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COMPARISON OF MULTIPATH ULTRASONIC METER CALIBRATION DATA FROM TWO LIQUID HYDROCARBON FACILITIES AND ONE WATER FACILITY

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1 INTRODUCTION

The comparison exercise presented here started as a bilateral inter-laboratory comparison of the Cameron calibration facility at the Caldon Ultrasonics Technology Centre in Pittsburgh with the oil flow facilities of TUV NEL Ltd in Scotland. The primary driver for the intercomparison was to provide results of proficiency testing in support of the laboratory's ISO 17025 accreditation. NEL was selected as the second laboratory for a number of reasons, including their ability to cover an overlapping flow and Reynolds number range, the low uncertainty of their facilities and their position holders of the UK national standards. Most importantly, NEL also has ISO 17025 accreditation for their facilities and regularly participates in international intercomparison exercises, thus ensuring a high level of confidence in the validity of the comparison. The facilities at NEL are based on gravimetric (weighing) systems, traceable to the UK's primary mass standards. The Cameron calibration laboratory uses a volumetric prover, which is in turn calibrated using a traceable volumetric tank. Good comparison results produced by these two different methods would therefore also demonstrate that the results obtained are independent of the calibration method used.

When designing the transfer package to be used at the two laboratories it became clear, as with any intercomparison, that the meters should be as immune as possible to installation effects. Also as it was necessary to transport the package across the Atlantic, it would need to be compact and robust. To meet these requirements, and bearing in mind that the Cameron calibration facility is used primarily for calibration of ultrasonic meters, the decision was made use the Caldon 280Ci eight path ultrasonic in the package. The transfer package was assembled in the Cameron lab and included two 280Ci flowmeters, with an upstream straight run and a perforated plate (CPA) flow conditioner. The 8-path configuration of the Caldon 280Ci usually negates the need for a flow conditioner, but in this case the CPA plate was included in the package as additional insurance against installation effects, as the requirement was to reduce any possible meter related differences to an absolute minimum. The package was calibrated at the Cameron laboratory against the ball prover and then transferred by ship to NEL where the oil intercomparison tests were completed. The opportunity was then taken to also perform a water calibration at NEL, which would add a further data set, against another independent calibration system, and with a fluid having differing properties.

Subsequently, further tests have been carried out at Cameron Caldon with the package, using a small volume prover and turbine meter combination for calibration and compared with calibrations obtained using the ball prover. By virtue of the different flow lines used, the package has been shown to have changes in calibration that are within the combined uncertainty of the measurement methods with 5 different installations. In addition to validating the traceability and uncertainty of the facilities, this also demonstrates the robustness of the package and the metering technology.

2 THE CALIBRATION FACILITIES

Both the Cameron and TUV NEL calibration facilities have been described in detail elsewhere, but a brief description is given here for information.

2.1 The Cameron Calibration Facilities

The Cameron calibration facilities are comprised of oil storage tanks, pumps, test sections, a ball prover and a piston prover. Three types of oil are available, allowing for calibration at different viscosities. The chosen oil is pumped into the system until full and then shut off from the loop. The calibration facility is then operated as closed re-circulating loop; oil is pumped around the loop, through the selected test section, prover and reference meters. Control of temperature is carried out by passing the fluid through an in-line shell and tube heat exchanger, which is cooled by glycol passing through a chiller.

The primary references in the Caldon facility are a 10m^3 unidirectional ball prover and a 0.11 m^3 Brooks small volume prover (SVP). Meters above 10 inches in diameter are usually calibrated using two 10-inch 8-path ultrasonic reference meters, while meters between 6 and 10 inches are calibrated against the ball power. Small meters are calibrated against the small volume prover, normally in combination with a turbine master meter.

The ball prover is equipped with multiple switches allowing different calibration volumes to be chosen to suit the meter and flow rate for a test, two volumes were used for the inter-comparison calibration, the larger being a nominal volume of 10m^3 and the smaller being 3.3m^3. For the intercomparison between NEL and Cameron the ball prover was used to calibrate the package, using a combination of the 10 m^3 and 3.3 m^3 volumes. A similar process was used when comparing the ball prover with the small volume prover. The calibration facility as a whole has a range of 20 m^3/hr up to 3800 m^3/hr. Above 2200m^3/hr the ultrasonic master meters are used, and below 100m^3/hr the SVP is normally used. The ISO17025 accredited uncertainty for the ball prover is +/- 0.065% for the 3.3m^3 volume, and +/- 0.04% for the large 10m^3 volume (at 95% confidence limits). The uncertainty for the SVP and turbine master meter method has been certified by NMI to be 0.04% (these tests are part of the exercise for obtaining ISO 17025 for the SVP). These uncertainties are quoted with a coverage factor of k = 2.

A photograph of the Cameron calibration facility is shown in Figure 1.

Figure 1 The Cameron calibration facilities

2.2 The NEL Calibration Facilities

The NEL oil calibration facility has oil storage tanks, pumps and a choice of test sections where meters are installed. Oil is circulated from the storage tanks, through the test section and either returned to the storage tank or collected in gravimetric weighing tanks prior to return to the storage tank. The temperature of the oil in the storage tanks is controlled by means of a conditioning circuit with hot and cold heat exchangers. Test meters can be calibrated either directly against the primary gravimetric standard or against a choice of reference turbine and positive displacement flowmeters. The gravimetric calibration method is a standing start and finish method, where the required flowrate is established in the test line, the flow stopped, the collection tank drained, the test started, the tank filled and then the flow stopped again and the vessel weighed.. The largest collection tank in the gravimetric facility has a capacity of 6 tonnes and the maximum flowrate for this system is 360 m^3/hr. For flowrates greater than 360 m^3/hr, secondary reference meters are used. The reference flowmeters are regularly calibrated at their conditions of use against the primary gravimetric standards. The ISO 17025 accredited uncertainties of the NEL oil facilities are +/- 0.03% for the gravimetric system and +/- 0.08% for calibration against reference meters (these uncertainties also being stated with a coverage factor k = 2).

The specification for the 6-inch Caldon 280Ci flowmeter covers a range of 74 to 740 m^3/hr. Therefore, in order to achieve the maximum flowrates required, the NEL turbine reference meters were used for the comparison. NEL offers a range of oils, and combined with good temperature control this made it possible to reproduce very similar conditions to the calibration carried out in the Cameron laboratory.

A picture of the liquid flow laboratory area is shown in Figure 2, and a schematic of one of the circuits of the oil facilities is shown in Figure 3.

Figure 2 The NEL oil (blue, right) & water (silver, left) calibration facitlites

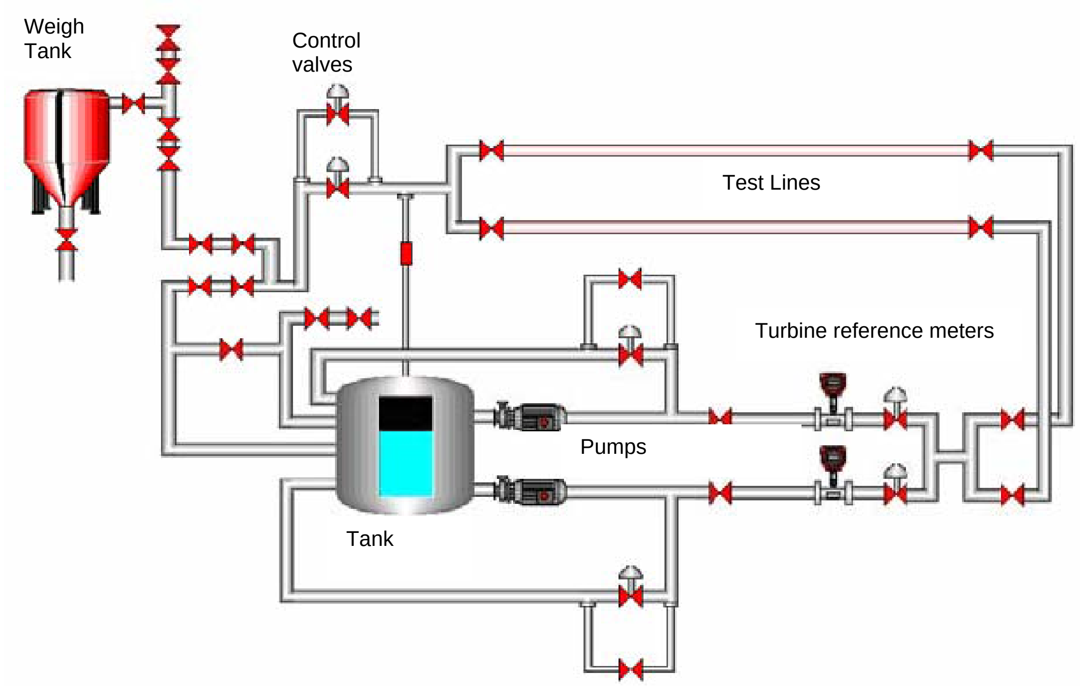


Figure 3 A schematic of one of the NEL oil facility circuits

NEL's water flow calibration facility is very similar in principle to the oil flow facilities, with the primary references being a series of gravimetric collection tanks. The facility has four separate flow lines, covering a wide range of flowrates in different line sizes. The main difference between the oil and water facilities at NEL is that the water facility uses a knife-edge diverter to switch the flow between the return to the sump tank and the diversion to the collection tank. As a result, the calibration points are taken with a 'flying start and finish', i.e. the flow through the test meter is not stopped. The largest weightank in the water facility is a 12 tonne tank which can be used for flowrates up to with 720 m^3/hr. Above 720 m^3/hr, up to a maximum of 1440 m^3/hr, parallel reference meters can be used. The uncertainty of the gravimetric calibration system in the water lab is +/- 0.1%. A schematic of the facility is shown in Figure 4.

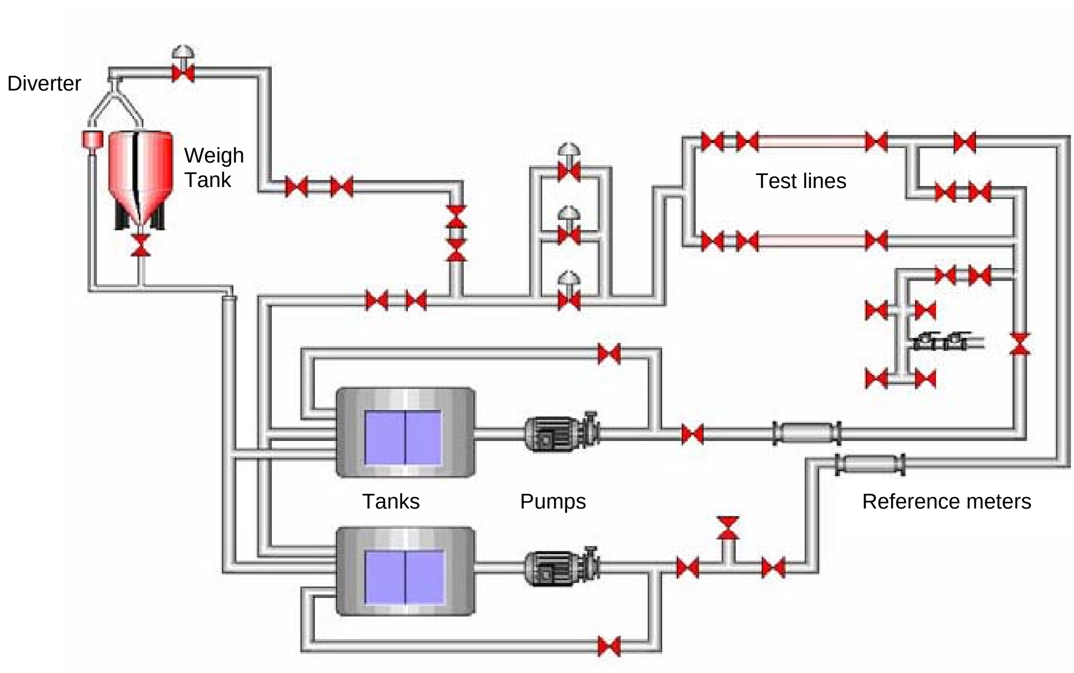


Figure 4 A schematic of the NEL water calibration facility

3 THE TRANSFER PACKAGE

The meters used for this exercise were 6-inch Caldon LEFM 280Ci meters. These meters have been described in detail in previous publications [1], but briefly they are meters with two planes each of four paths, the paths being at right angles to one another. The basis of this design is that the pairs of crossed paths cancel the effects of non-axial (swirling) flow on the axial velocity measurement, and hence enable the 4-chord Gaussian integration technique to accurately integrate the axial velocity profile. An illustration of the 8-path meter design is shown in Figure 5.

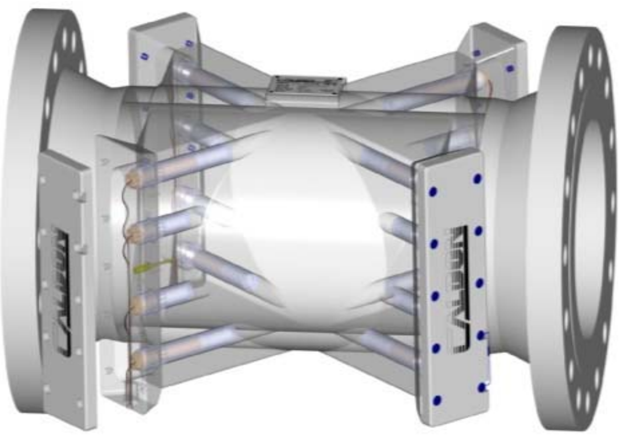
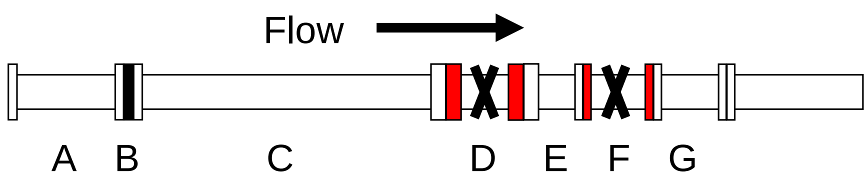


Figure 5 An illustration of the Caldon 280Ci 8-path ultrasonic meter

Testing of the 280Ci meter design has shown that even with fairly extreme upstream installation conditions the calibration is not significantly affected, and hence a flow conditioner is not normally required. However, in this case a CPA plate was included in the package as additional insurance against installation effects, as the requirement was to reduce any possible meter related differences to an absolute minimum. The CPA plate was chosen because it has a relatively low pressure drop compared to other plates, and because it has performed well in tests in combination with Caldon ultrasonic meters. A 5 diameter pipe section upstream of the CPA was included as a settling length to minimize any interactions between the plate and the pipe work of the calibration facilities.

As a further safeguard to ensure that moving from one lab to another would not introduce any hydraulic changes, such as might be caused by protruding gaskets or misaligned flanges, the whole package was kept bolted together for all tests at Cameron and NEL.

A schematic of the transfer package is shown in Figure 6. Two 8-path meters were included in the package in order that any fault with either of the meters might be readily identified and ensure that and differences in results might be more readily traced to either the meters or the calibration facilities. The two meters were separated by 3 pipe diameters of straight pipe of matching schedule.



A and G	– 5D straight length (matched schedule with internal welds ground flush)
B	– Perforated plate flow conditioner (CPA)
C	– 15D straight length (matched schedule with internal welds ground flush)
D & F	– 280Ci ultrasonic flow meters
E	– 3D 150# to 300# flange adaptor spool

Figure 6 A schematic of the transfer package

Photographs of the intercomparison package installed in the Cameron and NEL laboratories are shown in Figure 7.

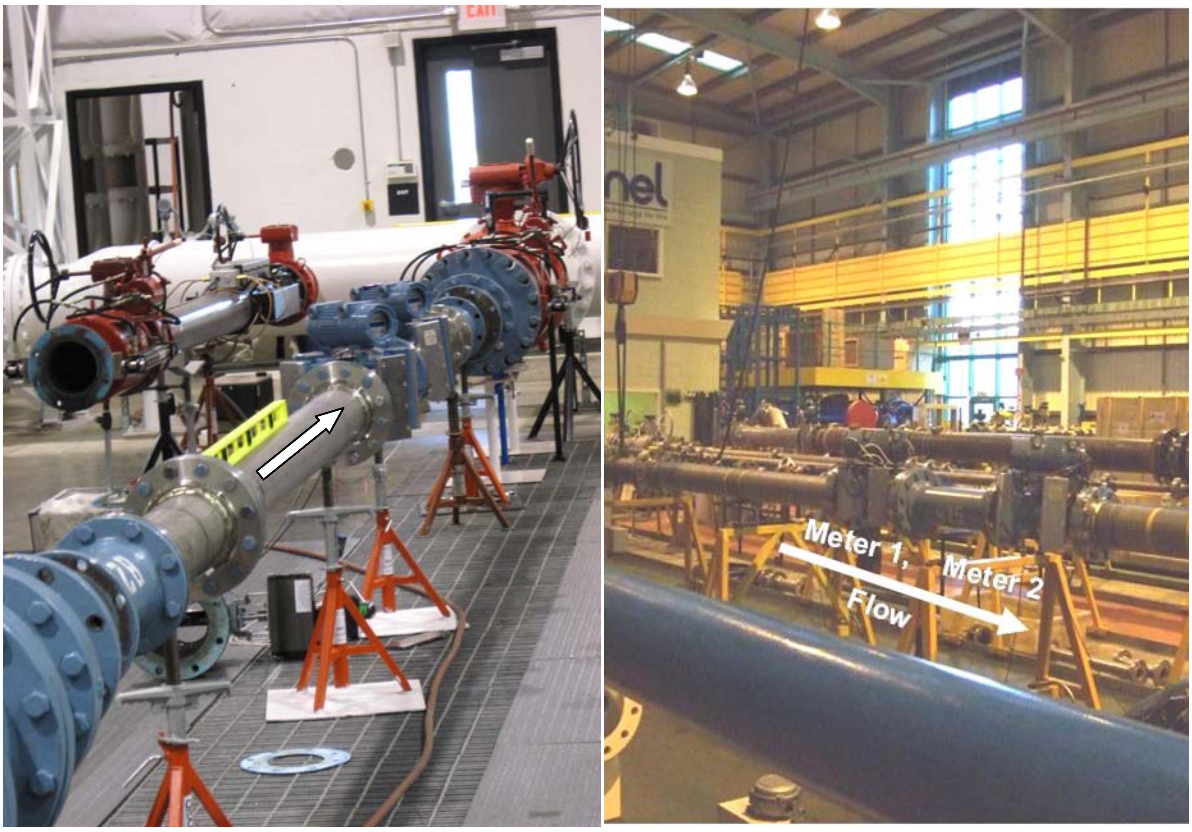


Figure 7 The transfer package installed in the Cameron (left) and NEL (right) labs

4 THE METHOD OF COMPARISON

The method of comparison used, was to leave the meters uncharacterized and compare the calibrations on the basis of pipe Reynolds number, i.e. only geometric and time constants were used in the meters, no empirical corrections were applied. The nominal Reynolds numbers chosen for the test were evenly distributed on a log scale to lie inside the normal operating flowrate range of the meters. The oil product used for the calibrations was an Exxon kerosene product with a nominal viscosity of 2.4cSt at 20^{o}C, as this was available at both laboratories.

The nominal flow range for the intercomparison was 100 - 600 m^3/hr. The nominal Reynolds numbers chosen selected to give equal spacing on a logarithmic scale are given below:

Nominal Reynolds Numbers				
92 829	113 278	138 231	168 681	306 514
205 839	251 182	374 034	456 429	556 973

At each Reynolds number, for both the tests at NEL and at Cameron, repeat points were carried out, in accordance with the API Manual of Petroleum Measurement Standards, Chapter 5.8, Table B-1. This table provides the spread of repeats that will give an uncertainty of the mean of better than +/- 0.027%.

The meter factor used for the comparisons is defined as the ratio of reference volume (volume obtained from the facility) to the indicated volume from the meter. The differences shown in the comparison graphs are defined as the percentage difference between the meter factor obtained in the NEL facility and the value obtained at the Cameron facility. A similar approach is used for the comparison between different calibrations carried out in the Cameron facility. For the initial testing at Cameron, the baseline is taken as the tests carried out in line 1.

The acceptance limits for each comparison is taken as the total uncertainty obtained by calculating the combined uncertainties due to the each facility and the uncertainty due to the repeatability of the data. Thus:

Total Uncertainty = $U_T = \sqrt{U_1^2 + U_2^2 + U_{1R}^2 + U_{2R}^2}$

Where:

U_1 = Uncertainty in the first facility (e.g. Cameron ball prover)
U_2 = Uncertainty in the second facility (e.g. NEL oil or NEL water facility or Cameron SVP)
U_{1R} = Uncertainty due to meter repeatability in the first facility
U_{2R} = Uncertainty due to meter repeatability in the second facility

5 INITIAL TESTING IN THE CAMERON LABORATORY

Initially, to check the quality of the package design, it was calibrated at the Cameron facility in two different test lines to confirm the reproducibility of the results would be satisfactory. The package was first calibrated on line 1. This has a nominal 8" line coming directly from the 24" header, and so the meter has an 8" to 6" reduction upstream of the package. After the calibration the package was moved to line 2. Line 2 has a 24" outlet from the header, this was coned down to the 6" package.

The comparison of the results from these two installations are are shown in Figures 8 and 9 below. The data plotted, is the difference in the mean meter factors at the specified Reynolds numbers. As can be seen both meters fall well within the combined uncertainty of the two calibrations, and so the conclusion was that the package appeared to be stable and capable of handling substantial change in installation conditions.

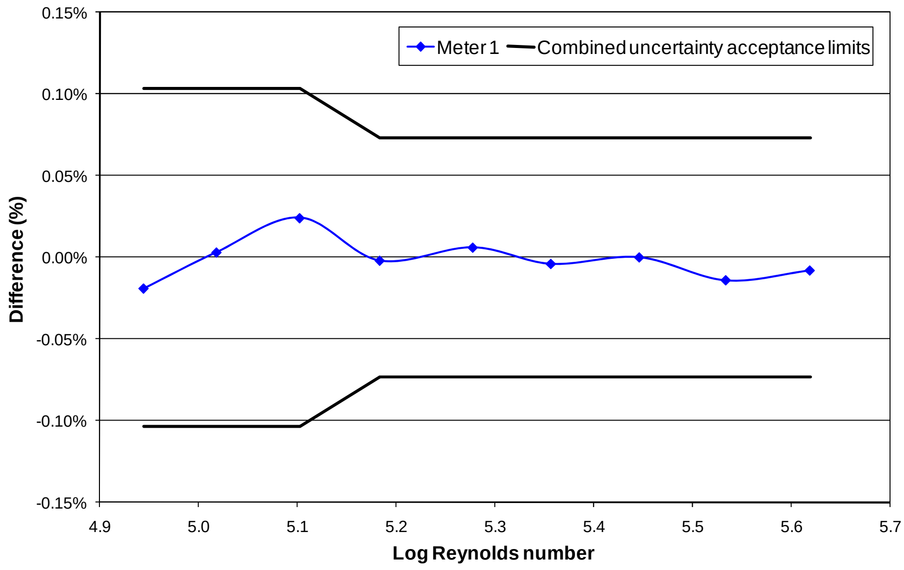


Figure 8 Difference in calibration between lines 1 and 2 in the Cameron lab – Meter 1

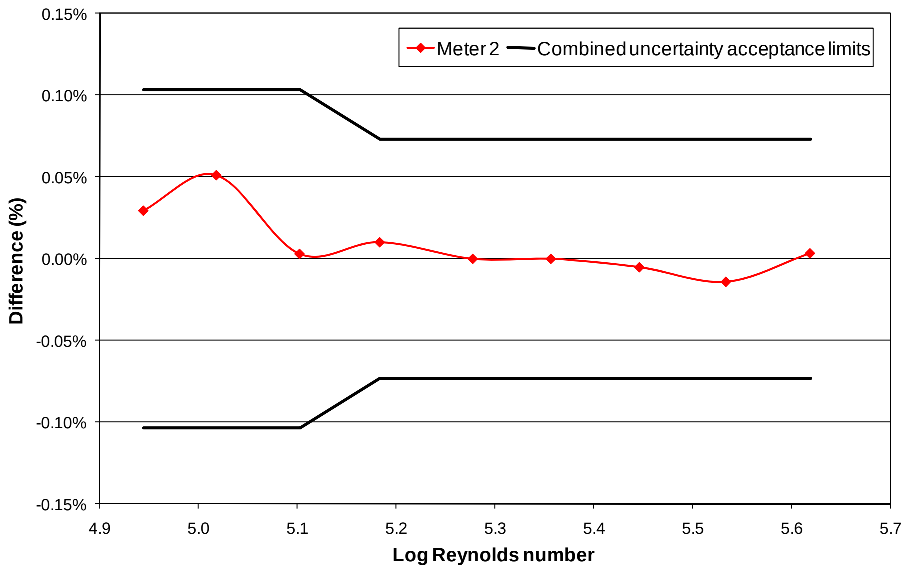


Figure 8 Difference in calibration between lines 1 and 2 in the Cameron lab – Meter 2

6 OIL LABORATORY INTERCOMPARISON RESUTLS

The package was shipped as a complete assembly to NEL in Scotland, and installed in line B of the oil flow facility. As stated previously, the primary method of calibration is different, using a mass based system rather than the volume based system used by Cameron. In order to cover the flowrates above 360 m^3/hr and to avoid changing between references, the full range of the oil calibration was carried out using turbine master meters. As the viscosity of the kerosene at NEL was slightly lower than that in the Cameron facility (2.45 cSt vs 2.67 cSt), the flowrate used at NEL was adjusted to match the Reynolds numbers as closely as possible, as illustrated in Figure 10 below.

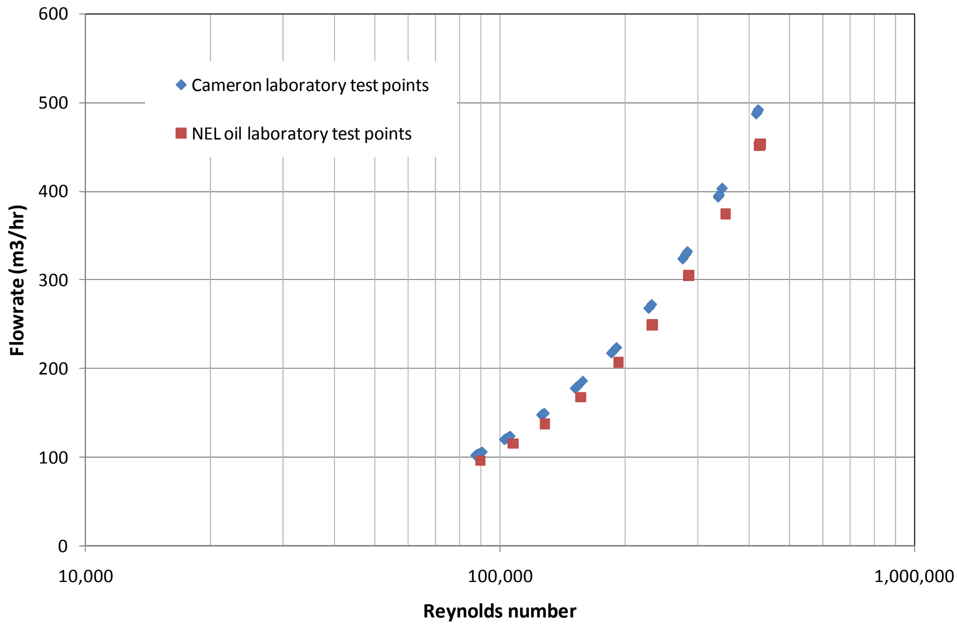


Figure 10 Comparison of calibration flowrates used at Cameron and NEL

As can be seen from the graphs Figures 11 & 12, the differences for both meters fall between the uncertainty acceptance limits. It should be noted, that both meters exhibit a similar difference curve peaking at a Reynolds number of approximately 230,000, with a non-linearity of around +/- 0.05%. As the curve lies inside the uncertainty bands, it is difficult to attribute this characteristic to any particular source but it suspected to arise from residual errors the characterization of the turbine meters. This is discussed further in the following section.

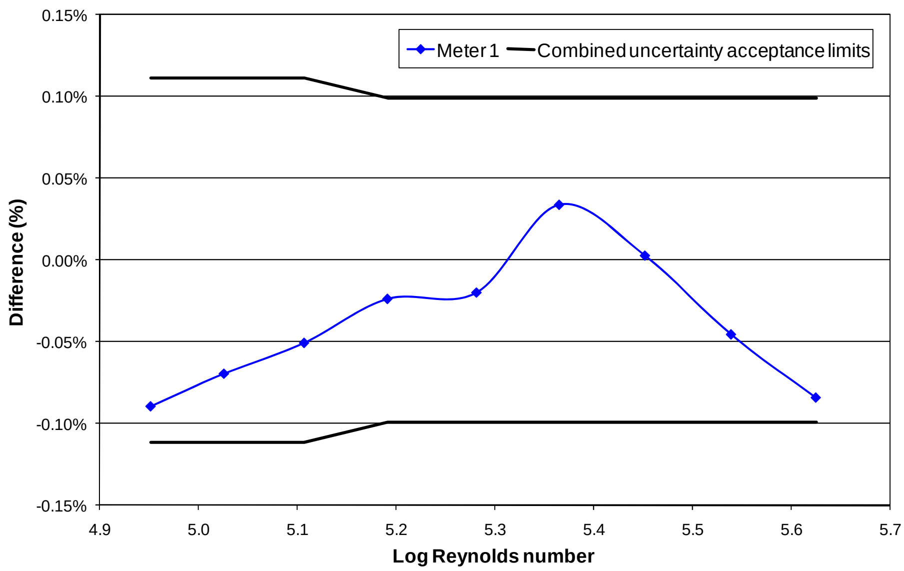


Figure 11 Difference in calibration between Cameron and NEL oil labs – Meter 1

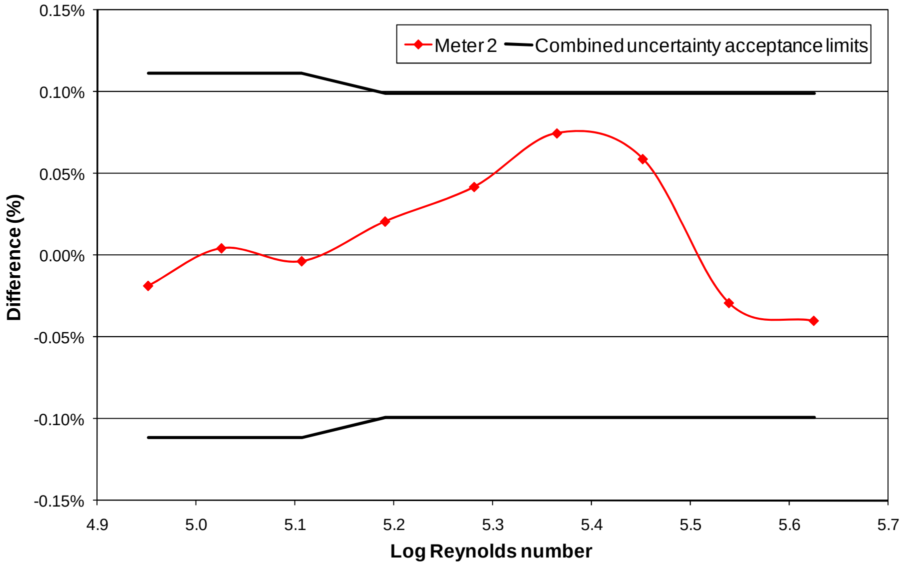


Figure 12 Difference in calibration between Cameron and NEL oil labs – Meter 2

7 WATER FACILITY CALIBRATION RESULTS

Following completion of the oil intercomparison, the package was tested in the NEL water flow facility. As the main intercomparison had been completed successfully, meter 2 was now used for some R&D testing and meter 1 was left unaltered. The flowrates for the water calibration were chosen to overlap with the oil calibration but also to remain within the normal volumetric flowrate/velocity range of the meters. The relationship between the oil and water test points in terms of Reynolds number and flowrate are shown in Figure 13 below. Note that only the four lowest flowrates were used for the comparison between water and oil.

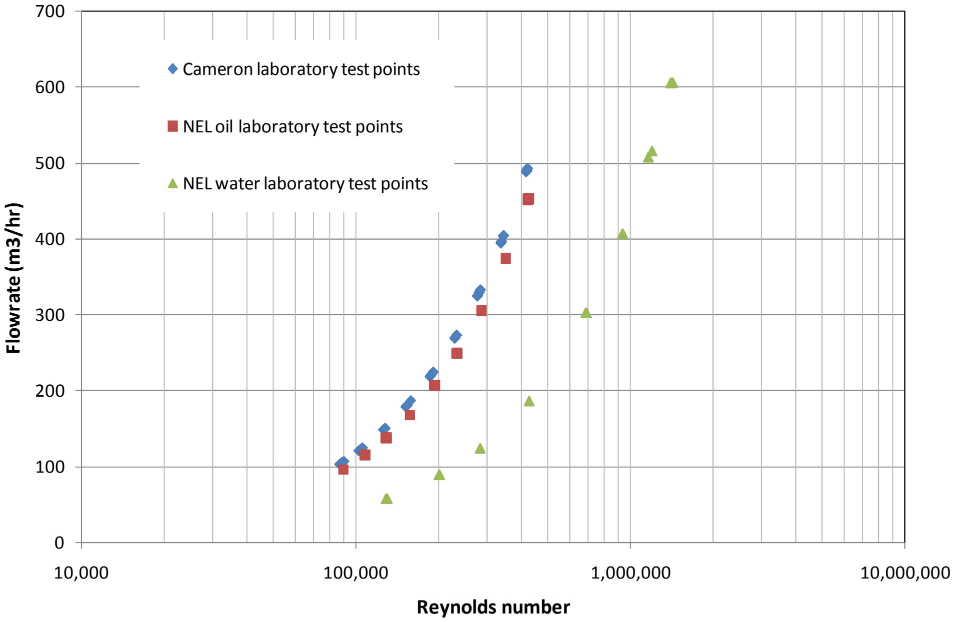


Figure 13 Flowrates and Reynolds numbers used for the comparison between oil and water

Figure 14 below shows the results from the water calibration of meter 1 compared against the oil calibration in the Cameron facility. Also shown on the graph for reference is the NEL/Cameron oil comparison data. It is interesting to note that the comparison appears better (almost constant at around + 0.02%) in the case of the NEL water calibration. The Cameron calibration was carried out against a volumetric prover. The water calibration was carried out against NEL's weightank system (i.e. a primary facility). The kerosene calibration at NEL however was carried out using calibrated turbine meters (i.e. secondary standards), as the oil tanks cannot be used directly over the flow range of the 6-inch meter. As such is appears that the non-linearity in kerosene comparison may its origin in the calibration curve of the turbine meters. This is also suggested in the previous data showing both meters calibrated on oil, where the difference curves of the two meters have very similar humps at a Reynolds number of around 230,000.

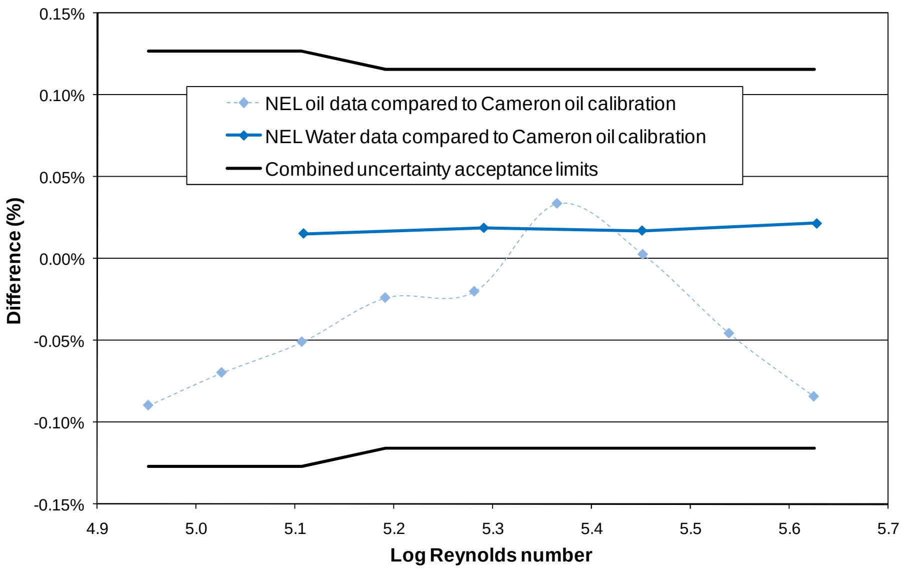


Figure 14 Difference in calibration between the Cameron oil calibration and the NEL water calibration – Meter 1

Two months after the initial intercomparison exercise, both meters were tested in both oil and water as part of an ongoing R&D project. The same calibration methods were used as before, i.e. turbine meters for the oil calibration and the weigh tank for the water calibration. The results of these calibrations are compared in Figure 15, this time in the form of the difference between the NEL oil and NEL water facilities. Again it can be seen that the results from both meters fall within the expected uncertainty bounds for this comparison.

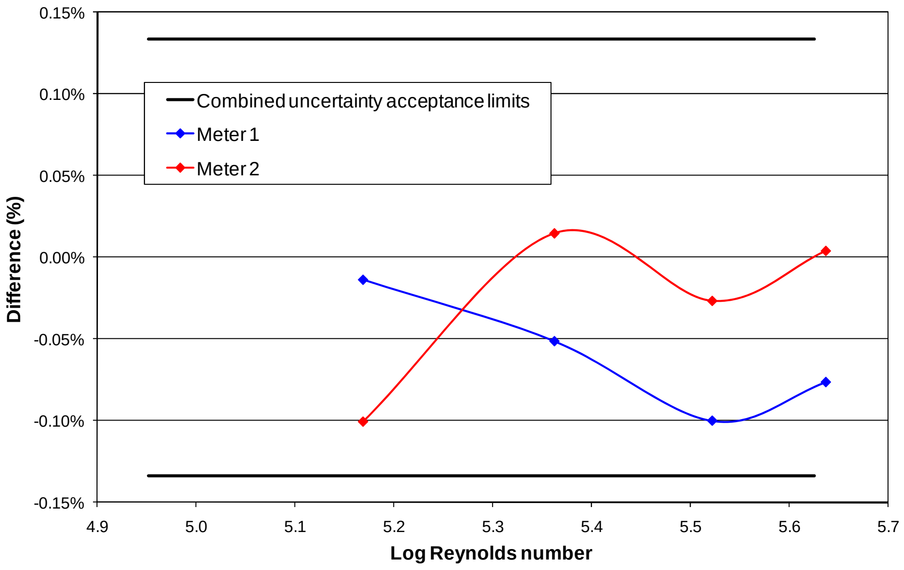


Figure 15 Difference in calibration between NEL oil facility and the NEL water facility

8 REPEAT TESTS ON RETURN TO THE CAMERON LAB

Some nine months after the transfer package was first calibrated it was returned to the Cameron facility and re-tested. Inadvertently, the transfer package had not be properly secured in it crate before shipping and showed some minor damage to the paint on the head-mounted electronics. Fortunately the damage was only superficial and when the meters were recalibrated it was found that they were both still in good agreement with the preceding oil calibration data, as shown in Figure 16 below.

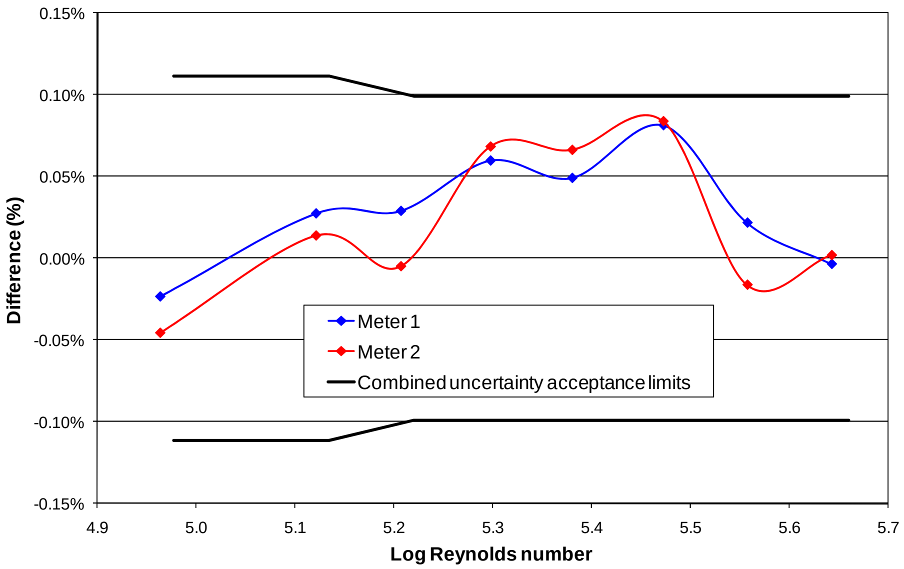


Figure 15 Difference in calibration between NEL oil facility and Cameron repeat calibration

9 SMALL VOLUME PROVER CALIBRATIONS

A final series of tests were carried out in the Cameron lab using the small volume prover in combination with a 6” turbine meter. The API master meter method of proving was used, where the turbine is calibrated against SVP, then the ultrasonic meter is calibrated against the turbine at the same rate and then the turbine is calibrated against SVP again. To reduce the uncertainty of the turbine meters, they were calibrated using 10 runs within a spread of 0.05%, bringing the meter factory uncertainty down to +/- 0.012%. The meter factors for the turbine taken before and after the calibration run must remain within 0.02% of one another resulting in an overall uncertainty in the master metering of method of +/- 0.04%. For these tests the ball prover was operated using the 10 m^3 volume, so that the uncertainty remained constant over the full flow range.

As can be seen from Figure 16 the differences are well within the combined uncertainty of the calibration methods. This verifies the uncertainty and traceability of the small volume prover by comparison with the large prover, and by virtue of using the transfer package, also directly links the comparison with the facilities at NEL.

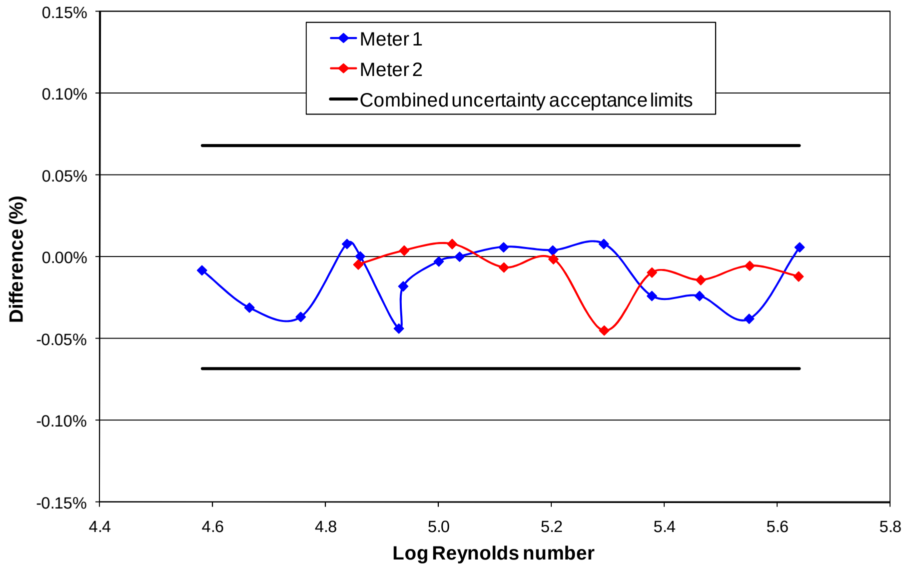


Figure 16 Difference in calibration between the Cameron ball prover and SVP

9 NEL’S PARTICIPATION IN INTERNATIONAL INTERCOMPARIONS

As mentioned earlier in the paper, NEL regularly participates in international intercomparison exercises. Of particular relevance to this paper is the BIPM International Key Comparison of Liquid Hydrocarbon Facilities (CCM-FF-K2). The intercomparison initially involved nine laboratories each designated as national standard calibration laboratories. The comparison was carried out using the BIPM guidelines for key comparisons and is included in the BIPM database to support the capability statements of the participating institutes.

The key comparison was carried out using light liquid hydrocarbon across a flow range 5 to 30 l/s. Two meters, a Kral positive displacement meter and a turbine meter, were used in the intercomparison package; however, the primary comparison used the Kral positive displacement meter.

Six laboratories finally provided results to allow the calculation of a Key Comparison Reference Value (KCRV) and all six sets of results were consistent with the KCRV. The deviations from the KCRV using the Kral meter lay within a band of ±0.026% as illustrated in Figure 17.

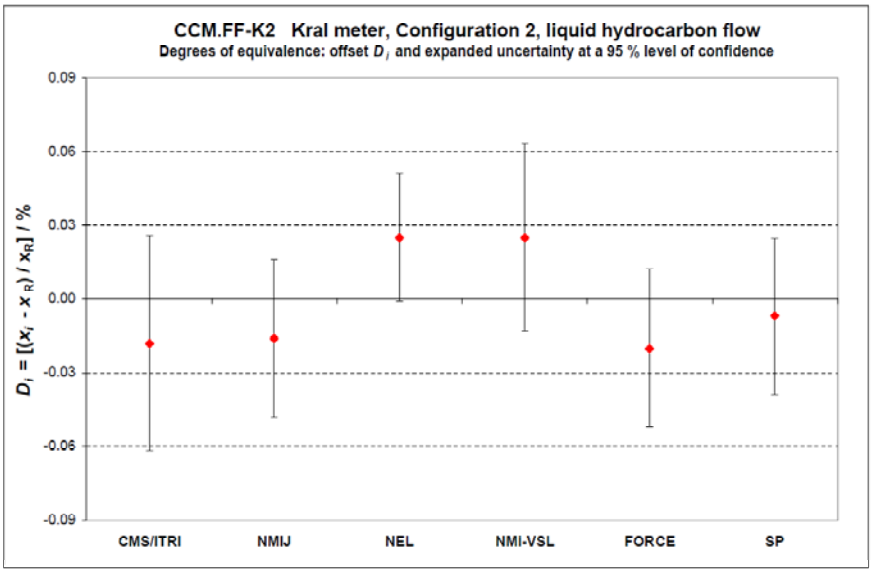


Figure 17 Results of the BIPM liquid hydrocarbon Key Comparision

The intercomparison was led by NEL as the designated pilot laboratory. The other participants named in the graph were SP (Sweden), NMi (NMi Van Swinden Laboratory - Netherlands), FORCE (Denmark), NMIJ (Japan) and CMS (Chinese Taipei).

10 CONCLUSIONS

From the comparision results given in section 6 above, it can be concluded that the Cameron calibration laboratory and the UK National Standards operated by NEL are equivalent in terms of their reference measurements. Underpinned by the inclusion of NEL in international intercomparisons of hydrocarbon facilities, this result validates the traceability of the Cameron laboratory and its associated statement of uncertainty.

The comparison results link together the Cameron lab, the NEL oil facility and the NEL water facility and act to demonstrate the validity of Reynolds number based calibration using dissimilar fluids. This form of Reynolds number calibration is appropriate when the velocities and the acoustic properties of the fluids can be shown to have little influence on the uncertainty of calibration.

The transfer package has also been utilized to provide validation of the traceability and uncertainty of the Cameron small volume prover reference standard.

The performance of the transfer package throughout this series of tests has demonstrated that the Caldon 280Ci flowmeters are stable and robust, both in terms of metrology and practicality, even after being inadvertently shipped back across the Atlantic without being properly secured in the packing crate. In the process of this exercise the transfer package reproduced its calibration in three completely separate facilities, with four different methods of calibration, giving further credence to the use of such systems for master metering.

REFERENCES

[1] G J Brown, D R Augenstein, H Estrada and T Cousins, "Metering of Liquefied Natural Gas Using 8-Path Ultrasonic Meters" NSFMW, 2008

[2] "Bi-lateral Intercomparison of Flow Facilities Between TUV NEL and Cameron Measurement Systems" TUV NEL report No: 2008/316