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High pressure comparison among seven European national laboratories

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Abstract

An inter-comparison in the high oil pressure range was arranged in 2005 – 2007. The participating laboratories were CMI / Czech Republic, Metas / Switzerland, MIKES / Finland, NMi-VSL / The Netherlands, PTB / Germany, SMD / Belgium and SP / Sweden. The transfer standard was a Desgranges & Huot piston-cylinder unit with a nominal effective area of 1,96 mm^2, mounted in a D&H 5316 balance body. The participants determined the effective area at ten nominal pressures from 50 MPa to 500 MPa in steps of 50 MPa. All the results were in a good agreement with the reference values, calculated as weighted means of the results from the four primary level laboratories. The results fully support the uncertainties claimed in the CMC tables of the participants.

1. Introduction

A comparison on high pressures between MIKES, Metas, NMi-VSL and CMI was started in summer 2005. In autumn 2005 PTB was asked to join in for better reference values. Later in 2006 SMD and SP joined in. The comparison was registered as EUROMET Project number 881. The measurements were completed in January 2007. The results were reported in detail in Reference [1].

Previous EUROMET comparison in the range 50 MPa to 500 MPa was arranged in 1993 – 1995 (EUROMET Project number 45), coordinated by LNE, France [2].

1.1 Participants

1.1.1 Primary pressure laboratories

Physikalisch-Technische Bundesanstalt (PTB), Germany, is one of the leading pressure laboratories in the world. PTB has participated in several CCM and regional key comparisons in the high pressure range. Two piston-cylinder units were used as standards in the present comparison: the first one with a nominal effective area of 8,4 mm^2, manufactured by Ruska, and the second with a nominal effective area of 4,9 mm^2, by DH-Budenberg.

Federal Office of Metrology (Metas) is the national metrology institute of Switzerland. Their standards used in this comparison were two piston cylinder units manufactured by Desgranges & Huot: up to 400 MPa one with a nominal

effective area of 2 mm^2 and another unit with a nominal area of 4,9 mm^2 with a pressure multiplier above 400 MPa.

Czech Metrology Institute (CMI) used a piston cylinder unit with a nominal effective area of 2 mm^2, manufactured by DH Instruments.

NMi-Van Swinden Laboratorium B.V (NMi-VSL), the Netherlands, used a Desgranges & Huot piston cylinder assembly with a nominal effective area of 2 mm^2.

1.1.2   Secondary level laboratories

The pressure laboratories of Belgium, Service de la Métrologie (SMD), Finland, Centre for Metrology and Accreditation (MIKES) and SP Technical Research Institute of Sweden (SP) are all traceable to Laboratoire National de Métrologie et d'Essais (LNE), France. They all used a Desgranges & Huot piston cylinder assembly with a nominal effective area of 2 mm^2.

1.1.3   Measurement schedule

The measurements were made according to the following schedule:
MIKES 1   Early July 2005
Metas   End of July 2005
CMI   Early December 2005
PTB   Early February 2006
MIKES 2   End of May 2006
SMD   Early July 2006
NMi-VSL   End of July 2006
SP   End of August 2006
MIKES 3   Early January 2007

1.2 Transfer Standard and Measurement Instructions

The transfer standard was a DH-Budenberg piston-cylinder assembly No. 9080 with a nominal effective area of 2 mm^2. The piston-cylinder unit was mounted in a Desgranges & Huot pressure balance body model 5316 No. 5130. The transfer standard and the balance body with a load carrying bell No. 3154 were provided by MIKES. Each laboratory used its own weights set on the transfer standard.

The piston-cylinder unit used as the transfer standard was found to be not so stable as expected. The unit was received from the manufacturer in April 2005. Its effective area was determined at MIKES for the first time in May 2005. Further measurements were made at MIKES in July - August 2005, May 2006, September – October 2006 and finally in January 2007. The results showed an increase in the effective area with time. The drift was found to be practically independent of the nominal pressure. A linear drift was assumed for simplicity and the best fitting straight line was calculated for the result points. An average drift rate was 0,000093 mm^2/year, with an uncertainty of 0,000022 mm^2/year (k = 2)

The measurement instructions were similar to those of EUROMET 45 [2] in 1993 – 95, and very short and straightforward: The participants were asked to determine the effective area of the transfer standard at the nominal pressures

from 50 MPa to 500 MPa in steps of 50 MPa at 20°C. Further, as supplementary information they were asked to determine the effective area at null pressure and at 20°C plus the pressure distortion coefficient. The number of measurement cycles was left to be decided by each laboratory.

As background information the participants were asked to give a description of the laboratory standards and their traceability, measurement method and conditions and other information relevant to the results.

2. Results on The Effective Area

The reference values for the comparison were calculated as weighted means for the effective areas at each nominal pressure in the range from 50 MPa to 500 MPa. Only the results from the primary level laboratories were included in calculating the weighted means.

As the first step the results of each laboratory were corrected for drift to correspond the situation of the 1st of January 2006. This date was selected because two of the primary laboratories made their measurements before and two after that date. The measurements at PTB were made in early February, and the corrections to their results with the lowest uncertainties were small.

The procedure applied for the drift corrections leads to reference values that are the same for all participants, the uncertainty values given by the laboratories remain unchanged, but the uncertainties of the reference values increase with the time interval from the date of the measurements to the reference date. The uncertainties of the drift corrections were added to the original reference value uncertainties as the square root of the sum of squares.

Figures 1 to 3 illustrate the procedure. The original and corrected laboratory results are shown, as well as the uncertainties (k = 2) and the deviations from the reference values. A summary of the relative deviations from the reference values are shown in Fig. 4.
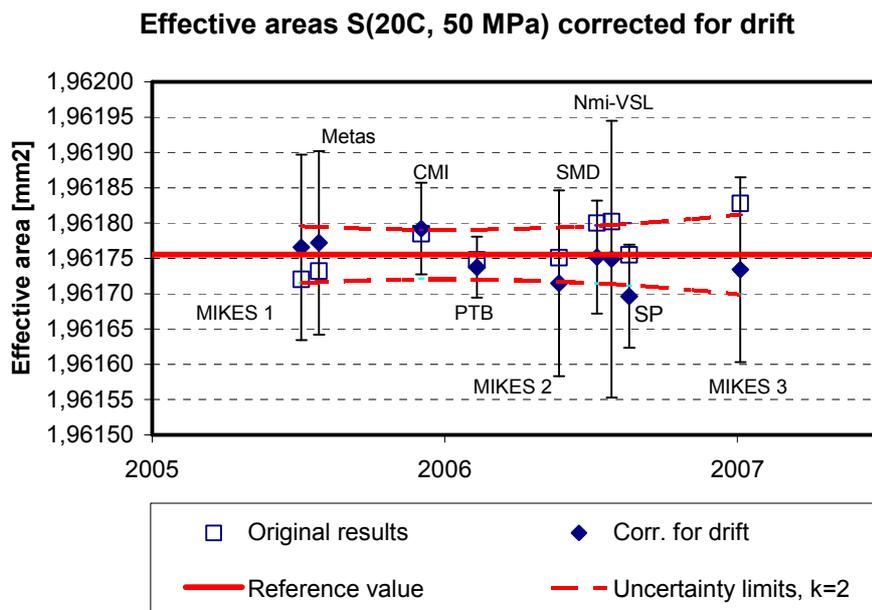
Effective areas S(20C, 50 MPa) corrected for drift

Fig. 1. Results at nominal pressure 50 MPa

Effective areas S(20C, 250 MPa), corrected for drift
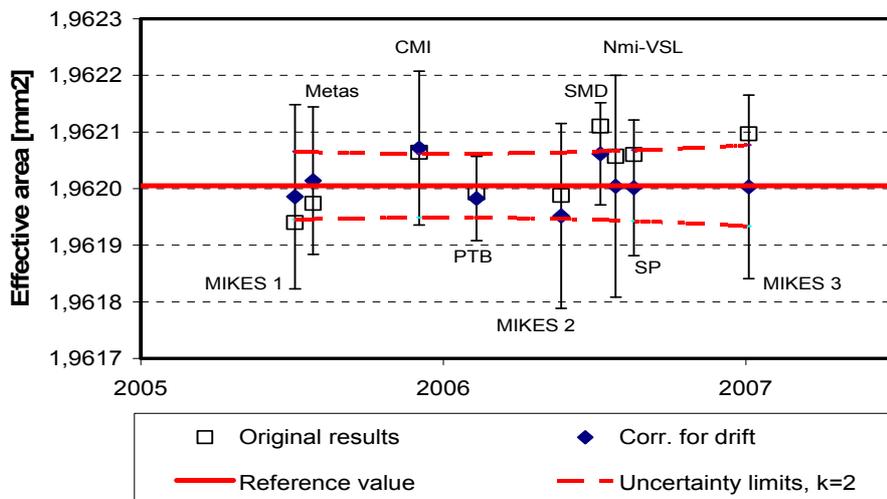

Fig. 2. Results at nominal pressure 250 MPa

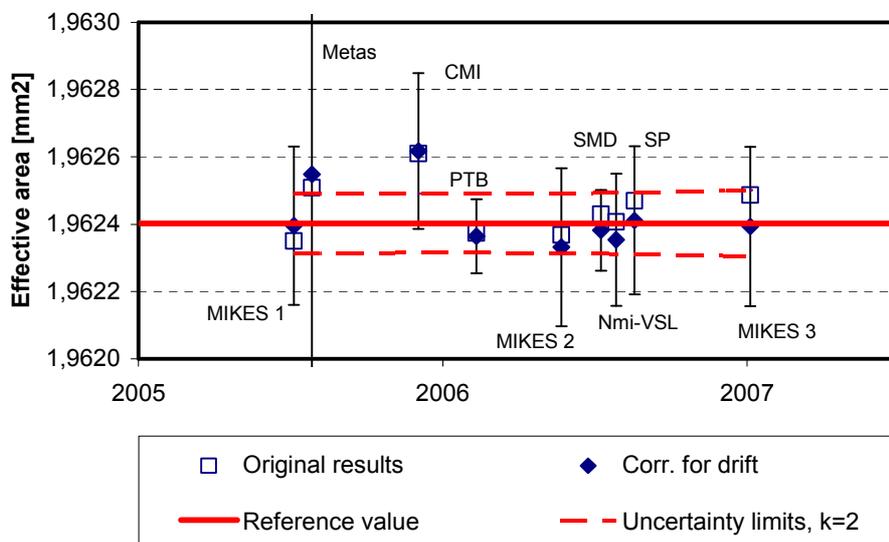**Effective areas S(20C, 500 MPa) corrected for drift**

Fig. 3. Results at nominal pressure 500 MPa

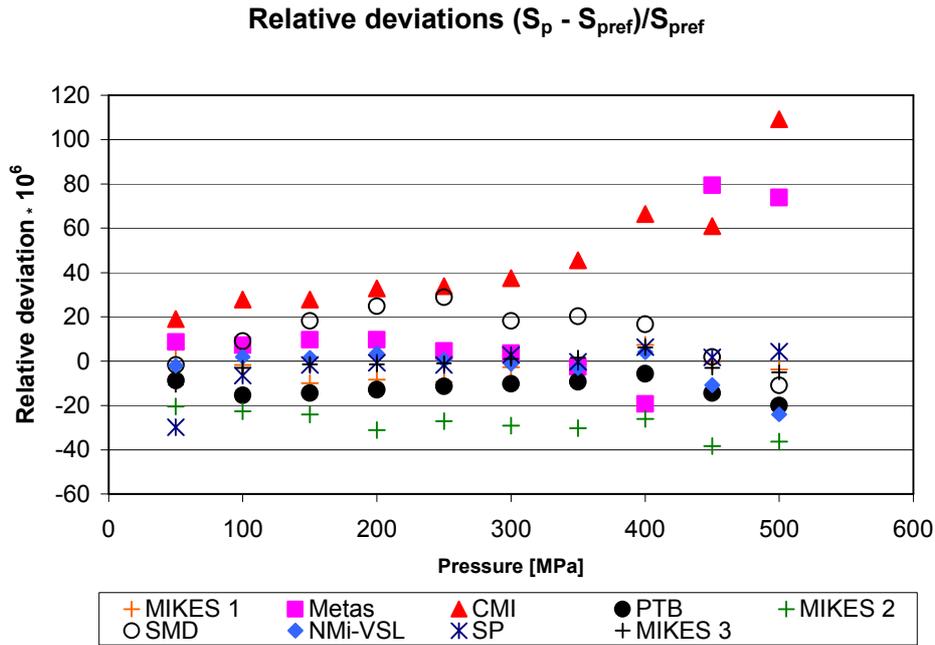**Relative deviations (S_p - S_{pref})/S_{pref}**

Fig. 4. Results $S_{p,20C}$ as relative deviations from the reference values $S_{p,20C,ref}$

2.1 Equivalence With Reference Values

The degree of equivalence of a laboratory result and the reference value is often expressed as normalised error E_n where the difference of these two values is divided by the square root of the sum of the squared uncertainties (with coverage factor k = 2).

A summary of the results as E_n - values is shown in Fig.5. All the results from the participating laboratories are equivalent with the reference values as the E_n-values are all in the range from -1,00 to +1,00.
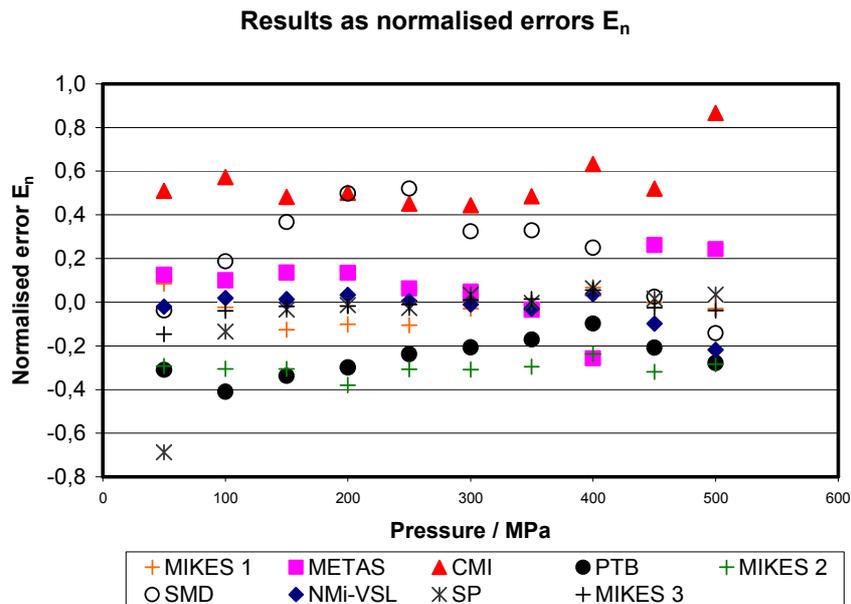
Results as normalised errors E_n

Fig. 5. Summary of normalised errors E_n in the range 50 MPa to 500 MPa

2.2 Results on Effective Area S_0 and Pressure Distortion Coefficient λ

The results of the effective area S_0 at 20°C and null pressure and the pressure distortion coefficient λ were supplementary information for the comparison. However, these results are interesting because these quantities are often reported in calibration certificates for pressure balances. $S_{0,20C}$ and the pressure distortion coefficient λ are typically calculated by fitting a straight line to the result points obtained on higher pressures.

Again, for the comparison the effective area results from each laboratory were corrected for the drift in the transfer standard to correspond the 1st of January 2006. The uncertainty of the drift correction for each laboratory and the uncertainties of the reference values were combined as the square root of the sum of the squares.

No correction was made on the values for the pressure distortion coefficient λ as there were practically no changes.

The reference values for the effective area S_0 at 20°C and null pressure for the comparison were calculated as weighted averages, based on the results from the laboratories of primary level. The reference values and the results from the participating laboratories are illustrated in Fig. 6. For the pressure distortion coefficient λ the results are presented and Fig. 7.
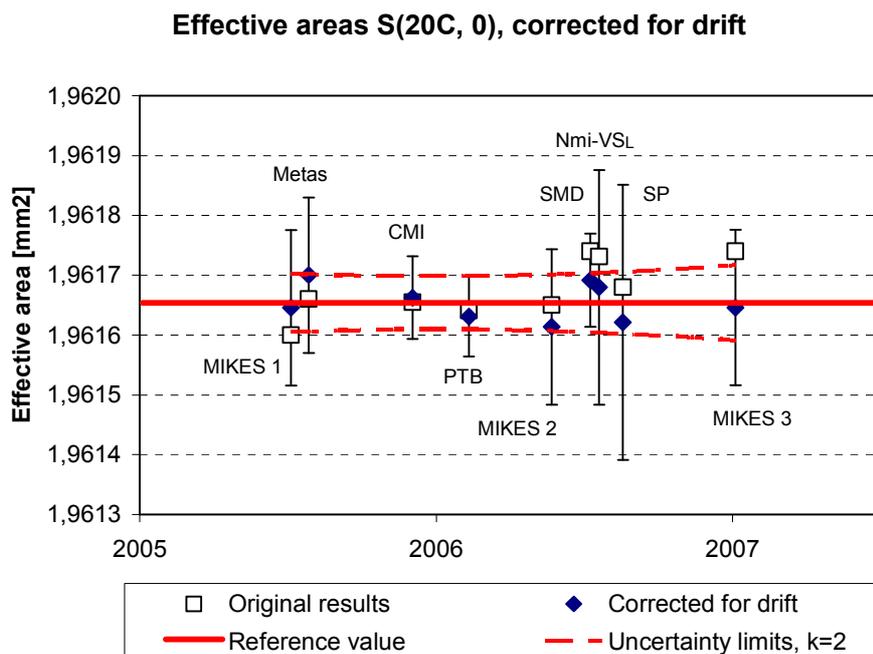
Effective areas S(20C, 0), corrected for drift

Fig. 6. The results at nominal pressure $p = 0$

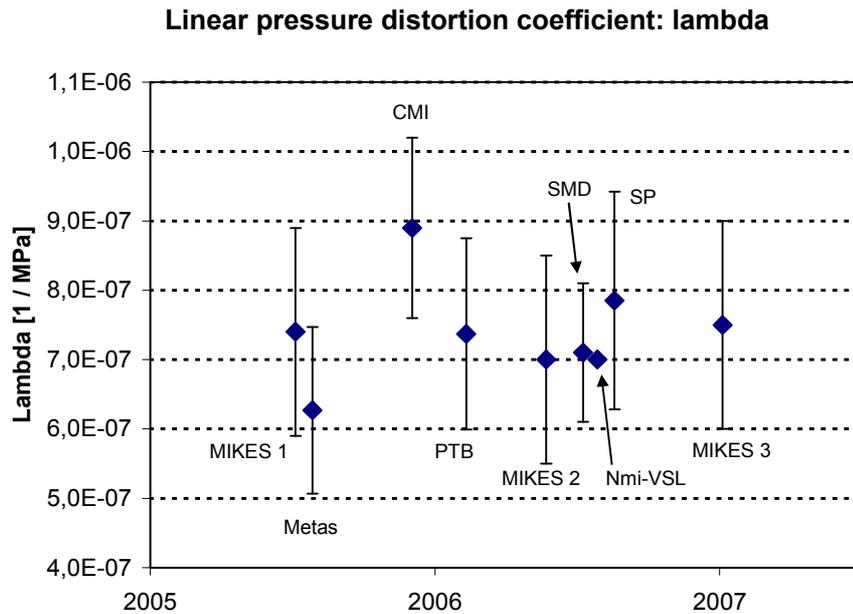**Linear pressure distortion coefficient: lambda**

Fig. 7. The results on the pressure distortion coefficient λ. The uncertainty value of the NMi-VSL result consists of the uncertainty from calculating the regression line only.

The participating laboratories seem to have various approaches in giving the uncertainties for S_0 and λ.

Obviously the combined uncertainties of S_0 and λ from each laboratory should be high enough to make an envelope to the uncertainty bars of the results obtained at each nominal pressure.

The uncertainty for λ given by NMi-VSL was only the (very small) uncertainty from calculating the regression line. The physical uncertainty of λ corresponding to the highest nominal pressure is included in the uncertainty of S_0. The results are consistent with the results obtained separately at each nominal pressure but obviously the uncertainties are overestimated at lower pressures.

SP gave a large uncertainty for S_0 similar to NMi-VSL in combination with an additional realistic uncertainty for λ. The uncertainties for the effective area based on S_0 and λ are overestimated at all nominal pressures. On the other hand the combined uncertainties from CMI and MIKES seemed to be slightly too low.

Fig. 8 shows a summary of the expanded relative uncertainties based on the uncertainties of S_0 and λ from each laboratory. A more detailed analysis of the results and a comparison to the uncertainties in the CMC-tables is found in Ref. [1].
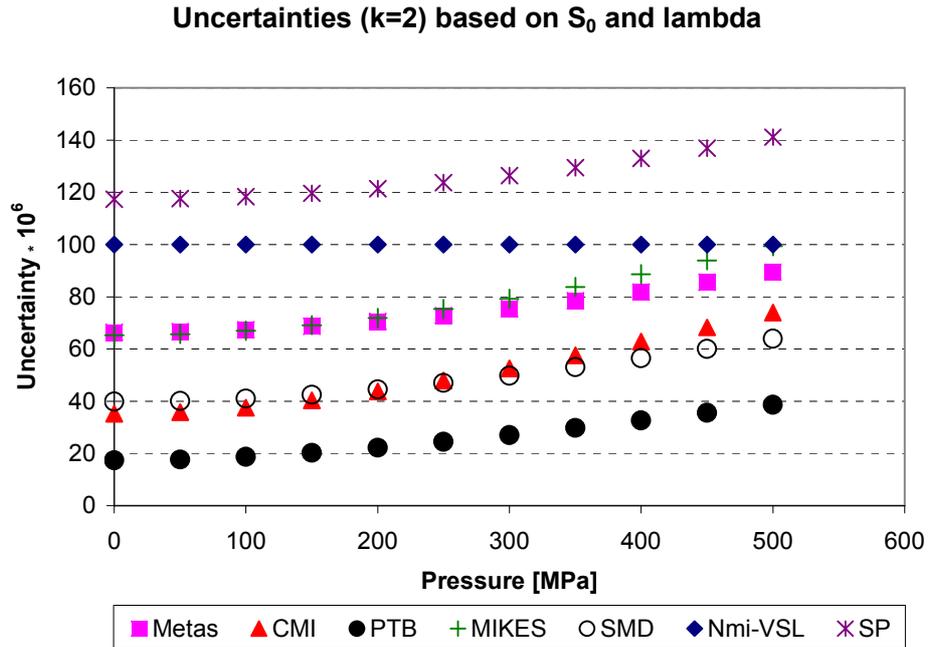
Uncertainties (k=2) based on S_0 and lambda

Fig. 8. Expanded relative uncertainties (k = 2) based on the uncertainties of S_0 and lambda.

3.   Conclusions

The effective area values determined by the participants at ten nominal pressures from 50 MPa to 500 MPa in steps of 50 MPa were in a good agreement with the reference values, calculated as weighted means of the results from the four primary level laboratories. The results fully support the uncertainties claimed in the CMC tables of the participants.

As the pressure distortion is the dominating source of uncertainty in this range, the claimed uncertainties were highest at 500 MPa, ranging from $5,6 \cdot 10^{-5}$ of PTB to $1,2 \cdot 10^{-4}$ of MIKES (expanded relative uncertainties, k = 2). Except for PTB, there were no big differences in the claimed uncertainties between the primary and the secondary level laboratories. The uncertainties given by Metas for the nominal pressures 450 MPa and 500 MPa were higher due to using a pressure multiplier. Their uncertainty at 500 MPa was $3,01 \cdot 10^{-4}$.

Some of the participants gave unnecessarily high uncertainties when giving their results in terms of the effective area at null pressure S_0 and the pressure distortion coefficient λ. On the other hand some of them underestimated the uncertainty of the pressure distortion coefficient.

The transfer standard was not as stable as expected, and the uncertainties of the reference values were to some extent increased by the observed drift.

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References

[1] M. Rantanen, S. Semenoja, M. Ackerholm, A. Condereys, Z. Krajicek, W. Sabuga, J. Verbeek & C. Wuethrich: High pressure comparison between seven European National Laboratories. Range 50 MPa to 500 MPa. Publication J4/2007. Centre for Metrology and Accreditation, Espoo, Finland.

[2] Legras, Jean-Claude: EUROMET intercomparison in the pressure range 50 – 500 MPa. EUROMET Project No 45. Final Report. BNM-LNE, 1997. 21 p.