An Inter-comparison of Bell Prover Facilities at Twelve European Laboratories Using a Rotary Gas Meter (EUROMET Project No 425)

A Report for

NMSPU
Department of Trade & Industry
151 Buckingham Palace Road
London, SW1W 9SS

Project No: FMMC70100

Report No: 040/2000

Date: 1 March 2000

This report is issued as part of the contract under which the work has been carried out for the client.

NOTES

1 This report may be published in full by the client unless it includes information supplied in confidence by NEL or any third party. Such information, if included within the report, shall be separately designated as confidential by NEL.

2a The prior written consent of NEL shall be obtained by the client before publication by him or any extract from, or abridgement of, this report.

2b The prior written consent of NEL shall be obtained by the client before publication:

- where such publication is made in connection with any public enquiry, legal proceedings or arbitration
- where such publication is made in, or in connection with, any company prospectus or similar document
- where the client has notice that NEL is seeking or intends to seek patent or like protection for any intellectual property produced in the course of rendering the services.

Flow Centre

National Engineering Laboratory
East Kilbride
Glasgow G75 0QU
Tel: 01355 220222
Fax: 01355 272999

An Inter-comparison of Bell Prover Facilities at Twelve European Laboratories Using a Rotary Gas Meter (EUROMET Project No 425)

A Report for

NMSPU
Department of Trade & Industry
151 Buckingham Palace Road
London, SW1W 9SS

SUMMARY

This report describes the results from the inter-comparison of the bell prover facilities of 12 national flow laboratories in Europe. The organisations taking part in the project were, NEL (UK), EAM (Switzerland), IMGC (Italy), BEV (Austria), CMI (The Czech Republic), OMH (Hungary), PTB (Germany), FI (Denmark), NMi (The Netherlands), MAE (Belgium), GUM (Poland) and UME (Turkey). The project was registered with EUROMET as Project Reference No 425.

An Instromet G16 rotary gas meter supplied by NMi, the Netherlands, was used as the transfer meter. The meter was calibrated at 4 flowrates, 0.4 l/s, 0.8 l/s, 1.2 l/s and 1.6 l/s.

The inter-comparison demonstrated that agreement between the mean values of all laboratories of ±0.25 per cent was achieved.

All the data supplied by the participating laboratories and a full analysis of the data is contained in a CD-ROM. NEL Report No 305/99.

Prepared by: Mr C Probert

Approved by: Mr R Paton

Date: 1 March 2000
for Dr F C Kinghorn
Director

CONTENTS

1 INTRODUCTION

This report describes the inter-comparison of bell prover facilities between 12 laboratories throughout Europe. The aim of the project was to ensure that there is good agreement between national laboratories. All the laboratories participating are members of EUROMET. The project was registered with EUROMET as Project Reference No 425.

The transfer meter was circulated in the following order:

NEL	United Kingdom	November 1997,
EAM	Switzerland	January 1998,
IMGC	Italy	February 1998,
BEV	Austria	March 1998,
OMH	Hungary	May 1998,
CMI	The Czech Republic	June 1998,
PTB	Germany	September 1998,
FI	Denmark	February 1999,
NMi	The Netherlands	April 1999,
MAE	Belgium	June 1999,
GUM	Poland	September 1999,
UME	Turkey	October 1999, and
NEL	United Kingdom	November 1999.

This report summarises the results and gives an overview of the laboratories and test methods. The full list of tables of results and associated figures is given in the report for reference but only the relevant inter-comparison graphs are included in this summary. All the tables and figures referenced are available in Microsoft Excel format in NEL report number FC 305/99 – Inter-comparison Work for 1996-1999 Flow Programme. This is available from NEL as a CD-ROM. This CD includes this report and also includes the reports of all other inter-comparisons carried out within the 1996–1999 flow programme.

2 TRANSFER STANDARD

The transfer meter used was an Instromet G16 rotary gas meter, which was supplied by NMi, the Netherlands. The meter had the following characteristics:

Serial No: 305382

Minimum flowrate: 0.35 m^3/h

Maximum flowrate: 25 m^3/h

Maximum pressure: 16 bar

K-factor: 42773.4 pulses/m^3

The meter was of the special type with "narrow tolerances" to ensure a minimal leakage gap. The meter is described in more detail in Reference 1.

3 DETAILS OF FACILITIES

The information below is reproduced from data provided by the individual laboratories.

National Engineering Laboratory (NEL) – UK

The National Engineering Laboratory (NEL) is an industrial research organisation concerned with many areas of mechanical engineering research. Within NEL, Flow Centre is the holder of the UK National Standards for flow measurement. Facilities exist for calibration and research involving, water, oil, gas and multiphase flow. All the measurement components are fully traceable to primary national standards and most are accredited by United Kingdom Accreditation Service (UKAS).

Bell prover:	0.142 m^3 (5ft^3)
Calibrated volume:	0.142 m^3 (5ft^3)
Displacement measure:	encoder/pulses
Flow range:	0.5 – 32.4 m^3/hr

Swiss Federal Office of Metrology (EAM) – Switzerland

The Swiss Federal Office of Metrology (EAM) is the holder of the National Standards for flow measurement for Switzerland.

Bell prover:	10 m^3
Calibrated volume:	10 m^3
Displacement measure:	electro-optic ruler
Flow range:	not given

Istituto di Metrologia "G. Colonnetti" (IMGC-CNR) – Italy

IMGC is the national measurement institute in Italy responsible for National Standards of thermal and mechanical quantities, including gas volume and flowrate measurement. The prover used in this inter-comparison is a medium sized unit between two piston provers (1.0 m^3 and 0.003 m^3 capacity)

Bell prover:	0.142 m^3 (5ft^3)
Calibrated volume:	0.142 m^3 (5ft^3)
Displacement measure:	encoder/pulses
Flow range:	0.012 – 25m^3/h

Bundesamt fur Eich und Vermessungswesen (BEV)– Austria

BEV is the holder of the National Standards for flow measurement for Austria.

Bell prover:	0.5 m^3
Calibrated volume:	0.5 m^3
Displacement measure:	photoelectric beam/pulses
Flow range:	not given

National Office of Measurement (OMH) – Hungary

The National Office of Measurement is the holder of the National Standards of measurement, including flow, for Hungary.

Bell prover:	0.5 m^3
Calibrated volume:	0.1 m^3
Displacement measure:	pulses
Flow range:	up to 64.8 m^3/hr

Czech Metrological Institute (CMI) – The Czech Republic

CMI is the holder of the National Standards of flow measurement and the bell prover used in this project is the primary standard for gas flow in the Czech Republic.

Bell prover:	not given
Calibrated volume:	not given
Displacement measure:	electro-optic ruler/pulses
Flow range:	4.0 – 400 m^3/h

Physikalisch Technische Bundesanstalt (PTB) – Germany

PTB is the National Standards laboratory for Germany and the bell prover used in this inter-comparison is the primary standard for gas flow measurement in Germany.

Bell prover:	1 m^3
Calibrated volume:	1 m^3
Displacement measure:	electro-optical/pulses
Flow range:	2.02 – 60.01 m^3/hr

Force Institute (FI) – Denmark

Force Institute is one of the National Standards laboratories for Denmark and the holder of the national standard for flow measurement.

Bell prover:	not given
Calibrated volume:	not given
Displacement measure:	electro-optical ruler/pulses
Flow range:	4 – 10 m^3/h

Nederlands Meetinstituut (NMi) – The Netherlands

NMi is the national laboratory for flow measurement in The Netherlands.

Bell prover:	0.5 m^3
Calibrated volume:	0.1 m^3 & 0.03 m^3
Displacement Measure:	Discrete optical/electronic pulse per volume
Flow range:	0.1 – 60 m^3/h

Ministere Des Affaires Economiques (MAE) – Belgium

Ministere des Affaires Economiques, Division Metrologie, is responsible for legal metrology in Belgium.

Bell prover:	0.2 m^3
Calibrated volume:	0.2 m^3
Displacement measure:	pulses
Flow range:	not given

Central Office of Measures (GUM) – Poland

GUM is the National Standards laboratory for Poland.

Bell prover:	0.2 m^3
Calibrated volume:	0.2 m^3
Displacement measure:	electro-optic rule/pulses
Flow range:	0.045 – 18 m^3/h

Ulusal Metroloji Enstitusu (UME) – Turkey

UME is the national metrology laboratory for Turkey and the bell prover used in this project is the primary standard for Turkey.

Bell prover:	0.28 m^3
Calibrated volume:	0.28 m^3
Volume measurement:	encoder/pulses
Flow range:	0.2 – 85 m^3/h

4 TEST PROCEDURE

The meter was installed according to the laboratories, normal practices. The meter was calibrated against the bell provers at four different flowrates, 0.4, 0.8, 1.2, and 1.6 l/s. This represents 5.8% to 23% of the full scale of the meter. One laboratory (CMI) was only able to carry out the calibration at 1.2 and 1.6 l/s because the lower flowrates were outside the range of their bell prover.

With the exceptions given below, air displaced from the bell prover was discharged through the meter under test. All laboratories used a flying-start–flying-finish method. This involved simultaneously triggering the pulses from the meter and the output of the bell displacement measure at the start and finish of each test. The volume of air passed through the meter varied between the laboratories and ranged from 23 litres at UME to 2000 litres at EAM.

Pressure at the test meter was measured on the gas meter body, at the point marked ‘P_r’. The test meter temperature was measured downstream of the test meter.

The reference volume at the transfer meter was obtained by correcting the volume measured by the bell to the conditions at the meter. The indicated volume from the meter was calculated from the pulses and the nominal K-factor of the meter. The flowrate was derived from measuring the time to discharge the bell.

Exceptions from the above practice were found at BEV and NMi. At BEV the temperature was measured upstream of the meter. At NMi two counters were used: one for the pulse count and timing of the discrete volumes, and one for the pulse count and timing of the meter pulses to improve the resolution by using pulse interpolation.

BEV also placed a plenum (the case of a G6 diaphragm gas meter) between the bell and the test meter to protect against pulsations.

UME had a number of different practices. The test meter was placed upstream of the bell. The air was taken from a 10 bar supply through a system of pressure regulators and control valves before passing through the test meter and filling the bell. Temperature and pressure were measured upstream of the meter. The meter output was measured using a frequency counter rather than a totaliser.

5 CALCULATION

The volume at the meter, as determined by the laboratories, was calculated from the measured volume at the bell.

Reference Volume $$V_R = V_B \times \frac{P_B T_M}{P_M T_B}$$

Indicated Volume $$V_I = \frac{N}{K_{NOM}}$$

Reference Flowrate $$Q_R = \frac{V_R}{t}$$, where $t = t_B$ or t_M in some cases

Indicated flowrate $$Q_I = \frac{V_I}{t}$$

Reference K –Factor $$K_R = \frac{N}{V_R}$$

Error (%) $$E = \frac{V_I - V_R}{V_R} \times 100$$

where

P_B Absolute pressure at bell prover (Pa),

P_M Absolute pressure at test meter (Pa),

T_B Absolute temperature at bell prover (K),

T_M Absolute temperature at test meter (K),

V_B Volume at bell prover (l),

N Number of meter pulses,

K_R K-factor of the meter as obtained from the test(pulses/l),

K_{NOM} K- factor of test meter (42.7734 pulses/l), t Measurement time (s), and

Q Volume flowrate (l/s).

Subscripts

R Reference as determined by the laboratory

I Indicated by the meter

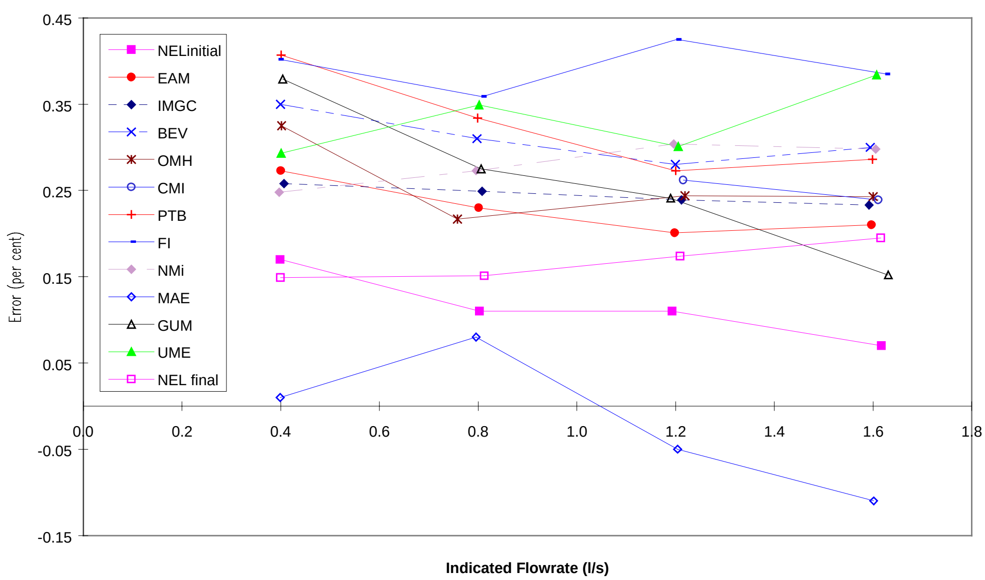
6 RESULTS

All the tables of results and figures are available in NEL report number FC 305/99 issued as a CD-ROM. Only figures and tables applicable to the conclusions are included here. The figure and table numbers refer to those provided in the full data set on the CD-ROM.

The mean error for each laboratory is shown in Figure 1 and the K-factor (K_R) is given in Figure 2. No difference is seen between the two presentations as both are derived from the same data. Figure 2 shows that the mean K-factor for the inter-comparison is approximately 42.9 p/l against the nominal value of 42.7734 p/l. Figure 1 indicates that the overall agreement between laboratories is within a range of 0.5 per cent, with a mean error of approximately 0.25 per cent. If data from MAE are ignored, this range drops to 0.4 per cent.

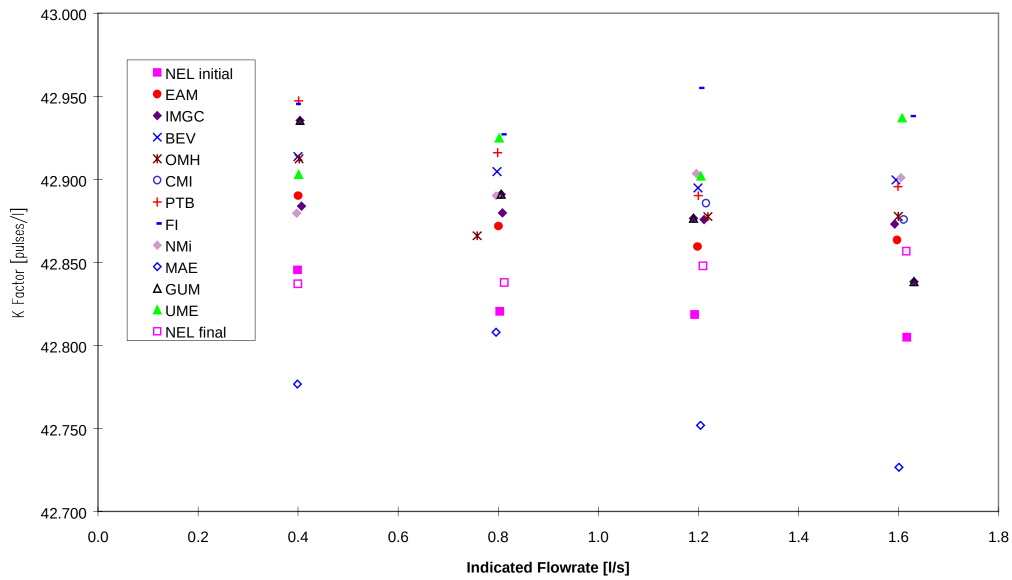
The NEL results at the beginning and end of the exercise show agreement within 0.1%. The NMi results agree closely with earlier tests performed at NMi[1], which gave a mean error of approximately 0.28 per cent. This shows that the meter has been stable over this period.

Fig 1 Comparison of Mean Error of Each Laboratory



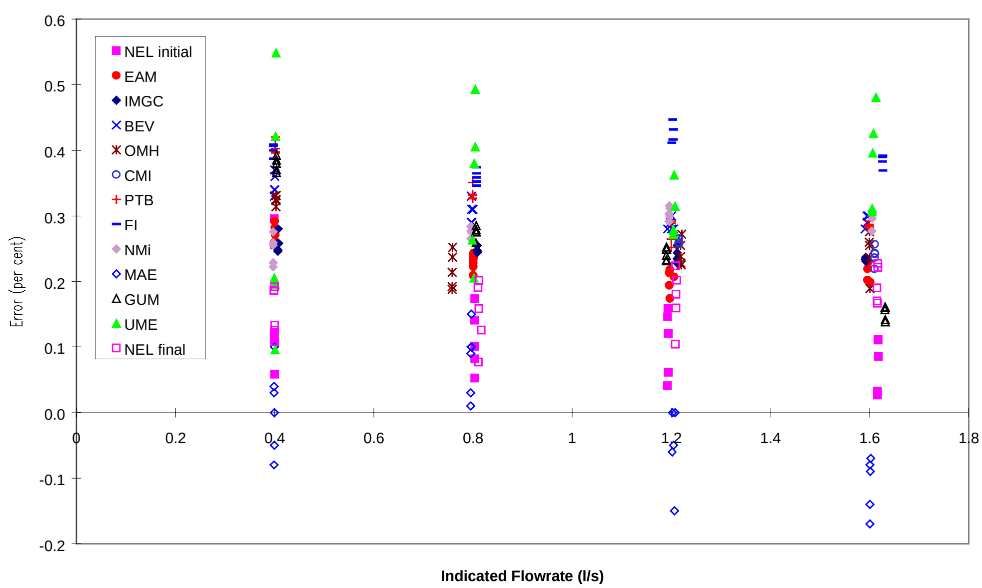
All laboratories show a linearity of within 0.1 per cent except the calibrations from GUM and MAE. GUM has a linearity of 0.23 per cent and MAE a linearity of 0.18 per cent, both display a falling characteristic. Within the linearity of 0.1 per cent most curves show a slight downward trend but some laboratories (NEL final, NMi and UME) have a small upward trend.

Fig 2 Comparison of Mean K Factors at Each Laboratory



The results from all the tests are shown graphically in Figure 3, which indicates that all the data lies in a range of 0.65 per cent. This is a very crowded presentation and the repeatability is better represented in tabular form, Table 3, which gives the standard deviation of the measured percentage error for each of the laboratories.

Fig 3 Error of Transfer Meter at Each Laboratory

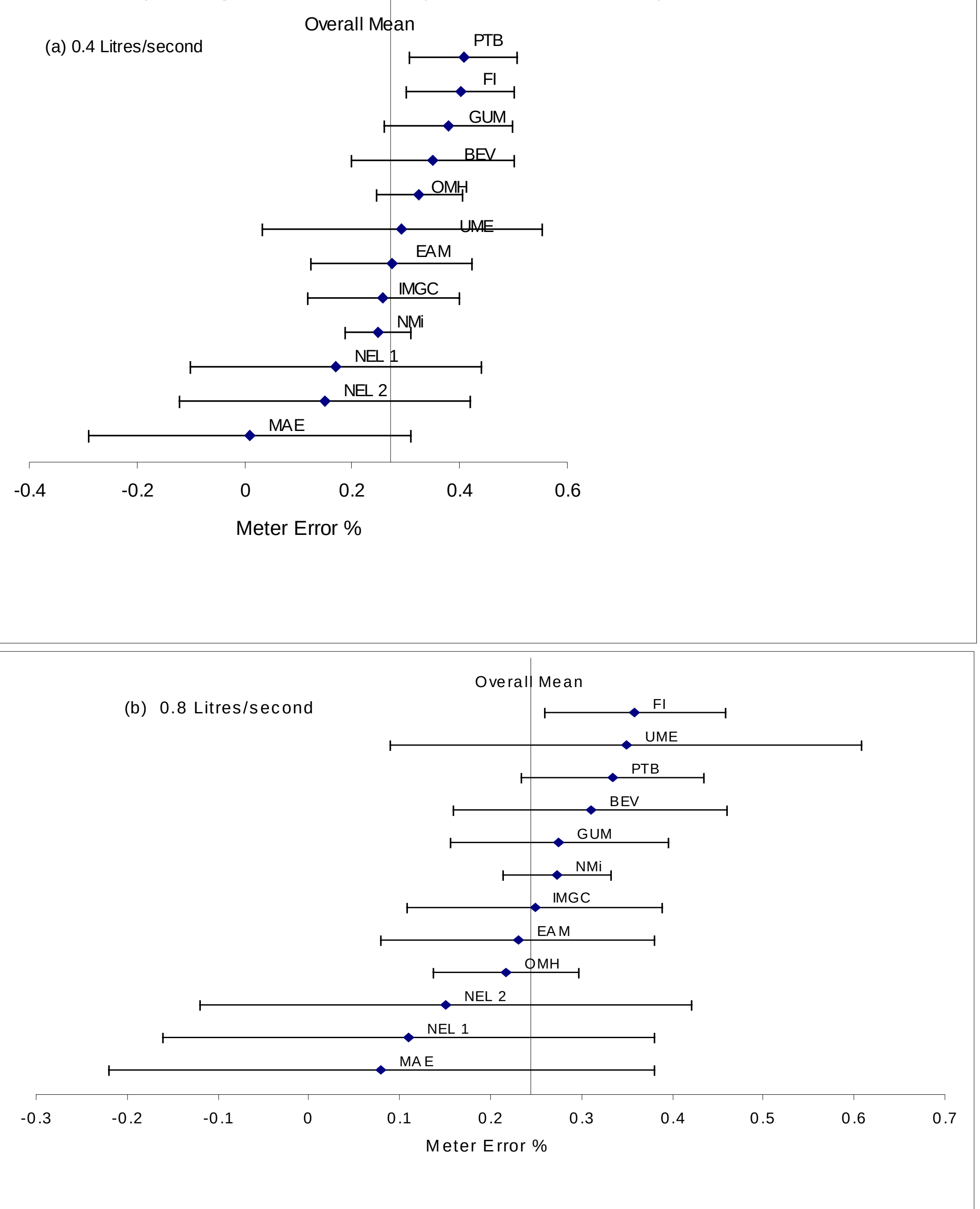


The standard deviation associated with the measured percentage error varies from 0.003 for both CMI at 1.2 l/s and IMGC at 1.6 l/s to 0.185 for UME at 0.4 l/s but was generally in the range 0.01 to 0.03 for most laboratories.

Fig. 4(Fig 16 in NEL Report No 305/99) shows, for each flowrate, the mean error recorded by each laboratory and the 95% uncertainty band either side of that mean. From there it can be seen that with few exceptions the uncertainty bands span the overall mean from all laboratories. It can also be seen that almost all the uncertainty bands overlap by substantial amounts. Good agreement was therefore obtained between the participating laboratories.

Figs 1 and 4 also show that, in general, each laboratory maintains a consistent position relative to the overall mean; for example, MAE and NEL are below the mean at all flowrates; UME and FI are always above the mean. This can be seen clearly in Figs 4-15 of NEL Report No 305/99. These trends suggest that there are some bias effects present between laboratories.

Fig 4 Comparison of Laboratory Means and Uncertainty Bands



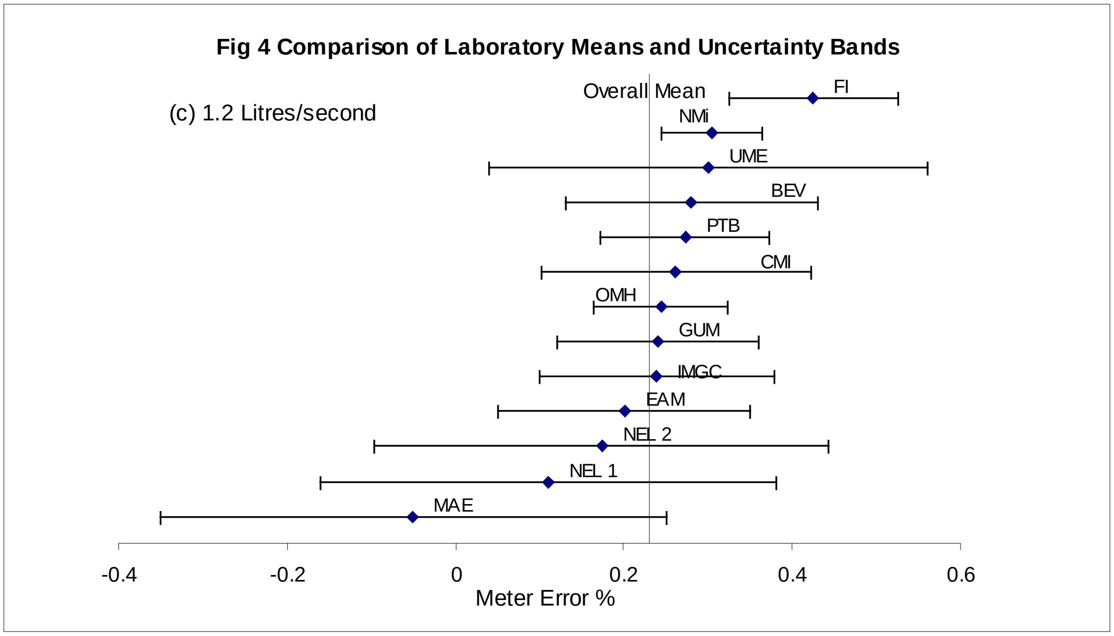


Fig 4 Comparison of Laboratory Means and Uncertainty Bands
(c) 1.2 Litres/second
Overall Mean
FI
NMi
UME
BEV
PTB
CMI
OMH
GUM
IMGC
EAM
NEL 2
NEL 1
MAE
-0.4
-0.2
0
0.2
0.4
0.6
Meter Error %

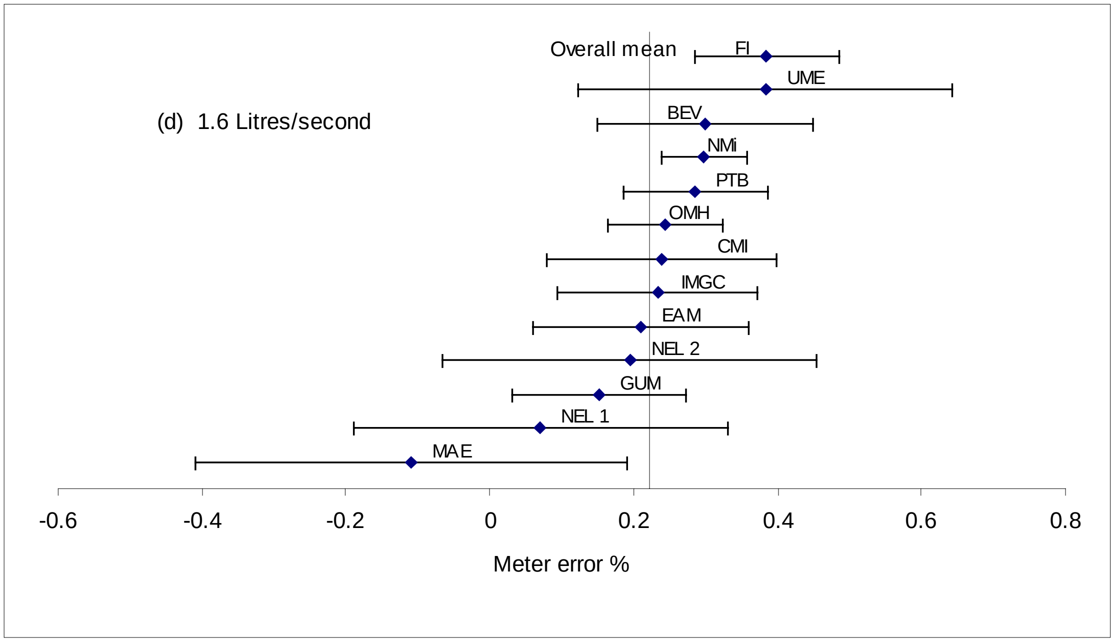

Overall mean
FI
UME
(d) 1.6 Litres/second
BEV
NMi
PTB
OMH
CMI
IMGC
EAM
NEL 2
GUM
NEL 1
MAE
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
0.8
Meter error %

TABLE 3

STANDARD DEVIATION AND UNCERTAINTY OF MEASURED PERCENTAGE ERROR FOR EACH LABORATORY

Laboratory	Flowrate (l/s)				Uncertainty (%)
	0.4	0.8	1.2	1.6	
NEL(initial)	0.102	0.048	0.052	0.041	0.27
EAM	0.014	0.012	0.018	0.013	0.15
IMGC	0.013	0.006	0.011	0.003	0.14
BEV	0.015	0.016	0.012	0.008	0.15
OMH	0.007	0.028	0.020	0.033	0.08
CMI			0.003	0.014	0.16
PTB	0.011	0.010	0.017	0.004	0.10
FI	0.009	0.011	0.015	0.009	0.10
NMi	0.022	0.008	0.009	0.013	0.06
MAE	0.063	0.051	0.062	0.043	0.30
GUM	0.011	0.01	0.009	0.011	0.12
UME	0.185	0.115	0.038	0.075	0.26
NEL(final)	0.038	0.051	0.046	0.028	0.27

The pressure at the test meter differed between laboratories and ranges from 8 Pa to 3818 Pa with most of the laboratories being in the range 600 – 2000 Pa. The pressure at the test meter and the bell was very close in all tests except those at NEL where the pressure difference was approximately 400 Pa. However, there is no correlation between the pressure and the differences in the error obtained by the laboratories.

The uncertainty associated with the measurement of the error for each of the laboratories is also given in Table 3. The expanded uncertainty is based on a standard uncertainty multiplied by a coverage factor k=2, providing a level of confidence of approximately 95 per cent. This is the figure provided by the Laboratories.

Most of the laboratories quote uncertainties of 0.16 per cent or less, but NEL, MAE and UME claim uncertainties between 0.26 and 0.30 per cent.

7 CONCLUSION

1 The mean errors from each laboratory, based on all the data from the inter-comparison, were within a range of 0.5 per cent.

2 The stated uncertainty band about the mean error from each laboratory encompassed the overall mean from all laboratories with few exceptions.

3 The stated uncertainty bands from different laboratories generally showed large overlaps indicating good agreement between laboratories.

4 The results, from all the individual data points in the tests, lie within a range of 0.65 per cent.

5 The mean values of the error obtained by NEL at the start and finish of the project showed good agreement. Additionally, the mean value of the error obtained by NMi showed good agreement with earlier tests(1). These observations indicate that the meter was stable over the test period.

6 The repeatability of laboratories, as represented by the standard deviation, showed wide variation ranging from 0.003 to 0.185.

REFERENCE

1 DIJSTELBERGEN, H. H., and VAN DER BEEK, M. P. A New Reference Meter for Gasmeter Calibration. FLOWMEKO '98, 9th International Conference on Flow Measurement, Lund, Sweden 1998 pp 37-42.

ACKNOWLEDGEMENT

The author would like to thank all the participants for their co-operation in this project and in particular Mr M Van der Beek, NMi for providing the transfer meter. Thanks also go to Mr H Lerch, EAM, Switzerland, Dr G Cignolo, IMGC, Italy, Mr M Macek, BEV, Austria, Mr Z Remenyi, OMH, Hungary, Mr T Valenta and Dr P Klenovsky, CMI. The Czech Republic, Mrs G Wendt, PTB, Germany, Mr K Rasmussan, FI, Denmark, Mr A Buisseret, MAE, Belgium, Mr M Tichy, COM Poland and Dr V Ciftci, UME, Turkey.

Detailed below is a List of Tables and Figures provided in (NEL Report No 305/99).

LIST OF TABLES IN (NEL Report No 305/99)

LIST OF FIGURES IN (NEL Report No 305/99)

APPENDIX I

PARTICIPATING LABORATORIES

Switzerland

Swiss Federal Office of Metrology
Lindenweg 50
CH-3003 Bern-Wabern

Italy

Istituto di Metrologia
" G Colonnnetti"
str della cacce, 73
10135 Torino

Austria

BEV
Arltgasse 35
Postfach 20
1163 Wien

Czech Republic

Czech Metrological Institute
Okruzni 31
638 00 Brno

Hungary

Orszagos Meresugyi Hivatal
H - 1535
Budapest Pf. 919

Poland

Central Office of Measures
Division of Thermodynamics
ul. Electoraina 2
00 - 950 Warszawa

Germany

Physikalisch Technische Bundesanstalt
Postfach 3345
38023 Braunschweig

Denmark

Force Institute
Navervej 1
6600 Vejen

The Netherlands

NMi
Van Swinden Laboratory
Department of Flow
PO Box 394
3300 AJ Dordrecht

Belgium

Minstere des Affaires Economiques
Administration de la Qualite et de la
Service de la Metrologie
Chaussee de Haecht, 1795
1130 Bruxelles

Turkey

Ulusal Metrolji Enstitusu
TUBITAK_MAM_UME
PO Box 21
41470 Gebze - Kocael

United Kingdom

National Engineering Laboratory
Flow Centre
Scottish Enterprise Technology Park
East Kilbride
G75 0QU