

Paper 6.2

Field Comparison of a Mechanical and Electronic Custody Measurement Loop for Hydrocarbon Liquids

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1 INTRODUCTION

Metering systems typically use turbine meter(s) and a prover as the primary source of measurement. Both the turbine meter and the prover are mechanical devices – mechanical loop. The performance of a turbine meter changes under various operating conditions and requires regular calibration using a prover for maintaining the accuracy. Mechanical loops are also prone to frequent failures during their life cycle. If the mechanical loop can be redesigned using the ultrasonic meters in a meter/prover combination (master metering) significant improvement can be realized in the operation and maintenance of these critical systems. The main concern is if the electronic loop can provide the same or better level of measurement accuracy while retaining the same repeatability, reproducibility, etc., of the presently accepted mechanical loop.

A number of tests have been conducted on the ultrasonic meter technology for liquids using various configurations and sizes of meters [1], [2], [3], [4], however, the authors have not found any published literature where this technology has been tested in not only comparing directly against the conventional metering system design (mechanical loop), but also the master metering using ultrasonic meters (electronic loop) within the same system with synchronized batching and proving. This type of configuration allows for various types of comparisons to be made with the 2 loops – proving a meter using the conventional prover and master metering using the ultrasonic meter to determine the meter factor, etc.

The field setup is comprised of a 20-inch turbine meter, two 20-inch ultrasonic meters and a 42-inch prover. The control system include each meter having its own flow computer with supervisory integrating the measurement functions for synchronized testing.

This paper discusses the system design and compares test results between a conventional custody metering system design (mechanical loop) and an electronic master metering loop. The mechanical and electronic loops were designed in the same system and tested with synchronized batching and proving to allow direct comparison of the conventional loop and master metering (ultrasonic as master) with ultrasonic to ultrasonic and ultrasonic to turbine meter. This design enables testing of all the meters within a closed loop along with a prover being subjected to the same operating conditions and synchronized in performing the measurement functions.

2 PHASE 1 TESTING OF ULTRASONIC METER

Initial tests conducted on this technology were with a turbine and a single ultrasonic meter connected to an online prover. The setup was designed to perform synchronized batching and proving. The control signals for starting and ending batches and proving was with the turbine meter/prover loop. The ultrasonic meter performed its tasks through activation signals from the turbine/prover metering control system.

Fig.1 provides the basic layout arrangement of measurement system setup used in phase 1. The test was performed at one of Saudi Aramco's operational facilities. Modifications to existing meter streams in the field and the metering control system were done to setup the test system. A separate test measurement system was developed to capture the data; however, master metering had to be activated manually in the test measurement system.

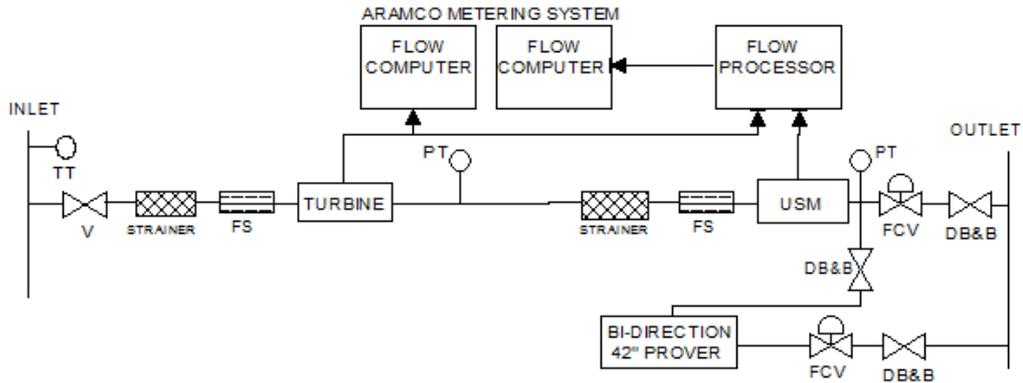


Fig. 1 Measurement system setup for phase 1 test

The primary purpose of the test was to verify the vendor's claims for this technology, in particular:

- Viscosity independent (no need for multi-product calibration)
- No need for frequent calibration
- High accuracy, repeatability and reliability
- Low pumping costs
- Low maintenance costs

If the above can be achieved, this technology would certainly improve some aspect of the widely accepted mechanical loop.

2.1 Viscosity Independent Test

The meter was tested with four types of crude (Arabian Light, Arabian Extra Light, Arabian Medium, and Arabian Heavy). The API range for these crudes is from 26.5 – 38 with a viscosity of 41 – 230 Centistokes at 70 Deg F.

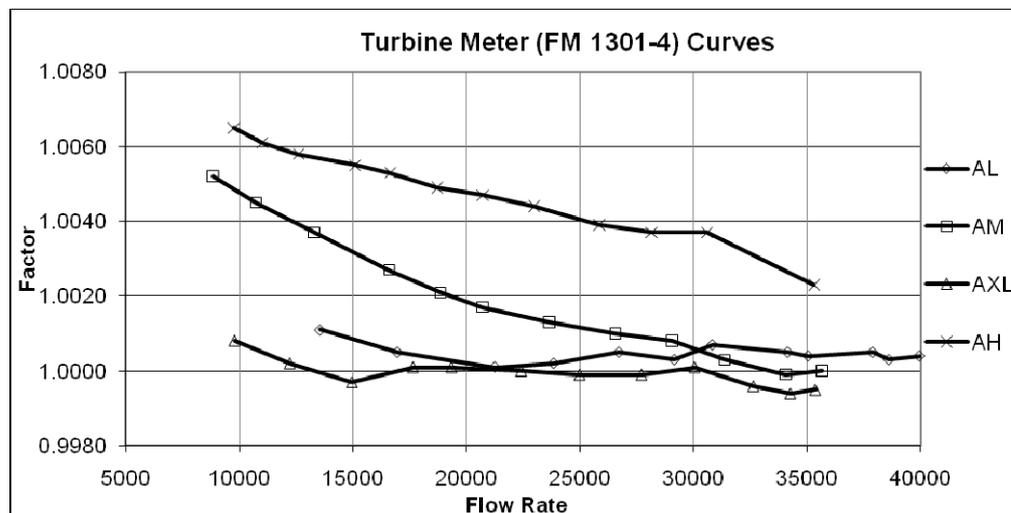


Fig. 2 Turbine meter calibration curves using online prover

Fig. 2 shows the calibration results of the turbine meter for the four types of crude oils. It can be seen from Fig. 2 the turbine meter shows variation in its performance with the different types of crude oils.

Fig. 3 shows the calibration results for the ultrasonic meter for the four types of crude oils.

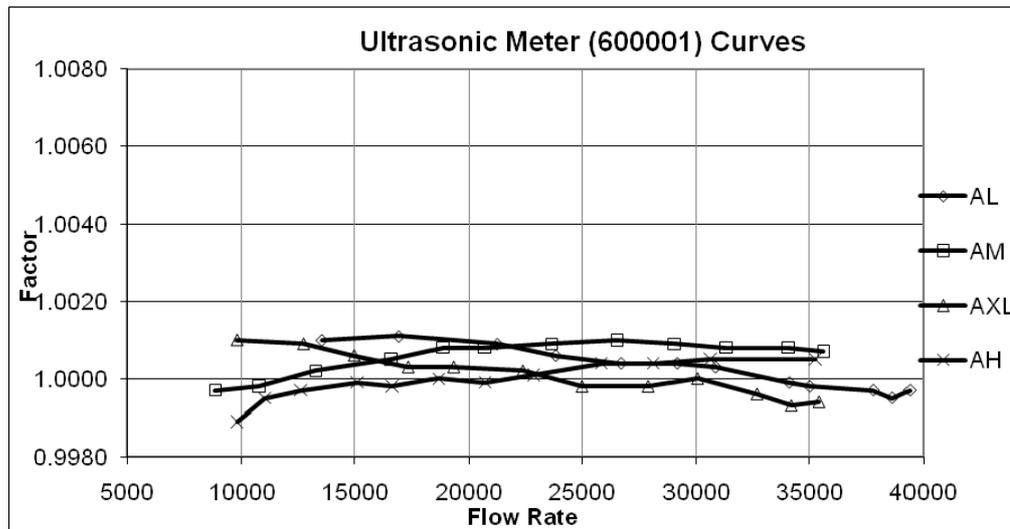


Fig. 3 Ultrasonic meter calibration using online prover

Comparing the results of Fig. 2 and Fig. 3, It can be seen that while the dispersion in the curves for the ultrasonic meter are less than the turbine meter, it cannot be stated that the meter's performance is exactly the same for all types of crude oils. This is after the ultrasonic meter was calibrated for the range of crudes to be measured at a calibration facility.

This test, which was repeated three times during the testing period of about two years for phase 1, shows that the ultrasonic meter will need to be calibrated for the types of liquid to be measured on-site. This is certainly the case found for Arabian crude oils.

2.2 No Need for Frequent Calibration

The most important aspect of the measurement process to which this technology can make a major contribution is in alleviating the frequent calibration of the primary sensor. The turbine meter works happily for several years as long as it is proved continuously for maintaining the accuracy in measurement. There are facilities with large number of meters for the custody transfer measurement; the prover can be used several times a day. The prover being a mechanical device is prone to failure demanding major operational effort to repair and bring back to service. The repair of such devices can take weeks/months depending on the type of failure. This is one of the major setbacks for this widely accepted turbine/prover measurement loop.

If the ultrasonic meter can provide the same or better levels of accuracy, reproducibility, repeatability and reliability, the frequent use of the prover can be reduced.

As the turbine and the prover loop is an acceptable worldwide standard, it is reasonable to use it as a reference in comparing it against any new technology which is looking to replace it. Tests to verify this aspect compared:

- Turbine/prover standard volume (GSV) with USM ISV
- Turbine/prover standard volume (GSV) with USM GSV using historical curve
- Turbine/prover gross standard volume (GSV) with USM GSV online proving

The first option is basically testing the idea that once the ultrasonic meter is calibrated at a calibration agency, there is no need for any further calibration. It will perform accurate measurement without the need for any reference prover to correct the meter performance. The first option failed to satisfy, based on results from Section 2.1.

The second option is basically to have the meter calibrated using a reference prover to develop a correction curve for each liquid being measured. The ultrasonic meter is then used only relying on this historical curve without the need for online prover correction.

If this second option could satisfy, this would imply the meter can be used without having an online prover or if the online prover was necessary then maybe reducing its frequent use.

Fig. 4 shows the results obtained using this comparison. It can be seen that the ultrasonic meter came very close in measurement to the turbine/prover loop when using only the historical calibration curve.

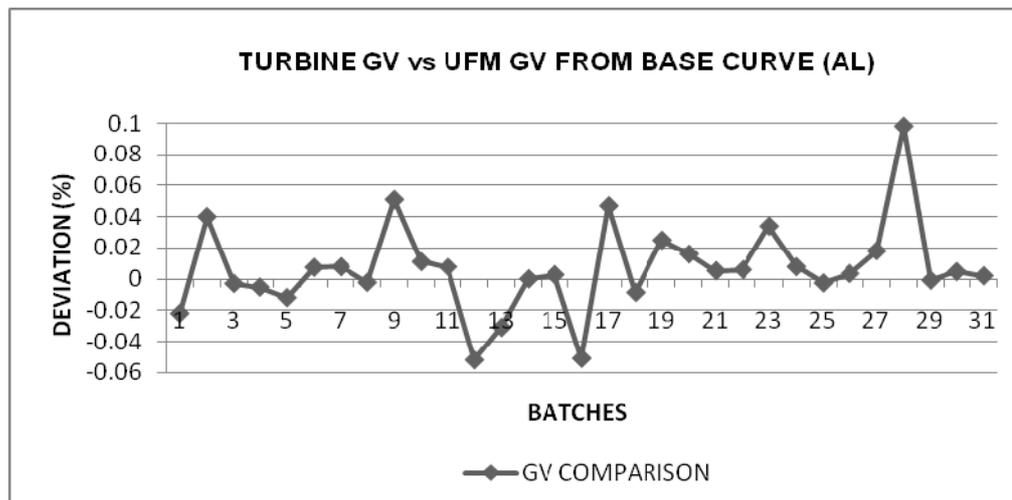


Fig. 4 Turbine/Prover GSV compared with USM GSV using base curve

While there was insufficient data and a point which is questionable, in the main the results provided some confidence in continuing the testing on this technology.

The third option was to use the ultrasonic meter as a direct replacement of the turbine meter in the mechanical loop keeping the prover. The third option has been approved in the API Chapter 5.8 [5].

The repeatability, reproducibility and reliability factor for the measurement process has to be tested.

2.3 Repeatability during Proving of the USM

There have been concerns on the repeatability requirement when proving this meter to generate a meter factor. API Chapter 5.8 [5] provides guidelines on meter size, prover volume, number of runs and repeatability criteria. While API has not stated the meter size and volume used in this test, Fig. 5 shows good results during phase 1 testing.

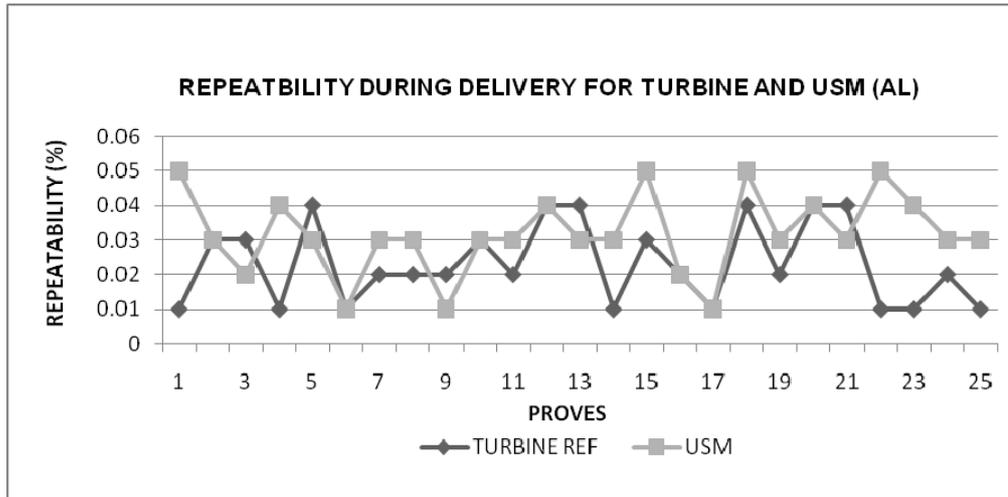


Fig. 5 Repeatability of the meters when proving with an online prover

3 PHASE 2 TESTING OF ULTRASONIC METER

Phase 1 testing provided some encouraging results prompting the continuation of testing the ultrasonic meter; however, there was a need to expand the types of tests to be performed in phase 2. Further tests needed to be performed to see the possibility of reducing the frequent use of the prover in the transfer process. This would imply reducing the usage of the prover, but remaining online. The ideal scenario would be to remove the prover from online to a centralized location. The ultrasonic meters can be calibrated using this centralized prover to develop performance curves for each liquid to be measured based on option 2 of Section 2.2. However for such a scenario, there is a need to check if the meters on duty continue to perform accurately. This can be achieved by having a check meter (master metering) using a second ultrasonic meter in a master/duty arrangement with both meters calibrated against the same reference.

The phase 2 testing will still require batching and proving to be performed using the prover as a reference on all three meters and in addition will have the ability to perform master metering to check the behavior of the turbine and the second ultrasonic meter using one of the ultrasonic's as a master. If we can perform parallel batching and master metering, this will provide us measurement from two different loops (mechanical and electronic) to compare their performances.

3.1 Testing the Design at a Calibration Agency

It was agreed with the manufacturer from the outset that this type of arrangement has to be tested at a calibration agency to gain some confidence in the results prior to installing on site. The test was setup at SPSE in France. The turbine meter from Saudi Aramco was sent to SPSE along with the two ultrasonic meters. Due to heavy usage of the calibration facility, a window was booked for testing the design. It was agreed that such testing would provide a good reference for the design to work in the normal day-to-day operation.

Several tests were performed on liquids with similar viscosity ranges to those to be measured in the field. The test performed at SPSE showed good results and provided some confidence the setup would at least provide a reasonable basis for testing the design.

3.2 The Field Setup View

The test setup is believed to be unique both in terms of size of the equipment being used and the types of tests being performed in a synchronized manner. Fig. 6 shows an overview of the field setup. The new loop is shown here



Fig. 6 U-Shape arrangement with three meters in series

It can be seen in Fig. 6, the mechanical engineering necessary to design and install the loop. The U-Shape comprises of three * 20 inch meters (one turbine and two ultrasonic). The existing meter stream was modified to fit this design into the same flanges that previously held the turbine meter stream. The structure connects at both ends of the previous meter stream, only now with three meters in series. The 42" prover is the second U-Shale below.

The phase 2 test loop design meets API requirements for each meter installed. Any liquid flowing in the line will flow through all 3 meters. There is no other path for the liquid to go. As can be seen considerable design modifications were required to not only setup the test but to install the new loop. This is on an offshore platform.

This unique design will provide a good basis for testing this technology

3.3 The Measurement System Setup

The mechanical loop designed for this setup allows liquid to flow through all the meters. This will ensure each meter will see the same liquid to be measured. However, to perform the various measurement functions, this has to be designed into the metering measurement/control system.

It was decided from the outset that the official delivery to ships was to be performed by the Saudi Aramco metering control system. In other words, the turbine/prover combination measurement functions will be performed by the Saudi Aramco metering control system. The start and end batching commands, proving, etc. are all to be performed by the Saudi Aramco metering control system. This will ensure there is very little impact on the normal daily operations. A separate test measurement system is to be setup that will use the various signals from the Saudi Aramco system to perform the required functions as a shadow – namely batching, proving, master metering, etc. and all to be performed automatically. The test measurement system will work independently while the loop is being used in any custody transfer. The field signals are shared between the two systems.

A separate panel was designed comprised of flow computers, manufacturer flow processors, and metering supervisory to integrate the complete test measurement requirements of batching, proving, master metering independent of the official delivery system.

Fig. 7 shows the architecture of the test measurement system. The system uses flow computers for performing the various measurement tasks. Each meter has its own dedicated flow computer.

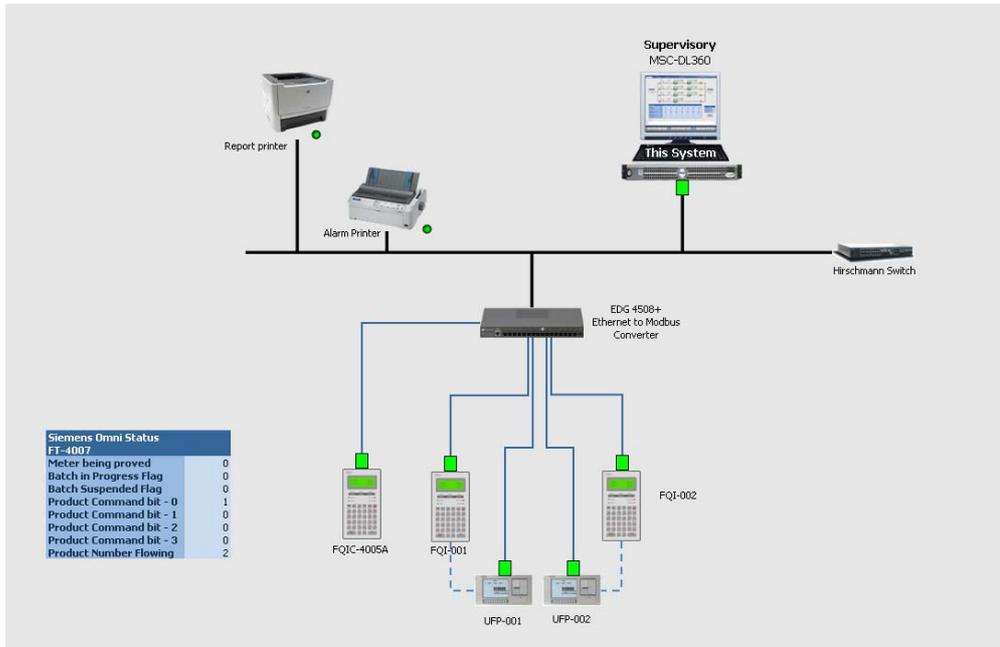


Fig. 7 Measurement system setup

The control of the loop is under the Saudi Aramco metering control system. The setup initiates data collection as soon as the loop is open for loading. Any liquid flow is captured by the three flow computers. Certain data from the Saudi Aramco system is copied by the test measurement system like batch number, etc. as shown in Fig. 8

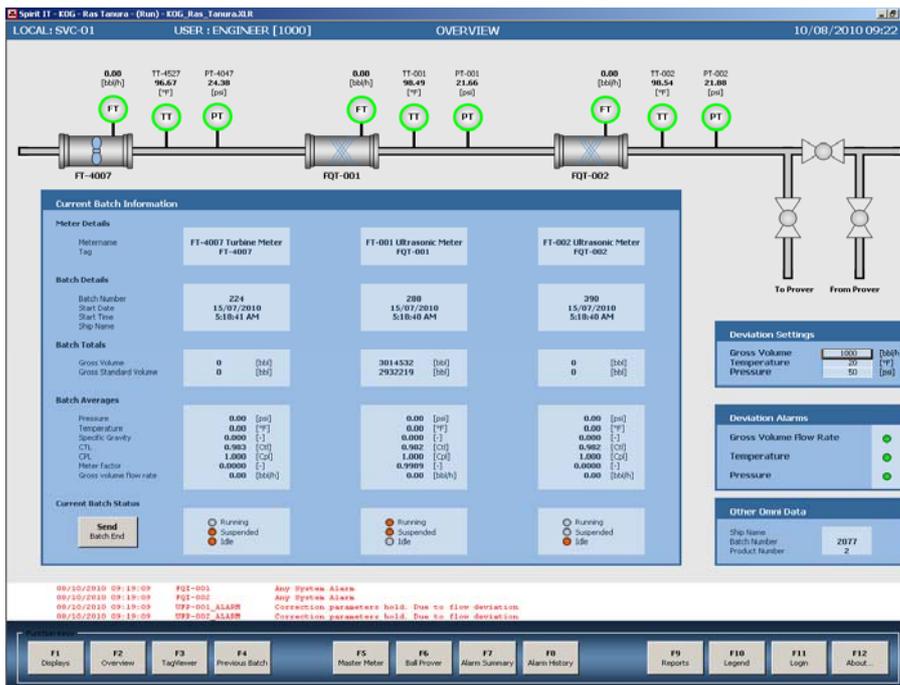


Fig. 8 Batch data for the 3 meters

Proving is performed on all three meters once in a batch. However, the system is setup to perform master metering every two hours in a batch. This will enable data to be collected showing the performance of the meters during the complete batch.

The system enables us to prove a meter using the conventional method and repeat the test using master metering. This will enable comparison of each meter performance as stated by the prover and the master metering method.

Initially, the master metering arrangements were such that the turbine would act as a master. However, this was changed with one of the ultrasonic meters dedicated as a master checking the turbine and the second ultrasonic meter. The prover will provide the performance of all three meters.

3.4 Types of Tests to be Performed

The primary goal for testing this technology is to establish whether it can perform to the same level or better than the accepted mechanical technology that has been going strong for the last 50 plus years. Despite considerable testing to date on this technology, a clear path has not been adopted.

The design adopted in this paper as stated above allows a number of tests to be performed as a direct comparison which to the best of the authors' knowledge has not been performed elsewhere in the world. This setup provides various scenarios to be tested between the conventional turbine/prover and the master metering arrangement within the same batch with full assurance that all the measurement devices are seeing the same liquid. This will provide a direct comparison of what is being reported in terms of volume or meter performance, etc. by the currently accepted loop (mechanical) and the master metering loop (electronic loop). We will be able to see what each is reporting with the hope they will be the same or if not, it will provide a basis for investigating their differences.

Typically the tests will be:

1. Proving using the ball prover on the three meters
2. Batching with volume comparison of turbine/prover vs. USMs (ISV, GSV using historical curve, GSV using current proof).
3. Master metering with USM as master on turbine and second USM.
4. Prover on three meters vs. master metering
5. Volume comparison from both loops

This will provide ample data for the various comparison tests on the performance of the presently acceptable turbine/prover (mechanical loop) and the master metering using ultrasonic meters (electronic loop).

4 THE TEST SYSTEM COMMISSIONING

The test system was commissioned in February 2010. Considerable effort was required from Saudi Aramco personnel to design and install the measurement loop as shown in Fig. 6. Dedicated support was provided from the manufacturer during this phase of the work and in the installation and commissioning of the test system. As expected, there were some logistical issues, system issues, etc. that needed to be resolved.

The test system was finally commissioned successfully. During commissioning, some additional modifications to improve the test system design were proposed. Some of these were addressed during commissioning and others were developed and installed at a later date.

There have been some logistical issues that have prevented us from setting up the complete system for the data collection phase. These are being addressed. It is envisioned additional

data to what is being presented will be available prior to the submittal of the presentation material.

5 INITIAL RESULTS

The sections below provide preliminary results from the test setup at Saudi Aramco.

5.1 Ball Prover Results

At this stage of the testing, only a limited data set has been captured. Fig. 9 gives the proving results of the three meters under test for Arabian Light crude oil. The data shows the turbine meter in need of larger correction as stated by the prover. This is in line with the known performance of this meter for this type of crude oil.

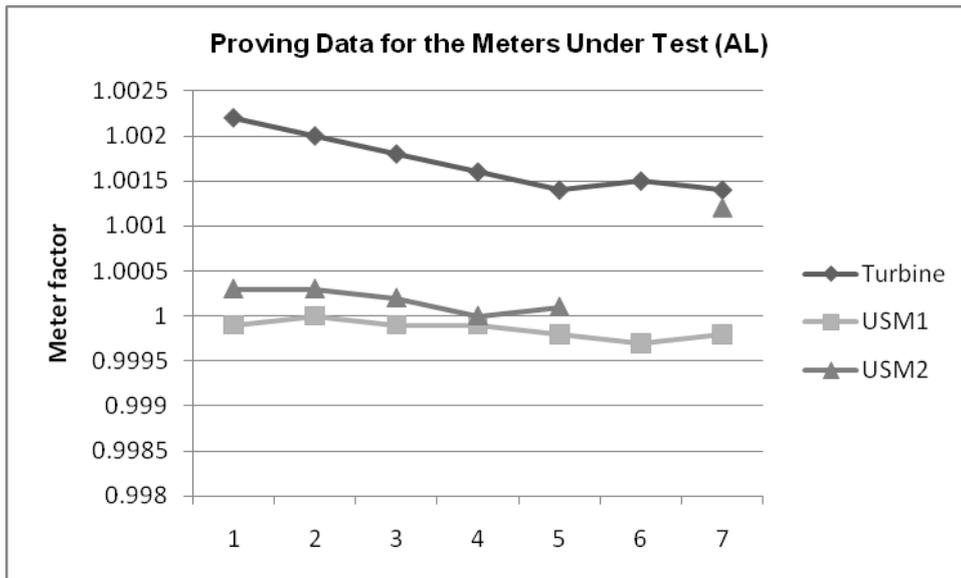


Fig. 9 Proving results for the three meters under test

Fig. 9 also shows the prover stating that the two ultrasonic meters are very close to reporting the actual flow without needing much adjustment. This would imply the reported standard volume of the two ultrasonic meters without any prover influence will be close to the delivered volume while the turbine will have to be adjusted using the meter factor accordingly. It will be shown in a later section how these are reflected in the final volume delivered.

5.2 Master Metering Results

Fig. 10 shows the master metering of the turbine meter as a master over the ultrasonic meter. Our expectations are to see how this links with Fig. 9 above since it is for the same crude type. We would expect to see the same result for Arabian Light from this testing as was seen from Fig. 9. Unfortunately, the data collected for this test was at a much higher flow rate than in Fig. 9 and hence a direct comparison cannot be made. However, it does show about a 0.5% change in the slope which is a concern and needs to be investigated.

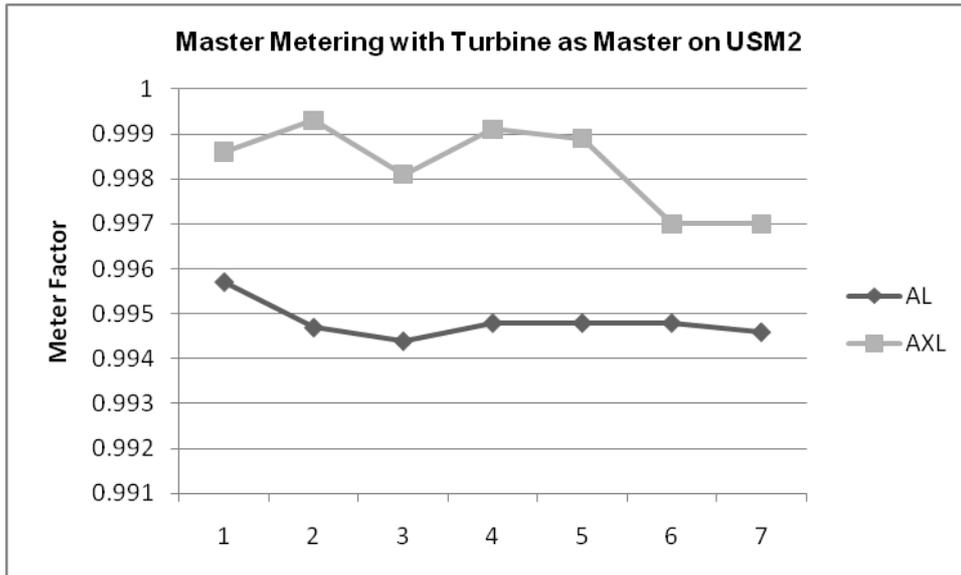


Fig. 10 Master metering turbine on USM

Table 1 shows the meter factor reported by the master meter method with USM 2 as the master on the turbine meter. For the same turbine meter using a prover for the first flow rate, the meter factor reported by the prover is 1.0018. This amount to a difference being report by the two loops of 0.05%. This is an encouraging result for the test setup.

Table 1 – Master metering USM 2 (600001) as master on turbine for AL

Flow Rate	11,122	11,262
Meter Factor	1.0023	1.0019

The master metering of one ultrasonic on another is presented in Fig. 11. It can be seen from the scatter the variation in meter factor. The change for Arabain Light crude is around 0.05% and for Arabian Extra Light is about 0.129%.

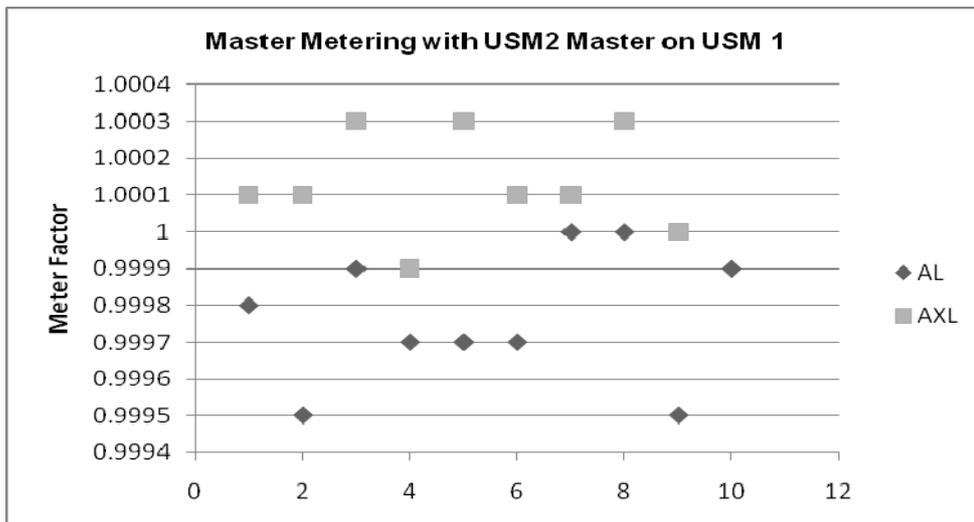


Fig. 11 Master metering with USM on USM

5.3 Batching Results

Table 2 and Table 3 represents a comparison of the gross standard volume being reported by the turbine/prover combination being compared with each USM indicated standard volume (no prover adjustment), the USM gross standard volume with prover meter factor applied and in one case USM gross standard volume with master metering meter factor applied.

Table 2 – Turbine/Prover GSV compared to USM 2 (600001) for AXL

Batch Volume Size	159,640	131,998
Indicated Standard Vol.	- 0.046%	-0.03%
Gross Standard Volume – Proving Meter Factor	- 0.136%	-0.13%
Gross Standard Volume – Master Metering Meter Factor		

Table 3 – Turbine/Prover GSV compared to USM 1 (25821210) for AXL

Batch Volume Size	159,640	131,998
Indicated Standard Vol.	+ 0.05%	+0.03%
Gross Standard Volume – Proving Meter Factor	-0.025%	-0.13%
Gross Standard Volume – Master Metering Meter Factor	-0.005%	

In reference to Tables 2 and 3, it can be seen for the case of the first batch, the uncorrected volumes for both meters are in close agreement; however, when they are corrected by the meter factor from the prover, the final volumes differ considerably. However, the same is not true when the master metering meter factor is applied to the final volume. In this instance, the final volume is much closer to the delivered ship value. Clearly something is not quite right and will need to be investigated. However, in the case of the second batch, both meters are in very close agreement to each other, but the result of applying the prover meter factor degrades both meters results equally.

Table 4 and 5 shows both meters reported volume to be different by an unacceptable amount from the turbine/prover reference volume for the Arabian Light crude. The master metering improves the result in the case of the second batch. This will need to be investigated.

Table 4 – Turbine/Prover GSV compared to USM 2 (600001) for AL

Batch Volume Size	268,516	81,345
Indicated Standard Vol.	- 0.289%	-0.268%
Gross Standard Volume – Proving Meter Factor	- 0.3%	-0.268%
Gross Standard Volume – Master Metering Meter Factor		-0.089%

Table 5 – Turbine/Prover GSV compared to USM 1 (25821210) for AL

Batch Volume Size	268,516	81,345
Indicated Standard Vol.	-0.265%	-0.237%
Gross Standard Volume – Proving Meter Factor	-0.24%	-0.21%
Gross Standard Volume – Master Metering Meter Factor		-0.058%

Tables 6 and 7 provides comparison of batching data between the two ultrasonic meters for various size batches. It can be seen that there are consistently coming close to each other for the two types of crude being measured.

Table 6 – Comparing ISV of USM 2 (600001) to USM 1 (25821210) for AL

USM 2 (600001) Batch Size	186,625	267,739	199,177	195,845
USM 1 (25821210) Batch Size	186,722	267,804	199,207	195,889
Deviation %	-0.052%	-0.024%	-0.015%	-0.022%

Table 7 – Comparing ISV of USM 2 (600001) to USM 1 (25821210) for AXL

USM 2 (600001) Batch Size	159,567	131,958	59,033	233,992
USM 1 (25821210) Batch Size	159,648	132,038	59,049	234,050
Deviation	-0.05%	-0.06%	-0.027%	-0.025%

6 SUMMARY

The results reported in this paper were obtained from the test measurement system with the loop being used for official deliveries to ships. The turbine meter and the prover are used for billing purposes, while data from the ultrasonic meter for the same delivery is used for the comparison tests. As stated, a parallel test measurement system performs all the required measurement functions and collects and archives the data. This test measurement system has no control over the measurement loop and performs all the necessary functions as a shadow system to the one being used in the official delivery. It performs these functions automatically without the need of any manual intervention. The operation staff use the turbine meter as they have done in the past. The difference now is that we have three meters in the same loop that are reporting to the test measurement system.

Some positive results were obtained from phase 1 testing of this technology as is reported in Section 2 of this paper. We have shown the ultrasonic meter while not impacted in the same way as the turbine for the different liquids to be measured, is never the less not totally linear for the types of liquids for which it was tested. This implies the need to calibrate the meter on-site for the liquids for which it will be used for measurement. This was despite being calibrated for the range of liquid viscosities at a calibration agency.

In Section 2.2, it was shown that the ultrasonic meter cannot be used by itself without a prover. However, there are some encouraging results when the meter is used with only a calibration curve and not having the prover correct its performance online as is the case with the turbine meter. The testing for this aspect will be closely observed. From the results, it is quite feasible one of the options will be acceptable; either reduce the prover usage while being online or remove it to a central location and only use the historical curve. In either case, it will provide significant benefit over the current scenario of having to use the prover every batch.

The proving repeatability of these ultrasonic meters has been highlighted in many publications including API Chapter 5.8 [5]. The data provided in [5] does not cover the meter/prover size being used in this test; however, [5] states that the number of runs required are far greater than what has been achieved in this test as shown in Fig. 5. This is a subject of further investigation.

The test measurement setup is unique both in terms of the size of meter being tested and types of tests being performed. It is hoped the results obtained will help to decide the use of this technology in the best configuration – without the direct need of mechanical prover. However, it is early to make any predictions.

The test measurement system has been commissioned and while some results have been reported, considerable more data needs to be collected on the various types of tests being proposed in this paper.

From the limited data available, it can be seen the prover is reporting the turbine meter in need of large correction, more so than the ultrasonic meters. This is in line with the results found in phase 1 as shown in Fig. 3.

The master metering of the turbine meter using one of the USM also shows close reporting of the meter factors between the mechanical loop and the electronic loop. However, due to only a couple of points being available, it is difficult to make any judgment. This will be followed closely as it is a critical test.

The master metering of ultrasonic meters show how close they are reporting their performance. This is to be expected and over the testing period will help in deciding if the master metering is adopted, and how to establish controlling limits when checking master/duty meters.

Tables 2 -7 provide various batching data. It is clear from these the ultrasonic meters are reporting volume close to each other, but not necessarily close to the reference loop which is the turbine/prover. One point that has been observed is while the prover is stating the ultrasonic meters are over stating their volume, the final batch value does not reflect this. This is one of the reasons when a prover correction is applied the final result is degraded rather than improved. This is another point that needs to be investigated.

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