IN-SITU VALIDATION OF USM BASED ON SPEED OF SOUND COMPARISON USING NON-FLOWING NATURAL GAS

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ABSTRACT
This paper describes a method of validation of Ultrasonic Flow Meters (USM), which does not require their removal from the pipeline. The test gas is the natural gas metered under normal operating conditions. The paper describes the pipeline fittings and their installation, the testing procedure and the software and hardware required for its implementation, together with an error analysis of the method. The overall uncertainty is better than 0.15%.
Keywords: Ultrasonic meters, Validation, Natural gas.

INTRODUCTION

Gas sales contracts throughout the world stipulate the obligation of the sellers to demonstrate at regular time intervals that the equipment used to determine the quantity and quality of the gas is performing within specifications. There are now well-established and accepted methods of validation for most types of instrumentation used in the gas metering stations.
The USM, as a newcomer to the field of gas metering, does not have yet the benefit of a well-established and universally accepted method of validation. Although the manufacturers claim that USM's are intrinsically stable in the long term due to their very principle of operation, the accuracy verification tests (AVT) are necessary for the time being to prove just that. Once the users' confidence builds up, the frequency of AVT's will most likely decrease as a matter of necessity.
At this point it is appropriate to clarify the distinction to be made between validation and calibration.
The former is subject only to bilateral contractual agreements between the parties involved. Although the validation procedures are generally very close or even identical to the corresponding calibration procedures performed based on national or international standards, they are not necessarily subject to legal scrutiny for compliance with existing metrological national and/or international rules and regulations. The main purpose of validation is to detect a potential deterioration in metrological characteristics of a measuring device, eg. accuracy or repeatability. Poor validation results indicate the need for a subsequent recalibration.
Calibrations however, in most countries, can only be performed by legally authorised operators who can demonstrate the traceability of their procedures and equipment to national standards. As a result they are authorised to issue legally binding calibration certificates.
There is another aspect worth mentioning. Calibrations tend to be expensive, none more so than that of USM. A quick and inexpensive in-situ validation for USM is a must in order to avoid either un-necessary and costly off-site calibrations or its opposite, running blind without having absolute confidence in the flow meter.
This paper will describe a low cost, in-line validation procedure.

EXISTING VALIDATION METHODS

In order to compare the method presented in this paper with the methods already in use, a brief review of the latter is provided, together with their pros and cons.

- **Series proving.** Consists of measuring the same gas flow with two different meters. Can be implemented either as an additional meter run or, in its most expensive form, as permanent dual meters installed in each meter run.
  Advantages:
  - Low cost and quick to perform.
  - In its dual meter implementation can be used on line at all times.

  Disadvantages:
  - High initial investment.
  - When there is a discrepancy between the two meters in series it is next to impossible to say which of them is at fault.
  - Unsuitable for existing metering systems that were not designed with this facility in mind.

- **On line speed of sound comparison.** Consists of comparison between the SOS obtained from the USM in operation with the SOS calculated based on the temperature, pressure and composition of the gas being metered. AGA9 recommends the use of this evaluation method without going into the details of how to do it [1].
  Advantage: Inexpensive to implement and run.
  Disadvantage:
  - Not suitable if line temperature and gas composition are not very stable.
  - The method accuracy is very much dependent on the operating conditions, which makes it difficult to keep track of the long-term performance of the meter.

- **Off-line dry validation/calibration.** Consists of removing the USM from line and pressurising it with a pure gas, usually nitrogen, followed by SOS comparison.
  Advantage: Excellent accuracy.
  Disadvantages:
  - Rather costly and inconvenient to perform.
  - The meter run affected cannot be quickly put back in operation in case of an emergency.

VALIDATION METHOD SELECTION

A recent upgrade of Woodside's old fiscal metering system based on orifice plates has seen the introduction of USM's, which brought about the challenge of devising a reasonably accurate, quick and inexpensive validation method for them.
Series proving is not possible because the piping layout does not allow it.
Dry validation was ruled out due to its cost and all the associated inconveniences.
On-line SOS validation was also ruled out due to the wide and unpredictable fluctuations of all variables involved (Fig.1).
In order to calculate the SOS with a reasonable accuracy it is essential that P, T, and gas composition are known at the same moment. The difficulty comes from the fact that although all of the parameters involved vary significantly, only P can be measured instantaneously.
The gas composition available from any process chromatograph always lags behind the current composition due to the sample transport time and the duration of the GC analysis. The delay can be anywhere from 5 to 15 minutes.
Temperature measurement is also affected by delays due to the response time of the probe-thermowell assembly. We have found delays ranging from 1 to 3 minutes, depending on the installation and operating conditions.
SOS difference spot checks based on data depicted in Fig.1 have shown values as high as 1.5%.

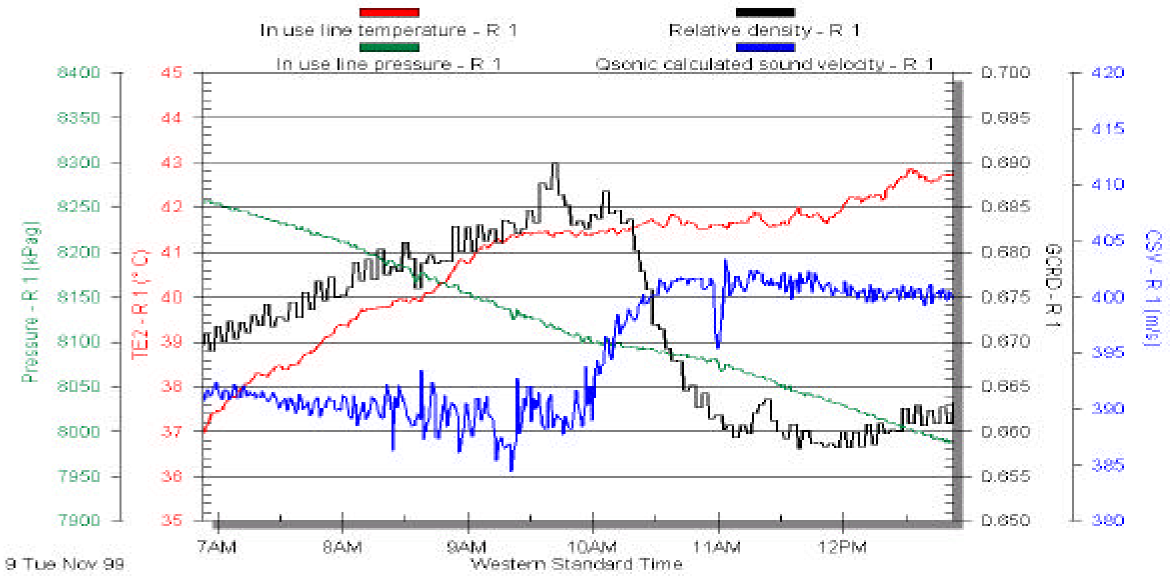

Fig. 1

THE NEW METHOD

The main conditions imposed on any validation method for industrial use are more or less the same: minimal cost, good accuracy and user friendly (ie. fast, safe and easy to perform and to abort if necessary).

Cost minimisation could only come from eliminating the need for removing the meter from line. The cost of removing, testing and reinstalling an USM varies greatly, depending on the size of the meter, the existing facilities on site, the cost of labour, whether the test is done on site or somewhere else, etc., but it is in the order of tens of thousand of dollars.
Performing the validation with the meter on line makes it intrinsically user friendly, because it eliminates all of the problems associated with removing/reinstating a piece of hardware in a high pressure natural gas pipeline, which is a very labour intensive job.

The accuracy problem was treated in the most pragmatic manner. The basic idea is to stabilise the pressure and the gas composition and allow a very slow variation of the temperature and SOS. These conditions can be easily achieved by isolating the section of the meter run containing the USM, but it must also contain the temperature sensor and the probes for the pressure Tx and the gas composition analyser.
Once the necessary stability has been obtained, the delays in gas analysis and temperature measurement become irrelevant. The overall accuracy of the method will only depend on the accuracy of the instrumentation used during the test, and that is completely under the control of the user. A brief overview of the errors involved is provided later.

Fig.2 shows a typical example of the kind of variations of the variables of interest that can be seen in our system over a 24-hour period when isolated. Relative density was included as a representative global parameter for the gas composition in preference to the component concentrations. The graph is based on data collected in the gas metering system using the built-in data logger. It can be seen on the graph that while the gas composition and the pressure are reasonably stable, the temperature and consequently the SOS vary in cycles mimicking the daily ambient temperature fluctuations.

The slowness in temperature variation is of significant benefit to the accuracy of the method for the temperature measurement is far more difficult than is usually realised, when high accuracy is required.
The temperature measurement under industrial conditions is generally affected by two kinds of errors.
The one type most widely known is due to the sensor itself and can be minimised to the desired level by proper calibration and subsequent use of the resulting corrections.
The other possible source of significant errors is the installation effect prevalent in the case of poorly designed thermowells. It is caused by the heat conduction along the stem and the thermowell and it

has the worst effects under no-flow conditions [2]. These errors can be minimised by reducing the difference between the gas temperature and the ambient temperature. This happens naturally, without our intervention, if the isolated meter run is left alone for long enough. The gas temperature inside mirrors the daily ambient temperature cycling and that means that the difference between the two is minimal at all times.
Let's note that there is one minimum and one maximum temperature point per day, each in the middle of relatively short time windows of very good stability.

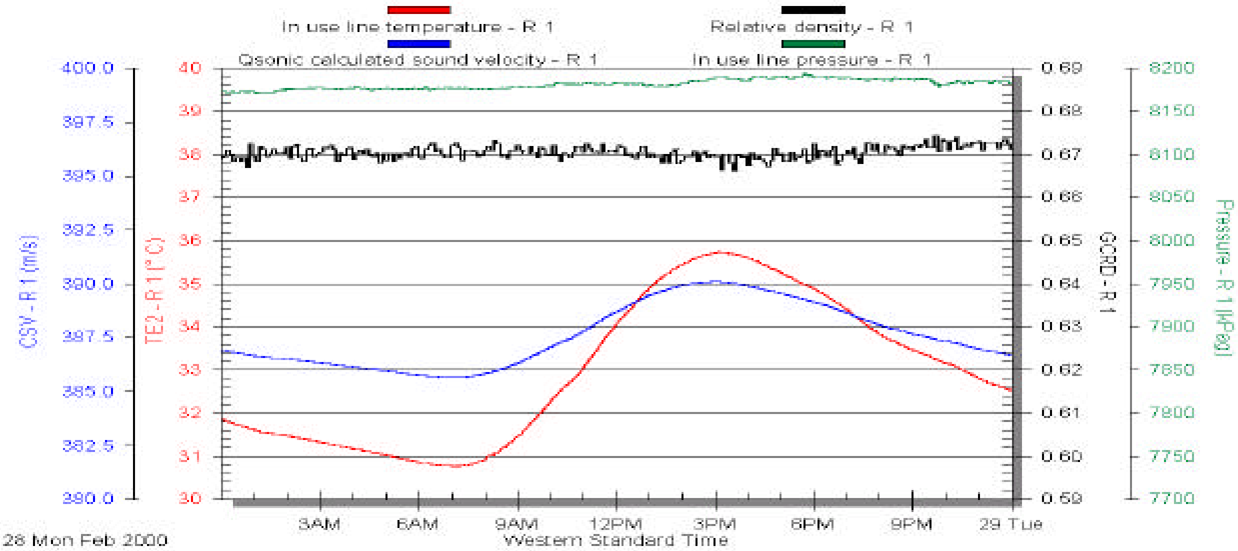

Fig. 2

The SOS comparison can be done in two different ways: either as a spot check (point calculation) using one set of instantaneous readings, or as a range check using the average readings over the selected time window. The latter is the preferred method for it has the benefit of reducing the random errors. In addition, the field data necessary for SOS calculation have to be manually entered only once.
For the purpose of illustrating the potential of the method, some actual test results obtained from our system are used below.
Table 1 shows the results of 4 random spot checks.

Time	Pressure kPa	Temperature deg.C	Meas. SOS m/s	Calc. SOS m/s	Difference %
6:30	8278.133	30.82	385.714	386.170	0.12
7:03	8176.190	30.75	385.671	385.709	0.01
18:01	8191.024	34.89	389.170	389.145	0.006
20:59	8186.812	33.47	387.681	388.506	0.14

Table 1

The gas composition is not shown for simplicity, but each time it was very close to the one in table 2. The largest difference in SOS is still a reasonable 0.14%, but the spread of results makes it difficult to come up with an overall figure for the USM. This means that monitoring the USM condition in the long run is also difficult, if we consider that the purpose of this periodic exercise is to identify small drifts over time.

The other option is to use the average values obtained within a carefully selected time window so that the temperature and the SOS are very stable. How stable is a rather subjective matter; it depends on the overall accuracy desired by the operator.
For the purpose of exemplifying the method, let's assume that the temperature variations must be within 0.1 degC. and the SOS variations must be within 0.1 m/s. If these two variables are stable it

results that the pressure and the gas composition are also stable on account of the interdependence between these two pairs of variables.
Fig. 1 shows that there are two time windows that could be used for validation purposes: one is around 7AM, the other is around 3PM. Expanding the time and the engineering scales around the 7AM point results in the graph in Fig.3 for temperature and SOS.

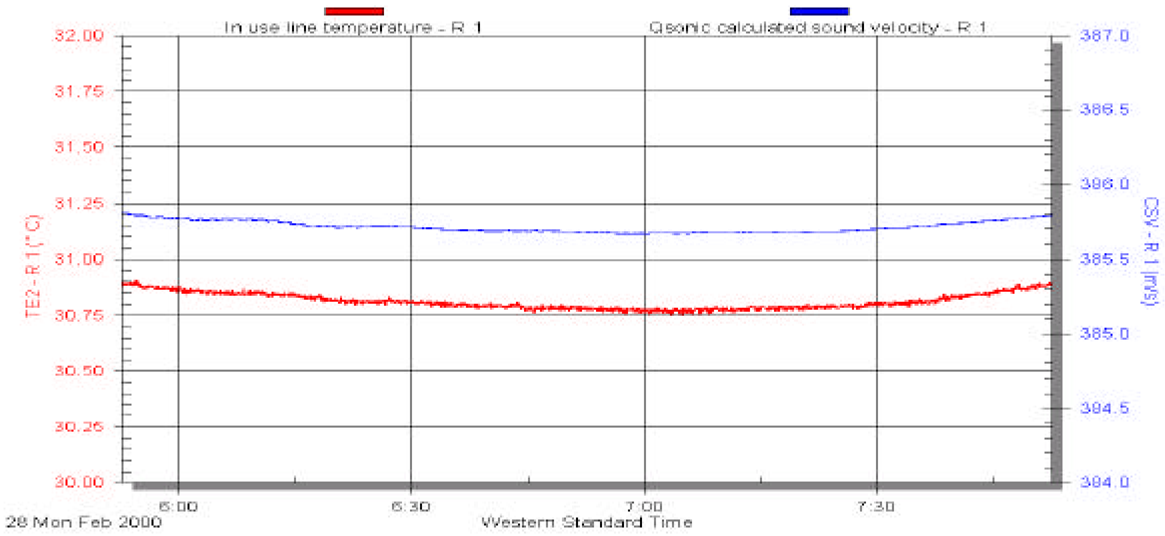

Fig.3

As it can be seen, the period between 6:30–7:30 hours meets the variations limits requirements.
A second, more rigorous assessment of the quality of the data is performed as part of the next step, which is the data processing within the selected time window. It consists of determining the average, maximum, minimum and standard deviation of each parameter involved in the calculation of SOS. Table 2 shows the results of processing the data gathered within the selected time window.

Item Name 1	Samples 2	Average 3	Std Deviation 4	Largest Value 5	Smallest Value 6	Max - Min 7
GCN2	721	2.340118	0.028347	2.376613	2.300502	0.076111
GCCO2	721	2.270410	0.012543	2.294393	2.254065	0.040328
GCC1	721	83.146446	0.052155	83.243896	83.077812	0.166084
GCC2	721	7.822461	0.019773	7.873832	7.803787	0.070045
GCC3	721	3.506939	0.024925	3.535212	3.459309	0.075903
GCNC4	721	0.469138	0.021138	0.490926	0.414441	0.076485
GCIC4	721	0.429120	0.010016	0.447249	0.416741	0.030507
GCNC5	721	0.003376	0.000032	0.003433	0.003320	0.000113
GCIC5	721	0.011931	0.000084	0.012032	0.011786	0.000246
GCNC6	721	0.000000	0.000000	0.000000	0.000000	0.000000
P (kPa)	721	8176.687500	0.448193	8178.007324	8175.584473	2.422852
T (degC)	721	30.783514	0.011747	30.815399	30.754736	0.060663
SOS (m/s)	721	385.684509	0.009698	385.713562	385.668579	0.044983
GV (m/s)	721	0.001460	0.000841	0.004350	-0.000579	0.004929

Table 2

As it can be seen in column 7 the temperature variation was 0.06 degC and the SOS variation was 0.045 m/s, both of them well within the 0.1 limit. The pressure and gas composition fluctuations were also very small.

The SOS can now be calculated using a specialised piece of software, using as input the values shown in column 3. The resulting SOS in this case is 386 m/s, which differs from the measured value by only 0.315 m/s or 0.08%. This value is deemed perfectly acceptable. The validations performed so far on our USM's have consistently returned differences well within 0.15%.

At this point it should be stressed that this method is not intended for comparison of the absolute SOS values because the uncertainty in the calculated SOS is higher in natural gas than in pure nitrogen commonly used for dry calibration. The method is suitable for detecting possible drifts in the measured SOS, if any, over longer periods of time.

METHOD ERROR ANALYSIS

The estimation of the overall uncertainty associated with this method requires the estimation of the error contribution of each of the input variables. The following assessment applies to our conditions. Each case should be considered based on its own merits.

- **Pressure**
  The sensitivity coefficient for pressure is 0.001m/s/kPa. A modern pressure transmitter can be calibrated with an uncertainty better than +/-10kPa in the 0-10MPa range, hence its contribution to the theoretical SOS is less than 0.01m/s, in other words negligible.

- **Temperature**
  The sensitivity coefficient for temperature is approximately 1m/s/degC. That translates into a possible error of 0.26%/degC based on the test conditions exemplified in this paper. This explains why the temperature measurement accuracy is so critical to this method. An error of no more than 0.3 degC is allowed for a reasonable overall accuracy, which means an error of 0.09% in SOS calculation.

- **Gas composition**
  Table 3 shows the SOS sensitivity to individual component variations. The basic composition in column 2 is taken as reference. It gives the value of 385.278m/s for SOS, at 30 degC and 8200kPa. Each row shows the variation in SOS when the corresponding component varies by the amount specified in column 6, while all the other components remain unchanged. The SOS was calculated after each component change, using the resulting normalised composition and the pressure and temperature above.

Item Name 1	Average mol% 2	Manufacturer's component tolerance (mol%) 3	St. deviation of calibration 4	Combined uncertainty +/- mol% 5	SOS m/s 6	SOS change % 7
GCN2	2.340118	0.02	0.008964	0.035	385.279	0.00026
GCCO2	2.270410	0.02	0.011463	0.042	385.163	-0.02985
GCC1	83.146446	0.09	0.047649	0.176	385.369	0.02362
GCC2	7.822461	0.02	0.009643	0.037	385.204	-0.01921
GCC3	3.506939	0.02	0.007418	0.031	385.143	-0.03504
GCIC4	0.429120	0.003	0.005490	0.018	385.158	-0.03115
GCNC4	0.469138	0.007	0.006165	0.021	385.139	-0.03608
GCIC5	0.011931	0.0008	0.000204	0.001	385.269	-0.00234
GCNC5	0.003376	0.0007	0.000185	0.001	385.269	-0.00234
GCNC6	0.000061	0.001	0.000219	0.001	385.266	-0.00311

Table 3

The component uncertainty in column 5 is the combination of the component uncertainty taken from the quality certificate issued by the manufacturer of the cal gas, and the uncertainty of our own calibration of the gas chromatograph. The uncertainty in column 3 is considered to have a rectangular frequency distribution, and the uncertainty in column 4 is the standard deviation of the errors in 4 successive GC calibration cycles. The combined uncertainty in column 5 is calculated at 95% confidence level as per [4] with the formula:

$$U_{95}=(t^2s^2+a^2)^{1/2} \qquad (1)$$

where
- t is the t statistic value at 95% confidence level and 3 degrees of freedom.
- s is the sample standard deviation.
- a is the semirange of the rectangular distribution, ie. the manufacturer's tolerance.

Column 6 gives the resulting absolute values for the SOS and column 7 shows the percentage variation in SOS referenced to the basic value of 385.278m/s.
It could be argued that there is no guarantee that only one component would be in error during a test. In practice all components are simultaneously affected by errors. The purpose of the table above is to estimate the order of magnitude of the errors involved relative to the other sources of errors, rather than providing an exhaustive analysis. Additional investigation into this problem, not included in this paper, has shown that even under the most unfavourable combination of component errors, a well calibrated chromatograph will not produce an analysis result generating an SOS error of more than 0.05%.

- **Calculated SOS.** The commercial software available nowadays for calculating the theoretical SOS in natural gas has an uncertainty of 0.05 – 0.1%. Let's consider an average figure of 0.075% for this component.

The combined uncertainty of the method based on the above standard uncertainties in temperature, gas composition and SOS calculation is:

$$U_{comb}=(0.09^2+0.05^2+0.075^2)^{1/2}=0.13\% \qquad (2)$$

This figure is more than adequate for testing under industrial conditions, especially when considering the low cost of the method.

PRACTICAL SET-UP AND THE TOOLS REQUIRED

The test results shown in this paper have been obtained in a metering system with the following parameters:
- USM model Qsonic-5, 14" diameter
- Gas probe and Pt.100 sensor situated 4.5D and 5D respectively downstream of the USM.
- Isolating ball valves, full-bore type, situated 23D upstream and 6D downstream of the USM.
- The meter run is thermally insulated on its entire length, exclusive the ball valves.

As noted before, the method relies on reasonable stability of pressure and gas composition trapped inside the meter run during the test. This was obtained in our case thanks to the following precautions:
- The ball valve was chosen in preference to other valve types due to its superior leak-tight shut-off qualities.
- There is always a parallel meter run in operation, which means that there is little differential pressure across the ball valves. This helps reducing the gas leaks past the valves.
- The gas sample system used in connection with the chromatograph is a special type. Instead of the usual fast loop with its large flow rate and the ¼" tubing, it uses a capillary transport line all the way from the take-off point to the analyser, without a pressure regulator. This allows a very short transport time (in the order of 30-40 sec.) and, more importantly, a very low flow rate of about 35 l/hr of gas at normal conditions. Such a low gas consumption of the gas trapped inside the meter run means that the leaks across the valves are reduced roughly to the same low level, which maintains the composition stable for long periods of time.

Before each validation test the pressure transmitter and the chromatograph should be calibrated. We use a Degranges & Huot class S deadweight pressure tester, with correction for local gravity. The chromatograph is calibrated using a gravimetric mixture having a composition similar to the pipeline gas to be analysed. It is important to obtain the cal gas mixture from a well-reputed manufacturer in

order to secure a good overall uncertainty of the method. The response factors are adjusted based on the average of 4 consecutive cycles, followed by another set of 4 cycles for final acceptance.
This prerequisite does not add to the normal workload. These AVT's are performed on a regular basis anyway, so the practical thing to do is to include the USM validation as part of the periodic testing activity, taking care of the right sequence.
Pt.100 thermometers have a well-established reputation for long term stability. As a consequence, they do not need calibration with the same frequency as the other instrumentation.

The other tools required for this validation method are:

- Data logger, necessary to collect the relevant data during the test. This component of the system can be implemented in various ways, depending on its intended use. In our case the data logger is built into the system and runs continuously. It is used to monitor the entire operation of the metering system, which means that it must capture about 100 different parameters.
- Data processing software used to produce both the graphs shown in this paper and the statistics in table 2. Again, the complexity of this tool depends on what it is used for and the type of data it has to process. Ours is a rather complicated piece of software, tailor made for our application. It can be used not only for this kind of validation, but also for troubleshooting, back corrections and a host of other investigative work.
  Let's note that the last row in table 2 contains the statistics of the gas velocity under no flow conditions, over one hour time interval. The figures show a very good stability, and considering that they reflect one hour of testing, there is no doubt with regard to the steadiness of the meter. It can be said that in this implementation the method can perform two tests at the same time.
- Software for SOS calculation. There are a few good quality commercial packages available, eg. SonicWare developed by Lomic in cooperation with GRI – USA, or the one available from NEL – UK.

PROCEDURE

Running a validation test according to this procedure is simplicity itself. It consists of only two steps:

- The USM to be tested is isolated and left alone for a suitable period of time. Basically it should catch at least one maximum or minimum point in the daily temperature fluctuations. The data logger must be in place to capture the relevant data.
- When enough data have been gathered, the post-processing can be done, which in our case is a half-hour job. Depending on the result, the meter can be returned to service.

CONCLUSION

An in-situ validation method for USM satisfying all the criteria set up initially has been successfully implemented at Woodside. It is so inexpensive and easy to use that it can be performed as frequently as desired. This makes possible the early detection of any deterioration in USM accuracy and subsequent corrective action, ie. timely recalibration.

References

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