.29	49.01947	0.00048	6.0E-06	0.31
1 000	**49.019083**	49.01933	0.00049	5.0E-06	0.25	49.01933	0.00048	5.1E-06	0.26
2 000	**49.018967**	49.01916	0.00048	3.9E-06	0.20	49.01916	0.00048	3.9E-06	0.20
3 000	**49.018850**	49.01899	0.00047	2.8E-06	0.14	49.01899	0.00048	2.8E-06	0.14
4 000	**49.018733**	49.01881	0.00047	1.6E-06	0.09	49.01882	0.00048	1.7E-06	0.09
5 000	**49.018617**	49.01864	0.00046	5.2E-07	0.03	49.01864	0.00048	5.6E-07	0.03
6 000	**49.018500**	49.01847	0.00046	-6.0E-07	-0.03	49.01847	0.00048	-5.7E-07	-0.03
7 000	**49.018383**	49.01830	0.00046	-1.7E-06	-0.09	49.01830	0.00048	-1.7E-06	-0.09
8 000	**49.018267**	49.01813	0.00046	-2.9E-06	-0.15	49.01813	0.00048	-2.8E-06	-0.14
10 000	**49.018033**	49.01778	0.00047	-5.1E-06	-0.27	49.01778	0.00049	-5.1E-06	-0.26
A_0 /mm²	**49.019200**	49.01950	0.00050	6.1E-06	0.30	49.01950	0.00048	6.2E-06	0.32
λ /Pa^{-1}	**-2.38E-12**	-3.50E-12	4.0E-13	47.2%	-1.4	-3.51E-12	3.0E-13	47.3%	-1.9

Nominal pressure	**Theoretical value of A_p**	**EIM**				**DANIAmet**			
kPa	**$\hat{A}_{p,th}$**	$\hat{A}_p$ mm²	u $\hat{A}_p$ mm²	Relative deviation	D	$\hat{A}_p$ mm²	u $\hat{A}_p$ mm²	Relative deviation	D
200	**49.019177**	49.01947	0.00061	5.9E-06	0.24	49.01912	0.00064	-1.2E-06	-0.04
1 000	**49.019083**	49.01933	0.00053	5.0E-06	0.23	49.01902	0.00047	-1.2E-06	-0.06
2 000	**49.018967**	49.01916	0.00049	3.9E-06	0.19	49.01890	0.00045	-1.3E-06	-0.07
3 000	**49.018850**	49.01899	0.00047	2.8E-06	0.14	49.01878	0.00046	-1.3E-06	-0.07
4 000	**49.018733**	49.01881	0.00046	1.6E-06	0.09	49.01867	0.00045	-1.4E-06	-0.08
5 000	**49.018617**	49.01864	0.00046	5.2E-07	0.03	49.01855	0.00045	-1.5E-06	-0.08
6 000	**49.018500**	49.01847	0.00047	-6.0E-07	-0.03	49.01843	0.00045	-1.5E-06	-0.08
7 000	**49.018383**	49.01830	0.00049	-1.7E-06	-0.09	49.01831	0.00045	-1.6E-06	-0.09
8 000	**49.018267**	49.01813	0.00051	-2.9E-06	-0.14	49.01819	0.00045	-1.6E-06	-0.09
10 000	**49.018033**	49.01778	0.00059	-5.1E-06	-0.21	49.01795	0.00045	-1.8E-06	-0.10
A_0 /mm²	**49.019200**	49.01950	0.00038	6.1E-06	0.39	49.019144	0.000027	-1.1E-06	-1.0
λ /Pa^{-1}	**-2.38E-12**	-3.5E-12	1.4E-12	47%	-0.40	-2.44E-12	7.6E-14	2.6%	-0.41

Nominal pressure	**Theoretical value of A_p**	**FSB-LPM**				**IMBiH**			
kPa		$\hat{A}_p$ mm²	u $\hat{A}_p$ mm²	Relative deviation	D	$\hat{A}_p$ mm²	u $\hat{A}_p$ mm²	Relative deviation	D
200	**49.019177**	49.01948	0.00043	6.1E-06	0.35	49.01947	0.00074	5.9E-06	0.20
1 000	**49.019083**	49.01934	0.00043	5.2E-06	0.30	49.01933	0.00055	5.0E-06	0.22
2 000	**49.018967**	49.01917	0.00043	4.1E-06	0.23	49.01916	0.00051	3.9E-06	0.19
3 000	**49.018850**	49.01900	0.00043	3.0E-06	0.17	49.01899	0.00048	2.8E-06	0.14
4 000	**49.018733**	49.01882	0.00043	1.8E-06	0.11	49.01881	0.00047	1.6E-06	0.09
5 000	**49.018617**	49.01865	0.00043	7.2E-07	0.04	49.01864	0.00047	5.2E-07	0.03
6 000	**49.018500**	49.01848	0.00043	-4.0E-07	-0.02	49.01847	0.00048	-6.0E-07	-0.03
7 000	**49.018383**	49.01831	0.00043	-1.5E-06	-0.09	49.01830	0.00050	-1.7E-06	-0.08
8 000	**49.018267**	49.01814	0.00043	-2.6E-06	-0.15	49.01813	0.00053	-2.9E-06	-0.13
10 000	**49.018033**	49.01779	0.00043	-4.9E-06	-0.28	49.01778	0.00062	-5.1E-06	-0.20
A_0 /mm²	**49.019200**	49.01950	0.00043	6.1E-06	0.35	49.01950	0.00042	6.1E-06	0.36
λ /Pa^{-1}	**-2.38E-12**	-3.50E-12	1.8E-13	47%	-3.2	-3.5E-12	1.6E-12	47%	-0.36

Nominal pressure	**Theoretical value of A_p**	**IMT**				**INRIM**			
kPa	**$\hat{A}_{p,th}$**	$\hat{A}_p$ mm²	u $\hat{A}_p$ mm²	Relative deviation	D	$\hat{A}_p$ mm²	u $\hat{A}_p$ mm²	Relative deviation	D
200	**49.019177**	49.01947	0.00063	5.9E-06	0.23	49.01918	0.00074	2.9E-08	0.00
1 000	**49.019083**	49.01933	0.00055	5.0E-06	0.23	49.01908	0.00060	-1.5E-07	-0.01
2 000	**49.018967**	49.01916	0.00051	3.9E-06	0.19	49.01895	0.00059	-3.6E-07	-0.02
3 000	**49.018850**	49.01899	0.00048	2.8E-06	0.14	49.01882	0.00059	-5.8E-07	-0.02
4 000	**49.018733**	49.01881	0.00047	1.6E-06	0.09	49.01869	0.00059	-8.0E-07	-0.03
5 000	**49.018617**	49.01864	0.00047	5.2E-07	0.03	49.01857	0.00059	-1.0E-06	-0.04
6 000	**49.018500**	49.01847	0.00048	-6.0E-07	-0.03	49.01844	0.00059	-1.2E-06	-0.05
7 000	**49.018383**	49.01830	0.00050	-1.7E-06	-0.08	49.01831	0.00059	-1.5E-06	-0.06
8 000	**49.018267**	49.01813	0.00053	-2.9E-06	-0.13	49.01818	0.00059	-1.7E-06	-0.07
10 000	**49.018033**	49.01778	0.00062	-5.1E-06	-0.20	49.01793	0.00059	-2.1E-06	-0.09
A_0 /mm²	**49.019200**	49.01950	0.00042	6.1E-06	0.36	49.01920	0.00059	7.3E-08	0.00
λ /Pa^{-1}	**-2.38E-12**	-3.5E-12	1.6E-12	47%	-0.36	-2.60E-12	2.5E-13	9%	-0.4

Nominal pressure	**Theoretical value of A_p**	**IPQ**				**LNE**			
	$\hat{A}_{p,th}$	$\hat{A}_p$	$u_{\hat{A}_p}$	Relative deviation	D	$\hat{A}_p$	$u_{\hat{A}_p}$	Relative deviation	D
kPa		mm^2	mm^2			mm^2	mm^2		
200	**49.019177**	49.01947	0.00066	5.9E-06	0.22	49.01918	0.00040	8.8E-08	0.01
1 000	**49.019083**	49.01933	0.00048	5.0E-06	0.26	49.01908	0.00040	-1.0E-07	-0.01
2 000	**49.018967**	49.01916	0.00047	3.9E-06	0.20	49.01895	0.00040	-3.4E-07	-0.02
3 000	**49.018850**	49.01899	0.00047	2.8E-06	0.14	49.01882	0.00040	-5.8E-07	-0.04
4 000	**49.018733**	49.01881	0.00047	1.6E-06	0.09	49.01869	0.00040	-8.2E-07	-0.05
5 000	**49.018617**	49.01864	0.00047	5.1E-07	0.03	49.01856	0.00040	-1.1E-06	-0.06
6 000	**49.018500**	49.01847	0.00047	-6.2E-07	-0.03	49.01844	0.00040	-1.3E-06	-0.08
7 000	**49.018383**	49.01830	0.00047	-1.7E-06	-0.09	49.01831	0.00040	-1.5E-06	-0.09
8 000	**49.018267**	49.01813	0.00047	-2.9E-06	-0.15	49.01818	0.00040	-1.8E-06	-0.11
10 000	**49.018033**	49.01778	0.00047	-5.1E-06	-0.27	49.01792	0.00040	-2.3E-06	-0.14
A_0 /mm^2	**49.019200**	49.01950	0.00013	6.1E-06	1.1	49.01921	0.00040	1.4E-07	0.01
λ /Pa^{-1}	**-2.38E-12**	-3.51E-12	4.9E-13	47%	-1.1	-2.62E-12	2.1E-13	10%	-0.58

Nominal pressure	**Theoretical value of A_p**	**METAS**				**MIKES**			
	$\hat{A}_{p,th}$	$\hat{A}_p$	$u_{\hat{A}_p}$	Relative deviation	D	$\hat{A}_p$	$u_{\hat{A}_p}$	Relative deviation	D
kPa		mm^2	mm^2			mm^2	mm^2		
200	**49.019177**	49.01923	0.00096	1.1E-06	0.03	49.01947	0.0011	5.9E-06	0.13
1 000	**49.019083**	49.01912	0.00048	8.1E-07	0.04	49.01933	0.00063	5.0E-06	0.19
2 000	**49.018967**	49.01899	0.00043	4.1E-07	0.02	49.01916	0.00058	3.9E-06	0.16
3 000	**49.018850**	49.01885	0.00043	1.4E-08	0.00	49.01899	0.00055	2.8E-06	0.12
4 000	**49.018733**	49.01871	0.00043	-3.9E-07	-0.02	49.01881	0.00053	1.6E-06	0.08
5 000	**49.018617**	49.01858	0.00043	-7.9E-07	-0.05	49.01864	0.00053	5.2E-07	0.02
6 000	**49.018500**	49.01844	0.00043	-1.2E-06	-0.07	49.01847	0.00054	-6.0E-07	-0.03
7 000	**49.018383**	49.01831	0.00043	-1.6E-06	-0.09	49.01830	0.00057	-1.7E-06	-0.07
8 000	**49.018267**	49.01817	0.00043	-2.0E-06	-0.11	49.01813	0.00061	-2.9E-06	-0.12
10 000	**49.018033**	49.01790	0.00043	-2.8E-06	-0.16	49.01778	0.00070	-5.1E-06	-0.18
A_0 /mm^2	**49.019200**	49.01926	0.00042	1.2E-06	0.07	49.01950	0.00042	6.1E-06	0.36
λ /Pa^{-1}	**-2.38E-12**	-2.78E-12	1.59E-13	17%	-1.3	-3.5E-12	1.6E-12	47%	-0.36

Nominal pressure	**Theoretical value of A_p**	**MKEH**				**PTB**			
	$\hat{A}_{p,th}$	$\hat{A}_p$	u $\hat{A}_p$	Relative deviation	D	$\hat{A}_p$	u $\hat{A}_p$	Relative deviation	D
kPa		mm^2	mm^2			mm^2	mm^2		
200	**49.019177**	49.01947	0.00060	6.0E-06	0.24	49.01911	0.00066	-1.4E-06	-0.05
1 000	**49.019083**	49.01933	0.00043	5.0E-06	0.29	49.01901	0.00041	-1.5E-06	-0.09
2 000	**49.018967**	49.01916	0.00042	3.9E-06	0.23	49.01889	0.00040	-1.6E-06	-0.10
3 000	**49.018850**	49.01899	0.00042	2.9E-06	0.17	49.01877	0.00040	-1.7E-06	-0.10
4 000	**49.018733**	49.01881	0.00042	1.6E-06	0.09	49.01865	0.00040	-1.8E-06	-0.11
5 000	**49.018617**	49.01864	0.00042	4.8E-07	0.03	49.01852	0.00040	-1.9E-06	-0.11
6 000	**49.018500**	49.01847	0.00042	-6.1E-07	-0.04	49.01840	0.00040	-2.0E-06	-0.12
7 000	**49.018383**	49.01830	0.00042	-1.7E-06	-0.10	49.01828	0.00041	-2.1E-06	-0.12
8 000	**49.018267**	49.01812	0.00042	-3.0E-06	-0.17	49.01816	0.00041	-2.2E-06	-0.13
10 000	**49.018033**	49.01778	0.00044	-5.2E-06	-0.29	49.01792	0.00043	-2.4E-06	-0.14
A_0 /mm^2	**49.019200**	49.01950	0.00060	6.1E-06	0.25	49.01913	0.00041	-1.4E-06	-0.08
λ /Pa^{-1}	**-2.38E-12**	-3.52E-12	4.9E-13	48%	-1.2	-2.48E-12	5.3E-13	4.1%	-0.09

Nominal pressure	**Theoretical value of A_p**	**UME**			
	$\hat{A}_{p,th}$	$\hat{A}_p$	u $\hat{A}_p$	Relative deviation	D
kPa		mm^2	mm^2		
200	**49.019177**	49.01936	0.00067	3.6E-06	0.13
1 000	**49.019083**	49.01923	0.00048	3.0E-06	0.15
2 000	**49.018967**	49.01908	0.00045	2.3E-06	0.12
3 000	**49.018850**	49.01892	0.00044	1.5E-06	0.08
4 000	**49.018733**	49.01877	0.00043	7.1E-07	0.04
5 000	**49.018617**	49.01861	0.00043	-6.9E-08	0.00
6 000	**49.018500**	49.01846	0.00043	-8.4E-07	-0.05
7 000	**49.018383**	49.01830	0.00044	-1.6E-06	-0.09
8 000	**49.018267**	49.01815	0.00045	-2.4E-06	-0.13
10 000	**49.018033**	49.01784	0.00049	-3.9E-06	-0.20
A_0 /mm^2	**49.019200**	49.01939	0.00048	**3.8E-06**	0.20
λ /Pa^{-1}	**-2.38E-12**	-3.15E-12	9.4E-13	**32%**	-0.41

In order to summarize this results, a graph have been generated (see Fig. 1 and Fig. 2). These graphs underlines the fact that the relative standard deviation can be fitted as a linear function. Therefore, a quantity can be defined to allow us to compare every methods easily. This quantity is defined as the maximum absolute value of the extrema of each linear fitting model of the relative deviation. These extrema are the relative deviation observed at the minimal nominal pressure and at the maximal nominal pressure in each case. This quantity will be refered in the document as “extremum”. The comparison of the methods are reported in Table 48.

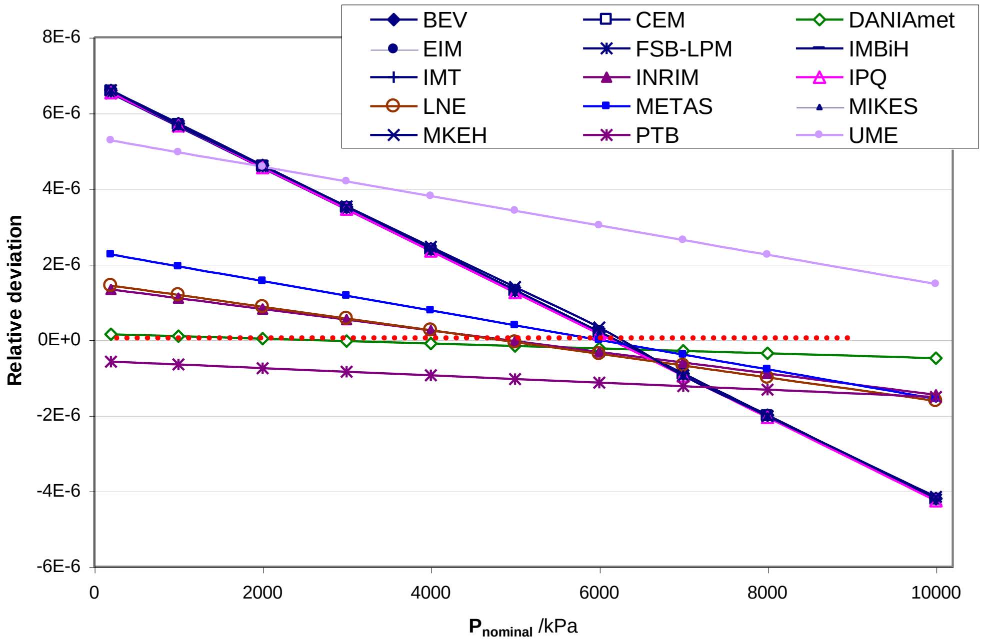

Fig. 9.   Illustration of the relative deviation of Âp versus the nominal pressure p: gas balance case n°1

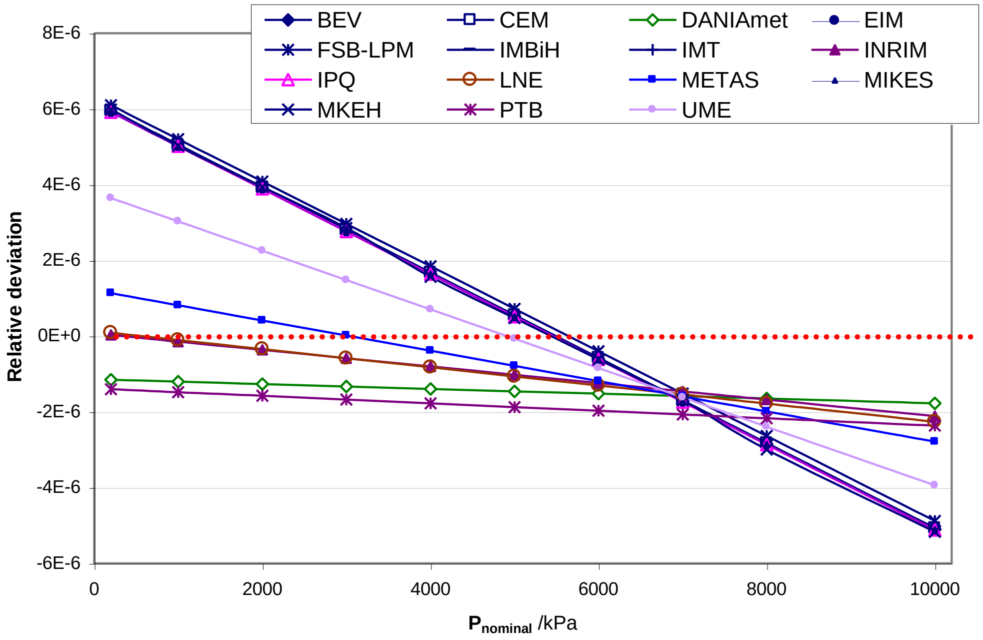

Fig. 10. Illustration of the relative deviation of $\hat{A}_p$ versus the nominal pressure p: gas balance case n°2

According to Table 48, for gas balance, from 0.2 MPa to 10 MPa, the most used method – the ordinary least square method – shows the less efficient results, as the deviation is the biggest for the NMI's that I have used this method. METAS gives better results by applying the same method without considering the first point, which is the less repeatable one. Also, UME gives better results by applying the weighed least square method. Indeed, the first pressure point is the data that deteriorate the determination of the fitting. By not considering this point or by considering that the first data has a bigger uncertainty than the others, the determination of the fitting parameters will be improved. However, it seems that the method of DANIAmet is the most efficient one. Even if UME and DANIAmet use the same method, the results are different because the calculation of the uncertainties – which defines the weight of all the values - is different: in the case of DANIAmet, the measurements of the first pressure points have been characterized by a huger uncertainty. That the methods used by INRIM, LNE and PTB are also good methods, although they seem complicated.

In any case, all the NMIs have provided results that are coherent, which means that the efficiency of the method is taken into account in the uncertainty. The uncertainty of the parameters of A_0 and λ are sometimes underestimated. However, it is counterbalanced with the uncertainty of the other parameter. Therefore, at each pressure point, the uncertainty of the fitted effective area is well estimated or overestimated. For instance, in the case of

DANIAmet, the uncertainty of A0 is underestimated because one Type A uncertainty was considered. However, the uncertainties of the fitted effective area are clearly overestimated: D < 0.1. In the same way, INRIM, LNE, METAS and PTB apply methods that overestimates the uncertainty (D < 0.1), while most of NMIs have estimated their uncertainties with a degree of equivalence that reaches about 0.3 for some pressure points. However, the uncertainties of the fits were derived from the Ap values and their uncertainties u(Ap). For a correct evaluation method u(Ap,fit) must reasonably agree with u(Ap), which indeed is observed for most results obtained with the advanced methods. Therefore, the overestimation of the uncertainties also implies to considerate the uncertainty of the input data. In order to better estimate the uncertainties, it would be useful to analyse how well the fitted uncertainties reflect the input (experimental) uncertainties. This might be the subject of another study. However, it won’t be analyse in this report.

Table 48. Summary of the methods applied by each NMI and the associated extrema for gas balance cases

Extremum	<	Extremum	<	Extremum	<	Extremum	<	Extremum	<	Extremum

NMIs	Method	Data	Extremum case 1	Extremum case 2
			Relative value	Relative value
BEV	OLS	Mean value of 5 cycles at each nominal pressure	6.6E-06	5.9E-06
CEM	OLS	Mean value of 5 cycles at each nominal pressure	6.6E-06	6.0E-06
EIM	OLS	Mean value of 5 cycles at each nominal pressure	6.6E-06	5.9E-06
DANIAmet	WLS	Mean value of 5 cycles at each nominal pressure. The weight of the values are calculated from the uncertainties calculated by DANIAmet in the fist loop.	4.9E-07	1.8E-06
FSB-LPM	OLS	Mean value of 5 cycles at each nominal pressure	6.5E-06	6.1E-06
IMBiH	OLS	Mean value of 5 cycles at each nominal pressure	6.6E-06	5.9E-06
IMT	OLS	Mean value of 5 cycles at each nominal pressure	6.6E-06	5.9E-06
INRIM	GLS	Mean value of 5 cycles at each nominal pressure, see description of the variance-covariance matrix in section 3.4.10	1.5E-06	2.1E-06
IPQ	OLS	Mean value of 5 cycles at each nominal pressure	6.5E-06	5.9E-06
LNE	GLS	Mean value of 5 cycles at each nominal pressure, see description of the variance-covariance matrix in section 3.4.12	1.6E-06	2.3E-06
METAS	OLS – 1st point excluded	Mean value of 5 cycles at each p, first value excluded	2.3E-06	2.8E-06
MIKES	OLS	Mean value of 5 cycles at each nominal pressure	6.6E-06	5.9E-06
MKEH	OLS	Mean value of 5 cycles at each nominal pressure	6.6E-06	6.0E-06
PTB	A_0,λ,F-model	Mean value of 5 cycles at each nominal pressure	1.5E-06	2.4E-06
UME	WLS	Mean value of 5 cycles at each nominal pressure	5.3E-06	3.9E-06

OLS	Ordinary least square method
WLS	Weighed least square method
GLS	Generalized least square method

7.2. Oil balances

The results of the oil balances cases are reported in Table 49 and 50.

Table 49. Results given by NMIs, relative deviation from the reference data and degree of equivalence: oil balance, case n°1 (red if |D|>1 ; blue if the relative deviation is the minimum value considering all the participants results; magenta if the relative deviation is the maximum value considering all the participants results)

Nominal pressure	**Theoretical value of A_p**	**BEV**				**CEM**			
/MPa	$\hat{A}_{p,th}$ /mm²	$\hat{A}_p$ mm²	u $\hat{A}_p$ mm²	Relative deviation	D	$\hat{A}_p$ mm²	u $\hat{A}_p$ mm²	Relative deviation	D
5.16	**1.902908**	1.902943	0.000039	1.9E-05	0.46	1.902943	0.000029	1.8E-05	0.60
51.55	**1.902976**	1.903006	0.000037	1.6E-05	0.40	1.903006	0.000029	1.5E-05	0.50
103.10	**1.903053**	1.903076	0.000036	1.2E-05	0.33	1.903076	0.000030	1.2E-05	0.39
154.65	**1.903129**	1.903146	0.000034	8.9E-06	0.25	1.903146	0.000031	8.9E-06	0.28
206.19	**1.903206**	1.903216	0.000033	5.6E-06	0.16	1.903216	0.000032	5.6E-06	0.17
257.74	**1.903282**	1.903286	0.000033	2.2E-06	0.06	1.903286	0.000034	2.3E-06	0.06
309.29	**1.903358**	1.903356	0.000032	-1.1E-06	-0.03	1.903356	0.000036	-1.0E-06	-0.03
360.84	**1.903435**	1.903426	0.000033	-4.5E-06	-0.13	1.903427	0.000038	-4.4E-06	-0.11
412.38	**1.903511**	1.903496	0.000033	-7.8E-06	-0.23	1.903497	0.000040	-7.7E-06	-0.18
515.48	**1.903664**	1.903637	0.000035	-1.4E-05	-0.40	1.903637	0.000046	-1.4E-05	-0.30
A_0 /mm²	**1.9029000**	1.902943	0.000039	1.9E-05	0.46	1.90294	0.000029	1.9E-05	0.61
λ /Pa^{-1}	**7.790E-13**	1.903006	0.000037	-8.3%	-0.46	7.15E-13	3.8E-14	-8.2%	-0.85

Nominal pressure	**Theoretical value of A_p**	**EIM**				**DANIAmet**			
/MPa	$\hat{A}_{p,th}$ /mm²	$\hat{A}_p$ mm²	u $\hat{A}_p$ mm²	Relative deviation	D	$\hat{A}_p$ mm²	u $\hat{A}_p$ mm²	Relative deviation	D
5.16	**1.902908**	1.902943	0.000040	1.8E-05	0.43	1.9029	0.0015	6.1E-06	0.00
51.55	**1.902976**	1.903004	0.000035	1.4E-05	0.39	1.90299	0.00015	4.8E-06	0.03
103.10	**1.903053**	1.903072	0.000032	1.0E-05	0.30	1.903059	0.000077	3.3E-06	0.04
154.65	**1.903129**	1.903140	0.000031	5.6E-06	0.17	1.903133	0.000056	1.8E-06	0.03
206.19	**1.903206**	1.903208	0.000031	1.1E-06	0.03	1.903206	0.000044	3.9E-07	0.01
257.74	**1.903282**	1.903276	0.000033	-3.3E-06	-0.10	1.903280	0.000038	-1.1E-06	-0.03
309.29	**1.903358**	1.903344	0.000036	-7.8E-06	-0.21	1.903354	0.000036	-2.5E-06	-0.07
360.84	**1.903435**	1.903412	0.000040	-1.2E-05	-0.29	1.903427	0.000030	-4.0E-06	-0.13
412.38	**1.903511**	1.903480	0.000045	-1.7E-05	-0.35	1.903501	0.000031	-5.5E-06	-0.17
515.48	**1.903664**	1.903616	0.000056	-2.6E-05	-0.43	1.903648	0.000028	-8.4E-06	-0.29
A_0 /mm²	**1.9029000**	1.902936	0.000034	1.9E-05	0.53	1.902912	0.000007	6.2E-06	0.86
λ /Pa^{-1}	**7.790E-13**	7.14E-13	6.3E-14	-8.3%	-0.51	7.51E-13	1.1E-14	-3.6%	-1.3

Nominal pressure		**FSB-LPM**				**IMBiH**			
/MPa	**Theoretical value of A_p** /mm²	$\hat{A}_p$ mm²	u $\hat{A}_p$ mm²	Relative deviation	D	$\hat{A}_p$ mm²	u $\hat{A}_p$ mm²	Relative deviation	D
5.16	**1.902908**	1.902973	0.000041	3.4E-05	0.80	1.902943	0.000075	1.9E-05	0.24
51.55	**1.902976**	1.903036	0.000041	3.1E-05	0.73	1.903006	0.000041	1.6E-05	0.36
103.10	**1.903053**	1.903106	0.000041	2.8E-05	0.65	1.903076	0.000037	1.2E-05	0.31
154.65	**1.903129**	1.903176	0.000041	2.5E-05	0.57	1.903146	0.000038	8.9E-06	0.22
206.19	**1.903206**	1.903246	0.000041	2.1E-05	0.50	1.903216	0.000037	5.5E-06	0.14
257.74	**1.903282**	1.903316	0.000041	1.8E-05	0.42	1.903286	0.000039	2.2E-06	0.05
309.29	**1.903358**	1.903386	0.000041	1.5E-05	0.34	1.903356	0.000043	-1.1E-06	-0.02
360.84	**1.903435**	1.903456	0.000041	1.1E-05	0.26	1.903426	0.000045	-4.5E-06	-0.10
412.38	**1.903511**	1.903526	0.000041	7.9E-06	0.18	1.903496	0.000051	-7.8E-06	-0.15
515.48	**1.903664**	1.903666	0.000041	1.2E-06	0.03	1.903637	0.000062	-1.4E-05	-0.22
A_0 /mm²	**1.9029000**	1.902966	0.000041	3.5E-05	0.80	1.902936	0.000037	1.9E-05	0.48
λ /Pa^{-1}	**7.790E-13**	7.14E-13	3.6E-14	-8.3%	-0.90	7.14E-13	6.9E-14	-8.3%	-0.47

Nominal pressure	**Theoretical value of A_p**	**IMT**				**INRIM**			
/MPa	**$\hat{A}_{p,th}$** /mm²	$\hat{A}_p$ mm²	u $\hat{A}_p$ mm²	Relative deviation	D	$\hat{A}_p$ mm²	u $\hat{A}_p$ mm²	Relative deviation	D
5.16	**1.902908**	1.902943	0.000043	1.9E-05	0.41	1.902922	0.000059	7.7E-06	0.12
51.55	**1.902976**	1.903006	0.000038	1.6E-05	0.39	1.902988	0.000023	6.2E-06	0.26
103.10	**1.903053**	1.903076	0.000034	1.2E-05	0.34	1.903061	0.000023	4.5E-06	0.18
154.65	**1.903129**	1.903146	0.000032	8.9E-06	0.26	1.903135	0.000025	2.8E-06	0.11
206.19	**1.903206**	1.903216	0.000032	5.5E-06	0.16	1.903208	0.000026	1.1E-06	0.04
257.74	**1.903282**	1.903286	0.000034	2.2E-06	0.06	1.903281	0.000029	-5.3E-07	-0.02
309.29	**1.903358**	1.903356	0.000038	-1.1E-06	-0.03	1.903354	0.000033	-2.2E-06	-0.06
360.84	**1.903435**	1.903426	0.000042	-4.5E-06	-0.10	1.903427	0.000034	-3.9E-06	-0.11
412.38	**1.903511**	1.903496	0.000048	-7.8E-06	-0.16	1.903501	0.000037	-5.6E-06	-0.14
515.48	**1.903664**	1.903637	0.000060	-1.4E-05	-0.23	1.903647	0.000043	-8.9E-06	-0.20
A_0 /mm²	**1.9029000**	1.902936	0.000037	1.9E-05	0.48	1.902915	0.000020	7.9E-06	0.37
λ /Pa^{-1}	**7.790E-13**	7.14E-13	6.9E-14	-8.3%	-0.47	7.46E-13	3.9E-14	-4.2%	-0.42

Nominal pressure	**Theoretical value of A_p**	**IPQ**				**LNE**			
	$\hat{A}_{p,th}$	$\hat{A}_p$	u $\hat{A}_p$	Relative deviation	D	$\hat{A}_p$	u $\hat{A}_p$	Relative deviation	D
/MPa	/mm²	mm²	mm²			mm²	mm²		
5.16	**1.902908**	1.902943	0.000068	1.9E-05	0.26	1.902914	0.000022	3.1E-06	0.13
51.55	**1.902976**	1.903006	0.000032	1.6E-05	0.46	1.902981	0.000024	2.3E-06	0.09
103.10	**1.903053**	1.903076	0.000033	1.2E-05	0.36	1.903056	0.000025	1.4E-06	0.05
154.65	**1.903129**	1.903146	0.000036	8.9E-06	0.23	1.903130	0.000027	5.4E-07	0.02
206.19	**1.903206**	1.903216	0.000036	5.6E-06	0.15	1.903205	0.000029	-3.3E-07	-0.01
257.74	**1.903282**	1.903286	0.000039	2.2E-06	0.05	1.903280	0.000031	-1.2E-06	-0.04
309.29	**1.903358**	1.903356	0.000042	-1.1E-06	-0.03	1.903355	0.000034	-2.1E-06	-0.06
360.84	**1.903435**	1.903426	0.000042	-4.5E-06	-0.10	1.903429	0.000036	-3.0E-06	-0.08
412.38	**1.903511**	1.903496	0.000046	-7.9E-06	-0.16	1.903504	0.000038	-3.8E-06	-0.10
515.48	**1.903664**	1.903636	0.000050	-1.5E-05	-0.28	1.903653	0.000042	-5.6E-06	-0.13
A_0 /mm²	**1.9029000**	1.902936	0.000012	1.9E-05	1.5	1.902906	0.000022	3.2E-06	0.14
λ /Pa^{-1}	**7.790E-13**	7.36E-13	3.7E-14	-5.5%	-0.59	7.62E-13	2.3E-14	-2.2%	-0.36

Nominal pressure	**Theoretical value of A_p**	**METAS**				**MIKES**			
	$\hat{A}_{p,th}$	$\hat{A}_p$	u $\hat{A}_p$	Relative deviation	D	$\hat{A}_p$	u $\hat{A}_p$	Relative deviation	D
/MPa	/mm²	mm²	mm²			mm²	mm²		
5.16	**1.902908**	1.902921	0.000093	6.9E-06	0.07	1.902942	0.000060	1.8E-05	0.29
51.55	**1.902976**	1.902987	0.000032	5.5E-06	0.17	1.903006	0.000048	1.6E-05	0.31
103.10	**1.903053**	1.903060	0.000031	4.0E-06	0.12	1.903076	0.000044	1.2E-05	0.26
154.65	**1.903129**	1.903134	0.000036	2.5E-06	0.06	1.903147	0.000043	9.1E-06	0.20
206.19	**1.903206**	1.903207	0.000034	9.1E-07	0.03	1.903216	0.000045	5.4E-06	0.11
257.74	**1.903282**	1.903281	0.000035	-6.3E-07	-0.02	1.903287	0.000050	2.4E-06	0.05
309.29	**1.903358**	1.903354	0.000036	-2.2E-06	-0.06	1.903356	0.000056	-1.3E-06	-0.02
360.84	**1.903435**	1.903428	0.000033	-3.7E-06	-0.11	1.903427	0.000064	-4.2E-06	-0.06
412.38	**1.903511**	1.903501	0.000035	-5.3E-06	-0.15	1.903496	0.000073	-7.9E-06	-0.10
515.48	**1.903664**	1.903648	0.000037	-8.4E-06	-0.22	1.903636	0.000092	-1.5E-05	-0.15
A_0 /mm²	**1.9029000**	1.902913	0.000028	7.1E-06	0.24	1.902936	0.000038	1.9E-05	0.47
λ /Pa^{-1}	**7.790E-13**	7.49E-13	3.8E-14	-3.8%	-0.39	7.15E-13	7.0E-14	-8.2%	-0.46

Nominal pressure	**Theoretical value of A_p**	**MKEH**				**PTB**			
/MPa	**$\hat{A}_{p,th}$** /mm²	$\hat{A}_p$ mm²	$u_{\hat{A}_p}$ mm²	Relative deviation	D	$\hat{A}_p$ mm²	$u_{\hat{A}_p}$ mm²	Relative deviation	D
5.16	**1.902908**	1.902943	0.000061	1.9E-05	0.29	1.902916	0.000050	4.5E-06	0.09
51.55	**1.902976**	1.903006	0.000027	1.6E-05	0.55	1.902983	0.000024	3.3E-06	0.13
103.10	**1.903053**	1.903076	0.000027	1.2E-05	0.43	1.903057	0.000026	2.0E-06	0.07
154.65	**1.903129**	1.903146	0.000030	8.8E-06	0.28	1.903131	0.000028	7.2E-07	0.02
206.19	**1.903206**	1.903216	0.000030	5.4E-06	0.17	1.903205	0.000030	-5.7E-07	-0.02
257.74	**1.903282**	1.903286	0.000033	2.1E-06	0.06	1.903279	0.000032	-1.9E-06	-0.05
309.29	**1.903358**	1.903356	0.000037	-1.3E-06	-0.03	1.903352	0.000035	-3.2E-06	-0.09
360.84	**1.903435**	1.903427	0.000037	-4.1E-06	-0.11	1.903426	0.000038	-4.5E-06	-0.11
412.38	**1.903511**	1.903497	0.000042	-7.5E-06	-0.17	1.903500	0.000041	-5.8E-06	-0.13
515.48	**1.903664**	1.903637	0.000048	-1.4E-05	-0.28	1.903648	0.000047	-8.4E-06	-0.17
A_0 /mm²	**1.9029000**	1.902936	0.000061	1.9E-05	0.30	1.902909	0.000024	4.6E-06	0.18
λ /Pa^{-1}	**7.790E-13**	7.15E-13	2.2E-14	-8.2%	-1.5	7.54E-13	3.7E-14	-3.2%	-0.34

Nominal pressure	**Theoretical value of A_p**	**UME**			
/MPa	**$\hat{A}_{p,th}$** /mm²	$\hat{A}_p$ mm²	$u_{\hat{A}_p}$ mm²	Relative deviation	D
5.16	**1.902908**	1.902924	0.000062	8.8E-06	0.13
51.55	**1.902976**	1.902990	0.000026	7.1E-06	0.26
103.10	**1.903053**	1.903063	0.000025	5.3E-06	0.20
154.65	**1.903129**	1.903136	0.000028	3.5E-06	0.12
206.19	**1.903206**	1.903209	0.000028	1.6E-06	0.05
257.74	**1.903282**	1.903282	0.000028	-2.3E-07	-0.01
309.29	**1.903358**	1.903355	0.000031	-2.1E-06	-0.06
360.84	**1.903435**	1.903427	0.000035	-3.9E-06	-0.11
412.38	**1.903511**	1.903500	0.000040	-5.8E-06	-0.14
515.48	**1.903664**	1.903646	0.000048	-9.5E-06	-0.19
A_0 /mm²	**1.9029000**	1.902917	0.000026	9.0E-06	0.33
λ /Pa^{-1}	**7.790E-13**	7.44E-13	5.2E-14	-4.6%	-0.34

Table 50. Results given by NMIs, relative deviation from the reference data and degree of equivalence: oil balance, case n°2 (red if |D|>1 ; blue if the relative deviation is the minimum value considering all the participants results; magenta if the relative deviation is the maximum value considering all the participants results)

Nominal pressure	**Theoretical value of A_p**	**BEV**				**CEM**			
	$\hat{A}_{p,th}$	$\hat{A}_p$	u $\hat{A}_p$	Relative deviation	D	$\hat{A}_p$	u $\hat{A}_p$	Relative deviation	D
/MPa	/mm²	mm²	mm²			mm²	mm²		
5.16	**1.902928**	1.902889	0.000032	-2.0E-05	-0.59	1.902889	0.000030	-2.0E-05	-0.64
51.55	**1.902997**	1.902963	0.000031	-1.8E-05	-0.54	1.902963	0.000030	-1.8E-05	-0.55
103.10	**1.903073**	1.903045	0.000030	-1.5E-05	-0.46	1.903045	0.000031	-1.5E-05	-0.46
154.65	**1.903150**	1.903127	0.000030	-1.2E-05	-0.38	1.903127	0.000032	-1.2E-05	-0.35
206.20	**1.903226**	1.903209	0.000029	-9.1E-06	-0.30	1.903209	0.000034	-9.1E-06	-0.26
257.74	**1.903303**	1.903291	0.000028	-6.3E-06	-0.21	1.903291	0.000036	-6.2E-06	-0.16
309.29	**1.903379**	1.903373	0.000028	-3.4E-06	-0.12	1.903373	0.000039	-3.4E-06	-0.08
360.84	**1.903456**	1.903454	0.000028	-5.8E-07	-0.02	1.903455	0.000041	-4.8E-07	-0.01
412.39	**1.903532**	1.903536	0.000028	2.3E-06	0.08	1.903537	0.000044	2.4E-06	0.05
515.49	**1.903685**	1.903700	0.000028	7.9E-06	0.27	1.903701	0.000051	8.1E-06	0.15
A_0 /mm²	**1.902920**	1.90288	0.000033	-2.1E-05	-0.60	1.90288	0.000030	-2.1E-05	-0.64
λ /Pa^{-1}	**7.800E-13**	8.36E-13	8.0E-14	7.1%	0.35	8.36E-13	4.4E-14	7.1%	0.63

Nominal pressure	**Theoretical value of A_p**	**EIM**				**DANIAmet**			
	$\hat{A}_{p,th}$	$\hat{A}_p$	u $\hat{A}_p$	Relative deviation	D	$\hat{A}_p$	u $\hat{A}_p$	Relative deviation	D
/MPa	/mm²	mm²	mm²			mm²	mm²		
5.16	**1.902928**	1.902889	0.000050	-2.0E-05	-0.38	1.9029	0.0015	-4.9E-06	0.00
51.55	**1.902997**	1.902960	0.000044	-1.9E-05	-0.41	1.90299	0.00015	-4.5E-06	-0.03
103.10	**1.903073**	1.903040	0.000039	-1.7E-05	-0.42	1.903066	0.000079	-3.9E-06	-0.05
154.65	**1.903150**	1.903119	0.000036	-1.6E-05	-0.42	1.903143	0.000055	-3.4E-06	-0.06
206.20	**1.903226**	1.903199	0.000036	-1.4E-05	-0.38	1.903221	0.000044	-2.9E-06	-0.06
257.74	**1.903303**	1.903278	0.000037	-1.3E-05	-0.33	1.903298	0.000038	-2.4E-06	-0.06
309.29	**1.903379**	1.903358	0.000041	-1.1E-05	-0.26	1.903375	0.000034	-1.9E-06	-0.05
360.84	**1.903456**	1.903437	0.000046	-9.6E-06	-0.20	1.903453	0.000031	-1.4E-06	-0.04
412.39	**1.903532**	1.903517	0.000052	-8.1E-06	-0.15	1.903530	0.000030	-8.8E-07	-0.03
515.49	**1.903685**	1.903676	0.000067	-5.0E-06	-0.07	1.903685	0.000029	1.2E-07	0.00
A_0 /mm²	**1.902920**	1.902881	0.000046	-2.1E-05	-0.43	1.902911	0.000010	-5.0E-06	-0.49
λ /Pa^{-1}	**7.800E-13**	8.4E-13	8.4E-14	7.1%	0.33	7.90E-13	1.6E-14	1.3%	0.33

Nominal pressure		**FSB-LPM**				**IMBiH**			
	Theoretical value of A_p	$\hat{A}_p$	u $\hat{A}_p$	Relative deviation	D	$\hat{A}_p$	u $\hat{A}_p$	Relative deviation	D
/MPa	/mm²	mm²	mm²			mm²	mm²		
5.16	**1.902928**	1.902928	0.000047	2.9E-07	0.01	1.902889	0.000080	-2.0E-05	-0.24
51.55	**1.902997**	1.903002	0.000047	2.9E-06	0.06	1.902963	0.000052	-1.8E-05	-0.32
103.10	**1.903073**	1.903084	0.000047	5.7E-06	0.12	1.903045	0.000047	-1.5E-05	-0.30
154.65	**1.903150**	1.903166	0.000047	8.6E-06	0.18	1.903127	0.000042	-1.2E-05	-0.27
206.20	**1.903226**	1.903248	0.000047	1.1E-05	0.23	1.903209	0.000041	-9.1E-06	-0.21
257.74	**1.903303**	1.903330	0.000047	1.4E-05	0.29	1.903291	0.000042	-6.3E-06	-0.14
309.29	**1.903379**	1.903412	0.000047	1.7E-05	0.35	1.903373	0.000046	-3.4E-06	-0.07
360.84	**1.903456**	1.903494	0.000047	2.0E-05	0.41	1.903454	0.000051	-5.9E-07	-0.01
412.39	**1.903532**	1.903576	0.000047	2.3E-05	0.47	1.903536	0.000058	2.3E-06	0.04
515.49	**1.903685**	1.903740	0.000047	2.9E-05	0.58	1.903700	0.000074	7.9E-06	0.10
A_0 /mm²	**1.902920**	1.902920	0.000047	0.0E+00	0.00	1.902881	0.000050	-2.1E-05	-0.39
λ /Pa^{-1}	**7.800E-13**	8.4E-13	4.2E-13	7.2%	0.07	8.35E-13	9.3E-14	7.1%	0.30

Nominal pressure	**Theoretical value of A_p**	**IMT**				**INRIM**			
	$\hat{A}_{p,th}$	$\hat{A}_p$	u $\hat{A}_p$	Relative deviation	D	$\hat{A}_p$	u $\hat{A}_p$	Relative deviation	D
/MPa	/mm²	mm²	mm²			mm²	mm²		
5.16	**1.902928**	1.902889	0.000054	-2.0E-05	-0.36	1.902918	0.000057	-4.9E-06	-0.08
51.55	**1.902997**	1.902963	0.000047	-1.8E-05	-0.36	1.902988	0.000028	-4.5E-06	-0.15
103.10	**1.903073**	1.903045	0.000042	-1.5E-05	-0.34	1.903066	0.000028	-3.9E-06	-0.14
154.65	**1.903150**	1.903127	0.000038	-1.2E-05	-0.30	1.903143	0.000025	-3.4E-06	-0.13
206.20	**1.903226**	1.903209	0.000037	-9.1E-06	-0.23	1.903221	0.000028	-2.9E-06	-0.10
257.74	**1.903303**	1.903291	0.000039	-6.3E-06	-0.15	1.903298	0.000029	-2.4E-06	-0.08
309.29	**1.903379**	1.903373	0.000043	-3.4E-06	-0.08	1.903375	0.000032	-1.9E-06	-0.06
360.84	**1.903456**	1.903454	0.000048	-5.9E-07	-0.01	1.903453	0.000034	-1.4E-06	-0.04
412.39	**1.903532**	1.903536	0.000055	2.3E-06	0.04	1.903530	0.000037	-8.7E-07	-0.02
515.49	**1.903685**	1.903700	0.000071	7.9E-06	0.11	1.903685	0.000045	1.6E-07	0.00
A_0 /mm²	**1.902920**	1.902881	0.000050	-2.1E-05	-0.39	1.902911	0.000021	-5.0E-06	-0.22
λ /Pa^{-1}	**7.800E-13**	8.35E-13	9.3E-14	7.1%	0.30	7.90E-13	4.2E-14	1.3%	0.12

Nominal pressure	**Theoretical value of A_p**	**IPQ**				**LNE**			
	$\hat{A}_{p,th}$	$\hat{A}_p$	u $\hat{A}_p$	Relative deviation	D	$\hat{A}_p$	u $\hat{A}_p$	Relative deviation	D
/MPa	/mm^2	mm^2	mm^2			mm^2	mm^2		
5.16	**1.902928**	1.902889	0.000068	-2.0E-05	-0.28	1.902959	0.000019	1.7E-05	0.82
51.55	**1.902997**	1.902963	0.000040	-1.8E-05	-0.42	1.903024	0.000022	1.4E-05	0.63
103.10	**1.903073**	1.903045	0.000040	-1.5E-05	-0.35	1.903096	0.000025	1.2E-05	0.47
154.65	**1.903150**	1.903127	0.000039	-1.2E-05	-0.29	1.903168	0.000027	9.6E-06	0.34
206.20	**1.903226**	1.903209	0.000041	-9.1E-06	-0.21	1.903240	0.000030	7.2E-06	0.23
257.74	**1.903303**	1.903291	0.000042	-6.3E-06	-0.14	1.903312	0.000032	4.7E-06	0.14
309.29	**1.903379**	1.903372	0.000044	-3.5E-06	-0.07	1.903383	0.000034	2.3E-06	0.06
360.84	**1.903456**	1.903454	0.000046	-6.2E-07	-0.01	1.903455	0.000037	-1.1E-07	0.00
412.39	**1.903532**	1.903536	0.000049	2.2E-06	0.04	1.903527	0.000039	-2.5E-06	-0.06
515.49	**1.903685**	1.903700	0.000055	7.9E-06	0.14	1.903671	0.000044	-7.4E-06	-0.16
A_0 /mm^2	**1.902920**	1.902881	0.000016	-2.0E-05	-1.2	1.902952	0.000019	1.7E-05	0.84
λ /Pa^{-1}	**7.800E-13**	8.61E-13	4.3E-14	10%	0.94	7.33E-13	2.1E-14	-6.0%	-1.1

Nominal pressure	**Theoretical value of A_p**	**METAS**				**MIKES**			
	$\hat{A}_{p,th}$	$\hat{A}_p$	u $\hat{A}_p$	Relative deviation	D	$\hat{A}_p$	u $\hat{A}_p$	Relative deviation	D
/MPa	/mm^2	mm^2	mm^2			mm^2	mm^2		
5.16	**1.902928**	1.90292	0.00011	-4.5E-06	-0.04	1.902889	0.000067	-2.1E-05	-0.29
51.55	**1.902997**	1.902989	0.000030	-4.1E-06	-0.13	1.902963	0.000055	-1.7E-05	-0.30
103.10	**1.903073**	1.903066	0.000031	-3.6E-06	-0.11	1.903044	0.000050	-1.5E-05	-0.29
154.65	**1.903150**	1.903143	0.000031	-3.2E-06	-0.10	1.903127	0.000048	-1.2E-05	-0.23
206.20	**1.903226**	1.903221	0.000030	-2.7E-06	-0.09	1.903208	0.000049	-9.3E-06	-0.18
257.74	**1.903303**	1.903298	0.000033	-2.3E-06	-0.06	1.903291	0.000054	-6.0E-06	-0.11
309.29	**1.903379**	1.903376	0.000037	-1.8E-06	-0.05	1.903372	0.000061	-3.6E-06	-0.06
360.84	**1.903456**	1.903453	0.000038	-1.4E-06	-0.03	1.903455	0.000069	-3.0E-07	0.00
412.39	**1.903532**	1.903530	0.000043	-9.5E-07	-0.02	1.903536	0.000079	2.1E-06	0.03
515.49	**1.903685**	1.903685	0.000050	-8.7E-08	0.00	1.903700	0.000101	7.8E-06	0.07
A_0 /mm^2	**1.902920**	1.902911	0.000029	-4.6E-06	-0.15	1.902881	0.000050	-2.1E-05	-0.40
λ /Pa^{-1}	**7.800E-13**	7.89E-13	4.0E-14	1.2%	0.12	8.36E-13	9.2E-14	7.2%	0.31

Nominal pressure	**Theoretical value of A_p**	**MKEH**				**PTB**			
	$\hat{A}_{p,th}$	$\hat{A}_p$	u $\hat{A}_p$	Relative deviation	D	$\hat{A}_p$	u $\hat{A}_p$	Relative deviation	D
/MPa	/mm^2	mm^2	mm^2			mm^2	mm^2		
5.16	**1.902928**	1.902889	0.000060	-2.0E-05	-0.32	1.902926	0.000063	-6.8E-07	-0.01
51.55	**1.902997**	1.902963	0.000031	-1.8E-05	-0.54	1.902995	0.000025	-6.7E-07	-0.03
103.10	**1.903073**	1.903045	0.000031	-1.5E-05	-0.45	1.903072	0.000026	-6.5E-07	-0.02
154.65	**1.903150**	1.903127	0.000029	-1.2E-05	-0.39	1.903148	0.000028	-6.4E-07	-0.02
206.20	**1.903226**	1.903209	0.000031	-9.0E-06	-0.28	1.903225	0.000031	-6.3E-07	-0.02
257.74	**1.903303**	1.903291	0.000033	-6.1E-06	-0.18	1.903301	0.000033	-6.2E-07	-0.02
309.29	**1.903379**	1.903373	0.000036	-3.2E-06	-0.08	1.903378	0.000035	-6.1E-07	-0.02
360.84	**1.903456**	1.903455	0.000038	-3.1E-07	-0.01	1.903454	0.000038	-5.9E-07	-0.01
412.39	**1.903532**	1.903536	0.000042	2.0E-06	0.05	1.903531	0.000040	-5.8E-07	-0.01
515.49	**1.903685**	1.903700	0.000051	7.8E-06	0.15	1.903684	0.000045	-5.6E-07	-0.01
A_0 /mm^2	**1.902920**	1.902881	0.000060	-2.0E-05	-0.32	1.902919	0.000022	-6.8E-07	-0.03
λ /Pa^{-1}	**7.800E-13**	8.36E-13	2.9E-14	7.2%	1.0	7.80E-13	2.9E-14	0.0%	0.00

Nominal pressure	**Theoretical value of A_p**	**UME**			
	$\hat{A}_{p,th}$	$\hat{A}_p$	u $\hat{A}_p$	Relative deviation	D
/MPa	/mm^2	mm^2	mm^2		
5.16	**1.902928**	1.902909	0.000066	-9.7E-06	-0.14
51.55	**1.902997**	1.902980	0.000034	-8.5E-06	-0.24
103.10	**1.903073**	1.903060	0.000033	-7.1E-06	-0.20
154.65	**1.903150**	1.903139	0.000030	-5.7E-06	-0.18
206.20	**1.903226**	1.903218	0.000032	-4.3E-06	-0.13
257.74	**1.903303**	1.903297	0.000034	-2.9E-06	-0.08
309.29	**1.903379**	1.903376	0.000037	-1.5E-06	-0.04
360.84	**1.903456**	1.903455	0.000041	-1.6E-07	0.00
412.39	**1.903532**	1.903534	0.000045	1.2E-06	0.03
515.49	**1.903685**	1.903693	0.000055	3.9E-06	0.07
A_0 /mm^2	**1.902920**	1.902901	0.000029	-9.8E-06	-0.33
λ /Pa^{-1}	**7.800E-13**	8.07E-13	5.7E-14	3.5%	0.24

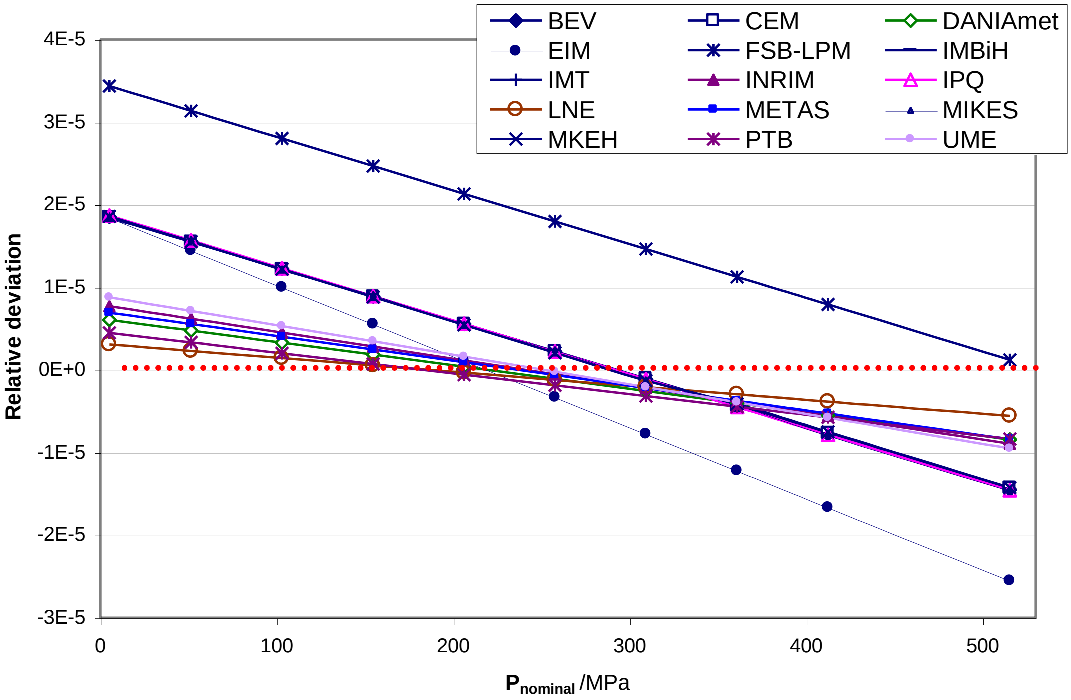

Fig. 11. Illustration of the relative deviation of Âp versus the nominal pressure p: oil balance case n°1

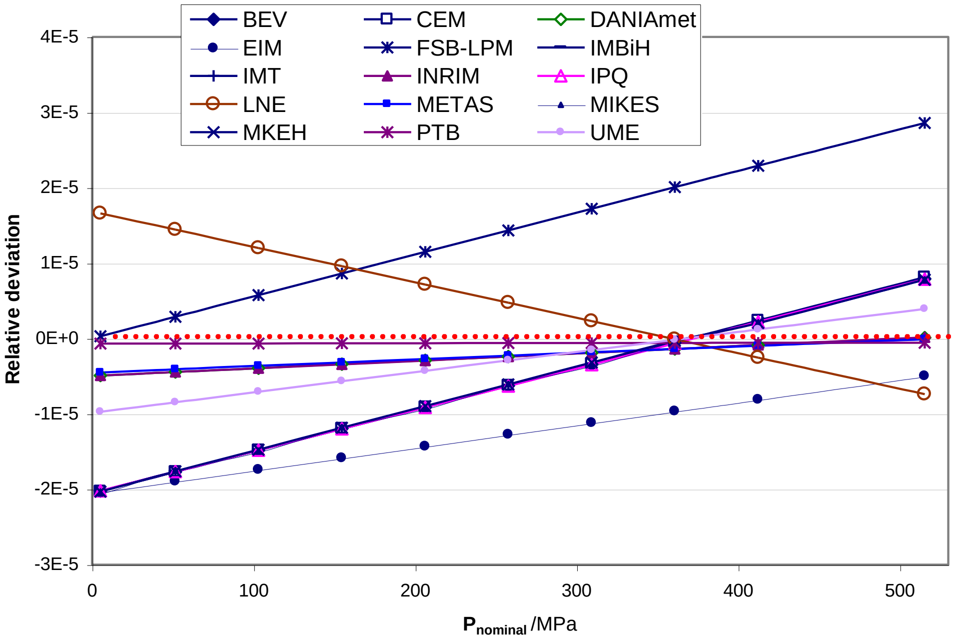

Fig. 12. Illustration of the relative deviation of $\hat{A}_p$ versus the nominal pressure p: oil balance case n°2

In order to summarize this results, a graph have been generated (see Fig. 3 and Fig. 4). These graphs underlines the fact that the relative standard deviation can be fitted as a linear function. Therefore, a quantity can be defined to allow us to compare every methods easily. This quantity is defined as the maximum absolute value of the extrema of each linear fitting model of the relative deviation. These extrema are the relative deviation observed at the minimal nominal pressure and at the maximal nominal pressure in each case. This quantity will be refered in the document as “extremum”. The comparison of the methods are reported in table 51.

For oil balances, from 5 MPa to 500 MPa, the most used method – the ordinary least square method – shows the less efficient results, as the deviation for all the NMIs using this method is the biggest. METAS gives better results by applying the same method without considering the first point, which is the less repeatable one. In reality, by only suppressing the first point to calculate the fitting parameters, the results are significantly better and it can be said that this method seems to be one of the most efficient one. However, some cases that were not studied here can raise questions about the number of points that may be suppressed. Also, UME gives better results by applying the weighed least square method instead of the ordinary least square method. Like the cases of gas balances, DANIAmet method seems to give one of the best results here. Even if UME and DANIAmet use the same method, the results are different because the calculation of the uncertainties – which defines the weight of all the values - is different: in the case of DANIAmet, the measurements of the first pressure points have been characterized by a huger uncertainty. INRIM also gives good results. LNE gives good results but the results are a little mitigated. If for the first case, the results are really good, for the second case, the deviation is significant and quite close to the one observed with the ordinary least square method. Therefore, we can say that the efficiency of the generalized least square method depends on the estimation of the variance-covariance matrix. The lowest deviations observed in the case of oil balances are the one observed from the data of PTB.

In any case, all the NMIs have provided results that are coherent, which means that the efficiency of the method is taken into account in the uncertainty. The uncertainty of the parameters of A_0 and λ are sometimes underestimated. However, it is counterbalanced with the uncertainty of the other parameter. Therefore, at each pressure point, the uncertainty of the fitted effective area is well estimated or overestimated. There is however a tendency to underestimate the uncertainty of the first pressure points (D can reach 0.7 or 0.8 for FSB-LPM and LNE). DANIAmet and PTB have a tendency to overestimate their uncertainties: $D < 0.1$. However, like the gas cases (see Section 7.1), the uncertainties of the fits were derived from the Ap values and their uncertainties u(Ap). In order to better estimate the uncertainties, it would be also useful to analyse how well the fitted uncertainties reflect the input (experimental) uncertainties. It won’t be analyse in this report.

Table 51. Summary of the methods applied by each NMI and the associated extrema for gas balance cases

Extremum	<	Extremum	<	Extremum	<	Extremum	<	Extremum	<	Extremum

NMIs	**Method**	**Data**	**Extremum case 1**	**Extremum case 2**
			Relative value	Relative value
BEV	OLS	Mean value of 5 cycles at each nominal pressure	1.9E-05	2.0E-05
CEM	OLS	Mean value of 5 cycles at each nominal pressure	1.8E-05	2.0E-05
EIM	OLS	Mean value of 5 cycles at each nominal pressure	2.6E-05	2.0E-05
DANIAmet	WLS	Mean value of 5 cycles at each nominal pressure. The weight of the values are calculated from the uncertainties calculated by DANIAmet in the fist loop.	8.4E-06	4.9E-06
FSB-LPM	OLS	Mean value of 5 cycles at each nominal pressure	3.4E-05	2.9E-05
IMBiH	OLS	Mean value of 5 cycles at each nominal pressure	1.9E-05	2.0E-05
IMT	OLS	Mean value of 5 cycles at each nominal pressure	1.9E-05	2.0E-05
INRIM	GLS	Mean value of 5 cycles at each nominal pressure, see description of the variance-covariance matrix in section 3.4.10	8.9E-06	4.9E-06
IPQ	OLS	Mean value of 5 cycles at each nominal pressure	1.9E-05	2.0E-05
LNE	GLS	Mean value of 5 cycles at each nominal pressure, see description of the variance-covariance matrix in section 3.4.12	5.6E-06	1.7E-05
METAS	OLS – 1st point excluded	Mean value of 5 cycles at each p, first value excluded	8.4E-06	4.5E-06
MIKES	OLS	Mean value of 5 cycles at each nominal pressure	1.9E-05	2.0E-05
MKEH	OLS	Mean value of 5 cycles at each nominal pressure	1.8E-05	2.0E-05
PTB	A_0,λ,F-model	Mean value of 5 cycles at each nominal pressure	8.4E-06	6.8E-07
UME	WLS	Mean value of 5 cycles at each nominal pressure	9.5E-06	9.7E-06

OLS	Ordinary least square method
WLS	Weighed least square method
GLS	Generalized least square method

8. Conclusion

To conclude, even if this study is not complete as only four cases were considered, it can be said that for all cases the most used method – the ordinary least square method – to determine the fitting parameters of the effective area of a piston-cylinder assembly is not the most efficient one. Therefore, although the uncertainty is still well estimated, the determination of the fitting parameters can be improved by using other methods. A summary of the other methods, with some comments about their advantages or disadvantages, is reported in Table 52.

The pairs of results could be presented in the form of youden plot [11] in which relative differences for case 1 are plotted as a function of case 2. However, the original type of diagram, which is useful to show systematic bias, is difficult to apply in the case of this project. For the graphical interpretation of the results, it is preferable not to plot the relative differences but the absolute ones. The points plotted in this way reflect the robustness of the method: the closer are the points to the origin the more robust is the method. Figures 5 and 6 show, as expected, that the methods based on OLS give the less robust results. These graphical analyses have been done for each maximum pressure points (10 MPa et 500 MPa). It could be done with the other ones with similar interpretations. In any case, all the methods give results with deviation that are coherent considering the associated uncertainties.

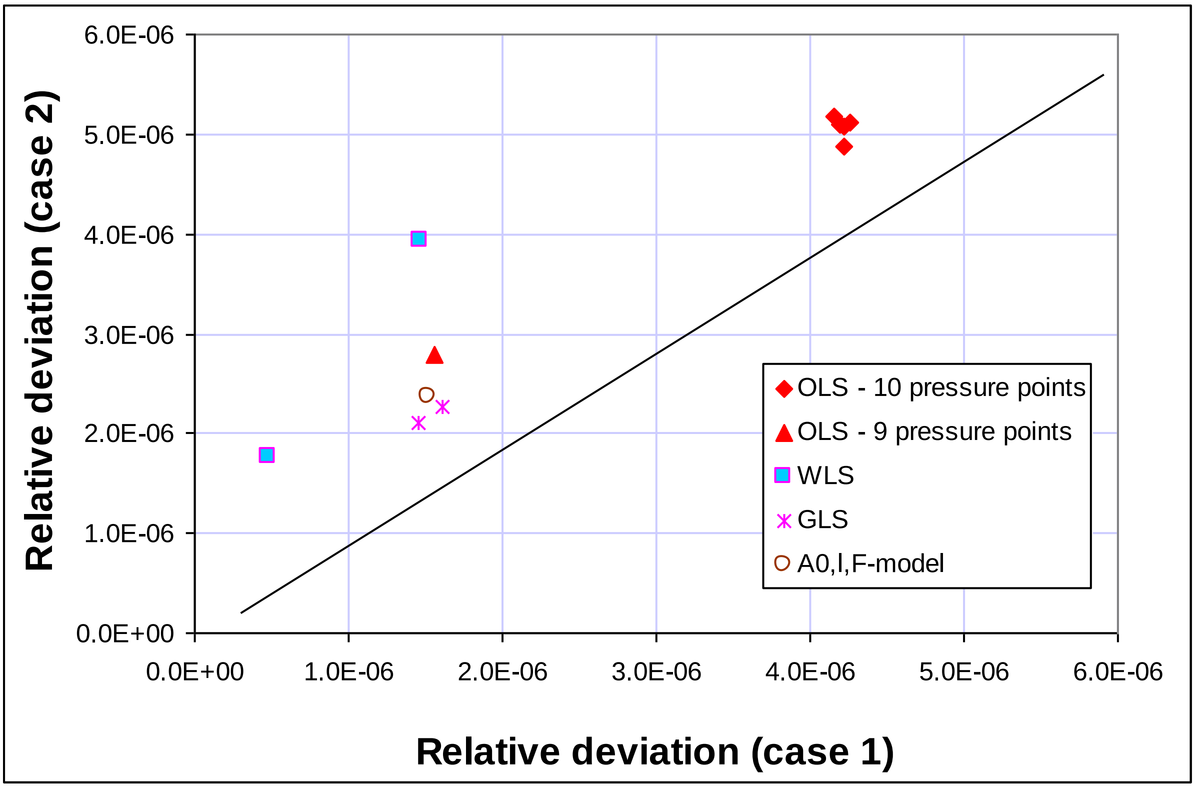

Fig. 13. Youden diagram: absolute relative deviations from the gas balance calibration (case 2) versus the ones from the gas balance calibration (case 1), at the pressure point 10 000 kPa.

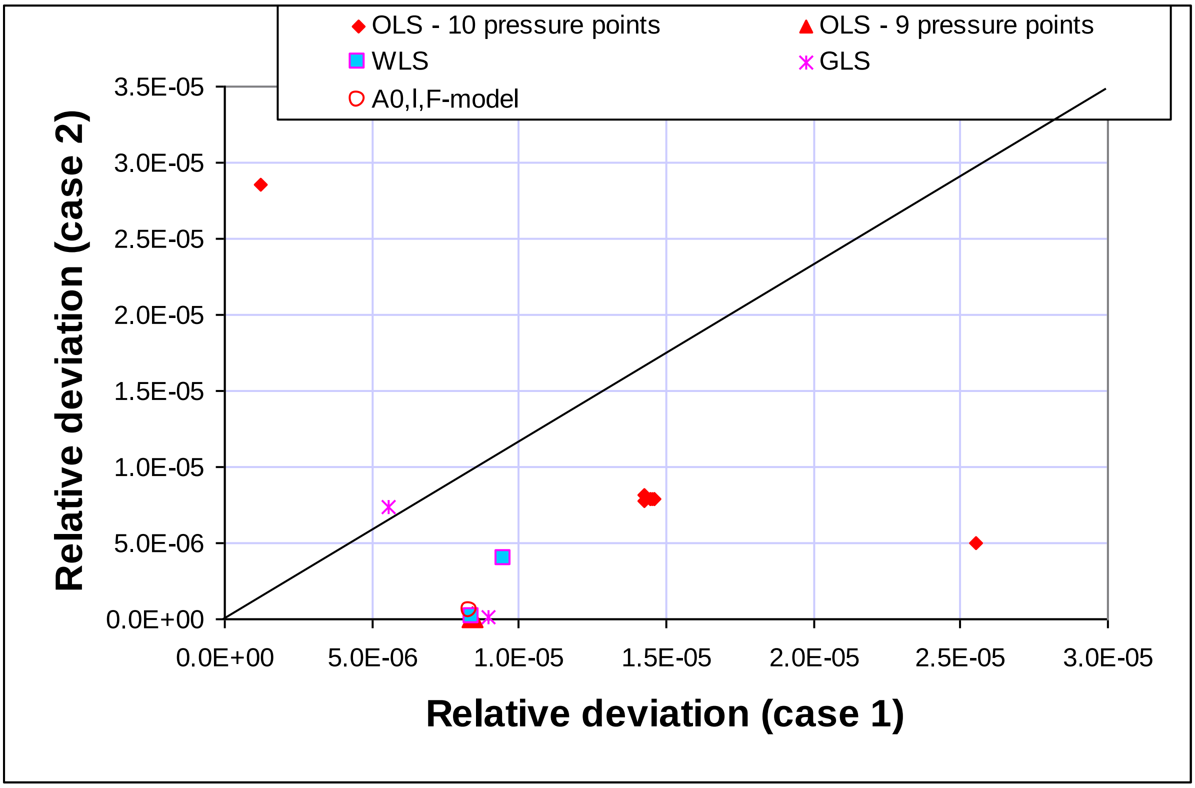

Fig. 14. Youden diagram: absolute relative deviations from the oil balance calibration (case 2) versus the ones from the oil balance calibration (case 1), at the pressure point 500 MPa.

Table 52. Notes about the methods to determine the fitted effective area at each pressure points, as presented in this report

Method	**Advantage/Disadvantage**
Ordinary least square method (OLS)	▪ Less robust method ▪ The easiest method and the most used one ▪ Good estimation of the uncertainties
Ordinary least square method (OLS) first value excluded	▪ More robust than OLS ▪ Even more suited in the case of oil balances ▪ How to determine which points can be suppressed ?
Weighed least square method (WLS)	▪ More robust than OLS ▪ It can be a very robust method if the uncertainties are well evaluated. ▪ No need to suppress some points ▪ What to do in the case where the first points is too deviated from the fitting although the repeatability is observed low in 5 cycles?: one possibility is to consider the fitting curve and the repeatability as two separately parameters.
GLS	▪ Good results but the robustness of the method depends on the estimation of the variance-covariance matrix ▪ Method that is more difficult than the OLS or WLS ▪ Difficulty to estimate the variance-covariance matrix ▪ Uncertainties overestimated in the case of oil balances. However, an analyse of how well the fitted uncertainties reflect the input (experimental) uncertainties is necessary to conclude if it is due to the method. ▪ Uncertainties a little underestimated in the case of oil balance when considering the first pressure points.
A_0,λ,F-model	▪ One of the most robust ▪ Method that is more difficult than the OLS or WLS ▪ Uncertainties may be overestimated in the four cases. However, an analyse of how well the fitted uncertainties reflect the input (experimental) uncertainties is necessary to conclude if it is due to the method.

9. References

[1] July 1997, Calibration of Pressure Balances, EAL-G26, European cooperation for Accreditation of Laboratories, Edition 1

[2] 1993, Guide to the expression of uncertainty in measurement, BIPM, ISO, ISBN 92-96-10188-9

[3] J. Johnston, 1963, Econometric Methods, Second Edition, McGraw-Hill, New York, 208-221

[4] M. G. Cox, The evaluation of key comparison data, Metrologia 39 (2002), 589-595

[5] Draft March 2010, Calibration of pressure balances, Euramet Calibration Guide 03

[6] Evolution of measurement data – Supplement 2 JCGM 102 final draft 2009, to be published

[7] September 2008, Evaluation of measurement data — Guide to the expression of uncertainty in measurement, JCGM 100:2008

[8] R S Davis, 1992, Equation for the Determination of the Density of Moist Air, Metrologia, Vol. 29, 67-70

[9] W Sabuga et al, Final Report on Key Comparison CCM.P-K7 in the range 10 MPa to 100 MPa of hydraulic gauge pressure, Metrologia 42 (2005) 07005

[10] A Picard, R S Davis, M Glaser and K Fujiiin, 2008, Revised formula for the density of moist air (CIPM-2007), Metrologia, Vol. 45, 149–155

[11] W. J. Youden Industrial quality control, 1959, Vol.15, N0 11

ANNEX A : determination of the additional masses

Considering the theoretical true values $\mathbf{A_{0c\_th}}$ and $\boldsymbol{\lambda_{c\_th}}$, the pressure points generated on the calibrated PCAs is calculated by the following equation:

$$p_{c\_th} = \frac{\sum_i m_{ai\_c} \cdot g + \Gamma \cdot C}{A_{0c\_th} \cdot \left[1 + \lambda_{c\_th} \cdot p_{nom}\right] \cdot \left[1 + \alpha \cdot \left(t_c - 20\right)\right]},$$

Where

$\alpha = \alpha_p + \alpha_c$	Calibrated PCA's thermal expansion coefficient
t_c	Calibrated PCA’s temperature
g	local gravity
Γ	Surface tension of the oil (Γ=0 in the case of a gas balance)
C	Circumference of the piston
m_{ai_c}	Apparent value of each mass applied on the piston
P_{nom}	Nominal pressure

Next, the theoretical reference pressure can be calculated:

$$p_{ref\_th} = p_{c\_th} + \left(\rho_f - \rho_a\right) \cdot g \cdot \left(h_c - h_{ref}\right) \quad ,$$

Where

ρ_a	Air density
ρ_f	fluid density
h_c	Calibrated PCA’s height
h_{ref}	Reference PCA’s height

Therefore, the sum of the masses that must be applied on the reference piston is defined by the expression:

$$\sum_i m_{ai\_ref\_th} = \frac{p_{ref\_th} \cdot A_{0ref\_th} \cdot \left[1 + \lambda_{ref\_th} \cdot p_{nom}\right] \cdot \left[1 + \alpha \cdot \left(t_{ref} - 20\right)\right] - \Gamma \cdot C}{g}$$

The additional masses are then the difference between the sum of the masses pieces applied – that are known without systematic errors – and the sum of the masses that must be applied. As an operator cannot do the equilibrium perfectly, a resolution on the application of these additional masses is applied:

$$m_{addi}\left(P_{nom},Cycle\right)=resolution \cdot Round\left[\left(\left|\sum_i m_{ai\_ref\_th}-\sum_i m_{ai\_ref\_without\ syst\ error}\right|\right)/\,resolution\right]+k\cdot resolution$$

where k may be randomly equal to –1, 0 or +1, and resolution is set by the following equation: $resolution = m_0 + 1\cdot 10^{-6}\cdot P_{nom}$, with m_0 = 10 mg in the case of a gas balance and m_0 = 50 mg in the case of an oil balance.