**34th International North Sea Flow Measurement Workshop**
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**Technical Paper**

# Using an Ultrasonic Flowmeter in the Transition Zone

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## 1 INTRODUCTION

The abstract for this paper contained the following statement:-

*Liquid flow measurement is essential throughout the oil and gas industry. Ideally a flow measurement system would have high turndown and low measurement uncertainty, maintained over the complete flow range. Unfortunately velocity based meters such as turbine and ultrasonic meters can show significantly degraded linearity at low flows. Provided the measurements are repeatable this non-linearity can be defined and corrections applied in order to maintain a good turndown. If repeatability is not good, the overall uncertainty of measurement will be worse at the low flow end and may not be acceptable. This will result in much higher costs for metering as more meter tubes will be required to cover the overall flow range. These turndown effects become more and more significant as viscosity increases.*

*OIML R 117 for a class 0.3 meter requires the difference between the largest and smallest results of 3 successive (flow) measurements to be within 0.12% for flow greater than 5 times the minimum specified meter flow.*

*Flow below this point will typically be approaching the transition zone which is the flow region between turbulent flow (typically Reynold's Number (Re) >4,000 and laminar flow Re< 2,500). Flow in this transition zone is chaotic, where vortex sizes can vary from microscopic to a significant part of the pipe diameter. As they are chaotic in nature they are not evenly distributed across the pipe section and have rotational characteristics differing in magnitude and direction as well as linear velocities along the pipe axis. A turbine meter has mechanical inertia and as it occupies almost the complete cross section of the pipe can "smooth out" these effects, whereas a typical planar chordal liquid ultrasonic flow meter can suffer from degraded repeatability and thus worsened measurement performance. This effect can begin to be seen below Reynold's numbers as high as 10,000 for some USMs and the repeatability spread can be 10 times greater than the OIML requirement of 0.12% when in the transition zone.*

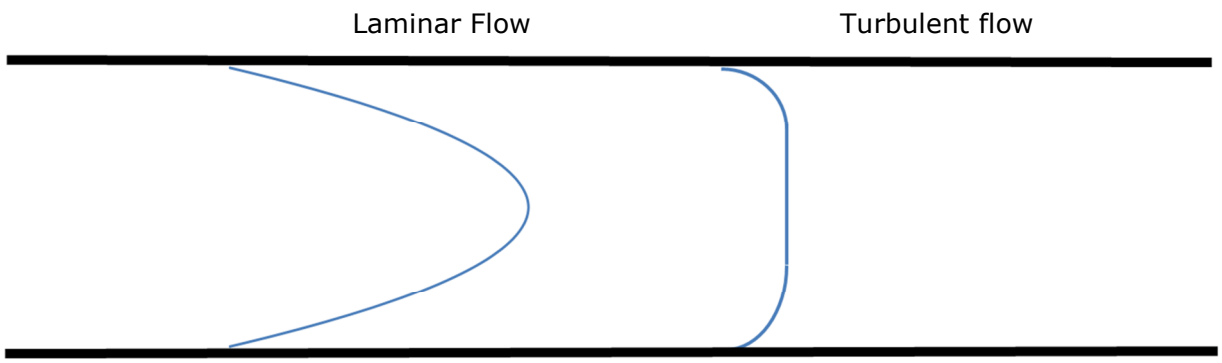
*The Nyquist sampling theorem states that a sampling rate of twice the highest frequency component enables a complete re-construction of the original signal. This suggests that a high sampling rate in the meter would overcome the problem; however, increasing the sampling rate in a planar chordal meter is likely to "over-sample" larger vortices and will not add extra linear velocity information above a certain sample rate as over-sampling in the time domain will not add extra linear velocity information.*

Reproducibiity of measurement, not only short term repeatability - three consecutive measurements for example - but long term repeatability – do we achieve the same value the next day, or the next week, or even the next year, given at what we believe to be the same process conditions?

This is fundamental to high quality measurement.

Reynold's number is the dominant factor. As seen above, OIML R117 is effectively silent for low Reynold's number and typically liquid USMs are considered to have worsening repeatability as Re reduces below 10,000.

At very low flow rates flow is laminar with fluid motion being parallel to the pipe walls and with a parabolic flow profile, and at higher flow rates flow is turbulent and with a much flatter flow profile:-




The line drawings above represent ideal cases: in the real world the flow may include swirl or a profile which is not symmetrical about the pipe axis. Crossed, horizontal chordal beams can cope well with swirl, but clearly would not cope well, when for example, the profile "nose" is predominantly below the lowest beam path.

The laminar flow regime typically exists below Re <2,000

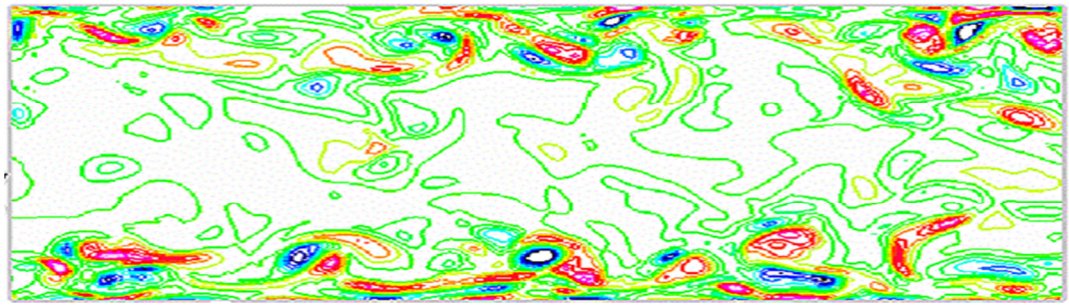
At higher flow rates, typically at Re> 4,000 the profile becomes flatter as the flow becomes turbulent. In the region between laminar and turbulent flow the characteristics change rapidly and in a random manner where laminar flow dominates at low Reynold's numbers and turbulent flow dominates at higher Reynold's numbers. This is the transition zone.

Flow in the transition zone was described as *chaotic*. In the English language this usually means *complete disorder and confusion* and in physics to be *the property of a complex system whose behaviour is so unpredictable as to appear random, owing to great sensitivity to small changes in conditions.* Again in the abstract, chaotic flow was described as *where vortex sizes can vary from microscopic to a significant part of the pipe diameter. As they are chaotic in nature they are not evenly distributed across the pipe section and have rotational characteristics differing in magnitude and direction as well as linear velocities along the pipe axis.*

## Technical Paper

A paper presented at the 6th Symposium. Smart Control of Turbulence, Tokyo March 6 to 9, 2005 [1] stated *The visualized flow field and the turbulent statistics suggest that the streaky structures……. exist only near the wall, while the large scale structures extend from the centre of the channel to the near wall region. Therefore, the near wall turbulence depends not only of the near wall fine scale structure, but also on the large scale structures.*

The image below shows a CFD model of such a flow, where the small structures near the pipe wall can be clearly seen, as can the large scale structures, which are predominantly visible within the central area of the pipe, but can also be seen extending near to the wall of the pipe. This image only shows a 2 dimensional "slice" cut through the centre line of the pipe, whereas the actual structure shapes in the 3 dimensional space would show random variability of cross section and shape in much the same way as those in the 2 dimensional slice. Velocities in those large scale structures will include both angular and axial velocities which will be constantly changing and thus changing the shape of the structure. Total flow momentum will be maintained, but will transfer from structure to structure as they change shape in this chaotic regime.



A transit time USM measures upstream and downstream transit times along the same path and calculates the axial fluid velocity:-

The diagram below shows a single beam. The velocity of fluid can be calculated from:-

$V = ((t_2 - t_1)/(t_2 * t_1)*(L / 2\cos\theta)$

Where

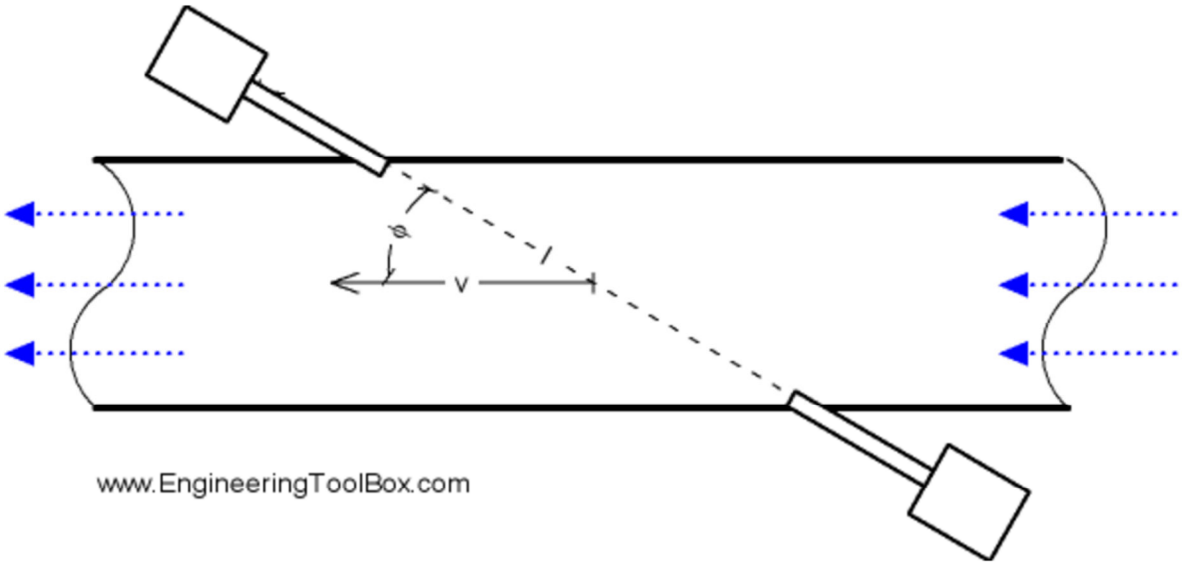
V = fluid velocity

$t_2$ = transmission time upstream

$t_1$ = transmission time downstream

L = distance between sensors

Θ = angle between beam and pipe axis

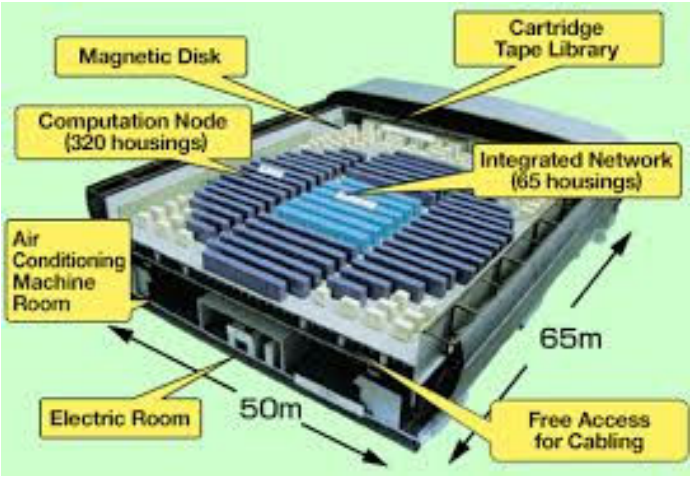



USMs used for custody transfer and other "high end" duties have more than one beam, arranged in a variety of different ways, with chordal beams arranged in horizontal planes being the most common. Some meters use dedicated beams arranged to obtain diagnostic data.

A single beam can only provide a *good* measurement when the flow profile is fully developed and there is no swirl at the measurement position.

How many beams, and how should they be arranged to obtain this *good* measurement?

Let us look at the question in a reverse and consider the computational fluid dynamics problem in reference [1]. This simulation used around 16 billion grid points with calculations being performed using 2048 CPUs with 4TB of memory – and even with all this computing power it did not work in "real time"!




The Earth Simulator computer used for the CFD modelling in reference [1]

This is not a good solution – a flowmeter electronics housing 65m x 50m and occupying 2 floors is definitely not practical!

This is not a reasonable comparison as the problem is different; the CFD simulation is looking at the properties of the individual cells defined by the matrix of those 16 billion grid points and determining the effect of one cell on the adjoining cells whilst maintaining overall momentum of the flowing fluid; the USM is **measuring** time of flight (TOF) along a small number of fixed paths, and is then using these TOF values as the basis for calculating, or rather *estimating*, the flow rate.

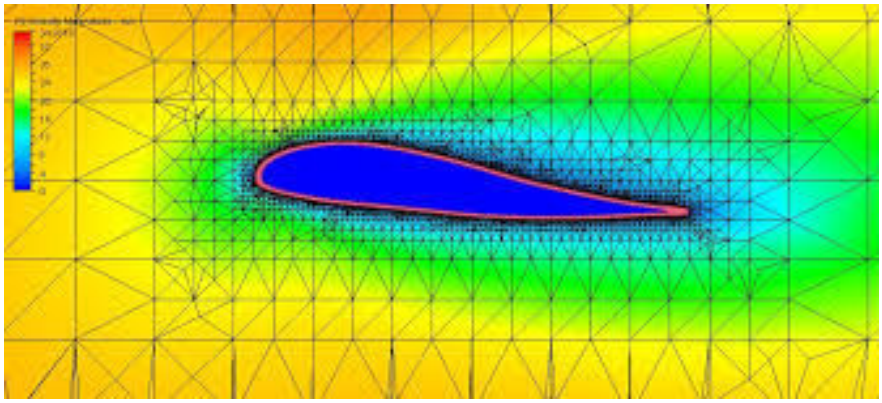
The processing power required to simulate flow in this regime is clearly very high indeed, so can we hope to achieve acceptable results by just measuring TOF along these few paths?

What is the optimum arrangement of these beams in order that sufficient information is provided to enable the mean axial velocity, V along the pipe to be determined? Provided V is known, then flowrate is simply:

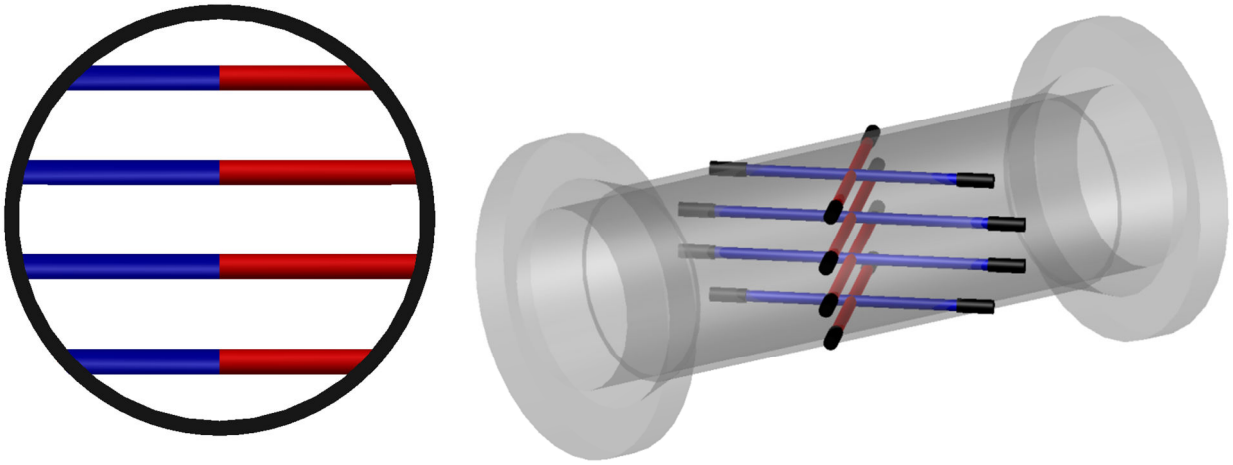
$$V \times A\, m^3/h$$

Where *V* is in *m/s* and *A, the cross sectional area of the pipe,* is in $m^2$

The CFD simulation does provide useful indicators for the USM; the simulation uses very small grid matrix sizes where flow patterns are complex; the flow simulation in reference [1] is a good example, where a very small mesh size was used close to the wall, and a larger size in the centre of the pipe; around the surface of an aircraft wing is a common example where grid matrices are very detailed around the wing surface, and particularly where flow directions change rapidly and larger, simpler grid matrices where flow patterns are simpler at greater distances from the wing surface – in other words more information equates to a "tighter" matrix.

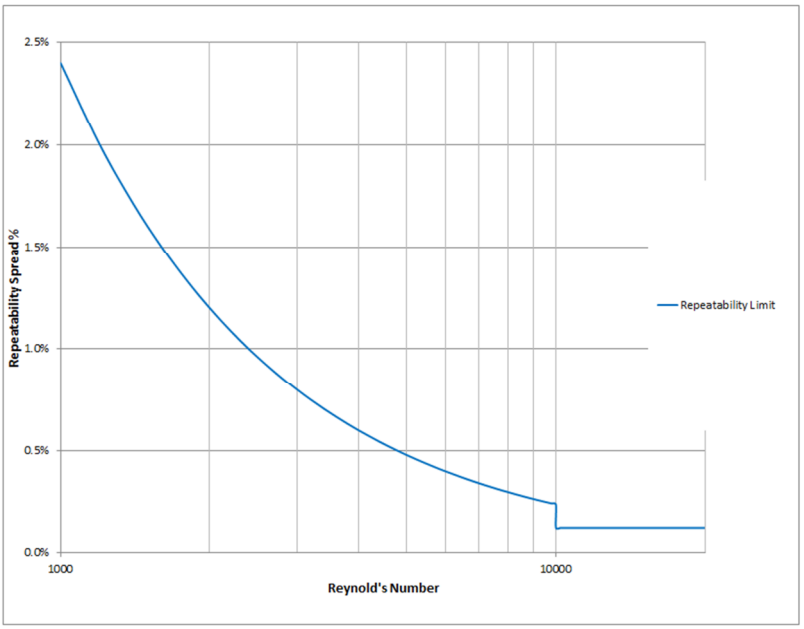


A typical 8 beam chordal meter path layout is shown below:

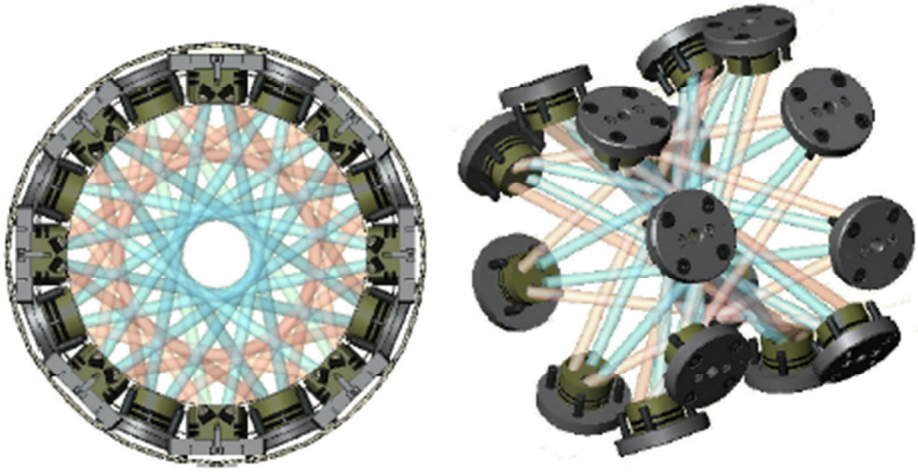


Reference [2] explains clearly that changes between laminar like and turbulent like flow regimes in the transition zone causes non-axial flow components to be developed. The velocity profile thus changes rapidly and prevents good repeatability being achieved. This referenced paper was based on chordal meter designs and notes that "a lower Reynold's number limit of 10,000" is recommended. Although not referenced in [2], but elsewhere in the same manufacturer's literature it is also stated that for the 8 chordal path meter the maximum spread in three repeats below Re =10,000 is ≯ 20,000 x 0. 12/Re.

This is graphically represented below. It should be noted that it shows the repeatability spread acceptance limits, and does not necessarily represent the results which would be obtained in practice.



The 32 beam layout for DFX meter used for the tests in this paper is shown below:



The 32 beam design gives an axially symmetric layout. This ensures that the meter is installation insensitive to the plane of an upstream bend and the beam coverage provides much enhanced information on the flow profile. See reference [3] for examples.

Given this "enhanced information" can we expect to achieve a high order of repeatability, or will it still require "averaging" over a longer period of time? [cf. turbine meter which "averages" thanks to mechanical inertia and almost full coverage of the pipe cross section]

The tests carried out concentrated on low Reynold's numbers (<10,000). Results have been included for Reynold's numbers >20,000 for comparison purposes when the meter(s) are used well above the transition zone and where flow can be assumed to be well developed turbulent flow.

## 2 DESCRIPTION OF TESTING CARRIED OUT

Three main groups of test results are included in Appendix A.

Tests 1 and 2 were carried out using M&T DFX liquid USMs. As described above, these meters have 32 beams arranged in an axially symmetric design. Each of the 16 transducer assemblies contains four separate transducers with 2 of the transducers handling the outer ring of 16 beams (shown in red above) and the other 2 transducers handling the inner ring of 16 beams (shown in blue above).

Test 1 <u>4 inch DFX calibration, NEL, East Kilbride - UKAS 0009</u>

Test 1.1 Velocite with a viscosity of ~45 cSt at ~12$^{o}$C . Reynold's number from ~1,600 to 22,000

Test 1.2 Gas oil with a viscosity of 6cSt at 44$^{o}$C. Reynold's number ~10,000 to 163,000

Test 2 8 inch DFX calibration, IMS Calibration Facility, Belgorod - VSL CMC Certification LF2015.04.0012

These tests were carried out specifically for this presentation using oil with a viscosity of ~26 cSt at ~25°C. Reynold's number from ~2,900 to 26,300

Test 3 16 inch USM (3 off) from A.Nother Company

These calibrations were carried out by ANO Company, using their accredited flow calibration laboratory as part of their "contract to supply and calibrate" 3 off liquid ultrasonic meters to Oil & Gas Systems. The calibration fluid was Drakeol 32 with a viscosity of ~80 cSt at ~ 20°C. Reynold's numbers for ~1,700 to 37,000.

The meters have been installed offshore as 2 off 100% meter tubes, with a "spare" meter on hand to be used when either of the two working meters are sent on–shore for re-calibration. Due to the size of the assembled meter/meter run assembly, it was proposed that only the meter should be sent on–shore. Although these meters are described as being very tolerant of upstream flow conditions, bored and axially aligned upstream meter tubes were required by the end customer to confirm that measurement results would be acceptable if only the meter body itself were to be re-calibrated without its installed meter tubes. A pair of upstream and downstream meter tubes manufactured in the same way as the installed meter tubes were retained at the USM suppliers and have been used for all subsequent calibrations.

Test 3 results were extracted from calibration data for 3 off 16 inch liquid USMs supplied to Oil & Gas Systems for a customer contract. Details are given in the test results.

## 3 DISCUSSION OF TEST RESULTS

Test result data is given in Appendix 1 for reference purposes. All data shown in the figures is taken directly from the calibration results.

Repeatability spread in all cases is simply calculated as:-

$$\frac{(Kfactor\ max - Kfactor\ min)\ \text{x}\ 100\%}{Kfactor\ min}$$

4 inch 32 beam USM

The volumes used for the 4 inch 32 beam meter were dependent on flow rate and varied from nominally 1.48 $m^3$ to 12.2 $m^3$. These volumes were measured using PD meters as master meters.

8 inch 32 beam USM

As can be seen from the detailed results in Appendix A the bi-directional prover volumes were nominally 3.18$m^3$ for the 8 inch 32 beam meter. This was the complete swept volume for the combined forward and reverse passes of the sphere.

All test sequences were of 4 runs only.

16 inch 8 beam meters

The low flow tests (~150 $m^3$/h and 450 $m^3$/h) were run with a nominal 10.06 $m^3$ uni-directional prover.

Test sequence run lengths were not consistent, with 20 at 3 runs, 2 at 4 runs, 6 at 5 runs and 1 at 9 runs. It is understood that extra runs were made when the repeatability required by the formal test procedure could not be reached with 3 runs.

All higher flow rate tests used a USM master meter system with measured volumes varying from ~21 $m^3$ to ~38 $m^3$.

Pulses counted by the master meter obviously corresponded to these volumes and varied from 20,000 to 57,000.

### 3.1 Test 1

This 4 inch meter was calibrated on 2 products with different viscosities for use in metering oil flow from an offshore separator where both varying amounts of water and gas slugs occur in practice. This application has previously been discussed in references [3] [4]

Figure 1 shows the repeatability spread for each point in the calibrated flow range.

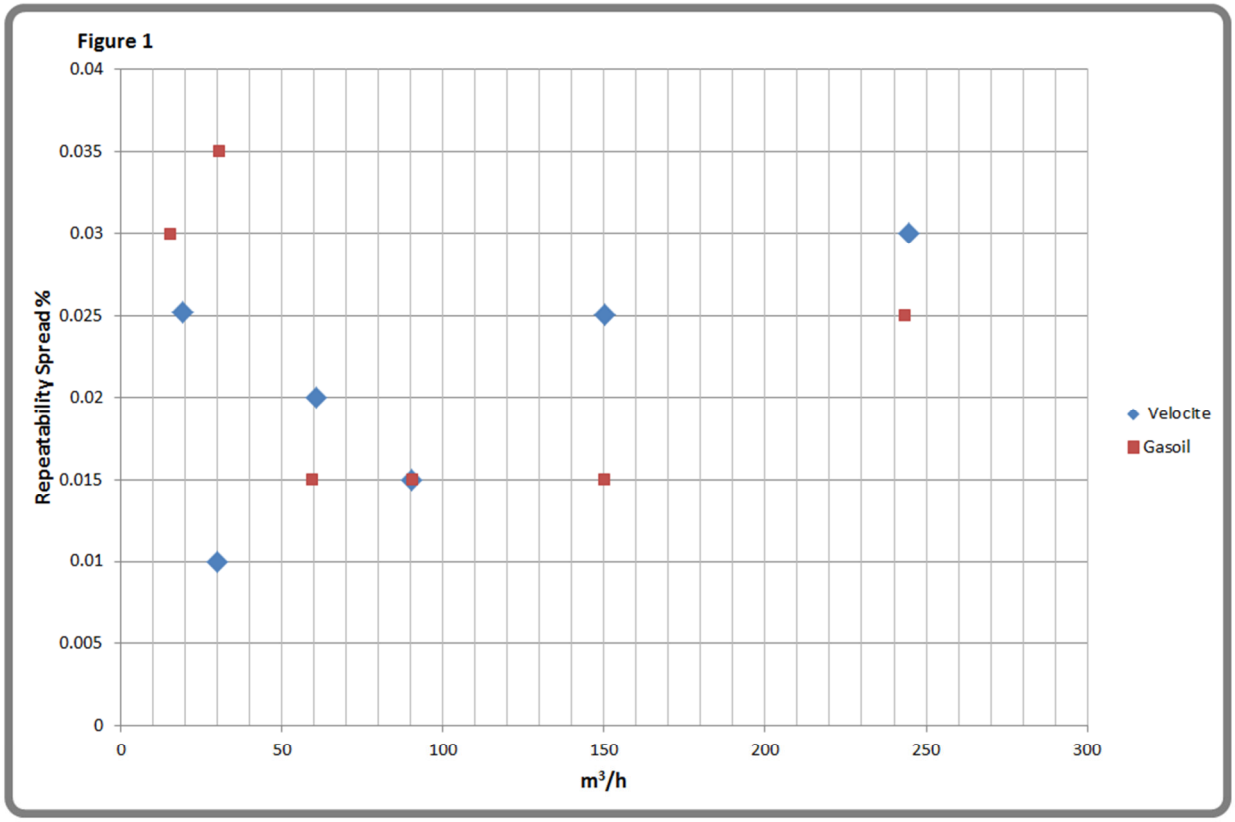
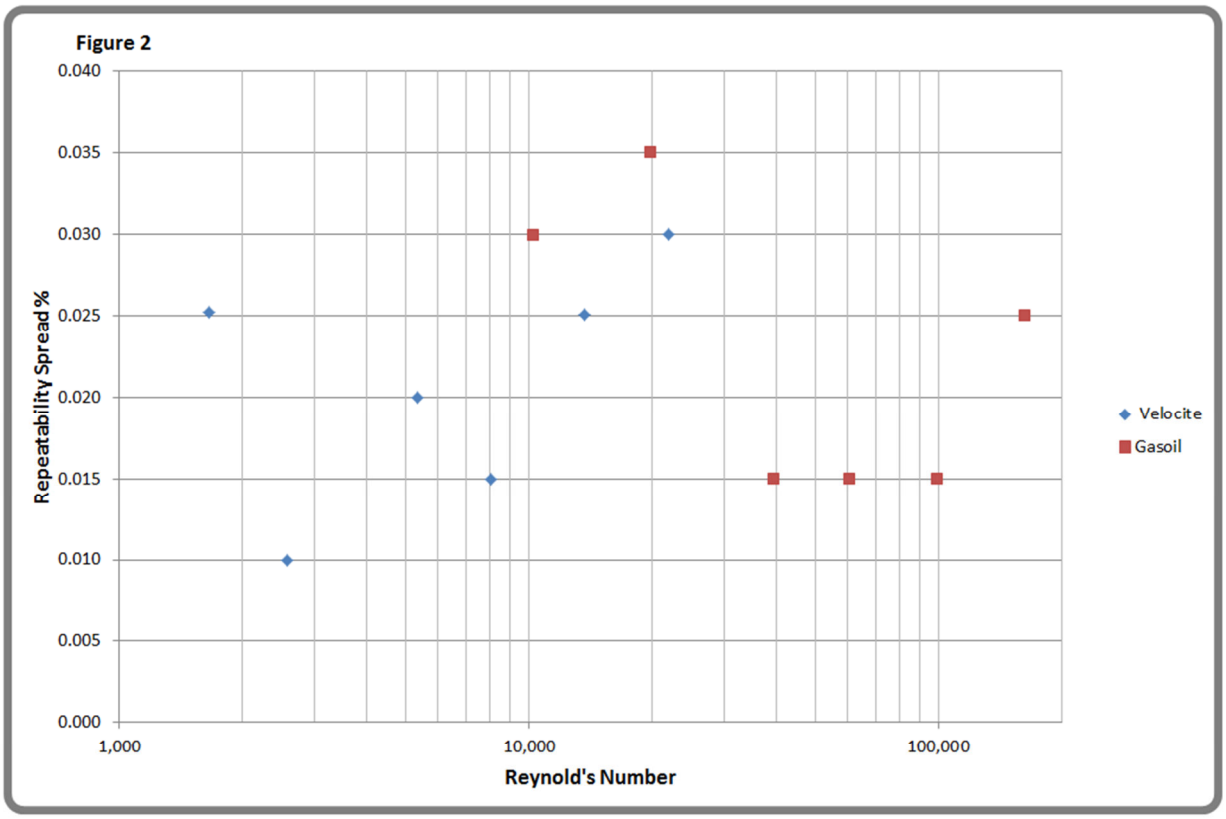



Figure 1

The volumetric flow rate measurement points go from the laminar flow region, through the transition zone and extend up well into the turbulent flow region. As has been discussed at many conferences, Reynold's number is the key factor in the characterisation of all velocity meters, such as USMs and turbines. In the case of the USM the flow profile, described in various ways including *profile number* and *flatness ratio*, for example, is often used as part of the initial characterisation of a USM before final calibration and this value can be derived from the initial characterisation results.

When examined in volumetric terms, the results for the two products show good correlation, with worst case occurring at ~30m$^3$/h, and even there the difference in repeatability spread is only 0.025%.

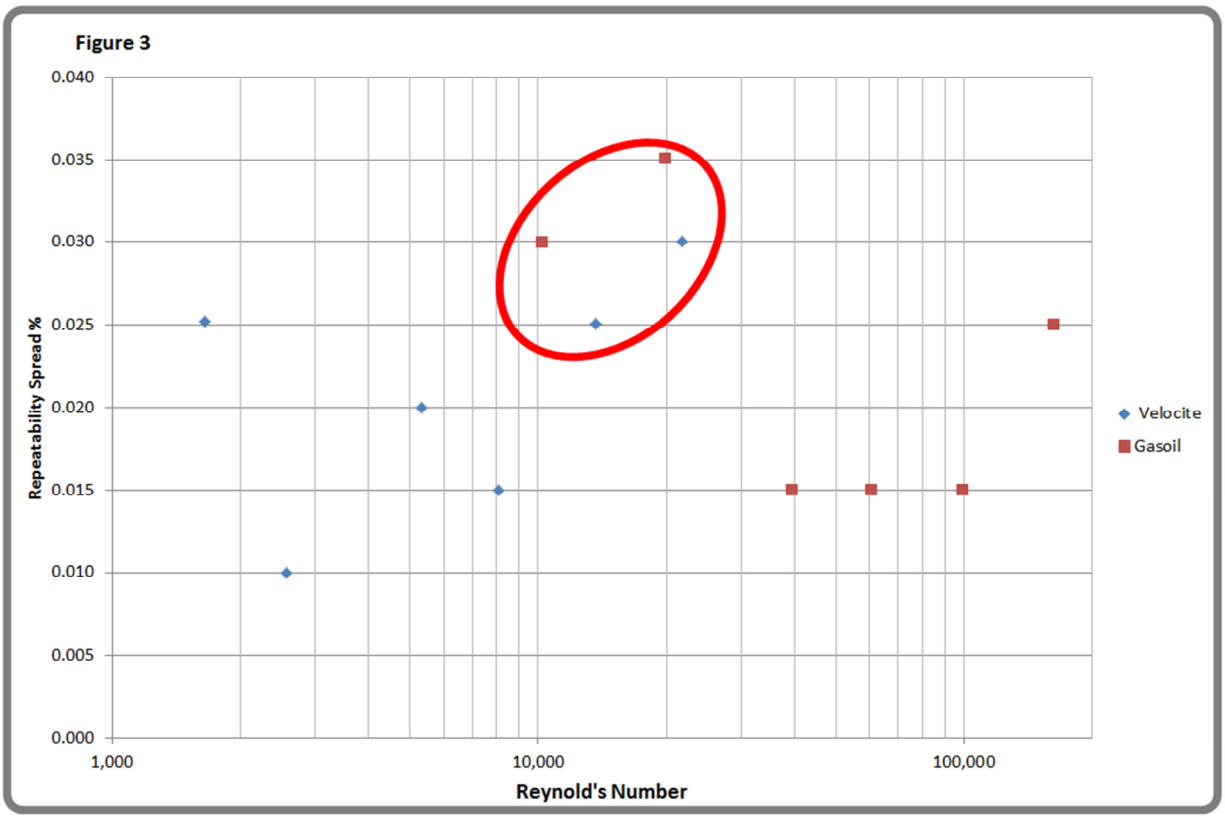
Figure 2 shows the repeatability spread when plotted against Reynold's number, plotted here, conventionally, on a logarithmic scale.




As mentioned above, since Reynold's number is a key parameter in USM characterisation, the use of 2 calibration fluids of different viscosities is accepted for calibration purposes where the calibration laboratory cannot achieve a high enough volume flow rate on a high viscosity fluid, but can achieve a high enough Reynold's number flow rate by using a lower viscosity fluid. In the case of this testing the two viscosities were used in order that the meter could be used on crude oil and also crude oil with high water content, where the apparent viscosity can rise rapidly as water content rises.

Figure 3 shows the four calibration points highlighted where the Reynold's numbers overlap.

These points correspond to about 150 $m^3/h$ and 250 $m^3/h$ for the velocite calibration and 15 $m^3/h$ and 30 $m^3/h$ for the gasoil calibration. Although outside the main transition zone area of interest for this paper it is a good demonstration that repeatability for this meter was largely independent of viscosity. In practice, good profile number characterisation and modelling would also be required to ensure that volumetric flow calibration linearity could be obtained, although neither can be obtained without good repeatability.



### 3.2 Test 2

These tests were carried out using an 8 inch DFX 32 beam meter specifically for this presentation using oil with a viscosity of ~26 cSt at ~25°C. The tests were repeated 3 days later for comparison purposes.

Figure 4 shows repeatability spread for all test carried out on February 9th

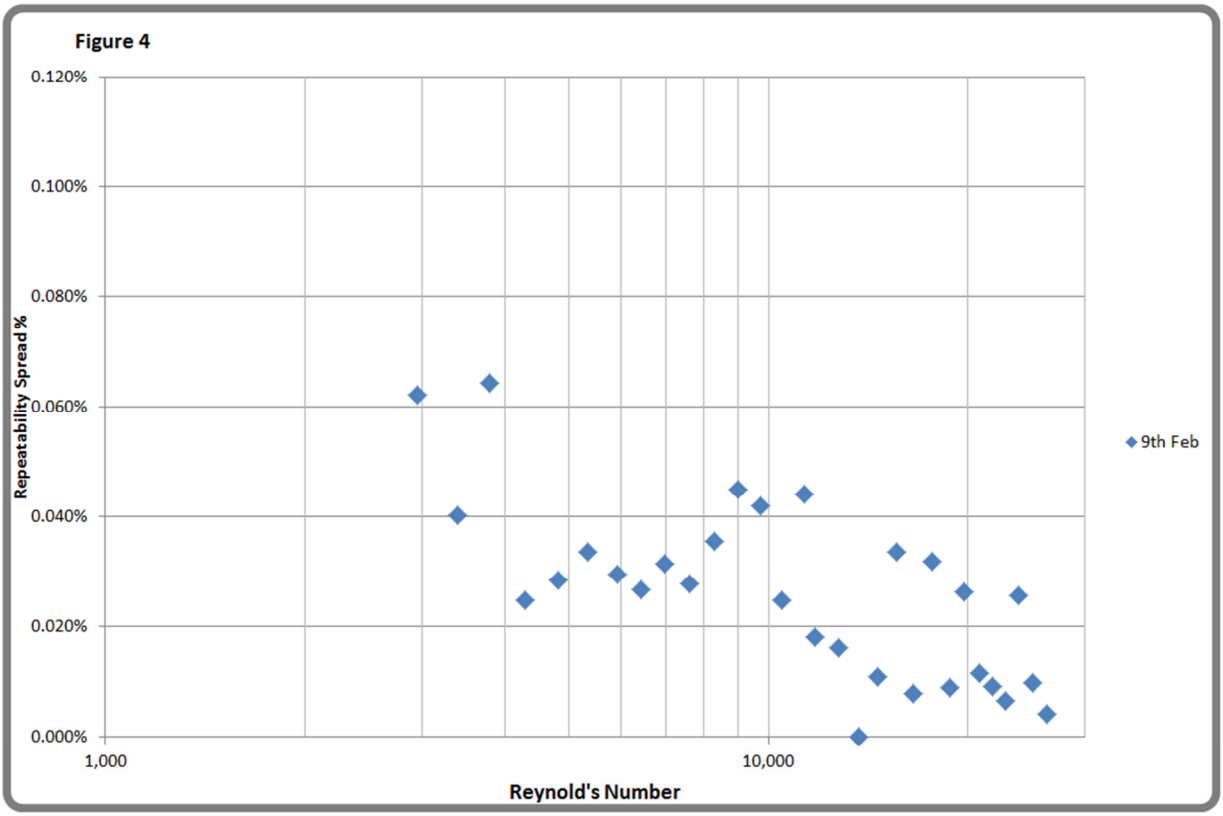


Figure 5 shows uncertainty spread for all test carried out on February 12th

The results show a similar pattern to those in figure 4, with the exception of the three ringed results, although even the 2 higher values are within the OIML requirements for a 0. 3 class meter when being used at >5 times $Q_{min}$.

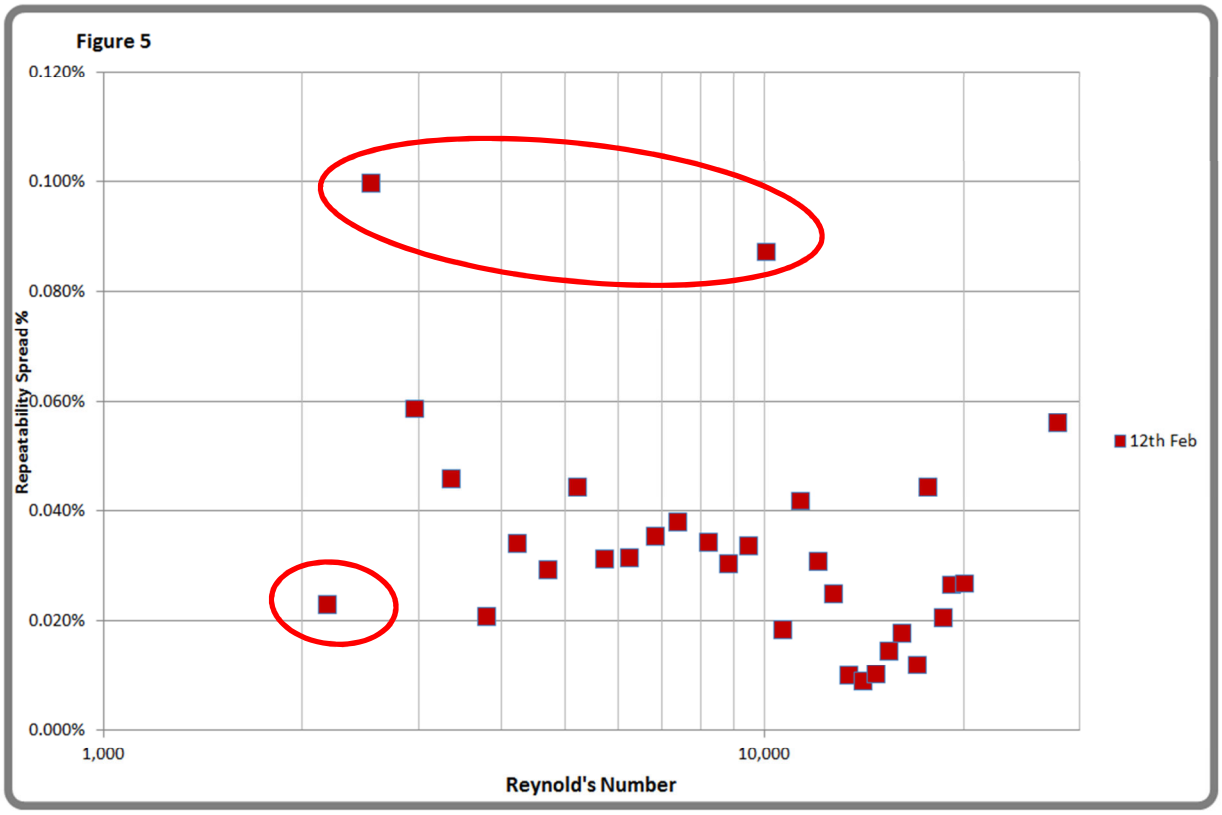


Figure 6 shows uncertainty spread for both sets of tests.

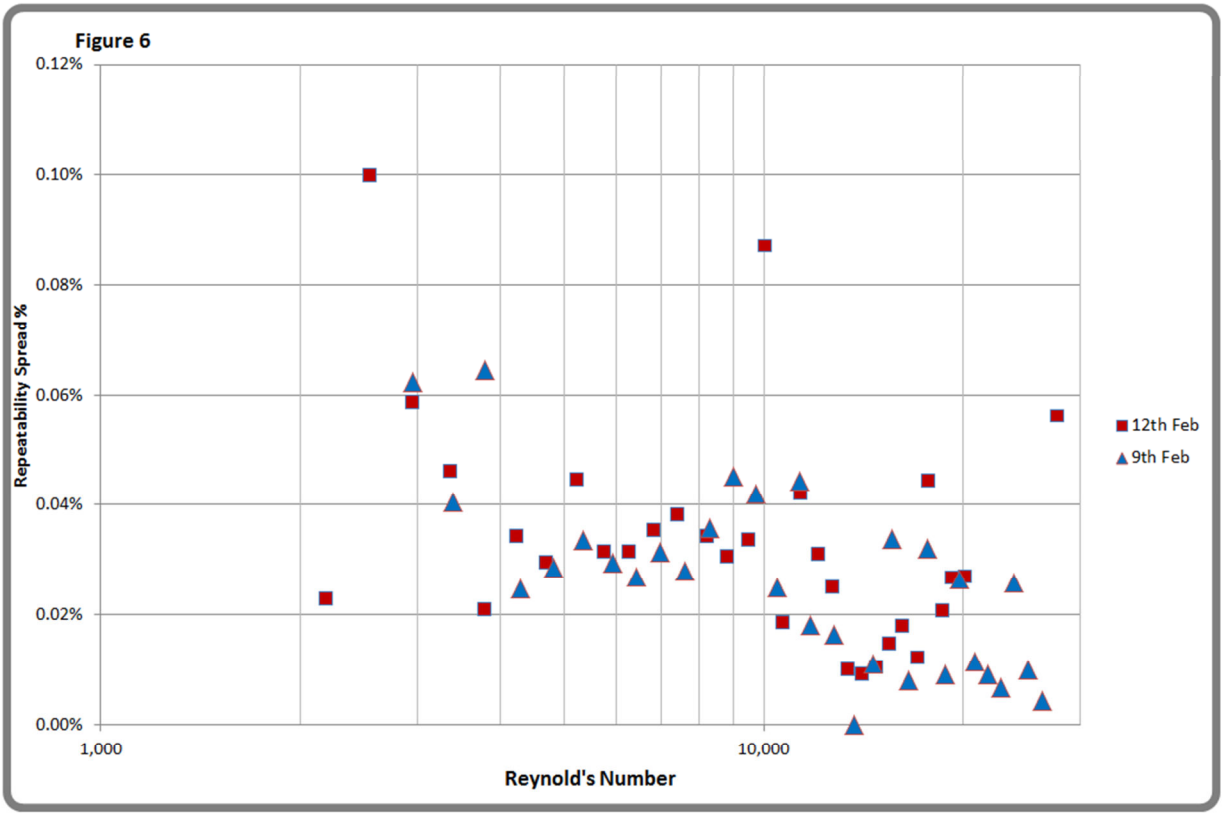
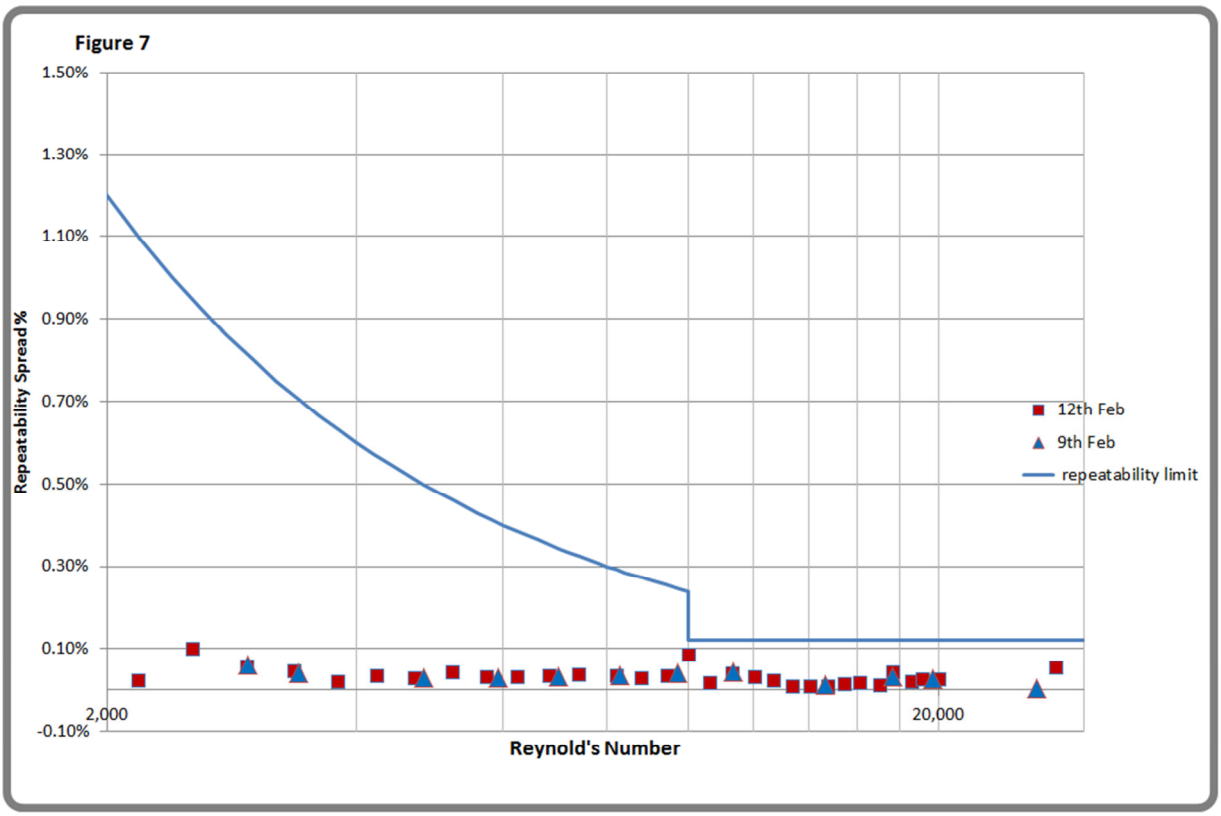


Figure 7 shows both the February 9th and 12th results plotted along with the "allowable repeatability spread" curve discussed earlier. It can be seen that all results, including those in the transition zone fall within the 0.12% band, with no significant degradation in repeatability performance for $R_e$ <10,000.



### 3.3 Test 3

As discussed earlier, this data is from calibration testing of 3 USMs with different upstream and downstream piping configurations, to confirm that any of the 3 meters could be calibrated when using the upstream and downstream meter spools held at the calibration laboratory. These spools were all bored through to within ±1 mm and were axially located to the meter(s) using shoulder bolts. The manufacturer, our Company and the end user all believed that this "interchangeability" would be demonstrated during calibration and that the planned routine "in service" procedure referred to in **DESCRIPTION OF TESTING CARRIED OUT** would be achievable.

Figure 8 shows the repeatability spread for the data points for each test. All results are within the acceptance limits as described for figure 7. However, for those results in the previous Figure 7, the repeatability spreads were all within the 0.12% band required for and OIML 0. 3 meter even at flow rates (Reynold's numbers) below that required by that standard.

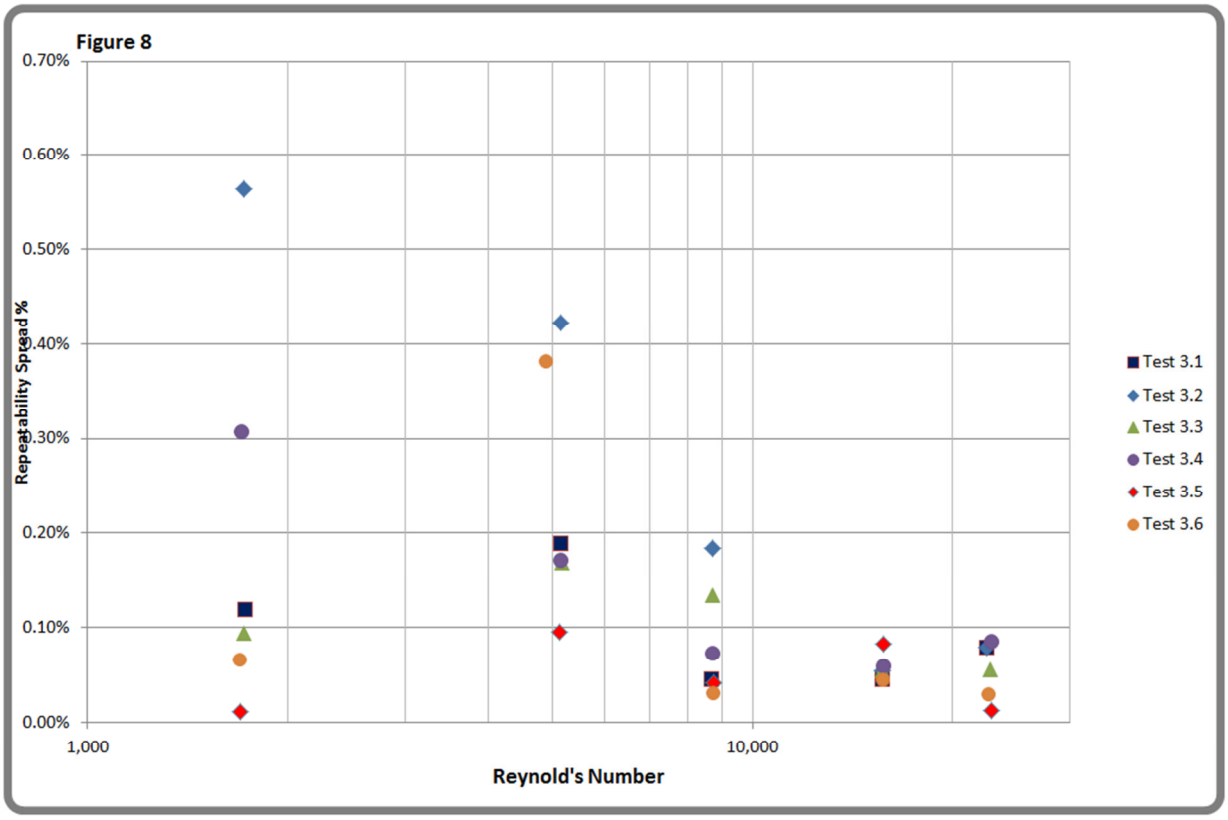


Figure 9 shows the same results when plotted along with the Repeatability Limit curve. Although the tests were carried out on 3 meters, with varying upstream and downstream spools, these spools were manufactured to close tolerances and were expected by the meter manufacturer to not cause significant "shifts" in the meter calibrations. In the context of the intended use of those meters, the final calibration results were all acceptable. However when analysed as has been done here, it is evident that the repeatability at low Reynold's numbers – in fact at Reynold's numbers below 10,000, is not good.

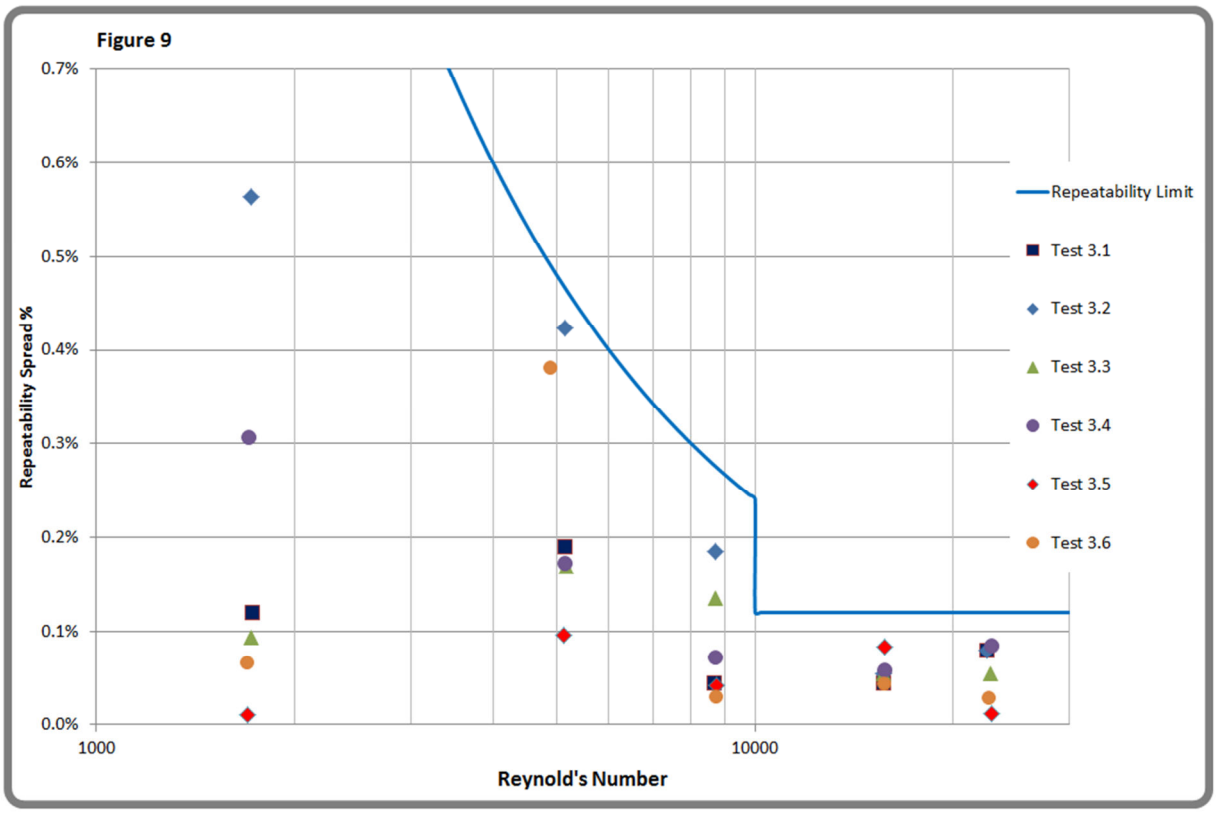


Figure 10 shows the repeatability spreads for all results for all 3 sets of tests and includes the repeatability limit curve.

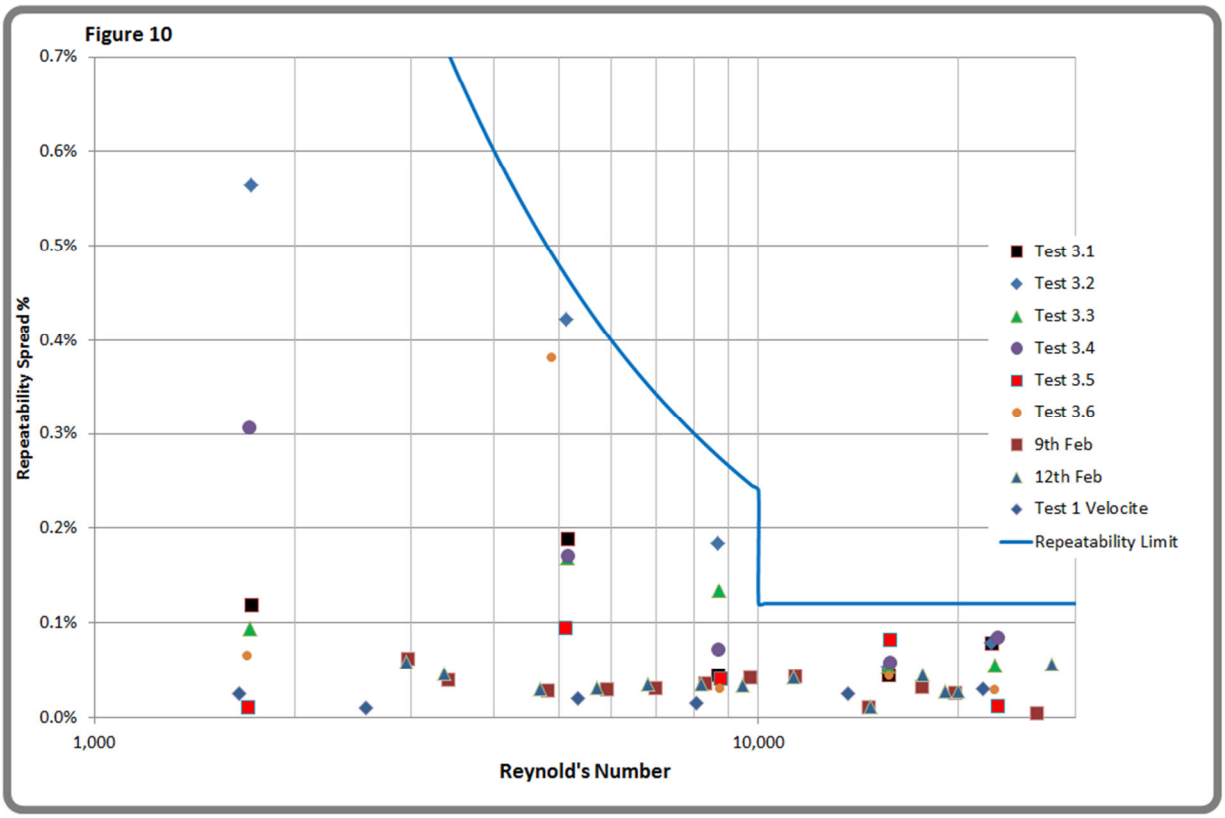
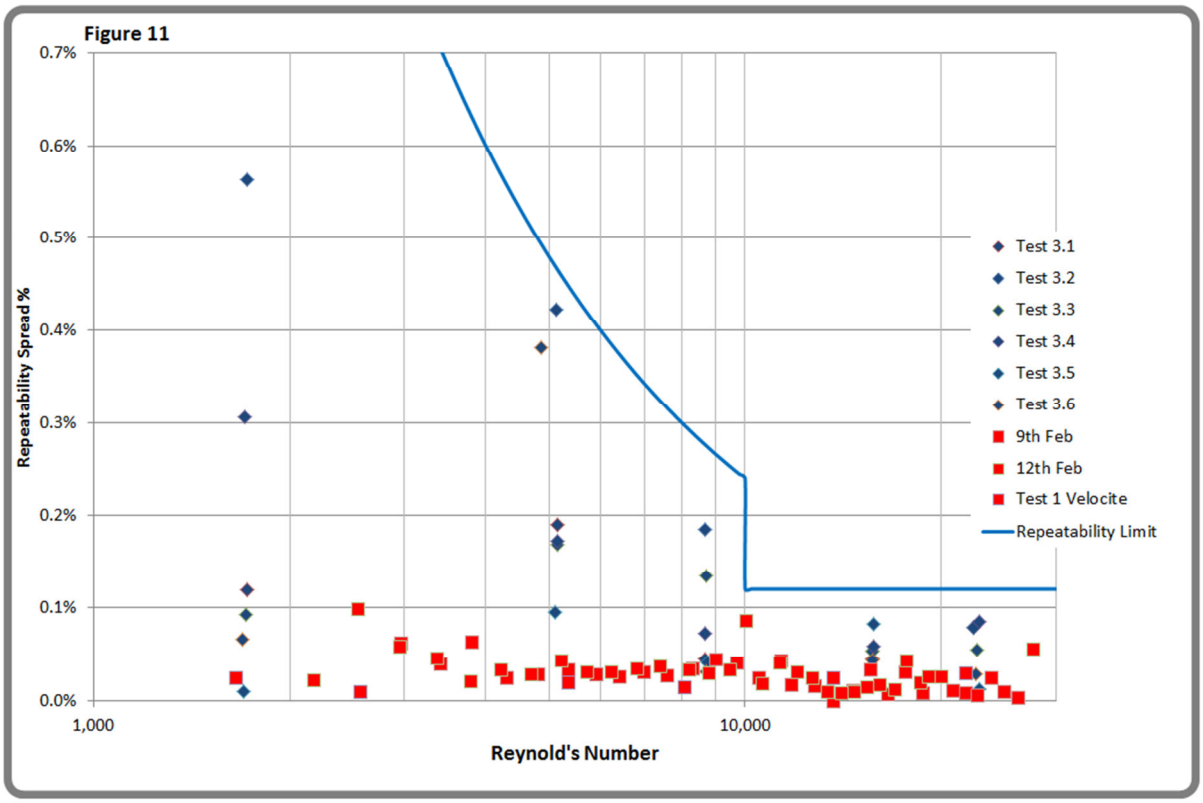


Figure 11 shows the repeatability spreads for all tests, including the repeatability limit curve. All 32 beam results have been shown in red and all 8 beam chordal meter results have been shown in blue

The figure shows clearly that the 32 beam meter has a consistently better performance in terms of repeatability spread both above and below Re = 10,000 and in fact shows very little loss of repeatability throughout the whole transition zone.




## 4 CONCLUSIONS

These results show that the 32 beam, axially symmetric USM has a repeatability performance which is largely unaffected by Reynold's number and can be used at flow rates which correspond to Reynold's number from below the transition zone, through the transition zone and up into the turbulent flow region. The OIML requirement for a class 0. 3 meter requires *3 consecutive runs*; these tests were carried out with 4 consecutive runs; however when the repeatability spread for the first three runs is calculated no repeatability spreads are greater than for 4 runs.

In these tests the 8 chordal beam meter demonstrated repeatability within the defined repeatability limits, but showed large spreads in repeatability within these limits.

It can be concluded from these results that the 32 beam axially symmetric USM has a superior repeatability performance which allows it to be used at low Reynold's numbers, and in particular, through the transition zone, where repeatability performance hardly varies from that in the turbulent flow region

The test results provide the data, but how can the reasons behind the results be explained?

Good Repeatability of a measurement is obviously a combination of stable conditions of the measured quantity (measurand as per VIM version 3) and the intrinsic meter stability.
In our application, the measurand is a derived quantity and is not directly measured, which adds complexity.

Flow stability as volume over time (for volumetric meters), requires stability of product characteristics such as viscosity, density and composition and also process conditions including flow and turbulence intensity as well as environmental conditions. This control is effected by pressure, temperature and flow regulation during each calibration point measurement.

From the meter point of view repeatability would be directly linked to the meter sensitivity to small differences in the measurand, process and environmental conditions.

Each meter technology will react differently to those differences.

In the case of a USM, as it is a time measurement machine, everything is down to the time measurement stability.

This time measurement is directly proportional to the average flow velocities along the ultrasonic path and therefore is constantly changing through turbulent flow.

The integration methods used to locate the path of standard USM assume averaged flow profile. Even when they are based on CFD modelling it is likely to be based on a RANS model producing an averaged flow profile.

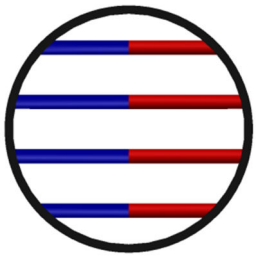
The less you measure, the more you have to rely on the average converging to a non-biased value. In other words, longer times for the measurement of the point requires bigger volumes, which creates more difficulties in keeping stable conditions during proves. It can be noted here that the 8 inch 32 beam results were all obtained using a nominal 3.18 $m^3$ prove volume and that the 16 inch 8 beam results used volumes from a nominal 10.06 $m^3$ to over 38 $m^3$.

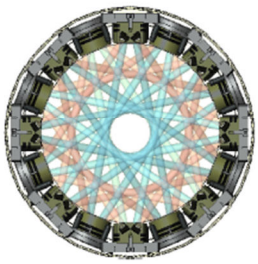
The ways to improve the time measurement in a USM are well known:

- Stability of the electronics ( clock, signal to noise ratio, pulse output)
- Signal processing ( the way we perform the time measurement on the ultrasonic pulse)
- The transducer quality ( stability and repeatability of the signal rising edge, amplitude, temperature stability of the electronics)

We believe that, the number of beams and their location should be added to the list.

We return to the comparison of the chordal meter and the 32 beam meter:-





The more you cover the pipe cross section, the less you need to average spatially. This is particularly important In the transition zone where turbulence can occur at any moment anywhere in the cross section.

The Results presented in this paper showed that the combination of high end electronic, signal processing and transducers with an innovative 32 beam design covering the pipe cross section, brings a significant improvement to the repeatability of USMs especially for Reynolds numbers below 10 000 and through the transition zone.

This combination of features is essential to be able to prove and use this technology efficiently and effectively in this flow regime region.

## 5 REFERENCES

[1] Direct Numerical Simulation of Turbulent Channel Flow at $Re_T$ =2320, Kaoru Iwamoto, Nobuhide Kasagi and Yuji Suzuki Department of Mechanical Engineering, the University of Tokyo, 6th Symp. Smart Control of Turbulence, Tokyo March 6 – 9, 2005

[2] A Multipath Ultrasonic Meter with Reducing Nozzle for improved performance in the laminar/turbulent flow region, Gregor J Brown, et al, Cameron, 27th International North Sea Flow Measurement Workshop October 20 – 23, 2009

[3] Use of a Liquid Ultrasonic Flow Meter in Mixed Phase Flow, David Mills, Julien Porré, Advances and Developments in Industrial Flow Measurement , University of Warwick July 1-2 2015

[4] Separator Oil Metering Using 32 Beam USM, Julien Porré, 2016 European Flow Measurement Workshop, Netherlands

[5] 32 Beam Ultrasonic Technology for Multi Viscosity Custody Transfer Applications, Special Case Applications, Julien Porré, 2016 CEESI North American Custody Transfer Measurement

**Appendix A - Test Results**

Test 1

4 inch DFX calibration at NEL, East Kilbride UKAS 0009

These results were obtained as part of normal calibration on two different viscosity products (Velocite with a viscosity of ~45 cSt at ~12°C and Gasoil with a viscosity of ~6 cSt at ~44°C)

1. 1 Velocite

| | T°C | cSt | $m^3/h$ | V m/s | Re | pulses/$m^3$ | %spread | proved vol $m^3$ |
|---|---|---|---|---|---|---|---|---|
| 1 | 12.61 | 46.50 | 19.008 | 0.882 | 1,656 | 19.844 | 0.025 | 1.48 |
| 2 | 12.57 | 46.59 | 19.044 | 0.883 | 1,656 | 19.844 | | PD meter |
| 3 | 12.53 | 46.69 | 19.044 | 0.883 | 1,652 | 19.839 | | |
| 4 | 12.21 | 47.45 | 29.736 | 1.379 | 2,538 | 20.043 | 0. 010 | 2.32 |
| 5 | 12.34 | 47.14 | 29.772 | 1.381 | 2,558 | 20.044 | | PD meter |
| 6 | 12.59 | 46.56 | 29.808 | 1.383 | 2,593 | 20.042 | | |
| 7 | 12.72 | 46.25 | 60.660 | 2.814 | 5,312 | 19.983 | 0.020 | 3.04 |
| 8 | 12.83 | 46.00 | 60.732 | 2.817 | 5,348 | 19.982 | | PD meter |
| 9 | 12.96 | 45.72 | 60.696 | 2.815 | 5,377 | 19.979 | | |
| 10 | 13.08 | 45.44 | 90.108 | 4.180 | 8,032 | 20.011 | 0.015 | 4.50 |
| 11 | 13.18 | 45.23 | 90.072 | 4.178 | 8,066 | 20.013 | | PD meter |
| 12 | 13.28 | 45.00 | 90.072 | 4.178 | 8,107 | 20.014 | | |
| 13 | 13.36 | 44.82 | 150.336 | 6.973 | 13,586 | 19.957 | 0.025 | 7.52 |
| 14 | 13.40 | 44.73 | 150.336 | 6.973 | 13,613 | 19.952 | | PD meter |
| 15 | 13.47 | 44.58 | 150.336 | 6.973 | 13,659 | 19.954 | | |
| 16 | 13.36 | 44.82 | 244.692 | 11.350 | 22,113 | 19.998 | 0.030 | 12.24 |
| 17 | 13.12 | 45.43 | 244.728 | 11.352 | 21,819 | 19.997 | | PD meter |
| 18 | 12.83 | 46.00 | 244.728 | 11.352 | 21,549 | 19.992 | | |

1.2 Gasoil

| | T°C | cSt | $m^3/h$ | V m/s | Re | pulses/$m^3$ | %spread | proved vol $m^3$ |
|---|---|---|---|---|---|---|---|---|
| 1 | 44.73 | 6.09 | 15.516 | 0.720 | 10,319 | 20,031 | 0.030 | 2.16 |
| 2 | 44.32 | 6.15 | 15.516 | 0.720 | 10,219 | 20,025 | | PD meter |
| 3 | 43.95 | 6.21 | 15.552 | 0.721 | 10,144 | 20,025 | | |
| 4 | 43.53 | 6.28 | 30.528 | 1.416 | 19,689 | 19,993 | 0.035 | 2.32 |
| 5 | 43.48 | 6.28 | 30.744 | 1.426 | 19,829 | 19,987 | | PD meter |
| 6 | 43.86 | 6.22 | 30.888 | 1.433 | 20,114 | 19,986 | | |
| 7 | 44.37 | 6.15 | 59.364 | 2.754 | 39,097 | 19,997 | 0.015 | 2.97 |
| 8 | 44.71 | 6.09 | 59.364 | 2.754 | 39,482 | 20,000 | | PD meter |
| 9 | 45.04 | 6.04 | 59.364 | 2.754 | 39,809 | 19,999 | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 10 | 45.25 | 6.01 | 90.684 | 4.206 | 61,115 | 20,004 | 0.015 | 4.54 |
| 11 | 45.01 | 6.05 | 90.720 | 4.208 | 60,735 | 20,001 | | PD meter |
| 12 | 44.72 | 6.09 | 90.792 | 4.211 | 60,384 | 20,002 | | |
| 13 | 44.45 | 6.13 | 150.228 | 6.968 | 99,262 | 19,994 | 0.015 | 7.52 |
| 14 | 44.35 | 6.15 | 150.264 | 6.970 | 98,963 | 19,997 | | PD meter |
| 15 | 44.50 | 6.12 | 150.300 | 6.972 | 99,472 | 19,996 | | |
| 16 | 44.78 | 6.08 | 242.172 | 11.233 | 161,330 | 19,989 | 0.025 | 12.26 |
| 17 | 44.87 | 6.07 | 243.900 | 11.313 | 162,749 | 19,994 | | PD meter |
| 18 | 44.97 | 6.05 | 244.584 | 11.345 | 163,744 | 19,991 | | |

Test 2

8 inch DFX Calibration at Belgorod, VSL CMC Certification LF2015.04.0012

2.1 These tests were carried out using oil with a viscosity of ~26 cSt at ~25°C. Test date 9th

| | T°C | cSt | $m^3/h$ | V m/s | Re | pulses/m3 | %spread | proved vol $m^3$ |
|---|---|---|---|---|---|---|---|---|
| 1 | 11.27 | 43.80 | 63.35 | 0.748 | 2,956 | 9,810.392 | 0.062% | 3.18 |
| 2 | 11.27 | 43.80 | 63.35 | 0.748 | 2,956 | 9,814.206 | | bi-di |
| 3 | 11.29 | 43.80 | 63.35 | 0.748 | 2,956 | 9,808.094 | | |
| 4 | 11.29 | 43.80 | 63.35 | 0.748 | 2,956 | 9,811.543 | | |
| 5 | 11.36 | 43.60 | 72.64 | 0.858 | 3,404 | 9,837.319 | 0.040% | 3.18 |
| 6 | 11.36 | 43.60 | 72.63 | 0.857 | 3,404 | 9,841.282 | | bi-di |
| 7 | 11.37 | 43.60 | 72.62 | 0.857 | 3,404 | 9,837.600 | | |
| 8 | 11.37 | 43.60 | 72.64 | 0.858 | 3,404 | 9,839.139 | | |
| 9 | 11.46 | 43.4 | 80.69 | 0.953 | 3,799 | 9,868.948 | 0.064% | 3.18 |
| 10 | 11.46 | 43.4 | 80.69 | 0.953 | 3,799 | 9,872.275 | | bi-di |
| 11 | 11.48 | 43.3 | 80.70 | 0.953 | 3,808 | 9,865.926 | | |
| 12 | 11.48 | 43.3 | 80.70 | 0.953 | 3,808 | 9,869.808 | | |
| 13 | 11.59 | 43.1 | 90.68 | 1.071 | 4,299 | 9,903.524 | 0.025% | 3.18 |
| 14 | 11.59 | 43.1 | 90.68 | 1.071 | 4,299 | 9,905.978 | | bi-di |
| 15 | 11.63 | 43.1 | 90.69 | 1.071 | 4,300 | 9,903.543 | | |
| 16 | 11.63 | 43.1 | 90.70 | 1.071 | 4,300 | 9,905.534 | | |
| 17 | 11.76 | 42.7 | 100.42 | 1.186 | 4,806 | 9,930.529 | 0.028% | 3.18 |
| 18 | 11.76 | 42.7 | 100.41 | 1.185 | 4,805 | 9,933.173 | | bi-di |
| 19 | 11.81 | 42.6 | 100.42 | 1.186 | 4,817 | 9,930.904 | | |
| 20 | 11.81 | 42.6 | 100.41 | 1.185 | 4,816 | 9,933.355 | | |
| 21 | 11.95 | 42.2 | 110.09 | 1.300 | 5,331 | 9,950.931 | 0.034% | 3.18 |
| 22 | 11.95 | 42.2 | 110.09 | 1.300 | 5,331 | 9,953.717 | | bi-di |
| 23 | 12.00 | 42.1 | 110.20 | 1.301 | 5,349 | 9,951.161 | | |
| 24 | 12.00 | 42.1 | 110.19 | 1.301 | 5,348 | 9,954.269 | | |
| 25 | 12.22 | 41.6 | 120.10 | 1.418 | 5,899 | 9,966.848 | 0.030% | 3.18 |
| 26 | 12.22 | 41.6 | 120.08 | 1.418 | 5,898 | 9,969.790 | | bi-di |
| 27 | 12.27 | 41.5 | 120.15 | 1.419 | 5,916 | 9,968.779 | | |
| 28 | 12.27 | 41.5 | 120.16 | 1.419 | 5,917 | 9,969.652 | | |
| 29 | 12.44 | 41.5 | 129.89 | 1.534 | 6,396 | 9,980.315 | 0.027% | 3.18 |
| 30 | 12.44 | 41.5 | 129.89 | 1.534 | 6,396 | 9,981.640 | | bi-di |
| 31 | 12.50 | 41.3 | 129.92 | 1.534 | 6,428 | 9,978.966 | | |
| 32 | 12.50 | 41.3 | 129.91 | 1.534 | 6,428 | 9,980.585 | | |
| 33 | 12.68 | 40.8 | 140.27 | 1.656 | 7,025 | 9,989.523 | 0.031% | 3.18 |
| 34 | 12.68 | 40.8 | 140.27 | 1.656 | 7,025 | 9,991.062 | | bi-di |
| 35 | 12.76 | 41.3 | 140.33 | 1.657 | 6,943 | 9,987.923 | | |
| 36 | 12.76 | 41.3 | 140.31 | 1.657 | 6,942 | 9,989.925 | | |
| 37 | 12.99 | 40.5 | 149.67 | 1.767 | 7,552 | 9,992.912 | 0.028% | 3.18 |
| 38 | 12.99 | 40.5 | 149.66 | 1.767 | 7,551 | 9,994.567 | | bi-di |
| 39 | 13.07 | 40.3 | 150.48 | 1.777 | 7,630 | 9,994.037 | | |
| 40 | 13.07 | 40.3 | 150.46 | 1.776 | 7,629 | 9,995.692 | | |
| 41 | 13.30 | 39.7 | 160.70 | 1.897 | 8,272 | 9,998.309 | 0.036% | 3.18 |
| 42 | 13.30 | 39.7 | 160.68 | 1.897 | 8,270 | 10,000.339 | | bi-di |
| 43 | 13.40 | 39.5 | 160.75 | 1.898 | 8,316 | 9,996.780 | | |
| 44 | 13.40 | 39.5 | 160.74 | 1.898 | 8,315 | 9,998.595 | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 45 | 13.67 | 38.9 | 170.87 | 2.017 | 8,976 | 10,002.491 | 0.045% | 3.18 |
| 46 | 13.67 | 38.9 | 170.83 | 2.017 | 8,974 | 10,005.095 | | bi-di |
| 47 | 13.77 | 38.7 | 170.94 | 2.018 | 9,026 | 10,000.584 | | |
| 48 | 13.77 | 38.7 | 170.90 | 2.018 | 9,024 | 10,002.930 | | |
| 49 | 14.12 | 38.1 | 180.49 | 2.131 | 9,680 | 10,000.379 | 0.042% | 3.18 |
| 50 | 14.12 | 38.1 | 180.45 | 2.130 | 9,678 | 10,003.036 | | bi-di |
| 51 | 14.24 | 37.8 | 180.45 | 2.130 | 9,755 | 10,003.455 | | |
| 52 | 14.24 | 37.8 | 180.44 | 2.130 | 9,754 | 10,004.575 | | |
| 53 | 14.58 | 37.3 | 190.78 | 2.252 | 10,452 | 10,002.229 | 0.025% | 3.18 |
| 54 | 14.58 | 37.3 | 190.77 | 2.252 | 10,451 | 10,003.350 | | bi-di |
| 55 | 14.71 | 37.1 | 190.82 | 2.253 | 10,510 | 10,001.075 | | |
| 56 | 14.71 | 37.1 | 190.78 | 2.252 | 10,508 | 10,003.557 | | |
| 57 | 15.12 | 36.4 | 201.20 | 2.375 | 11,295 | 10,002.666 | 0.044% | 3.18 |
| 58 | 15.12 | 36.4 | 201.19 | 2.375 | 11,294 | 10,003.210 | | bi-di |
| 59 | 15.25 | 36.2 | 201.37 | 2.377 | 11,367 | 9,998.796 | | |
| 60 | 15.25 | 36.2 | 201.32 | 2.377 | 11,364 | 10,001.300 | | |
| 61 | 15.42 | 35.9 | 206.15 | 2.434 | 11,734 | 9,990.539 | 0.018% | 3.18 |
| 62 | 15.42 | 35.9 | 206.14 | 2.434 | 11,733 | 9,991.642 | | bi-di |
| 63 | 15.51 | 35.8 | 205.97 | 2.432 | 11,757 | 9,989.834 | | |
| 64 | 15.51 | 35.8 | 205.96 | 2.432 | 11,756 | 9,990.817 | | |
| 65 | 15.86 | 35.3 | 220.43 | 2.602 | 12,760 | 9,994.776 | 0.016% | 3.18 |
| 66 | 15.86 | 35.3 | 220.43 | 2.602 | 12,760 | 9,995.756 | | bi-di |
| 67 | 15.96 | 35.2 | 220.38 | 2.602 | 12,793 | 9,994.808 | | |
| 68 | 15.96 | 35.2 | 220.41 | 2.602 | 12,795 | 9,994.127 | | |
| 69 | 16.36 | 34.5 | 230.00 | 2.715 | 13,623 | 9,995.698 | 0.045% | 3.18 |
| 70 | 16.36 | 34.5 | 230. 00 | 2.715 | 13,623 | 9,995.992 | | bi-di |
| 71 | 16.47 | 34.3 | 230.03 | 2.716 | 13,704 | 9,998.248 | | |
| 72 | 16.47 | 34.3 | 230.00 | 2.715 | 13,702 | 10,000.209 | | |
| 73 | 16.88 | 33.7 | 240.32 | 2.837 | 14,572 | 9,998.037 | 0.011% | 3.18 |
| 74 | 16.88 | 33.7 | 240.32 | 2.837 | 14,572 | 9,998.735 | | bi-di |
| 75 | 17.01 | 33.5 | 240.27 | 2.837 | 14,656 | 9,997.641 | | |
| 76 | 17.01 | 33.5 | 240.26 | 2.837 | 14,655 | 9,998.700 | | |
| 77 | 17.36 | 33.0 | 250.36 | 2.956 | 15,503 | 9,999.037 | 0.034% | 3.18 |
| 78 | 17.36 | 33.0 | 250.39 | 2.956 | 15,505 | 9,998.355 | | bi-di |
| 79 | 17.49 | 32.7 | 250.53 | 2.958 | 15,656 | 9,996.496 | | |
| 80 | 17.49 | 32.7 | 250.55 | 2.958 | 15,657 | 9,995.670 | | |
| 81 | 17.86 | 32.3 | 260.75 | 3.078 | 16,496 | 9,999.438 | 0.008% | 3.18 |
| 82 | 17.86 | 32.3 | 260.74 | 3.078 | 16,495 | 9,999.766 | | bi-di |
| 83 | 18.00 | 32.1 | 260.76 | 3.079 | 16,600 | 9,999.324 | | |
| 84 | 18.00 | 32.1 | 260.78 | 3.079 | 16,601 | 9,998.975 | | |
| 85 | 18.45 | 31.5 | 270.66 | 3.195 | 17,558 | 9,997.763 | 0.032% | 3.18 |
| 86 | 18.45 | 31.5 | 270.64 | 3.195 | 17,557 | 9,998.606 | | bi-di |
| 87 | 18.60 | 31.3 | 270.92 | 3.199 | 17,687 | 9,995.410 | | |
| 88 | 18.60 | 31.3 | 270.85 | 3.198 | 17,683 | 9,998.082 | | |
| 89 | 19.04 | 30.7 | 280.76 | 3.315 | 18,688 | 9,996.298 | 0.009% | 3.18 |
| 90 | 19.04 | 30.7 | 280.76 | 3.315 | 18,688 | 9,996.692 | | bi-di |
| 91 | 19.21 | 30.5 | 280.70 | 3.314 | 18,806 | 9,996.705 | | |
| 92 | 19.21 | 30.5 | 280.69 | 3.314 | 18,806 | 9,997.196 | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 93 | 19.54 | 30.1 | 290.24 | 3.427 | 19,704 | 9,991.106 | 0.026% | 3.18 |
| 94 | 19.54 | 30.1 | 290.23 | 3.427 | 19,703 | 9,991.685 | | bi-di |
| 95 | 19.61 | 30.0 | 290.10 | 3.425 | 19,760 | 9,993.168 | | |
| 96 | 19.61 | 30.0 | 290.09 | 3.425 | 19,759 | 9,993.739 | | |
| 97 | 19.93 | 29.6 | 300.94 | 3.553 | 20,775 | 9,993.507 | 0.011% | 3.18 |
| 98 | 19.93 | 29.6 | 300.91 | 3.553 | 20,773 | 9,994.402 | | bi-di |
| 99 | 20.01 | 29.5 | 300.77 | 3.551 | 20,834 | 9,993.461 | | |
| 100 | 20.01 | 29.5 | 300.78 | 3.551 | 20,835 | 9,993.259 | | |
| 101 | 20.21 | 29.3 | 311.65 | 3.679 | 21,735 | 9,995.875 | 0.009% | 3.18 |
| 102 | 20.21 | 29.3 | 311.66 | 3.680 | 21,736 | 9,995.730 | | bi-di |
| 103 | 20.29 | 29.2 | 311.53 | 3.678 | 21,801 | 9,994.969 | | |
| 104 | 20.29 | 29.2 | 311.53 | 3.678 | 21,801 | 9,995.090 | | |
| 105 | 20.52 | 28.9 | 321.60 | 3.797 | 22,739 | 9,996.180 | 0.007% | 3.18 |
| 106 | 20.52 | 28.9 | 321.59 | 3.797 | 22,739 | 9,996.814 | | bi-di |
| 107 | 20.62 | 28.9 | 321.56 | 3.796 | 22,736 | 9,996.833 | | |
| 108 | 20.62 | 28.9 | 321.57 | 3.797 | 22,737 | 9,996.696 | | |
| 109 | 20.94 | 28.4 | 330.95 | 3.907 | 23,812 | 9,997.058 | 0.026% | 3.18 |
| 110 | 20.94 | 28.4 | 330.94 | 3.907 | 23,812 | 9,997.775 | | bi-di |
| 111 | 21.06 | 28.3 | 330.94 | 3.907 | 23,896 | 9,995.204 | | |
| 112 | 21.06 | 28.3 | 330.93 | 3.907 | 23,895 | 9,995.582 | | |
| 113 | 21.42 | 27.9 | 340.63 | 4.022 | 24,948 | 9,995.649 | 0.010% | 3.18 |
| 114 | 21.42 | 27.9 | 340.61 | 4.021 | 24,947 | 9,996.262 | | bi-di |
| 115 | 21.55 | 27.8 | 340.60 | 4.021 | 25,036 | 9,995.554 | | |
| 116 | 21.55 | 27.8 | 340.62 | 4.021 | 25,037 | 9,995.286 | | |
| 117 | 21.92 | 27.4 | 351.04 | 4.144 | 26,180 | 9,998.182 | 0.004% | 3.18 |
| 118 | 21.92 | 27.4 | 351.04 | 4.144 | 26,180 | 9,998.329 | | bi-di |
| 119 | 22.05 | 27.2 | 350.76 | 4.141 | 26,351 | 9,997.900 | | |
| 120 | 22.05 | 27.2 | 350.76 | 4.141 | 26,351 | 9,998.109 | | |

2.2 A repeat of the test 3 days earlier to check on repeatability when compared with the earlier tests.

| | T°C | cSt | $m^3/h$ | V m/s | Re | pulses/m3 | %spread | proved vol $m^3$ |
|---|---|---|---|---|---|---|---|---|
| 1 | 6.80 | 57.6 | 61.31 | 0.724 | 2,175 | 9,876.008 | 0.023% | 3.18 |
| 2 | 6.80 | 57.6 | 61.33 | 0.724 | 2,176 | 9,878.059 | | bi-di |
| 3 | 6.84 | 57.4 | 61.27 | 0.723 | 2,181 | 9,875.829 | | |
| 4 | 6.84 | 57.4 | 61.29 | 0.724 | 2,182 | 9,877.719 | | |
| 5 | 6.93 | 57.1 | 70.83 | 0.836 | 2,535 | 9,934.091 | 0.100% | 3.18 |
| 6 | 6.93 | 57.1 | 70.83 | 0.836 | 2,535 | 9,937.001 | | bi-di |
| 7 | 7.03 | 56.8 | 70.65 | 0.834 | 2,542 | 9,927.091 | | |
| 8 | 7.03 | 56.8 | 70.67 | 0.834 | 2,542 | 9,928.826 | | |
| 9 | 7.24 | 56.2 | 81.06 | 0.957 | 2,947 | 9,947.059 | 0.059% | 3.18 |
| 10 | 7.24 | 56.2 | 81.07 | 0.957 | 2,948 | 9,948.820 | | bi-di |
| 11 | 7.32 | 55.9 | 80.70 | 0.953 | 2,950 | 9,942.965 | | |
| 12 | 7.32 | 55.9 | 80.72 | 0.953 | 2,951 | 9,943.926 | | |
| 13 | 7.43 | 55.5 | 90.89 | 1.073 | 3,346 | 9,951.624 | 0.046% | 3.18 |
| 14 | 7.43 | 55.5 | 90.89 | 1.073 | 3,346 | 9,953.621 | | bi-di |
| 15 | 7.55 | 55.2 | 90.90 | 1.073 | 3,365 | 9,949.029 | | |
| 16 | 7.55 | 55.2 | 90.90 | 1.073 | 3,365 | 9,950.168 | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 17 | 7.76 | 54.5 | 100.74 | 1.189 | 3.777 | 9967.784 | 0.021% | 3.18 |
| 18 | 7.76 | 54.5 | 100.74 | 1.189 | 3,777 | 9,969.150 | | bi-di |
| 19 | 7.85 | 54.2 | 100.77 | 1.190 | 3,799 | 9,968.330 | | |
| 20 | 7.85 | 54.2 | 100.78 | 1.190 | 3,800 | 9,969.879 | | |
| 21 | 8.09 | 53.5 | 110.13 | 1.300 | 4.206 | 9984.516 | 0.034 | 3.18 |
| 22 | 8.09 | 53.5 | 110.13 | 1.300 | 4,206 | 9,985.990 | | bi-di |
| 23 | 8.18 | 53.2 | 110.15 | 1.300 | 4,231 | 9,982.562 | | |
| 24 | 8.18 | 53.2 | 110.16 | 1.301 | 4,231 | 9,983.538 | | |
| 25 | 8.44 | 52.5 | 119.95 | 1.416 | 4,669 | 9,998.267 | 0.030% | 3.18 |
| 26 | 8.44 | 52.5 | 119.95 | 1.416 | 4,669 | 9,999.904 | | bi-di |
| 27 | 8.54 | 52.1 | 119.99 | 1.417 | 4,706 | 9,996.939 | | |
| 28 | 8.54 | 52.1 | 119.99 | 1.417 | 4,706 | 9,998.500 | | |
| 29 | 8.78 | 51.5 | 130.91 | 1.546 | 5,194 | 10,011.117 | 0.045% | 3.18 |
| 30 | 8.78 | 51.5 | 130.88 | 1.545 | 5,193 | 10,014.489 | | bi-di |
| 31 | 8.89 | 51.1 | 130.88 | 1.545 | 5,234 | 10,010.018 | | |
| 32 | 8.89 | 51.1 | 130.86 | 1.545 | 5,233 | 10,013.088 | | |
| 33 | 9.28 | 50.2 | 139.97 | 1.653 | 5,698 | 10,017.235 | 0.032% | 3.18 |
| 34 | 9.28 | 50.2 | 139.94 | 1.652 | 5,696 | 10,020.398 | | bi-di |
| 35 | 9.38 | 49.9 | 140.00 | 1.653 | 5,733 | 10,018.019 | | |
| 36 | 9.38 | 49.9 | 140.00 | 1.653 | 5,733 | 10,019.699 | | |
| 37 | 9.59 | 49.3 | 149.97 | 1.771 | 6,216 | 10,023.196 | 0.032% | 3.18 |
| 38 | 9.59 | 49.3 | 149.94 | 1.770 | 6,215 | 10,025.977 | | bi-di |
| 39 | 9.72 | 49.0 | 150.01 | 1.771 | 6,256 | 10,022.808 | | |
| 40 | 9.72 | 49.0 | 150.01 | 1.771 | 6,256 | 10,023.969 | | |
| 41 | 9.98 | 48.3 | 160.28 | 1.892 | 6,781 | 10,025.759 | 0.035% | 3.18 |
| 42 | 9.98 | 48.3 | 160.26 | 1.892 | 6,780 | 10,027.719 | | bi-di |
| 43 | 10.10 | 47.9 | 160.32 | 1.893 | 6,839 | 10,025.146 | | |
| 44 | 10.10 | 47.9 | 160.28 | 1.892 | 6,838 | 10,028.702 | | |
| 45 | 10.38 | 47.3 | 170.40 | 2.012 | 7,362 | 10,030.067 | 0.038% | 3.18 |
| 46 | 10.38 | 47.3 | 170.40 | 2.012 | 7,362 | 10,030.828 | | bi-di |
| 47 | 10.52 | 46.9 | 170.34 | 2.011 | 7,422 | 10,026.996 | | |
| 48 | 10.52 | 46.9 | 170.33 | 2.011 | 7,421 | 10,028.319 | | |
| 49 | 11.00 | 45.7 | 182.85 | 2.159 | 8,176 | 10,030.206 | 0.034% | 3.18 |
| 50 | 11.00 | 45.7 | 182.83 | 2.159 | 8,175 | 10,031.602 | | bi-di |
| 51 | 11.15 | 45.3 | 182.05 | 2.149 | 8,212 | 10,028.146 | | |
| 52 | 11.15 | 45.3 | 182.03 | 2.149 | 8,211 | 10,029.272 | | |
| 53 | 11.43 | 44.7 | 191.50 | 2.261 | 8,754 | 10,023.847 | 0.031% | 3.18 |
| 54 | 11.43 | 44.7 | 191.46 | 2.260 | 8,752 | 10,026.242 | | bi-di |
| 55 | 11.59 | 44.3 | 191.50 | 2.261 | 8,833 | 10,025.065 | | |
| 56 | 11.59 | 44.3 | 191.47 | 2.261 | 8,832 | 10,026.926 | | |
| 57 | 11.95 | 43.5 | 200.29 | 2.365 | 9,409 | 10,026.145 | 0.034% | 3.18 |
| 58 | 11.95 | 43.5 | 200.28 | 2.365 | 9,408 | 10,027.519 | | bi-di |
| 59 | 12.12 | 43.1 | 200.37 | 2.366 | 9,500 | 10,024.136 | | |
| 60 | 12.12 | 43.1 | 200.36 | 2.366 | 9,499 | 10,024.960 | | |
| 61 | 12.18 | 43.0 | 210.32 | 2.483 | 9,995 | 10,027.015 | 0.087% | 3.18 |
| 62 | 12.18 | 43.0 | 210.33 | 2.483 | 9,995 | 10,026.925 | | bi-di |
| 63 | 12.28 | 42.7 | 210.06 | 2.480 | 10,053 | 10,018.271 | | |
| 64 | 12.28 | 42.7 | 210.02 | 2.480 | 10,051 | 10,020.768 | | |
| 65 | 12.52 | 42.3 | 219.74 | 2.594 | 10,615 | 10,017.629 | 0.019% | 3.18 |
| 66 | 12.52 | 42.3 | 219.74 | 2.594 | 10,615 | 10,018.260 | | bi-di |
| 67 | 12.61 | 42.1 | 219.63 | 2.593 | 10,660 | 10,018.892 | | |
| 68 | 12.61 | 42.1 | 219.63 | 2.593 | 10,660 | 10,019.501 | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 69 | 12.82 | 41.8 | 230.74 | 2.724 | 11,280 | 10,017.579 | 0.042% | 3.18 |
| 70 | 12.82 | 41.8 | 230.74 | 2.724 | 11,280 | 10,018.292 | | bi-di |
| 71 | 12.92 | 41.6 | 230.58 | 2.722 | 11,326 | 10,021.218 | | |
| 72 | 12.92 | 41.6 | 230.57 | 2.722 | 11,326 | 10,021.786 | | |
| 73 | 13.17 | 41.1 | 241.25 | 2.848 | 11,995 | 10,020.943 | 0.031% | 3.18 |
| 74 | 13.17 | 41.1 | 241.30 | 2.849 | 11,997 | 10,019.372 | | bi-di |
| 75 | 13.26 | 40.9 | 241.38 | 2.850 | 12,060 | 10,018.156 | | |
| 76 | 13.26 | 40.9 | 241.39 | 2.850 | 12,060 | 10,017.831 | | |
| 77 | 13.42 | 40.6 | 250.99 | 2.963 | 12,633 | 10,020.639 | 0.025% | 3.18 |
| 78 | 13.42 | 40.6 | 251.01 | 2.963 | 12,634 | 10,020.380 | | bi-di |
| 79 | 13.51 | 40.4 | 251.23 | 2.966 | 12,707 | 10,018.130 | | |
| 80 | 13.51 | 40.4 | 251.21 | 2.966 | 12,706 | 10,019.034 | | |
| 81 | 13.72 | 40.0 | 260.99 | 3.081 | 13,333 | 10,023.047 | 0.010% | 3.18 |
| 82 | 13.72 | 40.0 | 260.99 | 3.081 | 13,333 | 10,023.188 | | bi-di |
| 83 | 13.80 | 39.8 | 260.78 | 3.079 | 13,389 | 10,023.630 | | |
| 84 | 13.80 | 39.8 | 260.78 | 3.079 | 13,389 | 10,024.063 | | |
| 85 | 13.99 | 39.5 | 270.82 | 3.197 | 14,010 | 10,021.274 | 0.009% | 3.18 |
| 86 | 13.99 | 39.5 | 270.83 | 3.198 | 14,011 | 10,021.246 | | bi-di |
| 87 | 14.07 | 39.3 | 270.65 | 3.195 | 14,073 | 10,022.159 | | |
| 88 | 14.07 | 39.3 | 270.67 | 3.196 | 14,074 | 10,021.421 | | |
| 89 | 14.21 | 39.1 | 281.37 | 3.322 | 14,705 | 10,026.104 | 0.011% | 3.18 |
| 90 | 14.21 | 39.1 | 281.4 | 3.322 | 14,706 | 10,025.397 | | bi-di |
| 91 | 14.3 | 39.0 | 281.17 | 3.320 | 14,732 | 10,025.298 | | |
| 92 | 14.3 | 39.0 | 281.18 | 3.320 | 14,733 | 10,025.049 | | |
| 93 | 14.44 | 38.6 | 290.78 | 3.433 | 15,394 | 10,025.117 | 0.015% | 3.18 |
| 94 | 14.44 | 38.6 | 290.82 | 3.434 | 15,396 | 10,024.229 | | bi-di |
| 95 | 14.54 | 38.6 | 290.91 | 3.435 | 15,400 | 10,024.030 | | |
| 96 | 14.54 | 38.6 | 290.93 | 3.435 | 15,401 | 10,023.642 | | |
| 97 | 14.83 | 38.0 | 298.44 | 3.523 | 16,048 | 10,023.698 | 0.018% | 3.18 |
| 98 | 14.83 | 38.0 | 298.45 | 3.524 | 16,049 | 10,023.384 | | bi-di |
| 99 | 14.93 | 37.7 | 298.34 | 3.522 | 16,171 | 10,025.187 | | |
| 100 | 14.93 | 37.7 | 298.38 | 3.523 | 16,173 | 10,023.957 | | |
| 101 | 15.26 | 37.5 | 311.79 | 3.681 | 16,990 | 10,026.508 | 0.012% | 3.18 |
| 102 | 15.26 | 37.5 | 311.82 | 3.681 | 16,992 | 10,025.290 | | bi-di |
| 103 | 15.37 | 37.3 | 309.87 | 3.658 | 16,976 | 10,025.663 | | |
| 104 | 15.37 | 37.3 | 309.87 | 3.658 | 16,976 | 10,025.314 | | |
| 105 | 15.68 | 37.2 | 320.44 | 3.783 | 17,602 | 10,025.375 | 0.045% | 3.18 |
| 106 | 15.68 | 37.2 | 320.47 | 3.784 | 17,604 | 10,024.649 | | bi-di |
| 107 | 15.8 | 37.0 | 320.31 | 3.782 | 17,690 | 10,021.297 | | |
| 108 | 15.8 | 37.0 | 320.33 | 3.782 | 17,691 | 10,020.910 | | |
| 109 | 16.04 | 36.2 | 329.70 | 3.893 | 18,611 | 10,024.478 | 0.021% | 3.18 |
| 110 | 16.04 | 36.2 | 329.72 | 3.893 | 18,612 | 10,023.984 | | bi-di |
| 111 | 16.15 | 36.4 | 329.95 | 3.895 | 18,523 | 10,022.565 | | |
| 112 | 16.15 | 36.4 | 329.95 | 3.895 | 18,523 | 10,022.389 | | |
| 113 | 16.35 | 36.6 | 339.34 | 4.006 | 18,946 | 10,019.935 | 0.027% | 3.18 |
| 114 | 16.35 | 36.6 | 339.38 | 4.007 | 18,948 | 10,019.200 | | bi-di |
| 115 | 16.48 | 35.9 | 339.25 | 4.005 | 19,310 | 10,021.882 | | |
| 116 | 16.48 | 35.9 | 339.27 | 4.006 | 19,311 | 10,021.649 | | |
| 117 | 16.71 | 35.9 | 349.03 | 4.121 | 19,867 | 10,021.845 | 0.027% | 3.18 |
| 118 | 16.71 | 35.9 | 349.05 | 4.121 | 19,868 | 10,021.589 | | bi-di |
| 119 | 16.85 | 35.4 | 349.14 | 4.122 | 20,154 | 10,019.134 | | |
| 120 | 16.85 | 35.4 | 349.15 | 4.122 | 20,154 | 10,019.231 | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 121 | 6.17 | 59.8 | 805.13 | 9.506 | 27,512 | 10,038.174 | 0.056% | 3.18 |
| 122 | 6.17 | 59.8 | 805.05 | 9.505 | 27,509 | 10,039.311 | | bi-di |
| 123 | 6.38 | 59.2 | 805.96 | 9.515 | 27,820 | 10,033.666 | | |
| 124 | 6.38 | 59.2 | 805.83 | 9.514 | 27,815 | 10,035.177 | | |

Test 3

Three off 16 inch USM calibrated using Drakeol 32 using three sets of upstream and downstream spools.

The meters have been designated Meter A, Meter B and Meter C

The spools have been designated Upstream 1, Upstream 2, Upstream Spare, Downstream 1, Downstream 2 and Downstream Spare

The following tests were carried out:

| Test | Upstream Spool | Meter | Downstream Spool |
|---|---|---|---|
| 3.1 | Spare | A | Spare |
| 3.2 | Spare | A | 1 |
| 3.3 | 1 | A | 1 |
| 3.4 | Spare | B | Spare |
| 3.5 | 2 | B | 2 |
| 3.6 | Spare | C | Spare |

Test 3.1 Test setup Upstream Spare/ Meter A/ Downstream Spare

| | T°C | cSt | $m^3/h$ | V m/s | Re | pulses/m3 | %spread | proved vol $m^3$ |
|---|---|---|---|---|---|---|---|---|
| 1 | 19.95 | 79.21 | 149.500 | 0.217 | 1,722 | 940.462 | 0.119 | 10.06 |
| 2 | 19.92 | 79.36 | 149.600 | 0.218 | 1,721 | 940.053 | | Uni |
| 3 | 19.96 | 79.20 | 149.500 | 0.217 | 1,724 | 939.341 | | |

| | T°C | cSt | $m^3/h$ | V m/s | Re | pulses/m3 | %spread | proved vol $m^3$ |
|---|---|---|---|---|---|---|---|---|
| 1 | 19.98 | 79.10 | 447.000 | 0.650 | 5,156 | 940.738 | 0.190 | 10.06 |
| 2 | 19.93 | 79.30 | 446.100 | 0.649 | 5,136 | 940.054 | | Uni |
| 3 | 19.93 | 79.31 | 447.300 | 0.650 | 5,151 | 939.637 | | |
| 4 | 19.94 | 79.24 | 446.900 | 0.650 | 5,142 | 941.418 | | |

| | T°C | cSt | $m^3/h$ | V m/s | Re | pulses/m3 | %spread | proved vol $m^3$ |
|---|---|---|---|---|---|---|---|---|
| 1 | 20.00 | 78.98 | 751.500 | 1.093 | 8,682 | 940.543 | 0.045 | 21.26 |
| 2 | 20.00 | 78.98 | 750.700 | 1.092 | 8,672 | 940.754 | | USM master |
| 3 | 19.99 | 79.05 | 750.500 | 1.091 | 8,660 | 940.964 | | meter |

| | T°C | cSt | $m^3/h$ | V m/s | Re | pulses/m3 | %spread | proved vol $m^3$ |
|---|---|---|---|---|---|---|---|---|
| 1 | 20.08 | 78.65 | 1356.500 | 1.972 | 15,737 | 940.543 | 0.045 | 21.26 |
| 2 | 20.06 | 78.73 | 1356.300 | 1.972 | 15,716 | 940.754 | | USM master |
| 3 | 20.02 | 78.89 | 1355.600 | 1.971 | 15,680 | 940.964 | | meter |
| 4 | 19.97 | 79.13 | 1353.100 | 1.967 | 15,608 | 940.754 | | |
| 5 | 19.91 | 79.39 | 1353.100 | 1.967 | 15,558 | 940.964 | | |

| | T°C | cSt | m³/h | Re | pulses/m3 | %spread | proved vol m³ |
|---|---|---|---|---|---|---|---|
| 1 | 19.99 | 79.06 | 1950.300 | 22,517 | 940.342 | 0.079 | 38.28 |
| 2 | 19.90 | 79.43 | 1954.700 | 22,450 | 940.761 | | USM master |
| 3 | 19.91 | 79.41 | 1952.600 | 22,449 | 940.017 | | |

Test 3.2 Test setup Upstream Spare/ Meter A/ Downstream 1

| | T°C | cSt | m³/h | V m/s | Re | pulses/m3 | %spread | proved vol m³ |
|---|---|---|---|---|---|---|---|---|
| 1 | 20.11 | 78.52 | 148.600 | 0.216 | 1,728 | 940.022 | 0.564 | 10.06 |
| 2 | 19.92 | 79.37 | 148.900 | 0.217 | 1,709 | 941.987 | | Uni |
| 3 | 20.03 | 78.88 | 148.900 | 0.217 | 1,721 | 941.594 | | |
| 4 | 20.11 | 78.51 | 148.800 | 0.216 | 1,729 | 941.084 | | |
| 5 | 19.88 | 79.55 | 149.300 | 0.217 | 1,704 | 945.320 | | |

| | T°C | cSt | m³/h | V m/s | Re | pulses/m3 | %spread | proved vol m³ |
|---|---|---|---|---|---|---|---|---|
| 1 | 19.86 | 79.62 | 446.500 | 0.649 | 5,110 | 942.033 | 0.423 | 10.06 |
| 2 | 19.92 | 79.37 | 447.000 | 0.650 | 5,129 | 942.585 | | Uni |
| 3 | 19.93 | 79.30 | 445.400 | 0.648 | 5,132 | 939.313 | | |
| 4 | 20.00 | 78.99 | 446.400 | 0.649 | 5,159 | 940.110 | | |
| 5 | 19.88 | 78.81 | 445.300 | 0.647 | 5,167 | 938.616 | | |

| | T°C | cSt | m³/h | V m/s | Re | pulses/m3 | %spread | proved vol m³ |
|---|---|---|---|---|---|---|---|---|
| 1 | 20.02 | 78.92 | 754.700 | 1.097 | 8,711 | 942.174 | 0.185 | 31.86 |
| 2 | 19.95 | 79.22 | 753.900 | 1.096 | 8,685 | 940.437 | | USM master meter |
| 3 | 19.93 | 79.32 | 754.700 | 1.097 | 8,678 | 940.991 | | |
| 4 | 19.93 | 79.28 | 755.800 | 1.099 | 8,693 | 941.297 | | |
| 5 | 19.97 | 79.12 | 756.300 | 1.100 | 8,715 | 941.456 | | |

| | T°C | cSt | m³/h | Re | pulses/m3 | %spread | proved vol m³ |
|---|---|---|---|---|---|---|---|
| 1 | 20.08 | 78.65 | 1356.500 | 15,737 | 940.664 | 0.054 | 26.60 |
| 2 | 20.06 | 78.73 | 1356.300 | 15,716 | 940.752 | | USM master meter |
| 3 | 20.02 | 78.89 | 1355.600 | 15,680 | 940.631 | | |
| 4 | 19.97 | 79.13 | 1353.100 | 15,608 | 940.377 | | |
| 5 | 19.91 | 79.39 | 1353.100 | 15,558 | 940.242 | | |

| | T°C | cSt | m³/h | Re | pulses/m3 | %spread | proved vol m³ |
|---|---|---|---|---|---|---|---|
| 1 | 19.99 | 79.06 | 1950.300 | 22,517 | 940.342 | 0.079 | 38.28 |
| 2 | 19.90 | 79.43 | 1954.700 | 22,450 | 940.761 | | USM master meter |
| 3 | 19.91 | 79.41 | 1952.600 | 22,449 | 940.017 | | |

Test 3.3 Test setup Upstream 1/ Meter A / Downstream 1

| | T°C | cSt | m³/h | Re | pulses/m3 | %spread | proved vol m³ |
|---|---|---|---|---|---|---|---|
| 1 | 19.88 | 1709.00 | 148.900 | 1,709 | 941.576 | 0.094 | 10.06 |
| 2 | 16.96 | 1718.00 | 149.000 | 1,718 | 940.797 | | uni |
| 3 | 20.03 | 1724.00 | 149.000 | 1,724 | 940.696 | | |

| | T°C | cSt | m³/h | Re | pulses/m3 | %spread | proved vol m³ |
|---|---|---|---|---|---|---|---|
| 1 | 20.06 | 78.70 | 447.300 | 5,182 | 941.420 | 0.169 | 10.06 |
| 2 | 19.96 | 79.15 | 446.900 | 5,156 | 939.851 | | uni |
| 3 | 19.92 | 79.37 | 446.700 | 5,141 | 939.836 | | |

| | T°C | cSt | m³/h | Re | pulses/m3 | %spread | proved vol m³ |
|---|---|---|---|---|---|---|---|
| 1 | 19.92 | 79.34 | 754.300 | 8,672 | 940.922 | 0.135 | 10.06 |
| 2 | 19.92 | 79.35 | 754.500 | 8,676 | 940.559 | | uni |
| 3 | 19.93 | 79.28 | 756.200 | 8,692 | 941.825 | | |
| 4 | 19.98 | 79.10 | 755.900 | 8,718 | 940.810 | | |
| 5 | 20.02 | 78.90 | 756.600 | 8,750 | 940.641 | | |

| | T°C | cSt | m³/h | Re | pulses/m3 | %spread | proved vol m³ |
|---|---|---|---|---|---|---|---|
| 1 | 20.13 | 78.43 | 1361.600 | 15,848 | 940.295 | 0.051 | 37.20 |
| 2 | 20.10 | 78.52 | 1358.800 | 15,787 | 940.771 | | USM master |
| 3 | 20.05 | 78.79 | 1358.600 | 15,737 | 940.413 | | |

| | T°C | cSt | m³/h | Re | pulses/m3 | %spread | proved vol m³ |
|---|---|---|---|---|---|---|---|
| 1 | 19.93 | 79.31 | 1967.900 | 22,654 | 940.010 | 0.055 | 38.20 |
| 2 | 19.94 | 79.25 | 1970.500 | 22,705 | 939.838 | | USM master |
| 3 | 20.00 | 79.00 | 1974.100 | 22,809 | 940.353 | | |

Test 3.4 Test setup Upstream Spare/ Meter B/ Downstream Spare

| | T°C | cSt | m³/h | Re | pulses/m3 | %spread | proved vol m³ |
|---|---|---|---|---|---|---|---|
| 1 | 19.93 | 79.31 | 147.900 | 1,703 | 940.319 | 0.307 | 10.06 |
| 2 | 19.98 | 79.08 | 147.800 | 1,708 | 939.321 | | Uni |
| 3 | 19.97 | 79.14 | 148.300 | 1,706 | 942.201 | | |

| | T°C | cSt | m³/h | Re | pulses/m3 | %spread | proved vol m³ |
|---|---|---|---|---|---|---|---|
| 1 | 20.03 | 78.85 | 447.200 | 5,176 | 940.404 | 0.172 | 10.06 |
| 2 | 19.93 | 79.20 | 446.900 | 5,142 | 940.860 | | Uni |
| 3 | 19.98 | 79.50 | 446.800 | 5,136 | 939.243 | | |

| | T°C | cSt | m³/h | Re | pulses/m3 | %spread | proved vol m³ |
|---|---|---|---|---|---|---|---|
| 1 | 19.91 | 79.41 | 754.700 | 8,671 | 940.636 | 0.072 | 31.88 |
| 2 | 19.93 | 79.32 | 755.700 | 8,690 | 941.078 | | USM master |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 3 | 19.96 | 79.16 | 755.600 | 8,712 | 940.397 | | |

| | ToC | cSt | m3/h | Re | pulses/m3 | %spread | proved vol m3 |
|---|---|---|---|---|---|---|---|
| 1 | 19.99 | 79.03 | 1358.200 | 15,689 | 940.157 | 0.059 | 37.20 |
| 2 | 20.02 | 78.92 | 1360.800 | 15,735 | 940.621 | | USM master |
| 3 | 20.06 | 78.73 | 1358.700 | 15,757 | 940.067 | | |

| | ToC | cSt | m3/h | Re | pulses/m3 | %spread | proved vol m3 |
|---|---|---|---|---|---|---|---|
| 1 | 20.06 | 79.03 | 1358.200 | 22,845 | 938.883 | 0.085 | 38.30 |
| 2 | 20.04 | 78.92 | 1360.800 | 22,832 | 939.404 | | USM master |
| 3 | 20.07 | 78.73 | 1358.700 | 22,909 | 939.680 | | |

Test 3.5 Test Setup Upstream 2/ Meter B / Downstream 2

| | T°C | cSt | $m^3/h$ | Re | pulses/m3 | %spread | proved vol $m^3$ |
|---|---|---|---|---|---|---|---|
| 1 | 20.17 | 78.22 | 146.300 | 1,694 | 939.801 | 0.011 | 10.06 |
| 2 | 20.11 | 78.50 | 146.100 | 1,699 | 939.902 | | Uni |
| 3 | 20.04 | 78.79 | 146.200 | 1,708 | 939.834 | | |

| | T°C | cSt | $m^3/h$ | Re | pulses/m3 | %spread | proved vol $m^3$ |
|---|---|---|---|---|---|---|---|
| 1 | 20.05 | 78.76 | 441.200 | 5,122 | 938.626 | 0.095 | 10.06 |
| 2 | 20.05 | 78.77 | 441.900 | 5,124 | 939.521 | | Uni |
| 3 | 20.04 | 78.80 | 441.200 | 5,117 | 939.124 | | |

| | T°C | cSt | $m^3/h$ | Re | pulses/m3 | %spread | proved vol $m^3$ |
|---|---|---|---|---|---|---|---|
| 1 | 20.04 | 78.81 | 756.300 | 8,756 | 940.699 | 0.042 | 31.88 |
| 2 | 20.04 | 78.80 | 756.000 | 8,752 | 940.820 | | USM master |
| 3 | 20.05 | 78.78 | 756.200 | 8,754 | 941.091 | | |

| | T°C | cSt | $m^3/h$ | Re | pulses/m3 | %spread | proved vol $m^3$ |
|---|---|---|---|---|---|---|---|
| 1 | 20.02 | 78.91 | 1358.600 | 15,717 | 940.174 | 0.083 | 37.20 |
| 2 | 20.03 | 78.85 | 1357.600 | 15,731 | 939.454 | | USM master |
| 3 | 20.07 | 78.68 | 1359.900 | 15,778 | 940.232 | | |

| | T°C | cSt | $m^3/h$ | Re | pulses/m3 | %spread | proved vol $m^3$ |
|---|---|---|---|---|---|---|---|
| 1 | 20.11 | 78.51 | 1968.600 | 22,902 | 939.712 | 0.013 | 38.30 |
| 2 | 20.08 | 78.66 | 1969.000 | 22,861 | 939.798 | | USM master |
| 3 | 20.07 | 78.70 | 1970.200 | 22,866 | 939.680 | | |

Test 3.6 Test Setup Upstream Spare/ Meter C/ Downstream Spare

| | T°C | cSt | $m^3/h$ | Re | pulses/m3 | %spread | proved vol $m^3$ |
|---|---|---|---|---|---|---|---|
| 1 | 19.95 | 79.22 | 146.700 | 1,690 | 940.657 | 0.067 | 10.06 |
| 2 | 20.00 | 79.00 | 146.700 | 1,695 | 940.031 | | Uni |
| 3 | 20.01 | 78.95 | 146.400 | 1,693 | 940.128 | | |
| 4 | 19.95 | 79.19 | 146.600 | 1,690 | 940.541 | | |

| | T°C | cSt | m³/h | Re | pulses/m3 | %spread | proved vol m³ |
|---|---|---|---|---|---|---|---|
| 1 | 20.02 | 78.88 | 421.500 | 4,871 | 939.733 | 0.382 | 10.06 |
| 2 | 19.99 | 79.04 | 420.800 | 4,861 | 940.117 | | Uni |
| 3 | 19.98 | 79.06 | 420.700 | 4,856 | 940.531 | | |
| 4 | 20.02 | 78.91 | 421.700 | 4,866 | 942.412 | | |
| 5 | 20.04 | 78.84 | 421.700 | 4,971 | 942.498 | | |
| 6 | 19.97 | 79.11 | 421.900 | 4,855 | 942.703 | | |
| 7 | 19.98 | 79.09 | 421.300 | 4,856 | 941.414 | | |
| 8 | 19.99 | 79.03 | 421.700 | 4,858 | 942.701 | | |
| 9 | 19.98 | 79.11 | 421.700 | 4,850 | 943.322 | | |

| | T°C | cSt | m³/h | Re | pulses/m3 | %spread | proved vol m³ |
|---|---|---|---|---|---|---|---|
| 1 | 19.98 | 79.07 | 756.300 | 8,729 | 940.168 | 0.031 | 31.90 |
| 2 | 91.94 | 79.26 | 756.000 | 8,703 | 940.223 | | USM master |
| 3 | 19.91 | 79.37 | 756.200 | 8,681 | 939.932 | | |

| | T°C | cSt | m³/h | Re | pulses/m3 | %spread | proved vol m³ |
|---|---|---|---|---|---|---|---|
| 1 | 19.98 | 79.07 | 756.300 | 8,729 | 940.168 | 0.031 | 31.90 |
| 2 | 91.94 | 7926.00 | 756.000 | 8,703 | 940.223 | | USM master |
| 3 | 19.91 | 79.37 | 756.200 | 8,681 | 939.932 | | |

| | T°C | cSt | m³/h | Re | pulses/m3 | %spread | proved vol m³ |
|---|---|---|---|---|---|---|---|
| 1 | 19.95 | 79.23 | 1358.800 | 15,652 | 940.451 | 0.044 | 37.20 |
| 2 | 19.98 | 79.07 | 1357.100 | 15,671 | 940.034 | | USM master |
| 3 | 19.99 | 79.03 | 1357.600 | 15,684 | 940.113 | | |

| | T°C | cSt | m³/h | Re | pulses/m3 | %spread | proved vol m³ |
|---|---|---|---|---|---|---|---|
| 1 | 19.94 | 79.26 | 1960.800 | 22,582 | 940.293 | 0.029 | 38.30 |
| 2 | 19.97 | 79.11 | 1960.000 | 22,611 | 940.457 | | USM master |
| 3 | 19.97 | 79.14 | 1958.400 | 22,591 | 940.180 | | |