An Inter-comparison of High Pressure Gas Facilities at Six European Laboratories Using a Turbine Meter and a Venturi Meter Calibration Package (EUROMET Project No 474)

A Report for

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

Project No: FMMC70100

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Approved by: Mr R Paton

Date: 29 August 2000
for Dr F C Kinghorn
Director

EXECUTIVE SUMMARY

This report describes the results from the inter-comparison of six high pressure flow facilities in Europe. The organisations taking part in the project were NEL (UK), K-Lab (Norway), NMi (The Netherlands), Gaz de France, CESAME LN Ouest (France) and PTB/Ruhrgas (Germany). The project was registered with EUROMET as Project Reference 474.

A transfer package was designed and assembled at NEL. The package consisted of a 6 inch turbine meter and a 6 inch Venturi (β=0.6) with associated pipework.

Overall the inter-comparison demonstrated that good agreement between laboratories was achieved. For the turbine meter all data points were within a band of ±0.40 per cent. The results from the Venturi showed poorer agreement with differences, at low Reynolds number, between laboratories of up to ±0.75 per cent on the discharge coefficient but this improved to ±0.15 per cent at higher Reynolds numbers.

All the data supplied by the participating laboratories and a full analysis of the data is contained in the NEL Report No 305/99 entitled “Inter-comparison Work for 1996-1999 Flow Programme” and is available on Compact Disk.

CONTENTS

1 INTRODUCTION

This report describes the inter-comparison of high pressure gas facilities at six European laboratories. The aim of the project was to ensure that there is good agreement between national laboratories. All the organisations participating are members of EUROMET. The project was registered with EUROMET as Project Reference No 474.

The transfer meter was circulated in the following order:

NEL	United Kingdom	January 1999
K-Lab	Norway	March 1999
NMi	The Netherlands	May 1999
G de F	France	October 1999
CESAME	France	November 1999
PTB	Germany	February 2000
NEL	United Kingdom	April 2000

PTB used the Ruhrgas Pigsar facility based at Dorsten.

These National flow laboratories are involved in the maintenance of national standards for flow measurement and in the metrological control of revenue meters in their respective countries.

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 No 305/99 “Inter-comparison Work for 1996-1999 Flow Programme”. This is available from NEL as a CD-ROM. This CD includes the reports of all other inter-comparisons carried out within the 1996-1999 Flow Programme.

2 CALIBRATION PACKAGE

The calibration package used in the inter-comparison consisted of a turbine meter and a Venturi with associated pipework (Figure 1).

The turbine meter used was an Instromet type SM-1-XE.

Model No:	G650
Serial No:	62423
Nominal bore:	150 mm
Max pressure:	70 bar g
Max flowrate:	1000 m^3/h
Pick-up:	high frequency
K –Factor:	3850 pulses/m^3

The Venturi was manufactured by ISA Controls Ltd and has a machined finish. Details of the Venturi are as follows:

Serial No: A0-FM-2893-A

Inlet dia: 154.03 mm

Throat dia: 92.40 mm

Beta ratio: 0.5999

Flanges: ANSI 600

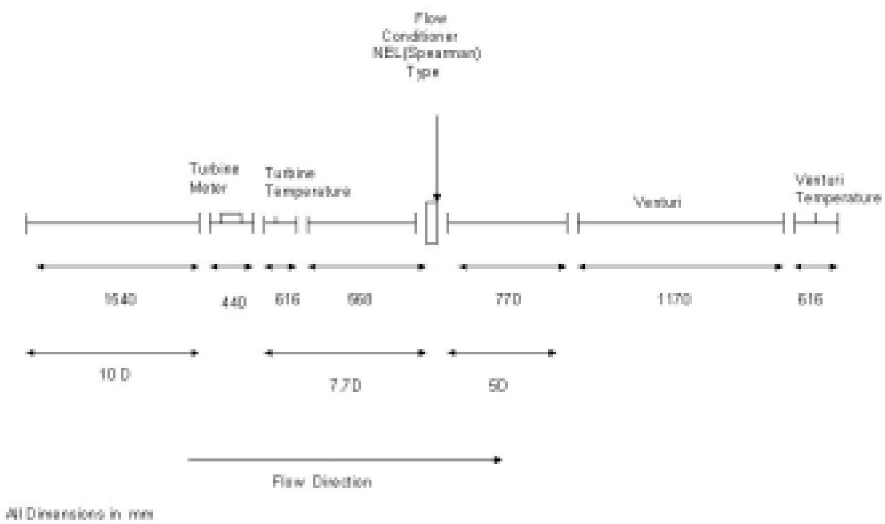
Max Pressure: 70 bar

Four equi-spaced pressure tappings were located at both the Venturi inlet and throat to allow the differential pressure across the Venturi to be measured.

An NEL flow conditioner was placed between the turbine meter and Venturi meter at a distance of 7.7D from the exit of the turbine meter and 5D upstream of the Venturi.

FIG 1

DETAILS OF HIGH PRESSURE CALIBRATION PACKAGE



3 DETAILS OF FACILITIES

3.1 NEL

NEL has a closed re-circulating test loop. For the initial calibrations the loop was used with air as the test gas. While the package was being circulated around the other laboratories, the loop was modified to give a capability for testing with 'wet gas' two phase mixtures using kerosene as the liquid. For safety reasons, this has resulted in a change of the test gas to Nitrogen for both 'dry' and 'wet' gas testing. The loop can be pressurised to between 10 and 68 bar and the gas circulated around the loop by a high pressure blower. The temperature is controlled by means of a heat exchanger.

The reference meter for the test loop is a 150 mm turbine meter. The frequency output from the meter was measured to give the reference flowrate.

Static pressure at the reference turbine and Venturi was measured using Yokogawa pressure transmitters. A Mensor pressure gauge was used at the test turbine. The differential pressure across the Venturi was measured with a Yokogawa pressure transmitter in the 40 and 60 bar tests and a Mensor pressure gauge in the 20 bar tests.

The temperature at the 3 meters was measured using PRTs.

All instrumentation was traceable to National standards in UK and the Netherlands and the facility is accredited by UKAS. Due to the calibration cycle, one reference turbine meter was used for the initial test and a second for the final test. Both meters were calibrated by NMi at their Bergum facility.

The uncertainty associated with the measurement of mass flow rate is estimated to be 0.4 per cent.

3.2 K-Lab

K-Lab has a closed test loop using natural gas. The temperature is controlled by means of a heat exchanger and the gas is circulated around the loop by a centrifugal compressor.

The reference system is a bank of 8 sonic nozzles of differing capacities, which are installed in parallel. The reference mass flowrate through the sonic nozzles is calculated as per ISO 9300 and is converted to volume flow rate at the conditions of the turbine and Venturi, using the density calculated from AGA 8 (1985). The expanded uncertainty is 0.3 per cent for the mass flow and 0.4 per cent for volume flow.

The sonic nozzles are calibrated on a gyroscopic balance weight system, which is accredited by the Norwegian Metrology and Accreditation Service.

3.3 NMi

The high pressure test facility at Bergum is owned by NMi. The test installation is built in parallel with the gas supply metering station to a 660 MW electric power plant. The test facility has an operating range of 9 – 51 bar. The maximum flow rate is 90000 nm^3/h for pressures up to 21 bar and 130000 nm^3/h for pressures between 21 and 51 bar.

The test facility has the following reference meters:

4 turbine meters with a maximum flow of 4000 m^3/h,
1 turbine meter with a maximum flow of 2500 m^3/h,
2 turbine meters with a maximum flow of 1000 m^3/h,
1 turbine meter with a maximum flow of 160 m^3/h, and
1 turbine meter with a maximum flow of 100m^3/h.

The reference meters are calibrated at 9, 21, 36, and 51 bar. The meter factor of the reference meters at pressures between the calibration pressures is obtained by interpolation in an error plot in which the calibration curves are plotted against the Reynolds number corresponding to the flow rate. The calibration is via a traceability route from air bell provers to rotary gas meters.

The gas entering the test installation passes through two safety shut off valves, a filter and a heat exchanger before it reaches a two-stage pressure reducer. This reducer controls the test pressure. After the reducer there are five parallel test lines. After passing the meter under test, the gas flows through one or more reference gas flow meters and then the pressure is reduced and the gas returned to the supply lines of the power plant.

3.4 Gaz de France

The flow metering test facility "COKE" of the "Metering and Network Auxiliaries Section" of Gaz de France Research Division has been certified by the COFRAC (No 2.1195) and the Bureau de Métrologie (BNM). The flow references are traceable to the national primary test bench "PISC".

The calibration method is based on the assessment of the mass flow rate using Venturi nozzles operated at sonic conditions. The mass flow through the set of 7 nozzles is determined from the upstream stagnation pressure and the upstream density. The flow coefficients of each nozzle are determined beforehand by an individual calibration. The mass flow indicated by the test device is determined from the pressure and temperature measured at its location, the raw flow indicated by it and the density that is measured upstream of the nozzles. Real gas effects are taken into account by applying compressibility factor corrections for the thermodynamic conditions at the measurement locations. These various measurements and calculations allow the reference and test device mass flows to be compared and thus to determine the device deviation.

The bench uses natural gas supplied by GdF's network as the test fluid.

The facility has a flow range of between 9 and 40000 m^3(s)/hr.

The facility has a relative pressure range of 0.1 – 30 bar. The gas temperature is controlled at 20±2ºC.

The uncertainty associated with the measurement of mass flow on the COKE facility is 0.31 per cent.

3.5 CESAME LNE Ouest

CESAME LNE Ouest is a national non-profit organisation independent of Gaz de France.

The transfer package was calibrated in dry air on the test bench used for gas flow meter calibrations, at the CESAME LNE Ouest premises in Poitiers. The bench has been certified by the COFRAC (No 2.1320) and the BNM.

The reference meters used for the calibration are a set of sonic nozzles. These nozzles are calibrated on GdF's primary test bench in Alfortville. The nozzle equations used for the calibration are provided by the ISO 9300 standard. The critical flow function C^* is calculated from CESAME's tables using the pressure and temperature measurements.

The CESAME facility has a pressure range of 1-50 bar and a flow range of 10 – 80000 m^3/h.

The uncertainty associated with the measurement of mass flow is 0.25%.

3.6 Ruhrgas

PTB used the Ruhrgas high pressure 'Pigsar' facility at Dorsten for this inter-comparison. This facility is the national standard for high pressure natural gas flow measurement. The test facility has a pressure range of 14 – 50 bar and a flow range of 8 to 6500 m^3/h.

The facility has a computer operated flow system that divides the gas into a test stream and a bypass stream. The gas first passes through the reference turbine meters and then through the meter under test. After passing through the test facility the gas flow rejoins the bypass flow. A set of turbine meters located in parallel lines act as the reference meters. The turbine meters are the following sizes and number, 4 off G250, 4 off G1000, 1 off G100.

In the first part of the calibration process gas is passed through a mobile piston prover with a downstream piston prover transfer standard. These are installed in parallel with the test meter.

The reference turbine meters are traceable to a high pressure piston prover.

The uncertainty associated with the measurement of volume flow is 0.2 per cent[(1)].

4 CALIBRATION PROCEDURE

4.1 NEL

The opening calibration at NEL was undertaken prior to major changes being made to the facility. In this configuration the reference turbine meter was downstream of the test package and an NEL (Spearman) flow conditioner was located 24D upstream of the test turbine meter.

The package was first calibrated at 60 bar then 40 bar and finally 20 bar. The minimum flow measured was 200 m^3/h due to the limitations in measuring the small differential pressure across the Venturi. At each pressure, measurements were taken at the lowest flowrate first and then the flow increased by increments until the maximum flowrate was achieved. The flowrate was then decreased to the middle of the flow range and the repeat points were taken at the different flowrates as required.

On return to NEL the package was installed in the refurbished facility. Nitrogen was the test gas instead of air used in the initial test. For these tests the reference meter was placed upstream of the test package. Again a turbine meter acted as the reference, but as the reference meters are changed through calibration cycles, a different reference meter was used due to the meter used in the initial test being unavailable.

For the final calibration an NEL flow conditioner was placed 20D upstream of the reference meter with a similar conditioner placed between the reference turbine meter and the test turbine meter at a location of 12D downstream of the reference meter and 38D upstream of test package.

The static and differential pressures at the Venturi were measured using a ‘triple-T’ arrangement.

Both the initial and final calibrations were carried out over a temperature range of 15 – 22ºC.

In the initial calibration the densities and expansibility were calculated using thermodynamic properties based on equations from Panasati et al[(2)]. For the final calibration using Nitrogen the densities and expansibility were calculated from the equations of state from Span et al[(3)].

4.2 K-Lab

The transfer meter was installed in a 6-inch test section and their normal transmitters used for measurement of pressure, differential pressure and temperature.

K-Lab measured the Venturi temperature in a spool piece downstream of the test package as they were unable to use the temperature tapping provided.

Two differential pressure transmitters were installed in parallel (range 0-52 mbar and 0-1000 mbar) at the 90 degree clockwise position of the Venturi pressure tapping seen in the positive flow direction. The results from the low range pressure transmitter were used when in range. The static and differential pressures were measured using a single tapping point on either side of the Venturi.

A test matrix based on the range of the turbine meter was set up with 10 different flow rates measured at the 3 different pressures. For each flow rate 3 consecutive runs of about 180 s were carried out.

All test points were carried out with the reference temperature in the range 29 – 37ºC.

4.3 NMi

In the NMi facility the test gas flows through the test meter and then through one or more of the reference meters. The calibration was carried out at pressures of 20, 40 and 50 bar. The reference meter and the test meter were operated at approximately the same pressure in order to avoid additional uncertainty from gas compressibility.

After the meter has been installed and conditioned, measurements are taken over a period of about 100 s or until at least 10,000 pulses from the high frequency counter (if available) have been recorded.

For differential pressure the mean values are determined over a period of 100 seconds.

The density of natural gas is determined from GERG Report, 8410-3, “Physical Properties of Natural Gases”, Gasunie , The Netherlands, 1988.

At 20 bar the temperature was in the range 21 – 23ºC while at 40 bar the temperature range was 29 – 31ºC and at 50 bar 31 – 35ºC.

The uncertainty associated with the high pressure test facility at Bergum is between 0.23% and 0.30% depending on the calibration pressure.

4.4 Gaz de France

The transfer package was set up in the COKE test line with a 50D length of pipework upstream and calibrated at a pressure of 20 bar. Three points were taken at each flow rate starting with the maximum flow and then gradually decreasing the flow to a minimum of 50 m^3/hr.

The compressibility factor Z of the gas was obtained using the GERG method from the molar gas composition as measured by a chromatographic device. The real gas coefficient (C_R) was determined using the ISO 9300/Johnson’s method, from the molar gas composition, the upstream pressure and temperature. As the density is not measured upstream of each nozzle, a temperature correction is made. C_R was used because it is less sensitive to variations in gas composition than the critical flow factor (C^*).

The temperature during the 20 bar calibration was 19 – 21ºC.

The density at the reference meter was measured using a density meter type AGAR 22722A11759, while the density for the transfer package was obtained from the thermodynamic conditions at the meters.

4.5 CESAME LNE Ouest

The calibration method used several sonic nozzles installed in parallel, as the reference flow meters, with pressure and temperature measured upstream of the nozzles. The meters under test were installed downstream of the reference nozzles on the long straight pipes. The calibration was performed using dry air supplied from compressors via two large storage tanks of 50 m^3. The bench operates in an open loop.

The tests were carried out at 40 bar only.

The reference volume flowrate was calculated from the reference mass flowrate determined by the sonic nozzle. The Reynolds number for the turbine meter was calculated using the nominal diameter of 150 mm, while for the Venturi meter the Reynolds number was based on the measured diameter of 154.03 mm. The dynamic viscosity was determined by the Sutherland equation.

The actual volume flow at the turbine meter was obtained by multiplying the measured frequencies by the nominal meter factor (3850 pulses/m^3).

The discharge coefficient was calculated in conformance with ISO 5167.

4.6 PTB/Ruhrgas

Ruhrgas encountered some difficulties in calibrating the Venturi meter and so withdrew the results for the Venturi from the inter-comparison.

The turbine meter was calibrated at 50 bar then 40 bar and finally at 20 bar. At all pressures the temperature was in the range 13 –16ºC.

4.7 PTB/NMi Harmonisation

An agreement exists between PTB and NMi that harmonises the value of the volume passed through the respective test facilities to an agreed common value. This ensures consistency of results between the two facilities. For this inter-comparison, NMi calibrated the meters before the harmonisation came into place, and PTB offered results with the harmonisation correction.

5 CALCULATION

Turbine Meter:

The error in the turbine meter was calculated as follows:

$$\text{Error} = \frac{K_I - K_N}{K_N} \times 100$$

or

$$\text{Error} = \frac{m_t - m_r}{m_r} \times 100$$

where K_I is the measured K factor (pulses/m^3),
K_N is the nominal K factor (pulses/m^3),
m_r is the reference mass flowrate (kg/s), and
m_t is the turbine meter mass flowrate (kg/s).

Venturi Meter:

The discharge coefficient for the Venturi meter was calculated as follows:

$$C_d = \frac{4m_r}{E\varepsilon\pi d^2\sqrt{2\Delta P\rho}}$$

where m_r is the reference mass flowrate (kg/s), and
E is the velocity of approach factor expressed as

$$E = \frac{1}{\sqrt{1-\beta^4}} \quad \text{and} \quad \beta = \frac{d}{D}$$

ε is expansibility expressed as

$$\varepsilon = \left[\left(\frac{\kappa\tau^{\frac{2}{\kappa}}}{\kappa-1}\right)\left(\frac{1-\beta^4}{1-\beta^4\tau^{\frac{2}{\kappa}}}\right)\left(\frac{1-\tau^{\frac{\kappa-1}{\kappa}}}{1-\tau}\right)\right]^{\frac{1}{2}}$$

where d is the Venturi throat diameter (m),
D is the Venturi pipe diameter (m),
ΔP is the Venturi differential pressure (Pa),
ρ is the density of the test gas (kg/m^3),
κ is the isentropic exponent, and
τ is the pressure ratio $\frac{P_2}{P_1}$.

Subscripts

1 refers to the cross-section at the plane of the upstream pressure tapping.
2 refers to the cross-section at the plane of the downstream pressure tapping.

6 RESULTS

All the tables of results and figures are available in NEL Report No 305/99 issued as a CD-ROM. Only figures and tables applicable to the conclusion are included here. The figure and table numbers refer to those provided in the full data set on the CD-ROM.

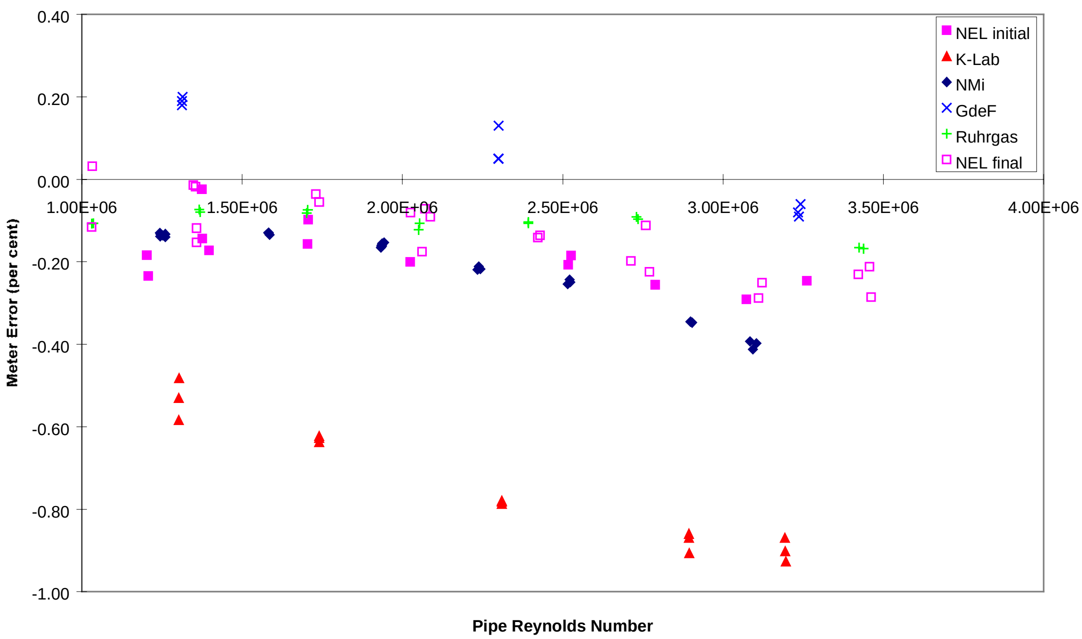
Retrospectively, it was decided to limit the minimum Reynolds number to 10^6 as this was the lower limit of the curve fit used with the NEL reference meter. The results from individual laboratories are presented in Figures 8 – 18, with the data given in Tables 1- 13 in NEL Report No 305/99.

The results from tests at 50 and 60 bar were combined in Figures 6 and 7. Ruhrgas withdrew their Venturi meter results from the exercise, because of their lack of familiarity with this type of device.

6.1 Turbine Meter

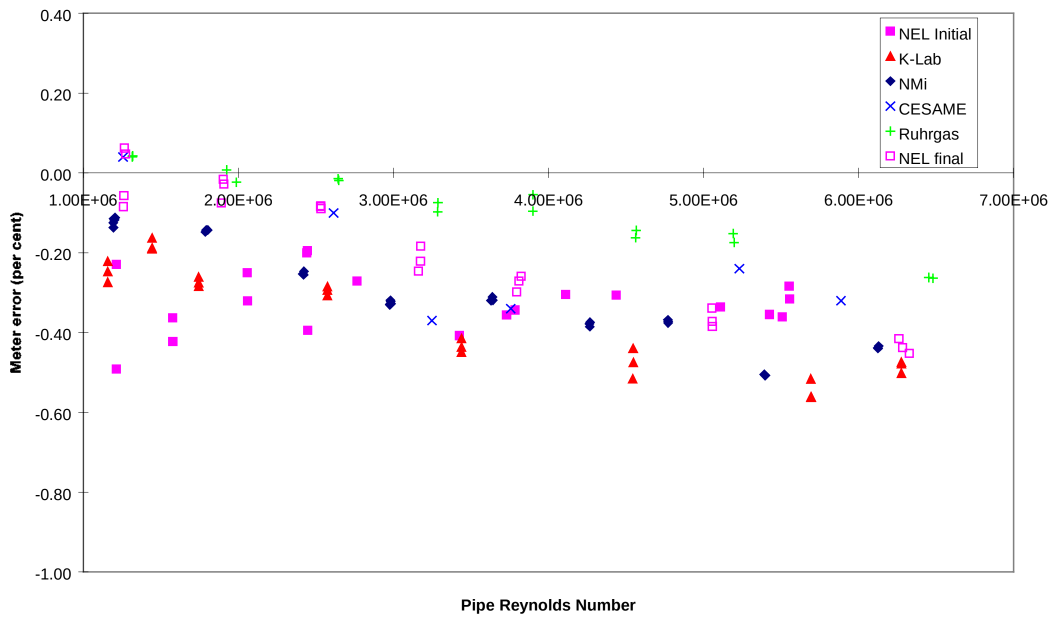
At 20 bar all laboratories are within a range of ±0.4 per cent and show a slightly falling trend as the Reynolds Number increases. If the results from K-Lab are excluded then the range decreases to ±0.2 per cent. There was no obvious reason for difference between K-Lab and the other participants and it should be noted that at other pressures K-Lab showed good agreement with the other participants. Normally K-Lab would not operate their facility at pressures as low as 20 bar.

Figure 2 - Turbine Meter Error at 20 bar for All Laboratories



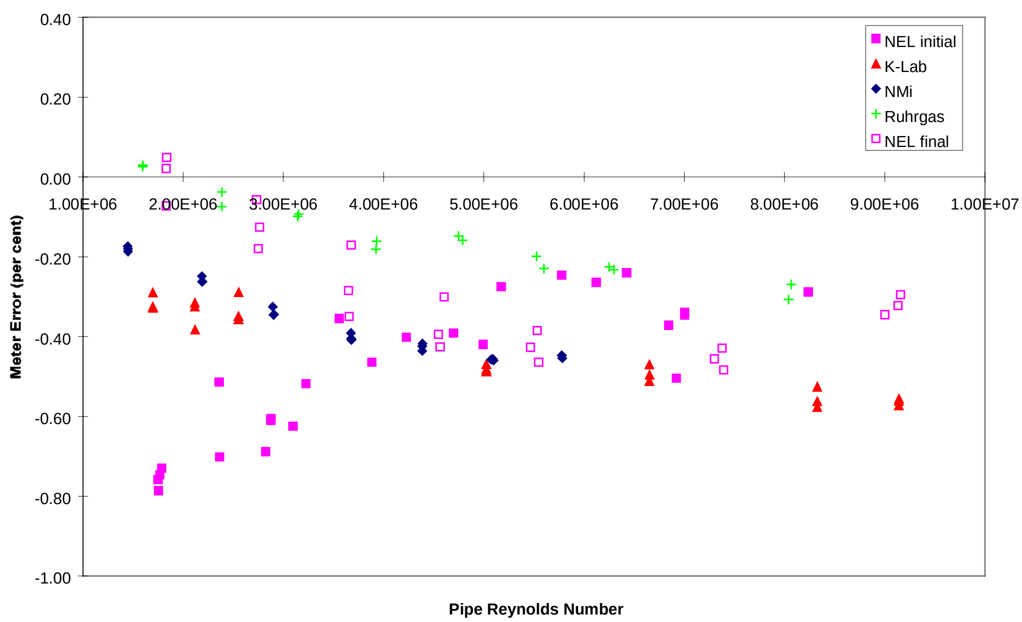
The results at 40 bar (Figure 3) show that all points lie within a range of ±0.3 per cent and generally show a downward trend as Reynolds Number increases. At lower Reynolds numbers there is some divergence between the initial and final calibrations with the final calibration following the same trend as the other laboratories while the initial calibration remained relatively flat over the Reynolds number range.

Figure 3 - Turbine Meter Error at 40 bar for All Laboratories



The results from CESAME at 40 bar show the mean values from their recorded data. The spread in the data of the other laboratories varies from less than 0.1 per cent from NMi to 0.3 per cent from the initial NEL calibration. This may reflect differences in the test procedures of the laboratories.

Figure 4 - Turbine Meter Error at 50/60bar for All Laboratories



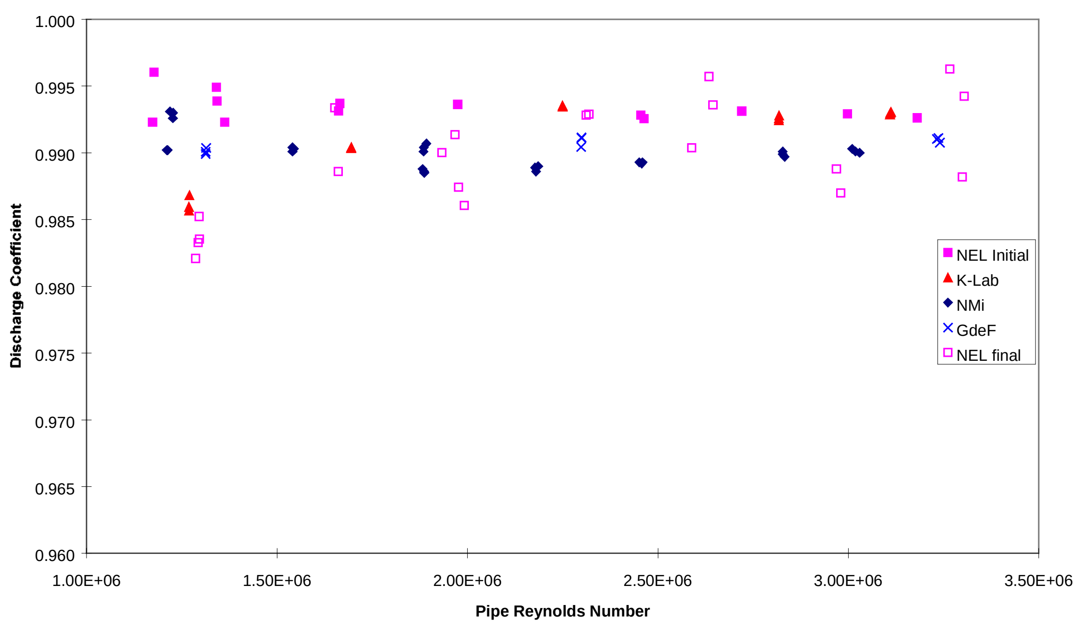
The calibration of the turbine at 50/60 bar g (Figure 4) shows a meter error which decreases as the Reynolds number increases, the exception being the opening calibration from NEL which gave an upward trend as the Reynolds number increased. No explanation could be found for this difference and the trend was not reproduced in the Venturi results implying that the divergence is a factor affecting the turbine only.

If the data from the NEL opening calibration below a Reynolds number of $3x10^6$ is excluded then all the data points are within a band of ±0.25 per cent. The spread in the data of the laboratories varied from better than 0.1 per cent for NMi and Ruhrgas to 0.2 per cent for the initial NEL calibration.

6.2 Venturi

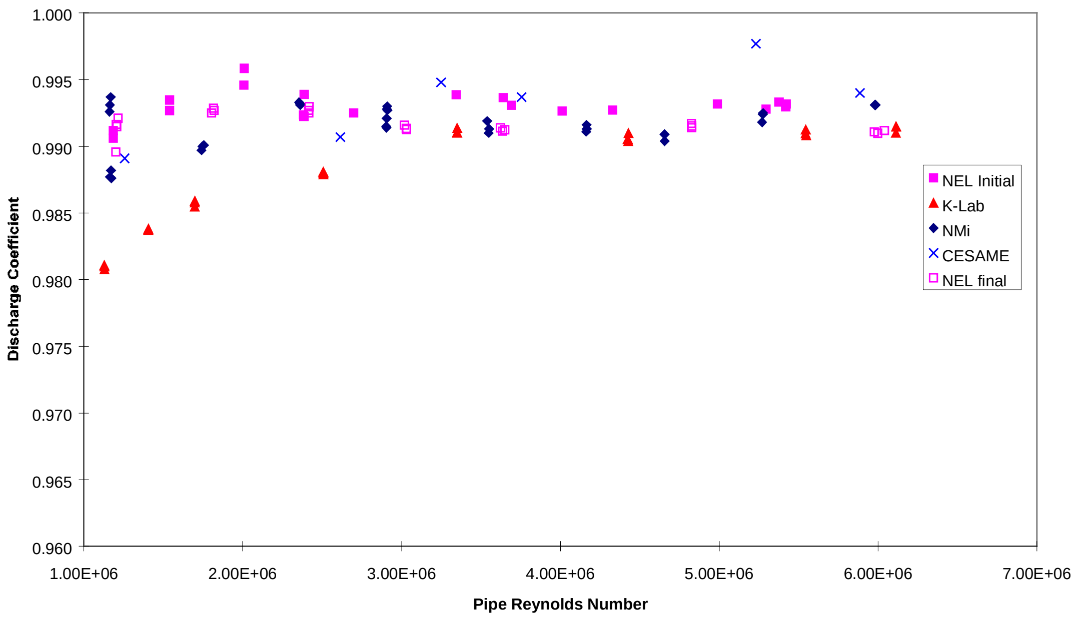
Figure 5 shows the Venturi discharge coefficient (C_d) at 20 bar, with most laboratories showing a flat trend, while K-Lab and the NEL final calibration show a small rising trend as the Reynolds number increases. At the lowest Reynolds number there is a spread of about 1.5 per cent in the C_d between participants. This spread reduces as the Reynolds number increases. The poor repeatability in the NEL final results was probably due to problems with the measurement of the Venturi differential pressure.

Figure 5 - Venturi Discharge Coefficient at 20 bar for All Laboratories



At 40 bar (Figure 6) all laboratories show a similar trend with the C_d increasing and then levelling off as Reynolds number increases. At lower Reynolds numbers the C_d obtained by K-Lab is slightly lower than the other laboratories. The data for CESAME shows the mean values. The spread in the C_d varies from 1.5 per cent at the lowest Reynolds number to 0.3 per cent at the highest Reynolds number. All laboratories show similar repeatability.

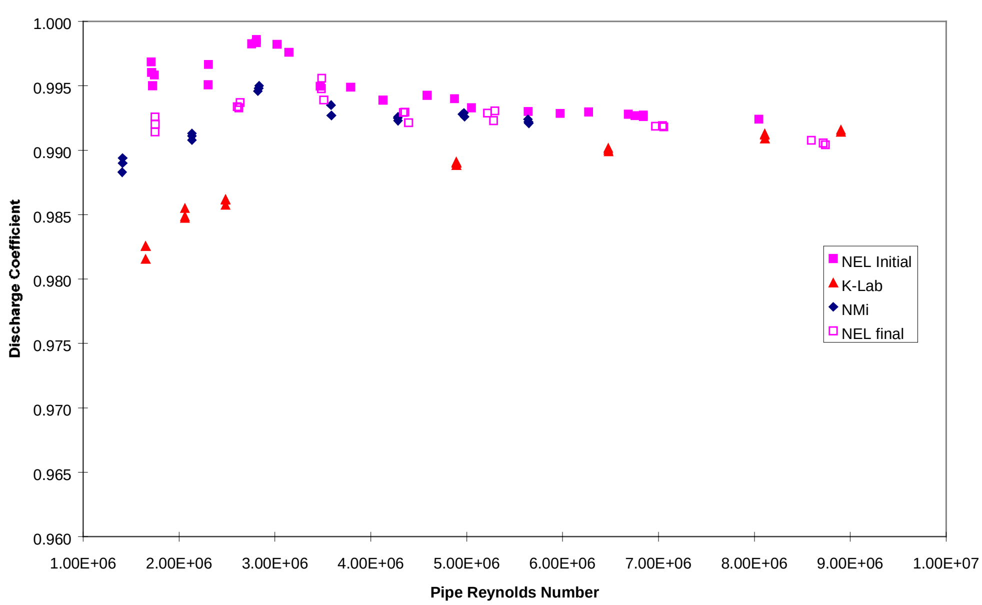
Figure 6 - Venturi Discharge Coefficient at 40 bar for All Laboratories



The initial 60 bar calibration at NEL (Figure 7) shows a peak in the C_d at a Reynolds number of 3×10^6. This peak is present, but to a lesser extent in the results from NMi and the final calibration from NEL. At low Reynolds numbers the results from K-Lab are slightly lower than the other laboratories and this may possibly be due to the way in which the Venturi pressure was measured. If the results from K-Lab below a Reynolds number of 3×10^6 are excluded then the spread in the Cd varies from 1.0 per cent to 0.3 per cent at the highest Reynolds number.

The final calibration from NEL and the NMi data show good agreement, while the initial calibration from NEL was slightly higher than the other laboratories. All laboratories show good repeatability at 50/60 bar.

Figure 7 - Venturi Discharge Coefficient at 50/60 bar for All Laboratories



The facility uncertainties quoted by the participants were in the range 0.3 to 0.4 per cent and so there is generally good overlap between laboratories.

7 CONCLUSIONS

The results from all the individual data points for the turbine meter lie within a range of ±0.4 per cent. If the results at 20 bar from one laboratory are ignored then the results from the turbine meter show agreement of ±0.3 per cent.

At low Reynolds number the difference in discharge coefficient between the laboratories was approximately ±0.75 per cent. This difference decreased to ±0.15 per cent as the Reynolds number increased.

The repeatability of laboratories based on the spread of the data points varied from better than 0.1 per cent to 0.3 per cent.

Overall the laboratories showed good agreement with each other, although there are some anomalies at the different pressures which cannot be fully explained at this time.

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Detailed Below is a List of Tables And Figures Provided In (NEL Report No 305/99).

LIST OF TABLES

LIST OF FIGURES

APPEDIX

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