A COLLABORATIVE PROJECT TO ASSESS A CORIOLIS METER INTERCOMPARISON PACKAGE

EURAMET PROJECT NO 1020

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Contents

1 INTRODUCTION

This project addresses the uncertainties involved when a flowmeter is calibrated using a different fluid from the working fluid. The main impetus for the work arose from concerns over potential uncertainties introduced through the practice in the UK of calibrating Liquid Petroleum Gas (LPG) flowmeters using water.

It has long been a concern to standards laboratories and industry alike that a flowmeter calibrated in one fluid may show a significantly different result when calibrated or used in a another fluid. The uncertainties arising from the effects of varying fluid properties may be significantly greater than the uncertainty attributed to the calibration of a flowmeter. For example, the fluid viscosity affects both the calibration and the characteristic curve of positive displacement and turbine flowmeters. In a standards laboratory the effect of fluid properties can sometimes be characterised, but this is not always possible within the limits of the laboratory's uncertainty claims.

Calibration of a flowmeter using LPG is both difficult and expensive. LPG is a vapour at ambient conditions, and in the liquid state must be contained in a closed pressure system. Measurement of liquid volume is difficult since either a piston prover or a pressurised volume tank must be used. Alternatively the difficulties of weighing a sealed weigh vessel have to be overcome. In each case there are significant safety issues. As a result reference flowmeters are used for LPG and are generally calibrated using water.

LPG trade meters (e.g. fuel dispensers) are typically calibrated in-situ against a reference meter that has been calibrated at a laboratory using water. There is therefore uncertainty over the transferability of the reference meter calibration from water to LPG. Alternatively, the reference meter can be calibrated using LPG, but there is also a lack of knowledge as to the accuracy of different calibration methods and standards. LPG calibration may be carried out by weighing or by volumetric means utilising either a piston prover or a pressurised volume tank. In any case the volatility of LPG introduces design problems and uncertainties not found with water.

The project was designed to address these concerns by assessing the performance of a reference meter in different fluids and using it to characterise different LPG calibration methods. A Coriolis mass flowmeter was chosen as the reference device in view of its increasing use in LPG measurements. Calibrations of Coriolis flowmeters are also believed to be relatively insensitive to the effects of variations in fluid properties.

The research presented in this report is the first phase of a European (EURAMET) collaborative research project between three National Measurement Institutes; TUV NEL (UK), NMi (The Netherlands) and CMI (Czech Republic). TUV NEL have reported the results to date which describe the findings of test programmes to assess the transferability of Coriolis flowmeter calibrations from water to a range of oils of varying viscosity.

2 COLLABORATION

2.1 Introduction

At an early stage in the project it was established that TUV NEL, the Netherlands Measurement Institute – Van Swinden Laboratory (NMi VSL) and the Czech Metrology Institute (CMI) were all starting similar projects with slightly different aims and objectives.

Discussions were initiated, and it was apparent that linking the three projects and exchanging data would provide significantly more information and confidence in the results than working separately. It was therefore agreed to combine resources and modify the planned project scopes where appropriate.

The project was accepted as a EURAMET collaborative research project; number 1020.

The TUV NEL project scope is summarised in 2.2. Project justifications and scope were provided by NMi VSL and CMI and are summarised in sections 2.3 and 2.4.

2.2 TUV NEL Collaboration

The background to the project from the TUV NEL perspective is basically in alignment with the overall project background as outlined in the Introduction above. The primary objective is to investigate the transfer of a calibration of a reference meter in a controlled fluid such as water or kerosene to LPG.

TUV NEL had already identified three collaborators within UK. National Weights and Measures Laboratory (NWML) had a project looking at the traceability and calibration for LPG dispensers. To this end NWML were working closely with a provider of on-site calibration services, John Wigfull and Co Ltd and the primary provider of LPG in UK, Calor Ltd. Both these companies were heavily committed to providing improved measurement of LPG product. Wigfull and Calor agreed to support the project by providing LPG facilities and a variety of calibration methodologies. TUV NEL would provide the transfer package and NWML would support the project through transfer of knowledge and provision of support for volume measures.

At the end of the project TUV NEL, NMi VSL, and CMI would each prepare their own reports but also provide a single compilation document summarizing the outcome which will be made public as a registered cooperation project within EURAMET.

TUV NEL offered to test the reference flowmeter in water, different oils, and LPG.

2.3 NMi VSL Project and Collaboration.

Netherlands Measurement Institute-Van Swinden Laboratory (NMi VSL) had two goals in the project:

- To investigate the shift in the results in transferring water calibrations to real product calibrations
- To answer the question “if a mass flow meter is used as a master meter for calibrating other flow meters on site, will a water calibration of the master meter be representative and provide adequate field accuracy”

The initial water calibration performance of the master meter would be determined by the manufacturer. It would then be checked at NMi VSL water flow test rig before the Mass Flow Meter is build into a skid. The complete skid would be tested in the same test rig at NMi VSL using the same references.

At NMi VSL, tests would be performed on Petrol, Kerosene, Diesel and Natural Gas to compare with the results of the water calibrations.

2.4 CMI Project and Collaboration.

The Czech Metrology Institute (CMI) had two goals in the collaboration project:

- To obtain test data to separate and determine temperature, density and viscosity effects on the calibration of Coriolis mass flowmeters. CMI hope that this will help prove the validity of accepting water calibration traceability of Coriolis mass flow meters used for high accuracy measurement of various liquids in the field (LPG, CNG, LPG, Ethylene, Hydrogen, Asphalt etc.). Many of these applications involve extreme conditions where there is no economic possibility to perform validation tests using calibration methods on site. The calibrations in water may also be used when Coriolis mass flow meters are used as master meters.

- To use the test data to establish uncertainty estimates that can be used in developing uncertainty budgets where Coriolis mass flow measurement is involved. There is no published, sophisticated and validated method of uncertainty evaluation where Coriolis meters are traceable to a water calibration and then used with other fluids and locations. Often the uncertainty of the water calibration is assumed without additional components for use in the final application. CMI hopes that the collaborative results from multiple applications and locations can provide this information.

CMI would perform several measurements in the CMI hydrocarbon flow laboratory using a Small Volume (piston) Prover (SVP) as the reference standard. As a reference device which displaces an accurately known volume of liquid, an SVP should provide a reference standard which is effective across a wide range of temperatures, densities and viscosities. Several hydrocarbon liquids can be used ranging from a very light solvent oil (“technical gasoline“) with viscosity of 1 cSt to a heavy oil with a viscosity of 512 cSt.

2.5 Selection of the Transfer Package.

The collaborators agreed that a Coriolis flowmeter would provide the type transfer device between fluids. In theory Coriolis technology provides a solution that is fluid independent. Coriolis flowmeters are frequently employed within UK to measure LPG and also act as a mobile reference meter for use in calibrating LPG meters in the field.

Emerson Process Measurement was selected by the partners to be a collaborator in the project. Emerson undertook to supply a suitable flowmeter, design a transport skid, and provide ongoing support during the project.

Coriolis meters can be sensitive to mechanical installation. Since the project includes an assessment of the use of a meter for a mobile duty, the meter and associated instrumentation were fitted into a transportable skid.

Given this specification, Emerson undertook the mechanical design of the skid to ensure stable performance of the meter across different installations in the laboratory and in outdoor locations for field installation. The design was provided to CMI who organised the manufacture of the skid. NMi VSL undertook final assembly, provision of the instrumentation and commissioning.

3 METERING PACKAGE AND PROTOCOL

3.1 Metering Package

The metering package consists of an Emerson model CMF 100 Coriolis flowmeter. This is a 1 inch twin tube Coriolis meter fitted with 1 inch ANSI 300 flanges. The meter is fitted with fixed inlet and outlet pipes again terminating in ANSI 300 flanges. The package is manufactured in stainless steel pipe allowing compatibility with water, oils and LPG. The package length is 1100 mm.

The meter and pipework are supported and secured on a rigid steel support stand which supports the package at two points 280 mm from the inlet and outlet flanges. The supports are Stauff type resilient clamps. This support method will be discussed later. The package is designed to be installed in any location in or out of doors.

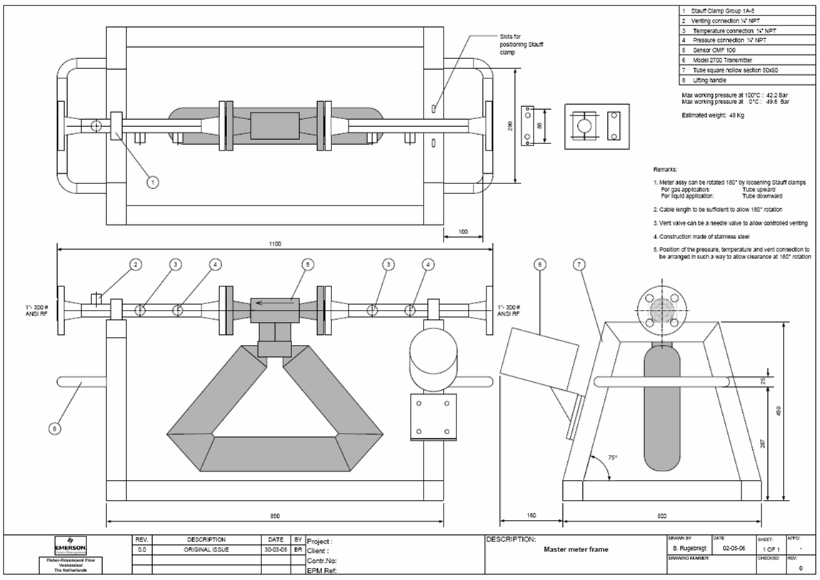
Temperature and pressure tappings are provided on both upstream and downstream pipe sections. Platinum Resistance Thermometer probes are installed in the temperature fittings and static pressure transmitters are fitted to the pressure tappings. The thermometer probes were selected to give an adequate immersion depth whilst minimising blockage of the flow through the pipes.

Although the instrumentation fitted to the meter package is certified for use in hazardous areas, the wiring, connections and associated connections are not similarly certified. However modifications could be made retrospectively if required.

Signal cables are connected to power supplies and a data logging system which will record temperature and pressure. This system can also communicate with the flowmeter and other data logging equipment using the HART interface. A laptop computer is provided to carry out the logging and monitoring of the instrumentation package.

A pulsed output is made available directly from the flowmeter and this signal is used as the primary calibration signal rather than the HART signal via the laptop. The laptop can also be used to interrogate the internal settings of the meter and set and record zero setting values.

The meter package design is shown in Figure 1 and photographed in Figure 2.



1	Stauff Clamp Group 1A-8
2	Venting connection ¼" NPT
3	Temperature connection ¼" NPT
4	Pressure connection ¼" NPT
5	Sensor CMF 100
6	Model 2700 Transmitter
7	Tube square hollow section 50x50
8	Lifting handle

Max working pressure at 100°C : 42.2 Bar
Max working pressure at 0°C : 49.6 Bar

Estimated weight: 48 Kg

Remarks:

1. Meter assy can be rotated 180° by loosening Stauff clamps
   For gas application: Tube upward
   For liquid application: Tube downward
2. Cable length to be sufficient to allow 180° rotation
3. Vent valve can be a needle valve to allow controlled venting
4. Construction made of stainless steel
5. Position of the pressure, temperature and vent connection to be arranged in such a way to allow clearance at 180° rotation

Figure 1 Drawing of the Metering Skid.

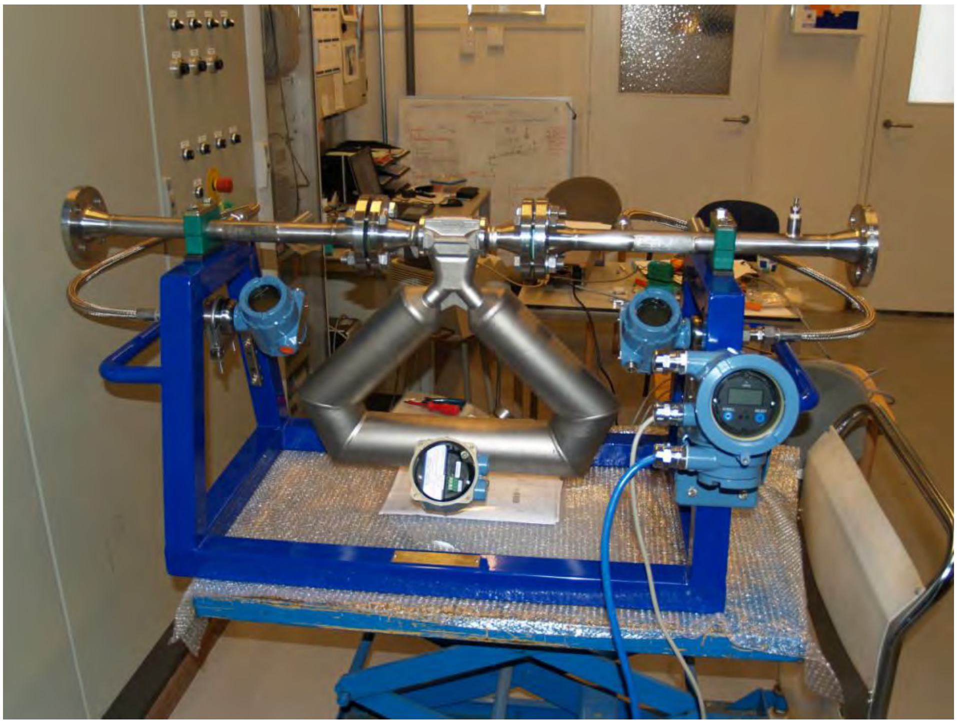


Figure 2 Metering Skid at NMi VSL after Construction

3.2 Protocol for Zeroing

It is very important that, for a Coriolis meter, the installation is carried out correctly and the electronic zero setting is performed to an agreed procedure. After the meter is installed in the test facility, it should be filled and the electronics switched on and allowed to stabilise. The following procedure was prepared by Emerson and accompanied the meter.

1. Flush the meter for at least 5 minutes on 75% Q_{nom} (where Q_{nom} = 227 kg/min).
2. Flush the meter for at least 15 minutes on 20% Q_{nom}.
3. Block the meter in on both sides.
4. Make a note of the stored zero.
5. Zero the meter for 60 seconds: do this at least 3 times. If the zero is changing and there is a trend in one direction, repeat this exercise until no trend in the readings is found.
6. Observe the flow counter for 6 minutes when flow cut-off has been set to Zero and the meter set for bi-directional measurement. This should be within the meter's specification for zero flowrate performance.

After performing the tests do the following:

7. Again block the meter in on both sides.
8. Ensure the low flow cut-off has been set to Zero and the meter set for bi-directional measurement.
9. Observe the flow counter for 6 minutes.
10. The resultant indicated flowrate should remain within the meter's specification for zero flowrate performance.

3.3 First Test Programme at NMi VSL

The package was installed in the NMi VSL water flow standard laboratory. It was installed on the floor and connected to the flow lines using long lengths of flexible hose. The meter was calibrated against a small volume prover.

3.4 First Test Programme at TUV NEL

The initial test programme at TUV NEL was directed towards becoming familiar with the performance of the package, how it was affected by installation, and how the package was affected by different fluids and installations.

The meter was calibrated against the primary gravimetric standards using a diverter flying start and finish method for water and a standing start and finish method for oil.

3.5 First Test Programme at CMI

At CMI the package was tested in the oil flow laboratory and tested with four oils with viscosities of 1, 20, 160 and 540 cSt. The full flow range could not be covered at 160 and 540 cSt. The meter was calibrated against a Flow Dynamics small volume prover.

3.6 Second Test Programme at TUV NEL. (Planned)

The second test programme at TUV NEL is planned to calibrate the meter again in water using long hoses, and then commission LPG testing and calibration at either the Calor gas facility or at J Wigfull Ltd. It is planned to use both volumetric tank calibration standards and gravimetric methods based on truck mounted scales.

3.7 Second Test Programme at NMi VSL. (Planned)

The second test programme at NMi VSL is planned to be carried out in the oil flow laboratory and external locations. It is planned to perform calibrations using Diesel, Kerosene and Natural Gas.

3.8 Second Test Programme at CMI. (Planned)

It was originally planned that CMI would test the meter at an LPG field site. However it is not clear at the moment if this will be available to them.

4 INITIAL TEST PROGRAMME AT TUV NEL.

4.1 Initial Water Flow Tests

Following receipt from NMi VSL, the package was first tested in the TUV NEL water test facility. In the first test programme the package was located on the concrete floor adjacent to the test line. As there were no long lengths of hose available to connect the meter to the test line, rigid steel pipework was installed to line up with the centre of the package inlet and outlet. The steel pipe and bends were 2” NB, having been reduced from the larger test line diameter. The final connections were made via two lengths of 50 mm flexible hose 1 metre long followed by a steel reducer to the 1” diameter ANSI 300 flanges of the package. The installation was arranged to minimise forces being exerted by the hoses on to the package.

The meter was installed and zeroed according to the procedure in Section 3.2.

Photographs of the installation and the inlet pipework are shown in Figures 4 and Fig 5 respectively.

Figure 4 TUV NEL 1st water installation

Figure 5 TUV NEL 1st water installation - Inlet

Two calibrations were performed and the results are shown in Figure 6.

In these tests it was ensured that the installation was being held as stable as possible, that the zero procedure had been followed with due care and that on each occasion the zero appeared to be stable within the criteria supplied by the manufacturer.

Figure 6 shows that the meter was linear in both calibrations within ±0.1 % with a mean error of approximately +0.15 % over the flow range from 1 to 5 kg/s.

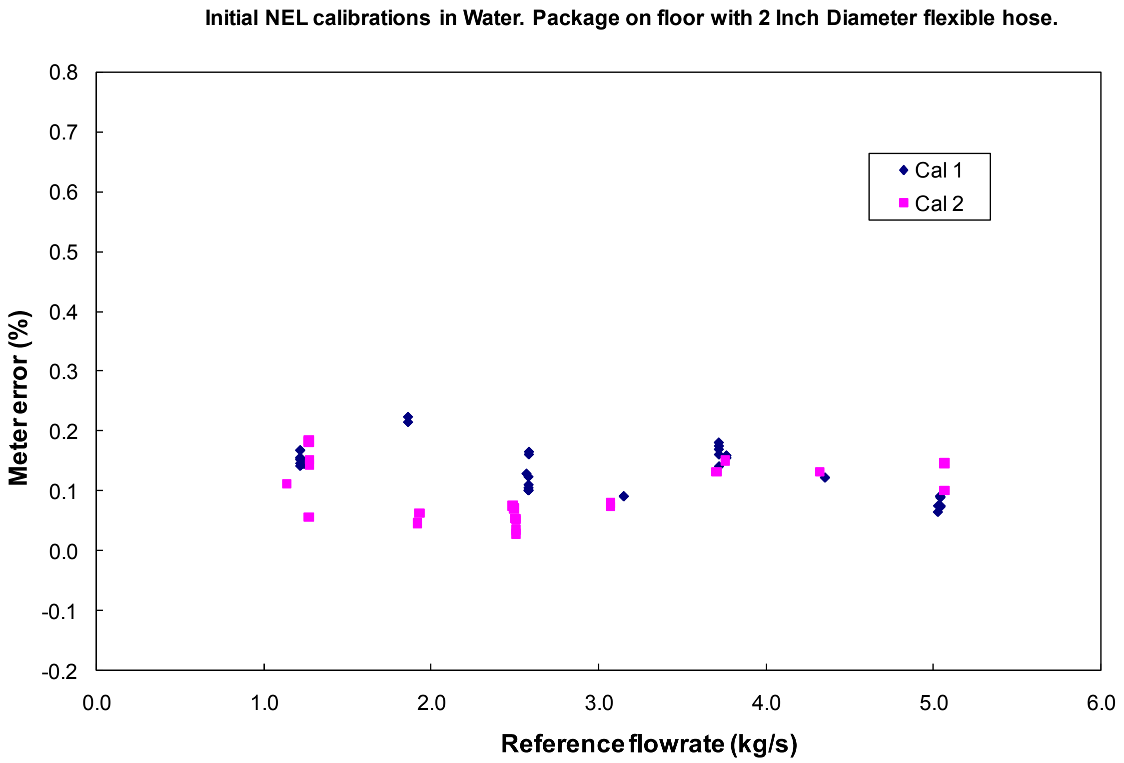


Figure 6 Initial Water Test Results at TUV NEL.

During the calibrations, it was observed that any mechanical disturbance of the 2 inch flexible hoses changed the flowrate reading significantly when the meter was closed off for zero setting. Sometimes the reading returned to the stable zero value, but at other times an offset reading was retained.

There was clearly a mechanical concern regarding the installation of the meter and the meter itself. It may be concluded that the meter is sensitive to mechanical stress and the support stand is not providing adequate isolation of external stress to maintain the meter within specification.

4.2 Kerosene and Primol Tests

The package was tested in two oils, Kerosene with a viscosity of nominally 2.2 cSt and Primol with a viscosity of nominally 200 cSt at 20 °C. The oils were made available from two separate but nominally identical flow lines. The installation was carried out in an identical manner in each case and the package was moved between tests.

The package skid was mounted on top of a rigid stand bringing the inlet and outlet pipework in line with the test facility test line. Short lengths of steel pipe (approximately 300 mm were used to adapt the class 300 flanges of the package to the Class 150 flanges of the facility. Flexible hoses 1 metre long and 1 inch NB were connected directly to the adaptors from 1 inch to the 3 inch diameter pipework of the test facility. The package was secured rigidly to the stand and hence the floor of the building. The fixed pipework of the test facility was supported and secured firmly.

The installation is shown in the Figure 7.

Figure 7 Installation in TUV NEL Oil Flow Line

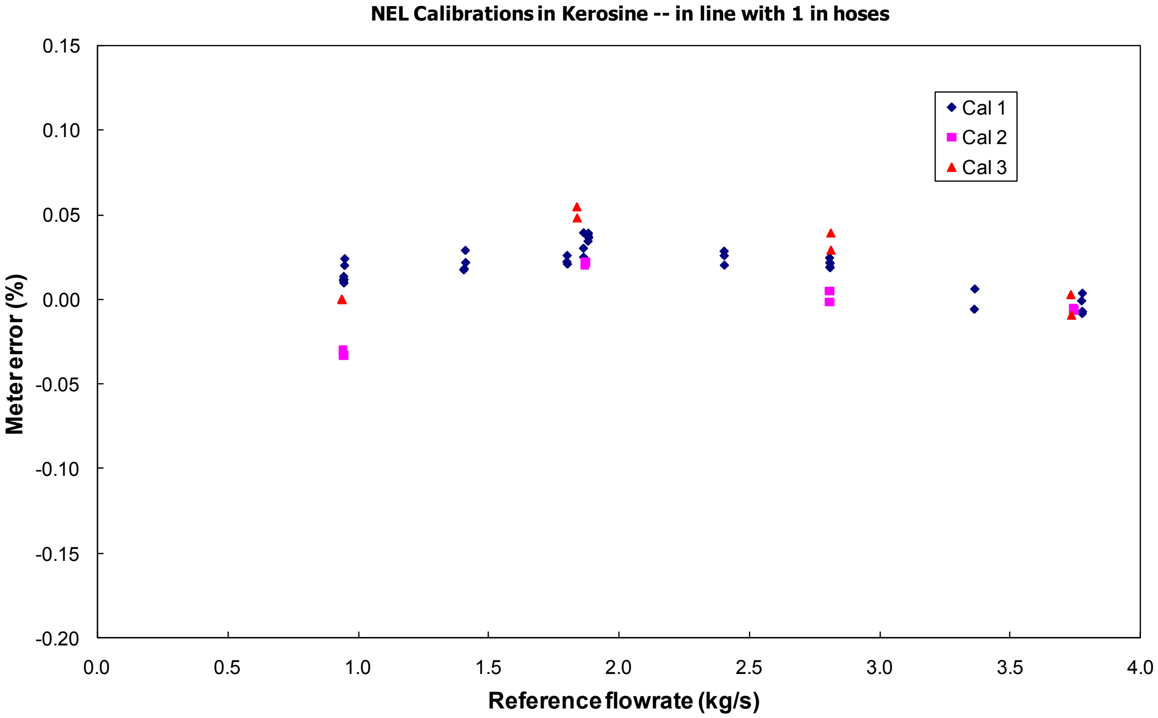


Figure 8 TUV NEL Calibration in Kerosene

The results from the Kerosene tests at 20°C are shown in Figure 8. Over the flowrate range from 1 to 5 kg/s the linearity and reproducibility of the meter (over the three calibrations) is within ±0.02% with a clear performance curve being developed. In this installation the scatter of results is within ±0.02% for calibrations one and three and within ±0.05 % for calibration two.

The meter was then moved to the test line used for high viscosity (160 cSt at 20°C) oil (Primol). Two calibrations were carried out with Primol at 20°C and then, to assess the effect of temperature (and reduced viscosity), two further calibrations were carried out at 40°C.

Due to the increased pressure drop resulting from the high viscosity, the 20°C tests were restricted to a maximum flowrate of 2.5 kg/s while the 40°C tests were performed up to 3.5 kg/s.

The results are shown in Figure 9.

The repeatability of the meter across all the tests at both temperatures is again generally within ±0.02 % over the range 1 to 3.5 kg/s and the linearity is within ±0.03 %. The characteristic curve has a similar trend to the Kerosene curve. Again the repeatability of the results remains relatively good across the range; within ± 0.05% for calibrations one, two and four. Calibration three shows a larger scatter (±0.15%).

There is no obvious difference between the calibrations at the two different temperatures.

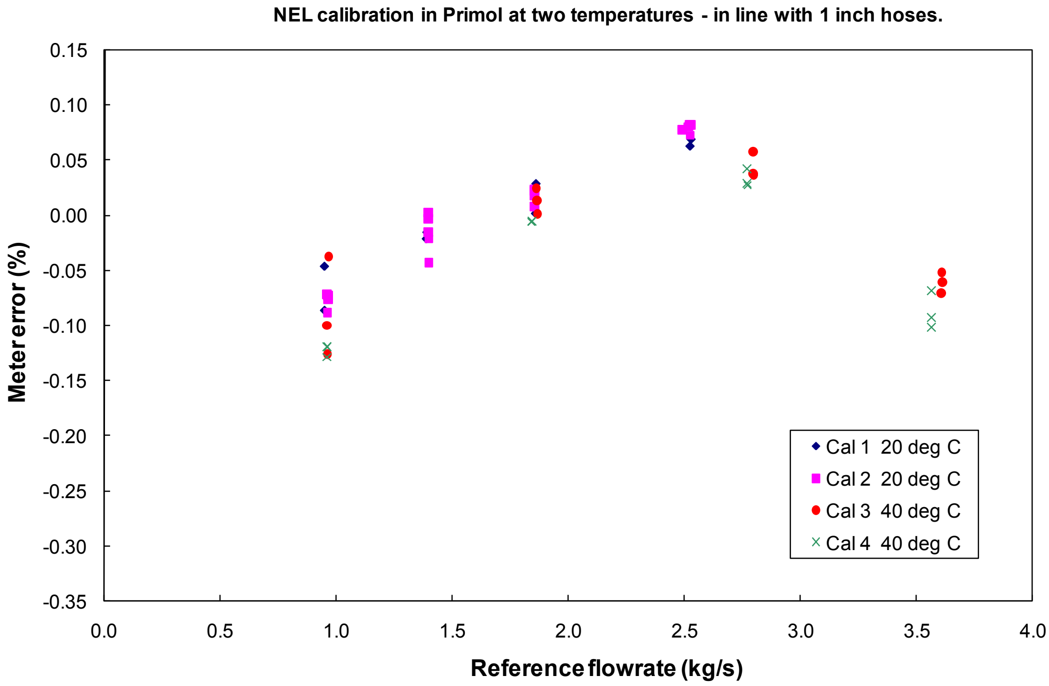


Figure 9 TUV NEL Calibration in Primol (160 and 60 cSt)

4.3 Repeat Tests in Water.

On completion of the oil tests the package was reinstalled in the water test facility using the same installation as was used for the oil testing – firmly secured to a stand and installed in-line with two 1 metre, 1 inch diameter flexible hoses.

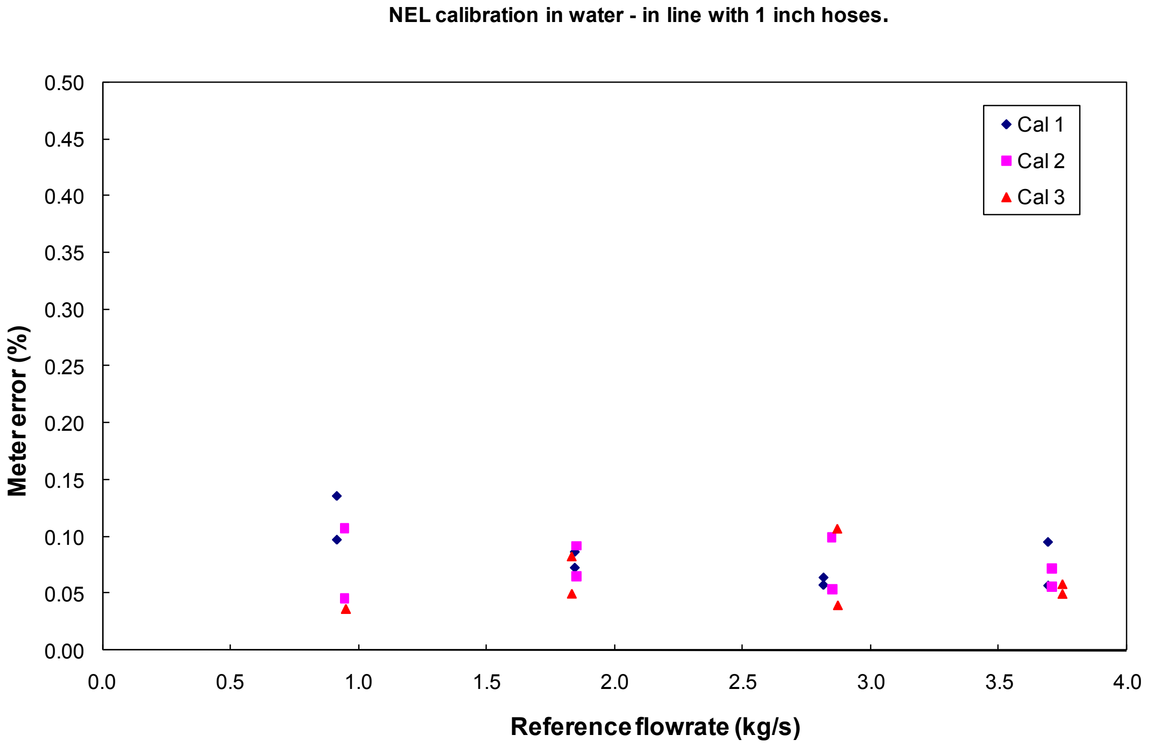


Figure 10 TUV NEL Calibration in Water – In Line

Three calibrations were carried out, and the results are shown in Figure 10. At the higher flowrates the repeatability is within ± 0.025% although it increases to ±0.04% at 1 kg/s. This suggests a less stable zero. This latter value can be compared with the scatter observed previously in water and shown in Figure 6.

4.4 Installation Comparison in Water

Three different installations were tested in the water flow facility.

- Floor mounted with connections via short, fairly stiff, large diameter flexible hoses (Floor short hoses)
- In-line with lengths of 1 inch diameter flexible hoses and firm clamped supports (In line)
- Floor mounted with long lengths of small diameter (1 inch) flexible hoses (Floor: long hoses).

A comparison of the results is shown in Figure 11 below.

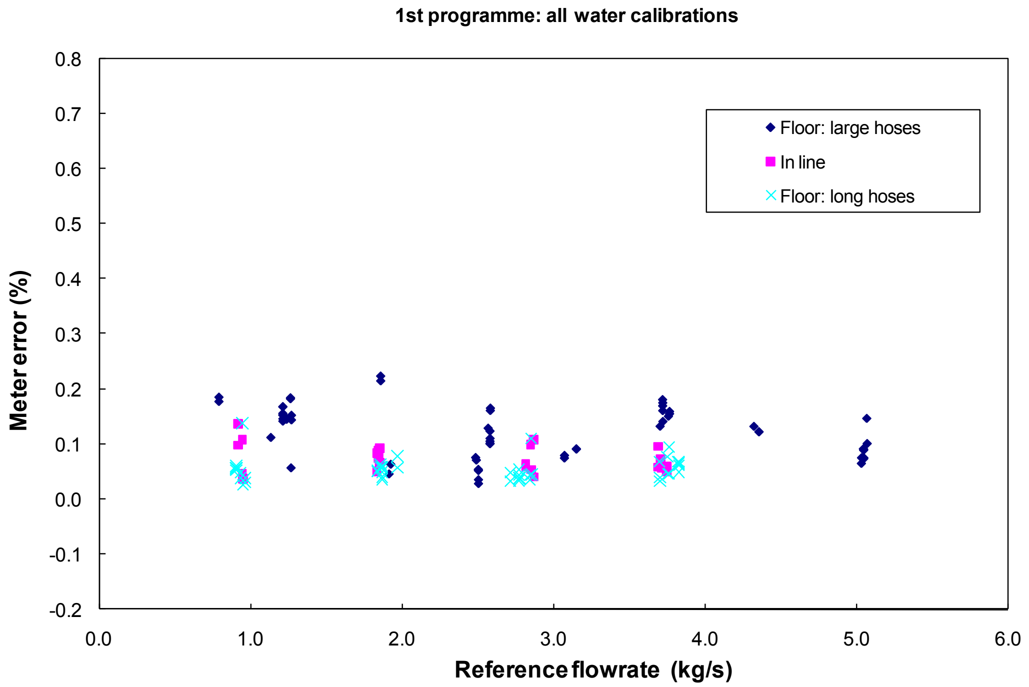


Figure 11 TUV NEL Calibrations in Water

There is no significant difference in the performance of the meter. In all three installations the meter scatter is predominately positive relative to the main calibration curve. Generally for water the results at flowrates have an error of +0.1% ± 0.05%.

The high pressure hydraulic hose used in the TUV NEL tests was fairly heavy and stiff. As observed above, variations in the zero setting could be observed when the hoses were disturbed. It is concluded that the support frame does not isolate the meter from external stress to the level which is required for field test use if the flowrate is below 1 kg/s.

4.5 Comparison Between Fluids

The effect of changing the working fluid can be assessed using the data from the in-line tests, in which the meter was located at the same height as the test lines and zeroed for each installation. Both the oil and water facilities use gravimetric flow standards. However the water facility uses a continuous flow diverter type reference method while the oil facility uses a standing start and finish method. The results are shown in Figure 12.

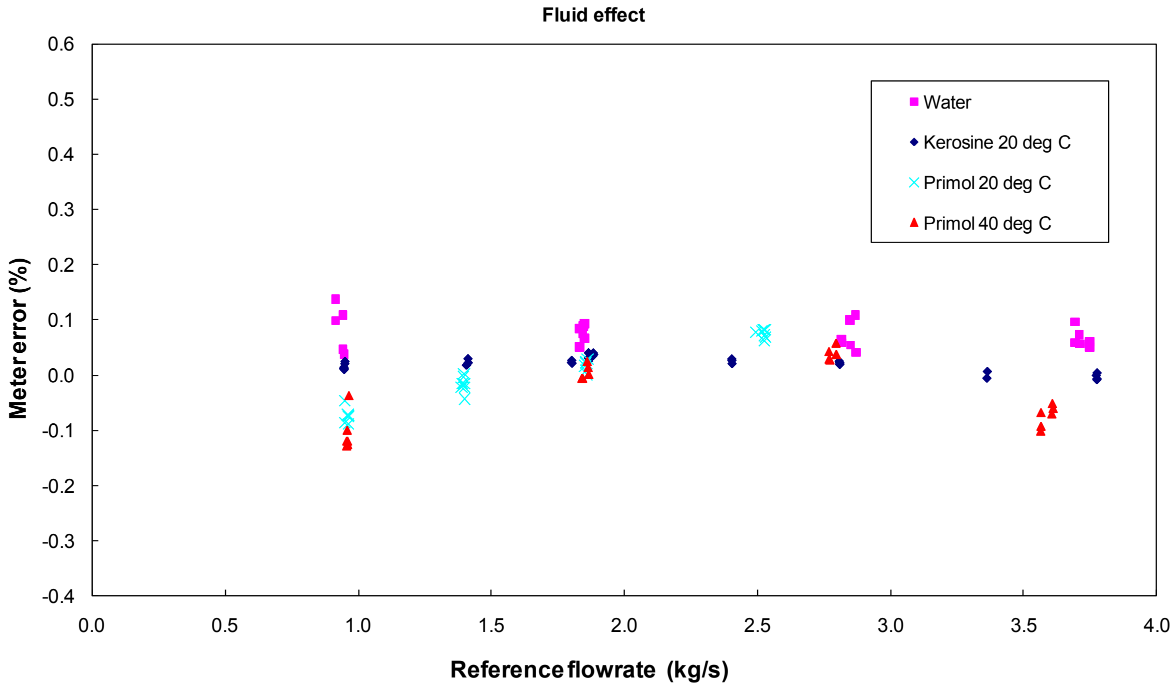


Figure 12 TUV NEL Calibrations in Water and Oil

Between 1 and 5 kg/s the mean percentage errors for the water and oil calibrations differ by no more than 0.2%. The difference is much less over a large part of this flow range.

5 COMPARISON OF TUV NEL RESULTS WITH NMI VSL AND CMI RESULTS

5.1 Comparison with NMi VSL Initial Tests

NMi VSL tested the flowmeter package by mounting it directly in the test line (Test 15/6/2008) and with the skid mounted on the floor (31/7/2008). No obvious difference in performance was observed. When installed on the floor the installation was similar to the initial TUV NEL installation. Rigid pipe took the flow down to the level of the skid and flexible hoses and adaptors to ANSI 300 flanges were used to make the connection. The main difference was that NMi VSL used 3 metre long hoses of relatively low pressure rating (hence of lower weight and stiffness than those used at TUV NEL).

NMi VSL calibrated the meter against a small volume prover with a volume large enough to allow each pass to have adequate resolution. The test data are shown in Figure 13. Two tests were carried out almost a month apart. Each test point represents the result from one pass of the prover piston.

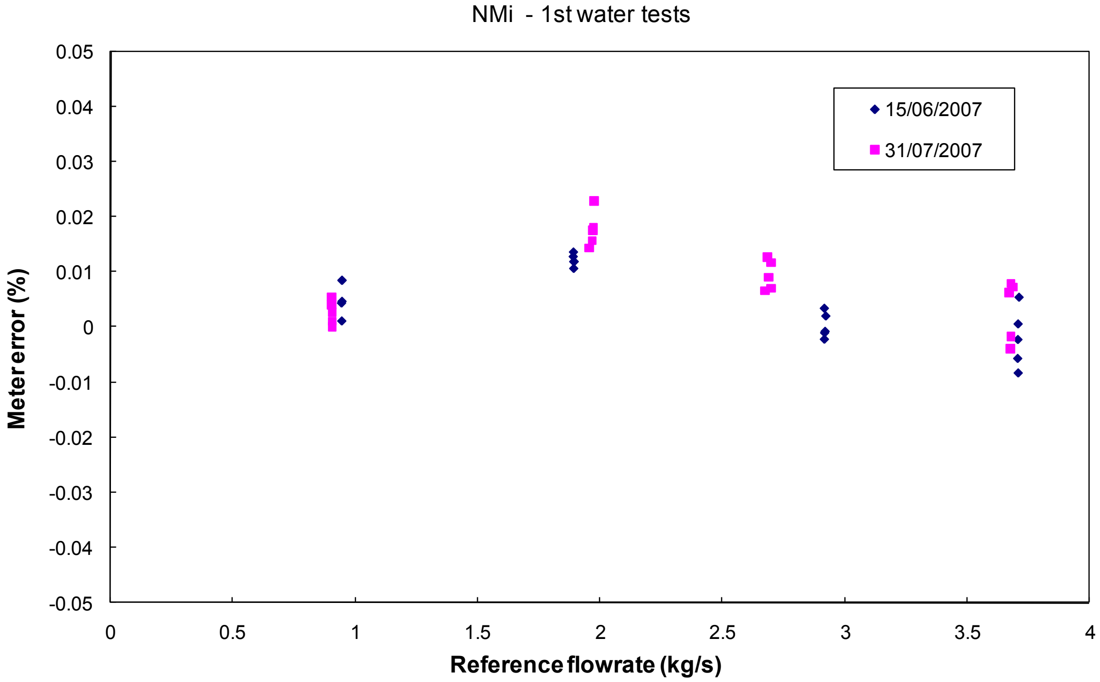


Figure 13 NMi VSL Calibration in Water

The results show a specific curve, good reproducibility, and repeatability within ±0.01%, across the range.A comparison of the NMi VSL results with the TUV NEL results taken in water with long hoses is shown in Figure 14.

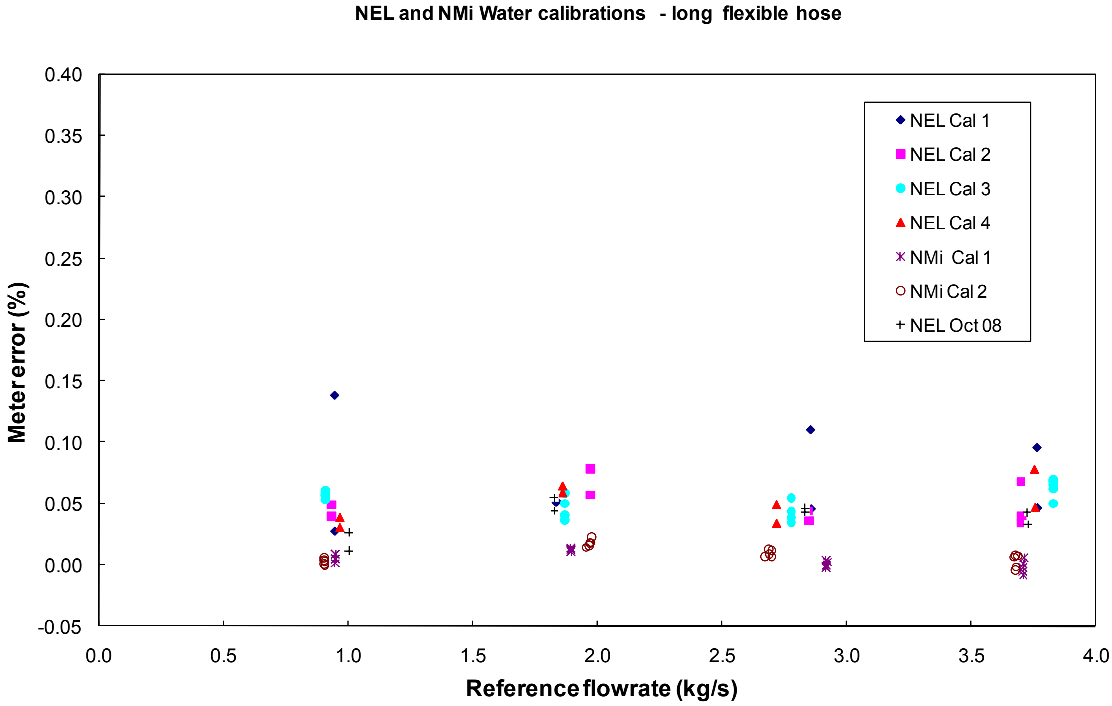


Figure 14 Comparison of NMi VSL and TUV NEL Water Calibrations using Long Flexible Hoses

This shows that the NMi VSL results are more stable and repeatable than the TUV NEL results. The mean TUV NEL and the NMi VSL calibrations generally agree to within 0.05% which indicates that the facilities are operating within the expected uncertainty claims and the meter quantity measurement has not changed.

5.2 Comparison of TUV NEL and CMI Results

CMI tested the package in four oils with viscosities varying between 1 and 540 cSt., The full range of the meter was covered for the 1 and 20 cSt tests. However the increased pressure loss for the 160 and the 540 cSt tests meant that only a limited range of flowrates could be covered.

The tests were carried out using a Small Volume Prover with the volume large enough to justify accepting individual passes of the piston prover as valid test points.

The results of the four calibrations are shown in Figures 15 to 18.

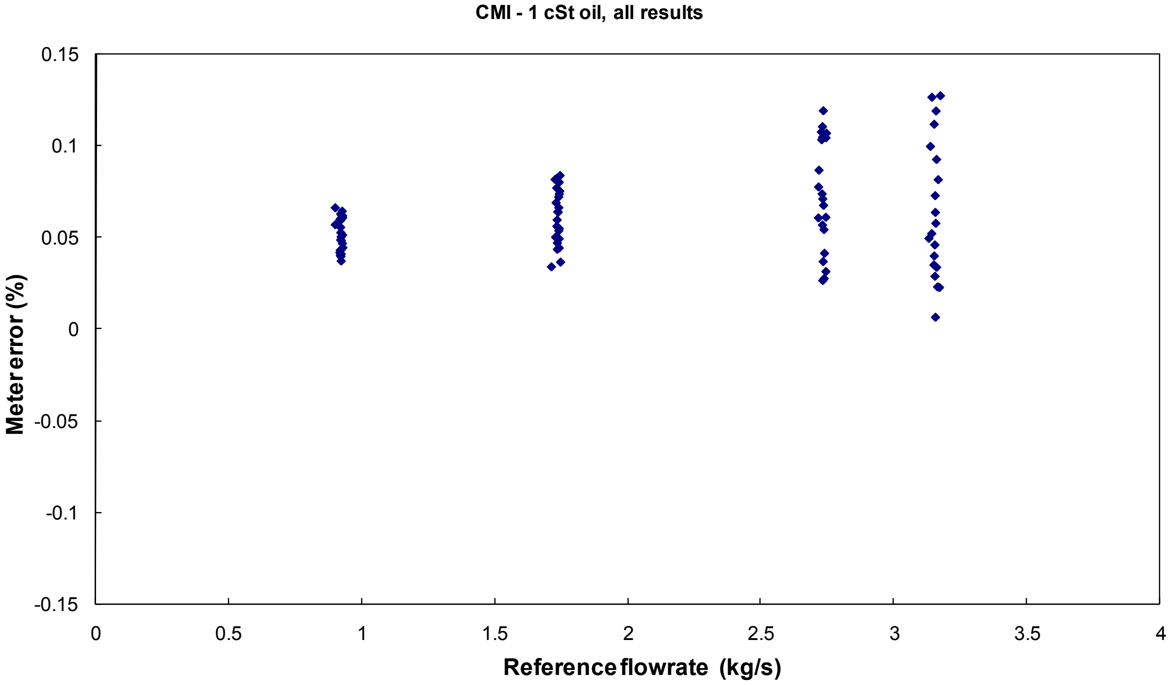


Figure 15 Calibration at CMI in 1 cSt Oil

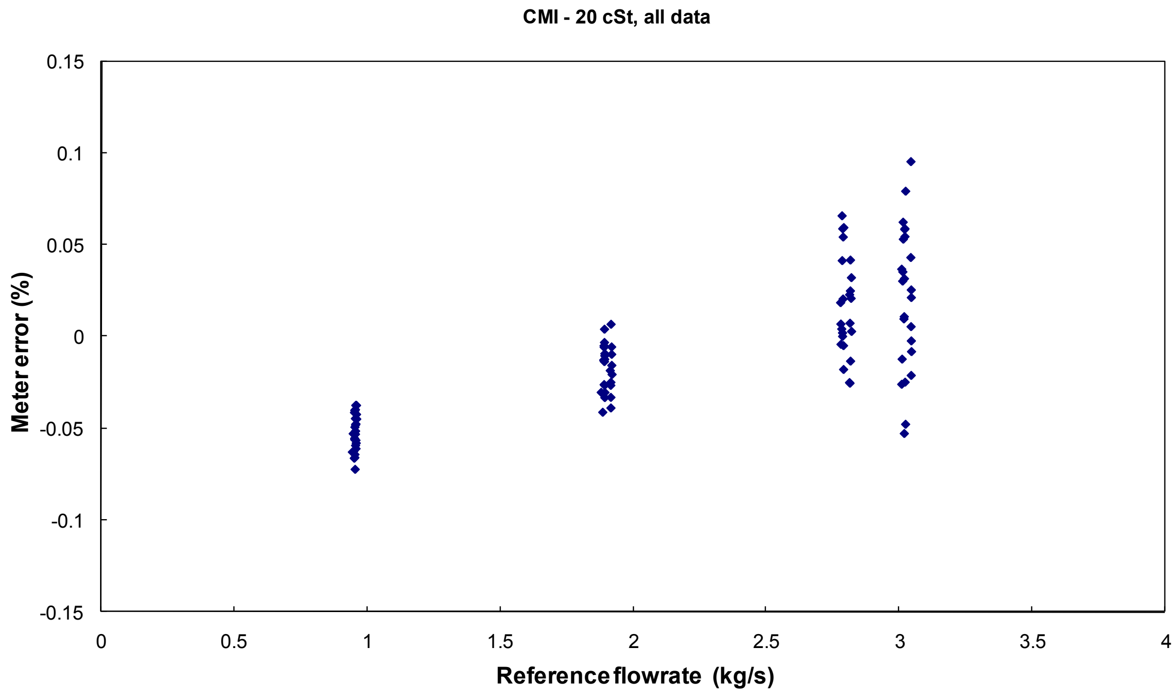


Figure 16 Calibration at CMI in 20 cSt Oil

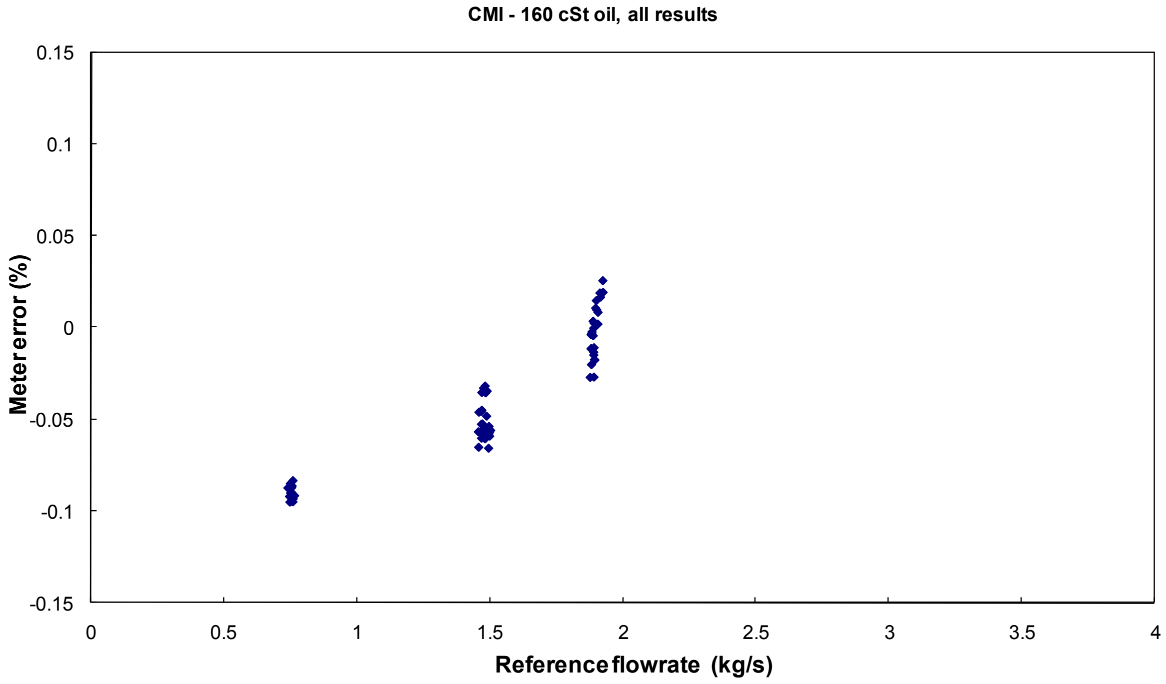


Figure 17 Calibration at CMI in 160 cSt Oil

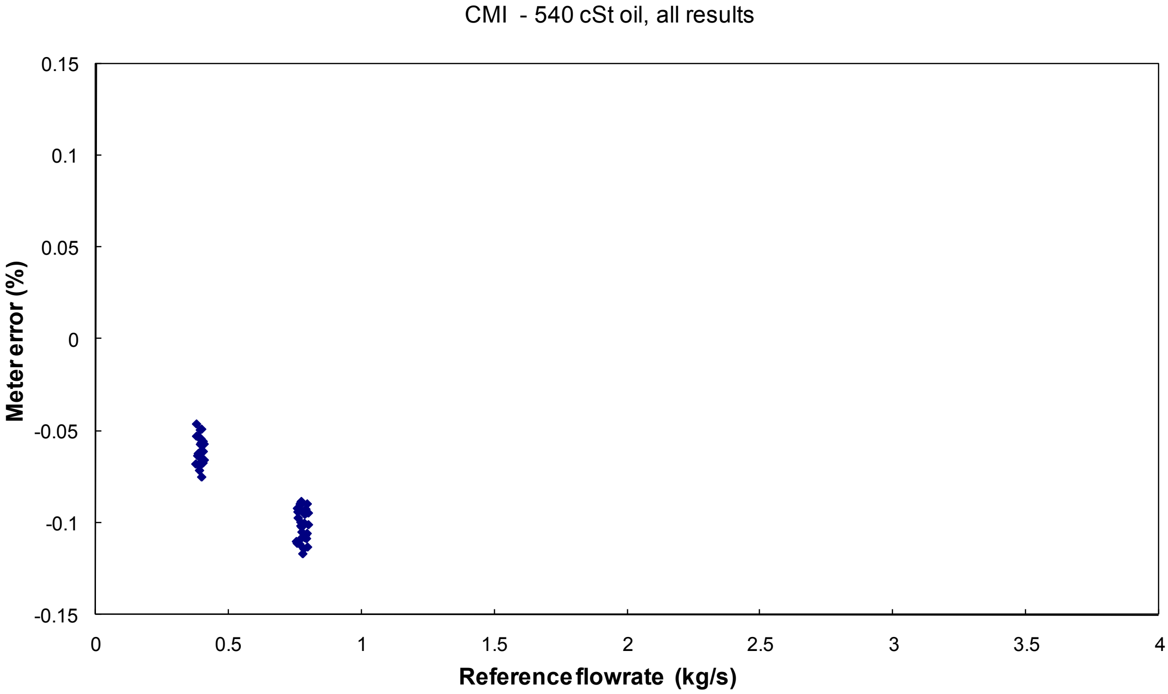


Figure 18 Calibration at CMI in 540 cSt Oil

For each of the tests the scatter of results at any one flowrate is around ±0.025 % at flowrates up to about 2 kg/s. At the higher flowrates the scatter increases to ± 0.07% at 3.5 kg/s. The TUV NEL results show a much smaller scatter of around ± 0.02% across the range.

There was no increased scatter of results at low flowrates for any of the tests. This suggests that the CMI installation provided a stable zero. The increased scatter at the highest flowrates may require further investigation and explanation. There is no obvious recognised performance characteristic of a Coriolis meter which would explain such behaviour. The test method, installation or operation of the SVP would be the areas which should be investigated first. Flashing or instability of the fluid at higher flowrates or the speed of operation of the small volume prover related to the ‘run up’ time and meter response time are other possible areas to be considered..

A comparison between the CMI results and the TUV NEL results for oil is shown in Figure 19. The mean values at each flowrate are plotted rather than the individual test points, in order to highlight the dependence on fluid in the results. The TUV NEL results plotted are Calibration 1 for Kerosene and Calibration 2 for Primol.

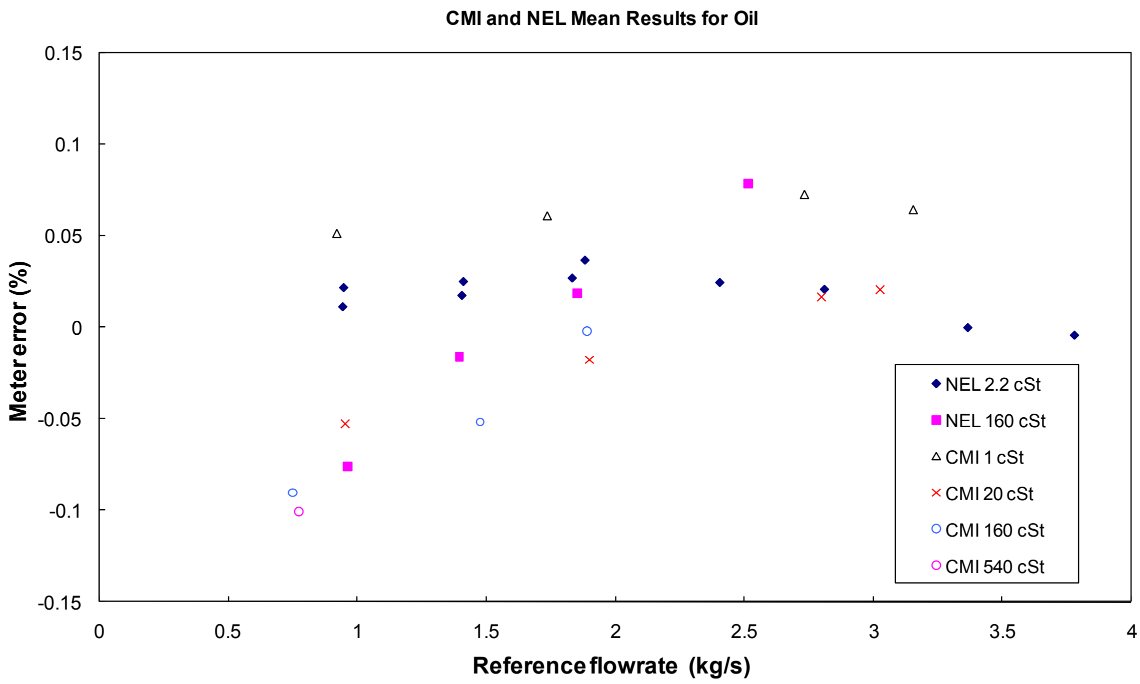


Figure 19 Comparison of CMI and TUV NEL Results for Oils

The results all fall within an error band of ±0.1%, and they suggest a characteristic curve with a maximum error at around 2.5 kg/s. Below 2.5 kg/s the slope of the decrease appears to steepen as the viscosity increases. In general the low viscosity oil provides a higher (more positive) error than the higher viscosity oils.

6 DISCUSSION

The results of independent tests on a Coriolis flowmeter package at three laboratories with several different fluids show broad general agreement accompanied by some differences in detail.

In the flow range from 1 kg/s to 3.7 kg/s the mean meter error varied between +0.15% and -0.1 % across all the fluids and laboratories. This suggests that the meter performance is relatively insensitive to the effects of the different fluid properties in this flow range.

The repeatability of results at TUV NEL and NMi VSL varies between ±0.025% and ±0.01%. The CMI results show an increase in scatter at higher flowrates which suggests some influence of the velocity or pressure drop, or that the test method may not be suitable for the higher velocities.

It was observed at TUV NEL there were significant transient and sometimes permanent changes in the meter zero if the connecting hoses were disturbed in any way. Changes in stress on the meter due to differences in the hose characteristics may be the cause of the scatter of results. It is not clear why this effect was not observed at CMI and NMi VSL.

The CMI results, supported by the TUV NEL oil results, suggest that there may be a lower error in higher viscosity fluids, though this is probably not significant.

7 CONCLUSIONS

The general good agreement among the results for a range of different fluids supports the view that Coriolis flowmeter liquid calibrations are independent of the fluid properties.

The viscosity range of the fluids tested was from 1 to 540 cSt, which is a much larger difference than that between water and LPG. The results therefore suggest that water calibrations should be transferable to LPG. The possible effects of low viscosity and highly volatile fluid will of course have to be recognised.

The collaborative project, EURAMET 1020, will now continue to address transferability to other fluids such as LPG, and gas both in the UK and the collaborating countries.

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