Qualification of Fiscal Liquid Ultrasonic Meter for Operation on Extended Viscosity Range

Øyvind Nesse and Tore Bratten
Statoil

Contents

1 Introduction

Statoil is developing the Mariner and Bressay fields which are heavy oil discoveries in the UK sector of the North Sea. The Mariner project includes one platform called the PDQ with process, drilling and living quarters and one ship called the FSU with oil storage, oil export and diluent import. A jack-up drill rig will be temporary connected to the PDQ. The oil production is dependent on continuous injection of a diluent - a light oil from other offshore fields - in each production well. The diluent will be imported in batches from shuttle tankers to the permanently installed floating storage units (FSU). Heavy crude oil shall be exported from the same storage unit. The diluent import and the heavy crude export shall be fiscally metered by a common batch metering station. The metering station must handle low viscosity diluent and various high viscosity diluted crude oil qualities. The resultant liquid flows will represent turbulent flow, transition flow and laminar flow through the ultrasonic flow meters.

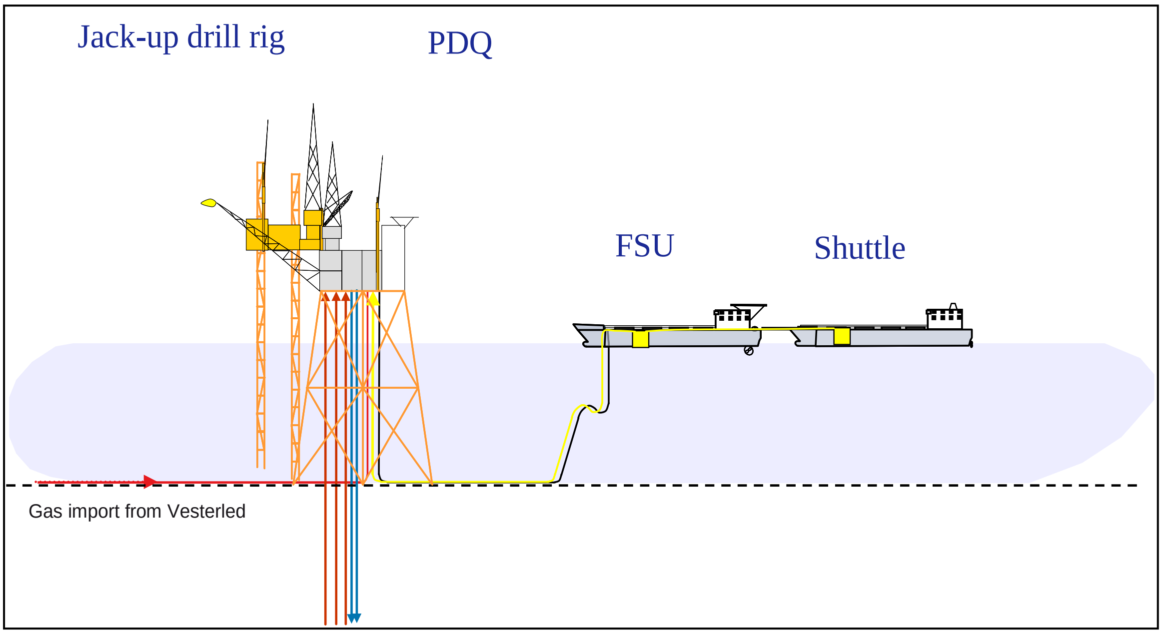

Figure 1.1 Mariner field development concept.

A Technical Qualification Program (TQP) for liquid multipath ultrasonic meters used on an extended Reynolds number range was initiated by Statoil in 2012. Three different multipath ultrasonic liquid meters were tested in the first and third quarter of 2013 at three ISO certified flow test facilities; SPSE in Marseille, Trapil in Paris, both in France, and FMC Technologies Flow Research and Test Center, Erie PA, USA. The tests fluids ranged from 0,8 cSt to 350 cSt which correspond to the actual design limits for the Mariner metering application.

This paper will share the results and experience gained during testing and characterising of the ultrasonic crude oil meters, as well as give a brief introduction to Statoil's Technical Qualification Program.

2 Background

Fiscal batch metering of the export to shuttle tankers is a proven concept within Statoil and amongst several other offshore operators. However, fiscal metering at the Mariner and Bressay storage units involves operational procedures and challenges different from the commonly known and well-proven offshore batch metering operations. The shuttle tankers have to be modified for the reversed transfer from the shuttle tanker bow via the loading hose to the floating storage unit. The main challenge with regards to metering at the storage unit is the operating conditions at the metering station. Unstable pressure and potential risk of flashing during the operation is a challenge which has to be overcome by operational procedures.

During the Mariner Field development phase several metering principles and metering station concepts were evaluated. Installing dedicated and separate metering stations for diluted crude oil and diluent represented a "worst case" scenario, and was abandoned due to the space requirements, investment and maintenance costs. The concept chosen was a common fiscal/custody transfer batch metering system for diluted crude and diluent using ultrasonic flow meters in combination with a bi-directional prover. The flow capacity of the metering system shall be 7000 m3/h for export diluted crude from storage tanks to Shuttle Tanker, and 8000 m3/h for import of diluent from Shuttle Tanker. The Mariner metering design data are given in Table 2.1 and 2.2

Table 2.1 Mariner export fiscal metering design data per meter run.

	Minimum	**Maximum**	**Units**
Requested Flow	300	1750	m3/h
Pressure	10	12	Barg
Temperature	40	50	°C
Density	930	985	kg/m3
Viscosity	200	350	cSt
Reynolds number (12'' pipe)	1000	10 000	

Table 2.2 Mariner import fiscal metering design data per meter run.

	Minimum	**Maximum**	**Units**
Requested Flow	300	2000	m3/h
Pressure	4	5	Barg
Temperature	20	55	°C
Density	700	854	kg/m3
Viscosity	0.8	1,5	cSt
Reynolds number (12'' pipe)	250 000	3000 000	

Statoil has gained considerable experience using ultrasonic flow meters in fiscal liquid metering systems, but not on any application similar to the ones at Mariner Floating Storage Unit (FSU). Furthermore, Statoil has with varying success experienced the challenge of using ultrasonic meters with velocity profile correction in the transmission area between laminar and turbulent flow. An example is from the New Oseberg Blend metering station where there was a large deviation between the K-factors achieved under the calibration at TRAPIL and the first 1.5 years in operation, see Fig. 2.1.

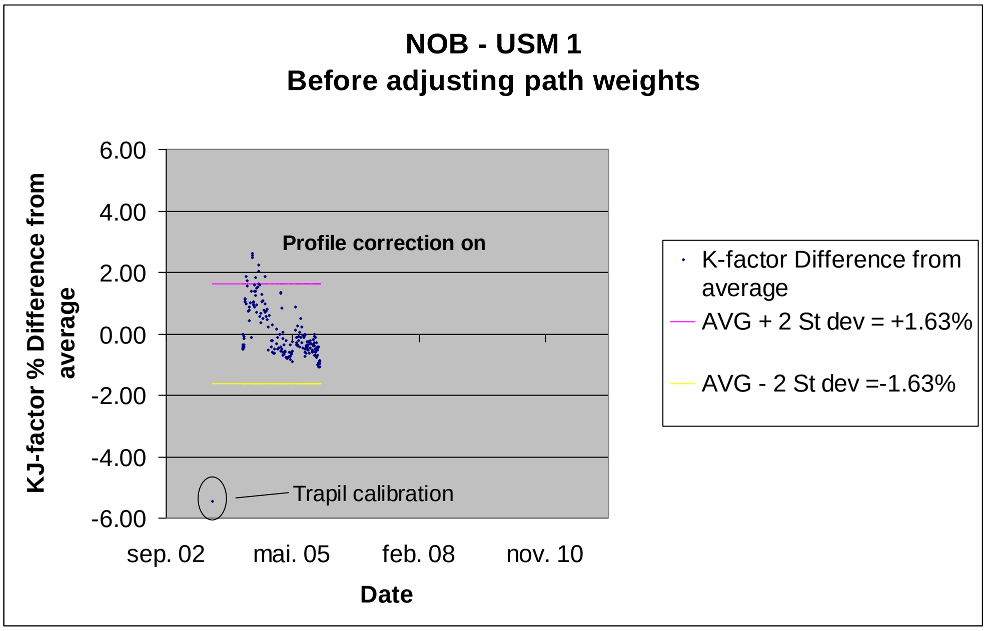

Figure 2.1 Ultrasonic liquid meter with velocity profile correction.

The calibration in Trapil was performed on a fluid with viscosity of 4.72 cSt, while at operational conditions the viscosity is approximately 200 cSt. The K-factor achieved in TRAPIL was 5712 [pulses/m3]. The average K-factor achieved in operation was 6040.8 [pulses/m3]. It is worth noting that if the K-factor achieved under the calibration at Trapil calibration facility had been used during operation, a systematic error of approximately 5% would have been the result. Optimisations of the meters were then performed ref: "Experience with ultrasonic meters on high viscosity oil" [2] presented by Øyvind Nesse at the North Sea Flow Measurement Workshop in Tønsberg 2007.

However, testing and optimisation in the field shall be minimised because of its inherent risk and cost. The fiscal liquid meters for Mariner must go through a technology qualification program before installation. The ultrasonic meters must be tested over an extended Reynolds number range and with different liquids reflecting the design parameters in Tables 2.1-2.2.

3 Technology Qualification Program in Statoil

Statoil proven technology: Documented track record for a defined environment, operating window and fluid, with respect to the ability of the technology to meet the specified requirements. In general, a technology shall have a successful or acceptable track record from Statoil portfolio in order to be classified as proven.

New technology in Statoil is a technology that is not proven according to the definition above. This also implies that the first application of proven technology in a new environment or an unproven technology in a known environment, are both by definition new technology, which must go through a technology qualification program before integration into intended operating system.

All technology elements within the new technical solution shall be classified according to a Technology Assessment based on:

1. No new technical uncertainties
2. New technical uncertainties
3. New technical challenges
4. Demanding new technical challenges

This classification can be used for the totality of the application of the technical solution, as well as parts of it, functionality and part systems. Establishment of classification category is based on degree of new technology and application area, as shown in the following matrix:

Table 3.1 Classification categories

Application area	Technology Maturity		
	Proven	Limited field history	New or unproven
Previous experience	1	2	3
No experience in Statoil	2	3	4
No industry experience	2	4	4

All new technologies in Statoil shall be approved according to this procedure.

Some ultrasonic flow meter manufacturers would claim their liquid flow meter is ready for accurate measurement on an extended Reynolds number range. Statoil has yet to verify this statement. In other words, we need to test ultrasonic liquid flow meter with increasing Reynolds number. Table 3.2 summarizes the Technology Assessment for Ultrasonic liquid flow meters.

Table 3.2 Classification of ultrasonic liquid meter

Item	Application Area (AA)			Technology Maturity (TM)			Cat	Remark
	Prev exp.	No exp. Statoil	No industr. exp.	Proven	Limited history	New/ Unproven		
Design Manufacture Installation	X			X			1	AA: Ultrasonic liquid flow meters are widely used in Statoil on oil flow. TM: There are several manufacturers with decades of experience. The uncertainty of ultrasonic liquid meters is traceable to accredited laboratories.
Extended Reynolds number range		X			X		3	AA: Ultrasonic liquid meters have been used to measure oil flow over a rather limited Reynolds number range, and mainly in the turbulent area. TM: Little independent data available on the performance of ultrasonic liquid meters applied over an extended Reynolds number range. Measurements in the transition area are known to be a challenge.

As can be seen from the assessment there is a technical challenge for ultrasonic liquid flow technology. That is to identify measurement uncertainty and/or systematic error of the meters when applied across the transition area from laminar flow to turbulent flow. This challenge will be addressed as main part of the technology qualification program to ensure that the installation will lead to a proven technology.

3.1 Introduction to Technology Readiness Level

The Technology Readiness Level (TRL) of a technology shall be considered according to Table 3.3.

Table 3.3 Technology Readiness Level

Level	Development stage	Description
TRL 0	Unproven Idea	Paper Concept. No analysis or testing has been performed
TRL 1	Analytically Proven Concept	Functionality proven by analysis , reference to common features of existing technology or testing on individual subcomponents /subsystems. The concept may not meet all of the technical requirements at this level, but demonstrates the basic functionality with promise to meet all the requirements with additional testing.
TRL 2	Physically Proven Concept	Concept design or novel features of design validated by model or small scale testing in laboratory environment. The system validates that it can function in a "realistic" environment with the key environmental parameters simulated.
TRL 3	Prototype Tested	Full scale prototype built and put through product qualification test program. The prototype is tested in a robust designed development test program over a limited range of operating conditions to demonstrate is functionality
TRL 4	Environment Tested	Full scale prototype (or production unit) built and put through a qualification test program in (simulated or actual) intended environment
TRL 5	System Integration Tested	Full scale prototype (or production unit) built and integrated into intended operating system with full interface and functionality tests
TRL 6	System Installed	Full scale prototype (or production unit) built and integrated into intended operating system with full interface and functionality test program in intended environment. The technology has successfully operated < 10% of its expected life.
TRL 7	Proven Technology	Production unit integrated into intended operating system. The technology has successfully operated with acceptable performance and reliability for > 10% of its specified life.

3.2 Technology Readiness Level for ultrasonic liquid meter

Ultrasonic oil meters have been tested at full scale with low and high viscos oil and in laboratory environment by third part, and Statoil has broad experience with use of these meters on limited Reynolds number applications. These meters are thus regarded currently to be at TRL 3. Next section describes the required activities to be able to move the ultrasonic liquid flow meter technology to TRL 5. First step is to test the meters at the intended environment at a full scale laboratory based on Mariner design parameters (TRL 4) and thereafter install ultrasonic meters at the import/export metering station at Mariner.

The next step after successful integration and test period at Mariner will be to develop sufficient operating experience with the ultrasonic meters to reach TRL 6 and further TRL 7.

4 Technology Qualification Activities and Acceptance Criteria

This Chapter describes in general the activities and acceptance criteria found necessary to qualify ultrasonic liquid meter for fiscal metering on an extended Reynolds number range. The meter must fulfil the general allowable measurement uncertainty required to satisfy custody transfer liquid metering requirements. In the UK sector, by consensus the total combined uncertainty is ±0.25% (dry mass) for liquid. On the Norwegian sector oil metering for sale and allocation purposes has allowable expanded uncertainty of 0.30 % of standard volume. The acceptance criteria chosen for the current TQP are linearity band 0,3 % and proving repeatability uncertainty of 0,027% .

Table 4.1 summarizes the general technology uncertainties, but also the required qualification activities including the acceptance criteria, for qualifying ultrasonic liquid meter. Table 4.2 describes how these qualification activities will lift the technology from TRL 3 and to TRL7. However, this paper covers TRL4.

Table 4.1 Required qualification activities and acceptance criteria for qualifying fiscal liquid ultrasonic meters for operation on extended Reynolds number range.

No	Technology Uncertainty	Qualification Activity (QA)	Acceptance Criteria (AC)
TRL 4			
1	Key test parameters • Viscosity • Liquid flow rate • Density	Carry out flow tests of ultrasonic meters at a recognized laboratory. Test matrix shall be based on Mariner design parameters.	Working range: • Linearity band 0,3 % (same band as defined by NPD) • Repeatability uncertainty of 0,027% ○ Maximum 20 repeats
2	Ultrasonic design	Test ultrasonic meters from minimum two different manufacturers.	Verify the performance of the meters
TRL 5			
3	Functionality test	Factory Acceptance Test (FAT) of metering control system.	Fulfil standard FAT accept criteria for metering control system
4	Flow	FAT each of ultrasonic flow meter at accredited test facility	Fulfil DECC's requirements to oil metering for fiscal purposes.
TRL 6			
5	Batch measurements	Install 5 ultrasonic flow meters in parallel. The import and export metering station shall comprise ball prover and redundant instrumentation.	• The meters shall perform within uncertainty limits required by DECC. • Fulfil the historical limit of 0,3% band for the last 30 accepted k-factors.
TRL 7:			
6	Final evaluation	After10% of lifetime an evaluation of the ultrasonic meters will be performed. The evaluation shall consider individual proving results and long term K-factor stability.	All the above acceptance criteria to be fulfilled

5 Semantics

One of the experiences made during testing of the ultrasonic meters is that the manufacturer and customer do not speak the same "language". Before presenting the results there is a need to explain the following concepts: calibration, verification, characterisation, simulation and optimisation, see Table 5.1. In this paper we use the concepts of the manufacturer.

Table 5.1 Concepts used by manufacturer and operator

Manufacturer	Customer
Calibration	Characterisation
Verification	Calibration
Simulation	Optimisation

Calibration: When the ultrasonic meter leaves the factory it is configured with specific weights per ultrasonic path. At the calibration site the meter is corrected relative to the reference using a method called Velocity Profile Correction (VPC). The correction factors are based off of velocities on the inner (A) and outer paths (B) of the meter along with the bulk average velocity. Through calibration on multiple liquids a lookup table (A, B, Correction) is generated for the ultrasonic meter's intended operating process range. This process is frequently called Reynolds number correction, but note that the flow profile at a given Reynolds number is not necessarily unique. The lookup table is stored in the meter. The updated configuration is traceable through a belonging checksum value.

To our knowledge there are no limitations to how much the meter can deviate from reference before application of correction. This is in contrast to ultrasonic gas meters which in order to be accepted and considered to be of acceptable quality the maximum deviation from the reference during flow calibration shall be less than ± 1,5 % [Norsok I-104]. There are not any standard requirements to the manufacturer's calibration procedure.

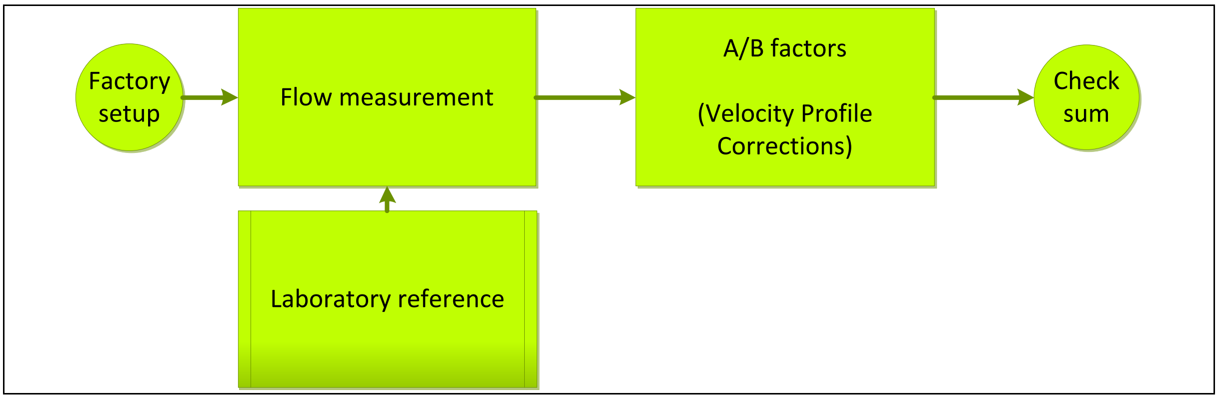

Figure 5.1 Calibration procedure

Verification: After the meter has been calibrated and the corrections factors have been implemented the meter performance needs to be verified at an accredited laboratory. From the customers point of view this is the Factory Acceptance Test (FAT) where the liquid ultrasonic meter shall be tested to verify the accuracy (Linearity) and repeatability (uncertainty) requirements according to an agreed standard or guideline e.g. API MPMS ch. 5.8. The FAT is documented by a calibration report and a "COFRAC Certificate of Calibration" showing that the calibration, hence verification, was performed in compliance to the framework of the accreditation of the laboratory. The meter is usually tested on a single fluid.

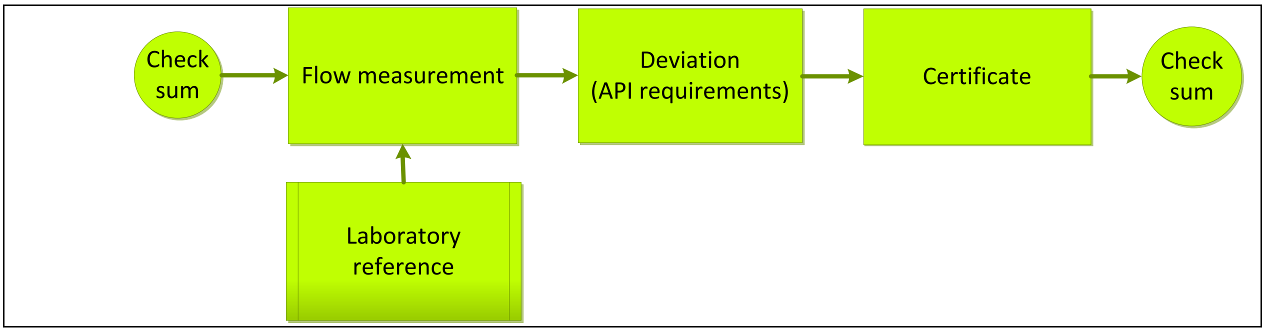

Figure 5.2 Verification procedure

Simulation: It's all about the mathematics. Additional calibration may be used to improve previous verification. By using new and old calibration data the manufacturer can optimise path weights and velocity profile corrections to minimise the deviation between corrected flow measurement and reference. This results in a new configuration of the meter, hence new checksum.

During verification the manufacturer may propose to further improve the correction factors by simulation to enhance the performance of the meter. In other words the manufacturer continues his calibration during verification. The FAT program normally has a tight schedule and there are limited possibilities to do extra flow tests. The customer may then face a dilemma. Should he accept an improved meter where some flow rates are not repeated with the new checksum, hence the calibration certificate will cover two different setups, or should he only accept a meter which has gone through a strict verification with fixed checksum throughout the FAT/verification? Is it acceptable that the manufacturer tampers with the meter during verification? We recommend simulation only if the meter shall be installed in a system with prover.

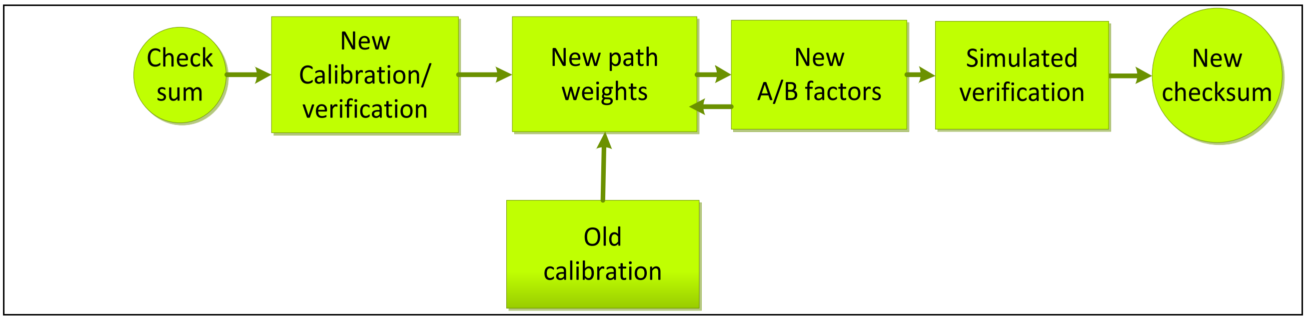

Figure 5.3 Simulation procedure

6 Test of 12''ultrasonic 5 paths reduced bore meter

The first test was carried out at SPSE test site in Fos sur mer in France, where the Krohne Altosonic V flow meter was calibrated and verified against an uni-directional prover station with a volume of approximately 15m^3 between detector switches. The piping and prover in the test loop had no heat insulation and weather protection. The test was carried out in early February, week 7, in order to minimize the temperature instability which may cause problems obtaining good repeatability and reliable results, particularly for high vicious oil.

The project meter run installed was the following configuration:
Inlet with ISO Tube bundle Flow Conditioner 12", overall length 10D, 150 lbs RF flanges / Flow meter 12", 150lbs RF flanges / SPSE system outlet, length min. 5D, 12", 150lbs RF, see Fig. 6.1.

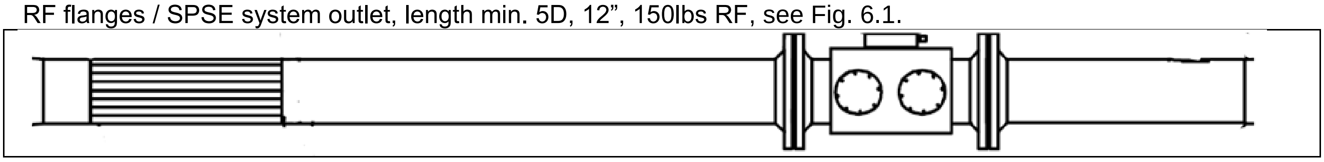

Figure 6.1 Meter run with Krohne Altosonic V installed at SPSE. Tube bundle and 10D spool upstream, and 5 D spool downstream flow meter.

A test plan was set up for week 7 in 2013 by the manufacturer and SPSE. The flow meter was going to be calibrated and verified with the products in Table 6.1. The preferred test points are: 2500 m3/hr – 1925 m3/hr – 1350 m3/hr – 775 m3/hr and 200 m3/hr (200 m³/hr is the minimum possible test flow rate at SPSE prover loop).

Table 6.1 Oil products *planned* for the first test at SPSE

Product	Viscosity (cSt) at 20 ^{o}C and Patm	Density (kg/m3) at 15^{o}C and Patm
Nafta	1.3	750
Oural	5,5	800
Arabian heavy	25	850
Heavy fuel2	350	929

The 3 first days were intended for the manufacturer's standard calibration tests and then the two last days were intended for verification tests. Due to delivery of incorrect heavy oil quality (the viscosity was 450 cSt and the oil minimum pour point was far above the current temperature of 20 ^{o}C) to SPSE test site at the beginning of week 7, the complete test schedule had to be shifted and it became impossible to complete within the 5 days available at SPSE. The incorrect heavy oil was replaced with heavy fuel with viscosity of about 200 cSt. At the end of week 7 successful calibration tests on 4 fluids had been accomplished and a preliminary correction curve and a check sum were established. A final calibration test on heavy oil, about 350 cSt, was done early week 8.

The heavy oil calibration in week 8 resulted in *modified calibration factors* (in low end of Re-scale) and a new check sum. A verification test on this heavy oil was done.

Temperature stability is always a challenge during calibration and verification. The viscosity of the heaviest oil depends strongly on the temperature. Fig. 6.2 shows this relationship for heavy fuel2.

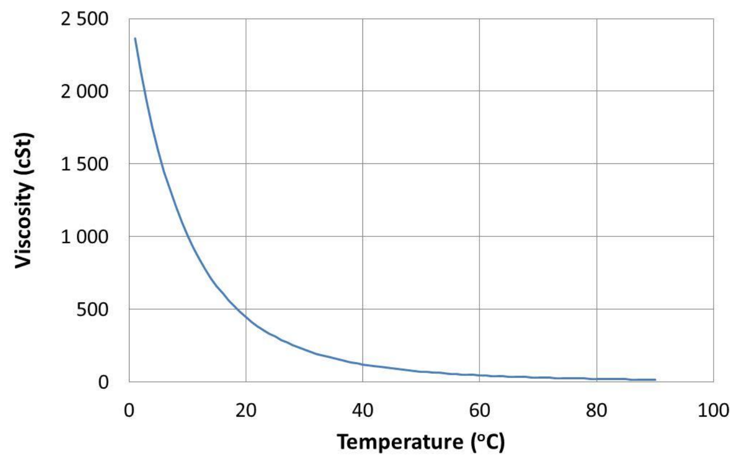

Figure 6.2 Relationship between viscosity and temperature for Heavy fuel2.

The first calibration with original factory setup is shown in Fig. 6.3. Each calibration point is a 3 points calibration (three repeats) with no requirement to repeatability. The Reynolds number range is from 630 Re to 2.2 MRe, and deviation span 2.3% relative reference, the SPSE prover. There is overlap between the calibrations on different liquids for Re > 10 000. This is in agreement with a common understanding that meter performance at a given Reynolds number is the same no matter the combination of flow, viscosity, and meter size. However, this may not be the case in the transition area where the flow changes continuously between laminar and turbulent flow. In the lower Re range, < 10 000 Re, there is a significant deviation between the calibrations, see Fig. 6.3.

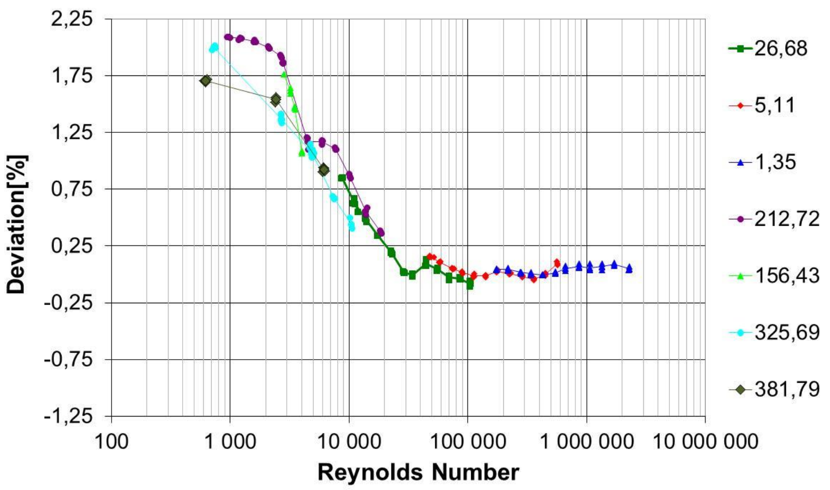

Figure 6.3 First SPSE calibration with original weighting factors.

Verification based on the first calibration is shown in Fig. 6.4. The measurements are within the NPD linearity requirement of 0,3% band. Measurements with different liquids overlap at the same Reynolds number except the heavy fuel with viscosity of 290 cSt. The manufacturer suggested improving the meter performance by using all calibration data and introducing new weighting factors to generate a simulated calibration curve, see Fig. 6.5. In this case measurements with different liquids overlap at the same Reynolds number. Compared to the first calibration curve the simulated one takes an opposite shape at Re below 10 000 Re and ending with a correction of -1,25% at Re equal to 600.

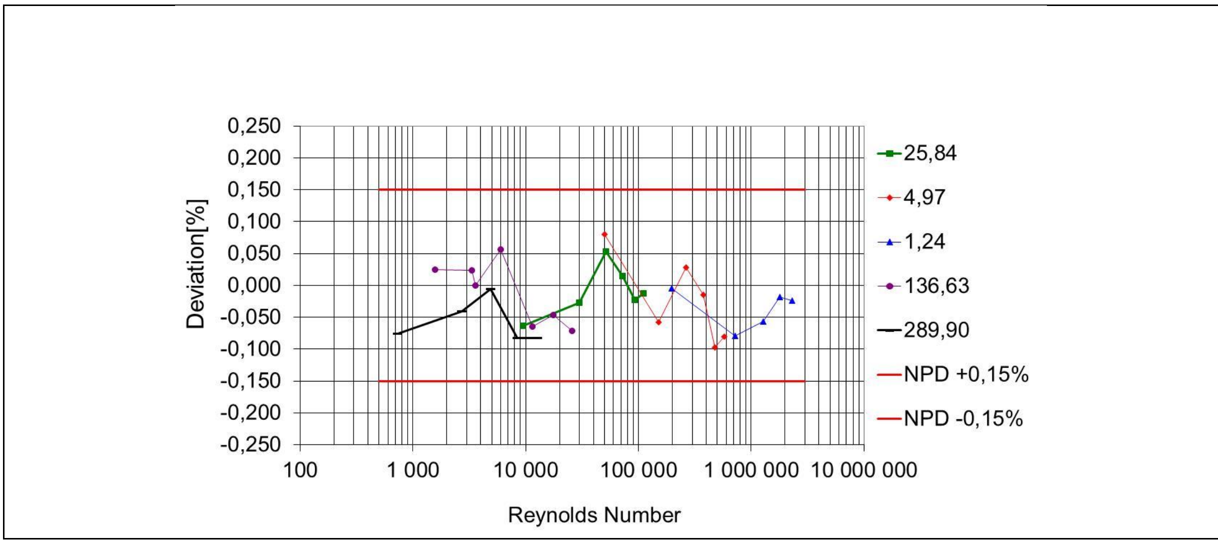

Figure 6.4 Verification with original configuration of the meter, i.e. with the first checksum.

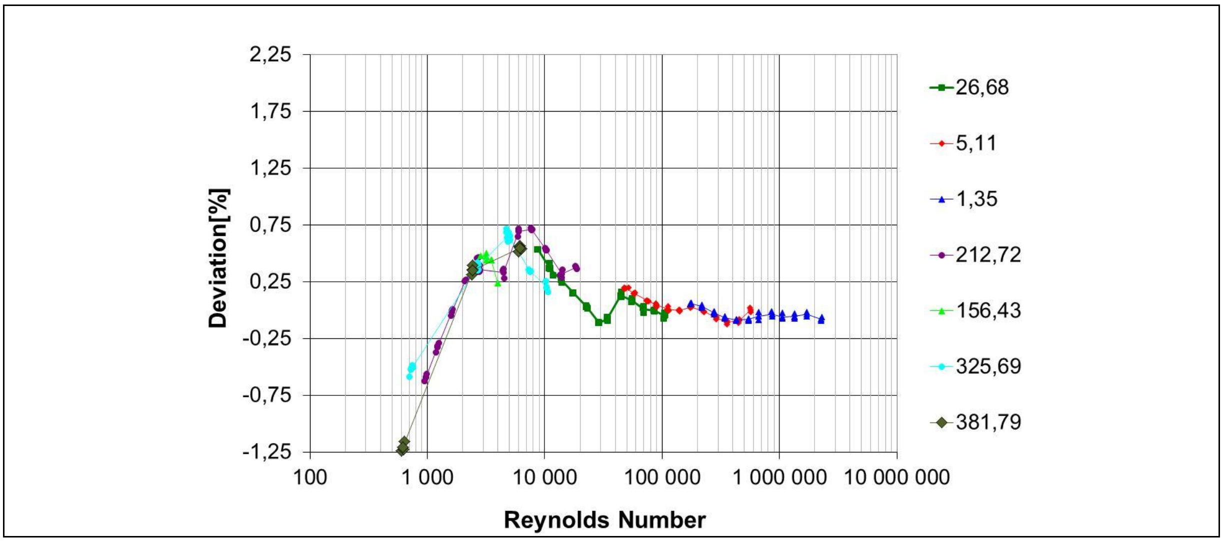

Figure 6.5 Simulated SPSE calibration (correction curve) established by use of modified weighting factors.

A simulated verification of all SPSE data is generated by applying the correction curve in Figure 6.5. The data are processed through Krohne calibration tool and corrected. The resulting simulated verification is shown in Figure 6.6. The corrected data are within the NPD requirements of +/- 0,15%. Despite a significant improvement of the correction curve in Fig. 6.5, with Reynolds number overlap, the new weighting factors and correction curve did not improve the simulated corrected data. The Reynolds number non overlap between different liquids have been moved from low Re area to about Re 8000. The maximum error span between the different liquids is about of 0,2%.

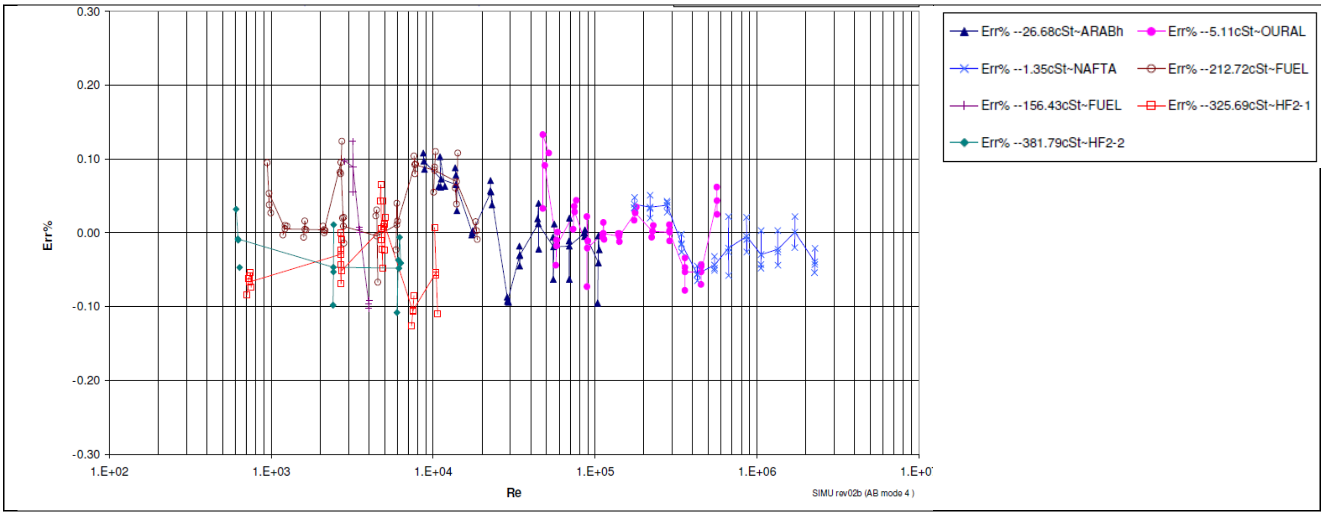

Figure 6.6 Simulated verification based on new weighting factors.

The results so far are within the acceptance criteria for this TQP. However, measurements at lower Re are a challenge and the non-overlap between different liquids called for further testing. A verification with the simulated correction curve, hence the new checksum, test took place at Trapil, France, in week 35 2013. The calibration setup and prover volume are equal to the oils used are listed in Table 6.2. The temperature range was 21-31 ^{o}C which resulted in a broad viscosity range per liquid.

All consecutive verification measurements are shown in Fig. 6.7 and are not sorted as a function of increasing Re. The meter does not fulfil the linearity requirements. It is below the limit at low Re and above at high Re. The result does not resemble the verification obtained at SPSE.

A new calibration, hence third checksum, was established at Trapil. Calibration curve is not shown, but the consectutive verification points are shown in Fig. 6.8. There is a single outlier at low Re for the heavy fuel. No plausible explanation has been found. At higher Re, measurements with gasoline, the meter factor increases gradually and it continues outside the NPD linearity limits. This is also seen in Fig. 6.9 where each data point is a result of accepted proving with minimum 5 repeats. Further investigation revealed coating particles in the oil. The contamination stems from the new coating of the pipeline at Trapil. The coating obviously did not tolerate low viscous oil. Picture of the tube bundle with coating particles seen at the bottom of each tube is shown in Fig. 6.10.

In week 38 Trapil had installed a filter to filter out the paint particles that were found in week 35. When Krohne checked what the filter contained after 2 hours of filtering, it was found that there was hardly any residue. This was mainly due to the fact that the filter had a mesh of approximately 6-7 mm. So the functionality of the filter turned out negligible. The amount of particles found in the pipe in week 38 was less because the liquid was exchanged, but estimated at 50% less than in week 35. Krohne will continue the research on the meter.

Table 6.2 Oil products used at Trapil

Oil	Viscosity (cSt)
Heavy fuel	151-247
Heavy crude	34-52
Domestic	3.5-4.4
Gasoline	0.7-0.8

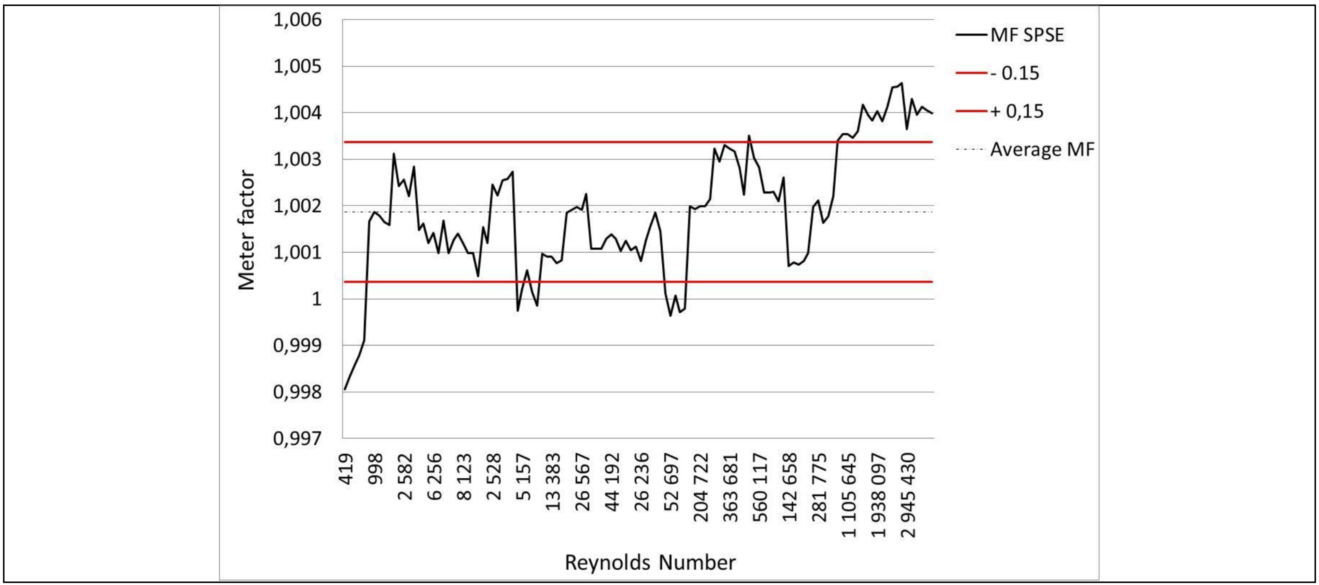

Figure 6.7 Consecutive verification measurements in Trapil with the second checksum, i.e. the correction curve in Fig. 6.5.

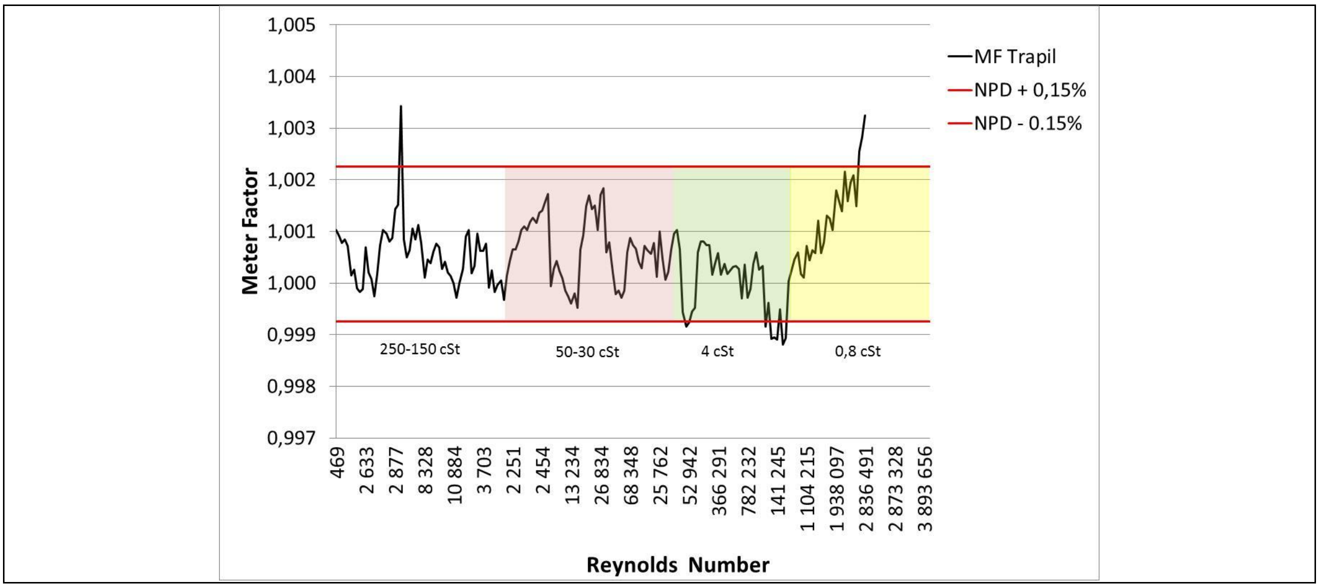

Figure 6.8 Consecutive verification measurements with a third checksum established at Trapil.

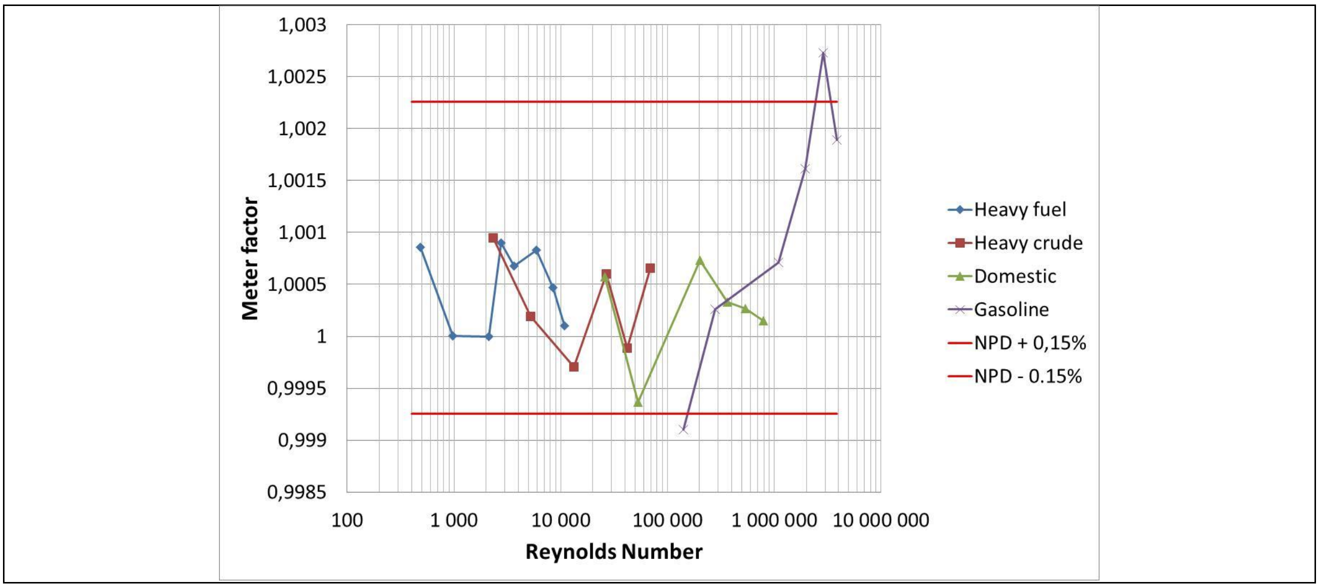

Figure 6.9 Verification in Trapil with third checksum

Figure 6.10 ISO tube bundle with coating particles.

7 Test of 8 paths full bore meter

The second 12’’ meter to go through the technology qualification program is the Smith Meter Ultra8 Liquid Flowmeter from FMC. The meter has 8 ultrasonic paths as shown in Fig. 7.1. The test setup is identical to the 5 paths meter from Krohne with 10D spool upstream and 5D spool downstream the meter. However, in this case the ISO tube bundle has been replaced by a high performance flow conditioner shown in Fig.7.2

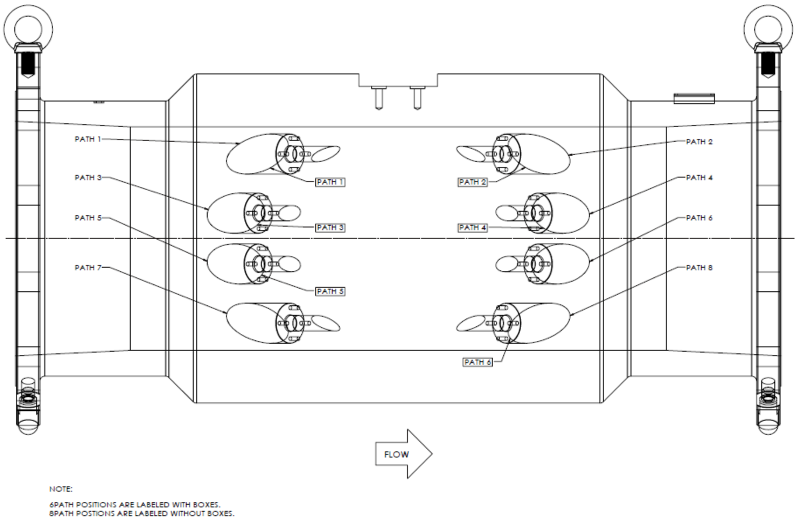

Figure 7.1 8 paths full bore meter.

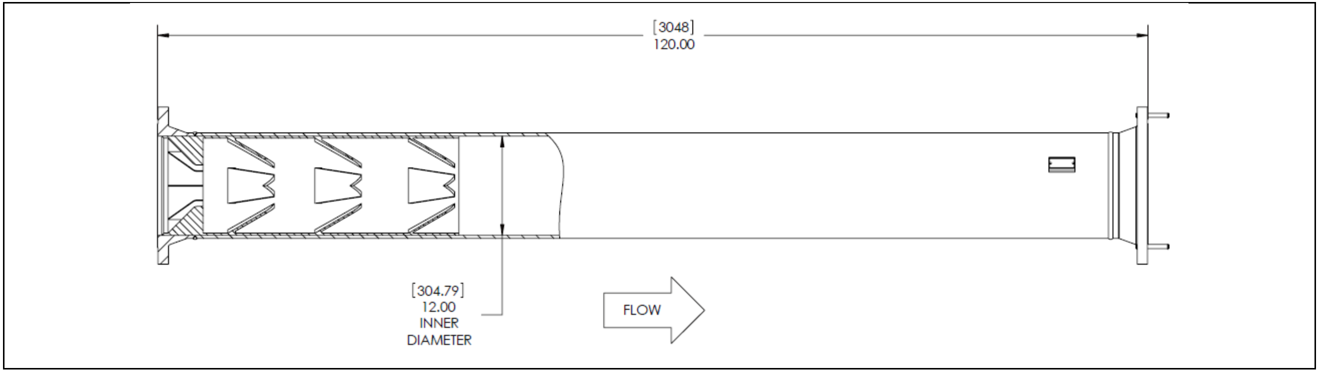

Figure 7.2 High performance flow conditioner.

The flow tests were carried out at FMC Technologies Flow Research and Test Center, Erie, Pa, USA. The calibration laboratory received ISO/IEC 17025:2005 certification August 2012. Traditional unidirectional ball prover is not used. Instead the reference is a master meter prover. Its uncertainty is traceable to an unidirectional fixed piston displacement prover. The latter is calibrated by onsite gravimetric calibration facility. The number of pulses from the master meter per proving run corresponded to a prover volume of 14.1 m3 (89 bbl). According to earlier version of API MPMS Ch. 5.8 this should give 0,027%repeatability from 10 runs for an ultrasonic meter, see Table 7.1. Each flow rate was verified according to the acceptance criteria in Table 4.1.

Table B-2—Suggested Prover Volume For ± 0.027% Uncertainty of Meter Factor

Prover Volume vs. Meter Size			
	5 Runs 0.05%	8 Runs 0.09%	10 Run 0.12%
Meter Size (in.)	Prover Size (bbl)		
4	33	15	10
6	73	34	22
8	130	60	40
10	203	94	62
12	293	135	89
14	399	184	121
16	521	241	158

Table 7.1 Prover volume for USMs, with 0,027% uncertainty from repeatability. Table B-2 from API MPMS Ch. 5.8.

A calibration curve, hence a correction lookup table, was established prior the testing witnessed by Statoil. The calibration curve, shown in Fig. 7.3, has a non-overlap between different liquids at low Re area from 5000-15000. The manufacturer did not respond to this as nonconformity because the meter correction is based off of velocities on the inner and outer paths of the meter along with the bulk average velocity. The non-overlap in Fig. 7.3 may then demonstrate that the velocity profile at a given RE is not unique. The velocity profile correction for the meter in question is shown in Fig. 7.4. This correction curve is based on the same calibration data. The non-overlaps between the liquids are not near as apparent and the “gaps” are minimized. The fine black line is a 3rd order polynomial fit curve.

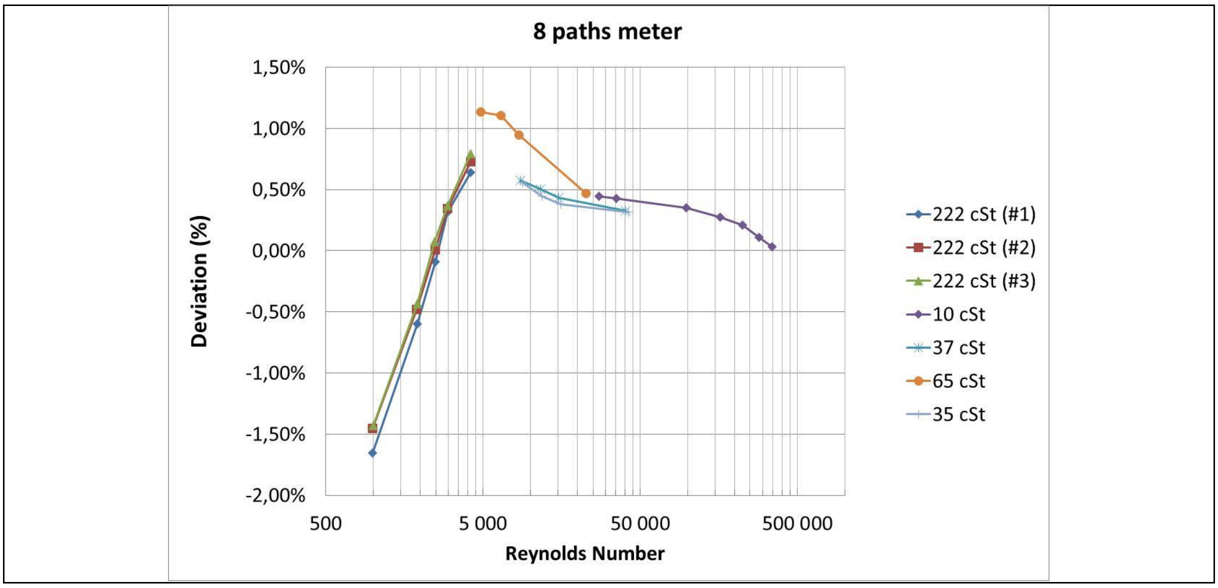

Figure 7.3 Erie calibration of 8 path meter with original weighting factors.

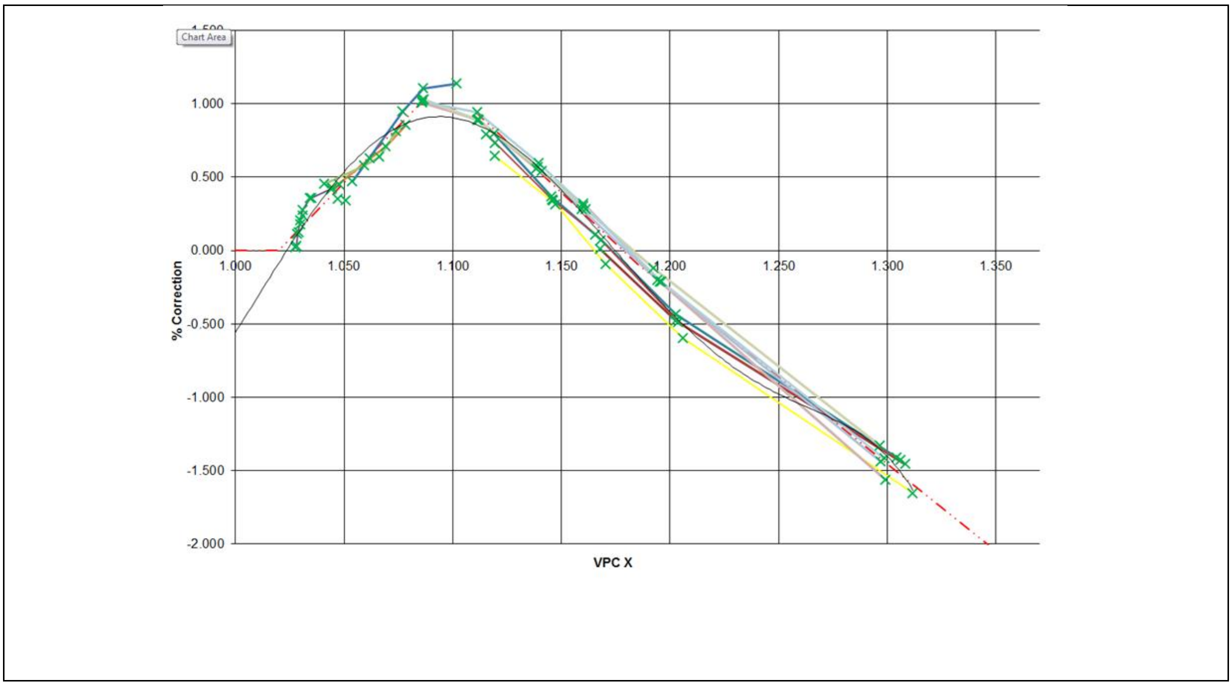

Figure 7.4 Velocity profile correction (VPC) for the 8 paths meter.

Verification of the 8 paths meter was carried out using four different liquids using four liquids with the following viscosity: 2, 11, 35, and 225 cSt. A functional test was performed at a viscosity of 350 cSt. But due to limited chilling capacities, and hence temperature instability at the higher viscosities, the calibration and the following verification with the 350 cSt oil did not fulfil the linearity requirement. A new chiller system is currently being installed which may provide the opportunity to test to uncertainty at higher viscosities.

The verification in terms of accepted provings and in the sequence the tests were done are shown in Fig. 7.5. At 11 cSt, the second liquid used in the verification, the meter span the whole linearity band. The results was unexpected because the measurements with the 11 cSt liquid covers a Re range 30 000-300 000 which is supposed to not be a challenge. The results with the three other liquids are well within the required linearity limits.

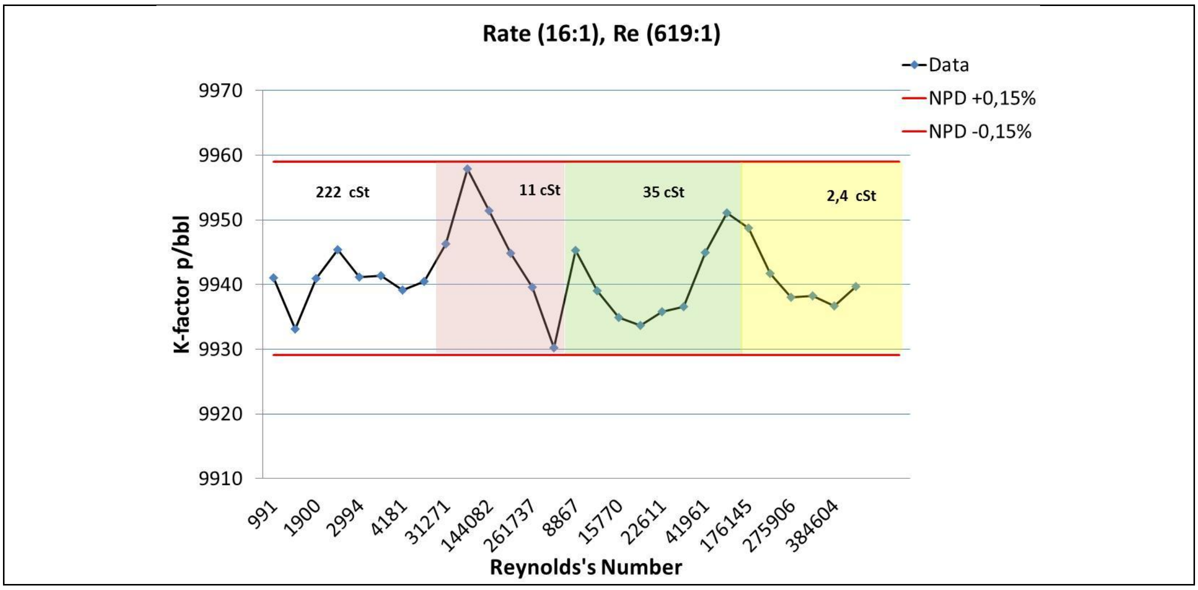

Figure 7.5 Consecutive verification measurements of 8 path meter

Verification of the 8 path meter as function of flow rate and Re are shown in Fig. 7.6 and 7.7 respectively. With respect to Re the verification extends the calibration range. In this case the extrapolation of the VPC was successful. It is not clear if it is the black 3rd order polynomial fit or the red line in Fig. 7.4 that is used at the higher Re.

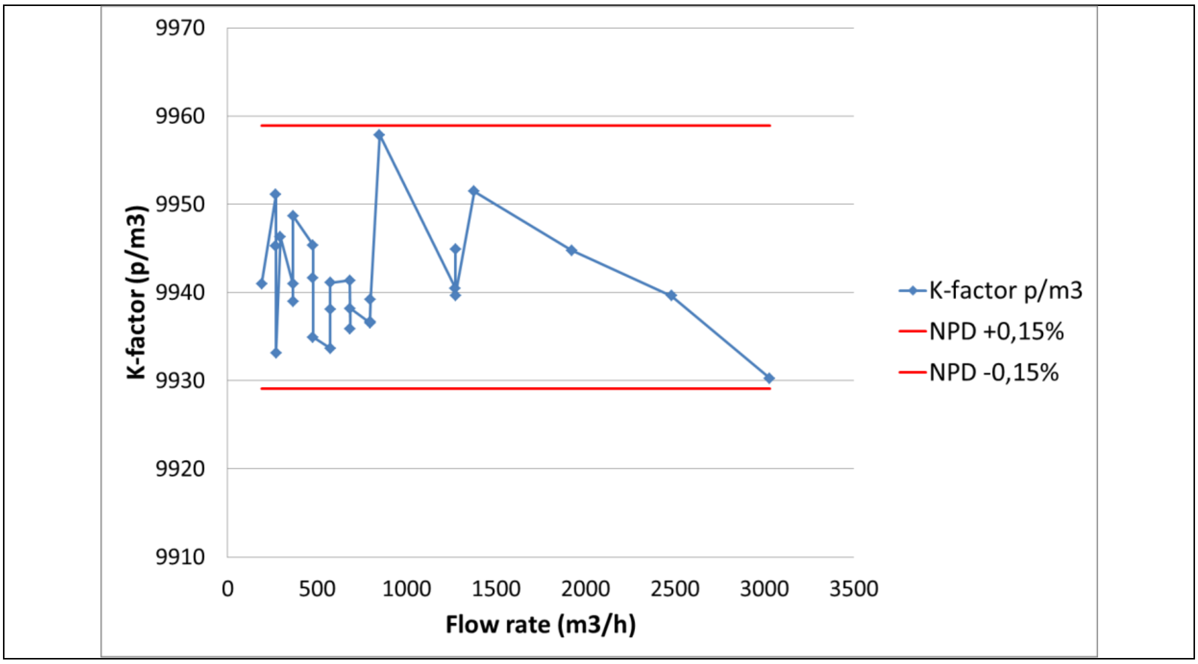

Figure 7.6 Verification of 8 path meter as function of flow rate

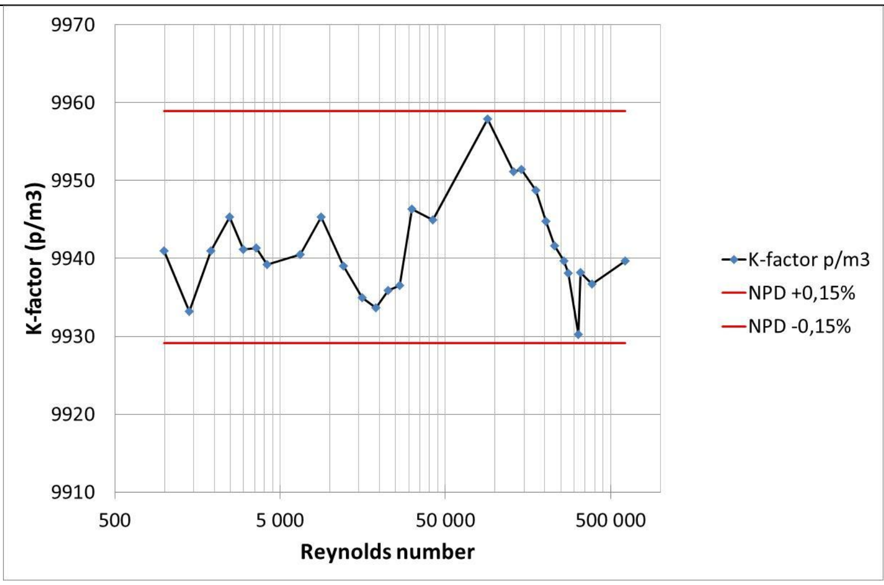

Figure 7.7 Verification of 8 path meter as function of Re.

Verification with the liquids 222 and 11 cSt were repeated with a transducer pair disconnected. Path 3 being close to centre of the pipe was chosen. These measurements are just for demonstration and are not subject to the acceptance criteria in Table 4.1. The meter performance is mainly maintained and follows the trends of the verification. A maximum change of about 0,1% is found at Re=31 000.

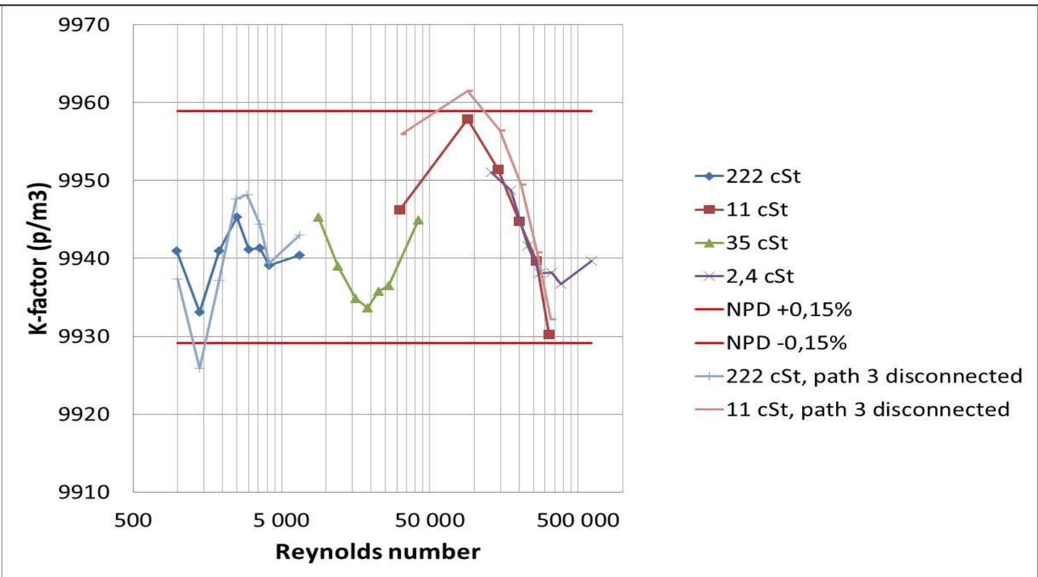

Figure 7.7 Verification of 8 path meter and demonstration of transducer failure, path 3 disconnected.

8 Test of 6 path full bore meter

The Smith Meter Ultra6 Liquid Flowmeter is identical to Ultra8 except that path 6 and 7 are not used, see Fig. 7.1 for path configuration. For this qualification program Ultra6 uses the same calibration (velocity profile correction lookup table) as established for Ultra8, see Fig. 7.4. As expected the verification of Ultra6 follows the main characteristics Ultra8, but Ultra6 is outside the NPD linearity limits and thus failed the qualification. Fig. 8.1 shows Ultra6 and Ultra8 verifications. The results suggest the Ultra6 does not control measurements in the transition area between laminar and turbulent flow in a linear way. Below 5000 Re the meter factor drops significantly. However, the meter has acceptable performance at higher Re and is there within the NPD linearity band of 0,3%, see Fig. 8.2. Above 5000 Re Ultra6 also has a Re overlap between the different liquids, but the overlaps are not as close as the ones found for Ultra8.

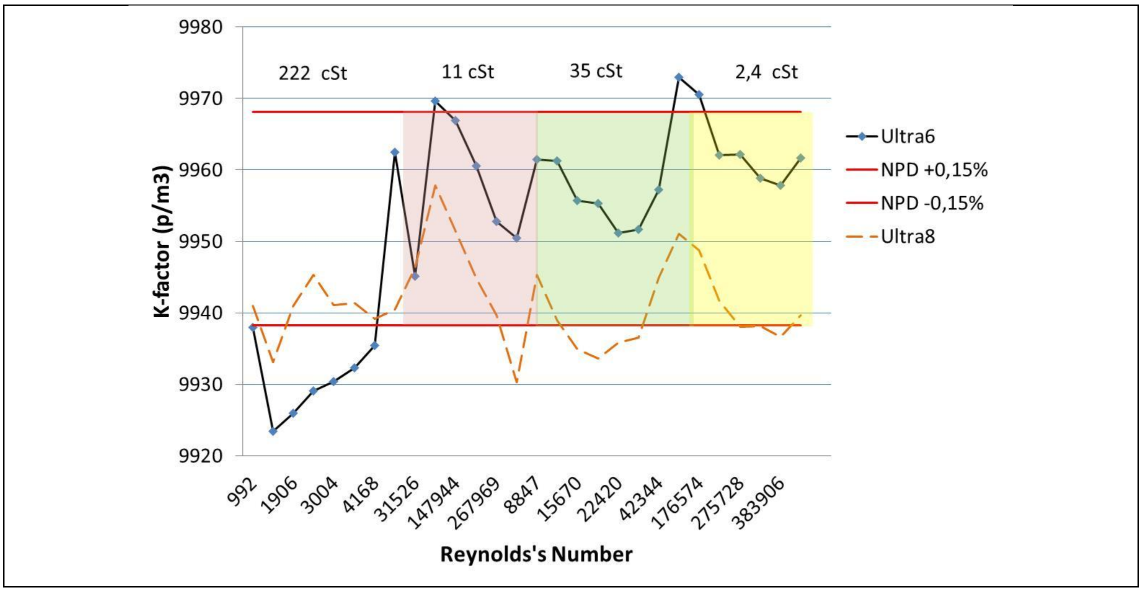

Figure 8.1 Consecutive verification measurements of Ultra6 and Ultra8 liquid meters.

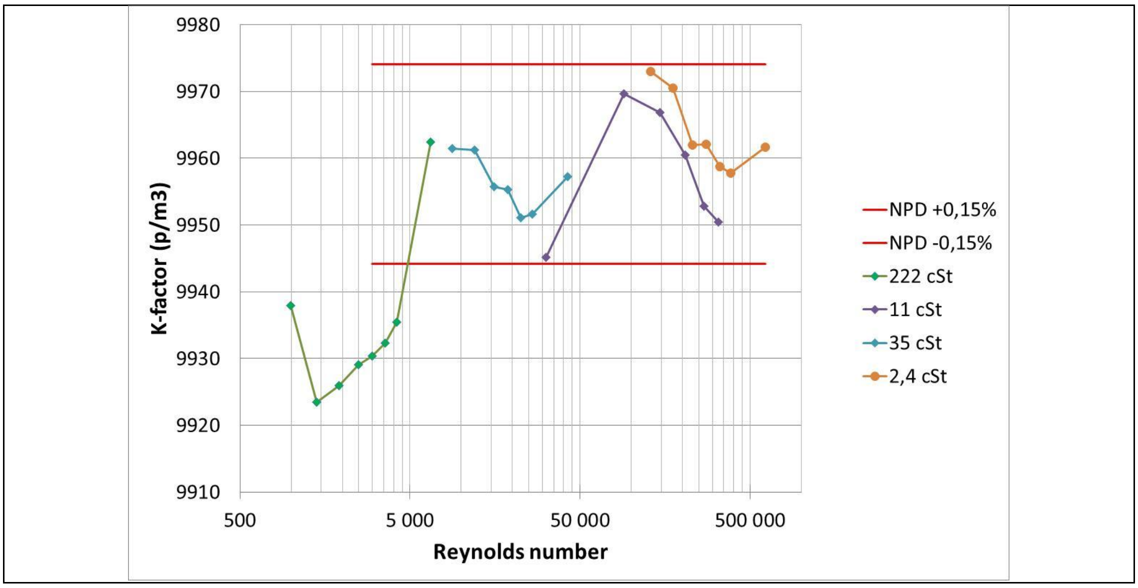

Figure 8.2 Verification of 6 path meter

9 Summary

To carry out a technical qualification program like this one done for Mariner and Bressay project involves access to one or several flow test facilities in order to cover predefined test conditions. There is no known accredited test site which can run continuous and stable testing at the maximum viscosity and flow rates we needed. A common flow test would be ideal so the different flow meters could be tested under exact same conditions. An ultrasonic meter intended for a wide Reynolds range, should be calibrated and verified on more than one liquid and on more than the regular 5 or 6 test flow rates normally required by a customer.

Using a multipath liquid ultrasonic meter in the transient area is possible, but extensive calibration (many test points) is required in order to fit the flow meters for the operating Reynolds ranges. In this project two 12’’ ultrasonic liquid for use on extended viscosity range are qualified for technology readiness level 5. A third tested meter did not fulfil the linearity requirement of 0.3% band over the whole operating range.

The results from this technology qualification program show that a common liquid metering station for heavy crude oil and diluent on Mariner FSU and Bressay FSU is a feasible metering concept.