GULFMET.M.P-S1

Supplementary Pressure Comparison from (0.7 to 7) MPa in Gas Media at Gauge Mode

FINAL REPORT

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Abstract

This report gives the results of a comparison of pressure standards of three National Metrology institutes in the range of 0.7 MPa to 7 MPa. This comparison was piloted by UME and was carried out from February 2017 to March 2019. This work is a part of the GULFMET project and is registered as a supplementary comparison GULFMET.M.P-S1. The transfer standard used was a digital pressure gauge, model 745-1K, serial number 114944 and, manufactured by Paroscientific Inc, with a resolution of 1 hPa. The reference values have been determined from the weighted mean of the deviations which is a measurement error of test instrument reported by the participants for each specified pressure.

January 2020

Contents

List of Tables

List of Figures

1. Introduction

Interlaboratory comparisons are a significant parameter for the calibration laboratories for assuring the quality of test and calibration results. Accredited laboratories and other laboratories that have a quality system for their working areas are expected to join into multi-participant intercomparisons in certain time periods to show and assure their service quality.

GULFMET.M.P-S1was planned as a supplementary comparison [1,2] in the GULFMET TC-M SC Pressure meeting dated November 2016. The objective of this comparison is to state the degree of equivalence of measurements maintained by National Metrology Institutes (NMIs) – the signatories of the Mutual Recognition Arrangement (MRA) [2]. So, laboratories will have the opportunity to support their uncertainty statements made in their Calibration Measurement Capability (CMC) Tables.

The pressure range up to 7 MPa in gas media is the pressure range where many NMIs have measurement capability. So, after a discussion at the TC-M SC Pressure meeting dated 2016, 7 MPa pressure range was selected for the comparison. For the proposed comparison, three participants have applied to participate in the GULFMET.M.P-S1. Out of three applicants, one member of the European (EURAMET), two institutes are the member of GULFMET. The UME agreed to be the pilot laboratory in this comparison.

The comparison was conducted in accordance with the Technical Protocol prepared by the UME and approved by the participants.

Comparison reports of draft A, draft B and the final report are going to be prepared and distributed according to the “Report will be CCM Guidelines for approval and publication of the final reports of key and supplementary comparisons” [2]. In this guide in chapter 4, it is highlighted that information on pair-wise degrees of equivalence published in comparison reports be limited to the equations needed to calculate them, with the addition of any information on correlations that may be necessary to estimate them more accurately. The CCM stresses the importance of continuing to report the values and the graphs representing the degrees of equivalence relative to the comparison reference value.

2. Participants

2.1 Pilot laboratory

This comparison is piloted by TUBITAK UME. The pilot laboratory is responsible for preparing the measurement instructions, controlling the stability of the transfer standard, calculating the results and preparing the final report.

2.2 Participant laboratories

List of participating laboratories is given in Table 1.

Table 1. List of participating laboratories

No	Laboratory	Country	Contact Person	Measurement Date	Traceability	CMC
1	UME	Turkey	Yasin Durgut	03.04.2018	PTB	Yes
2	SASO–NMCC	Kingdom of Saudi Arabia	Homood M. Alotaibi	11.12.2017	NIST	No
3	EMI	United Arab Emirates	Brian K. Justice	22.05.2018	CMI	No

3. Laboratory standards and measurement details of the participants

3.1 Measurement at UME

Details of performed measurement at UME are given in Table 2.

Table 2. Measurement at UME

Participant laboratory and its full address		National Metrology Institute of Turkey (UME) Gebze-Kocaeli/Turkey
Contact person name, e-mail, phone		Yasin Durgut yasin.durgut@tubitak.gov.tr +90 262 679 50 00
Notes of inspection of the package (e.g. Damages, missing items any problems)		Hand-carried, satisfactory condition
Reference instrument information	Manufacturer	Fluke/DHI
	Model	PG7601 base with sensors, 200 kPa/kg piston, MS-AMH-38 Mass Set
	Serial No	Base 430, piston 778, mass 2272
	Measurement range and uncertainty	(0.14 – 7.63) MPa $U(p)=1.2\ \text{Pa}+1.8\cdot 10^{-5}\cdot p$
	Traceability Information	PTB
A detailed description of how the measurements were performed (general procedure, a schematic/photo of the experimental set-up, the duration of the temperature stabilization at (20 ± 1) °C etc.).		A description is given in the following text.
Date of receipt of the transfer standards by laboratory		30.01.2018
Date of dispatch of the transfer standards from laboratory		25.04.2018
Date of measurements		03.04.2018
Measurement environmental conditions	Temperature (°C)	(20.0 ± 1) °C
	Relative humidity (%rh)	(45 ± 15) rh%
	Atmospheric pressure (hPa)	(995 to 997) ± 0.1 hPa

As a reference standard, a pressure balance was used manufactured by Fluke. Piston-cylinder unit has 50 mm^2 nominal area. Measurement range is up to 7 MPa. The piston-cylinder parameters (A_o and λ) are traceable to the PTB. Loading masses are traceable to the UME. As pressure transmitting medium nitrogen was used. For each pressure point density of nitrogen was re-calculated dependent on the actual pressure. The reference level of the transfer standard is the middle point of the pressure connection port. The reference level of the reference standard is labelled on the base by the manufacturer. The height difference between the reference standard and the transfer standard was measured and taken into account. The measurements were performed in accordance with the instructions of section 6.2 of the Technical Protocol. The uncertainty of the calibration results was evaluated according to GUM, EA 4/02. Calibrations were performed based on Euramet technical guide of “Guidelines on the Calibration of Electromechanical and Mechanical Manometers” [3]. The measurement set-up is given in Figure 1.

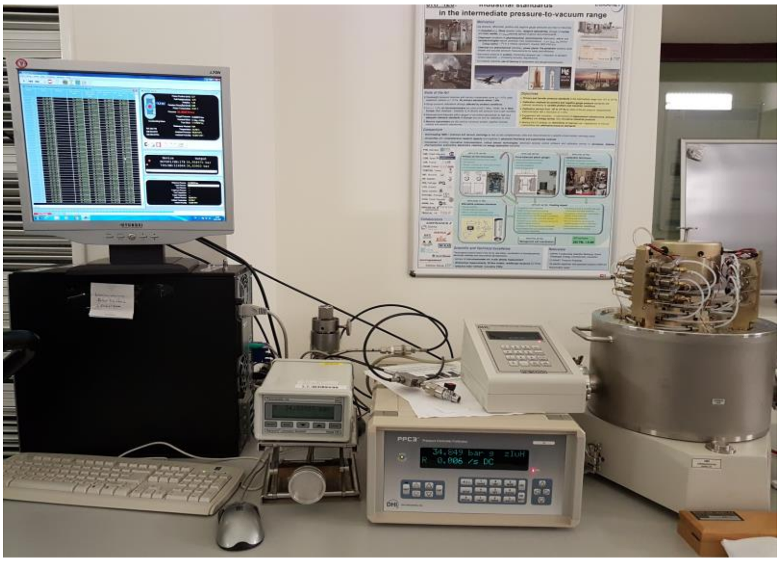


Figure 1. Measurement set-up at UME

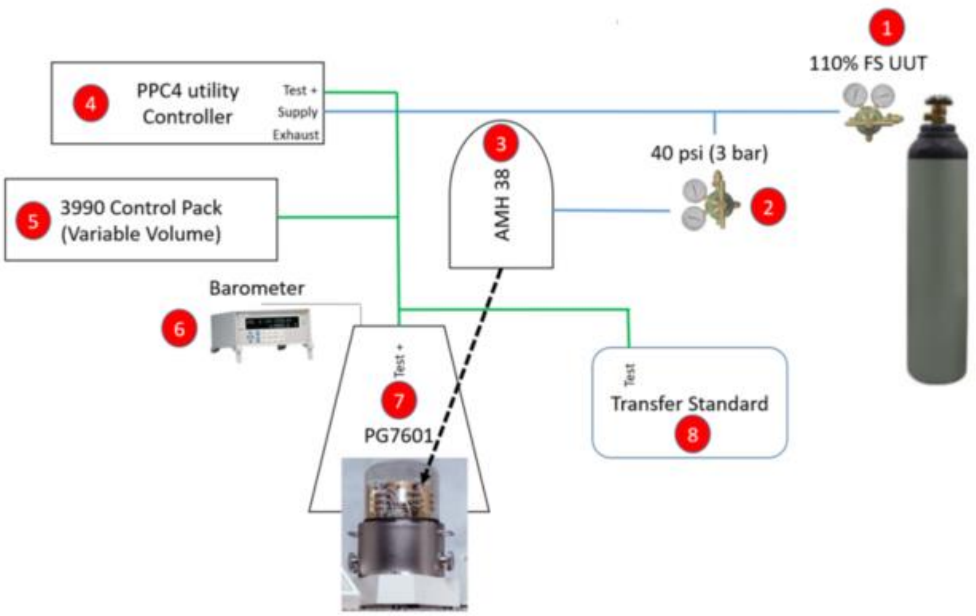
3.2 Measurement details of EMI

Details of performed measurement at EMI are given in Table 3.

Table 3. Measurement at EMI

Participant laboratory and its full address		Emirates Metrology Institute, Centre of Excellence for Applied Research and Training (CERT) PO Box 853, Sultan Bin Zayed The First Street Abu Dhabi, UAE
Contact person name, e-mail, phone		Brian Justice brian.justice@qcc.abudhabi.ae +971 2 406 6540
Notes of inspection of the package (e.g. Damages, missing items any problems)		Hand-carried, satisfactory condition
	Manufacturer	Fluke/DHI

Reference instrument information	Model	PG7601 base with sensors, 200 kPa/kg piston, MS-AMH-38 Mass Set
	Serial No	Base 960, piston 1825, mass 2768
	Measurement range and uncertainty	(0.2 – 7.6) MPa $U(p) = 0.2\ \text{Pa} + 1.0 \cdot 10^{-5} \cdot p + 2.0 \cdot 10^{-13} \cdot p^2$
	Traceability Information	CMI Czech Republic Base: 6013-KL-C0019-18; 2018.01.05, 6036-KL-V0608-17; 2017.12.20 Piston: 6013-KL-P0001-18; 2018.01.03 EMI Abu Dhabi Mass: 0215/M/2017; 2017.12.10 to 2017.12.17 Barometer: 0002/P/2018; 2018.02.05 Gravity: Local gravity measured using gravity comparator and three absolute gravity reference stations.
A detailed description of how the measurements were performed (general procedure, a schematic/photo of the experimental set-up, the duration of the temperature stabilization at (20 ± 1) °C etc.).		Data collected using a compass for pressure software to communicate with the base and Paroscientific transducer. Reference level was the center of pressure connection to the transducer and height set the same as the reference plane of the PG7601. The protocol dated 2017.02.21 from the BIPM website was followed. A period of 24 hours was allowed for thermal equilibrium and warm up. Before commencing each cycle, the transfer standard was set to zero by following the tare procedure. Schematic of experimental setup seen in Figure 2.
Date of receipt of the transfer standards by laboratory		2018.04.30
Date of dispatch of the transfer standards from laboratory		Pending Shipment Date. Expected by 2018.06.12
Date of measurements		2018.05.22
Measurement environmental conditions	Temperature (°C)	19.6 to 21.0
	Relative humidity (%rh)	38 to 46
	Atmospheric pressure (hPa)	1007.2 to 1009.5



1. Supply pressure – min 110% FS of UUT, max 1000 psi
2. AMH supply pressure – min 40 psi, max 45 psi
3. AMH-38 – automated mass handler, including trim mass
4. Utility pressure controller – supplies positive and negative pressure for piston float
5. 3990 Control Pack – variable volume for fine pressure control
6. Barometer – used for monitoring barometric pressure changes during measurement
7. PG7601 pressure balance – base for 200 kPa/kg piston, holds all metrological data and performs calculations
8. Transfer Standard – UUT

Figure 2. Measurement set-up at EMI

3.3 Measurement details of SASO-NMCC

Details of performed measurement at SASO-NMCC are given in Table 4.

Table 4. Measurement at SASO-NMCC

Participant laboratory and its full address		Saudi Standards, Metrology and Quality Org. (SASO-NMCC) Riyadh - Al Muhammadiyah - in front of King Saud University PO. B 3437 Riyadh 11471 Kingdom of Saudi Arabia
Contact person name, e-mail, phone		Homood M.Alotaibi h.otaibi@saso.gov.sa Naif A. AlAnazi n.aziz@saso.gov.sa
Notes of inspection of the package (e.g. Damages, missing items any problems)		Hand-carried, satisfactory condition
Reference instrument information	Manufacturer	Fluke
	Model	PG7601 base 200 kPa/kg piston
	Serial No	Base 545, piston 1934,AMH Mass 2919
	Measurement range and uncertainty	up to 7 MPa U(p)= ± (2 Pa + 20 ppm)
	Traceability Information	Traceability is provided through a calibration certificate by Fluke, which is an accredited laboratory with pressure standards traceable to NIST
A detailed description of how the measurements were performed (general procedure, a schematic/photo of the experimental set-up, the duration of the temperature stabilization at (20 ± 1) °C etc.).		The pressure medium was nitrogen. We put the transfer standard and reference at the same level. Before measurement, the transfer standard was kept in the laboratory for more than 24 hours for thermal equilibrium. the measurement for 3 cycles was performed in a day. Data collected manual and the mass loading on the piston automatically by using an automated mass handling system AMH38 as given in Figure 3.
Date of receipt of the transfer standards by laboratory		25.11.2017
Date of dispatch of the transfer standards from laboratory		20.01.2018
Date of measurements		11.12.2017
Measurement environmental conditions	Temperature (°C)	19.30 to 19.40
	Relative humidity (%rh)	25.38 to 25.70
	Atmospheric pressure (hPa)	950.13 to 951.90

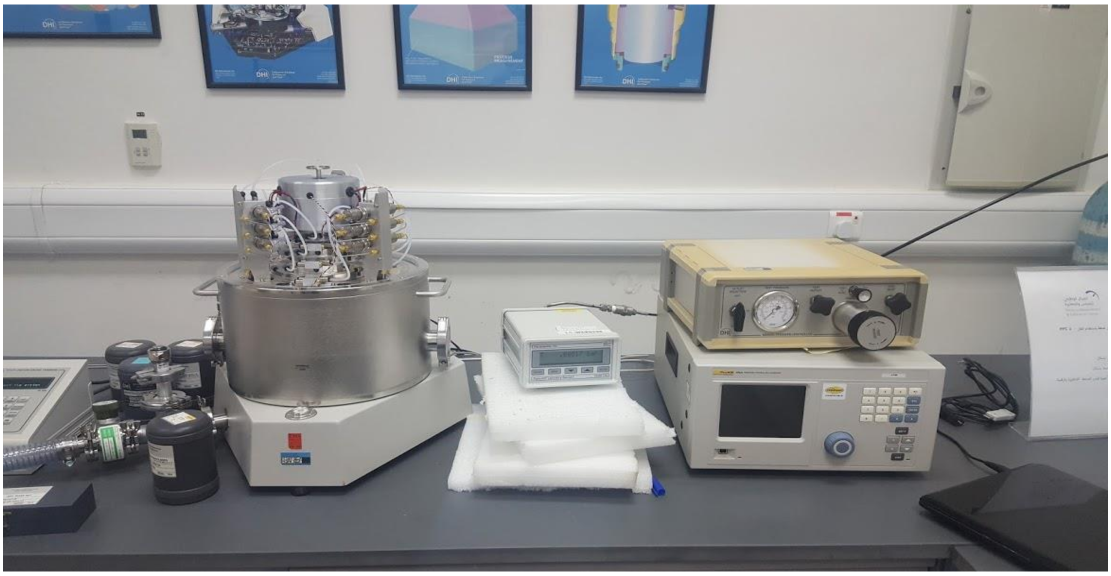


Figure 3. Measurement set-up at SASO-NMCC

4. Transfer standard

The transfer standard (TS) was a digital pressure gauge manufactured by Paroscientific, Inc. The serial number and model no are 114944 and 745-1K respectively. Battery charger (main power adaptor) and user manual guide were sent to participants together with the TS. Transfer standard details are given in Table 5 and Figure 4.

Table 5. Transfer standard

Name	Digital Pressure Gauge
Measurement Range	0 - 7 MPa
Manufacturer	Paroscientific, Inc.
Model No	745-1K
Serial No	114944
Pressure Connection	NPT 1/4″ female
Measurement Points	(0, 0.7, 1.4, 2.1, 2.8, 3.5, 4.2, 4.9, 5.6, 6.3, 7.0) MPa
Resolution	1 hPa
Pressure Media (operates with)	Gas (nitrogen)
Transfer Standard Package Including List	1. Paroscientific digital pressure gauge with NPT1/4″ female pressure adaptor (please try to use this adaptor and do not remove it) 2. Battery charger (main power adaptor)

Figure 4. Transfer standard (TS)

4.1 Stability of the transfer standard

The transfer standard was selected as a digital pressure gauge manufactured by Paroscientific. The transfer standard (TS) was calibrated three times at UME on the following dates 08/02/2017, 03/04/2018 and 19/06/2018 (day/month/year).

Above measurements result used to analyse the stability of the transfer standard during the comparison period given in Figure 5.

Stability of transfer standard represented as u_{stab} was evaluated out of three measurements equation 1 [4].

Equation 1

$$u_{stab} = \frac{\max(X_{UME}(\text{begin});\ X_{UME}(\text{middle});\ X_{UME}(\text{end})) - \min(X_{UME}(\text{begin});\ X_{UME}(\text{middle});\ X_{UME}(\text{end}))}{\sqrt{3}}$$

$$= 0.000087\ \text{MPa}$$

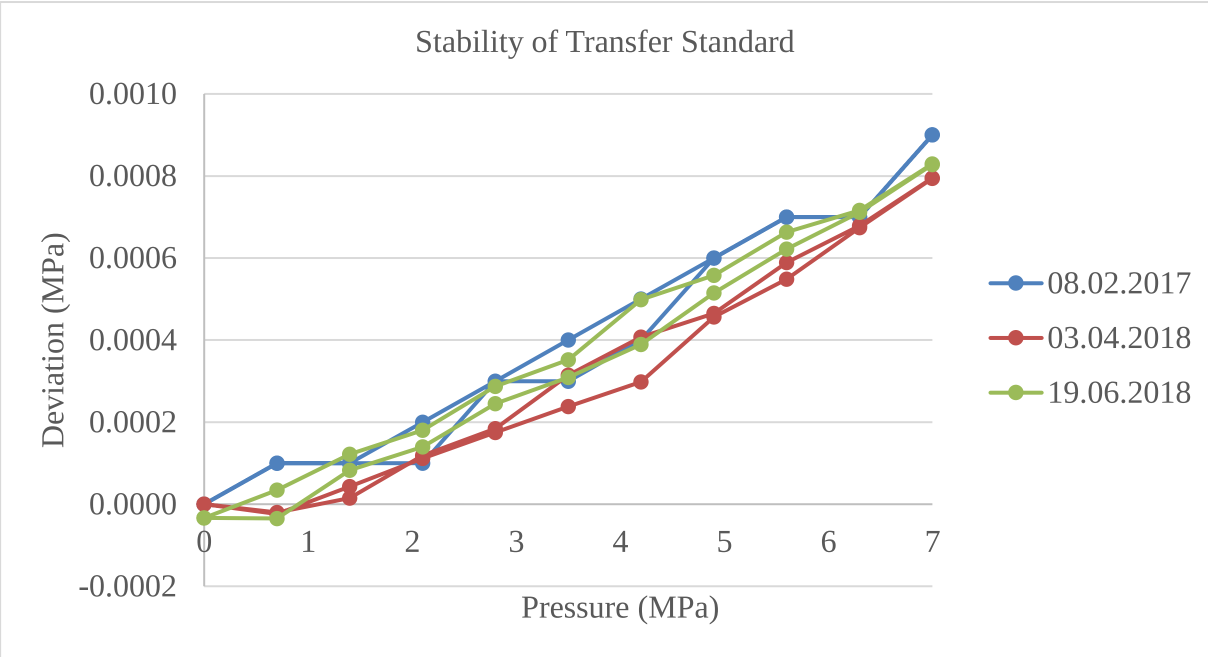


Figure 5. Stability of Transfer Standard (TS)

5. Measurement instructions

The measurement procedure was precisely described in the technical protocol. Unpacking, handling and care of the TS were explained. Some information about thermal stabilisation, using TS, measurement points were supplied. Also, reporting results were explained in the technical protocol.

Measurements were (0.7, 1.4, 2.1, 2.8, 3.5, 4.2, 4.9, 5.6, 6.3, 7) MPa in increasing and decreasing directions with 3 cycles.

6. Measurement results of participants

The mean deviations (x_i) measured by the participants and their standard uncertainties $u(x_i)$ are presented in Table 6 and Table 7.

Table 6. Measurement results of participants in increasing values

Nominal pressure / MPa	UME		SASO NMCC		EMI	
	xi / MPa	u(xi) / MPa	xi / MPa	u(xi) / MPa	xi / MPa	u(xi) / MPa
0.7	-0.00002	0.00003	-0.00001	0.00003	0.00001	0.00005
1.4	0.00004	0.00003	0.00004	0.00003	-0.00001	0.00006
2.1	0.00011	0.00004	0.00008	0.00003	0.00009	0.00005
2.8	0.00018	0.00004	0.00014	0.00004	0.00010	0.00006
3.5	0.00024	0.00005	0.00022	0.00004	0.00020	0.00006
4.2	0.00030	0.00006	0.00031	0.00005	0.00029	0.00006
4.9	0.00046	0.00006	0.00039	0.00006	0.00040	0.00007
5.6	0.00055	0.00006	0.00048	0.00006	0.00050	0.00007
6.3	0.00067	0.00007	0.00057	0.00007	0.00059	0.00008
7.0	0.00079	0.00007	0.00069	0.00008	0.00070	0.00008

Table 7. Measurement results of participants in decreasing values

Nominal pressure / MPa	UME		SASO NMCC		EMI	
	xi / MPa	u(xi) / MPa	xi / MPa	u(xi) / MPa	xi / MPa	u(xi) / MPa
0.7	-0.00002	0.00003	-0.00006	0.00003	-0.00009	0.00006
1.4	0.00002	0.00003	0.00001	0.00003	-0.00001	0.00006
2.1	0.00012	0.00004	0.00008	0.00003	0.00009	0.00005
2.8	0.00018	0.00004	0.00015	0.00004	0.00020	0.00006
3.5	0.00031	0.00005	0.00024	0.00004	0.00029	0.00007
4.2	0.00041	0.00006	0.00033	0.00005	0.00030	0.00007
4.9	0.00047	0.00006	0.00042	0.00006	0.00040	0.00007
5.6	0.00059	0.00006	0.00050	0.00006	0.00050	0.00007
6.3	0.00068	0.00007	0.00059	0.00007	0.00059	0.00008
7.0	0.00080	0.00007	0.00069	0.00008	0.00070	0.00008

7. Calculation of the reference value

Reference value and its assigned uncertainty of the comparison were calculated based on the “weighted mean” method using equation 2 and equation 3.

Equation 2

$$x_{ref} = \frac{\sum_{i=1}^{N} \frac{x_i}{u^2(x_i)}}{\sum_{i=1}^{N} \frac{1}{u^2(x_i)}}$$

Equation 3

$$u(x_{\mathrm{ref}}) = \left[\sum_{i=1}^{N} \frac{1}{u^2(x_i)}\right]^{-0.5}$$

Where
N refers to a number of participant laboratories.

x_{ref} is the reference value of the comparison and $u(x_{ref})$ is the standard uncertainty of the comparison reference value. A chi-square test has been applied to carry out a consistency check of the obtained results. The test consists of comparing the values of χ^2_{obs} calculated by equation 4 with the value of the chi-square distribution calculated for υ=3-1=2 degrees of freedom at probability 0.05.

Equation 4

$$\chi^2_{obs} = \sum_{i=1}^{3} \frac{(Xi - Xref)^2}{u^2\,(Xi)}$$

$$\chi^2_{obs} < \chi^2(2;0.05)$$

$$\chi^2(2;0.05) = 5.99$$

Comparison reference values with assigned uncertainties and χ^2_{obs} values are given in Table 8. Reference values were shown in Figure 6.

Table 8. Reference values with assigned standard uncertainty for increasing values

Nominal pressure (MPa)	Increasing			Decreasing		
	x_{ref} (MPa)	$u(x_{ref})$ (MPa)	χ^2_{obs}	x_{ref} (MPa)	$u(x_{ref})$ (MPa)	χ^2_{obs}
0.7	-0.00001	0.00001	0.31	-0.00005	0.00001	1.70
1.4	0.00003	0.00001	0.62	0.00001	0.00001	0.12
2.1	0.00010	0.00001	0.32	0.00010	0.00001	0.69
2.8	0.00015	0.00001	1.10	0.00017	0.00001	0.59
3.5	0.00022	0.00001	0.30	0.00028	0.00001	1.40
4.2	0.00030	0.00002	0.03	0.00035	0.00002	1.62
4.9	0.00042	0.00002	0.76	0.00043	0.00002	0.61
5.6	0.00051	0.00002	0.54	0.00053	0.00002	1.16
6.3	0.00061	0.00002	1.23	0.00062	0.00002	1.04
7.0	0.00073	0.00002	1.22	0.00073	0.00002	1.26

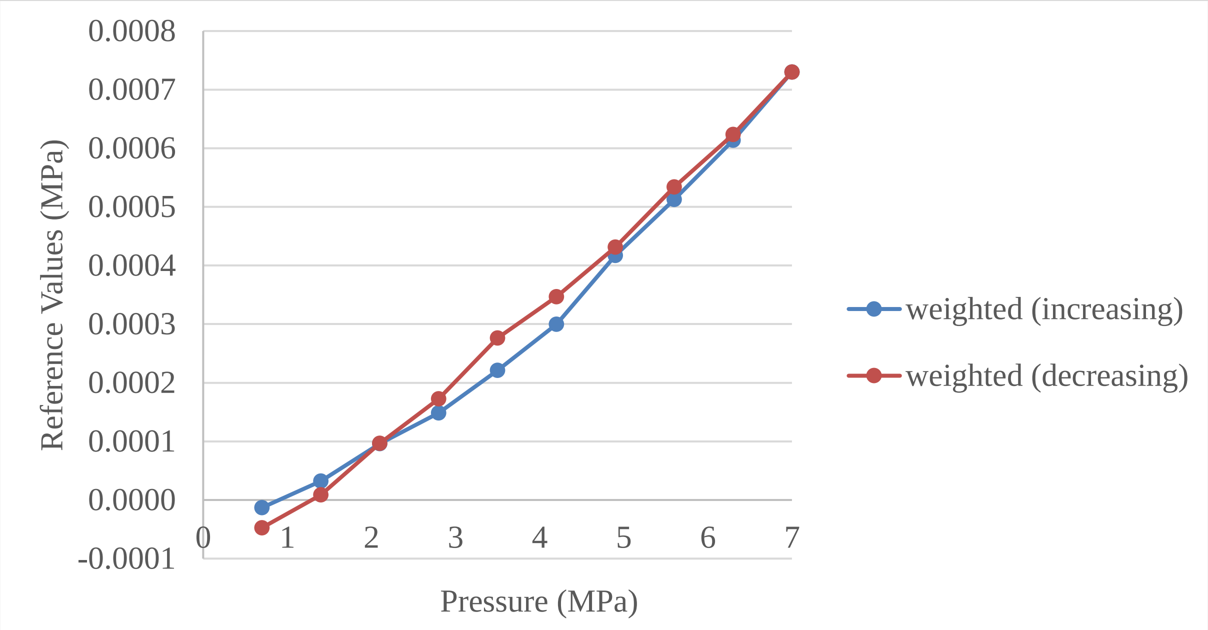


Figure 6. Reference Values

8. Deviations from the reference value

Deviations of participants which is measurement $d_i = (x_i - x_{ref})$ from the reference value with assigned uncertainties $U(d_i)$ are given in Table 9 and Table 10 for each pressure.

$U(d_i)$ is calculated as a combination of the uncertainty of the reference value, the uncertainty of the transfer standard stability and the uncertainty of laboratory deviation. Difference between the deviation of the laboratories and the reference values as given by equation 5 for each pressure and their expanded uncertainties as given by equation 6 and equation 7. This is established by Cox [5].

Equation 5

$$d_i = x_i - x_{\text{ref}}$$

Equation 6

$$u(d_i) = [(u^2(x_i) - u^2(x_{ref}) + u^2(stab)]^{0.5}$$

Equation 7

$$U(d_i) = 2u(d_i)$$

Table 9. Deviations of participants from the reference value with expanded uncertainties for increasing values

Nominal pressure	UME		SASO		EMI	
	di	U(di)	di	U(di)	di	U(di)
(MPa)	(MPa)	(MPa)	(MPa)	(MPa)	(MPa)	(MPa)
0.7	-0.00001	0.00018	0.00000	0.00018	0.00002	0.00020
1.4	0.00001	0.00019	0.00000	0.00018	-0.00004	0.00021
2.1	0.00002	0.00019	-0.00001	0.00019	0.00000	0.00020
2.8	0.00003	0.00019	0.00000	0.00019	-0.00005	0.00021
3.5	0.00002	0.00020	0.00000	0.00019	-0.00003	0.00021
4.2	0.00000	0.00021	0.00001	0.00020	-0.00001	0.00021
4.9	0.00004	0.00021	-0.00003	0.00021	-0.00002	0.00021
5.6	0.00004	0.00021	-0.00003	0.00021	-0.00001	0.00022
6.3	0.00006	0.00022	-0.00004	0.00022	-0.00002	0.00023
7.0	0.00006	0.00022	-0.00004	0.00023	-0.00003	0.00023

Table 10. Deviations of participants from the reference value with expanded uncertainties for decreasing values

Nominal pressure	UME		SASO		EMI	
	di	U(di)	di	U(di)	di	U(di)
(MPa)	(MPa)	(MPa)	(MPa)	(MPa)	(MPa)	(MPa)
0.7	0.00003	0.00018	-0.00001	0.00018	-0.00005	0.00021
1.4	0.00001	0.00019	0.00000	0.00018	-0.00002	0.00021
2.1	0.00002	0.00019	-0.00002	0.00019	0.00000	0.00020
2.8	0.00001	0.00019	-0.00002	0.00019	0.00003	0.00021
3.5	0.00004	0.00020	-0.00004	0.00019	0.00002	0.00022
4.2	0.00006	0.00021	-0.00002	0.00020	-0.00005	0.00022
4.9	0.00003	0.00021	-0.00002	0.00021	-0.00003	0.00022
5.6	0.00005	0.00021	-0.00003	0.00021	-0.00003	0.00022
6.3	0.00006	0.00022	-0.00003	0.00022	-0.00003	0.00023
7.0	0.00007	0.00022	-0.00004	0.00023	-0.00003	0.00023

Deviations from the reference value with assigned uncertainties were given in from Figure 7 to 26.

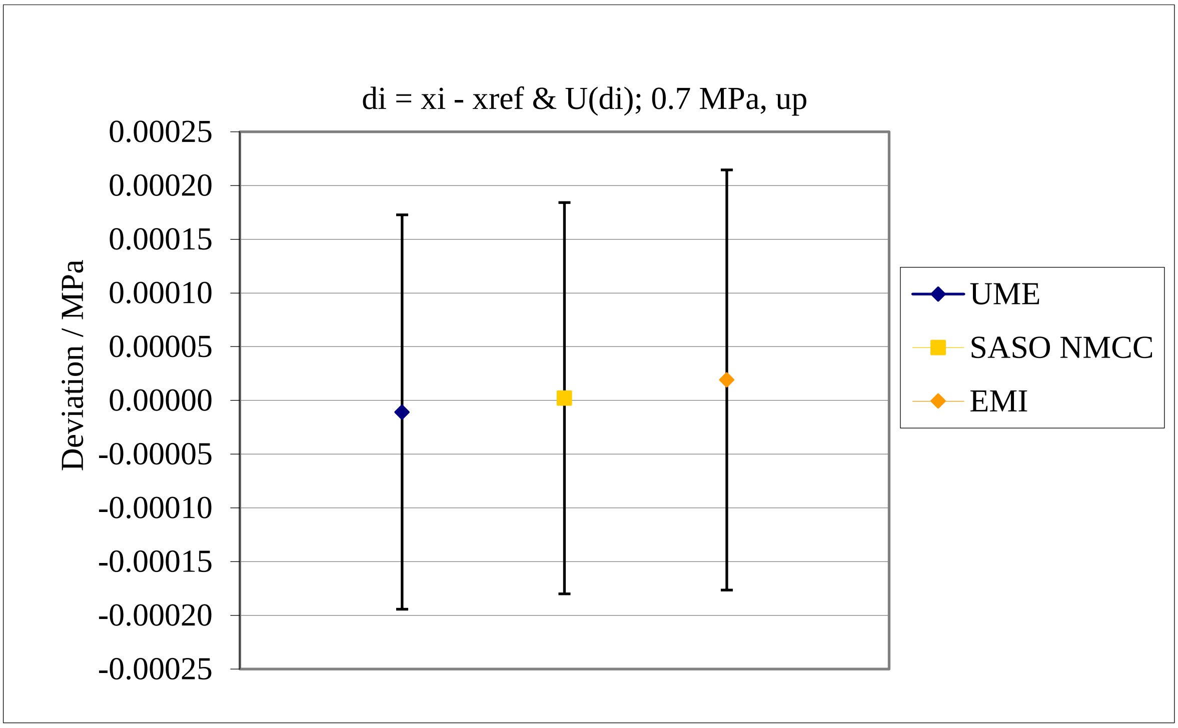


Figure 7. Deviations from the reference value with uncertainties at 0.7 MPa, up

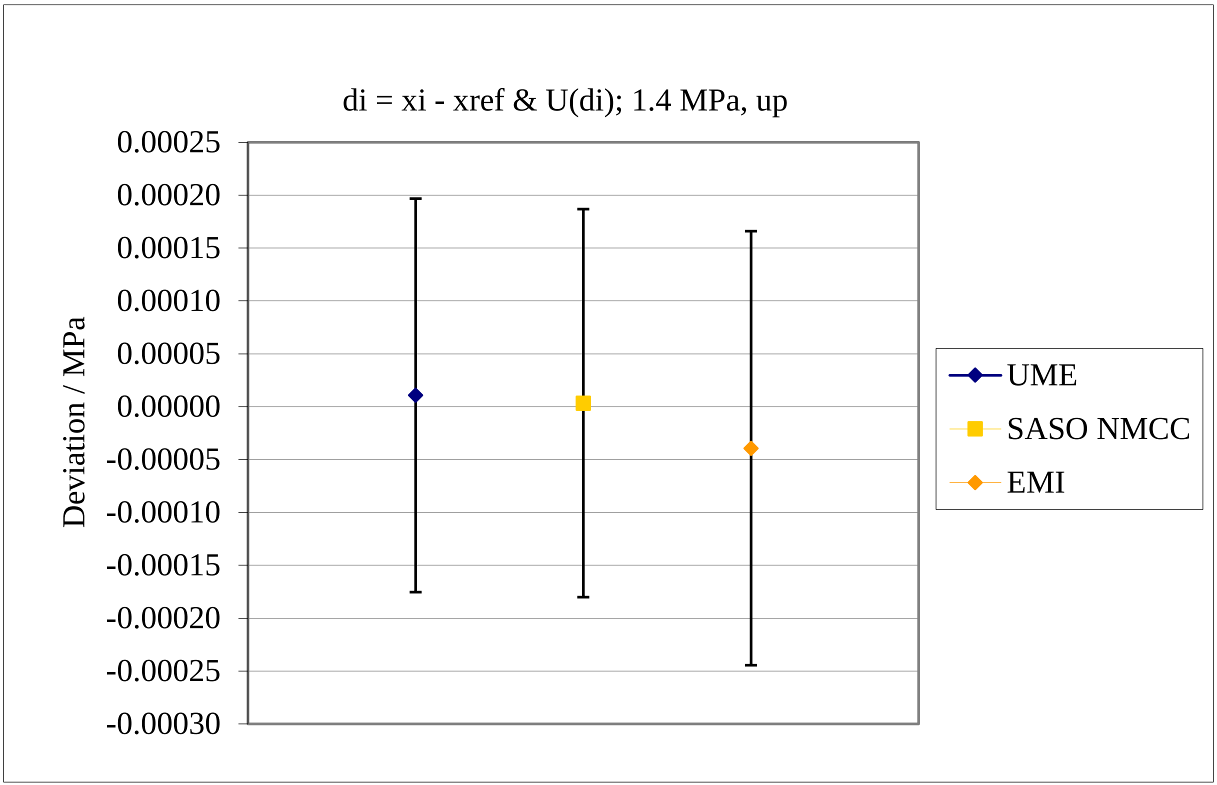


Figure 8. Deviations from the reference value with uncertainties at 1.4 MPa, up

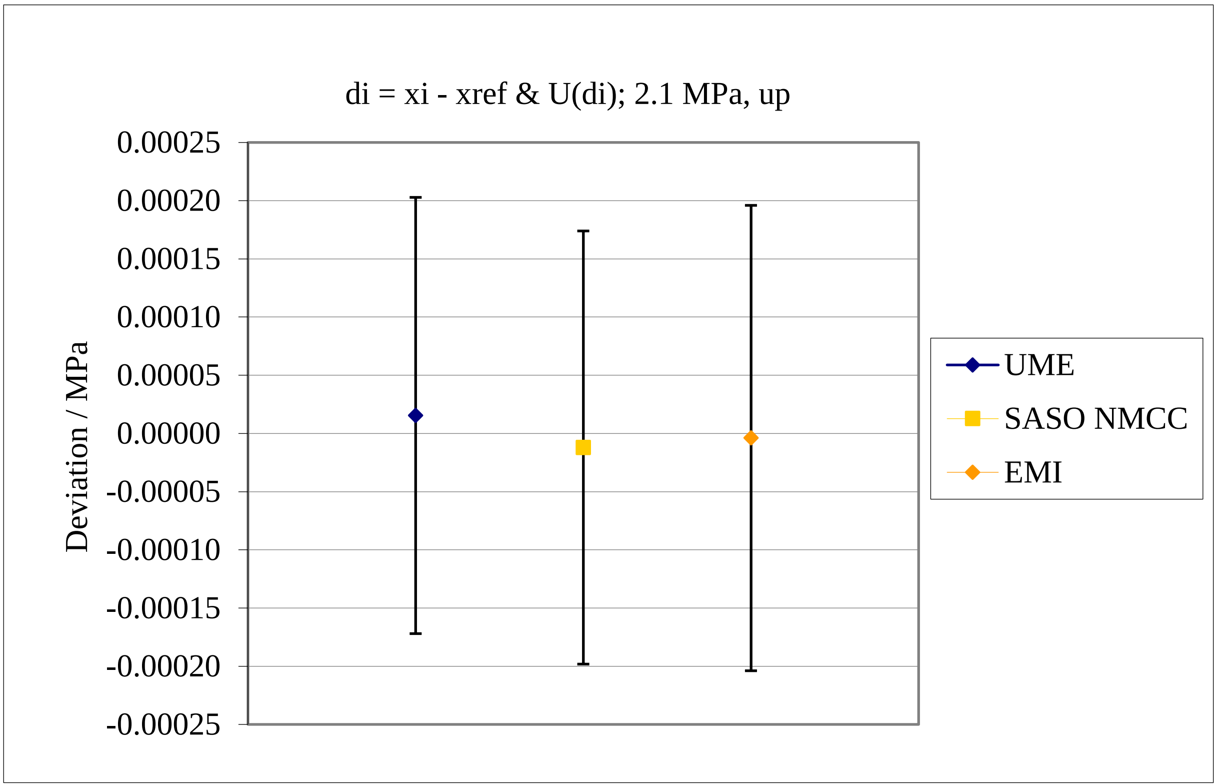


Figure 9. Deviations from the reference value with uncertainties at 2.1 MPa, up

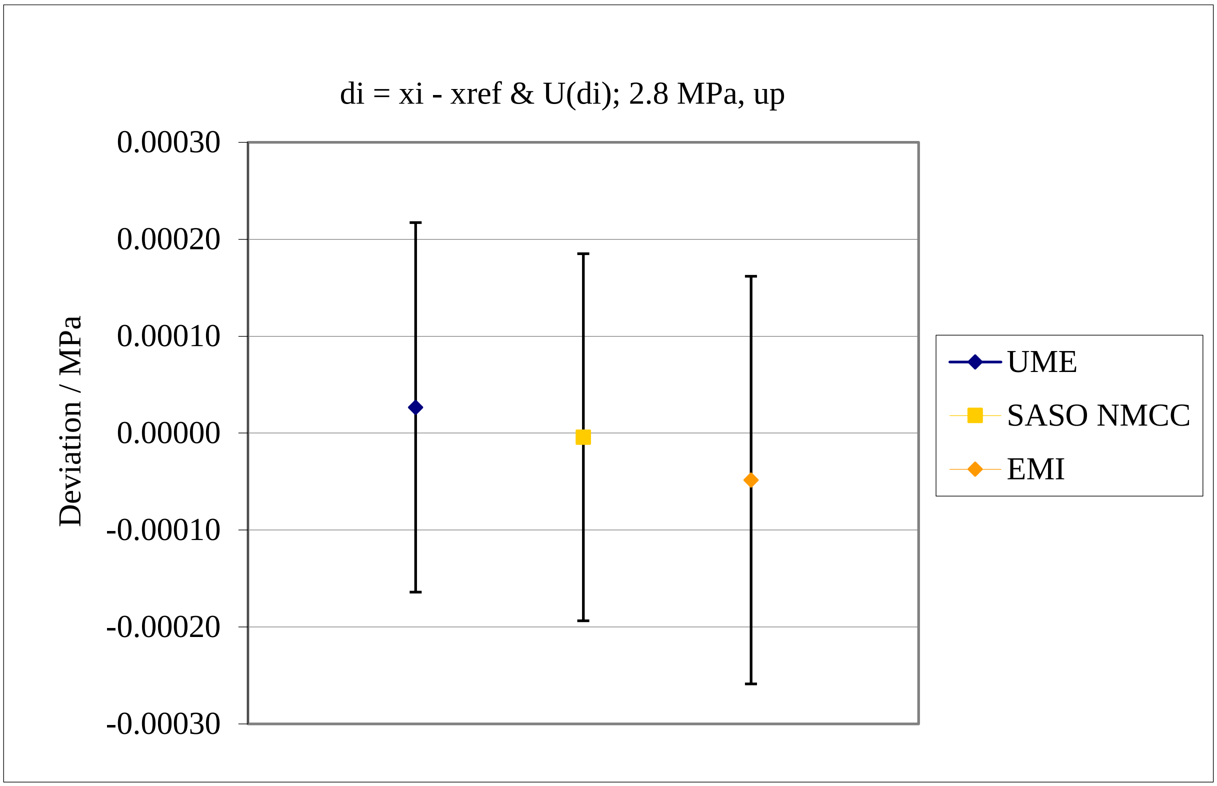


Figure 10. Deviations from the reference value with uncertainties at 2.8 MPa, up

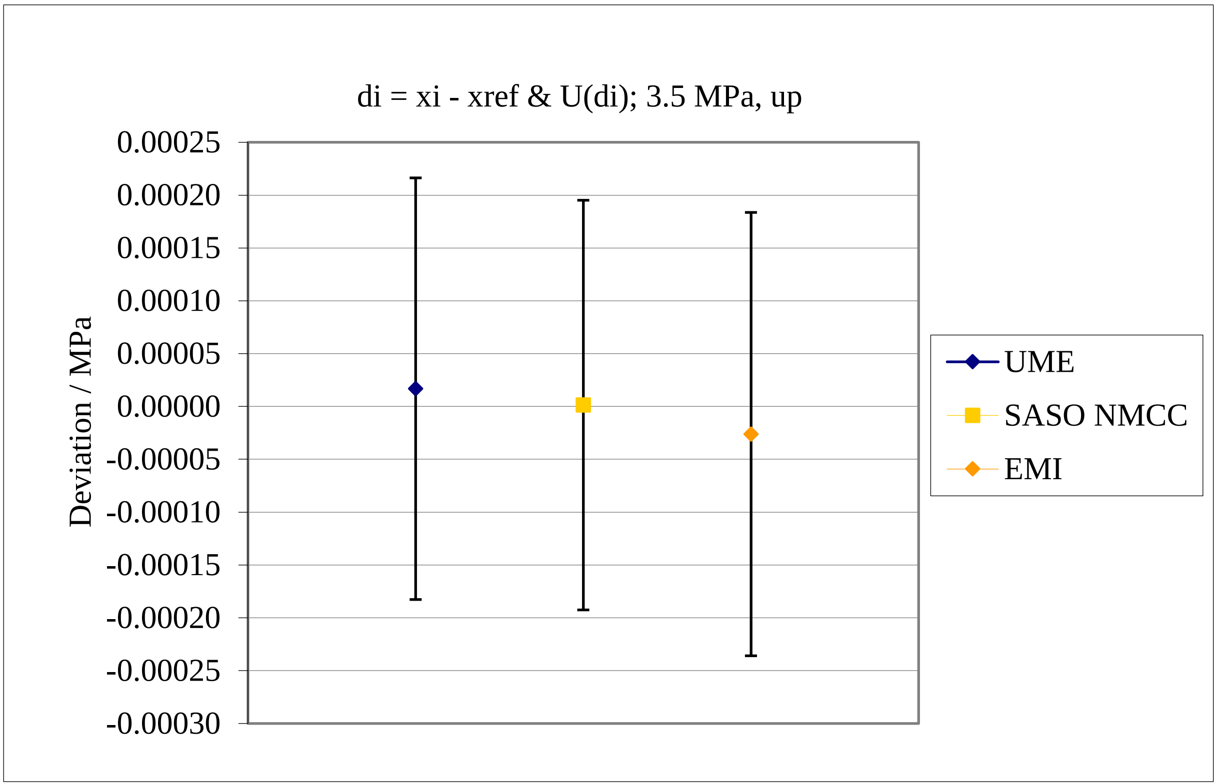


Figure 11. Deviations from the reference value with uncertainties at 3.5 MPa, up

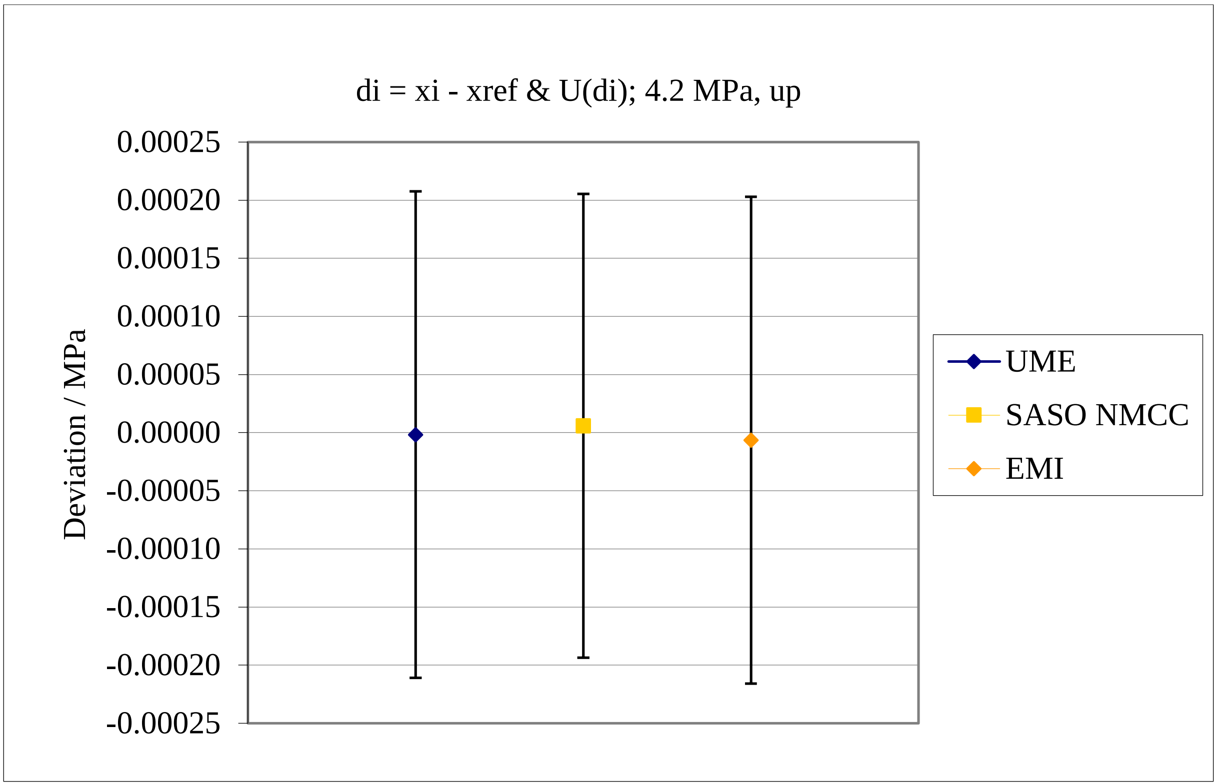


Figure 12. Deviations from the reference value with uncertainties at 4.2 MPa, up

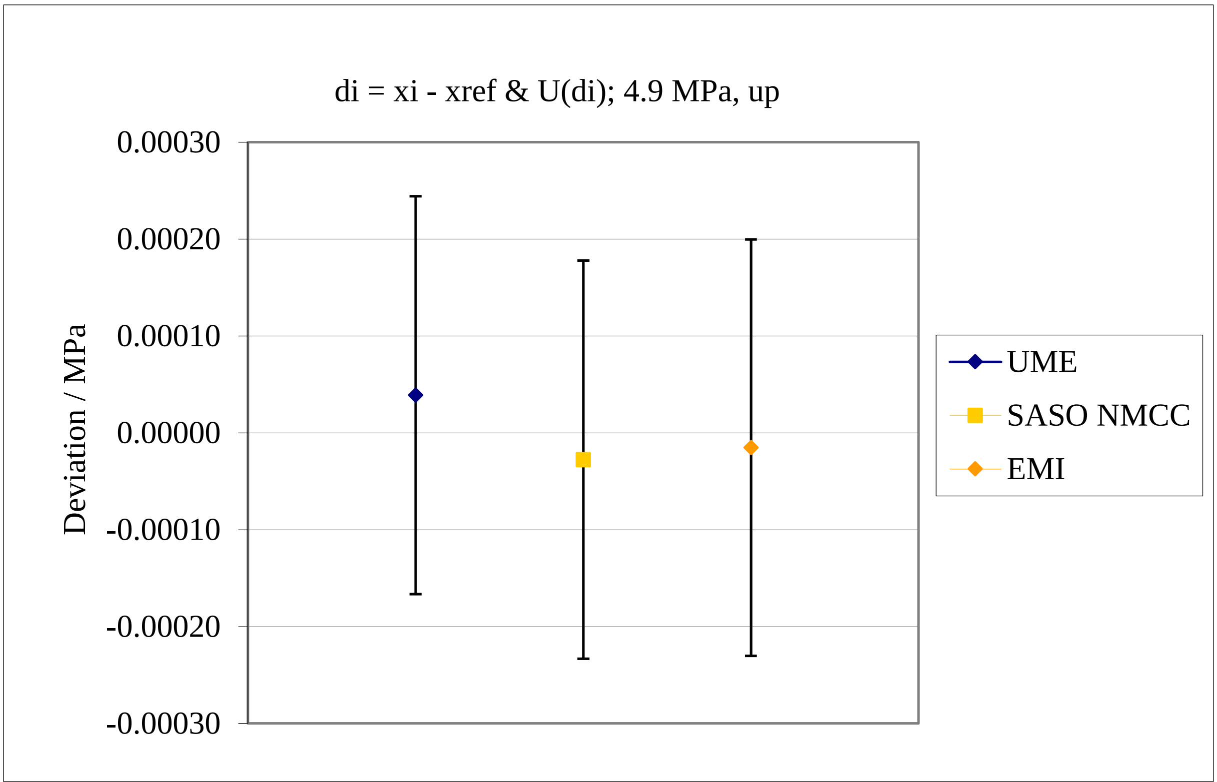


Figure 13. Deviations from the reference value with uncertainties at 4.9 MPa, up

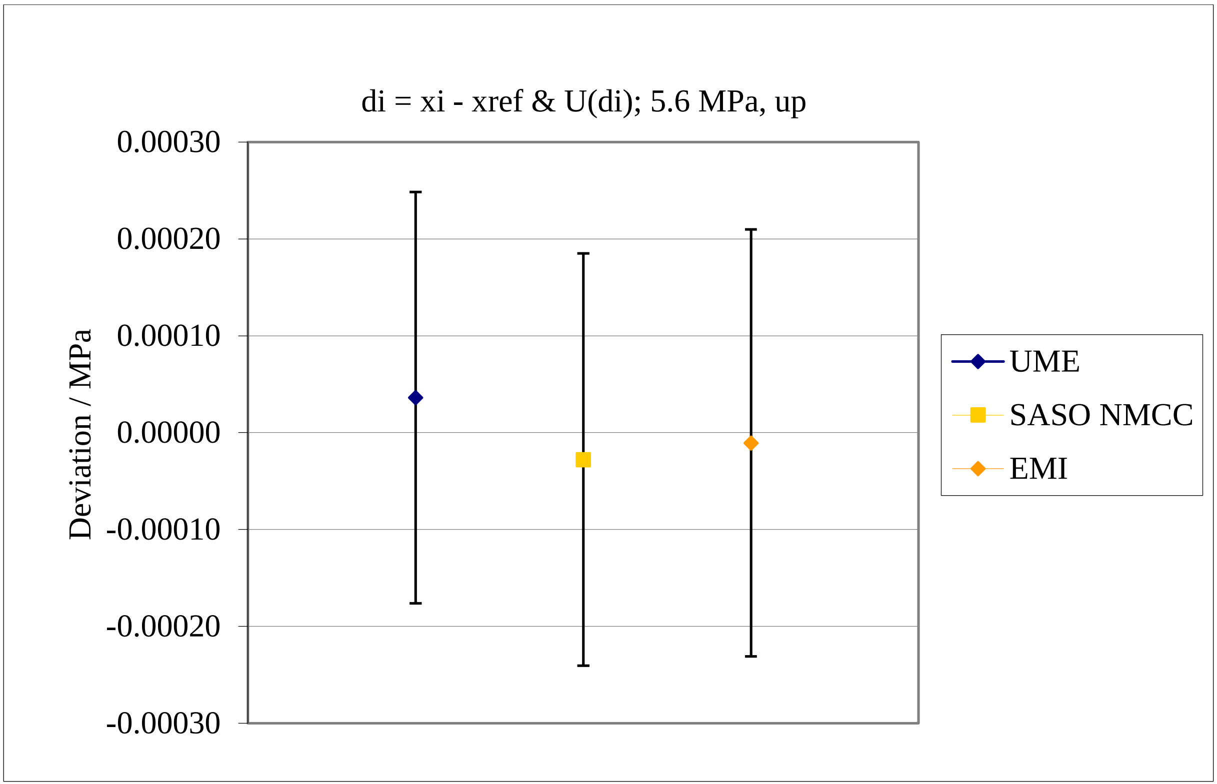


Figure 14. Deviations from the reference value with uncertainties at 5.6 MPa, up

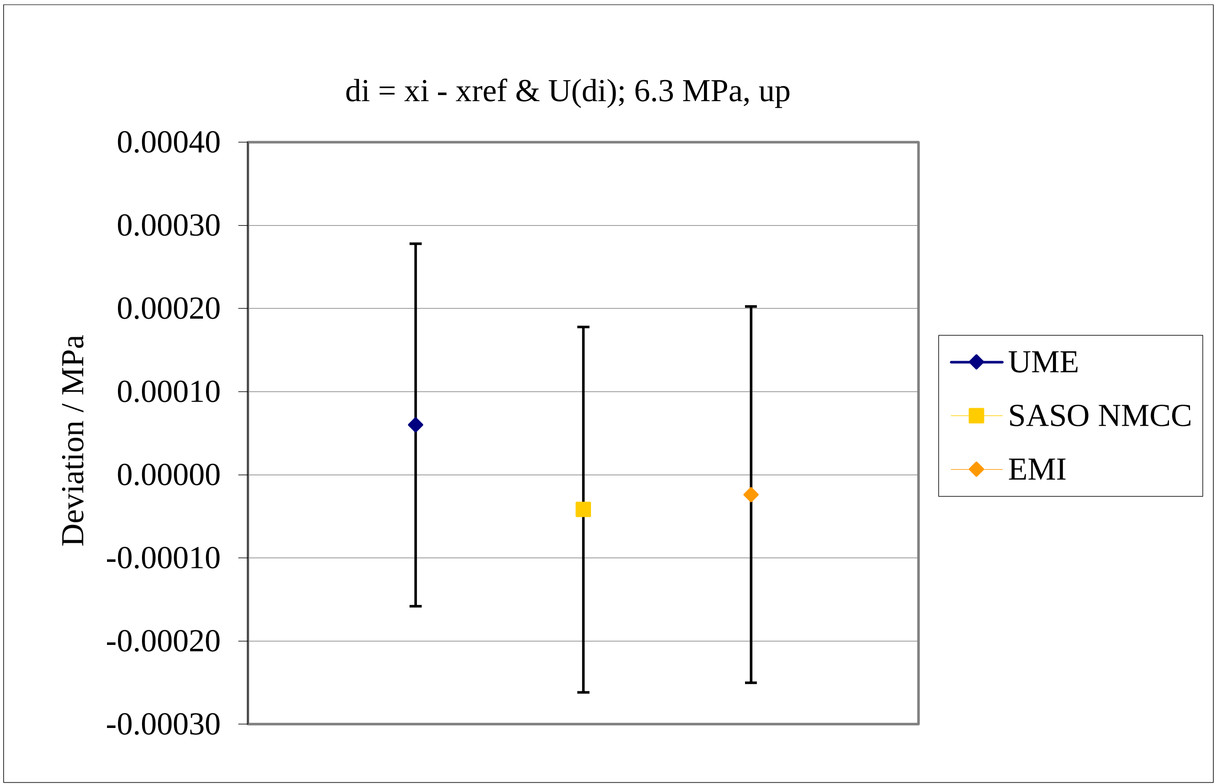


Figure 15. Deviations from the reference value with uncertainties at 6.3 MPa, up

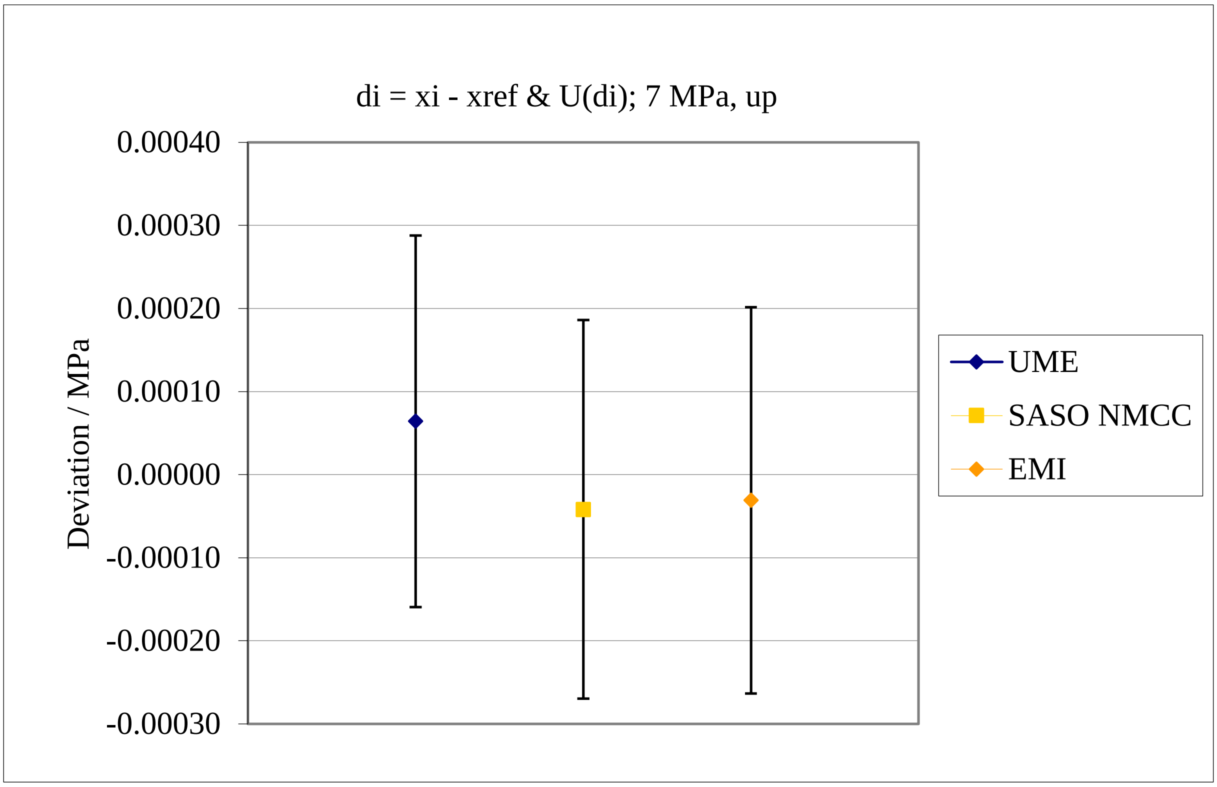


Figure 16. Deviations from the reference value with uncertainties at 7 MPa, up

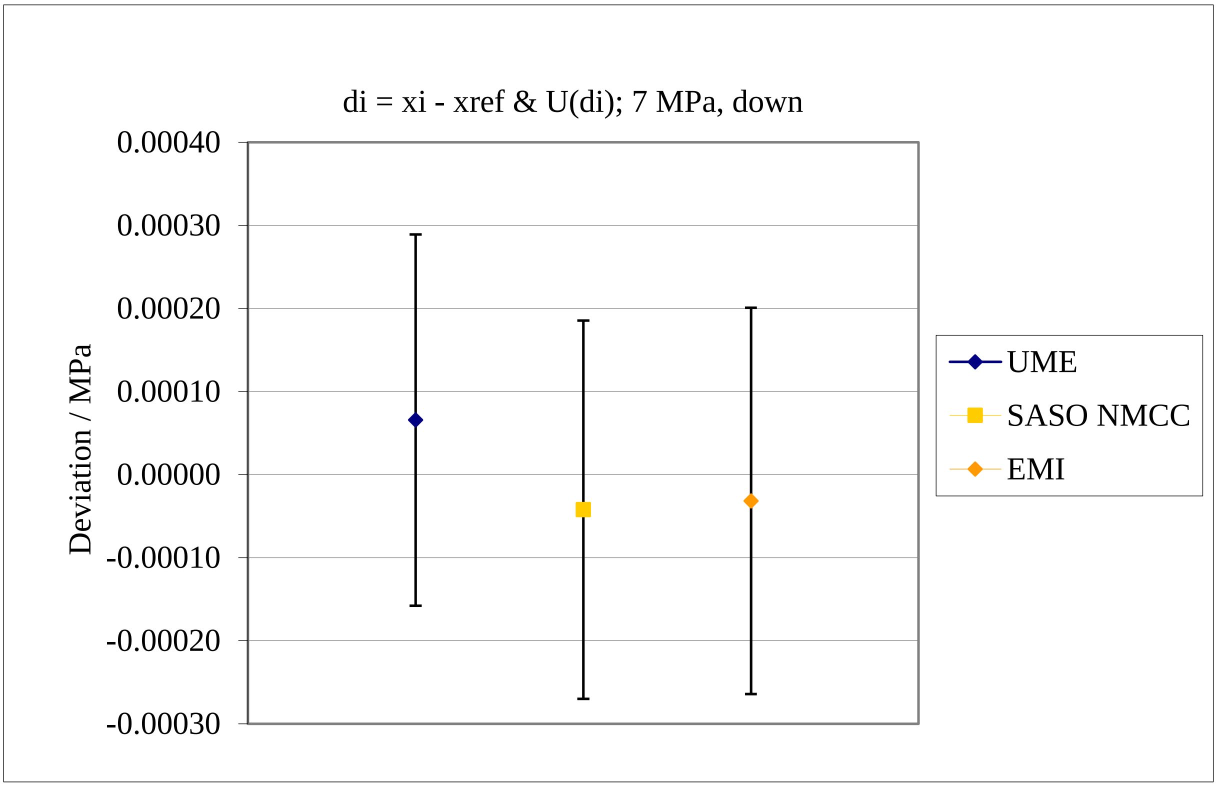


Figure 17. Deviations from the reference value with uncertainties at 7 MPa, down

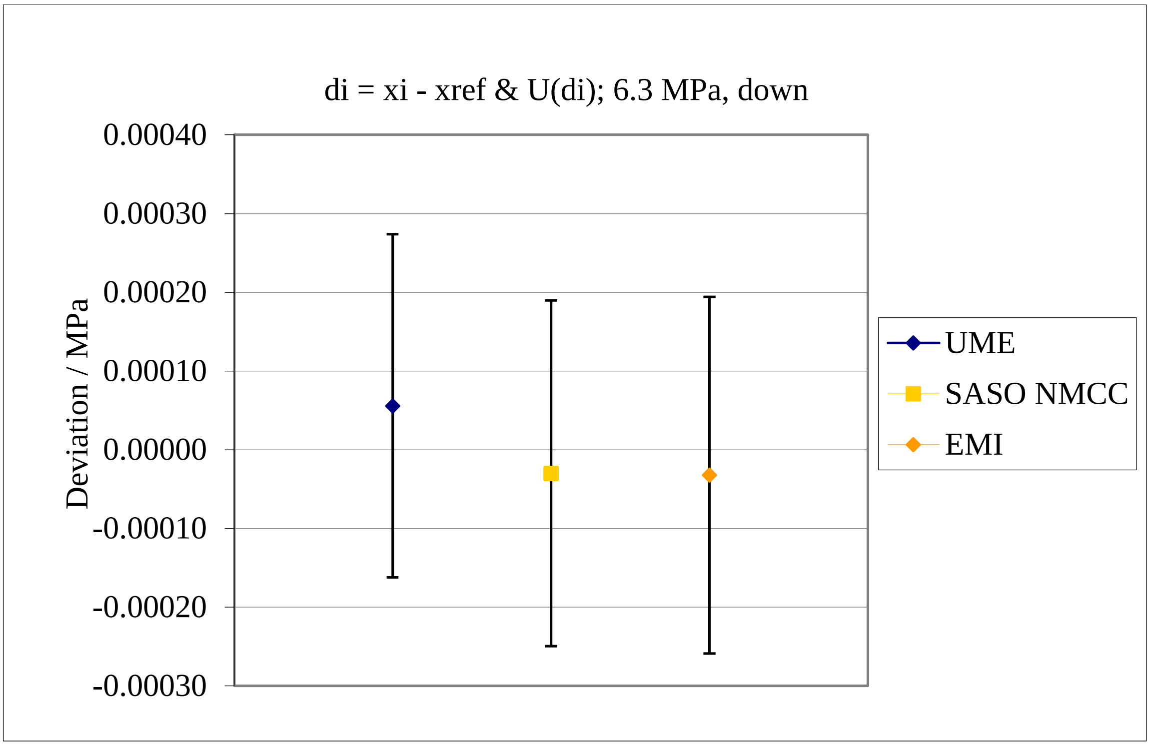


Figure 18. Deviations from the reference value with uncertainties at 6.3 MPa, down

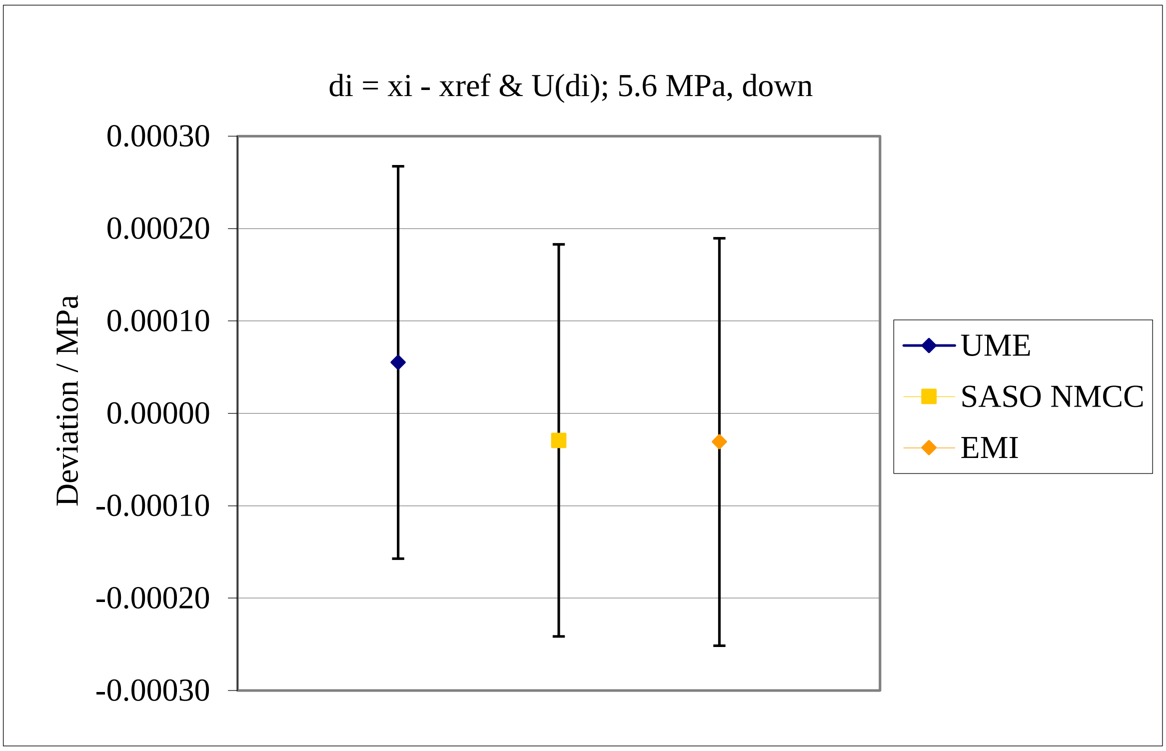


Figure 19. Deviations from the reference value with uncertainties at 5.6 MPa, down

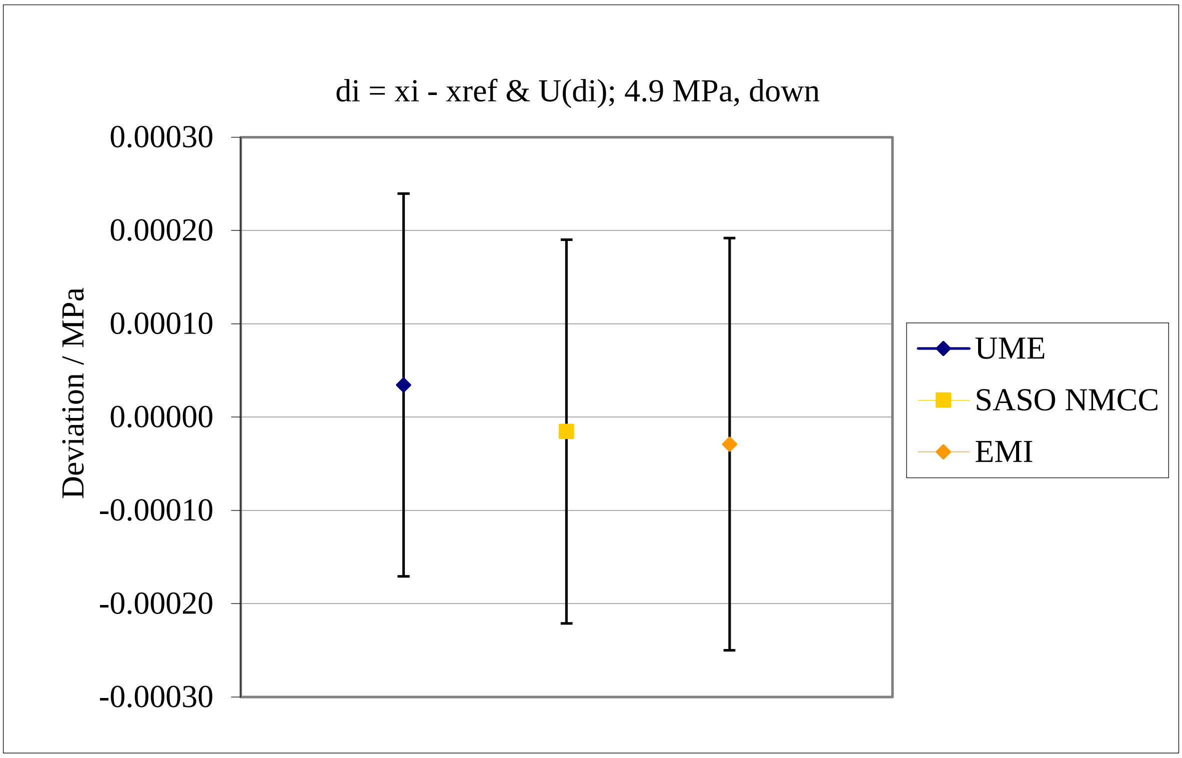


Figure 20. Deviations from the reference value with uncertainties at 4.9 MPa, down

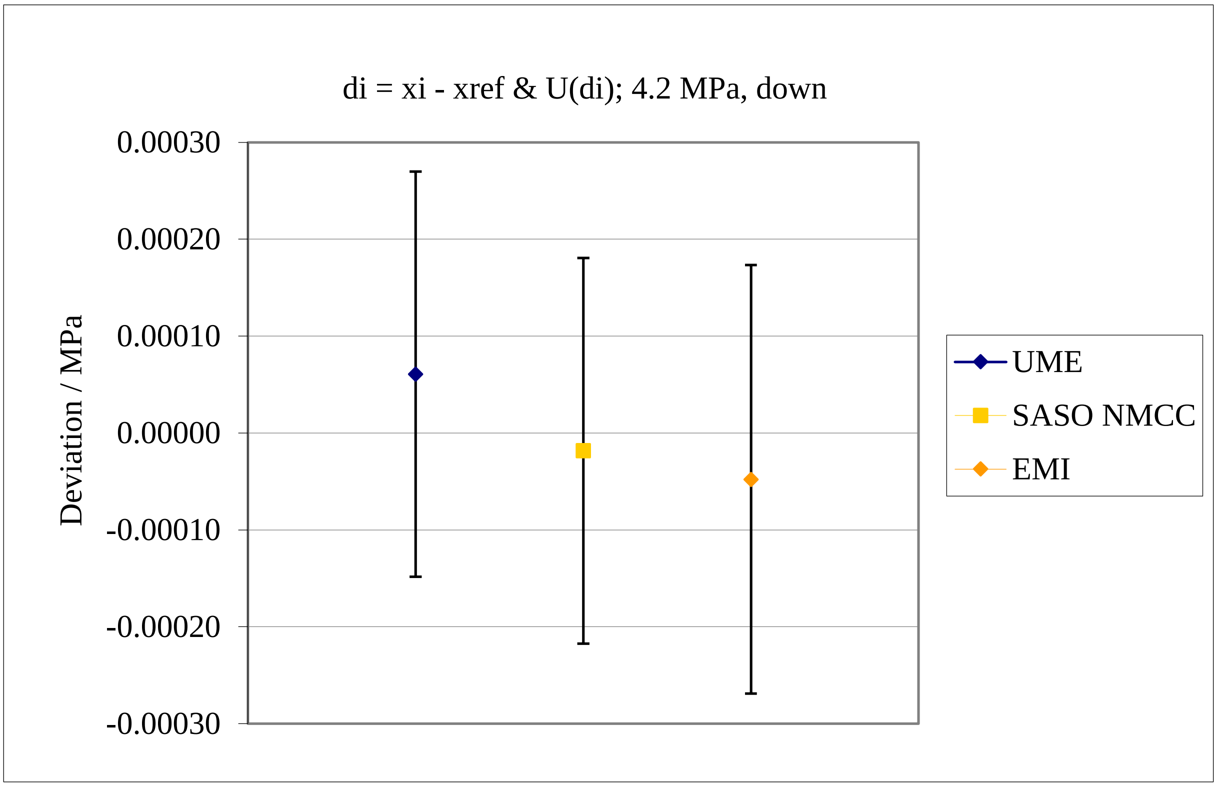


Figure 21. Deviations from the reference value with uncertainties at 4.2 MPa, down

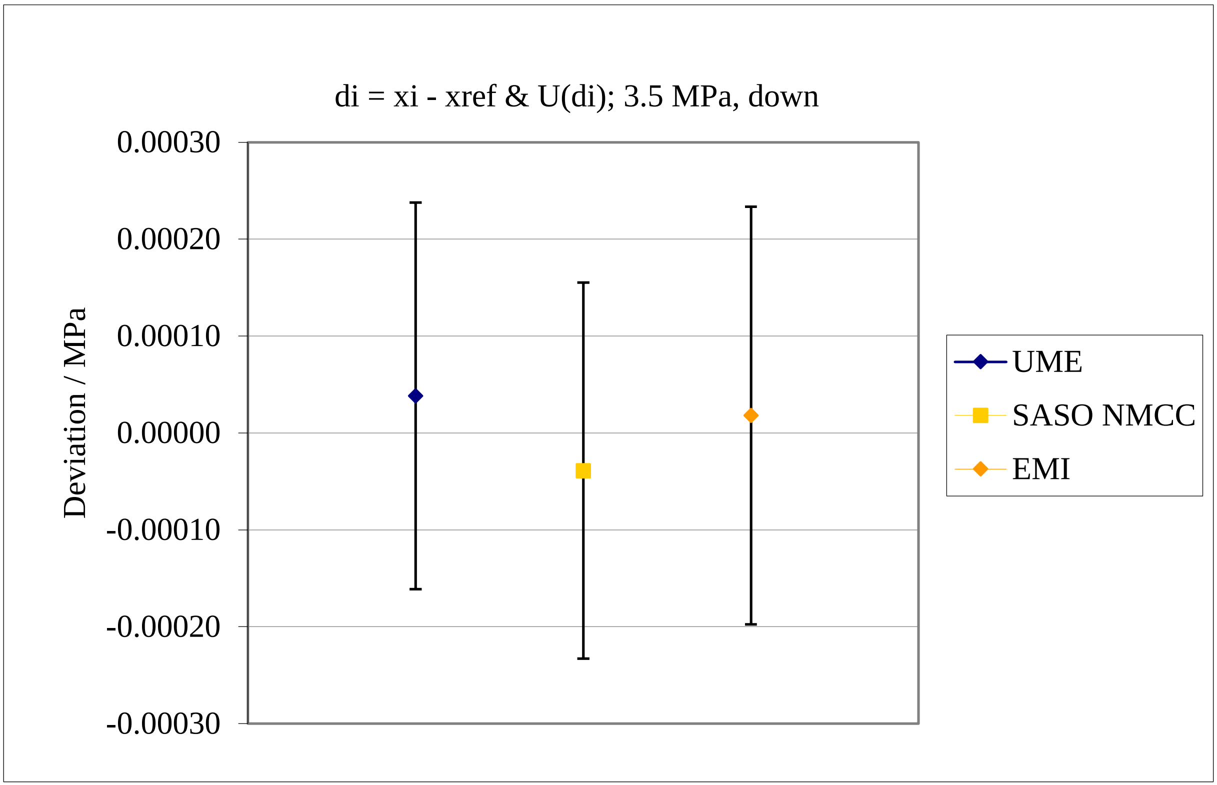


Figure 22. Deviations from the reference value with uncertainties at 3.5 MPa, down

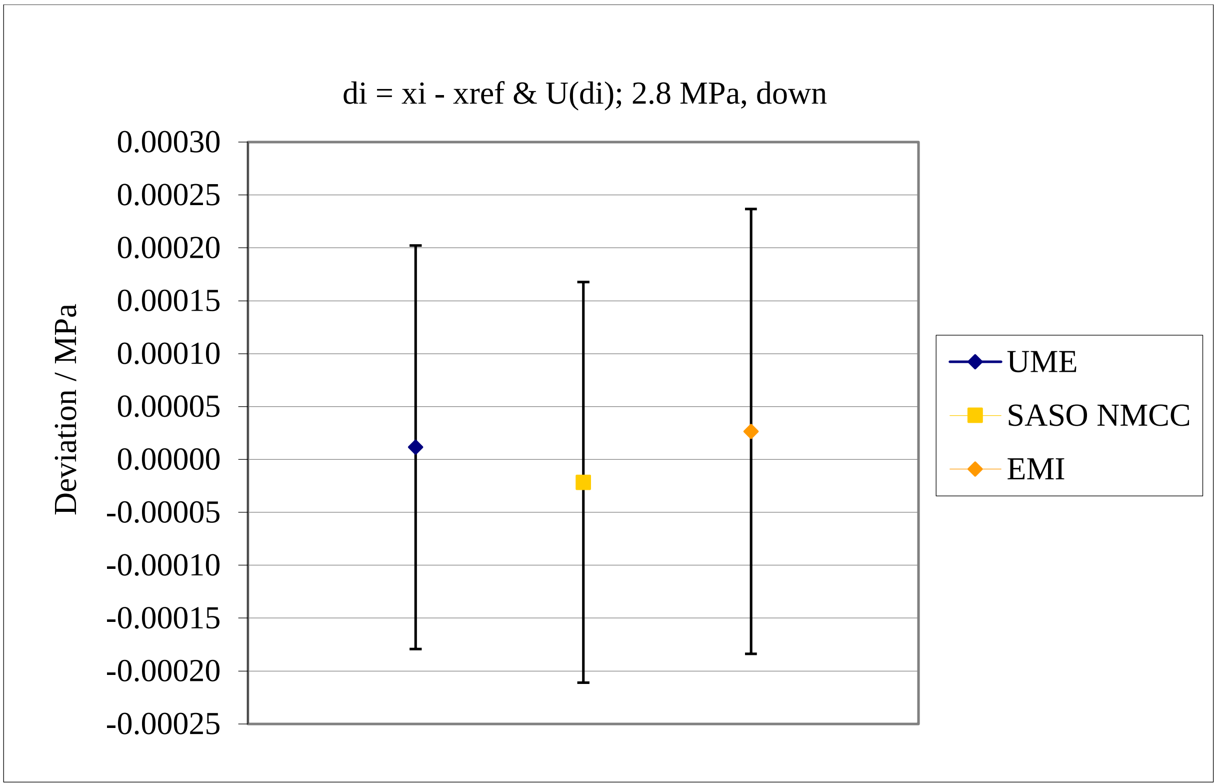


Figure 23. Deviations from the reference value with uncertainties at 2.8 MPa, down

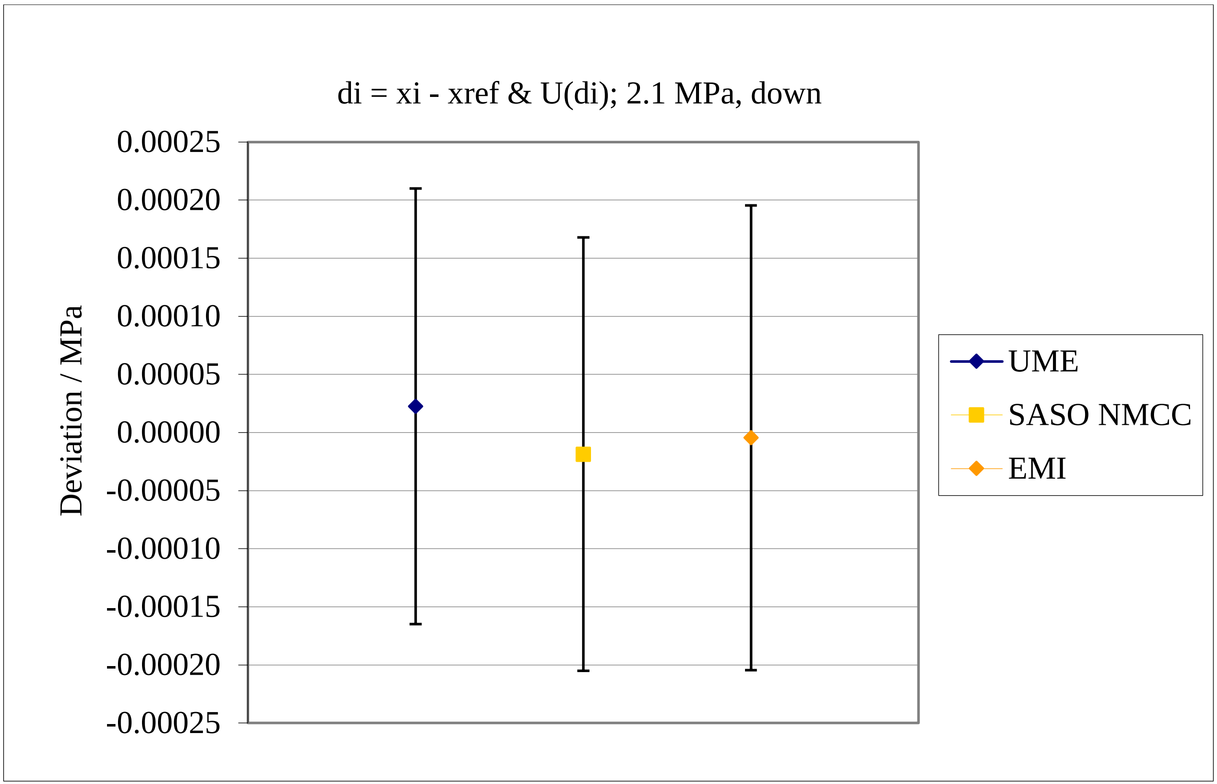


Figure 24. Deviations from the reference value with uncertainties at 2.1 MPa, down

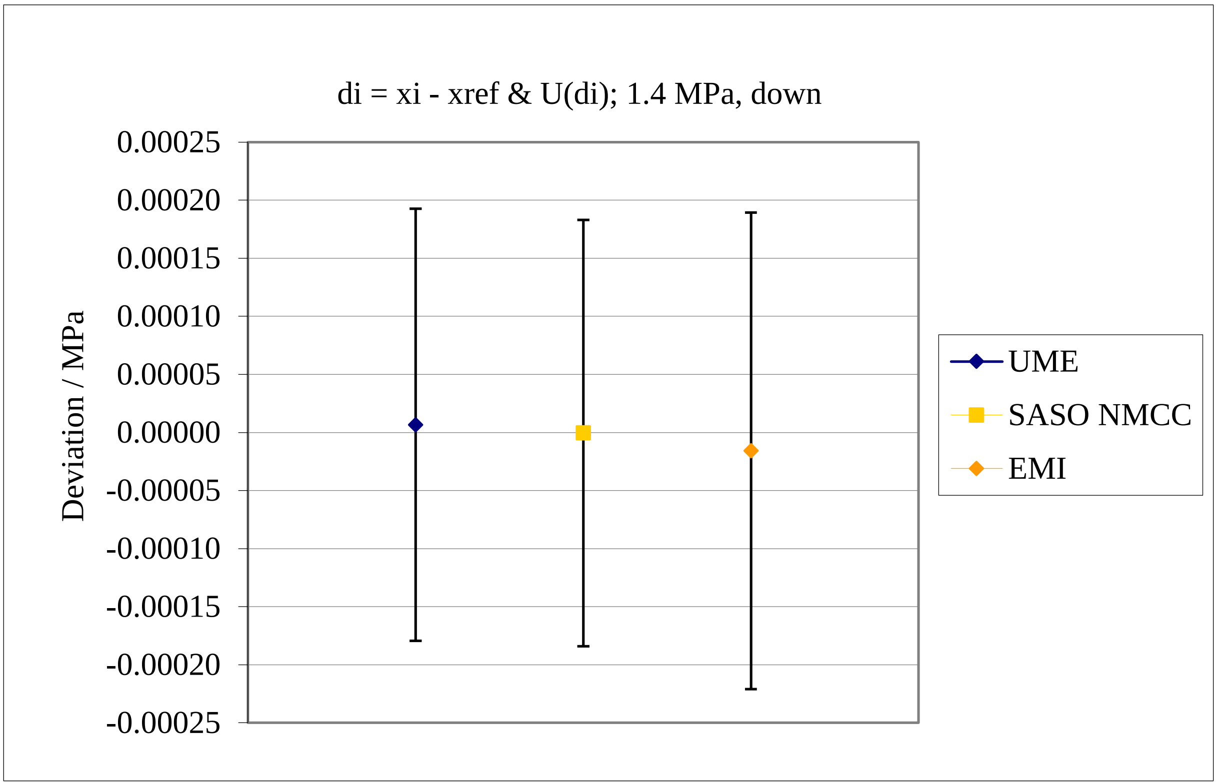


Figure 25. Deviations from the reference value with uncertainties at 1.4 MPa, down

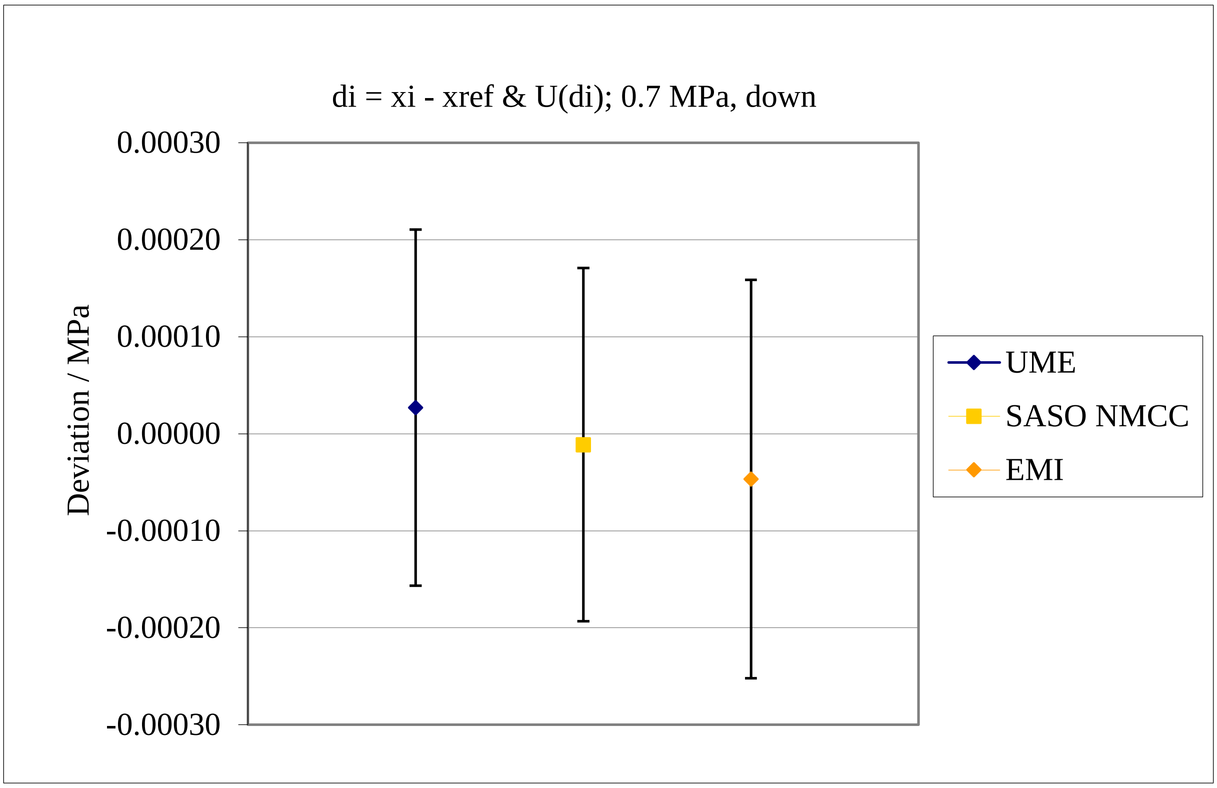


Figure 26. Deviations from the reference value with uncertainties at 0.7 MPa, down

9. Degree of equivalence

The degree of equivalence E_n is presented in Table 11 for each pressure and each laboratory and quantified by equation 8.

Equation 8

$$E_n = \frac{d_i}{U(_{di})}$$

The laboratories results are regarded as equivalent with the reference values if $-1 \leq E_n \leq 1$.

Table 11. The degree of equivalence En for each pressure and each laboratory

Nominal pressure / MPa	Increasing			Decreasing		
	UME	SASO NMCC	EMI	UME	SASO NMCC	EMI
0.7	-0.06	0.01	0.10	0.15	-0.06	-0.23
1.4	0.06	0.02	-0.19	0.04	0.00	-0.08
2.1	0.08	-0.07	-0.02	0.12	-0.10	-0.02
2.8	0.14	-0.02	-0.23	0.06	-0.11	0.13
3.5	0.08	0.01	-0.12	0.19	-0.20	0.08
4.2	-0.01	0.03	-0.03	0.29	-0.09	-0.22
4.9	0.19	-0.13	-0.07	0.17	-0.08	-0.13
5.6	0.17	-0.13	-0.05	0.26	-0.14	-0.14
6.3	0.28	-0.19	-0.11	0.26	-0.14	-0.14
7.0	0.29	-0.18	-0.13	0.29	-0.19	-0.14

10. Conclusion

One hundred per cent reported by the laboratories agreed with the reference values within the expanded uncertainties with a coverage factor k = 2. The comparison shows the performance of direct comparison methods test instrument to reference instrument. Although the results can be considered satisfactory for this comparison, a comparison with a transfer standard with better metrological features in terms of short-term stability and resolution will allow a deeper understanding of this widely used pressure range.

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