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Practical Experience of Bi Directional Prover Calibration

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1 INTRODUCTION

This paper describes Alderley's experience of some of the real world challenges and uncertainties associated with the calibration of the prover volume using the two methods defined in the MPMS standards

- Master Meter [1]
- Water Draw [2]

The two main areas covered will be

- Comparison of water draw and master meter calibration of a bi-directional prover
- Verification that the use of a 25% flow rate change during prover volume calibration will identify potential leaks
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The pulsed output from the primary meters on a custody transfer, fiscal or allocation metering system can vary with flow rate, temperature, pressure, density and viscosity. The characteristics can also vary with time. Therefore, it is necessary to recalibrate the meters at agreed frequencies as defined by local governmental organisations or the sales contract in place. There are several methods available to recalibrate the meters

- Calibration by another meter: often referred to as a "master meter" or "transfer standard"
- Volumetric tank method
- Gravimetric tank method
- Calibration by a pipe prover or compact prover

This paper will specifically look at the use of bi directional pipe provers. All bi-di provers require a calibration to determine their 'base volume' (or volumes in the case of multiple pairs of detectors).

Before being installed and operated the prover must be calibrated, ideally by an independent third party, to establish the base volume(s) and to demonstrate that the prover can meet the repeatability requirements stated in the standards. A governmental organisation and the operating company also possibly witness this calibration. The calibrated volume (or volumes) will be stated on the prover calibration certificate, provided by the authorised company that conducted the calibration of the prover.

Once the prover is in service, Alderley recommend that a recalibration be performed annually until at least five calibration results are available. The length between calibrations can then be extended based on cost/benefit analysis when agreed by the governmental regulators Again, ideally an approved independent would must conduct this and it is normal practise to invite witnesses from governmental organisations and the operating company.

MPMS Chpt.4 sect.8 – Operation of Proving Systems Section 10 Prover calibration frequency[3] states " a new certification of a displacement prover shall occur before its next intended use when any one of the following conditions exists:

- Calibration frequency calculated in annex B is met or exceeded
- The maximum time interval indicated below has elapsed
- 60 months (5 years) for stationary provers
- 36 months (3 years) for portable provers

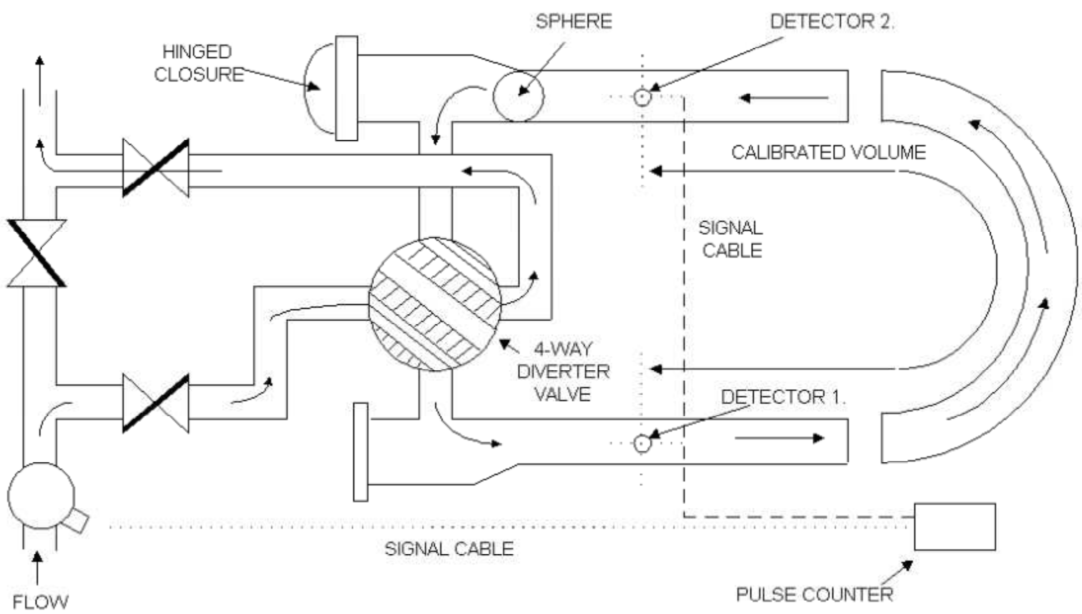
Additional considerations that may determine prover calibration frequency are , but not limited to:

- The fiscal value of the metered liquids
- Contractual or regulatory requirements
- Usage, time wear
- Certification history
- Fluid quality / contamination

2 BACKGROUND

The operating principle of a bi directional prover is relatively simple. The bi-directional prover uses a displacer to "sweep" the calibrated volume. This is usually a sphere. The sphere is inflated to form a leak-tight seal with the wall of the prover pipe.

Figure 1 – Typical prover arrangement



Flow is passed through the operating meter into the prover, part of which has a calibrated volume. When pressure and temperature are stabilized, the sphere is launched.

Since this creates a temporary slowdown in flow until the sphere gets up to speed, a pre-run length is required before measurement takes place of the displaced volume. The pre run length is also critical in terms of completion of the 4 way valve rotation and thus sealing.

At a point after flow rate stabilization, a switch (sphere detector) indicates entry of the sphere into the calibrated section and the meter pulses are sent to the prover counter or circuit.

Flow continues until a sufficient number of pulses (normally 10000) have been generated by the operating meter. It is noted that pulse interpolation allows reduction in the number of pulses.

A downstream detector switch then indicates the calibrated volume has been achieved, and pulses to the prover counter are interrupted. The collection of these pulses are repeated a number of times (set by individual company policy but typically 5 times) while recording the stabilized flow, pressure and temperature.

Calculations convert the pressure and temperature to the same base conditions for the meter and the prover. When volumes are compared, the ratio of the prover to the meter volume is obtained; this is called the meter factor. This is recorded for the given flow rate and is used to monitor the performance of the meter based on true 'results'.

3 PRACTICAL EXPERIENCE OF WATER DRAW VERSUS MASTER METER CALIBRATION OF A BI DIRECTIONAL PROVER

It is believed that water-draw has a slightly better uncertainty than the master meter method; however, both may be used provided they are applicable to the physical arrangement and mandated specifications. The technique used to calibrate the master meter introduces various levels of uncertainty into the measurement hierarchy. While this does not mean the master meter method is less accurate than other methods, the calibration chain is longer than that of a direct method.

The objective of this section of the paper is to look closely at the practical and cost issues associated with the water draw method and question when it is appropriate for this method to be mandated.

3.1 Background

Alderley recently manufactured a 30" bi-directional prover with an approximate calibrated round-trip volume of 14 m^3. The prover had connections for both water draw and master meter calibration as it was to be used offshore but the client mandated the use of water draw for the prover calibration at Alderley.

An independent accredited company using their water draw and master meter test procedures conducted the prover calibration

Calibration procedure consisted of

- Initial master meter determination of prover volumes for all four detector combinations to determine the test measures to be used and the order in which they will be used.
- Repeat until three consecutive round trip runs, together with their respective forward and reverse passes agree within a range of 0.020% or less after corrections for temperature and pressure are applied.

Water draw calibration

- Fill test measure 3, 75 litres to upper neck
- Fill test measure 1, 2367 litres to neck while starting to fill measure 2
- Close test measure 1 record scale reading and then drain down to the stated drain down time
- Fill test measure 2 2367 litres to neck, while starting to fill measure 1
- Close test measure 2, record scale reading and then drain down to the stated drain down time
- Repeat until three consecutive round trip runs, together with their respective forward and reverse passes agree within a range of 0.020% or less after corrections for temperature and pressure are applied.

3.2 Test measure sizing

MPMS 4.9.2 para 6.1.6.5 [2] states that for a water draw calibration of a pipe prover, the number and size of test measures should be selected to allow for filling and draining while maintaining continuous flow (where possible), with a minimum number of test fills.

MPMS 4.9.2 Appendix A2 states
"In the event that the largest test measures have higher uncertainties than some of the intermediate size test measures, other operational aspects, such as reducing the number of fills, should be considered"
"Generally a maximum of ten test measure fillings per pass is recommended.

Whenever they are available, the use of larger test measures is preferred and encouraged"

The normal method for the selection of the tank volumes required would be to do a master meter calibration of the prover to determine the calibrated volume and then select from appropriately sized, readily available test measures.

However to achieve the requirements referenced above, for a minimum number of fills and continuous flow the test measures were going to be very large and not readily available. Therefore, Alderley had to size and purchase two very large and one small, bottom fill and bottom draining, .prover volume specific, calibrated test measures. To achieve the project schedule the test measures had to be sized and purchased before the prover had been completed.

The sizing of the measures was complex, as all the prover volumes had to fall within the neck volume of the three tanks. The following factors also had to be considered;

- MPMS 4.9.2. section 6.1.6.3 [2] – requirement for high sensitivity discrimination on the neck of 0.1 -1 in^3
- MPMS 4.7 section 4.6 [6] – minimum scale spacing 2mm
- External diameter varied from 763.75 to 759.75 mm
- Wall thickness varied from 20.246 to 20.038 mm
- Uncertainty due to detector switch, sphere and pipe MPMS 4.9.2 appendix A1.3 [2] radius variation 2mm to 5mm due to combined effect of sphere variation its location and variation in pipe radius. Total variation can be from 8mm to 20mm for the two boundary conditions
- The time taken to empty the tank (as determined by the calibration) must be less than time taken to fill, to allow the tanks to be swapped over without stopping the flow
- Length of the test measure neck could not be too long. It had to be accessible to the engineer at eye level.

All of these factors resulted in a potential variation in volume of

- Maximum volume 7.2293 m^3
- Minimum volume 7.1311 m^3

This variation in volume could not be accounted for in the necks of the two large test measures without them being excessively long, so a small test measure was also used to give the required flexibility.

The three tanks were certified at

Tank 1	2367 litres	+/- 250 ml (0.011%) with K=2
Tank 2	2367 litres	+/- 250 ml (0.011%)with K=2
Tank 3	75 litres	+/- 10 ml (0.013%)with K=2

Tank 1 and 2 neck details: 1690 mm height 213 mm ID, +/- 25 litres, 50 litres over 1400mm sub divided into 0.1 litres (2.8mm approx.)

Tank 3 neck details: 1300 mm height 50 mm ID, +/- 1 litres, 2 litres over 1018 mm sub divided into 0.05 litres (2.5mm approx.)
Three-off temperature pockets were provided on the 2367 litre vessels because of their size.

Table 1 –Estimated Prover Volume based on prover geometry and measurements relative to actual calibration

S.I litres @ 15 deg C & 101.325kPa A	Dets 1 & 3	Dets 2 & 4	Dets 1 & 4	Dets 2 & 3
BPV	14187.796	14268.621	14350.399	14104.967
Calculated BPV for test measure sizing	14360	14360	14442	14278

The above results showed deviations of between 0.6 and 1.2% for four calibrated volumes

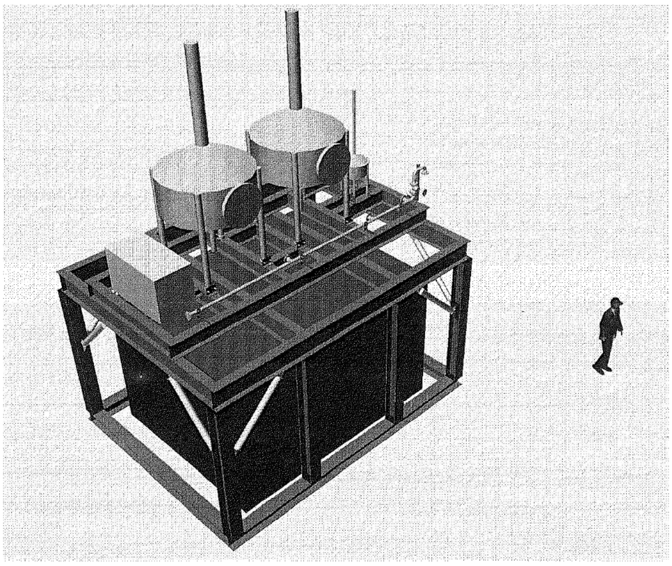
This confirms that calculating the test measure volumes to ensure they finish as close to the centre of the neck as possible must never be under estimated in terms of technical challenge. Furthermore for large bespoke test measures, this process needs to be completed before the true prover volume is known and water draw is commenced.

3.3 Practical issues with test measures

Combined with the prover calibration Alderley also needed to conduct a flow test. The water tank required to for this test was 6130 mm long, 2240 mm wide and 2120 mm high. The large size of the tank also allowed sufficient time for any air bubbles entrained in the water, as it entered the reservoir tank, to be disengaged. The test measures themselves had to be;

- located above the tank to allow free draining
- kept level even when full of water
- Engineers required access to read the calibrated necks and operate the valves.

This required a metal support frame and craneage to get the test measures onto the framework see below



3.4 Costs associated with the test measures

The following items contributed to the overall cost of conducting the water draw calibration

- Test measure costs
- Test measure calibration costs
- Metal frame work costs
- Craneage

As these test measures are specific to the prover volume it is unlikely that they will be able to be used again and therefore become a cost against the project.

3.5 Practical issues associated with the water draw method

Water draw requires a calibrated test measure as discussed above and the measure must not be exposed to anything that might have an effect on its volume such as contamination and rough treatment resulting in dents or damage. The water used must also be clean and free from air bubbles and the water draw completed under stable operating and ambient conditions. The flow rates involved in the water draw calibration are relatively low and the run times can be very long on a large prover. In circumstances where a large prover is being calibrated in a hot climate, temperature instability becomes a major problem.

The prover calibration was conducted at the Alderley site in the UK but at the time of the tests the UK was experiencing a heat wave and daytime temperatures in excess of 30 °C were seen. Ambient temperatures were not stable across the period of the calibration. The strong sun resulted in high levels of solar radiation, which caused thermal expansion of the test measures and the prover volume. To try to alleviate some of these issues and to make the working environment more tolerable scaffolding and sunscreens were installed above the metering skid and test measures.

3.6 Overall consideration of how a prover is used and maintained in the field

The water draw conducted at the manufacturers site is a base point for verification that the prover can be calibrated within the required repeatability to meet the uncertainty stated in the sytem uncertainty calculations. The operational water draw is the one performed in situ.

As per DECC guidelines the use of water as the fluid for the prover calibration must be fully evaluated. Wax deposited on the prover wall may remain after draining and the water will not remove it but it could be subsequently removed by the product. This can result in a negative step change in prover base volume. Therefore DECC should be consulted whenever it is proposed to use water as the calibration medium.

However invariably a master meter is used for re-verification of the base volume for offshore systems which is run on product.

3.7 Test results

Master Meter / Proving tank Method

The master meter method is normally carried out at higher flow rates and does not require the reduced flow rates as the test measure necks are being filled. The fact that the runs can also be continuous means that they take considerably less time and therefore reduce temperature instability problems.

The effects of extreme ambient temperatures on meter factor have also been demonstrated in section 4.3.2 master meter calibration.

Table 1 – Master Meter Prover Volume Results

Volume	Total volume Master Meter (litres)	Repeatability
Dets 1 & 3	14186.704	0.006%
Dets 2 & 4	14270.307	0.008%
Dets 1 & 4	14352.078	0.009%
Dets 2 & 3	14104.935	0.006%

Timescale: 4 hours for all tests
Sphere inflation 7.7.%
A summary of the test results is shown in the table above.

Water Draw Method

The practical issues stated above meant that the first water draw calibration failed to give satisfactory results and had to be re-run with the sphere further inflated.

Timescale between 3 and 7 hours per volume
First calibration sphere over inflation 4.8%
Second calibration sphere over inflation 5.8%

Even after further sphere inflation multiple runs had to be completed to achieve the 3 consecutive runs within repeatability which extended the time of the calibration.

Table 2– Base Prover Volume results

S.I litres @ 15 deg C & 101.325kPa A	**Dets 1 & 3**	**Dets 2 & 4**	**Dets 1 & 4**	**Dets 2 & 3**
BPV	14187.796	14268.621	14350.399	14104.967
Time taken to get 3 consecutive runs hrs:mins	3:35	4:50	3:25	3:45
Temperature difference across the 3 runs ^{o}C	0.22	0.556	0.611	0.33

It is worth noting that the largest difference between master meter and water draw were seen on the two volumes that saw the biggest change in temperature across the time of the 3 consecutive runs.

Table 3 – Results for Detectors 2 & 3 smallest volume

Detectors 2 & 3					
Pass no	Direction	Flow rate LPM	Measure reference	BMV (litres)	Scale reading correction
1	Forward	500	2	2367	-21.28
			1	2367	-21.48
			2	2367	-8.02
1	Reverse	500	2	2367	-21.12
			1	2367	-20.94
			2	2367	-2.40
2	Forward	375	2	2367	-21.00
			1	2367	-20.92
			2	2367	-8.30
2	Reverse	375	2	2367	-20.80
			1	2367	-21.04
			2	2367	-2.50
3	Forward	500	2	2367	-20.84
			1	2367	-21.08
			2	2367	-8.84
3	Reverse	500	2	2367	-20.66
			1	2367	-20.84
			2	2367	-2.58

Table 4 – Results for Detectors 1 & 4 largest volume

Detectors 1 & 4					
Pass no	Direction	Flow rate LPM	Measure reference	BMV (litres)	Scale reading correction
1	Forward	500	3	75	0.005
			2	2367	9.96
			1	2367	7.62
			2	2367	-0.34
1	Reverse	500	3	75	0.015
			2	2367	-7.60
			1	2367	-7.34
			2	2367	-1.16
2	Forward	375	3	75	0.020
			2	2367	8.94
			1	2367	9.00
			2	2367	-0.62
2	Reverse	375	3	75	0.020
			2	2367	-7.70
			1	2367	-7.82
			2	2367	-0.88
3	Forward	500	3	75	0.015
			2	2367	9.00
			1	2367	8.88
			2	2367	-1.38
3	Reverse	500	3	75	0.040
			2	2367	-6.98
			1	2367	-7.50
			2	2367	-2.56

The above results indicate that it would not have been possible to measure all 4 volumes using only the two large tanks and the third small tank was required to provide enough flexibility for the difference between all the volumes.

3.8 Master Meter vs water draw method verification results

Table 5 –Comparison of results for water draw and master meter methods

Volume	Total volume Master Meter (litres)	Repeatability	Total Volume Water Draw (litres)	Repeatability	Difference %
Dets 1 & 3	14186.704	0.006%	14187.796	0.007%	-0.007
Dets 2 & 4	14270.307	0.008%	14268.621	0.016%	+0.0118
Dets 1 & 4	14352.078	0.009%	14350.399	0.011%	+0.0117
Dets 2 & 3	14104.935	0.006%	14104.967	0.005%	- 0.0002

These results demonstrate that both the master meter and water draw method gave very similar results, all within the 0.02% required by the standards [1], [2]

From a paper written by SGS [9] demonstrates similar results

Prover 1	Water Draw	1001.405	1001.445
	Master Meter	1001.392	1001.465
	Difference %	-0.001	+0.002
Prover 2	Water Draw	1004.319	1004.191
	Master Meter	1004.381	1004.245
	Difference %	+0.006	+0.005

There is a suggestion of a small systematic difference between the two methods. Calibration of prover 1 were based on the use of the same prover tank Calibration of prover 2 a different tank was used for the water draw and master meter methods. It is therefore possible that the differences noted arise from small systematic errors in the calibration of the two prover tanks employed when calibrating prover 2.

3.9 Theoretical comparison between the two methods

The following features distinguish the two methods

Water Draw

Advantages

- Relatively simple technique under clean conditions
- Best results obtained when the prover volume is equal to, or an exact multiple of the nominal volume of the tanks
- Short traceability chain, listed below;

Prover
prover tank
primary measure
standard authority (mass)

Disadvantages

- Not general convenient under field conditions when availability of clean water may be limited, therefore not often used off shore.
- Limited to relatively low flowrates to ease filling the tank and stopping at the correct level in the volumetric tank.
- Large provers may require project specific prover tanks to meet the requirements of the standard for minimum fills and continuous flow.
- Large provers require a long test period and are therefore susceptible to temperature stability problems during the runs, particularly in hot climates and hence the uncertainty of the water draw method increases.
- For prover recalibration - the risk of hydrocarbon deposits causing a negative step change in prover base volume.

Master Meter/proving tank

Advantages

- The volume of the prover tank does not have to be closely tied to the volume of the prover on test as with water draw. This allows a single test rig to handle a wide range of pipe prover sizes and volumes.
- Repeated use of the same master meter and associated tank results in empirical data which improves the confidence in a given test.
- The shorter run times decrease the temperature instability and hence reduce the uncertainty of the master meter method.
- Offshore the shorter test times increase the overall availability of the prover and reduce manhours required to conduct the prover calibration.
- Off shore the use of a pre selected rig allows the correct lay down area to be considered in the design.

Disadvantages

- There is an extra step in the traceability chain of the master meter method, as listed below. This will increase the uncertainty in the method

  Prover
  Master Meter
  Prover Tank
  Primary Measure
  Standard Authority (mass)

3.9.1 Uncertainty Comparison

The uncertainty of the process defines the range within which the measurement errors can be expected to lie with a specified level of probability, and takes into account all steps in the traceability chain from the national standard.

To determine the level of uncertainty for both the water draw and master meter method the Petroleum measurement paper no 12 [8] has been referenced in conjunction with a paper previously presented at the 27th International North Sea Flow Measurement Workshop 20 – 23 October 2009, Tønsberg, Norway,[7]

- The extra step adds 0.008% to the uncertainty in the master meter method [8]

- It is estimated that an increase of 0.1 °C in temperature instability adds 0.008% to the uncertainty of the water draw method [9]

For interest

- Historic calibration results of in service provers demonstrate a significant increase in uncertainty of volume with higher temperature calibrations, this is a result of the increase in sensitivity of the cubical thermal expansion coefficient of the pipe prover steel. There may be a need for a reduction in the coefficient of thermal expansion uncertainty to maintain a pipe prover volume uncertainty in the order of +/-0.03%[7]
- Additional test work detailed in section 4.3 demonstrates that during testing in Dubai a temperature instability at the prover of 0.3 °C was seen across three sets of forward and reverse runs using a master meter/master prover method. The increased time taken for a water draw would have increased this effect significantly.

3.10 Conclusions

Overall, the theoretical calculations indicate that the two methods have very similar uncertainties. The practical results support these theoretical conclusions

For each project, the prover calibration method specified should be reviewed carefully. Based on the real world example above it is important that all measurement engineers within the project are aware of potential uncertainty, time and cost implications related to the calibration method they select as the best method is often project specific.

Verification that the use of a 25% flowrate change during prover volume calibration will identify potential leaks

Prover testing was conducted with the objective of validating the methodology stated in MPMS standards and DECC guidelines [1], [2], [4] for identifying the presence of the potential common types of leakage during the calibration of a typical bi directional pipe prover volume. The tests were devised to try to establish if a clear pattern of bias in volumes is obtained between slow and fast runs.

DECC Guidelines [4] section 5.6.4 Prover Calibration Acceptance Criteria refers to the expected repeatability of periodic prover re-calibrations and states that where the result differs from the previous calibration by more than the relevant tolerance, it must be verified by a repeat calibration at a different flow rate – preferably at least 25% different."

MPMS 4.9.3 section 4.5.6 flow rates [1]
In addition, between calibration sets, the flow rate shall be changed by an amount that is at least 25% of the greater of the flow rates of the two consecutive calibration sets being compared. Users may consider changing the flow rate by a percentage higher than 25% to provide more confidence in the ability of the rate change procedure to discover otherwise undetected leaks.

MPMS 4.9.2 section 6.1.12 [2]
states that for leak detection and reproducibility purposes the flow rate on displacement provers shall be changed between consecutive calibration runs by

25% or more for the water draw method. A very similar requirement is stipulated in MPMS 4.9.3 para 4.5.6 for the master meter method.

"On bi directional provers at least one of the passes in the "out" direction and at least one of the passes in the back direction shall be at a rate that represents a change of 25% or more from the other passes in their respective directions"
"The flow rate change can be determined by one of three methods

- Using a flow meter to monitor the flow rate while adjusting the filling valve
- Timing the filling of the largest test measure being used
- Timing the entire calibration pass {(total volume/time)} = flow rate

MPMS 4.9.2 section 8.2 Leaks [2]
Stresses the poor repeatability and possible over or under-statement of the prover volume that can be caused by leaks. The most obvious leak sources are external which are relatively easy to check for. Internal leaks are more difficult to detect and may be through four-way diverter valves or past the sphere displacer. The MPMS standard says there "may" be a clear bias in volumes obtained between slow and fast runs, which would indicate the presence of a leak.
"If enough information has been gathered from calibration run data, there may emerge a clear pattern of bias in volumes obtained between slow and fast runs"

MPMS 4.9.2 section 8.6.1 Elastomeric Sphere Displacers
"Changing the flow rate of the water can produce a different rate of leakage. Changing the flow rate, by as much as 50%, can make any sphere leakage problem more apparent and easy to detect"

3.11 Technical specification of the equipment

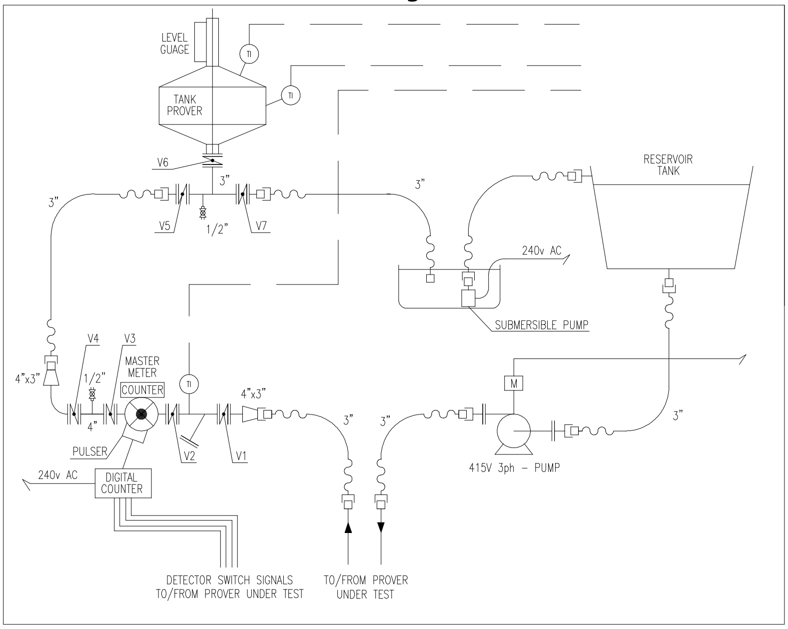
The following equipment was selected for the trials

- Prover: Project timescales allowed for testing to be conducted on a project specific prover. Due to project specific requirement, the prover only has two switches as opposed to the recommended 4 switches. This had no impact on the prover testing as the 4 switches are recommended to allow for redundancy in the field, which was not an issue for testing.

Prover ID	=	15.25"
Material	=	mild Steel
Sphere Material	=	Neoprene

- Master meter calibration rig – Alderley AFZE had a master meter rig available at their site consisting of a positive displacement meter and calibrated tank. The calibration rig was re-certified before the testing began.

Figure 2 – P&ID of master meter calibration rig



<u>Master Meter Details</u>

Manufacturer	=	Avery Hardoll
Type	=	PD meter
Pulses/unit vol	=	225

- Water pump nominally 700-2400 l/min flow rate
- VA meter to measure the artificially created leak

3.12 Trial Test Procedure

The prover testing was undertaken in Alderley's facility in Dubai.

The tests were conducted in a controlled manner following a predefined test procedure and generally in line with the MPMS standards [1] for prover calibration by master meter. The testing was undertaken by an Alderley engineer with over 20 years' experience in prover calibration and supervised by an independent authorised company (Steve Gwaspari – IKM measurement services)

The uncertainty of the prover volume has to be +/- 0,027% this can be achieved by using equation (1) [5] and the repeatability stated in the table below depending on the number of runs
The expected repeatability to meet 3 runs and an uncertainty of 0.027% is 0.02%

$$\alpha(PV) = \frac{[t(95, n-1)w_{(n)}}{(\sqrt{n})(D_{(n)}} \tag{1}$$

MPMS chapter 4.8 [3] Table A-1 Variable range criteria for +/- 0.00027 random uncertainty in average meter factor

Number of runs	Moving (variable) range limit
n	
3	0.002
4	0.003
5	0.005

Based on this level of repeatability the size of the leak required to show a change in prover volume could be very small.

The initial methodology called for multiple tests at differing flow rates using the master meter and volumetric tank to calibrate the volume of the pipe prover.
On arrival on site, it was clear that due to a number of factors this would not be practical.

3.12.1 Practical Issues faced during testing

3.12.1.1Ambient temperature variations
Due to equipment availability, the tests had to be conducted at Jebel Ali, Dubai, United Arab Emirates. During August, when the tests were conducted, the ambient temperatures were between 36°C and 46 °C across the day. This meant that achieving stable conditions for the tests was very difficult. All the tests were conducted after 4pm, as during the evening the temperature stability was better than the morning. However, the difficulties faced in achieving stable conditions did have an impact on the methodology adopted for the tests. It was common to see a temperature instability of 0.3 °C across three sets of forward and reverse runs. As seen in the first section of the paper, temperature fluctuation can have a significant impact on the repeatability of a prover calibration.

3.12.1.2Prover tank master meter method
Using the prover tank and master meter method may have introduced some additional uncertainty due to the standing start / stop of the flow through the master meter.
3.12.1.3Time constraints
The prover tank master meter method was very time consuming and the extended length of each test meant that the ambient temperature effects became significant and achieving repeatability became very difficult. There were also government restrictions in place, which did not allow outside working between 12 and 3.30pm. The above factors meant that there would not have been enough time to carry out the tests to completion using the master meter and volumetric tank method.

3.12.2 New methodology adopted

It was decided on site to come up with a comparative type test programme. That is, to compare the relative shifts in prover volume under each scenario. The absolute base volume was not required to be confirmed during the tests.

3.12.3 Inspection

Physically confirm that there were no leaks on the 4-way valve and drain/vent valves of the prover

3.12.4 Prover Calibration

The prover had been in storage for a significant amount of time and therefore the first step was to conduct a master meter/ proving tank calibration to establish the base prover volume within the required repeatability.

For leak detection and reproducibility purposes the flow rate on displacement provers shall be changed between consecutive calibration runs by 25% or more (e.g. fast/slow/fast or slow/fast/slow)

The purpose of this test was to determine:

- Actual Calibration Volume for comparison with results from induced leaks
- Time taken to complete forward and reverse pass to determine the required leak flow rate
- Record actual sphere inflation required for acceptable calibration

3.12.5 Master Meter Calibration

To reduce the time taken for each run it was decided to adopt the master meter/ master prover method. The master meter was calibrated using the bi-directional prover as a master prover to verify the prover repeatability at three different flow rates 850, 600 and 400 lpm. The relative shifts in volume were compared to each other to confirm that there were no leaks internally due to the sphere. This set the initial status of the prover

At the same time, information was gathered on the master meter k-factor in order to characterise the master meter performance with flow rate change and temperature change.

3.12.6 Leak across the 4 way valve

A hose and VA meter were connected to the manifold on the 4 way valve (vent on non-cavity side of the manifold) and a suitable connection on the other side of the valve (the downstream pressure transmitter connection). This simulated an interconnection leak across the 4-way valve seals.

A known leak rate was introduced across the 4-way valve and further proving of the master meter was carried out to produce a comparative volume for the prover under these conditions. Tests were run in the forward and reverse direction for three different flow rates 850 l/min, 600 l/min and 400 l/min. The leak induced at each flow rate was also recorded.

After testing the engineers ensured that any leaks artificially introduced had been stopped and valves operated had been restored to their original position.

3.12.7 Leak downstream of the prover

A hose and VA meter were connected to the manifold on the pressure indicator downstream of the prover.

A known leak rate was introduced downstream the 4-way valve, upstream of the master meter, to simulate an internal leakage to atmosphere or drain leak. This test was carried out at the three flow rates above and at various leakage rates

After testing the engineers ensured that any leaks artificially introduced had been stopped and valves operated had been restored to their original position.

3.12.8 Leak due to underinflated Sphere Displacer

Spheres are typically hollow and made of an oil resistant polymer and filled with water and 10% glycol through an inflation valve. The normal over inflation of a sphere is between 2-4%, this can be dependent on prover size, and larger provers may require more inflation. This over inflation ensures that the sphere has sufficiently tight fit to prevent liquid leaking past it and ensures the sphere travels smoothly. The normal sphere sizing technique is to use a diameter tape.

The original prover recalibration confirmed that a sphere over inflation of 3.5% resulted in an acceptable prover calibration.

The sphere was removed, and deflated to 1% and proving carried out at the three flow rates above to produce comparative prover volume from the raw meter pulse counts and the characterised k-factor for the meter conditions.

The sphere was then removed, and inflated to 1.6% and proving carried out at the three flow rates above to produce a comparative prover volume from the raw meter pulse counts and the characterised k-factor for the meter conditions.

After testing the engineers ensured that the sphere was re-inflated to the original 3.5%

3.12.9 Leak in the calibrated volume

The original testing procedure called for tests to be run with an artificial leak created by cracking a joint within the calibrated section. However, for the reasons explained above there was no time to conduct these tests. It was felt that the results from the 4way valve leakage test and sphere under inflation would provide the most useful information for real world experience as leaks in the calibrated volume should be easier to detect visually.

3.12.10 Prover Re-Calibration

To confirm that no changes had occurred during the testing the prover was recalibrated using the original method.

3.13 Test Results

3.13.1 Prover Calibration

Pulses per unit volume	=	225
Internal Diameter	=	15.25”
Sphere Diameter	=	15.79”
Sphere Inflation	=	3.5%

Water Draw Base Volume = 3524.520 litres

3.13.2 Master Meter/master prover Calibration

Table 6 – Results from Master Meter/master prover calibration

Method	Flowrate (l/min)	Corrected Volume (litres)	Difference from water draw (%)
Water Draw		3524.520	
Master meter/master prover	850	3524.572	+ 0.0015
Master meter/master prover	600	3524.688	+0.0048
Master meter/master prover	400	3524.419	-0.0029

The master meter/ master prover calibrations above demonstrate that the results show a close correlation with the prover calibration conducted using the master meter/ tank prover and water draw method and this is a valid method to adopt in this situation.

3.13.3 Leak across the 4 way valve

A leak of 0.6 l/min was established across the 4-way valve (using the connections on the instrument manifold for the differential pressure transmitter.) The leakage flows at a calibration flowrate of 600 and 400 l/min, with the flow restriction unchanged were noted. The leakage flowrates used in subsequent testing were:-

Calibration Flowrate (l/min)	Leak Flowrate (l/min)
850	0.6
600	0.4
400	0.2

It should be noted that for this particular leak scenario, the leak varies with the calibration flowrate.

A summary of the prover volumes for all cases are tabulated below:

Table 7 – Results from 4 way valve leakage test

Cal Flowrate (l/min)	Calc base volume (l)	Repeatability (%)	Leak (l/min)	Leak/flow (%)	Base Volume Change (%)
850	3524.299	0.0134	0		-0.006%
850	3527.302	0.0029	0.6	0.071%	0.079%
600	3524.675	0.0062	0		0.004%
600	3526.869	0.0153	0.4	0.067%	0.067%
400	3524.419	0.0048	0		-0.003%
400	3526.655	0.0019	0.2	0.050%	0.061%

As a tight seal is required between the inlet and outlet sides of the 4 way valve it is common practice to install a differential pressure transmitter to indicate seal leakage. If the 4-way valve fails to seal, the differential pressure caused during valve operation will reduce and raise an alarm on the associated flow computer. However, if this system has not been installed, or if it is not functioning correctly, the above tests demonstrate that a leak could be detected by changing the calibration flowrate.

The calculated change in prover volume generally correlates to the expected change from the known leak. It should also be noted that it is quite possible to achieve repeatable results while a leak is present. Whilst changing the calibration flowrate is of some value as a method to detect leaks at the 4-way valve it is still possible that a significant leak could remain undetected.

3.13.4 Leak downstream of the prover

A leak of 0.6 l/min was established downstream of the prover (using the connections on the instrument manifold for the outlet pressure transmitter.) The leakage flows at a calibration flowrate of 600 and 400 l/min, with the flow restriction unchanged were noted. The leakage flowrates used in subsequent testing were:-

Calibration Flowrate (l/min)	Leak Flowrate (l/min)
850	0.6
600	0.6
400	0.6

It will be noted that for this particular leak scenario, the leak doesn't vary with the calibration flowrate. Due to the testing arrangement, the prover outlet pressure was relatively constant. This scenario therefore relates to a number of possible leaks to atmosphere in a typical metering configuration.

Table 8 – Results from leak downstream of prover test

Cal Flowrate (l/min)	Calc base volume (l)	Repeatability (%)	Leak (l/min)	Leak/flow (%)	Base Volume Change (%)
850	3524.299	0.0134	0		-0.006%
850	3521.973	0.0055	0.6	0.071%	-0.072%
600	3524.521	0.0051	0		0.000%
600	3521.46	0.0255	0.6	0.100%	-0.087%
400	3524.055	0.0136	0		-0.013%
400	3522.588	0.0090	0.6	0.150%	-0.055%

The calculated change in prover volume generally correlates to the expected change from the known leak. It should also be noted that it is quite possible to achieve repeatable results while a leak is present. Whilst changing the calibration flowrate is of some value as a method to detect leaks at the outlet valve it is still possible that a significant leak could remain undetected.

3.13.5 Leak due to underinflated Sphere Displacer

3.13.5.1 Correctly Inflated Sphere – 3.5%

A summary of the raw prover volumes for all cases were collected and tabulated below:
First the data was analysed for repeatability across three runs but for only a single flow rate

Table 9 – Results from correctly inflated sphere displacer test - single flow rate

850 l/min	Average raw volume (litres)	Repeatability (%)
Runs 1-3	3528.28	0.004

600 l/min	Average raw volume (litres)	Repeatability (%)
Runs 1-3	3528.494	0.019

400 l/min	Average raw volume (litres)	Repeatability (%)
Runs 1-3	3529.294	0.009

The results demonstrate that with a correctly inflated sphere the prover was repeatable within the required 0.02% for all three flowrates.

The next data compares the repeatability when the fast/slow/fast method was adopted. Three sets of runs were conducted following the fast/slow/fast method at 850 l/min, 600 l/min and 850 l/min. The repeatability for each set of forward, reverse and total volumes is shown below.

Table 10 – Results from correctly inflated sphere displacer test – 850 l/min, 600 l/min, 850 l/min

Test	Flow Direction	Repeatability (%)
1	Forward	0.014
	Reverse	0.008
	Total	0.003
2	Forward	0.008
	Reverse	0.019
	Total	0.009
3	Forward	0.026
	Reverse	0.02
	Total	0.02

The results demonstrate that with a correctly inflated sphere the prover was repeatable within the required 0.02% for all but one forward run.

The same test were conducted but using a much lower flow rate, 850 lpm, 400 lpm, 850lpm.

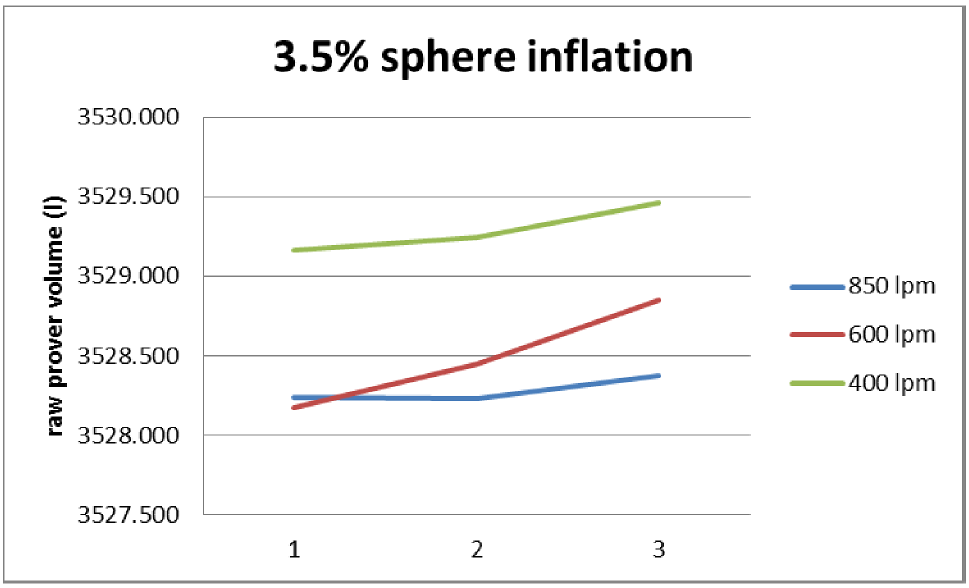
Table 11 – Results from correctly inflated sphere displacer test – 850 l/min, 400 l/min, 850 l/min

Test	Flow Direction	Repeatability (%)
1	Forward	0.032
	Reverse	0.022
	Total	0.026
2	Forward	0.027
	Reverse	0.043
	Total	0.031
3	Forward	0.032
	Reverse	0.049
	Total	0.037

The results demonstrate that with a correctly inflated sphere the prover was not repeatable within the required 0.02% for any of the fast/slow/fast runs.
This would imply that there was another factor at play during these tests.

For the 400lpm flow rate case, the lower velocity could be causing the sphere to constantly start and stop (judder) which in itself may also cause poor repeatability. It may also cause a backpressure to build up in the system

Figure 3 – Results from correctly inflated sphere displacer test – comparison of raw prover volumes at three flowrates



The above graph demonstrates

- The 850 and 600 l/min runs returned raw prover volumes that were repeatable and similar
- The 400 l/min case although repeatable show a consistent shift from the 850 l/min case always returning a larger prover volume which indicates that some of the issues stated above are being seen in these cases.

3.13.5.2Under-inflated Sphere – 1%

A summary of the raw prover volumes for all cases were collected and tabulated below:
First the data was analysed for repeatability across three runs but for only a single flow rate

Table 12 – Results from underinflated sphere displacer 1% - single flow rate

850 l/min	Average raw volume (litres)	Repeatability (%)
1-3	3529.99	0.044
2-4	3530.208	0.025
3-5	3530.132	0.025
4-6	3530.277	0.037
5-7	3530.573	0.035
6-8	3530.977	0.012
7-9	3530.623	0.030

The results show that if we analyse the results in sets of 3 consecutive runs there is only one case where the prover would have been repeatable within 0.02%

600 l/min	Average raw volume (litres)	Repeatability (%)
1-3	3531.337	0.037
2-4	3531.793	0.024
3-5	3532.125	0.007
4-6	3532.324	0.015
5-7	3532.545	0.014
6-8	3532.755	0.007
7-9	3532.883	0.007

The results show that if we analyse the results in sets of 3 consecutive runs there are 5 cases where the prover would have been repeatable within 0.02%

400 l/min	Average raw volume (litres)	Repeatability (%)
1-3	3531.75	0.042
2-4	3532.094	0.013
3-5	3530.857	0.109
4-6	3530.46	0.097
5-7	3530.456	0.096
6-8	3531.77	0.036
7-9	3532.268	0.022

The results show that if we analyse the results in sets of 3 consecutive runs there is only one case where the prover would have been repeatable within 0.02%

The next data compares the repeatability when the fast/slow/fast method was adopted. Three sets of runs were conducted following the fast/slow/fast method at 850 l/min, 600 l/min and 850 l/min. The repeatability for each set of forward, reverse and total volumes is shown below.

Table 13 – Results from under-inflated sphere displacer test 1%– 850 l/min, 600l/min & 850 l/min

Test	Flow Direction	Repeatability (%)
1	Forward	0.075
	Reverse	0.057
	Total	0.066
2	Forward	0.068
	Reverse	0.034
	Total	0.048
3	Forward	0.056
	Reverse	0.019
	Total	0.038
4	Forward	0.057
	Reverse	0.334
	Total	0.194
5	Forward	0.048
	Reverse	0.087
	Total	0.067
6	Forward	0.036
	Reverse	0.050
	Total	0.043
7	Forward	0.058
	Reverse	0.062
	Total	0.058

The results demonstrate that with an under inflated sphere the prover was repeatable within the required 0.02% for only one total run and not across a set of forward, reverse total runs..

The same test were conducted but using a wider flow range i.e. 850 l/min, 400 l/min, 850 l/min.

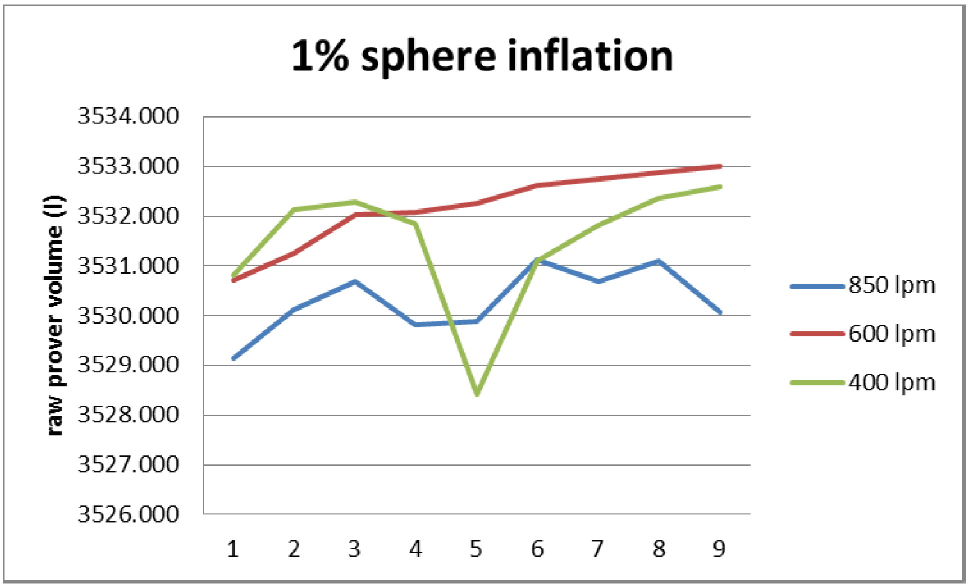
Table 14 – Results from underinflated sphere displacer test 1%– 850 lpm/ 400lpm/850 lpm

Test	Flow Direction	Repeatability (%)
1	Forward	0.075
	Reverse	0.057
	Total	0.066
2	Forward	0.069
	Reverse	0.045
	Total	0.057
3	Forward	0.050
	Reverse	0.041
	Total	0.045
4	Forward	0.082
	Reverse	0.334
	Total	0.194
5	Forward	0.122
	Reverse	0.093
	Total	0.107
6	Forward	0.046
	Reverse	0.045
	Total	0.039
7	Forward	0.058
	Reverse	0.058
	Total	0.058

The results demonstrate that with an under inflated sphere the prover was not repeatable within the required 0.02% for any of the fast,slow,fast runs.

Under inflated spheres can result in the velocity of the liquid in the prover being greater than the velocity of the sphere and the pulses counted during the prove will be too high causing the K factor to be too high.

Figure 4 – Results from under inflated sphere displacer test 1%– comparison of raw prover volumes at three flow rates



The above graph demonstrates

- For 850 and 600 l/min the raw volumes were not within the repeatability range of 0.02% but did show a consistent shift in prover volume. The prover volume increased with the lower flowrate which would be consistent with an increased, but consistent, leak past the sphere at this lower flowrate.
- The 400 lpm case results demonstrated no clear pattern at this sphere inflation, which is consistent with the low flowrate issues already discussed.
- There may also have been another factor involved with the 400 l/min results. Due to the extreme working conditions the sphere had been taken into the air-conditioned work shop when it was deflated and measured at 1%. When the sphere was removed at the end of the test the sphere had increased in diameter to 1.3%. This was put down to the increased operating temperatures inside the prover. It is hard to establish the impact this may have had on the results.

3.13.5.3Under-inflated Sphere – 1.6%

A summary of the raw prover volumes for all cases were collected and tabulated below:
First the data was analysed for repeatability across three runs but for only a single flow rate

Table 15 – Results from underinflated sphere displacer 1.6% - single flow rate

850 l/min	Average raw volume (litres)	Repeatability (%)
1-3	3530.566	0.022
2-4	3530.559	0.022
3-5	3530.439	0.023
4-6	3530.156	0.002

The results show that if we analyse the results in sets of 3 consecutive runs there is only one case where the prover would have been repeatable within 0.02%

600 l/min	Average raw volume (litres)	Repeatability (%)
1-3	3531.749	0.033
2-4	3532.551	0.038
3-5	3533.101	0.044
4-6	3533.619	0.009

The results show that if we analyse the results in sets of 3 consecutive runs there is only one case where the prover would have been repeatable within 0.02%

400 l/min	Average raw volume (litres)	Repeatability (%)
1-3	3529.579	0.023
2-4	3530.05	0.032
3-5	3530.64	0.035
4-6	3530.841	0.018

The results show that if we analyse the results in sets of 3 consecutive runs there is only one case where the prover would have been repeatable within 0.02%

Three sets of runs were conducted following the fast/slow/slower method at 850 l/min, 600 l/min and 400 l/min. The repeatability for each set of forward, reverse and total volumes is shown below.

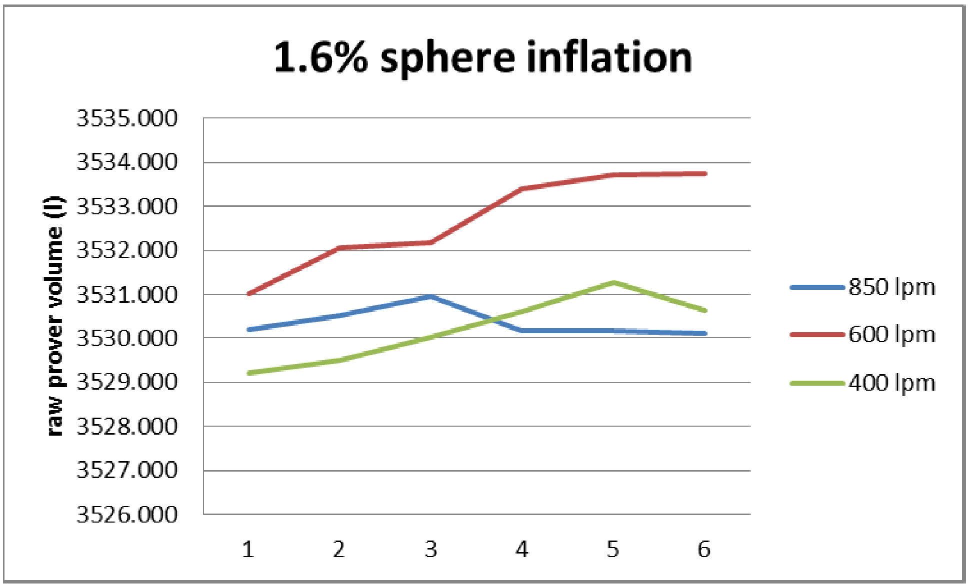
Table 16 – Results from underinflated sphere displacer test 1.6%– 850 lpm/ 600lpm/400 lpm

Test	Flow Direction	Repeatability (%)
1	Forward	0.023
	Reverse	0.033
	Total	0.028
2	Forward	0.050
	Reverse	0.008
	Total	0.029
3	Forward	0.022

	Reverse	0.031
	Total	0.027
4	Forward	0.003
	Reverse	0.027
	Total	0.012
5	Forward	0.004
	Reverse	0.067
	Total	0.031
6	Forward	0.025
	Reverse	0.003
	Total	0.014

The results demonstrate that with an under inflated sphere the prover was repeatable within the required 0.02% for 6 of the results but not for a set of, forward, reverse and total, therefore the prover would not have been calibrated.

Figure 5 – Results from under inflated sphere displacer test 1.6%– comparison of raw prover volumes at three flow rates



The above graph demonstrates

- For 850 and 600 l/min the raw volumes were not within the repeatability range of 0.02% but did show a consistent shift in prover volume. The prover volume increased with the lower flowrate which would be consistent with an increased, but consistent, leak past the sphere at this lower flowrate.
- The 400 l/min case results demonstrated no clear pattern at this sphere inflation, which is consistent with the low flowrate issues already discussed.
- An area of concern is that for this case the 400 l/min flow rate seems to be returning volumes close to the 850 l/min but it has already been demonstrated that the 400 l/min case is unreliable.

4 OVERALL CONCLUSIONS

4.1 Practical experience of water draw versus master meter calibration of a bi directional prover

Overall, the theoretical calculations indicate that the two methods have very similar uncertainties. The practical results support these theoretical conclusions

For each project, the prover calibration method specified should be reviewed carefully. It is important that all measurement engineers within the project are aware of potential uncertainty, time and cost implications related to the calibration method they select as the best method is often project specific.

In general when conducting a calibration on a large prover with large ambient temperature swings the master meter method is the most appropriate and lowest cost method for calibration.

4.2 Verification that the use of a 25% flowrate change during prover volume calibration will identify potential leaks

Underinflated Sphere

- It would have been possible to get a repeatable result from the prover with a leak present at the 850 l/min and 600 l/min flowrates without using the fast/slow/fast method.
- When the fast/slow/fast or fast/slow/slower methods were applied the prover was not repeatable when a leak was present but did demonstrate a consistent shift in prover volume from the fast to slow run.
- Great care should be taken when very low flowrates are used as other factors can have a greater impact on the results.
- The tests have demonstrated that the fast-slow-fast method with a change in flowrate of at least 25% is a valid method for detecting potential leaks due to underinflated sphere. From our experience, an incorrectly sized sphere is the most common cause of leak.

Other Leaks

- It is quite possible to achieve repeatable results with a significant leak present. Using the fast-slow-fast method will assist in detecting these leaks but is still possible that a significant leak would not be detected. This reinforces the necessity for proper isolation and leakage checks before and during the calibration process.

5 TERMS AND DEFINITIONS

5.1 General Abbreviations

DECC Department of Energy and Climate Change
MPMS Manual of Petroleum Measurement Standards

5.2 Terms

Detector - The device used to signal the passing of a displacer. In a bi-di pipe prover, this is a high accuracy electro-mechanical switch, with a 'plunger' that protrudes into the calibrated pipe section and is moved by the passage of the sphere. In a SVP piston prover it will most likely be an electro-optical detector that monitors the piston position from the piston rod or an auxiliary 'switch-bar' attached to it.

Calibrated Length - The section of the pipe prover (or 'barrel' for piston provers) between detectors. This section has an accurately measured or 'calibrated' volume.

Pulse Interpolation - If a displacer passes a detector between any two whole pulses from a meter, then one of a number of pulse interpolation techniques can improve the resolution by calculating/inferring that part of a whole pulse that has been registered.

Displacing Device - Prover displacers are devices, which travel through the calibrated section, operating the detector switches and sweeping out the calibrated liquid volume. There are two types of displacer in common use, inflatable elastomeric spheres and pistons.

K Factor - Number of pulses generated by a meter in relation to the volume passed

Master Meter - A meter that serves as the reference for he proving of another meter or pipe volume.

Pass - A single movement of the displacer between detectors

α Random uncertainty of the average of a set of prover calibration runs
t (95,n-1) student "t" distribution factor for 95% confidence level and n-1 degrees of freedom

w range of values (high minus low) in the proving set number of calibration runs

D(n) conversion factor for estimating standard deviations for n data point

6 REFERENCES

[1] Manual of Petroleum Measurement Standards Chapter 4 Section 9 part 3 – Determination of the Volume of Displacement Provers by the Master Meter Method of Calibration

[2] Manual of Petroleum Measurement Standards Chapter 4 Section 9 part 2 – Determination of the Volume of Displacement and Tank Provers by the Water Draw Method of Calibration

[3] MPMS Chpt.4 sect.8 – Operation of Proving Systems

[4] DECC guidance notes for petroleum measurement – Issue 9

[5] MPMS Chapter 13 - Statistical aspects of measuring and sampling

[6] MPMS Chapter4.section 7 "field standard test measures"

[7] 27th International North Sea Flow Measurement Workshop 20 – 23 October 2009, Tønsberg, Norway, Realistic Pipe Prover Volume Uncertainty, Paul Martin, IMASS (formerly Smith Rea Energy Limited).

[8] Petroleum Measurement Paper No. 12: guidelines for the development of uncertainty estimates for pipe prover calibrations

[9] Pipe Prover calibration water draw and master meter methods Dr J Mills 2001