

**North Sea Flow Measurement Workshop
24-26th October 2017**

The Search for Gas Chromatograph Operational Nirvana

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1 Introduction

In the summer of 2017, the author went for a holiday with his family and was lucky to stay in a hotel which got to be pretty close, in author's notion, to what is often called a Nirvana. It was not only because the whole complex was amazingly beautiful and the tropical Island itself was gorgeous, but mainly because of the feelings experienced by guests when they see what happened around them when some imperfections or nuisances occurred.

Responses of the hotel staff to all emerging shortcomings were practically instant. All hotel employees have been seemingly trained to immediately spot weak issues: they just know when wet towels are to be replaced, empty glasses to be filled, rooms to be tidied, etc. If the guests looked a bit confused, the help was there at once as if the crew can read the guests' minds and were ready, just like angels, to fulfil every need of each hotel guest.

They don't wait until the guests start complaining, or until something failed to function. Instead, they immediately react to any appearing shortcoming, however small, and this attitude makes the environment close to almost 100% perfection practically within the entire time.

This presents a good analogy to what we are trying to achieve with the gas chromatograph. We would like to be able to have the GC to measure the gas with the highest accuracy possible 100% of the time. Current methods of validation and performance evaluation benchmarks provides good enough method to be compliant with the current regulations and standards, however it does not provide enough detection to allow GC to run under its full performance capability.

Most regulations and standards requires GC to run within $\pm 0.3\%$ of CV, whereas the most of GC capability in metering industry are capable of measurement within 0.12%. Using the current validation method, the GC is allowed to run with its imperfections until the point where the GC completely fail before any maintenance is initiated. This paper shows through case studies that using conditional based monitoring system, it is possible to maintain the GC within its highest accuracy capability close to 100% of the time.

By applying methods shown in this paper, operator would not only comply with standards and regulations, but also exceed the standard and set a new benchmark in the maintenance of gas chromatography.

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2 Executive Summary

This paper presents that:

1. GC CBM can be in compliance with ISO 6974-1:2012 [1] standard
2. GC under this case study have been performing much better than required by standards and regulations
3. Calibration gas accuracy for GC calibration is crucial in maintaining GC
This is implied in this paper and discussed in detail on North Sea Flow Measurement Workshop 2016 paper [2]
4. All ISO 10723:2012 [3] test results and NORSOK I-106 [4] test on this paper is done using high quality calibration gas.
It is also to be noted that it is crucial to perform these tests using high quality test gases with low uncertainty
5. Four methods of calibrations are discussed as follows:
 - Single point calibration.
It is the most basic form of calibration.
 - Multi-level calibration.
Requires ISO 10723 performance evaluation test [3] using 7 gases. Constants generated are based on the results of 7 different ranges of gases.
 - Exponential calibration.
This is used exclusively on ABB GC.
 - Dual-level calibration.
It is like multi-level calibration. However, constants are created based on two ranges of gases thereby facilitating creation of linear function.
6. When gas working range is narrow, selection of calibration gas composition is crucial for accurate measurement of the gas. Single point calibration (type 2 analysis according to ISO 6974-1:2012 [1]) will provide negligible bias in measurement when calibration gas composition is representative of process gas composition.
7. When the gas working range is wider, selection of calibration method is crucial to minimise bias due to lack of detector linearity. Correct calibration method can reduce bias due to lack of linearity to a negligible level.
8. Calibration method of the GC can be selected to achieve the optimal maintenance for the GC dependent on the working range of the pipeline gas.
9. GC health monitoring using live uncertainty method can ensure that GC is healthy at all time. When problem starts arising, early detection and troubleshooting can be done.
10. Current validation regime may not be the best method to achieve highest GC accuracy
11. Hybrid method of validation is introduced. This method only applies to redundant GCs that measure the same gas. One GC is being calibrated on a daily basis, whereas measurement of the second GC is compared against the first GC on a continuous basis.

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3 EN ISO 6974-1:2012

EN ISO 6974-1:2012 [1] is a European Standard with the following scope quoted from the standard:

“This part of ISO 6974 gives methods for calculating component mole fractions of natural gas and specifies the data processing requirements for determining component mole fractions. This part of ISO 6974 provides for both single and multiple operation methods and either multi-point calibration or a performance evaluation of the analyser followed by single-point calibration. This part of ISO 6974 gives procedures for the calculation of the raw and processed (e.g. normalized) mole fractions, and their associated uncertainties, for all components. The procedures given in this part of ISO 6974 are applicable to the handling of data obtained from replicate or single analyses of a natural gas sample.”

This paper shows how a CBM can be in compliance with ISO 6974-1:2012 [1] by following the steps specified in the standard, and also show how by applying CBM much better accuracy level from required tolerance specified in regulations can be achieved.

3.1 Working Range

ISO 6974-1:2012 [1] step 1 requires to define the working range of GC. Using GCAS, which is a conditional based monitoring software for gas chromatograph, based on data from October 2016 to July 2017, the working range of the GC is shown on table 1 below:

Description	Average	Average - 2stdev	Average + 2stdev	Minimum	Maximum
Methane	84.1266	82.9451	85.3081	81.4076	87.7217
Nitrogen	0.7733	0.6682	0.8784	0.5392	1.0118
CO ₂	0.9097	0.6734	1.1461	0.4329	1.6955
Ethane	7.0690	6.5892	7.5489	5.9455	8.5208
Propane	3.9156	3.4953	4.3359	2.6530	5.0386
i-Butane	1.1630	1.0086	1.3174	0.6321	1.5773
n-Butane	1.0763	0.8851	1.2675	0.5122	1.4456
i-Pentane	0.3387	0.2939	0.3836	0.1904	0.4354
n-Pentane	0.2924	0.2544	0.3304	0.1497	0.3758
Hexane	0.3352	0.2982	0.3722	0.2327	0.4186

Table 1. Working range of Alvheim gas

Based on average \pm 2 standard deviation, test gas for NOROK I-106 [4] can be designed. Currently Alvheim performs the test using the following test gases:

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Description	NORSOK I-106 Test Gases			Pipeline Gas Range	
	Mid CV	Low CV	High CV	Average - 2stdev	Average + 2stdev
Methane	84.5723	87.9866	81.2405	82.9451	85.3081
Nitrogen	0.8061	0.629	0.9651	0.6682	0.8784
CO ₂	0.604	0.497	0.722	0.6734	1.1461
Ethane	7.1665	6.2462	8.0655	6.5892	7.5489
Propane	3.5882	2.6671	4.4893	3.4953	4.3359
i-Butane	1.1248	0.7673	1.4767	1.0086	1.3174
n-Butane	1.0608	0.6403	1.4829	0.8851	1.2675
i-Pentane	0.4551	0.2393	0.6501	0.2939	0.3836
n-Pentane	0.3521	0.179	0.5293	0.2544	0.3304
Hexane	0.2701	0.1482	0.3786	0.2982	0.3722

Table 2. Alvheim NORSOK gas test range in comparison to pipeline gas range

By performing NORSOK I-106 test [4], an understanding of GC performance across the operating range will be known. In Alvheim case, the whole range is covered correctly apart from CO₂ where the actual pipeline gas falls out of the NORSOK I-106 [4] test gas range.

Considering the above data, NORSOK I-106 [4] test will provide quite a representative test of actual GC performance when it measures pipeline gas.

3.2 Define Requirement of Analytical Method

The requirement of Analytical method is normally agreed among partners within the pipeline. Alvheim uses ABB 8206 GC that measures natural gases up to C₆+ as well as Nitrogen and CO₂.

3.3 Select Equipment and Working Conditions

Sampling and injection method is selected by operator to ensure that the GC takes a representative sample. This normally includes sampling probe and sample conditional system that is designed as per ISO 10715 [5] prior to gas injection into the GC.

GCAS looks at the data result to advise the likelihood of sample instability which may be caused by heavy end drop out or wet gas in the system. Figure 1 shows an example where normally the GC shows quite a stable reading and then on the evening of 8/5/2017, out of the blue, the GC starts giving more erratic CV reading.

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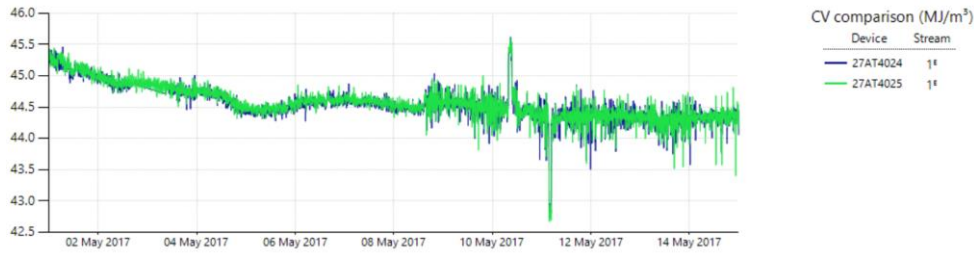


Figure 1. CV trend of both GC in Alvheim

If standard deviation of the GC reading on the date of 8/5/2017 taken for 3 hours between 00:00 – 03:00 shows 0.08 MJ/m³, in case of the three hours reading taken on the same date of 8/5/2017 between 20:00 – 23:00, it presents standard deviation of 0.144 MJ/m³.

Several sources can cause such an issue. It could be the introduction of wet gas to the GC or a heavy end drop out in the sample let down system which also tends to give similar effect. This information can be used to motivate further investigation of the reasons such as possibility of process upset upstream of the sampling point.

3.4 Primary Calibration / Performance Evaluation

The most basic calibration method a GC can have is called single point calibration. To minimise bias in the GC, ISO 6974-1:2012 [1] have specified that GC can run on Type 1 analysis mode. Using type 1 analysis mode, an analysis function is applied to the GC calibration and therefore the GC is capable to reduce bias on a wide range of gas measurement.

There are two methods of performance evaluation that are used in Norwegian and UK sectors. Norwegian sector uses method described in the NORSOK I-106 [4], and most of UK sector uses ISO 10723:2012 standard [3]. The performance evaluation can be performed on GC that is calibrated with any calibration method. Prior to presenting case studies results, the different calibration methods will be primarily discussed herein.

3.4.1 Single Point Calibration

Single point calibration is a method of calibration that is based on peak area or peak height and calibration gas concentration. Under single point calibration method, mole% is a function of peak area. The method can be explained as follows:

Calibration result is defined as response factor which is a function of peak area and calibration gas mole% is as shown in Equation 1.

$$\text{Response Factor} = \frac{\text{Peak Area}}{\text{Calibration Gas mole\%}}$$

Equation 1. Response factor formula

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Being based only on the peak area and calibration gas mole%, the response factor represents a straight line function which assumes that GC is linear across the whole range. The illustration of this is shown in Figure 2.

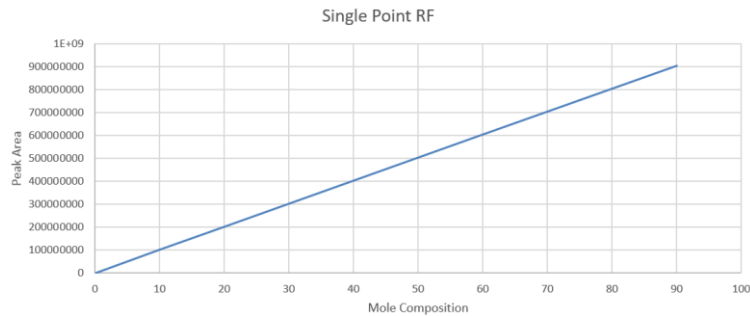


Figure 2. Example of single point response factor

Each individual component will have its own individual response factor. The single point calibration method is quite a powerful method. From the values of the response factors, there are two qualitative indicators that can be identified:

1. Correctness of the calibration gas composition as per the calibration gas certificate
2. Correctness of the GC configuration. This comprises component data in the GC as well as the timing configuration. The correct configuration will ensure correct pathways for each component which is being measured

Because of different thermal conductivity property of each gas, each individual component will have its own unique response factor. This allows verification of the calibration result, to ensure if it is good or bad. On a C6+ application, it is expected that the lightest gas will have lowest response factor and the heaviest gas will have highest response factor. The following trend as shown in Figure 3 is expected.

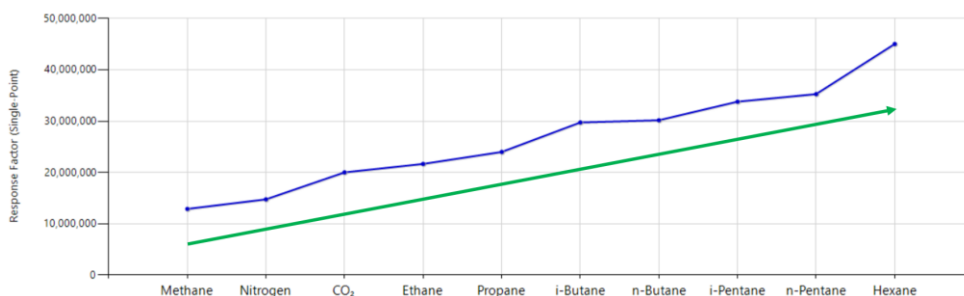


Figure 3. Expected RF trend of C6+ GC

Understanding what is expected from calibration result can provide confidence that the GC is calibrated in the correct way with the correct calibration gas. In one of the case studies it was identified that GC was calibrated with wrong calibration gas value which was entered in component data table therefore resulting in the trend shown in Figure 4.

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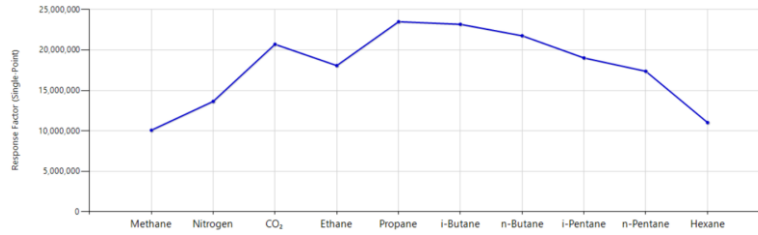


Figure 4. False calibration detected on GC causing 1.4% error in CV

Also, because the RF value of the gases is dependent on its thermal conductivity, the response factor of alkane's component and their molecular weights shall have high correlation. For example on the ABB GC in Alvheim, it is expected that there is high correlation among components of propane, n-butane, n-pentane, and n-hexane as shown by the calibration result from 1/8/2017 below.

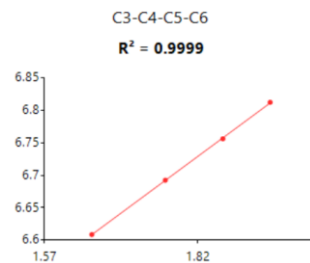


Figure 5. High correlation value on Alvheim GC from 1/8/2017 calibration

The closer the R^2 value is to 1, the better it is. Lower value from one can be accepted if the GC baseline isn't completely straight for instance due to the impact of valve upset.

Although single point calibration provides big advantage in determining correct calibration from the aspect of calibration gas as well as from GC configuration point of view, it also has certain limitation. The limitation is due to the detector property that is not completely linear. With single point calibration, it is assumed that the GC has linear function. However this may not represent the true function of the detector as illustrated in Figure 6.

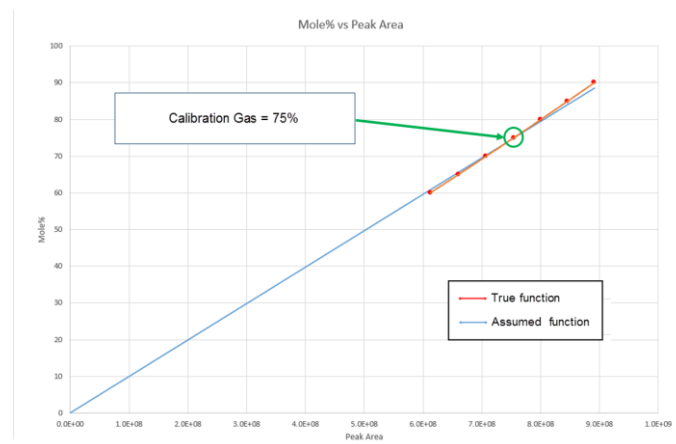


Figure 6. Single point function (assumed) vs true function

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From the picture above it can be seen that the further away the actual measurement is from the calibration gas composition, the higher bias is introduced to the measurement. This is why it has always been suggested to use calibration gas that is representative of process gas. This is also why ISO 6974-1:2012 [1] suggests an understanding of working range of the measured gas to see if it will or will not fit within linear range of the single point calibration function as illustrated in Figure 7 below.

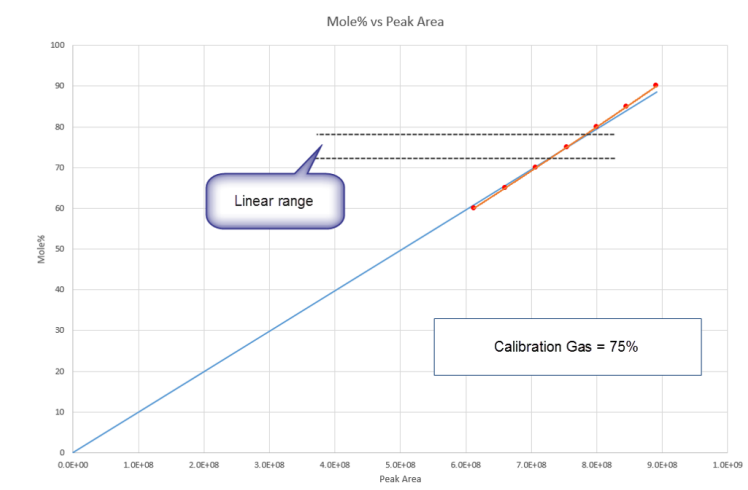


Figure 7. Linear range of mole composition based on true function vs assumed function

The bias or the magnitude of error that occurs due to non-linearity of the detector when measuring gas within working range is what ISO 10723:2012 [3] and NORSOK I-106 test define as part of its performance evaluation test. This is what makes the understanding of working range of the pipeline gas so crucial to become aware of the whole extent of bias that might be introduced by the system.

3.4.2 ABB Exponential Response Factor

ABB GCs that are being used in Alvheim are configured to have exponential response factor. The response factor on these GCs is a function of peak area and a multiplier value. This way the GC will not be impacted by non-linear effect of the detector as much as single point response factor because the exponential method tries to mimic the actual property of the detector. Figure 8 below shows the response of exponential RF in comparison to single point RF on Alvheim GC.

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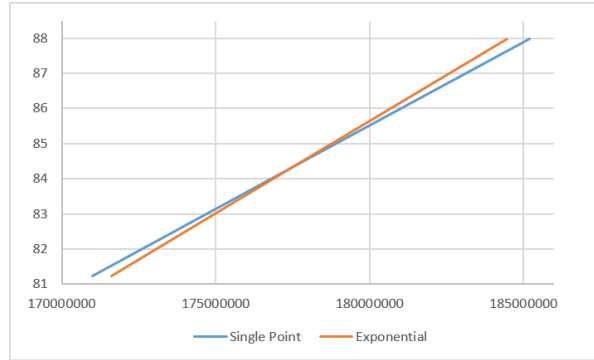


Figure 8. Alvheim single point vs exponential function response for methane

As shown in Figure 8 above, it can be seen that if methane composition of the test gas is larger than the calibration gas, single point function will give negative bias, and when the test gas is smaller than calibration gas, single point function will give positive bias.

Figure 9 shows second run of NORSOK I-106 [4] test that was done on 8/10/2017. Test gas has methane concentration of 81.2405% (lower than calibration gas concentration of 84.412%). Based on the function as per Figure 7, the single point mole% will give positive bias (read higher) than exponential mole%.

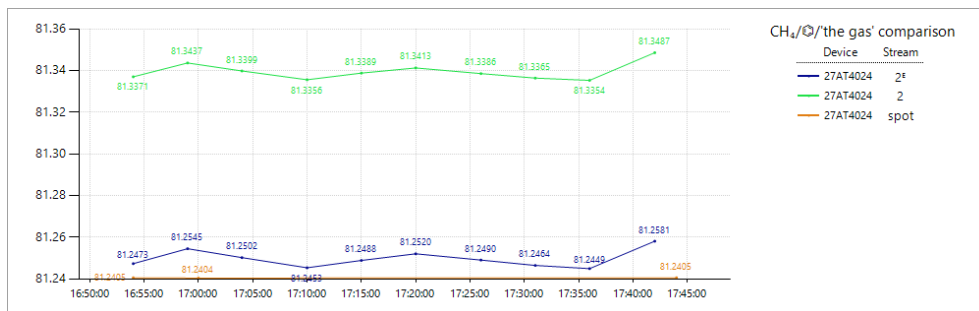


Figure 9. Single point vs exponential mole% with concentration lower than calibration gas

From Figure 9 above, methane exponential mole% has average of 81.2496, and methane single point mole% has average reading of 81.3396. In comparison to the test gas concentration of 81.2405, exponential mole% has discrepancy of +0.0091 while single point mole% has discrepancy of +0.0991.

Figure 10 shows the third run of NORSOK I-106 [4] test as at the date of 9/10/2017. Test gas has concentration of 87.9866% (higher than calibration gas concentration of 84.412%). Based on the function as per Figure 7, the single point mole% will give negative bias (read lower) than exponential mole%.

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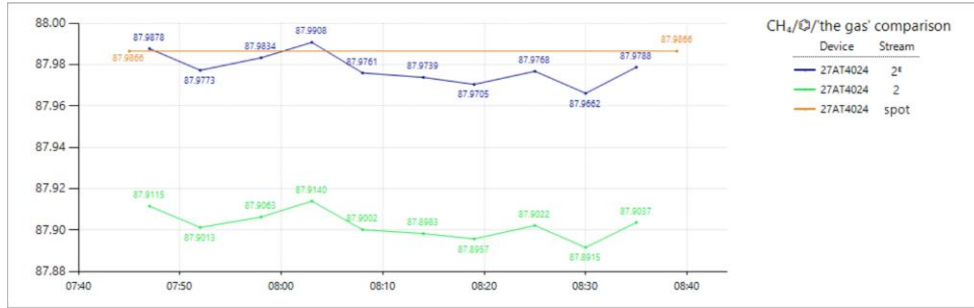


Figure 10. Single point vs exponential mole% with concentration higher than calibration gas

From Figure 10 above, methane exponential mole% has average of 87.9782, and methane single point mole% has average reading of 87.9025. In comparison to the test gas concentration of 87.9866, exponential mole% has discrepancy of -0.0084 while single point mole% has discrepancy of -0.0841.

This result is consistent with the response shown in Figure 8. This test also shows that the exponential function provides much higher accuracy in comparison to single point RF where the gas being measured has significant difference to the calibration gas. However, when the gas being measured is similar to the calibration gas, the bias introduced by single point calibration is minimal. Figure 11 shows test result from first run of NORSEK I-106 [4] test that was carried out on 8/10/2017.

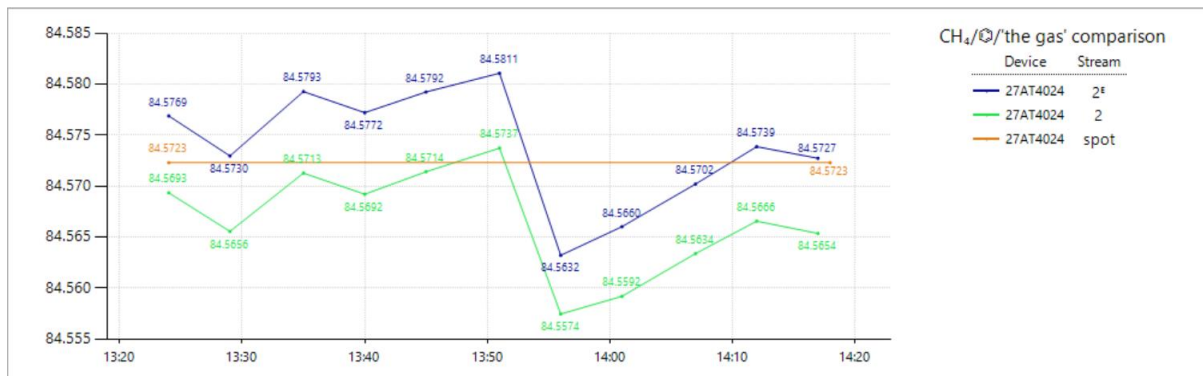


Figure 11. Single point vs exponential mole% with concentration similar to calibration gas

From Figure 11 above, methane exponential mole% has average of 84.5739, and methane single point mole% has average reading of 84.5666. In comparison to the test gas concentration of 84.5723, exponential mole% has discrepancy of +0.0016 while single point mole% has discrepancy of -0.0057. Both of measurements have negligible bias.

Although the exponential response factor provides a very good result, this function is specific to ABB GC only. Other GC does not use exponential response factor, however multilevel calibration can be used on these GCs as specified in ISO 10723:2012 [3].

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3.4.3 Multi-Level Calibration (MLC) Function Response Factor

MLC function has the same idea with exponential response factor function, which is to mimic the true function of the detector on the GC. On the MLC, instead of using exponential function, it uses polynomial function. And to work out the polynomial function curve a test using 7 different test gases is performed. Once a table of peak area vs mole% is created, a polynomial function can be generated using GLS method as defined in ISO 10723:2012 [3]. Dependent on how linear the result is, up to third order polynomial function can be created. Figure 12 shows an example of methane second order polynomial function.

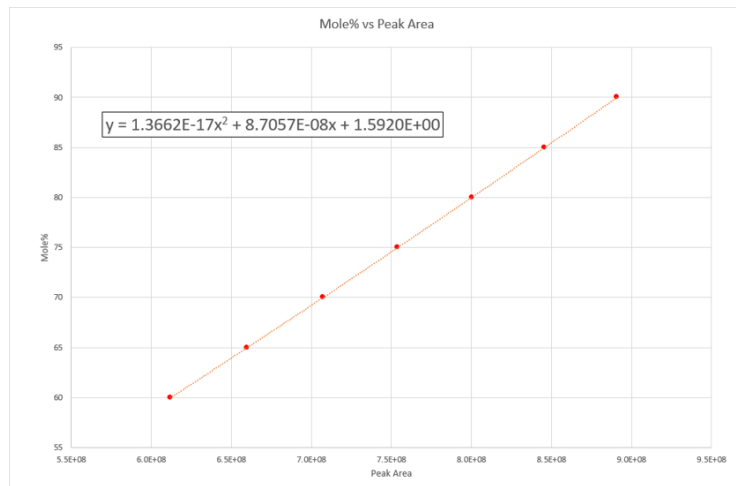


Figure 12. Methane second order polynomial function

Determination of calibration gas is dependent on the working range of the gas as most of the time MLC constants are not implemented in the GC (GC operates in the type two analysis as per ISO 6974-1:2012 [1]). This means that a single point calibration function is used. In this case selection of calibration gas is very important since different concentration of calibration gas will provide with different measurement bias as shown in Figure 13 below.

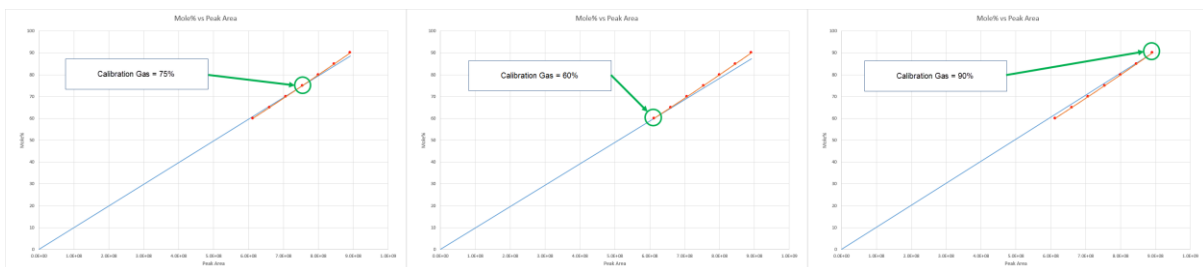


Figure 13. Different measurement bias with different concentration of calibration gas

As per the illustration on Figure 13, the further away the measurement is from the calibration gas concentration, the bigger the measurement bias will be. Therefore the selection of calibration gas needs to be as close as possible to the expected concentration of gas to be measured to minimise measurement bias. Alternatively to minimise the bias across the whole

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range, the MLC function can be implemented in the GC so that it operates in type one analysis as per ISO 6974-1:2012 [1].

The next three examples show the impact of calibration gas closeness to the process gas in terms of bias in CV.

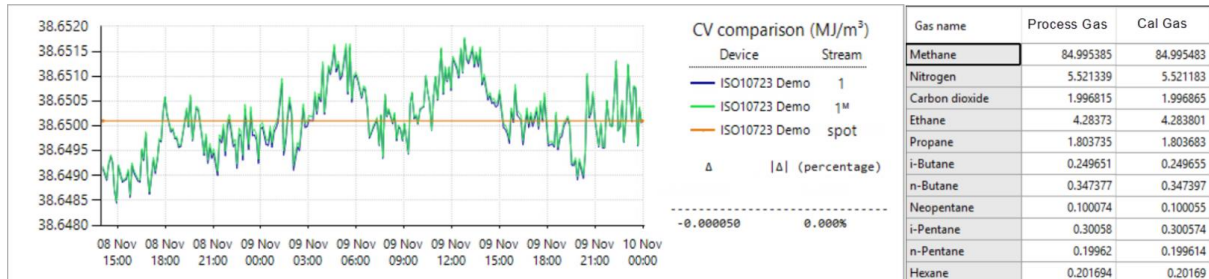


Figure 14. Bias when process gas measured is very similar to calibration gas concentration

From Figure 14 above, there is virtually no bias in case if the process gas being measured is very similar to the calibration gas concentration.

However, if we were to choose a calibration gas that is further away from the process gas concentration, bias will become noticeable. The following is a test done by using the calibration gas that is different from process gas composition.

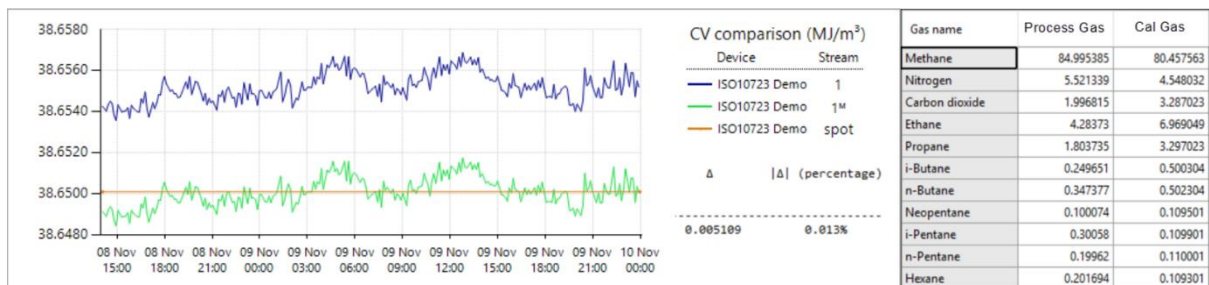


Figure 15. Bias when process gas measured differs from calibration gas concentration

From Figure 15 above, it is now noticeable that there is a bias, however from the discrepancy, there is only 0.013% bias which can be considered negligible. If the GC were to operate using Type 2 analysis as per ISO 6974-1:2012 [1], the addition 0.013% bias will be included as part of GC uncertainty. Therefore, the addition of 0.013% can be considered to be negligible.

However, if a calibration gas that is significantly different from process gas were to be used, the bias on CV measurement can become significant too. The following is a test done using calibration gas that is significantly different from process gas composition.

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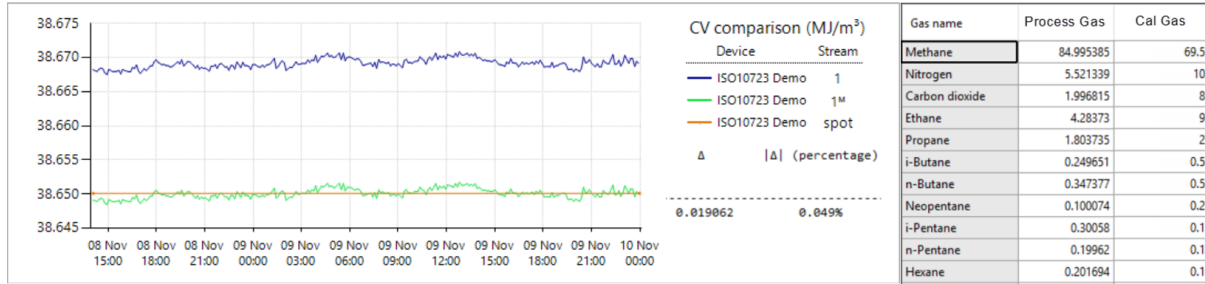


Figure 16. Bias when process gas measured differs significantly from calibration gas concentration

From Figure 16, it is obvious that there is a significant bias in measurement. The bias occurs if the GC operates using Type 2 analysis. However, if MLC constant is applied, the GC will then run using Type 1 analysis, and the bias due to non-linearity is then removed. The green chart above is the result of the application of MLC constant in the GC.

The MLC provides a very good result as it mimics the true response of the detector. However, the constants generated are only valid as long as the GC maintains the performance characteristics measured on the day of calibration. Unfortunately GC drifts with time as will be shown in case study in this paper. In order to get a new constant, performance evaluation using ISO 10723:2012 [3] needs to be performed. ISO 6974-1:2012 [1] specifies the cases in which performance evaluation needs to be performed:

1. Immediately following installation of the system by the supplier
2. Immediately following return to operation after replacement of major part of the system, e.g. injection valve, column, or detector
3. Immediately following return to operation after failure to pass a QA check of the system
4. At intervals that have been demonstrated to be appropriate for the application, e.g. no longer than 12 months

In an ideal world the specified requirement is achievable, however the part with an emphasis on the term “immediately” cannot be implemented as simply as it sounds. It is not very practical since it involves quite a significant preparation with the logistic to order and deliver 7 sets of calibration gases. The following are some of the practical issues associated with preparation for and implementation of ISO 10723 performance evaluation test [3]:

1. Logistic to deliver the 7 sets of gases
2. It can be costly. Cost – benefit analysis needs to be done. If process gas is stable, the cost may exceed the benefit.
3. When performed on a faulty GC, actual fault may be masked as non-linearity
4. Drifts may invalidate the constants values generated during calibration
5. When constants are implemented in GC, RF will be close to 1. Log-log plot cannot be used when all RF is close to 1 and therefore checks to ensure if GC is healthy is only possible by converting the MLC RF to single point RF
6. If tested in the wrong working range, failed result may give impression of faulty GC when if tested in the correct range the result may pass

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With the above reason, a more practical method that can achieve quite a similar result with the polynomial function based on 7 gases usage is introduced below. The method is called dual level calibration.

3.4.4 Dual-Level Calibration (DLC) Function Response Factor

Dual Level Calibration (DLC) eliminates the impracticality of ISO 10723 method [3] and reduces the bias of a single point calibration to negligible level. Instead of using seven sets of gases, DLC uses 2 sets of gases of which both calibration gases can be stored on site. Where storage space permits, it is recommended to have two big bottles. Both of the bottles can be used as daily calibration gas. However, if storage space is limited, it is recommended to have one big bottle for daily calibration usage, and the other small bottle for usage of performing DLC and monthly reproducibility check.

To perform DLC, the range of gas that is going to be measured need to be understood. The calibration gas is then designed to cover the range of the gas, one on the upper range, and the other one on the lower range as illustrated in Figure 17 below. On the below example, the methane measurement range will be between 70% - 80%.

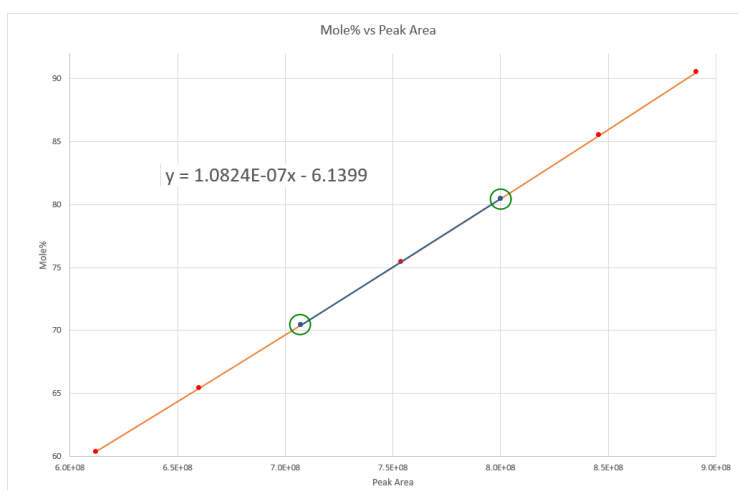


Figure 17. Dual Level Calibration Function

When this function is implemented on the GC, the bias on methane measurement on the range between 70%-80% is reduced to a negligible level. Bias resulting from single point calibration method and dual level calibration method is shown in Figure 16.

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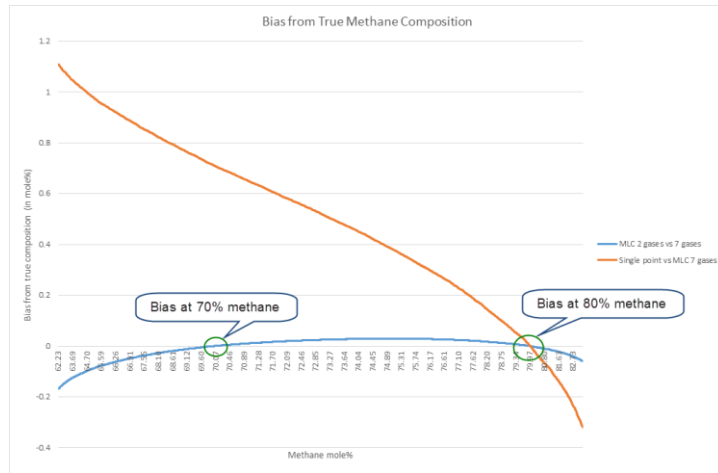


Figure 18. Bias reduced to negligible level

The impact on the CV and line density bias is also being reduced significantly. Figure 17 and Figure 18 shows the bias on CV and density respectively from one of the cases. This is done by performing Monte Carlo simulation of 10000 possibilities of data from a widely defined working range.

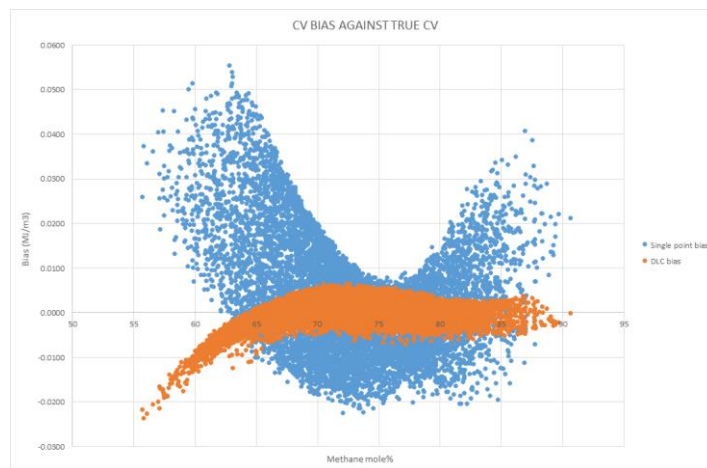


Figure 19. CV bias against true CV

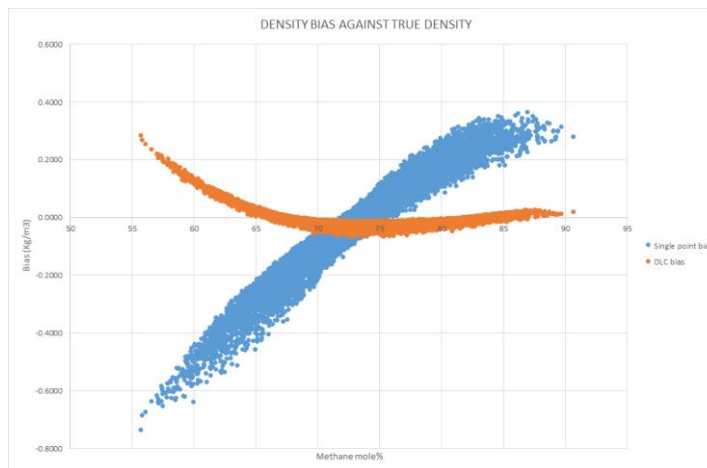


Figure 20. Density bias against true density

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From the Figure 19 and Figure 20 above it is clear that implementing dual level calibration constant can reduce the bias to a negligible level.

With regard to practicality, DLC can be performed without adding any significant cost to the operator. The only thing operators need is two sets of calibration gas that would cover the whole operational range. Both calibration gases can be used for daily calibration. Therefore when one bottle is depleted, the other composition can be used as calibration gas.

The spare calibration gas can then be used as reproducibility check. Rather than checking repeatability of GC using the same gas which the GC was calibrated on, it would become a very useful exercise to perform reproducibility test using another bottle with completely different composition. In effect, this test performs a linearity test. Rather than conducting performance evaluation test on yearly basis, this test can be done on monthly basis with no extra cost. Tolerance for reproducibility limits can be taken for instance from ASTM D1945:2001 [6].

In the events where linearity test fails, one of the following can be checked and done:

1. If linearity check fails due to some failure on the GC, further troubleshooting can be done immediately and fault can be identified and rectified.
2. If there are drifts that cause bias, new constant can be generated using available calibration gas on site.

3.4.5 NORSOK I-106 Case Study from Alvheim

NORSOK I-106 [4] test is based on 3 gases with High CV, mid CV, and Low CV gases. Mid CV test gas will be designed as per the expected average of gas composition, High CV test gas as per maximum expected CV based on working range, and Low CV test gas as per minimum expected CV based on working range.

Repeatability runs are then performed on each of these test gases, and the result from the GC is compared against the value stated on the test gas calibration certificate. The average deviation from low, mid, and high CV is combined and treated as uncertainty from lack of linearity.

Extensive test data have been gathered from Alvheim throughout the period of October 2016 – August 2017. From this test a new method of dual level calibration case is also presented and compared against ABB exponential method using NORSOK test.

Prior to NORSOK I-106 [4] test in October 2016, the GC was calibrated using ABB exponential Response Factor method. The NORSOK I-106 [4] test was performed on both GC. The following is the comparison between GC results against expected CV of test gases.

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GC Tag	Average CV	Expected CV	Discrepancy (%)
27AT4024 (exp)	44.4801	44.4803	-0.0004
27AT4024 (exp)	46.3895	46.3788	0.0232
27AT4024 (exp)	42.5346	42.5284	0.0145

Table 3. GC A NORSEK I-106 test result from 8/10/2016

GC Tag	Average CV	Expected CV	Discrepancy (%)
27AT4025 (exp)	44.4819	44.4803	0.0037
27AT4025 (exp)	46.3888	46.3788	0.0217
27AT4025 (exp)	42.5386	42.5284	0.0239

Table 4. GC B NORSEK I-106 test result from 8/10/2016

From Table 3 and Table 4 above, it can be seen that the test shows very good agreement between GC reading and the test gas.

NORSEK I-106 [4] specifies that the Calorific Value (CV) expanded uncertainty should be less than 0.3%. This means at any single time the measurement of CV from GC should be have discrepancy from the certified value of less than 0.3%. This is a very wide tolerance as most of modern GC is capable of performing much better than this tolerance.

Alvheim uses ABB 8206 GC. ABB datasheet shows that it has capability of repeatability of $\pm 0.025\%$. With the addition of uncertainty from non-linearity of detector, it should be capable of uncertainty of $\pm 0.05\%$. This means that at any single time the GC should be capable of measurement within $\pm 0.05\%$ from the certified test gas.

ISO 6974-1:2012 [1] suggested that frequency of performance evaluation are to be done at intervals no longer than 12 months. This leads to operator conducting the performance evaluation test every 12 months. However, for the purpose of this paper another NORSEK I-106 [4] test was performed in March 2017 (5 months after the previous NORSEK I-106 [4] test). This time test was only performed on high CV and low CV gases. The result for GC A and GC B is shown in table 4 and table 5 respectively.

GC Tag	Average CV	Expected CV	Discrepancy (%)
27AT4024 (exp)	46.4226	46.3788	0.0946
27AT4024 (exp)	42.4986	42.5284	-0.0701

Table 5. GC A high CV and low CV test results from 25/3/2017

GC Tag	Average CV	Expected CV	Discrepancy (%)
27AT4025 (exp)	46.3681	46.3788	-0.0230
27AT4025 (exp)	42.5404	42.5284	0.0281

Table 6. GC B high CV and low CV test results from 25/3/2017

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From Table 5, it can be seen that there has been a drift on GC A measurement that causes bias higher than was expected. The bias is well within the required tolerance of NORSOK I-106 [4] of 0.3%, however this is a systematic error that can be corrected.

This is also confirmed by average discrepancy between two GCs that is quite high. Below is CV trend from both GC within the period between 24/3/2017 18:00 – 25/3/2017 06:00.

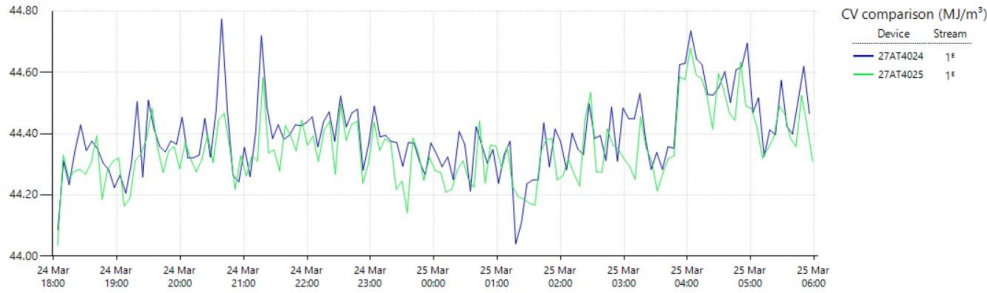


Figure 21. CV discrepancy between GC A and GC B

The average discrepancy on CV as shown in Figure 21 is 0.106%. This discrepancy happens despite the passed validation test that is performed on a weekly basis on both GC. After this result, it was then decided to perform calibration on GC A as it shows a worse result than GC B, and to keep the validation regime on GC B. CV comparison between GC A and GC B after calibration is shown in Figure 22.

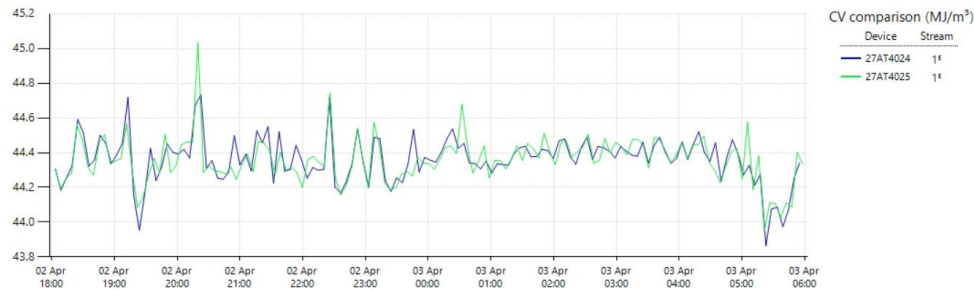


Figure 22. CV discrepancy between GC A and GC B after GC A calibration

Average CV discrepancy after GC A calibration as shown in Figure 22 is 0.006%. This shows that by performing calibration, it reduces the bias on the GC. To see the impact on the calibration on GC A, another NORSOK I-106 [4] test was performed on 10/6/2017 with the following result.

GC Tag	Average CV	Expected CV	Discrepancy (%)
27AT4024 (exp)	42.5241	42.5284	-0.0102
27AT4024 (exp)	46.3647	46.3788	-0.0304
27AT4024 (exp)	44.4619	44.4803	-0.0413

Table 7. GC A NORSOK I-106 test result from 10/6/2017

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GC Tag	Average CV	Expected CV	Discrepancy (%)
27AT4025 (exp)	42.5332	42.5284	0.0111
27AT4025 (exp)	46.3627	46.3788	-0.0346
27AT4025 (exp)	44.4689	44.4803	-0.0256

Table 8. GC B NORSOK I-106 test result from 10/6/2017

From Table 7 and Table 8 above, it can be seen that GC A result is much better in comparison to the test that was done in March 2017, however it shows much bigger bias than the test that was performed in October 2016. This shows how calibration can solve issues in the GC that was missed in the validation. The above data also shows that the GC performance characteristic has a drift since the test done in October 2016 as it is now showing inferior result in comparison to the previous test in 2016.

Another two tests were also performed. The first one is introduction of dual level calibration constant into the GC, and second test is introduction of new multiplier and response factor values into the exponential calibration parameters of ABB GC.

The full method of dual level calibration is explained in the North Sea Measurement Workshop Paper 2016 [2]. The following is the result after the dual level calibration constant is implemented in the ABB GC.

GC Tag	Average CV	Expected CV	Discrepancy (%)
27AT4024 (DLC)	42.5357	42.5284	0.01717
27AT4024 (DLC)	46.3843	46.3787	0.01207
27AT4024 (DLC)	44.4723	44.4803	-0.01799

Table 9. GC A DLC test result from 27/7/2017

The result of implementation of DLC constant is better than all NORSOK I-106 [4] previously done. This shows that for the working range where the GC operates, DLC method implementation can become the most effective way to maintain the health of the GC because of the simplicity of its implementation.

However, to proceed with the test on the extent of capability of the ABB GC, further changes were performed on ABB multiplier and Response factor to fit the curve from the previous NORSOK I-106 [4] test data. The result was very satisfactory. The following is the test result from last NORSOK I-106 [4] test after multiplier was changed and calibration was performed.

GC Tag	Average CV	Expected CV	Discrepancy (%)
27AT4024 (exp)	42.5282	42.5284	-0.00058
27AT4024 (exp)	46.3785	46.3787	-0.00025
27AT4024 (exp)	44.4768	44.4803	-0.00790

Table 10. GC A NORSOK I-106 test result from 1/8/2017

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Considering all the tests which have been performed, the last one gives the most superior result where it shows a miniscule bias on every range of the test gas.

It must be noted that these test results are also affected by the way calibration is performed in the GC. In many occasions calibration is accepted before the reading of the calibration gas is stable. This is mostly noticeable in the amount of Nitrogen that is descending during calibration which shows that there is air contamination in the sample line. This study shows that it takes quite a long time before the reading gets stabilised. Figure 23 shows Nitrogen reading during the first test of the DLC from 27/7/2017:

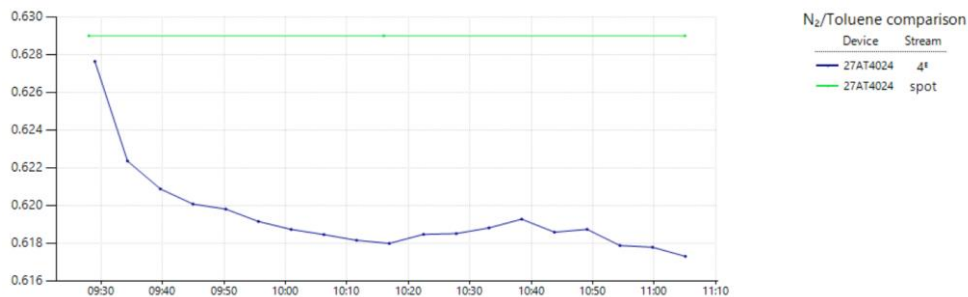


Figure 23. Nitrogen shows bias reading during the DLC test

The above chart reflects the results of the case when there was not enough calibration gas purged prior to calibration, which caused the GC to be calibrated with slight air contamination. Due to the fault in calibration, it caused the Nitrogen reading to be off. The nitrogen average bias from the last 6 data in the chart above is -0.01 mole% (-1.7%). This has caused the error on DLC test to be higher than what it can actually achieve. Calibration prior to the last NORSOK I-106 [4] test was done after the reading got stable and it gave massive impact on the measurement. The following is the first run of NORSOK I-106 [4] test done on 1/8/2017:

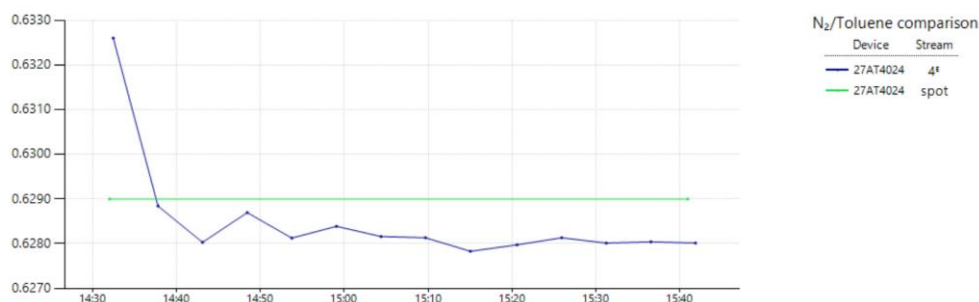


Figure 24. Nitrogen shows negligible bias during NORSOK I-106 test

From the above chart, nitrogen average bias from the last 6 data is showing negligible bias of -0.001 mole% (-0.16%). The impact is negligible CV discrepancy as shown in Table 10.

In spite of all the corrections that exponential response factor enables across the whole working range, it is important to note how big is an impact of such corrections in comparison to the results shown under condition of using the most basic calibration method of single point

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calibration. GCAS provides side by side comparison of every recorded composition between mole% resulted from exponential calibration and mole% resulted from single point calibration. The trend shown in Figure 25 below shows comparison of these two methods on the mole% measured between 20/7/2017 – 21/7/2017.

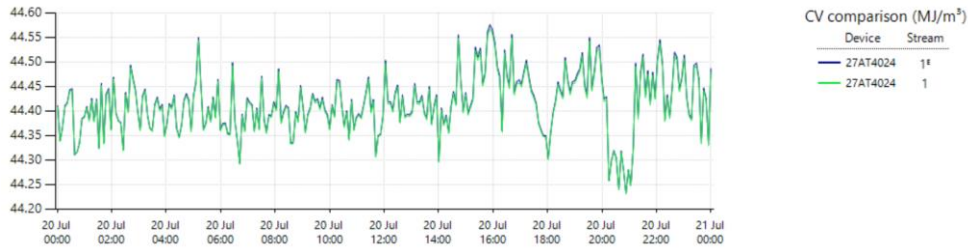


Figure 25. Exponential RF mole% vs single point RF mole%

From the above chart, it is visible that the difference is negligible. For the period shown above, the discrepancy between two methods is 0.009%. This means implementing the exponential RF does not give much corrections when the GC operates in small window of working range as long as the calibration gas is representative as the process gas. The following chart is the comparison between the actual working ranges for the whole month, in comparison to the NORSOK I-106 [4] test range.

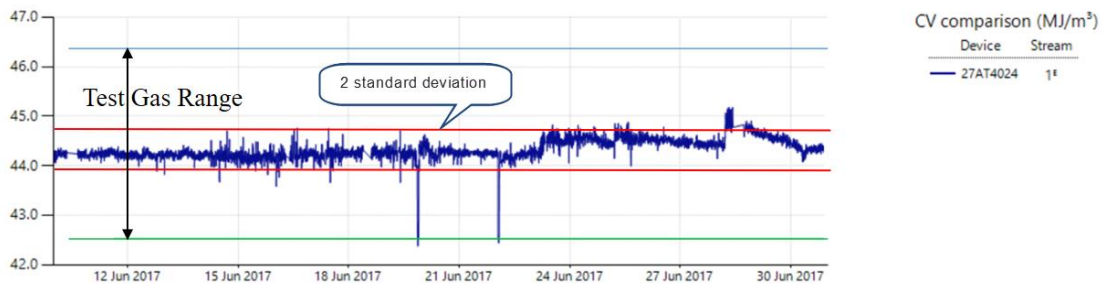


Figure 26. Actual working range vs NORSOK I-106 Test Range

From the above chart it is obvious that the test is done to cover much wider range than the actual range of the period. The average CV for the whole month in June was 44.327 MJ/sm³ with 2 standard deviations of ± 0.2 MJ/m³ giving working range of CV throughout the month from 43.915 MJ/sm³ to 44.738 MJ/sm³. The NORSOK I-106 [4] test was done in a much wider range between 42.528 MJ/sm³ and 46.379 MJ/sm³.

ISO 6974-1:2012 [1] step 3 provides option for operator to determine if primary calibration / performance evaluation is required. However it does not specify the parameter for determination. This paper suggests that it can be determined by looking at the bias introduced when using single point calibration. From the above example, the bias introduced is 0.009%. Where GC CV expected uncertainty to be 0.3% (from NORSOK I-106 [4] requirement), it can be determined that the bias introduced by using single point calibration is negligible.

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3.4.6 ISO 10723 Test Result

To provide a fair comparison to the NORSOK I-106 [4] test, ISO 10723:2012 [3] test result from PX in St Fergus UK is provided. This paper will discuss two of St Fergus GC of which both of them has ISO 10723:2012 [3] performance evaluation test done and operates on type 1 analysis according to ISO 6974-1:2012 [1] which means that the constant from ISO 10723 is implemented in both GC.

Throughout the period both GC have been showing good agreement. Figure 27 below is CV comparison of the two GCs from 1st of June 2017.

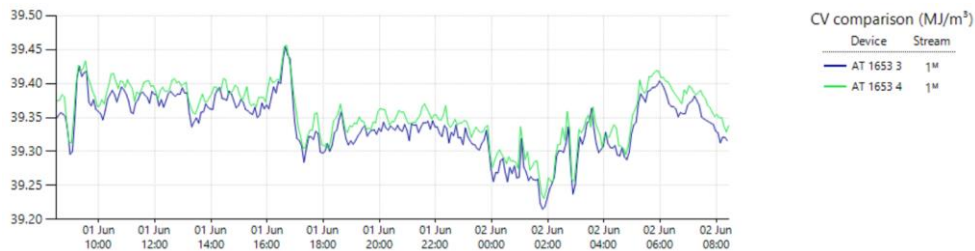


Figure 27. CV comparison between two GC from 1/6/2017

From the chart above, the average discrepancy between these two GC is 0.04%. This is as per expected to be below 0.05% discrepancy between two GCs. However over period of time, the discrepancy has drifted. The trend shown in Figure 28 is from 12/7/2017:



Figure 28. CV comparison between two GC from 12/7/2017

From the chart above, the average discrepancy between the two GCs has increased to 0.113%. This occurs although the GC operated in Type 1 analysis as per ISO 6974-1:2012 [1]. The cause of it is due to drift in response factor in one of the GC. This drift can be detected by monitoring the uncertainty value of the GC. This is a novel method that helps maintain the GC and identify issue before the issue becomes significant. The detail of this method can be found in previous North Sea Measurement Workshop paper from 2016 [2].

The following is the comparison between uncertainty of GC A and GC B throughout the time since the footprint was taken on 24/11/2016.

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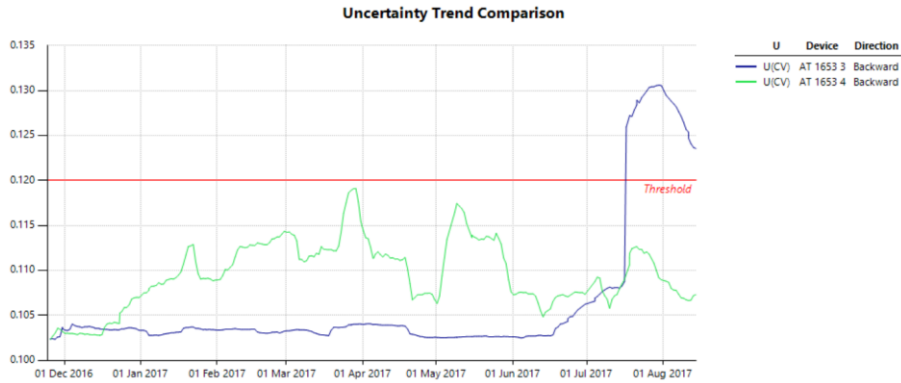


Figure 29. Uncertainty trend comparison between GC A and GC B

The uncertainty method is a very powerful method. It can help understand the true performance of the GC from the available information. Based on this information a tolerance threshold can be created. From the above chart, it is visible that over the period of time GC A is much more stable than GC B. As these are two identical GCs, there is some room for improvements for GC B if felt necessary. However from the information available, alarm limits can be set to flag that there might be something wrong with the GC as the uncertainty value has increased beyond the set limit.

The discrepancy on the data started on around 11/8/2017 which falls at the same time when the uncertainty on GC A increased above the expected threshold. Further to the overall CV uncertainty, individual uncertainty of each component can be drilled in to see where the high uncertainty is coming from. The following is the uncertainty value of each individual component from GC A for the period between 17/6/2017 – 17/7/2017.

Component	Normalised mole fraction	U(cal gas)	U(repro)	S(cal gas) S(repro)	U(repeat)	S(repeat)	Standard uncertainty
Methane	0.875640	0.011420	0.055324	-0.0230	0.000000	-0.0230	0.001299
Nitrogen	0.010100	0.198020	0.109992	-0.0101	0.000000	-0.0101	0.002295
Carbon dioxide	0.038070	0.144471	0.241320	-0.0380	0.000000	-0.0380	0.010681
Ethane	0.060030	0.133267	0.762879	0.0427	0.000000	0.0427	0.033074
Propane	0.011980	0.166945	0.656428	0.0172	0.000000	0.0172	0.011650
i-Butane	0.001000	0.300000	2.929691	0.0021	0.000000	0.0021	0.006331
n-Butane	0.000998	0.350701	2.058262	0.0022	0.000000	0.0022	0.004503
Neopentane	0.000494	0.708502	1.627419	0.0014	0.000000	0.0014	0.002508
i-Pentane	0.000499	0.801603	1.220889	0.0014	0.000000	0.0014	0.002097
n-Pentane	0.000499	0.801603	1.502403	0.0014	0.000000	0.0014	0.002454
Hexane	0.000495	1.111111	0.740989	0.0018	0.000000	0.0018	0.002388
Heptane	0.000099	1.515152	1.391299	0.0004	0.000000	0.0004	0.000884
Octane	0.000049	2.040816	22.179425	0.0002	0.000000	0.0002	0.005531
Nonane	0.000024	2.083333	2.567271	0.0001	0.000000	0.0001	0.000460

Table 11. Uncertainty of each individual component from GC A

From Table 11, it shows that ethane contributes mostly to the overall CV uncertainty. The ethane uncertainty figure is twice as big as data from the time when the GC was healthy. The following is 30 days uncertainty result for the period between 1/6/2017-30/6/2017.

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Component	Normalised mole fraction	U(cal gas)	U(repro)	S(cal gas) S(repro)	U(repeat)	S(repeat)	Standard uncertainty
Methane	0.875640	0.011420	0.018892	-0.0230	0.000000	-0.0230	0.000508
Nitrogen	0.010100	0.198020	0.107424	-0.0101	0.000000	-0.0101	0.002283
Carbon dioxide	0.038070	0.144471	0.094270	-0.0380	0.000000	-0.0380	0.006551
Ethane	0.060030	0.133267	0.217790	0.0427	0.000000	0.0427	0.010904
Propane	0.011980	0.166945	0.477719	0.0172	0.000000	0.0172	0.008704
i-Butane	0.001000	0.300000	2.359796	0.0021	0.000000	0.0021	0.005114
n-Butane	0.000998	0.350701	1.225656	0.0022	0.000000	0.0022	0.002749
Neopentane	0.000494	0.708502	1.430794	0.0014	0.000000	0.0014	0.002256
i-Pentane	0.000499	0.801603	1.245336	0.0014	0.000000	0.0014	0.002126
n-Pentane	0.000499	0.801603	1.612765	0.0014	0.000000	0.0014	0.002595
Hexane	0.000495	1.111111	0.624566	0.0018	0.000000	0.0018	0.002279
Heptane	0.000099	1.515152	1.013942	0.0004	0.000000	0.0004	0.000783
Octane	0.000049	2.040816	19.401269	0.0002	0.000000	0.0002	0.004844
Nonane	0.000024	2.083333	1.533250	0.0001	0.000000	0.0001	0.000360

Table 12. GC A uncertainty for period 1/6/2017 – 30/6/2017

From Table 11 and Table 12 above, it can be seen that ethane uncertainty has increased significantly for GC A. This is also reflected on the deviation on ethane measurement between the two GCs as shown in Figure 30.



Figure 30. Ethane drift on GC A

From the ethane comparison between GC A and GC B shown in Figure 30 above, the ethane drift is quite visible. Average discrepancy of ethane had increased to 0.05 mole% from originally 0.02%. This shows that the MLC constant has become invalid because the parameters in the GC have changed. It is normally difficult to see when the changes of these parameters initially took place and when it gets necessary to perform another ISO 10723 performance evaluation test [3]. However, it can be argued that performance evaluation test may not be necessary. ISO 6974-1:2012 [1] step 3 suggest that operator can decide if performance evaluation test or primary calibration is required or not. However it does not specify the criteria for it.

This paper suggests to see it from the cost benefit perspective. If the cost overcomes the benefit of performing the test, then operator can decide not to perform performance evaluation test or primary calibration. In this example, it is shown the CV result from the same GC comparing data from GC calibrated with multi-level calibration (MLC), and GC calibrated with single point calibration. It is to be noted that these are the same data coming from the same GC which have been processed slightly differently dependent on the calibration method. Figure 31 shows

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the comparison between the two methods for period between 11/7/2017 00:00 – 12/7/2017 00:00.

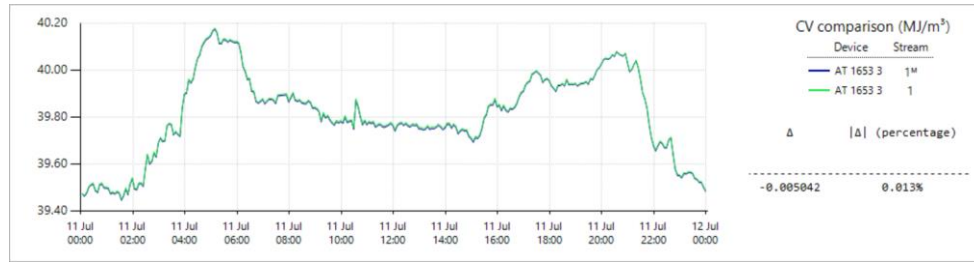


Figure 31. MLC vs single point CV calculation on GC A

The average discrepancy between the two methods is 0.013% (0.005 MJ/Sm³). Considering GC budgeted uncertainty of 0.3%, as well as looking at the GC live uncertainty for this particular GC of 0.108, bias of 0.013% is well within the uncertainty limit of the GC and can be considered to be negligible.

From both example above (i.e. NORSOK I-106 [4] test and ISO 10723:2012 [3] test), both results show that the bias introduced by performing single point calibration is negligible in the working range of the gas where these GCs operate. Therefore, it provides ground for operator to determine if primary calibration / performance evaluation is required.

3.5 Assign Relative Response Factors

The assignment of relative response factors occurs when the GC measures a component that is not available in calibration gas. For example GC is designed to measure up to C7+, however the calibration gas does not have C7+ component as part of its composition. In this case relative response factor to be assigned to C7+ component for instance relative to propane or other component. In fiscal metering, this step is normally skipped.

3.6 Quality Assurance / Routine Calibration

ISO 6974-1:2012 [1] Step 6 suggest that if the analyser were to be used for routine operation, Quality assurance check or routine calibration is to be performed.

Quality assurance check is a validation against calibration gas. Calibration gas will be analysed as an unknown mixture, and the result from GC will be compared against calibration gas certificate. If result passes, the GC will be put back to normal operation. If the result fails, calibration is to be performed.

Routine calibration is a periodic calibration that is performed at a certain frequency on the GC. New response factors will be accepted every time when calibration is performed. The only time calibration result is to be rejected is when the response factor deviates bigger than the defined tolerance.

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As shown in NORSOK I-106 [4] case study in section 3.4.5, GC A has always passed its calibration throughout the period of October 2016 to March 2017. As a result GC has introduced an unnecessary bias which means it gives a systematic error to the measurement.

This systematic bias was removed by performing calibration on the GC A. This is proven on the test that was done after the calibration as shown in Table 7. The Norwegian sector mostly use the validation regime with a certain tolerance. Calibration will only be performed after a validation process failed. However when validation failed, this should flag an alarm that GC is not performing as well as it should due to some characteristic changes and calibration will most likely not correct this faults.

The idea of validation is to maintain the parameters from Factory which can be treated as footprint. However, it is argued that after the first installation of the GC on site, there will be few drifts on the GC before it is completely stabilised. This is also shown in the case of GC A on Alvheim case where the GC has drifted from October 2016 to March 2017 that introduced bias of around 0.1%. In this case, it is not beneficial to maintain factory setting when in turn it gives bias to the measurement.

GCAS have benefit of both maintaining factory setting / setting when the GC parameters are known to be good (footprint) and combining it with daily / periodic calibrations on the GC. Therefore last calibration values can be compared against the footprint. This was done in Alvheim for GC A from period between 29/3/2017 – 26/7/2017. This provides the capability of looking at the true performance of the GC based on its calibration results.

Therefore, GCAS doesn't only provide control chart for individual components, it also enables to analyse performance of each component based on deviation from footprint shown in the same chart. Figure 32 shows the control chart of RF deviation from footprint for Alvheim GC.

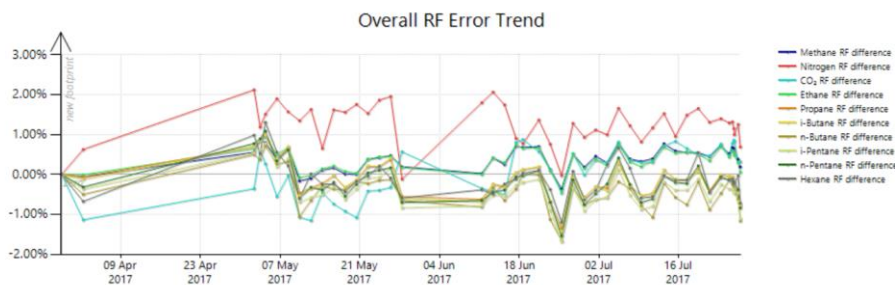


Figure 32. RF deviation from footprint chart on Alvheim GC A

From the above chart, uncertainty value based on reproducibility of calibration can be derived. The following is result of uncertainty calculation based on the above chart that includes uncertainty of calibration gas, calibration reproducibility, and uncertainty from ISO 6976 calculation standard of 0.1%.

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Uncertainty of calorific value	=	0.1103 %	(0.049187 MJ/m ³)
Uncertainty of molecular weight	=	0.1430 %	(0.028507 g/mol)
Uncertainty of Wobbe index	=	0.1039 %	(0.055730)
Uncertainty of relative density	=	0.1113 %	(0.000769)
Uncertainty of standard density	=	0.1432 %	(0.001211 kg/m ³)
Expanded relative uncertainty of each component (k = 2):			
Methane (C1)	=	0.067130 %	
Nitrogen (N2)	=	1.783032 %	
Carbon dioxide (CO2)	=	0.951209 %	
Ethane (C2)	=	0.497341 %	
Propane (C3)	=	0.653981 %	
Isobutane (IC4)	=	0.807096 %	
Butane (NC4)	=	0.768185 %	
Isopentane (IC5)	=	0.861647 %	
Pentane (NC5)	=	0.928414 %	
Hexane (C6)	=	1.348171 %	

Figure 33. Uncertainty calculation result of GC A for period 29/3/2017 – 26/7/2017

By monitoring the daily calibration result and updating uncertainty value of the GC, the natural variation of the GC calibration can be known. Based on this information the limit can then be determined to flag an alarm in case if GC uncertainty goes beyond defined limit. Figure 34 shows the uncertainty trend of GC A between 29/3/2017 – 26/7/2017.

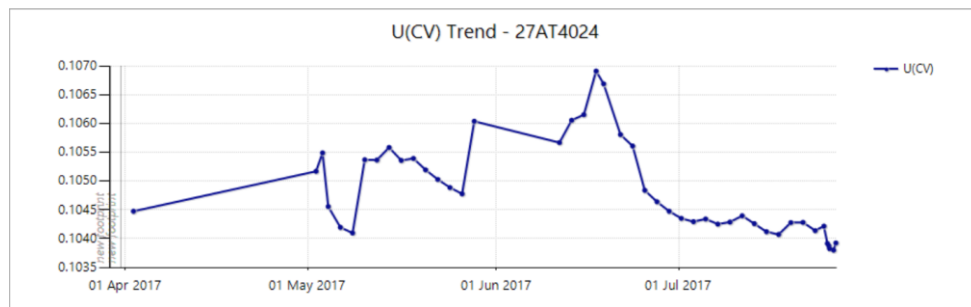


Figure 34. Uncertainty trend of Alvheim GCA for period between 29/3/2017-26/7/2017

Based on the above trend, it is expected that at any time GC will perform better than 0.11%, therefore alarm limit of 0.11% can be set and users will be flagged in case if uncertainty goes beyond 0.11% as shown in Figure 35 below.

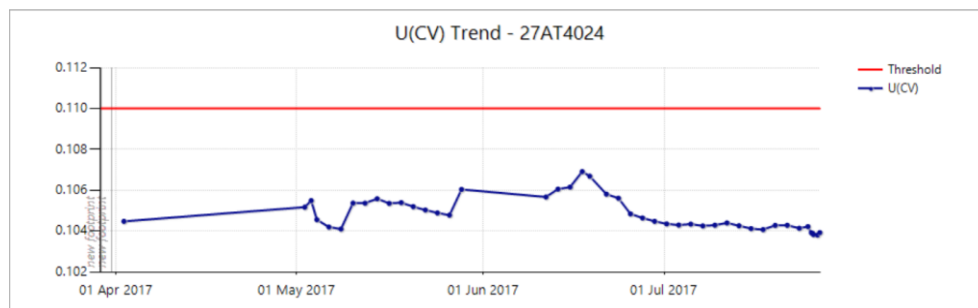


Figure 35. Uncertainty trend of Alvheim GC A with threshold

This method is extension of what is described in ISO 6974-1:2012 [1] on step 9 and 10 to calculate the uncertainty of individual mole fractions as well as expanded uncertainty of mole fractions and in turn calculation of uncertainty of calculation results of ISO 6976.

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Because of the test in Alvheim where calibration is only performed on GC A and not on GC B, another validation method came up. If the health of GC A can be proofed from its periodic calibration, the health of GC B can be monitored by continuous comparison of analysis result to GC A. For example, on the 24th of July GC A had a calibration and the result has proved that GC A is healthy. A CV comparison can then be performed between GC A and GC B to see the average discrepancy between them in the last 24 hours. Figure 36 shows CV trend comparison between GC A and GC B for period of 23/7/2017 00:00 – 24/7/2017 00:00.

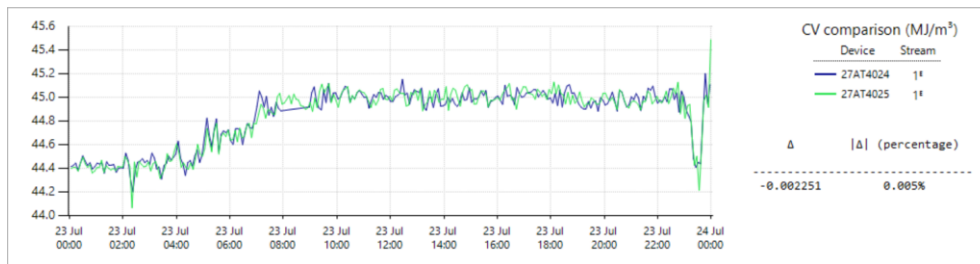


Figure 36. GC A vs GC B CV from Alvheim between 23/7/2017 00:00 – 24/7/2017 00:00

Figure 36 shows 0.005% discrepancy between these GC which means GC B is performing as well as GC A that is known to be healthy based on its historical calibration performance. Maintenance on these GCs can be determined based on daily discrepancy between the two GCs.

4 Conclusion

Throughout the section 3, it has been shown that by implementing GC CBM, compliance with ISO 6974-1:2012 [1] can be achieved. It has also been demonstrated that CBM implementation can achieve not only compliance to the standard, but also can surpass required indicators stated in current standards and regulations. For example, while regulations specify maximum uncertainty of 0.3% on CV uncertainty, CBM flags an alarm in Alvheim case at 0.11%.

From the two cases on Alvheim and PX described above, it is clear that selection of correct calibration gas is crucial for ensuring the accurate performance of gas chromatograph. When range is quite wide the use of exponential function in ABB GC as well as MLC on other type of GC shall reduce bias due to detector lack of linearity. However, there are limitations on these methods mostly due to the lack of understanding of how they work.

ABB has done a fantastic job implementing the exponential function within the GC, however lack of documentation on how this is done and how to generate new multiplier values in case of drifts makes it quite impractical for operators to change these values.

On the other hand generation of MLC constant requires 7 different gases that is provided by a specialised companies. And therefore for few reasons as explained in section 3.4.3, it can present a certain challenge to generate new constant upon each occurrence of drift or changes occurred due to valve overhaul or column change.

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While single point calibration is good to use for a narrow working range, it provides too big numbers of errors for a wider range of application. For the two cases described in this paper, both Alvheim and PX can use single point calibration method with negligible bias. Alvheim and PX have bias of 0.009% and 0.013% respectively from non-linearity when using single point method. Bias shown by each of them can be considered negligible in comparison to overall GC acceptable uncertainty of 0.3%.

DLC method has shown quite a similar accuracy in comparison to the exponential method in ABB GC and MLC method that was done on Daniel GC in PX. It also shows the easiest implementation among all the methods described above. It is very practical in a sense when a new constant may be required due to drift in GC measurement, it can be generated at the same day.

This case study also proves that the performance of small GC such as ABB 8206 compare well to the bigger and more expensive GC. The only limitation it shows is on components quantity that it measures. Other “bigger” GC may have the capabilities of measuring for example trace components such as H₂S and methanol etc. The ABB GC under the case study only measures natural gas components up to C₆₊, Nitrogen and CO₂. Other smaller GCs in the market may also do the same with similar accuracy, however the test was only done on ABB 8206 GC.

The test that was done on PX was using 700XA model capable of measurement up to C₉₊ and it shows very similar uncertainty compared to the Alvheim GC. It is to be noted that the uncertainty of gas chromatograph varies mainly depending on the quality of gas going through the GC. Pipeline with wet gas tends to give impact on GC measurement uncertainty. GC generally has higher uncertainty when measuring wet gas. This is why the uncertainty method limit is based on the natural variation of each individual GC and not on a prescribed value.

From Alvheim case study, the following have been concluded:

1. It has been determined that GC accuracy is much better than is required
2. Implementation of correct DLC constant and / or exponential multiplier values results in bias removal for measurement across the range
3. Actual GC uncertainty is determined to be less than 0.11%. This includes uncertainty from calibration gas, Reproducibility from periodic calibration, and ISO 6976 calculation uncertainty. Uncertainty from non-linearity at around 0.013% is considered to be negligible. If added arithmetically with the overall uncertainty, the GC overall uncertainty will be 0.123% which is much better than 0.3% that is specified in NORSOK I-106 [4]. This reduces economic risk by around 60%
4. GC accuracy can be monitored on daily basis based on the calibration of GC A and data comparison between GC A and GC B
5. The working range of the gas on Alvheim is fairly narrow where implementation of correct calibration gas based on the average composition is good enough that allow to reduce / eliminate the need for performance evaluation test

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6. GC drifts with time. With the current validation regime, unnecessary bias can be introduced by using the tolerance specified in the regulations. However, it is impractical to perform full performance evaluation every time GC performance characteristic is detected to change
7. On the other hand DLC constant can be generated and implemented to maintain GC accuracy and to conduct performance evaluation in a more practical manner.

From PX case study, the following have been concluded:

1. GC measurement accuracy is much better than required by regulations
2. GC live uncertainty can be used to determine issues in the GC, and therefore provide information to troubleshoot and fix the fault before the fault turns into major issue
3. MLC constants if implemented in GC will reduce measurement bias when process gas has significant difference from calibration gas
4. When GC drift happens it invalidates the MLC constant and introduce bias / error in the measurement
5. This bias can happen before next ISO 10723:2012 performance evaluation test [3] is due
6. DLC constant can be generated and implemented to maintain GC accuracy and to conduct performance evaluation in a more practical manner.

All of these case studies performed remotely with the help of site technician and onshore engineer, Frank Tinke and Børge Olafsen in Alvheim and Andrew Runcie, Jonathan Ritchie and Derek Reid in PX. This also demonstrates that GC operational Nirvana can be achieved by using GC CBM combined with the provision of remote support and efficient communication with end user.

5 References

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