An EEC intercomparison campaign on industrial gas meters

E. A. Spencer*
"Greenwood", Bridge of Earn, Perth, PH2 9BH, UK

Received 5 May 1987 and accepted for publication on 11 June 1987

The verification of industrial gas meters, though officially the responsibility of individual member states, is nevertheless of considerable importance to the community as a whole. An EEC directive on the required accuracy levels for such meters implies that the appointed calibrating laboratories shall be in agreement with each other within 0.3%. As a cross-check four gas meters, two CVM and two turbine meters, were calibrated at five laboratories in accordance with a program initiated through the EEC Commission's Bureau of Community Reference. The flowrates covered were from 16 to 4000 m^3/h. The tests were successfully completed during 1983–1985 and have now been fully analyzed. Test point scatter about individual mean lines was normally between 0.1 and 0.2%. The results from two laboratories were significantly different, however, to those from the other three, one being about 0.25% higher and the other 0.2% lower than the curves fitted to the complete set of results. However, direct comparison between calibrations obtained on any one meter in two different laboratories agreed to better than 0.3% in 22 of the 36 combinations tested.

Keywords: industrial gas metering; flow measurement; EEC intercomparison; CVM gas meter; turbine gas meter; calibrations; orthogonal polynomial curve fitting

Introduction

Gas meters are used in a vast number of industrial plants for the measurement of natural gas and the subsequent billing to the consumer. Their accuracy and stability for such purposes is of increasing importance. Although their verification is the responsibility of the national legal metrology authorities, the community-wide acceptability of these national verifications is the subject of a directive of the EEC Council[1]. On the basis that the absolute accuracy of successive levels in a measurement hierarchy should be in multiples of three, the ±1% tolerance allowed in practice for low-pressure industrial gas meters calls for a 0.3% accuracy in the calibration facilities.

The stimulus for the present study arose when a comparison carried out in 1981 between two national legal metrological authorities in the European Economic Community (EEC) showed a difference of 0.3% over part of their flow range. A proposal was subsequently made for an intercomparison campaign to be undertaken to confirm that systematic differences between any of the different national testing agencies were indeed within the recommended level of 0.3%.

The EEC Commission's BCR Applied Metrology Group gave its approval to the project, and the details were worked out by experts from the interested parties in the spring of 1983. The overall test program was successfully carried out in a time span of about two years, and the analysis of all the results was completed early in 1986. This paper summarizes the project and its conclusions (Reference 2 gives the full report).

Test program and description of gas meters

Five organizations agreed to participate in the intercomparison campaign:

PTB	Physikalische-Technische-Bundesanstalt, Braunschweig, Deutschland
NSM	Dienst van het IJkwezen, Dordrecht, Nederland
NEL	National Engineering Laboratory, East Kilbride, United Kingdom
SIM	Service de la Metrologie, Paris, France
SMB	Service de la Metrologie, Bruxelles, Belge

Four of these organizations are responsible for the legal verification of gas meters in their respective countries. The fifth, the National Engineering Laboratory, comes under the Department of Industry and not the Department of Energy. Also it may be noted that NSM stands for Netherlands Service of Metrology, and SIM (for Service des Instruments des Mesures) was the previous title of the French Service de la Metrologie.

The PTB and NSM each made available on loan two transfer standards for the purposes of the intercomparison campaign. These standards were normal industrial-type gas meters modified only by having dual-output pulse transmitters fitted for increased accuracy. Both meters supplied by the PTB were G650 (Figures 1 and 2), the CVM positive displacement meter having a flowrate range from 100 to 1000 m^3/h and the turbine meter from 200 to 1000 m^3/h. The positive displacement meter supplied by NSM was size G100 (Q from 16 to 160 m^3/h), and the turbine meter was size G2500 (Q from 800 to 4000 m^3/h).

Inlet and outlet pipes were supplied to ensure similarity of the flow conditions in the meters at each test installation. Drawings of the flange connections, thermometer pockets, and the connections for the pulse generator were circulated to participants early in the campaign to enable preparations to be made in advance.

Instructions accompanying the gas meters gave full details of how the meters were to be installed and checked before being calibrated and the criteria which were to be used, so any

---

* Formerly at the National Engineering Laboratory, East Kilbride, Scotland, UK

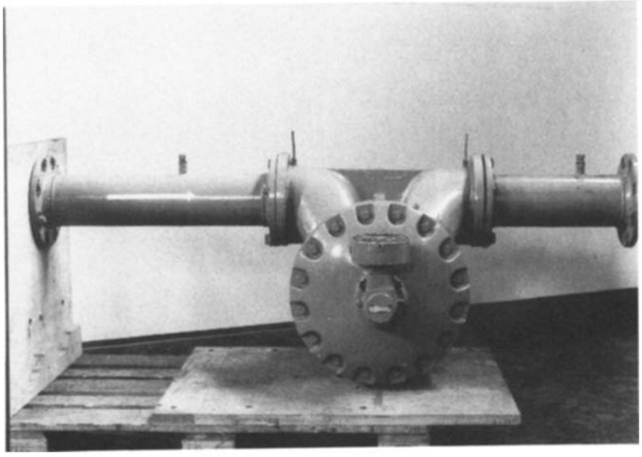

Figure 1 PTB G650 CVM gas meter package

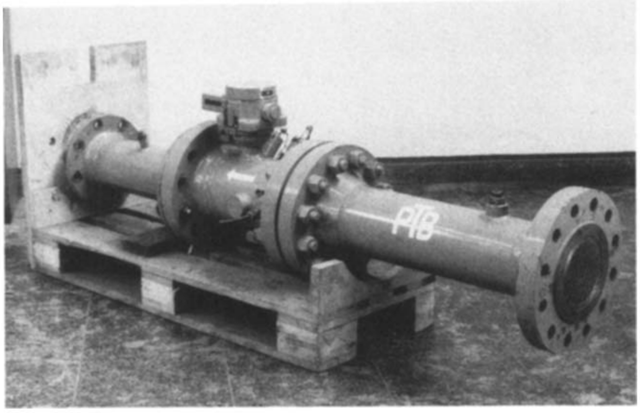

Figure 2 PTB G650 turbine meter package

deterioration in transit or in use could be quickly assessed. After preliminary checks for pressure drop and leakage from the CVM meters and spin response from the turbine meters, it was proposed that each of the participating laboratories should calibrate each meter three times, once with increasing flowrates, once with decreasing flowrates, and once with the flowrate being randomly changed from test to test. The calibrations were to be made at flowrates within 5% of the values given in Table 1, plus four other flowrates selected by the participant.

Description of tests

Full descriptions of the test facilities as well as extra details of the tests themselves at the five participating laboratories are described in the BCR report[2]. The sequence of testing and the actual timetable for the campaign was as follows.

Table 1 Prescribed test flowrates (in m^3/h)

G100 CVM meter	G650 CVM meter	G650 turbine meter	G2500 turbine meter
16	100	100	400
40	250	250	1,000
65	400	400	1,600
110	700	700	2,800
160	1,000	1,000	4,000

Table 2 Test timetable of intercomparison campaign

Location	CVM G100	CVM G650	Turbine G650	Turbine G2500
PTB		May '83	May '83	
PTB		Jul/Aug '83	July '83	
PTB		Oct '83		
NSM	Sept '83	Nov '83	Nov '83	Sept '83
PTB	Oct/Nov '83			Oct/Nov '83
NEL	July '84	July '84	July '84	July '84
NSM	Aug '84			Aug '84
SIM	Sept '84	Sept '84	Sept '84	Sept '84
PTB		Oct/Nov '84	Oct/Nov '84	
SMB	Nov/Dec '84	Jan/Feb '85		Mar/Apr '85
PTB		Mar '85		
NSM	Aug '85			Aug '85

Initial calibration of the campaign gas meters

As shown in Table 2, the two PTB gas meters were tested at the PTB in May 1983, and then two further independent test runs were made in July–August 1983. At each flowrate two separate measurements were made, each about 3-minute duration. Differences between the two measurements were generally within ±0.05%. A retest was made of the CVM meter in October, since in August the ambient temperature had risen to above 23°C during some of the tests. Small differences of up to 0.1% were found for flowrates over 400 m^3/h, but as the mean curves for all the results varied by less than 0.1%, the PTB decided that both meters were suitable for the campaign to be undertaken.

The two NSM gas meters, G100 and G2500, were first calibrated at Dordrecht in September 1983. Repeat measurements were made at each flowrate, and the agreement obtained was better than 0.05%.

Calibration of the NSM gas meters were carried out at the PTB during October to November 1983 in the same manner as for the PTB meters. It was commented that the slightly higher results which were obtained, when compared with the figures provided by NSM, may have been caused by lower air densities. The differences were not considered significant.

In the calibration of the NSM G100 CVM gas meter at the PTB, the critical-flow nozzles could not be used because the steps in flowrate would have been too large. The PTB standard

Notation

m	Powers of polynomial equation
P	Adjustable parameter
x	Flowrate
y	Percentage error

G100 CVM gas meter with servo drive was therefore used after it had been checked against the nozzles. Confidence in the results was felt to be greatest from 24 to 160 m^3/h.

The two PTB meters were calibrated in the test facility at Dordrecht in November 1983 without any problems and were then sent on to the National Engineering Laboratory in Scotland.

Intercomparison tests

Preliminary tests made at the NEL, East Kilbride, were as laid down in the agreed procedure. Thus, before installation the two turbine meters were tested to determine their spindown times to check that no damage had occurred during their shipment to NEL. The results were within the expected ranges given by PTB and NSM. As at the other laboratories after each meter had been installed in the test rig, the test line was rigorously leak tested, and the amount of leakage assessed. On the few occasions when the leak rate exceeded the specification, remedial action was taken until the criterion on leak rate was met.

Before the positive displacement CVM meters were calibrated at NEL, they were run at maximum flowrate for approximately 1 h and then tested over their flowrate ranges to establish their pressure-drop characteristics. These pressure-drop data were compared with those specified by PTB and NSM and were found to be acceptable. The sequence of testing at NEL was to test the two G650 meters first (the CVM followed by the turbine meter) and then the G100 CVM meter, leaving the G2500 turbine to the last. The tests were all carried out in July 1984 using the critical-flow nozzles calibrated by the weighing technique as the reference standards.

The only comment recorded by NEL of the tests was that at higher flowrates, for example for the NSM G2500 turbine meter, it was not always possible to meet the criteria that the difference between the temperatures at the meter inlet and outlet should not exceed 0.5°C and that the variation in temperature during a test point should not be greater than 0.3°C. Thus, some additional uncertainty had to be attributed to these results.

The two NSM meters were returned to Dordrecht after they had been tested in Germany and the UK and were recalibrated in August 1984 before being sent on to Paris. Repeatability at NSM was again very good, and the agreement with the first set of calibrations was excellent: the results were within 0.05% in almost all instances. The complete package containing the NSM meters and pipework, was then transported to the test laboratory of Flonic Schlumberger, who had agreed to undertake the tests on behalf of SIM. The PTB meters were sent direct from NEL.

The CVM G650 gas meter was calibrated in Paris in September 1984 using a bell prover and a reference volume of 10 m^3 (giving 10,000 pulses). A small variation in the recorded barometric pressure (101.4 to 100.85 kPa) during the course of the calibration was thought to explain the observed variations in the pressure measurements at the "standard" reference meter between the tests at 850 m^3/h and 200 m^3/h in the third test series.

No anomalies were found when the spin and leakage tests on the PTB G650 turbine meter were carried out, and a running-in time of 1 h at maximum flowrate was followed as prescribed. Schlumberger Fluxi G650 and G160 meters were used as references for the calibration. The ambient temperature was stable to within 0.2°C, and the atmospheric pressure was also virtually constant at 101.14 to 101.11 kPa.

Again, no abnormalities were found when the NSM meters were tested. It was noted that the atmospheric pressures varied between 98.98 and 98.57 kPa during the tests on the G2500 turbine meter, and was thought to account for the variation found between the test results at 1000 m^3/h and at 800 m^3/h.

When the gas meters arrived at the laboratories of the Service de Metrologie in Brussels, the pressure drop for the PTB G650 CVM meter was determined after an hour's running-in at 900 m^3/h, and leakage was found to be negligible. The PTB G650 turbine meter was not tested. For the NSM G100 CVM gas meter, after the first two series of tests had been completed, a second leakage test showed a leak at a valve shaft in its open position amounting to 0.45 mole of air per hour. A correction was therefore made in the calculations of the meter error.

The facilities at SMB are smaller than those at the other laboratories, so it was only possible to test the G2500 meter over part of its total range. It was noted as a general point that since all measurements of temperature and pressure were made by hand, meaningful measurements became more difficult as the flowrate increased.

Final test phase

The PTB meters were recalibrated in October–November 1984 at the PTB on their return from France, and it was found that both meters showed a slight upward shift from the earlier calibrations. For the turbine meter this same trend had been observed with successive tests since its first use in 1979, so it was not unexpected; in the CVM meter, however, the shift took the calibration back to that found in the August 1983 calibration. It was the view of the PTB therefore that the results of the calibrations carried out at the beginning and end of the intercomparison campaign were within the tolerances to be expected of such industrial-type transfer gas meters.

The G650 CVM gas meter, which was then sent to the Belgium Service de Metrologie, was again recalibrated at the PTB in March 1985 after its return. The results for the first two series of tests (with ascending and descending flowrates) were found to be within 0.06% of the results obtained the previous November, and it was not felt necessary to continue any further.

After being tested for SIM in the Flonic Schlumberger facility near Paris and at SBM in Belgium, the two NSM meters were again recalibrated at Dordrecht in the NSM facility in August 1985. The results for the G2500 turbine meter (Figure 3) showed a substantial shift over the whole flow range. The calibration characteristic of the G100 CVM meter was unchanged from the two previous calibrations, so the stability of this meter and of the small test facility was confirmed. Also no relative changes between the small and large NSM facilities had been observed since the previous tests.

When the G2500 meter was examined, it was seen that the

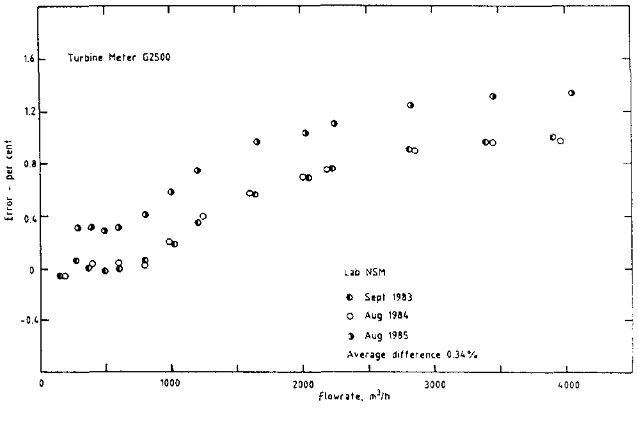

Figure 3 Calibrations of G2500 turbine meter at NSM, Dordrecht

Table 3 Mean test results for G100 CVM gas meter

PTB		NSM		NEL		SIM		SBM	
Flow	Error	Flow	Error	Flow	Error	Flow	Error	Flow	Error
160	0.59	160	0.69	160	1.06	160	0.62	159	0.43
149	0.59								
132	0.56	130	0.61	135	1.04	136	0.62	131	0.38
111	0.52	110	0.60	111	1.01	112	0.58	110	0.31
100	0.48	90	0.53	89	0.95				
73	0.41							84	0.27
65	0.37	65	0.45	65	0.67	64	0.41	65	0.14
50	0.31			52	0.68	48	0.39	50	0.07
40	0.26	40	0.27	40	0.60	40	0.34	40	0.00
33	0.16					32	0.23		
25	−0.01	25	0.11	28	0.30			25	−0.17
16	−0.25	16	−0.08	16	0.31	16	−0.08	16	−0.40
10	−0.65	10	−0.40						
		5	1.27						

Table 4 Mean test results for G650 CVM gas meter

PTB		NSM		NEL		SIM		SBM	
Flow	Error	Flow	Error	Flow	Error	Flow	Error	Flow	Error
1004	−0.09	1000	−0.10	993	0.08	1000	−0.16	991	−0.26
		910	−0.05						
795	0.03	800	−0.01	850	0.21	850	−0.06	835	−0.21
		700	0.06	697	0.39	700	−0.02	713	−0.10
603	0.17	610	0.13						
500	0.21	500	0.17	546	0.57			547	0.04
405	0.28	400	0.21	396	0.50	400	0.04	400	0.06
353	0.29	360	0.24						
293	0.32	300	0.24	322	0.50	300	0.04	321	0.14
247	0.30	250	0.26	247	0.45	250	0.06	252	0.13
200	0.31	200	0.27			200	0.10		
151	0.28	150	0.26	175	0.65			174	0.10
		130	0.23						
101	0.20	100	0.15	100	0.78	100	−0.11	100	−0.01
73	0.06	90	0.10						
50	−0.20	60	−0.14					51	−0.32
34	−0.56	50	−0.32						

Table 5 Mean test results for G650 turbine meter

PTB		NSM		NEL		SIM	
Flow	Error	Flow	Error	Flow	Error	Flow	Error
1004	0.28	1000	0.37	998	0.17	1000	0.08
		920	0.36				
796	0.31	810	0.31	848	0.19	850	0.07
		710	0.30	701	0.33	700	−0.01
498	0.16	590	0.26	549	0.36		
404	0.15	500	0.21	400	0.37	400	−0.24
353	0.13	390	0.14				
292	0.14	300	0.14	324	0.41	300	−0.17
246	0.23	250	0.21	249	0.36	250	0.25
200	0.39			175	0.77		
152	0.70	150	0.71				
102	1.28	100	1.30	100	1.53	100	1.10

turbine rotor had been damaged and that the seals were missing from the mechanical counter. The NSM was convinced that the meter had been in good condition when it had left Dordrecht after the first recalibration, so any inteference must have taken place subsequently.

From the 550 results taken during the campaign, the mean values obtained for each of the four gas meters are tabulated in Tables 3–6. They are collectively graphed in Figures 4–7.

Analysis of results and discussion

Results

The number of test points listed in Tables 3–6 varies from laboratory to laboratory. This is partly because the required minimum number was exceeded in most instances, but mainly because of the extra recalibrations carried out by the PTB and the NSM. The Netherlands Service of Metrology decided that since their final recalibration of the G2500 turbine meter showed that a shift had taken place in the characteristic, the mean declared values for their tests on this gas meter excluded the data obtained in the final tests. In the list of NSM data points in Table 4, therefore, the values given are for the original calibration plus the first recalibration only.

Table 6 Mean test results for G2500 turbine meter

PTB		NSM		NEL		SIM		SBM	
Flow	Error	Flow	Error	Flow	Error	Flow	Error	Flow	Error
4047	0.84	3980	1.00	3988	0.94	4000	1.00		
3712	0.81								
3413	0.76	3400	0.97	3393	1.03	3400	0.98		
3110	0.75								
2810	0.73	2810	0.91	2803	1.11	2800	0.97		
2510	0.69								
2206	0.60	2210	0.76	2222	0.90				
1903	0.52	2010	0.69						
1604	0.39	1610	0.56	1586	0.67	1600	0.70		
1282	0.22	1200	0.35	1304	0.45	1200	0.45	1338	0.82
1006	0.15	1000	0.20	1002	0.30	1000	0.41	1003	0.43
794	0.10	800	0.05	698	0.16	800	0.20	798	0.22
		600	−0.01						
		500	−0.02						
402	−0.09	400	0.01	397	0.08	400	−0.04	394	0.02
		290	0.06					297	−0.07
		200	−0.07					200	−0.13

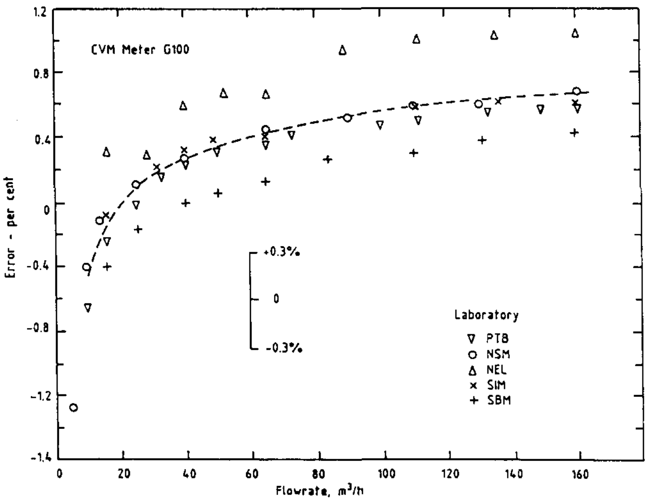

Figure 4 Calibrations and fitted curve for G100 CVM meter

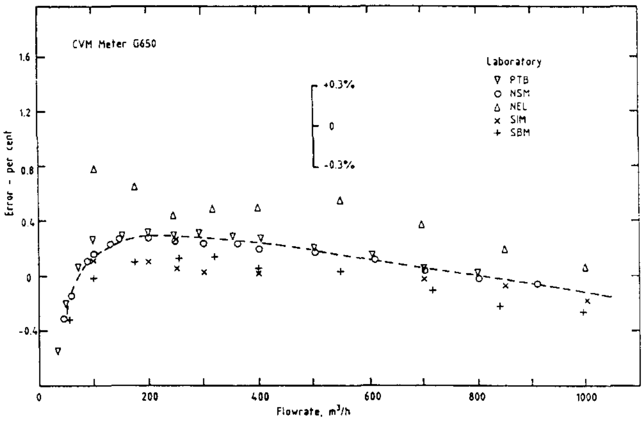

Figure 5 Calibrations and fitted curve for G650 CVM meter

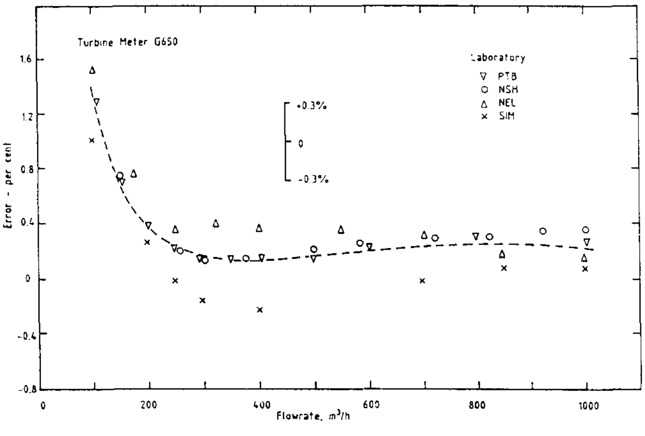

Figure 6 Calibrations and fitted curve for G650 turbine meter

Curve fitting

From the compilation of a data bank of the complete set of flowrate/error values, as listed by the participating organizations in their reports, polynomials were fitted by the method of least squares. The selected polynomial was of the form

$$y = f(x) = P_1 x^{m1} + P_2 x^{m2} + P_3 x^{m3} + P_4 x^{m4}$$

where y = percentage error
x = flowrate in cubic meters per hour
P_i = parameter to be adjusted
mi = appropriate power: $m1 = 0$, $m2 = -1$, $m3 = 1$, $m4 = 2$

The computed values of the P parameters in the equations fitted to the data given in Tables 3–6 are given in Table 7.

The curves represented by the above equations are plotted in Figures 4–7 for each of the gas meters together with the data points listed in Tables 3–6.

Discussion of CVM meter results

Examining each of these figures in turn, we see in Figure 4, which deals with the small G100 CVM meter, that there is very close agreement between the SIM, PTB, and NSM results. The NEL results are systematically about 0.4% higher than the fitted curve, and the SMB results systematically 0.25% lower.

Figure 5 shows the results for the G650 CVM gas meter and, similar to those of the G100, the NEL results are systematically higher than the fitted curve, but this time by about 0.3% on average. The SMB results are also closer to the fitted curve than for the G100 meter, but are again systematically below the curve with an average bias of a little over 0.15%. The SIM results agree with the PTB and NSM results at the upper and lower ends of the flow range, but diverge by up to 0.2% in the middle of the range.

It may be concluded from these intercomparison tests on the two CVM gas meters, that the range covering the entire set of results is, if the results from NEL are excluded, 0.3%. This is the target level originally aimed at to provide assurance that the calibration results at any two facilities should not differ by more than this value of 0.3%. The NEL results are only marginally outside this target if the comparison is being made between the NEL and three of the other four facilities, but if results of meters calibrated at NEL and the SMB facilities were being compared then a serious difference could exist.

Discussion of turbine meter results

Figure 6 shows the results for the G650 turbine meter, only four laboratories having carried out tests on this meter. The agreement between PTB and NSM was again very good, as would be expected in view of their previous intercomparison program. The SIM results are seen to be systematically about 0.3% below the fitted curve, and the NEL results are generally above the curve by up to 0.2% but are within the experimental scatter of the curve at the upper end of the flow range.

The results for the large G2500 turbine meter are shown in Figure 7, and the pattern here is at variance with the results for the other three meters. The results of four of the five laboratories agree quite well, but the exception this time is the PTB calibration. The PTB data points lie systematically below the fitted curve over almost the whole range by about 0.15%. Though the PTB and NSM results are still within about 0.2%, this time the SIM and SMB results lie above those of the PTB instead of below.

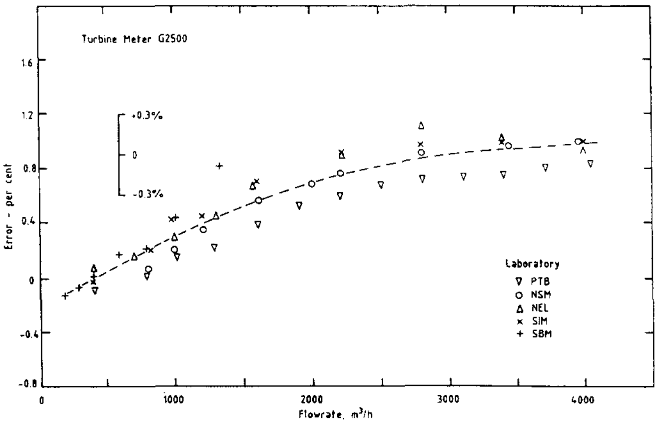

Figure 7 Calibrations and fitted curve for G2500 turbine meter

Table 7 Parameter values for curve-fit equations

Gas meter	P_1	P_2	$P_3 \times 10^{-3}$	$P_4 \times 10^{-6}$
CVM G100	0.2925	−8.073	5.027	−14.589
CVM G650	0.6334	−41.236	−73.916	0.0442
Turbine G650	−1.3767	245.820	2.847	−1.4895
Turbine G2500	−0.3040	10.719	0.683	−0.0946

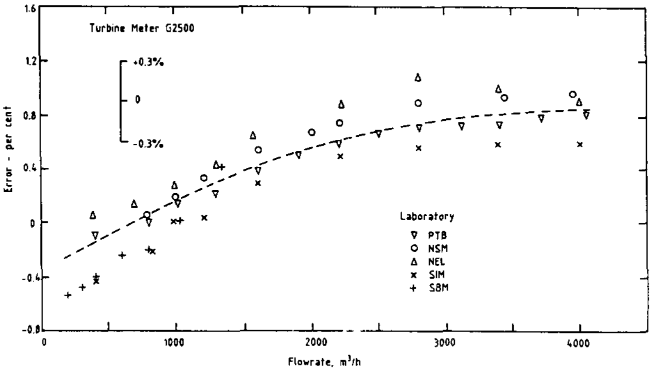

Figure 8 Calibrations (including midway shift) and modified fitted curve for G2500 turbine meter

This anomaly can be resolved if it is accepted that the G2500 turbine meter was damaged prior to the tests at SIM and SMB, and therefore that the shift of the characteristic had taken place before the SIM tests had started. The SIM and SMB results should then be compared with the final NSM recalibration data and not with the values presented on this graph. As seen from Figure 3, this will result in a downward shift of 0.4%, which will drop these SIM and SMB results to below the PTB values.

There can be no definite confirmation that this is the true situation, but there is additional circumstantial evidence for the date of the damage, since the results of the other meters agree in their lower flow range. If, then, it is taken as the likeliest explanation, the fitted curve to the modified set of results will be changed. Since a total shift of 0.4% for the recalibration will affect results over the whole range of flowrates equally, a quick assessment of the modified fitted curve can be obtained by changing only the parameter P_1. Such a change affects all points equally, raising or lowering the curve bodily, and the amount can be estimated by calculating the average shift on all data points to balance the 0.4% shift on the SIM and SMB data points. The P_1 parameter is then shifted down by 0.13%.

A fresh plot of the G2500 results is shown in Figure 8. It can be seen that the general pattern is then consistent with the results obtained for the other meters in this campaign.

Irrespective of this modification to the G2500 results, the total range covering all the results for the two turbine meters as shown in Figures 6 and 7 (or Figures 6 and 8) is again 0.7% as with the CVM meters. This time, however, it is the SIM results for the G650 meter which show the maximum bias, and if these SIM results are excluded then the range covering the remainder drops to 0.4%, neglecting a few wild points. This is not quite as good as for the CVM meters. It might be concluded that turbine meters may be more affected by the flow conditions in the different test sections, but further tests would need to be carried out to prove this conclusion. The pattern of both the CVM and turbine meter results is very similar.

General

The overall picture which emerges from this campaign is that the calibrations of these four gas meters were highly repeatable at each laboratory separately, both in the short term during a succession of tests carried out while the meter remained installed in the one facility and in the long term when a meter was brought back to the same test facility for recalibration.

The very close agreement between the calibration results obtained by the PTB and NSM for three of the four meters was not unexpected, since these laboratories had demonstrated good agreement from previous intercomparisons. Even in the case of the fourth meter the mean difference was only just over 0.15%. That their results also lie very close to the fitted curve for the gas meters must be regarded as in some degree fortuitous, since this came about because the results from the other laboratories lay on either side of the PTB/NSM results. If instead the NEL and SMB results had both had a bias in the same direction, the fitted curves would have shifted away from the PTB/NSM results.

The general shapes of the characteristic curves for each gas meter, though differing from meter to meter, were quite closely replicated by all the laboratories. Thus the differences in the results from one laboratory to another are broadly systematic over the whole flow range. It may be concluded therefore that the differences do not significantly depend on flow or Reynolds number over the meter's flow range. Indeed, the causes of these shifts between the various results must be attributed either to a systematic bias in the flow standards in the calibration facility or to an effect of turbulence or distribution of the fluid flowing in the test section on the particular gas meter. A further program of more controlled tests would be required with a number of different meters to establish the primary causes and amounts of the shifts noted above.

To illustrate that the results of this campaign are homogeneous for all four meters when treated globally, we have prepared Figure 9. The differences shown were determined between the data points and the fitted curves shown in Figures 4–6 and between the G2500 data points, with the SIM and SBM points corrected by the 0.4% shift and the fitted curve modified by a shift of 0.13%, as shown in Figure 8. These differences have then been plotted in Figure 9 against the flowrate (on a logarithmic scale) for each laboratory in turn so that the relationships can be seen more clearly.

The scatter of the NEL results for all four gas meters is of the same order for each meter, being ±0.2% about the average offset from the fitted curves. The reduction of the bias from 0.4% for the G100 CVM meter to about 0.2% for the G2500 turbine meter is not very marked, but clearly a general shift of just over 0.25% would bring all the results into line with the estimated true characteristic of the four gas meters.

The scatter on the PTB results is significantly less at about ±0.1%. This time there is a very slight difference between the G100 meter results, which are low, and the rest, but this is within the uncertainties on the fitted curves themselves.

The NSM results are similarly scattered at no more than ±0.1%, with the difference on the G2500 turbine seen to be increasing with flowrate.

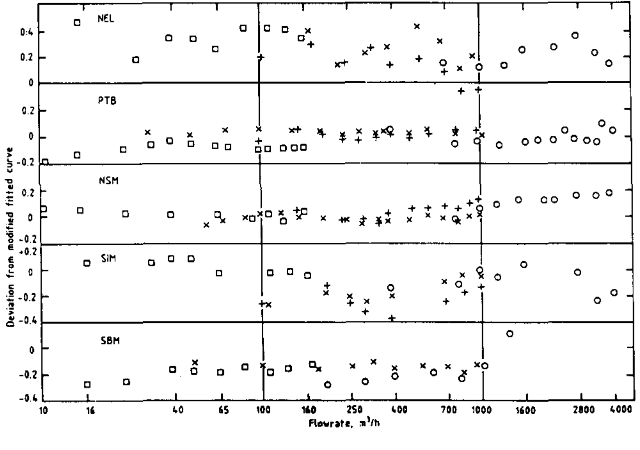

Figure 9 Differences from fitted curve for all gas meters using modified fitted curve for G2500 turbine meter

The S-shaped pattern of the SIM results at different flowrates may be attributable to variations of the characteristics of the reference standards which were used for different parts of the whole flow range. Though the scatter can be said to be within the uncertainties of the fitted curves, nevertheless the fluctuations shown by the S-shape do result in fairly significant offsets over certain sections of the flow range.

Finally, the SBM laboratory results are again quite consistent over the range, with just one outlier at the highest flowrate measured. The latter is not unexpected, since the SBM personnel had said before the tests started that the upper end of the G2500 turbine meter range was outside the limits of their test facilities. The remainder of the SBM results are within a scatter of ±0.1% but are almost 0.2% below the fitted curves. As with the NEL results, if a shift of this order were to be applied to the complete set of results, the agreement with the fitted curves would be excellent.

Conclusions

A gas meter intercomparison campaign carried out with the cooperation of five EEC laboratories has been successfully completed. Two CVM meters and two turbine meters were used, with three of the four meters showing virtually identical characteristics when they were recalibrated at the end of the campaign with those found at the beginning. The fourth meter repeated its calibration when retested halfway through the campaign, but the final recalibration showed a shift of 0.4%. This was attributed to damage to the meter.

The repeatability of test points at all five laboratories was good, being within 0.1 to 0.2% for nearly all the data. The results obtained by all the laboratories for any one meter gave similarly shaped characteristics (though these differed from meter to meter), and this made the intercomparison much easier to analyze, for the differences between the laboratories' results could be seen broadly as simple shifts over the whole range. In 22 of the 36 cross-combinations tested, the agreement between each pair of laboratories was within 0.3%. The overall spread, however, was up to 0.7%, one laboratory getting consistently higher (0.25%) and another consistently lower results (0.2%) than the mean fitted curves.

The campaign has been of considerable value in identifying confidence levels in the various facilities and calibration procedures. More work needs to be done to elucidate the anomalies found in some of the results, but because the pattern of the shifts between the results obtained at the various laboratories was reasonably consistent, it is probable that most of the bias, which has remained undetected until this campaign, is in the reference flow measurements at these laboratories.

Acknowledgments

This intercomparison campaign was undertaken as part of the Applied Metrology Programme of the EEC Commission's Bureau of Community Reference, and it received financial and technical support from BCR. The willing cooperation of the staff from all the participating organizations is gratefully recognized, especially the contribution of Dr. P. M. A. van der Kam, NSM, in the analysis.

This paper is published by permission of the Commission's Head of the Bureau of Community Reference, Dr. H. Marchandise.

References

1 Directive of the EEC Council on Industrial Gasmeters, No. 71318 CEE

2 Report on EEC Intercomparison Campaign on Industrial Gasmeters. Physical Sciences Report No: EUR-Brussels: EEC Commission, 1987