EUROMET.M.P-S4 FINAL REPORT
BILATERAL PRESSURE COMPARISON IN GAS MEDIA
BETWEEN LNE (FRANCE) and UME (TURKEY)
(GAUGE MODE)
IN THE RANGE FROM 0.04 to 1.75 MPa

İlknur KOÇAŞ, Jean-Claude LEGRAS, Pierre OTAL

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Bucharest/ROMANIA
The EUROMET project N° 861 is organised using the same procedures as for the CCM.P-K1 (b) key comparison, in the pressure range 0.04 to 1.75 MPa.

LNE participated in the CCM.P-K1 (b) comparison as co-pilot. Key pressure points 100 kPa, 500 kPa and 1 MPa have been selected in the present comparison in order to allow a link to the CCM one.
### Piston-cylinder characteristics

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nominal sensitivity</td>
<td>50 kPa/kg</td>
</tr>
<tr>
<td>Calculated pressure distortion coefficient</td>
<td>-1.67 x 10^{-6} 1/MPa</td>
</tr>
<tr>
<td>Thermal expansion coefficient</td>
<td>(9.0 x 10^{-6}) ° C^{-1}</td>
</tr>
<tr>
<td>Minimum operating pressure (gauge mode)</td>
<td>10 kPa</td>
</tr>
<tr>
<td>Maximum operating pressure (with 50 kg)</td>
<td>2500 kPa</td>
</tr>
<tr>
<td>Maximum drop rate</td>
<td>0.5 mm/min</td>
</tr>
</tbody>
</table>
### Data relating to the transfer piston-cylinder assembly

<table>
<thead>
<tr>
<th><strong>Piston characteristics</strong></th>
<th><strong>Cylinder characteristics</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Nominal diameter</td>
<td>Cylinder material</td>
</tr>
<tr>
<td>Piston material</td>
<td>Tungsten carbide</td>
</tr>
<tr>
<td>Equivalent piston density</td>
<td>Linear thermal expansion coefficient</td>
</tr>
<tr>
<td>Young’s modulus</td>
<td>(4.5x10^-6) °C^-1</td>
</tr>
<tr>
<td>Poisson’s ratio</td>
<td>Young’s modulus</td>
</tr>
<tr>
<td></td>
<td>Poisson’s ratio</td>
</tr>
<tr>
<td></td>
<td>Mounting system used</td>
</tr>
<tr>
<td></td>
<td>Negative, free deformation</td>
</tr>
<tr>
<td></td>
<td>(measured pressure applied outside the cylinder)</td>
</tr>
<tr>
<td>16 mm</td>
<td>600 GPa</td>
</tr>
<tr>
<td>Piston-tungsten carbide</td>
<td>0.22</td>
</tr>
<tr>
<td>6910 kg/m³</td>
<td></td>
</tr>
<tr>
<td>600 GPa</td>
<td></td>
</tr>
<tr>
<td>0.22</td>
<td></td>
</tr>
</tbody>
</table>
The LNE standard used for the comparison is a secondary one. The 2 MPa-unit is one of the piston-cylinder assemblies used for defining the LNE gas-operated pressure scale.

It is used for confirming the extrapolation of the scale from the primary standard “APX” to the 10 MPa pressure balance. The effective area at null pressure has been determined by direct comparison with the APX in the range from 40 to 1000 kPa.
UME laboratory standard’s effective area and uncertainty values are taken from PTB certificate (0089 PTB05).

The same piston-cylinder assembly has been measured dimensionally on 2 February 2006 by LNE through the DH Budenberg Company. The effective area issued from these measurements was 490, 2597 mm² with a standard uncertainty lower then 3 x 10⁻⁶

These values are not used in this work because they were obtained only by diameter measurements.
## Characteristics of the Laboratory standards

<table>
<thead>
<tr>
<th></th>
<th>LNE</th>
<th>UME</th>
</tr>
</thead>
<tbody>
<tr>
<td>Piston-cylinder serial number</td>
<td>6394</td>
<td>9145</td>
</tr>
<tr>
<td>Manufacturer</td>
<td>Desgranges et Huot</td>
<td>Desgranges et Huot</td>
</tr>
<tr>
<td>Model</td>
<td>DH 5111</td>
<td>DH 5111</td>
</tr>
<tr>
<td>Measurement range</td>
<td>0.04 -2 MPa</td>
<td>0.04 -2 MPa</td>
</tr>
<tr>
<td>Piston material</td>
<td>Tungsten carbide</td>
<td>Tungsten carbide</td>
</tr>
<tr>
<td>Cylinder material</td>
<td>Tungsten carbide</td>
<td>Tungsten carbide</td>
</tr>
<tr>
<td>Operation mode, free deformation or controlled clearance</td>
<td>Free deformation</td>
<td>Free deformation</td>
</tr>
<tr>
<td>Zero pressure effective area $A_0$ at reference temperature, in mm</td>
<td>490,2530</td>
<td>490,2587</td>
</tr>
<tr>
<td>Relative uncertainty of $A_0$, in $10^{-6}$ (k=1)</td>
<td>4.7</td>
<td>9.9</td>
</tr>
<tr>
<td>Pressure distortion coefficient ($\lambda$) in MPa$^{-1}$</td>
<td>$1.2 \times 10^{-6}$</td>
<td>$1.37 \times 10^{-6}$</td>
</tr>
<tr>
<td>Uncertainty of $\lambda$, in MPa$^{-1}$ (k=1)</td>
<td>$0.12 \times 10^{-6}$</td>
<td>$0.15 \times 10^{-6}$</td>
</tr>
<tr>
<td>Linear thermal expansion coefficient of piston (ac), in °C$^{-1}$</td>
<td>$(4.5 \times 10^{-6})$</td>
<td>$(4.5 \times 10^{-6})$</td>
</tr>
<tr>
<td>Reference temperature ($t_0$), in °C$^{-1}$</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>Local gravity (g), in m/s$^2$</td>
<td>9,809273</td>
<td>9,802310</td>
</tr>
<tr>
<td>Relative uncertainty of g, in $10^{-6}$ (k=1)</td>
<td>0.1</td>
<td>0.1</td>
</tr>
<tr>
<td>Height difference between laboratory standard (LS) and transfer standard (TS)</td>
<td>225 mm</td>
<td>29.6 mm</td>
</tr>
<tr>
<td>Uncertainty of h in mm (k=1)</td>
<td>0.5 mm</td>
<td>0.6 mm</td>
</tr>
</tbody>
</table>
Calibration procedure

- Height difference between reference gauge and transfer gauge are minimized, piston gauges are rotated manually during the measurement process,

- The calibration procedure followed well-known methods for cross-float comparison between laboratory standard and transfer standard. Piston gages were loaded with masses in ratios approximately the same as the ratios in effective area. The pressure was increased to float the pistons, and the pressure equilibrium between laboratory standard and transfer standard was determined by the fall rate analyse method. High purity nitrogen was used during the comparison,

- Temperature of the piston gauges was measured and monitored with platinum resistance thermometers (PRTs) attached near the pistons,

- For minimising air flow effects around piston gauges, bases are housed in an appropriate cabin,

- Both piston gauges were mounted on a rigid base to minimize vibration and magnetic effects,

- A pressure head correction term was applied to compensate for the difference in the reference levels of the pistons.
Mathematical model

The effective area at null pressure has been calculated from the equation;

\[
A'_{o} = \frac{\sum_{i} m_{i} g \left(1 - \frac{\rho_{a}}{\rho_{mi}}\right)}{p' \left[1 + (\alpha_{p} + \alpha_{c})(t' - t'_{o})\right] \cdot \left[1 + \lambda'_{th} p\right]} \pm \rho g \Delta h
\]
Effective area values against the pressure

<table>
<thead>
<tr>
<th>Nom.Pres</th>
<th>Cycle 1</th>
<th>Cycle 2</th>
<th>Cycle 3</th>
<th>Cycle 4</th>
<th>Cycle 5</th>
<th>Mean</th>
<th>Standard deviation (x 10^{-4} mm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MPa</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0,04</td>
<td>196,1079</td>
<td>196,1077</td>
<td>196,1077</td>
<td>196,1078</td>
<td>196,1084</td>
<td>196,1079</td>
<td>1,5</td>
</tr>
<tr>
<td>0,1</td>
<td>196,1067</td>
<td>196,1059</td>
<td>196,1067</td>
<td>196,1062</td>
<td>196,1069</td>
<td>196,1065</td>
<td>2,0</td>
</tr>
<tr>
<td>0,35</td>
<td>196,108</td>
<td>196,1076</td>
<td>196,108</td>
<td>196,108</td>
<td>196,1077</td>
<td>196,1079</td>
<td>0,9</td>
</tr>
<tr>
<td>0,5</td>
<td>196,1072</td>
<td>196,1074</td>
<td>196,1072</td>
<td>196,1074</td>
<td>196,1075</td>
<td>196,1073</td>
<td>0,7</td>
</tr>
<tr>
<td>0,6</td>
<td>196,1074</td>
<td>196,1076</td>
<td>196,1076</td>
<td>196,1072</td>
<td>196,1078</td>
<td>196,1075</td>
<td>1,3</td>
</tr>
<tr>
<td>0,8</td>
<td>196,107</td>
<td>196,1072</td>
<td>196,1071</td>
<td>196,1072</td>
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<td>196,1074</td>
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<td>196,1074</td>
<td>1,1</td>
</tr>
<tr>
<td>1,25</td>
<td>196,1077</td>
<td>196,1078</td>
<td>196,1076</td>
<td>196,1076</td>
<td>196,1078</td>
<td>196,1077</td>
<td>0,4</td>
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<tr>
<td>1,5</td>
<td>196,1078</td>
<td>196,1073</td>
<td>196,1072</td>
<td>196,1075</td>
<td>196,1077</td>
<td>196,1075</td>
<td>1,3</td>
</tr>
<tr>
<td>1,75</td>
<td>196,1073</td>
<td>196,1077</td>
<td>196,1076</td>
<td>196,1077</td>
<td>196,1078</td>
<td>196,1076</td>
<td>0,9</td>
</tr>
</tbody>
</table>
Effective area values against the pressure

<table>
<thead>
<tr>
<th>Nom. Pres</th>
<th>Cycle 1</th>
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<th>Cycle 5</th>
<th>Mean</th>
<th>Standard deviation (x 10^-4 mm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MPa</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.04</td>
<td>196,1085</td>
<td>196,1086</td>
<td>196,1091</td>
<td>196,1082</td>
<td>196,1085</td>
<td>196,1086</td>
<td>1,5</td>
</tr>
<tr>
<td>0.1</td>
<td>196,1071</td>
<td>196,1076</td>
<td>196,108</td>
<td>196,1073</td>
<td>196,1074</td>
<td>196,1075</td>
<td>1,8</td>
</tr>
<tr>
<td>0.35</td>
<td>196,1079</td>
<td>196,1082</td>
<td>196,1082</td>
<td>196,1078</td>
<td>196,108</td>
<td>196,108</td>
<td>0,9</td>
</tr>
<tr>
<td>0.5</td>
<td>196,1081</td>
<td>196,1081</td>
<td>196,1084</td>
<td>196,1079</td>
<td>196,1082</td>
<td>196,1081</td>
<td>0,9</td>
</tr>
<tr>
<td>0.6</td>
<td>196,108</td>
<td>196,1083</td>
<td>196,1083</td>
<td>196,1079</td>
<td>196,1081</td>
<td>196,1081</td>
<td>0,8</td>
</tr>
<tr>
<td>0.8</td>
<td>196,1075</td>
<td>196,1081</td>
<td>196,1082</td>
<td>196,108</td>
<td>196,108</td>
<td>196,1079</td>
<td>1,4</td>
</tr>
<tr>
<td>1</td>
<td>196,1082</td>
<td>196,1081</td>
<td>196,1083</td>
<td>196,1079</td>
<td>196,1081</td>
<td>196,1081</td>
<td>0,8</td>
</tr>
<tr>
<td>1.25</td>
<td>196,1085</td>
<td>196,1084</td>
<td>196,1084</td>
<td>196,1077</td>
<td>196,108</td>
<td>196,1082</td>
<td>1,6</td>
</tr>
<tr>
<td>1.5</td>
<td>196,1083</td>
<td>196,1083</td>
<td>196,1081</td>
<td>196,1078</td>
<td>196,108</td>
<td>196,1081</td>
<td>1,1</td>
</tr>
<tr>
<td>1.75</td>
<td>196,1085</td>
<td>196,1081</td>
<td>196,1085</td>
<td>196,1081</td>
<td>196,1081</td>
<td>196,1083</td>
<td>1,0</td>
</tr>
</tbody>
</table>
Mean effective area values vs pressure for each cycle obtained by LNE and UME

Mean $A'_0$ values obtained by LNE and UME

- **LNE**
- **UME**

<table>
<thead>
<tr>
<th>Pressure (MPa)</th>
<th>$A'_0$ (mm$^2$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>196,1060</td>
</tr>
<tr>
<td>0.5</td>
<td>196,1070</td>
</tr>
<tr>
<td>1</td>
<td>196,1080</td>
</tr>
<tr>
<td>1.5</td>
<td>196,1090</td>
</tr>
<tr>
<td>2</td>
<td>196,1075</td>
</tr>
</tbody>
</table>
Combined uncertainty value

- Type A uncertainty is added in quadrature with Type B uncertainty to give the combined uncertainty in the average effective area.

\[ u_C(A'_0) = \sqrt{u_A(A'_0)^2 + u_B(A'_0)^2} \]
## Uncertainty components (LNE)

<table>
<thead>
<tr>
<th>Nominal Pressure (MPa)</th>
<th>Average A'o Value (mm²)</th>
<th>Standard Deviation of A'o (x 10⁶)</th>
<th>Uncertainty due to p' (x 10⁶)</th>
<th>Uncertainty due to M' (x 10⁶)</th>
<th>Uncertainty due to λ' (x 10⁶)</th>
<th>Uncertainty of A'o (x 10⁶)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.04</td>
<td>196,1079</td>
<td>1.5</td>
<td>6.4</td>
<td>3.8</td>
<td>0.003</td>
<td>7.6</td>
</tr>
<tr>
<td>0.1</td>
<td>196,1065</td>
<td>2</td>
<td>5.6</td>
<td>2</td>
<td>0.008</td>
<td>6.3</td>
</tr>
<tr>
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<td>196,1078</td>
<td>0.9</td>
<td>5.2</td>
<td>1.1</td>
<td>0.029</td>
<td>5.4</td>
</tr>
<tr>
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<tr>
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<td>196,1075</td>
<td>1.3</td>
<td>5.2</td>
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<td>0.05</td>
<td>5.4</td>
</tr>
<tr>
<td>0.8</td>
<td>196,1072</td>
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<td>5.2</td>
<td>0.95</td>
<td>0.067</td>
<td>5.4</td>
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<td>196,1074</td>
<td>1.1</td>
<td>5.2</td>
<td>0.92</td>
<td>0.084</td>
<td>5.3</td>
</tr>
<tr>
<td>1.25</td>
<td>196,1077</td>
<td>0.4</td>
<td>5.1</td>
<td>0.9</td>
<td>0.11</td>
<td>5.2</td>
</tr>
<tr>
<td>1.5</td>
<td>196,1075</td>
<td>1.3</td>
<td>5.1</td>
<td>0.88</td>
<td>0.13</td>
<td>5.4</td>
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<td>1.75</td>
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<td>0.9</td>
<td>5.1</td>
<td>0.87</td>
<td>0.15</td>
<td>5.3</td>
</tr>
</tbody>
</table>
### Uncertainty components (UME)

<table>
<thead>
<tr>
<th>Nominal pressure (MPa)</th>
<th>Average A‘o value (mm²)</th>
<th>Standard deviation of A‘o (x 10⁶)</th>
<th>Uncertainty due to p’ (x 10⁶)</th>
<th>Uncertainty due to M’ (x 10⁶)</th>
<th>Uncertainty due to λ’ (x 10⁶)</th>
<th>Uncertainty of A‘o (x 10⁶)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0,04</td>
<td>196,1086</td>
<td>1,5 (x 10⁶)</td>
<td>10,3 (x 10⁶)</td>
<td>2,2 (x 10⁶)</td>
<td>0,007 (x 10⁶)</td>
<td>10,6 (x 10⁶)</td>
</tr>
<tr>
<td>0,1</td>
<td>196,1075</td>
<td>1,8 (x 10⁶)</td>
<td>9,9 (x 10⁶)</td>
<td>0,9 (x 10⁶)</td>
<td>0,018 (x 10⁶)</td>
<td>10,1 (x 10⁶)</td>
</tr>
<tr>
<td>0,35</td>
<td>196,1080</td>
<td>0,9 (x 10⁶)</td>
<td>9,8 (x 10⁶)</td>
<td>0,7 (x 10⁶)</td>
<td>0,063 (x 10⁶)</td>
<td>9,9 (x 10⁶)</td>
</tr>
<tr>
<td>0,5</td>
<td>196,1081</td>
<td>0,9 (x 10⁶)</td>
<td>9,8 (x 10⁶)</td>
<td>0,6 (x 10⁶)</td>
<td>0,089 (x 10⁶)</td>
<td>9,8 (x 10⁶)</td>
</tr>
<tr>
<td>0,6</td>
<td>196,1081</td>
<td>0,8 (x 10⁶)</td>
<td>9,8 (x 10⁶)</td>
<td>0,5 (x 10⁶)</td>
<td>0,107 (x 10⁶)</td>
<td>9,8 (x 10⁶)</td>
</tr>
<tr>
<td>0,8</td>
<td>196,1079</td>
<td>1,4 (x 10⁶)</td>
<td>9,8 (x 10⁶)</td>
<td>0,44 (x 10⁶)</td>
<td>0,143 (x 10⁶)</td>
<td>9,9 (x 10⁶)</td>
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<tr>
<td>1</td>
<td>196,1081</td>
<td>0,8 (x 10⁶)</td>
<td>9,7 (x 10⁶)</td>
<td>0,4 (x 10⁶)</td>
<td>0,179 (x 10⁶)</td>
<td>9,8 (x 10⁶)</td>
</tr>
<tr>
<td>1,25</td>
<td>196,1082</td>
<td>1,6 (x 10⁶)</td>
<td>9,8 (x 10⁶)</td>
<td>0,36 (x 10⁶)</td>
<td>0,224 (x 10⁶)</td>
<td>10 (x 10⁶)</td>
</tr>
<tr>
<td>1,5</td>
<td>196,1081</td>
<td>1,1 (x 10⁶)</td>
<td>9,8 (x 10⁶)</td>
<td>0,33 (x 10⁶)</td>
<td>0,268 (x 10⁶)</td>
<td>9,8 (x 10⁶)</td>
</tr>
<tr>
<td>1,75</td>
<td>196,1083</td>
<td>1 (x 10⁶)</td>
<td>9,7 (x 10⁶)</td>
<td>0,29 (x 10⁶)</td>
<td>0,313 (x 10⁶)</td>
<td>9,8 (x 10⁶)</td>
</tr>
</tbody>
</table>
The degree of equivalence

- The degree of equivalence, represented for each pressure point as the normalised error $E_n$ calculated with help of well-known mathematical expression

$$E_n = \frac{\left[ A_{0(LNE)} - A_{0(UME)} \right]}{\sqrt{U(A_0)^2_{LNE} + U(A_0)^2_{UME}}}$$
Expended uncertainty

- The combined uncertainty is expressed as $u_c$ and the expended uncertainty $U$ is expressed using a coverage factor $k=2$ and with the mathematical expression:

$$U = \frac{2\sqrt{u(A_0)^2_{LNE} + u(A_0)^2_{UME}}}{(A_0)_{Re f}}$$
### Results

<table>
<thead>
<tr>
<th>Nominal pressure (MPa)</th>
<th>LNE</th>
<th>UME</th>
<th>Combined uncertainty (k=2)</th>
<th>$E_n$ value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Average of A'o value</td>
<td>Uncertainty of A'o (k=2)</td>
<td>Average of A'o value</td>
<td>Uncertainty of A'o (k=2)</td>
</tr>
<tr>
<td>0.04</td>
<td>196,1079</td>
<td>15,1</td>
<td>196,1086</td>
<td>21,3</td>
</tr>
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For realising the link to CCM.P-K1b key comparison, the results of this comparison are compared with the results of CCM.P-K1b key comparison. UME results have been calculated using the formulas below:

$$(D_{UME,j})_{CCM} = (D_{UME,LNE})_{EUR} + (D_{LNE,j})_{CCM}$$

where $(D_{UME,j})_{CCM}$ is the difference between UME and the laboratory of rank $j$ in the CCM comparison.

$$(U_{UME,j})_{CCM} = u^2[(D_{UME,LNE})_{EUR}] + u^2[(D_{LNE,j})_{CCM}] + 2 \cdot u[(D_{LNE})_{CCM} \cdot \rho(LNE_{CCM}, LNE_{EUR})]^{0.5}$$

where $\rho(LNE_{CCM}, LNE_{EUR})$ is the correlation coefficient of the LNE values for the two comparisons, estimated to be 0.7.
Conclusion

- The effective area of the transfer standard used in this bilateral comparison was determined by cross-floating method. During the comparison period only the piston-cylinder assembly was circulated between laboratories. Other elements, such as the base, the temperature probe and the measuring system for the fall rate of the piston, were provided by both laboratories.

- The effective area and the standard uncertainty of the effective area were calculated for each pressure value. The results obtained by both laboratories are in agreement, as all the En values are less than 0.2. Both laboratories used the same type of piston cylinder assembly produced by the same manufacturer with similar physical characteristics, but the characterisation methods were different.

- If the UME laboratory standard piston-cylinder assembly had been fully measured dimensionally the uncertainty of effective area of this assembly could be in the same level uncertainty as the LNE piston-cylinder assembly.

- The bilateral comparison results validate and also demonstrate the method employed for linking the present comparison to the CIPM -K1b key comparison.
Thank you for your attention...