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Paper 1.2

Density and Calorific Value Measurement in Natural Gas Using Ultrasonic Flow Meters. Results from Testing on Various North Sea Gas Field Data

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ABSTRACT

Multipath ultrasonic transit time flow meters (USMs) are today extensively used in industry for volumetric flow metering of natural gas, for fiscal measurement, check metering, etc. As natural gas is typically sold on basis of mass or energy, the density and/or calorific value (GCV) of the gas is measured in addition. In current fiscal metering stations this is typically made using additional instrumentation like density meters or gas chromatographs.

In addition to the flow velocity and the volumetric flow rate, USMs give measurement of the velocity of sound (VOS) in the gas. The VOS is a quality parameter which contains valuable information about the gas. In last year's North Sea Flow Measurement Workshop (NSFMW) a new method for calculation of density and GCV of natural gas from measurements of the pressure, temperature and VOS was presented [1]. In this method no instrumentation is needed in addition to the USM itself and the pressure and temperature sensors. The method can be used on existing USM metering stations with only a software upgrade. Such a feature may be of interest for fiscal metering stations (e.g. for backup and redundancy) as well as simpler metering station (where density and GCV are not measured today, but where such information may be of interest e.g. for monitoring).

The present paper represents a follow-up of last year's NSFMW paper, and gives results using this method on data from several North Sea offshore gas field installations. The GCV and density are calculated from the VOS measured by commercially available USMs of various manufacturing types, installed on offshore metering stations. Additional instrumentation in the metering stations provides reference values for density and GCV, used for comparison. Time periods of several days are analyzed for each field, over varying pressure, temperature and gas composition.

The results indicate that the methods for GCV and density measurement are of high interest for several applications, including natural gas quality check, allocation, redundancy and quality check of the metering station instrumentation, with accuracy close to or in some cases even within fiscal accuracy.

1 INTRODUCTION

Multipath ultrasonic transit time flow meters (USMs) are today extensively used in industry for volumetric flow metering of natural gas, for fiscal measurement (e.g. sales and allocation metering), check metering, etc. As natural gas is typically sold on basis of mass or energy, the density and/or gross calorific value (GCV) of the gas is measured in addition. In current fiscal metering stations this is typically made using additional instrumentation like density meters, gas chromatographs (GC) or calorimeters, in addition to the pressure (P) and temperature (T) measurements.

Alternative ways of measuring the density and calorific value in fiscal metering stations may be of interest, for various reasons:

- The use and maintenance of e.g. GCs is work demanding and costly, and methods to reduce the number of GCs in metering stations is an actual topic.

- In case of two or more GCs in the metering station, replacement of e.g. one GC with an alternative measurement method could be useful, serving as a backup measurement.
- The ability to detect drift in GC instruments is important, for which an alternative measurement principle could be useful.
- Also, operation outside of the GC specifications may be of interest.
- Alternative and less expensive measurement methods may be of interest for monitoring and regulation purposes in connection with gas commingling for export, as well as for allocation metering.
- Also, such methods may be of interest for metering stations in which density and/or GCV measurement are not made at all today, if this can be done without introducing new hardware in the metering station.

Developments in recent years have resulted in methods for extending the applicability of USMs to also measuring the density and/or calorific value of the gas. Such developments are based on using the velocity of sound (VOS) measurements already available in USMs. A brief review of various approaches and work in this area was given in [1]. There is today an increasing interest in exploiting the potentials of USMs for direct mass and energy measurement, using the USMs' volumetric flow rate measurement in combination with their VOS measurement.

Two basically different types of approaches have been proposed in the literature:

- Methods based on additional measurement instrument(s) in the metering station (new hardware, such as e.g. a dedicated VOS measurement cell),
- Methods based on software upgrade of the metering station only (no additional measurement instrument introduced in the metering station) [1],

A method based on the latter approach was presented in [1], based solely on the measured VOS, pressure and temperature measurements, possible knowledge of a typical hydrocarbon gas composition, and estimates of the molar fractions of CO_2 or N_2. No instrument is required in addition to the USM and the pressure and temperature sensors.

Various strategies and options for density and GCV calculation were discussed, depending on the available knowledge on the gas composition:

- BCA1, “Blind composition approach 1”: No knowledge on the gas composition at all.
- BCA2, “Blind composition approach 2”: No knowledge on the hydrocarbon gas composition, but knowledge on the *typical* N_2 and CO_2 contents.
- TCA, “Typical composition approach”: Knowledge on the *typical* hydrocarbon gas composition and the *typical* N_2 and CO_2 contents.

The three options may be used in the following scenarios:

- BCA1: when no information about gas composition is available.
- BCA2: when the *typical* contents of the inert gas components (N_2 and CO_2) is available, but not their daily variation.
- TCA: when the *typical* gas composition is available (hydrocarbons, N_2 and CO_2), but not its daily variation.

In [1] the accuracy of these methods was investigated on basis of gas compositional data representative for different gas fields world-wide, covering a range of relatively different gas compositions. Typically, the accuracy of the density and the GCV estimate are improved by using the BCA2 option instead of the BCA1, and further improved by using the TCA option. The results shown in [1] indicated that accuracy close to fiscal accuracy may be achievable in many cases, depending on the uncertainty of the input data, and on the pressure and temperature in question. Among others, the accuracy of the density and calorific value measurements depends largely on the accuracy of the VOS measurement made in the USM.

Several challenges were discussed, including uniqueness problems, effects of higher order hydrocarbon components (C3+), and effects of the inert gas components (N_2 and CO_2).

The present paper represents a follow-up of last year's NSFMW paper [1], and gives results using these methods for GCV and density measurement on data from several North Sea offshore gas field installations. The GCV and density are calculated from the VOS measured by commercially available USMs of two manufacturing types, installed on offshore metering stations. Additional instrumentation in the metering stations provides reference values for density and GCV, used for comparison. Time periods of several days are analyzed for each field, over varying pressure, temperature and gas composition.

In addition to the three options BCA1, BCA2 and TCA discussed in [1], a fourth approach in relation to density and GCV calculation is proposed and used here:

- CCA, "Continuous composition approach": Continuous knowledge on the gas composition e.g. from GC data (all gas components).

The present paper first briefly presents the algorithms and the previous work (Section 2). In Section 3, results using measurements from the Gullfaks C platform are presented. In Section 4, results from Draupner are presented. Summary and conclusions are given in Section 5.

2 ALGORITHM AND EARLIER RESULTS

The algorithms for calculations of density and GCV from the velocity of sound were presented briefly in [1]. The input to the algorithms are (i) pressure, (ii) temperature, (iii) velocity of sound and (iv) gas composition in the form C1, C2, C3, C4+, N_2 and CO_2. There are four ways of specifying the gas composition input data:

- BCA1: "Blind composition approach 1". In this case the user has no information on the gas composition, and the program must specify the gas composition data. This has been carried out by averaging typical gas compositions from Kårstø, Statfjord, Åsgard, Troll and Oseberg, in order to find an "average North Sea composition". These five gas compositions represents a span of gas compositions from light to more heavy gases. The "average North Sea composition" is: C1: 84.20 %, C2: 9.40 %, C3: 2.88 %, C4+: 1.41 %, N_2: 0.86 %, CO_2: 1.25 %. When no gas composition information is available, this composition is used as input to the algorithm.
- BCA2: "Blind composition approach 2". In this case the user has no information on the hydrocarbon gas composition, but typical values of the N_2 and CO_2 contents for the metering station in question are available. In that case, the available typical values for N_2 and CO_2 are used, while the hydrocarbon composition from BCA1 (scaled in order to sum to 100 % in total, is used.
- TCA: "Typical composition approach". In this case typical values of C1, C2, C3, C4+, N_2 and CO_2 contents for the metering station in question are used.
- CCA: "Continuous composition approach". In this case continuously updated values of C1, C2, C3, C4+, N_2 and CO_2 contents for the metering station in question are used. This will typically be output from a GC, e.g. in cases where this method is used as a test of the GC output.

As will be seen below, the values of the N_2 and CO_2 content are important for the accuracy of the output density and GCV. This accuracy also to some extent depends on the hydrocarbon-composition that is specified. This dependency is weak, however, as the VOS is the main parameter that determines the density and the GCV.

The uncertainty contributions to the density and GCV were briefly discussed in [1], and are summarized in the following.

The uncertainty of the measured pressure and temperature will not typically be dominating contributions to the uncertainty of the calculated density and GCV [1].

Over a large range of gas compositions, a standard uncertainty of 0.3 m/s in VOS corresponds to a relative standard uncertainty of about 0.2 % for the calculated density and 0.1 % for the calculated GCV [1].

A standard uncertainty of 0.1 % (abs) in the N_2 concentration corresponds to a relative standard uncertainty of about 0.02 % in density and 0.15 % in GCV. Similarly, a standard uncertainty of 0.1 % (abs) in the CO_2 concentration corresponds to a relative standard uncertainty of about 0.03 % in density and 0.2 % in GCV [1].

Uncertainty in the input hydrocarbon composition typically often gives just minor corrections to the results. However, even large uncertainties in the input hydrocarbon gas composition may give about no output uncertainty contribution for the calculated density and GCV.

In addition to the uncertainty of the input parameters, there is an uncertainty contribution from the algorithm itself. This contribution was in focus in [1]. Typically, at low pressure, the algorithm uncertainty is small. As the pressure increases, the algorithm uncertainty increases, especially at lower temperatures. However, this behaviour is gas composition dependent. It should also be mentioned that a pressures below 100 bar, the algorithm uncertainty is quite small for a large variety of gas compositions and temperature. Also, for many gases, the algorithm uncertainty will be low also for higher pressure [1].

3 GULLFAKS DATA

In the present section, results from application of the methods on data from the Gullfaks C platform are presented.

3.1 Metering Station

The metering station at Gullfaks C consists of pressure and temperature measurements, on-line gas chromatography and 2 ultrasonic flow meters in parallel (6 path meters). From the USMs, the measured velocity of sound is taken as input to the density and calorific value calculation algorithms, in addition to the measured pressure and temperature. The gas composition measured by the gas chromatograph is used for calculation of reference values (for comparison), and as a basis for input of gas composition data to the algorithm (when the CCA, TCA and BCA2 methods are used).

Three measurement series have been analysed. These include two series using one of the USMs (USM1) and one series using the other USM (USM2). More precisely, date are collected for

- November 14 – 19, 2005 using USM 2
- May 25 – 28, 2005 using USM 1
- December 6 – 9, 2005 using USM 1

In all three cases, there are output measurement data each minute.

3.2 Algorithm Uncertainty

The composition of the gas flowing through the metering station on Gullfaks C is quite stable. As discussed in [1], the method depends to some extent on the gas composition. The uncertainty contributions to the calculated density and GCV by the present algorithm consists of contributions from the uncertainty of the input parameters and the algorithm uncertainty. This means that even if the input parameters were exact, the calculated density and GCV will be in error. This was discussed generally in [1]. For the case of the Gullfaks metering station, the algorithm uncertainty is presented through Fig. 1, where the deviation from reference for the calculated density (left) and GCV (right) is given for a typical Gullfaks gas for exact input parameters (gas composition, pressure, temperature and velocity of sound). The pressure is 160 bar, and results are shown over a temperature range from 35 °C to 60 °C, which will be seen to be typical for the metering station at Gullfaks C. For a temperature of 47 °C, a deviation from reference of about 0.6 % is expected for density and about 0.3 % for GCV, from the algorithm uncertainty. The results from the measured data presented below should be interpreted with this in mind.

It should also be mentioned that when the typical gas composition, pressure and temperature is known (which is the case here), it is possible to correct for the algorithm uncertainty because this will be a systematic effect that can be calculated. This has not been done in the discussion in section 3 and 4. In the summary (Figs. 17 and 18) results that are corrected for algorithm uncertainty are presented.

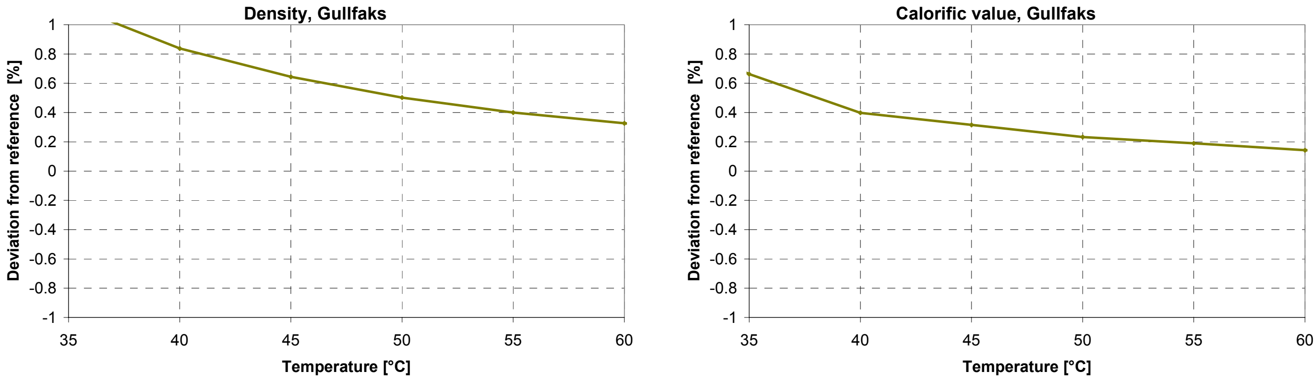

Figure 1. Algorithm uncertainty for density (left) and GCV (right) for the Gullfaks C natural gas, for temperatures from 35 to 60 °C and a pressure of 160 bara.

3.3 November Data

The measurement data from November 14 – 19, 2005 are presented first. The pressure is first around 166 – 170 bara for more than two days, before dropping down to about 156 – 160 bara, see Fig. 2. The temperature is around 47 °C for the whole period.

The density and GCV of the gas flowing through the metering station (as calculated from GC data, for reference) are shown in Fig. 3. It can be seen that the density variation is about similar to the pressure variation, while the GCV variation are small. This is expected since the density depends on the pressure and the temperature, while the GCV depends only on the gas composition. Thus, the dip in the GCV value the second day of the measurement period is due to gas composition changes.

A key input to the algorithm is the velocity of sound measured by the USM. The uncertainty of this VOS is of importance for the uncertainty of the estimated density and GCV. In Fig. 4, upper left figure, the measured VOS-values are shown for the 6 paths. The span between these 6 measured VOS is shown in the upper right figure. This span is typically 1 – 1.5 m/s. In [1], it was indicated that an uncertainty on the measured velocity of sound of 0.3 m/s can give about 0.2 % for the calculated density and 0.1 % for the calculated GCV.

In the lower left figure of Fig. 4, the average VOS (from the 6 acoustic paths) is compared to the VOS as calculated from the GC-measured gas composition, and the pressure and temperature. In the lower right figure, it is seen that the deviation between the average measured VOS and the calculated VOS (from gas composition) is between –1 m/s and 0 m/s. Effects of several tenths of a per cent are therefore to be expected on the calculated density and GCV, from the uncertainty of the velocity of sound.

In Fig. 5, the deviation from reference for the calculated density and GCV from the VOS is presented within the BCA1, BCA2, TCA and CCA schemes. First, by comparing BCA1 (where an average North Sea gas composition is assumed) and BCA2 (where typical N2 and CO2 contents from Gullfaks are used), there are quite small differences between the results for density, while the effect can be observable for the GCV. This must be due to the fact that the

BCA1 overestimates the nitrogen content by 0.36 % and underestimates the CO2 content by 0.21 % compared to the BCA2. This means that the density should be fairly similar in the two cases, while the GCA will be overestimated by the BCA1 by about 0.1 % as compared to the BCA2 case. This is what is seen in the plots. It can also be seen that there are no significantly difference between the BCA2, TCA and CCA cases. This means that a precise hydrocarbon gas composition input is not necessary for the algorithm that calculates density and GCV from VOS, for the Gullfaks case. However, it should be commented that it is a bit “on chance” that the BCA1, BCA2, TCA and CCA are that equal to each other on Gullfaks. On other gas fields, the differences between the four schemes may be larger, as is also demonstrated in section 4.

As can be seen in Fig. 5, the deviation from reference for the calculated density is about 1 %. The algorithm uncertainty, cf. Section 3.2 above, gives about 0.6 % in deviation from reference. VOS uncertainty of 1 m/s gives another 0.6 % in deviation. Combination of these effects gives a deviation from reference of about 1.2 %. This is in consistence with Fig. 5.

Similarly, the deviation from reference for the calculated GCV is about 0.6 %. Here, the algorithm uncertainty gives about 0.3 % and the VOS about 0.3 %. Therefore, both for the density and the GCV, the dominating uncertainty contributions come from the algorithm uncertainty and from the velocity of sound. The algorithm uncertainty is smaller for lower pressure, and may in many applications be negligible. The uncertainty of the measured velocity of sound then is a key parameter for the uncertainty of the calculated density and GCV.

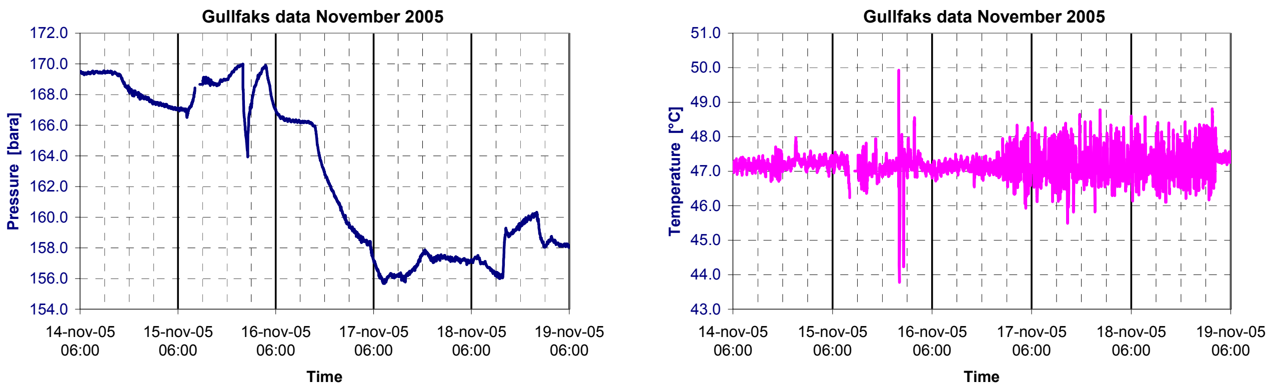

Figure 2 Line pressure (left) and temperature (right) at USM1 of the metering station at Gullfaks C, in the period November 14 – 19, 2005.

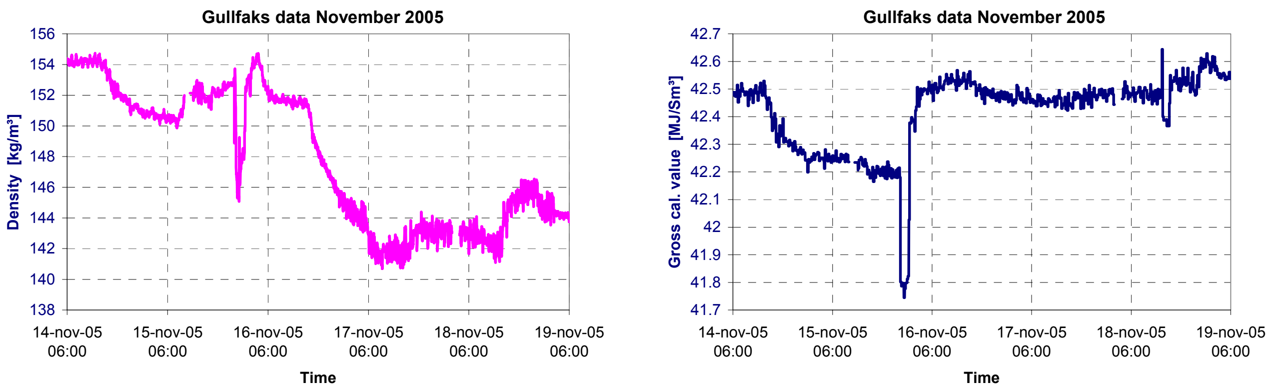

Figure 3 Density (left) and gross calorific value (right) for the gas through USM1 of the metering station at Gullfaks C, in the period November 14 – 19, 2005. Data based on GC measurements, serving as reference values here.

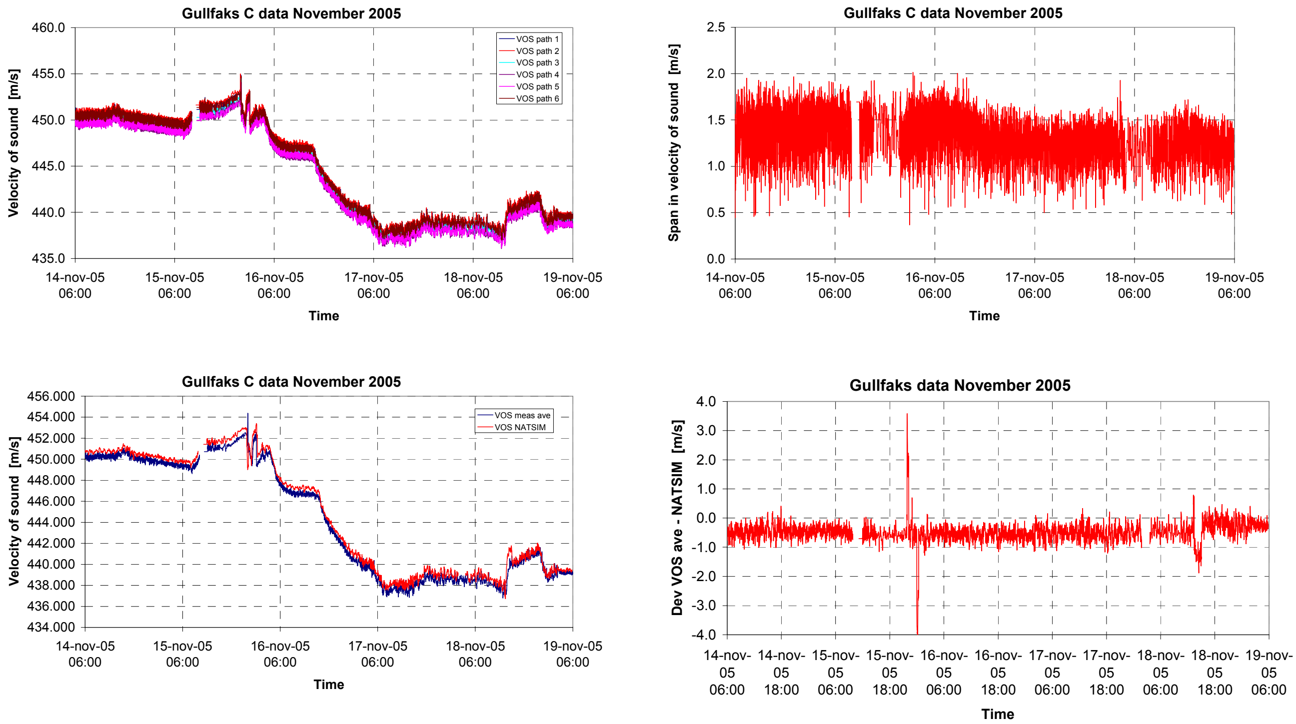

Figure 4 Measured velocity of sound (6 paths) (upper left), and span of the 6 measured velocities of sound (upper right). The average of the 6 measured velocities of sound (from various paths), and the calculated velocity of sound (from gas composition) (lower left), and the deviation between these two (lower right). The data are taken from USM1 of the metering station at Gullfaks C, in the period November 14 – 19, 2005.

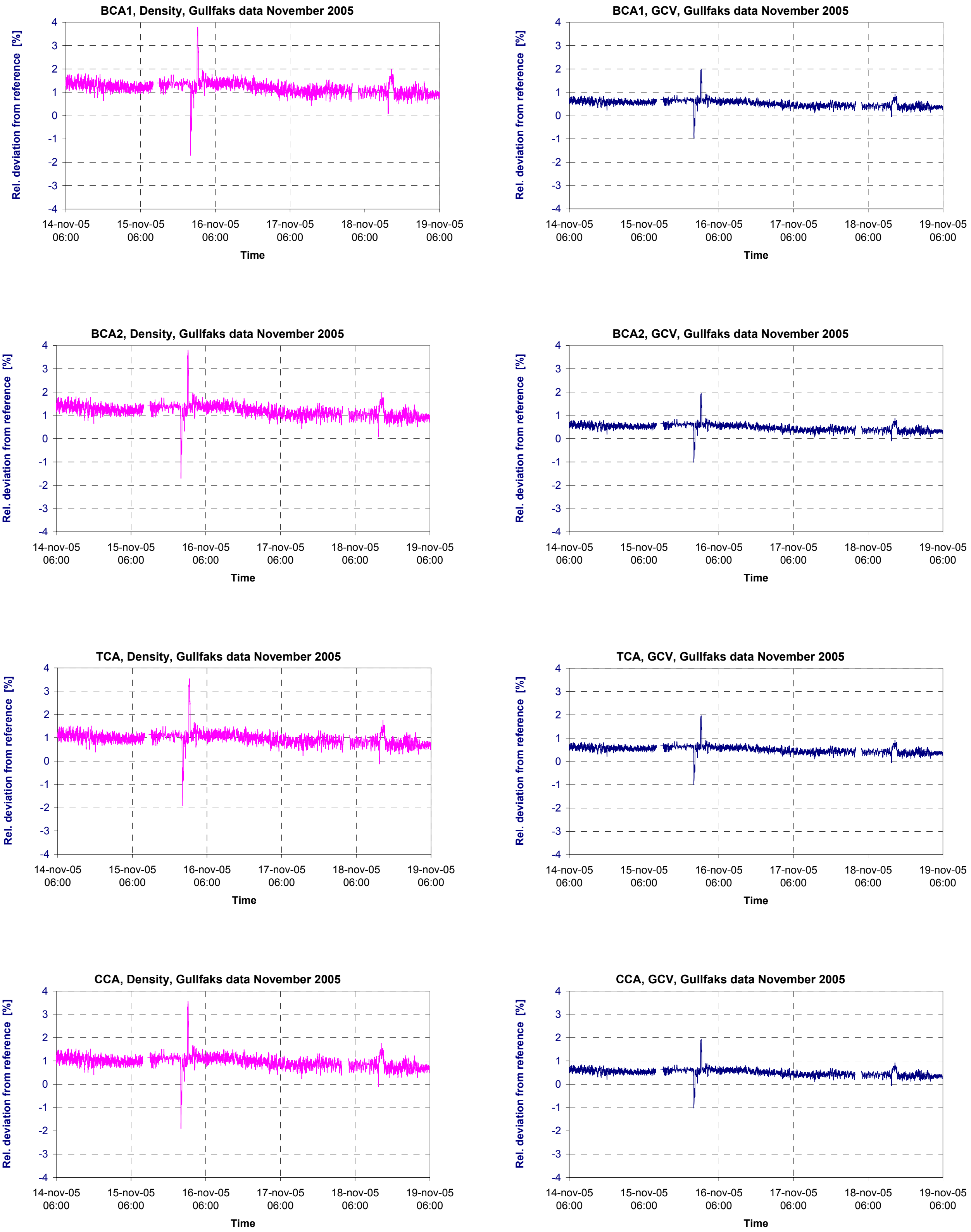

Figure 5 Deviation from reference for the calculated density (left) and GCV (right) from the measured velocity of sound. From the top and downwards, the BCA1, BCA2, TCA and CCA schemes are used. The data are taken from USM1 of the metering station at Gullfaks C, in the period November 14 – 19, 2005.

3.4 May and December Data

In addition to the November 2005 measurement series described above, two more series have been analysed. These are 3 days of data from December 2005 using the same USM as in November (USM 1), and 3 days of data from May 2005 using the other USM (USM 2). In Fig 6, deviation between average measured VOS and calculated VOS (from gas composition) is shown to the left, and deviation from reference for calculated density and GCV (from VOS) to the right.

For the December 2005 data, it can be seen that the deviation between average measured VOS and calculated VOS (from gas composition) on average is close to 0 m/s. The deviation from reference for the density and GCV are closer to the algorithm uncertainty (0.6 % for density and 0.3 % for GCV). This indicates again that for lower pressures, where the algorithm uncertainty is smaller, much lower uncertainties may be obtained for the calculated density and GCV, provided that the uncertainty in the measured VOS is small.

For the other USM (May 2005 data), the VOS is about 2 m/s off compared to calculated VOS values from gas composition. This has an immediate effect on the deviation from reference for the calculated density and GCV, as can be seen in Fig. 6. Again this illustrates that precise measurement of the VOS is a key parameter for precise calculation of density and GCV from VOS.

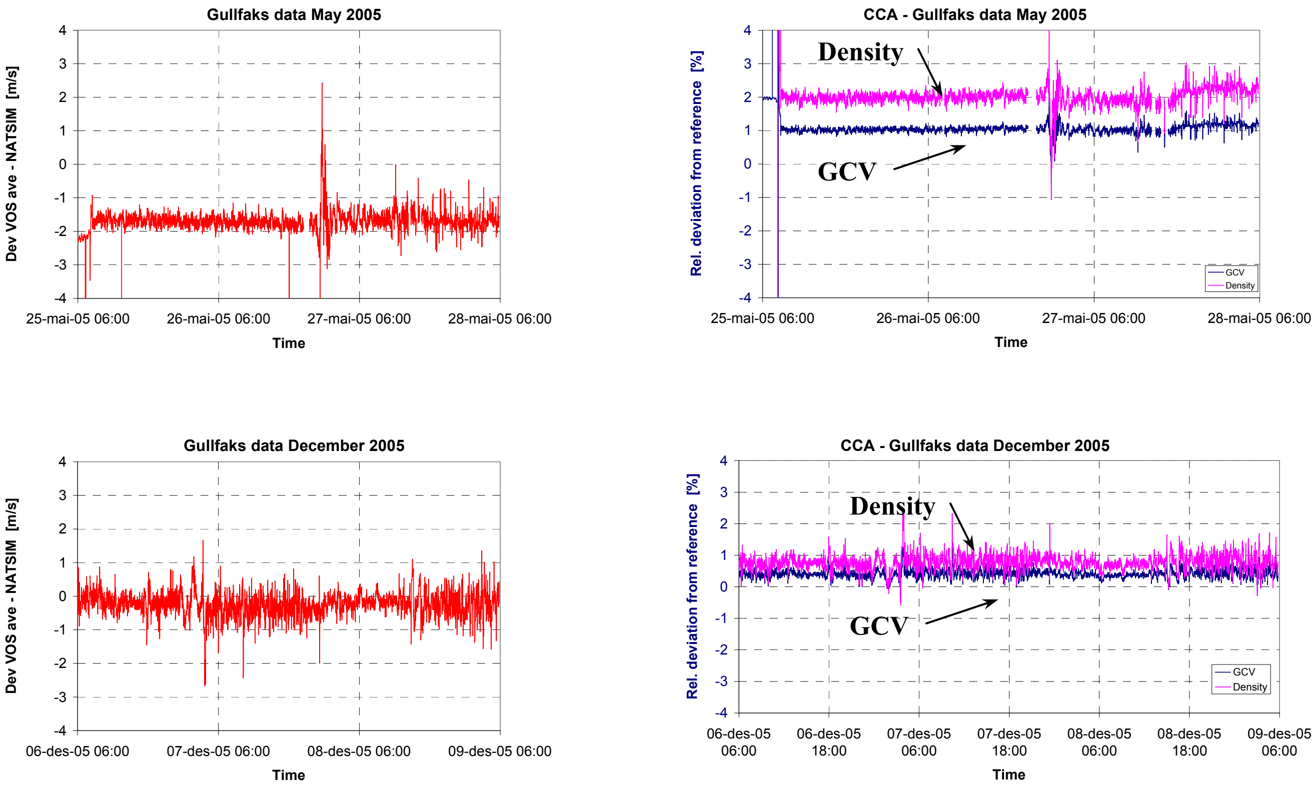

Figure 6 The difference between the average of the measured velocity of sound values (6 paths) and the calculated velocity of sound (from gas composition) (left), and deviation from reference for the calculated density and GCV (right) from the measured velocity of sound, within the CCA scheme. The data are taken from USM2 of the metering station at Gullfaks C, in the period May 25 – 28, 2005 (upper figures) and from USM1 of the metering station at Gullfaks C, in the period December 6 – 9, 2005 (lower figures).

4 DRAUPNER DATA

Draupner is a riser production platform, and a central point in the gas pipe network in the Norwegian Sector of the North Sea. Its main function is to monitor pressure, volume and quality. There are pipes to and from various offshore and onshore installations, in addition to direct export pipes to France and Germany.

4.1 Metering Station

At Draupner, there are 12 measurement points each equipped with a 4-path USM. In addition, each of the lines are equipped with pressure, temperature and density measurements. On 4 lines (denoted here as USM 1 – USM 4) there is also online gas chromatography for gas composition measurements.

From the USMs, measured velocity of sound is taken as input to the density and calorific value calculation algorithms, in addition to measured pressure and temperature. The gas composition measured by the gas chromatograph (for USM 1 – USM 4) can be used for calculation of reference values, and as a basis for input (when CCA, TCA and BCA2 are used) of gas composition data to the algorithm.

A 24-hour measurement period has been analysed for each line. For all lines, there are output data every five minutes.

For two of the meters (USM 3 and USM 1), detailed results will be presented. For the other meters, a short comment will be given at the end of the section.

4.2 Draupner – USM 3

As for the Gullfaks results, first, the algorithm uncertainty will be examined. This is presented in Fig. 7, where the deviation from reference for the calculated density (left) and GCV (right) is given for a typical gas at USM3, for exact input parameters (gas composition, pressure, temperature and velocity of sound). The pressure is 140 bar, and results are shown over a temperature range from -5 °C to +10 °C, which will be seen to be typical for the metering station. For a temperature of 7 °C, a deviation from reference of about 0.2 % is expected for density and about 0.1 % for GCV. The results from the measured data presented below should be interpreted with this in mind.

The pressure is quite stable at around 140 bara and the temperature is stable of around 7 °C, see Fig 8.

The density and GCV of the gas through the metering station (as calculated from GC data for reference) is shown in Fig. 9. It can be seen that the density varies between 150 and 155 kg/m³, while the GCV varies between 39 and 40 MJ/Sm³.

As mentioned in section 3, a key input to the algorithm is the velocity of sound measured by the USM. The uncertainty of this VOS is of importance for the uncertainty of the estimated density and GCV. In Fig. 10, upper left figure, the measured VOS by the 4 paths are shown. The span between these 4 measured VOS is shown in the upper right figure. This span is somewhat less than 2 m/s.

In the lower left figure of Fig. 10, the average VOS (from the 4 acoustic paths) is compared to the VOS as calculated from the GC-measured gas composition, and the pressure and temperature. In the lower right figure, it is seen that the deviation between the average measured VOS and the calculated VOS (from gas composition) is around 1 m/s. Effects of several tenths of a per cent are therefore to be expected on the calculated density and GCV, from the uncertainty of the velocity of sound.

In Fig. 11, the deviation from reference for the calculated density and GCV from the VOS is presented within the BCA1, BCA2, TCA and CCA schemes. First, by comparing BCA1 (where an average North Sea gas composition is assumed) and BCA2 (where typical N2 and CO2 contents from USM 3 are used), there are significant differences between the results both for density and GCV. The GCV changes with about 1 %, while the density by several tenths of a percent by switching from BCA1 to BCA2. This can be explained by the CO2 and N2 content that is estimated by a typical value for USM3-gas in BCA2, while the average value used in BCA1 does not fit to this metering station. By going from BCA2 to TCA, there is another significant change. This is due to the hydrocarbon gas composition. In this case it means that the hydrocarbon gas composition deviates so much from the average North Sea composition that there is an effect of this (the difference between BCA2 where this effect is not accounted for and TCA where it is accounted for). The difference between CCA and TCA is small. This means that the small gas composition fluctuations during the 24-hour period will not significantly affect the results.

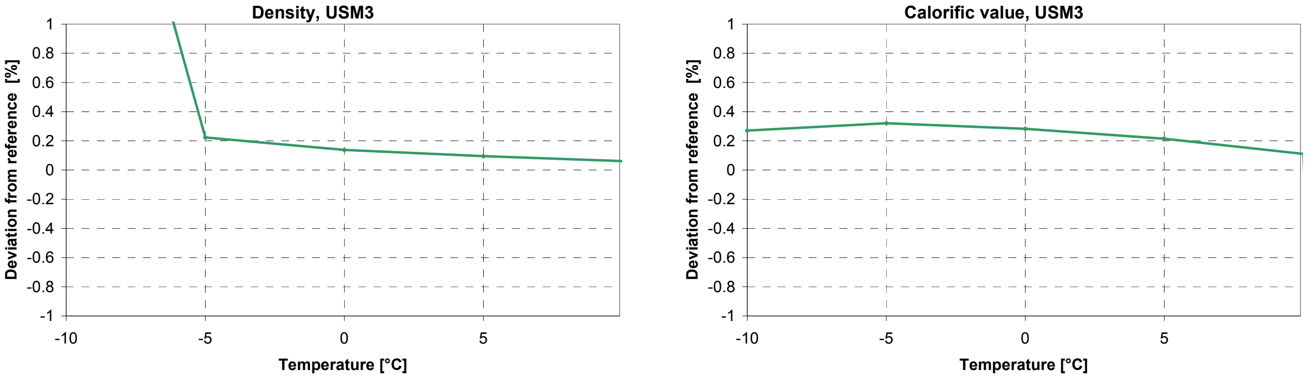

Figure 7. Algorithm uncertainty for density (left) and GCV (right) for the natural gas through USM3 on Draupner, for temperatures from -10 to 10 °C and a pressure of 140 bara.

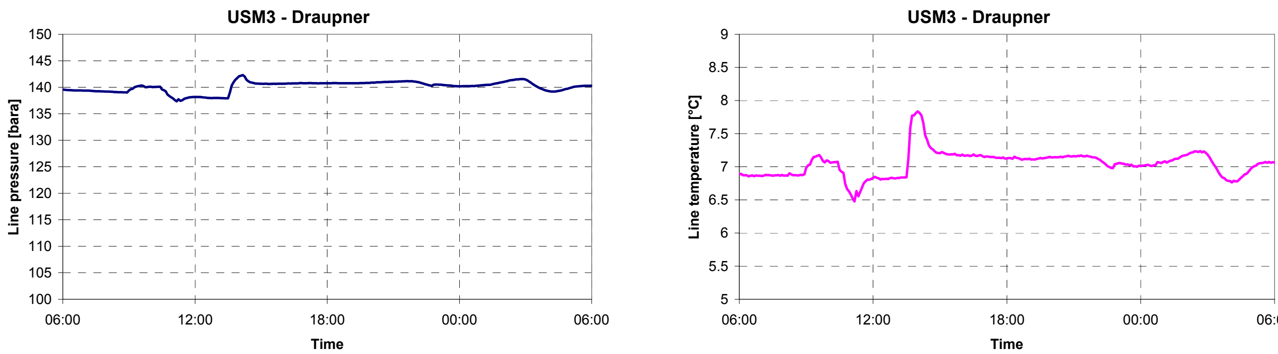

Figure 8 Line pressure (left) and temperature (right) at USM3 of Draupner over the measurement period of 24 hours.

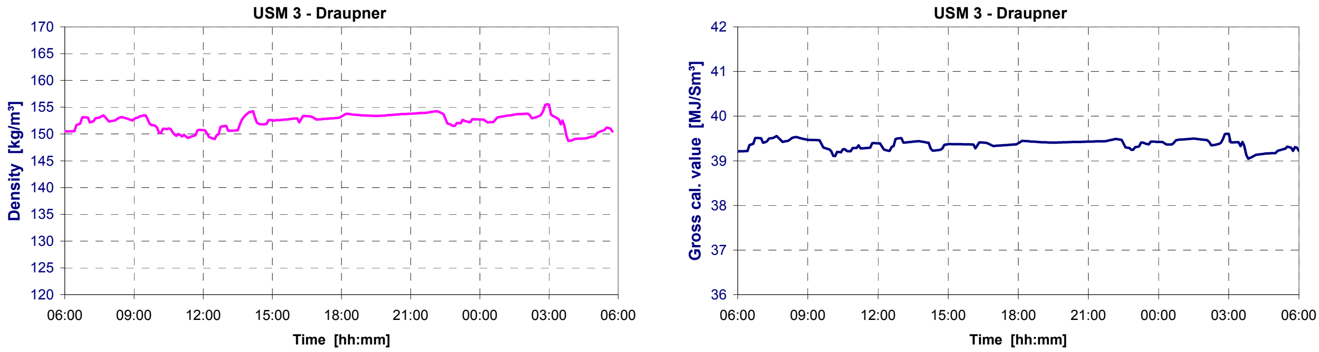

Figure 9 Density (left) and gross calorific value (right) at USM3 of Draupner over the measurement period of 24 hours. Data based on GC measurements, serving as reference values here.

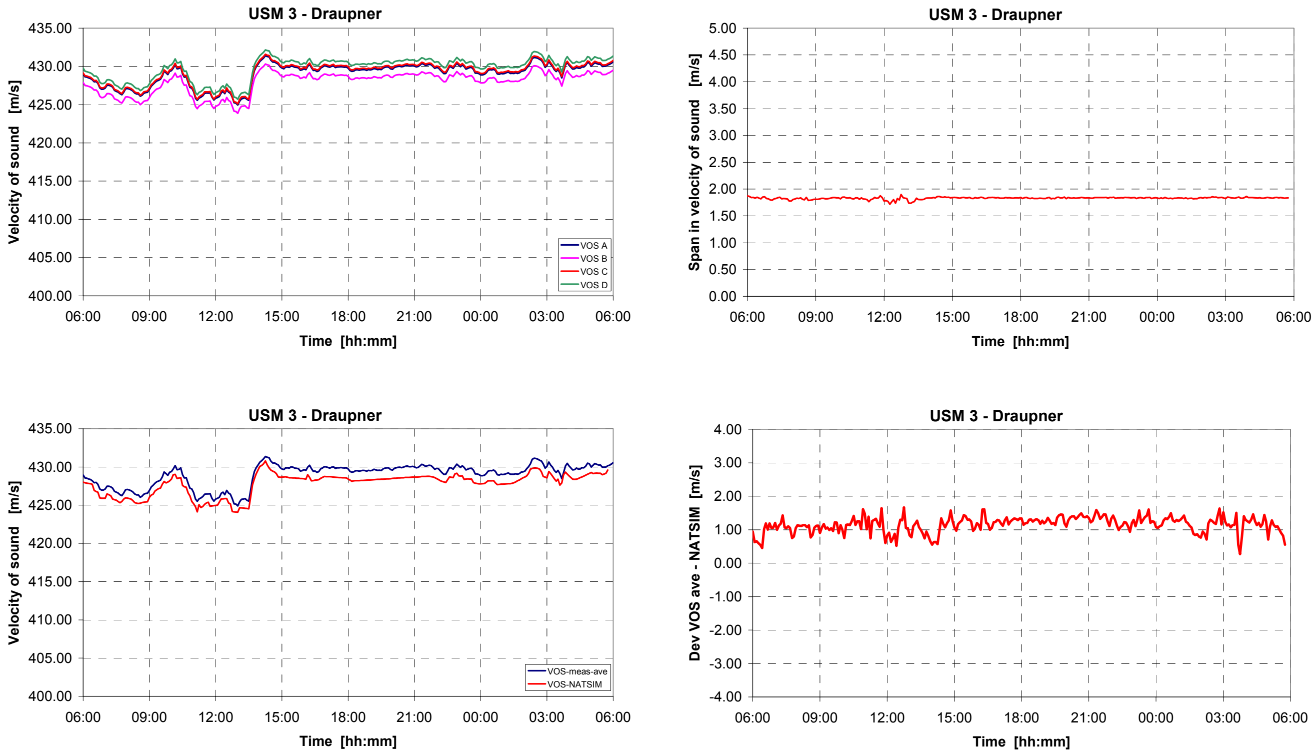

Figure 10 Measured velocity of sound (4 paths) (upper left), and span of the 4 measured velocities of sound (upper right). The average of the 4 measured velocities of sound (from various paths), and the calculated velocity of sound (from gas composition) (lower left), and the deviation between these two (lower right). The data are taken from USM 3 of Draupner over the measurement period of 24 hours.

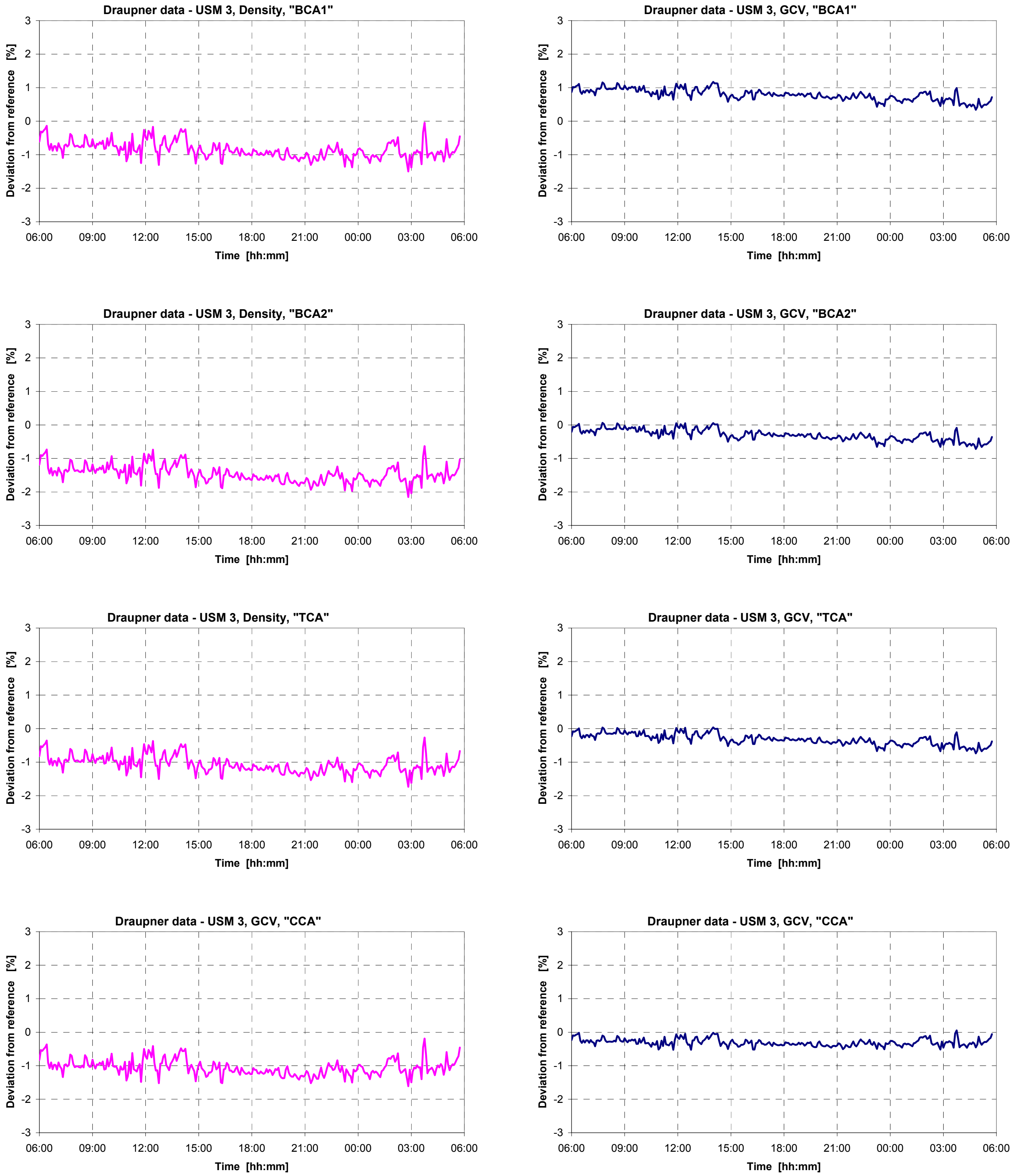

Figure 11 Deviation from reference for the calculated density (left) and GCV (right) from the measured velocity of sound. From the top and downwards, the BCA1, BCA2, TCA and CCA schemes are used. The data are taken from USM 3 at Draupner over the measurement period of 24 hours.

As can be seen in Fig. 11, the deviation from reference for the calculated density is about -1 %. The algorithm uncertainty, see above, gives about +0.2 % in deviation from reference. VOS deviation of -2 m/s gives about -1.3 % in deviation from reference of the density. Combination of these effects gives a deviation from reference of about -1.1 %. This is in consistence with Fig. 11.

Similarly, the deviation from reference for the calculated GCV is about -0.3 to -0.4 %. Here, the algorithm uncertainty gives about 0.1 % and the VOS about -0.5 %. Combination of these effects gives a deviation from reference of about –0.4 %. This is in consistence with Fig. 11.

Like for the Gullfaks results, this therefore illustrates that the dominating uncertainty contributions come from the algorithm uncertainty (smaller here than for Gullfaks) and from the velocity of sound. As the algorithm uncertainty may be negligible for low pressure applications, the uncertainty of the measured velocity of sound again is a key parameter for the uncertainty of the calculated density and GCV, in addition to the estimate of the nitrogen and carbon dioxide content.

4.3 Draupner – USM 1

Similar to USM3, the algorithm uncertainty can be found for the USM1 as about 0.3 % for density and about 0.2 % for GCV, see Fig. 12.

The pressure is quite stable at around 140 bara at the beginning of the period, going down to around 130 bar at the end. The temperature is stable of around 7 °C, see Fig 13

The density and GCV of the gas flowing through the metering station (as calculated from GC data, for reference) are shown in Fig. 14. The density starts at about 145 kg/m³ and decreases gradually to below 140 kg/m³. In the three last hours of the period, there is a large and continuous increase in the density. This can also be seen in the GCV that is stable at around 39 MJ/Sm³ except for the last three hours where there is a large and continuous increase in the GCV. This is because gas from another field is mixed into the gas line in this time interval. Therefore, there is not a stable gas composition in this period.

Two and two of the four acoustic paths in the USM measures about the same VOS. There is a span of about 3 m/s between all four paths, see Fig. 15. However, the deviation between the average of the measured VOS and the calculated VOS (from gas composition) is around –1 to 0 m/s, except for the last three hours when an unstable gas composition is observed.

In Fig. 16, the deviation from reference for the calculated density and GCV from the VOS is presented within the BCA1, BCA2, TCA and CCA schemes. In this case, typically the deviation in density is about 0-1 % while for GCV it is around 0 – 0.5 %. For the last three hours when the gas composition is unstable, the deviation is larger.

As can be seen in Fig. 16, the deviation from reference for the calculated density is about 0 – 1 %, except for the last three hours when the gas composition is unstable and the deviation is larger. For long periods (before the last three hours), the deviation is somewhat above 0.5 %. The algorithm uncertainty, see above, gives about +0.3 % in deviation from reference. VOS deviation of 0.5 m/s gives about 0.3 % in deviation from reference of the density. Combination of these effects gives a deviation from reference of about 0.6 %. This is in consistence with Fig. 16.

Similarly, the deviation from reference for the calculated GCV is about 0 – 0.5 %, except for the last three hours when the gas composition is unstable and the deviation is larger. For long periods (before the last three hours), the deviation is between 0.3 and 0.5 %. The algorithm uncertainty, see above, gives about +0.2 % in deviation from reference. VOS deviation of 0.5 m/s gives about 0.2 % in deviation from reference of the density. Combination of these effects gives a deviation from reference of about 0.4 %. This is in consistence with Fig. 16.

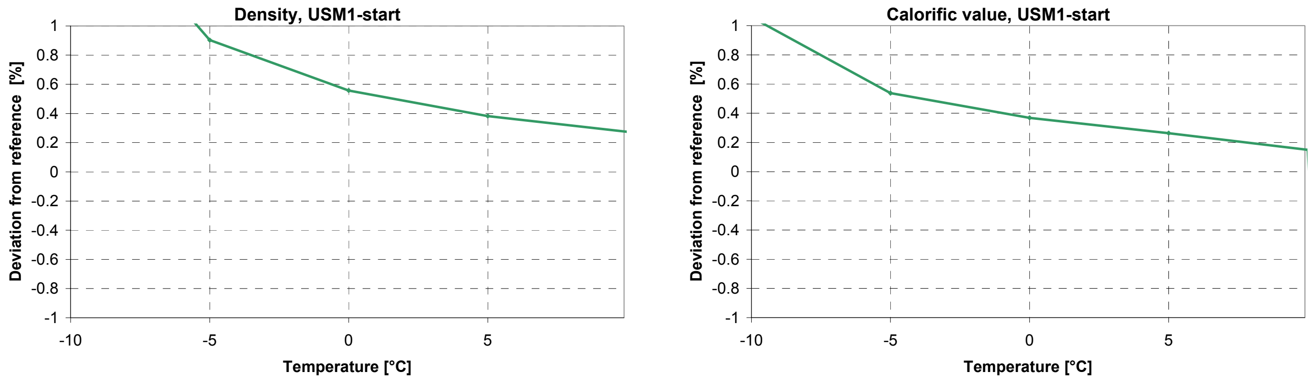

Figure 12. Algorithm uncertainty for density (left) and GCV (right) for the natural gas through USM1 on Draupner, for temperatures from -10 to 10 °C and a pressure of 140 bara.

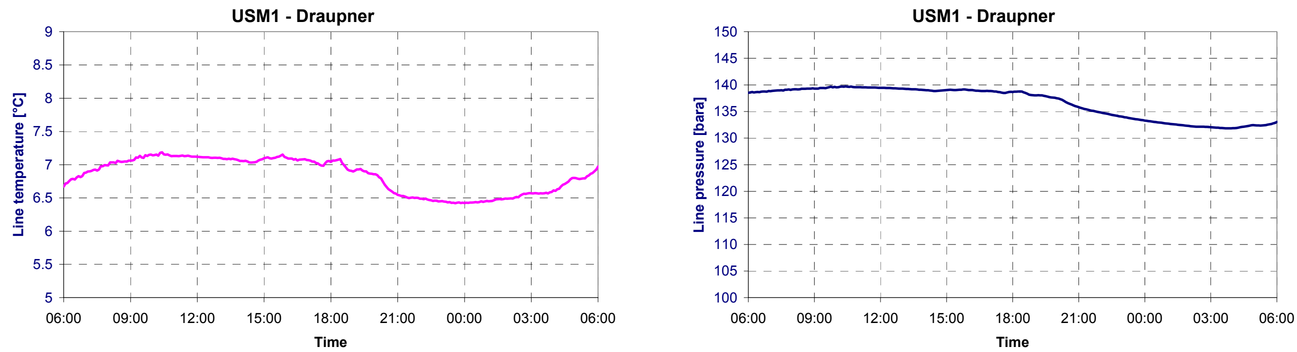

Figure 13 Line pressure (left) and temperature (right) at USM1 of Draupner over the measurement period of 24 hours.

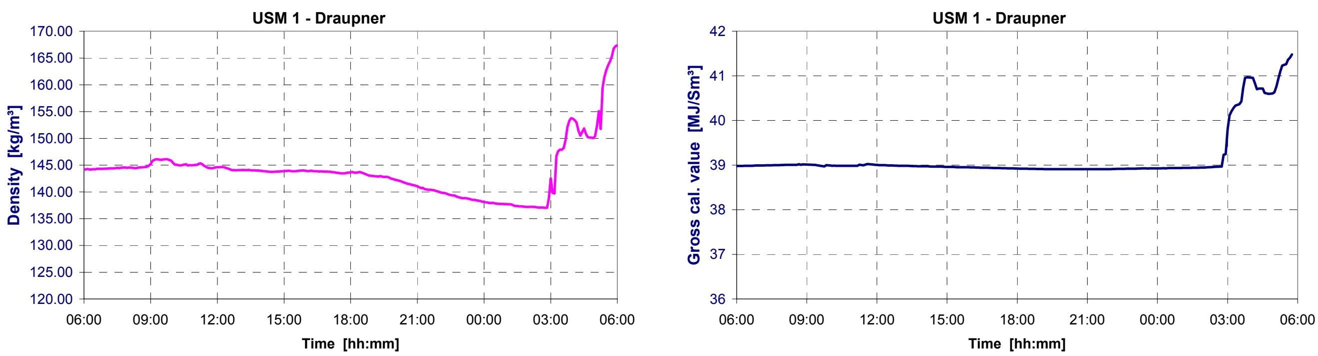

Figure 14 Density (left) and gross calorific value (right) at USM 1 of Draupner over the measurement period of 24 hours. Data based on GC measurements, serving as reference values here.

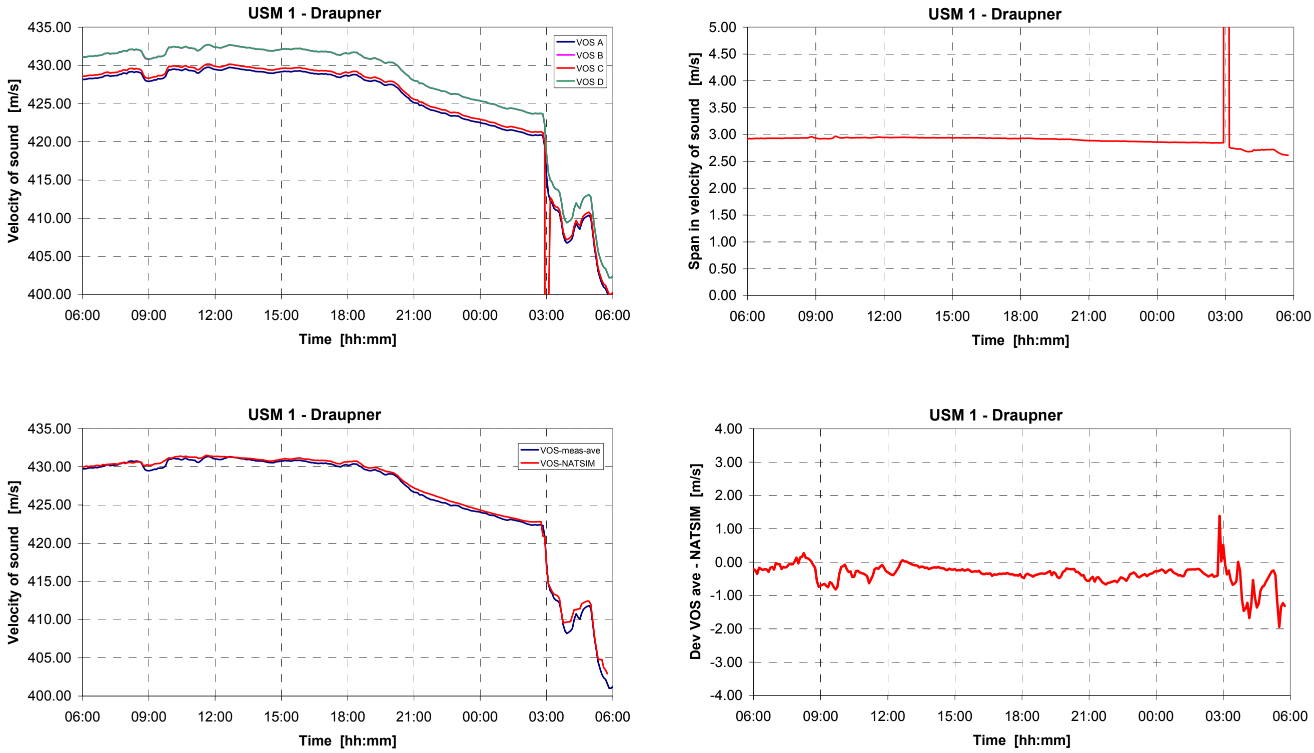

Figure 15 Measured velocity of sound (4 paths) (upper left), and span of the 4 measured velocities of sound (upper right). The average of the 4 measured velocities of sound (from various paths), and the calculated velocity of sound (from gas composition) (lower left), and the deviation between these two (lower right). The data are taken from USM 1 of Draupner over the measurement period of 24 hours.

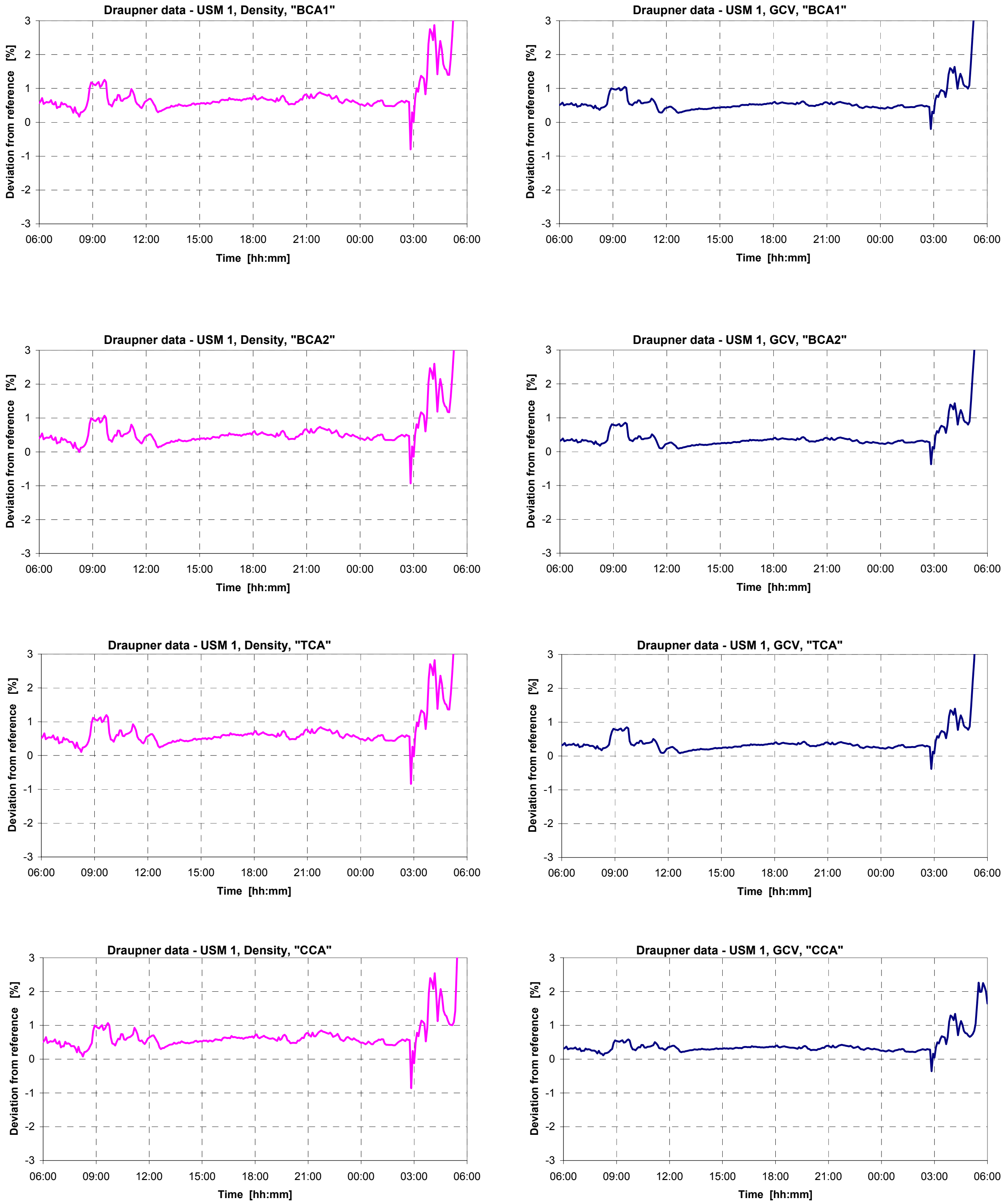

Figure 16 Deviation from reference for the calculated density (left) and GCV (right) from the measured velocity of sound. From the top and downwards, the BCA1, BCA2, TCA and CCA schemes are used. The data are taken from USM 1 at Draupner over the measurement period of 24 hours.

4.4 Draupner – Other Meters

The results from USM 2 are quite similar to USM 1, as the same type of gas goes through both meters. The same is the case with USM 4 relative to USM 3.

The other lines (USM 5 to USM 12) have not online GC that could have been used as reference. Results from these lines will therefore not be presented here.

5 SUMMARY AND CONCLUSIONS

Since the methods presented here require no additional instrumentation in the metering station, apart from the USM itself and the pressure and temperature sensors, existing USM metering stations can be updated to measure the gas density and the GCV (i.e. the mass and energy flow rates), by a software upgrade only. This may be of interest e.g. for USM based check metering stations and other USM metering stations in which density and/or GCV measurement are not made today. Also for metering stations where one or several GCs are installed, the method may be of relevance, as discussed in the introduction.

It may be noted that while the results discussed in [1] were related to the uncertainty of the algorithms involved for calculation of density and GCV from the measured VOS, i.e. only a part of the total measurement uncertainty, the results given in the present paper relate to the total measurement uncertainty for the density and GCV. This means that uncertainty of the input parameters (pressure, temperature, velocity of sound and gas composition (i.e. BCA1, BCA2, TCA or CCA)) is covered in addition to the algorithm uncertainty.

The results from testing on various North Sea gas field data using USMs of various manufacturing types, indicate that the methods for GCV and density measurement are of high interest for several applications, including natural gas quality check, allocation, redundancy and quality check of the metering station instrumentation, with accuracy close to or in some cases even within fiscal accuracy.

The tests reported here indicate that as long as the typical nitrogen and carbon dioxide content of the gas is known (i.e. within the BCA2, TCA and CCA schemes), the algorithm uncertainty and the uncertainty of the measured velocity of sound are the main uncertainty contributors. The algorithm uncertainty is in many applications low, and can, if the gas composition to some extent is known (e.g. TCA), be accounted for because it is a systematic uncertainty term. For the examples in this paper the algorithm uncertainty is between 0.1 % and 0.6 %. For lower pressures than the 140 – 160 bara experienced here, the algorithm uncertainty will be lower.

In Figs. 17 and 18, the results when using the TCA-scheme are represented for all three measurement periods on Gullfaks, and for USM 1 and USM 3 on Draupner. The deviations from reference for the calculated density (left) and GCV (right) are here corrected for the algorithm uncertainty. As pointed out in Sections 3 and 4, the uncertainty of the VOS is here the main uncertainty contribution. In the December 2005 data from Gullfaks (lower figures in Fig. 17), the deviation between the measured and calculated VOS is close to 0 m/s (much less than 1 m/s). In this case it is seen that the deviation from reference for the density and the GCV is low. For the other measurements, the VOS deviates more from the calculated, indicating a larger uncertainty in the VOS. In these cases the deviation from reference for the calculated density and GCV is larger.

The measurement of the velocity of sound by USMs ends up as a key parameter to this method. Deviation from reference velocity of sound (calculated from gas composition) of up to 2 m/s has been observed, giving an uncertainty contribution of about 1.2 % for density and 0.6 % for GCV. This demonstrates the importance of the VOS measurement in USMs. Today, flow calibration addresses the flow velocity and not the velocity of sound, and there is a need for traceable methods for measurement of the velocity of sound by USMs. This puts requirements to improved control of transit time measurements in the USM, such as systematic effects due to e.g. (a) transducer time delay correction (“dry calibration” values),

(b) diffraction time delay correction, (c) variation of these corrections with P, T, pipe diameter and gas composition, (d) sound refraction (flow profile effects on transit times), (e) finite beam effects, and (f) cavity flow effects.

In addition to the establishment of traceable methods for VOS measurements in USMs, there are several other possible next steps for this application. These include compensation of and possible reduction of the algorithm uncertainty. Implementation of the algorithm in a flow computer (for continuously on-line use of the method in stead of the post processing approach that has been used in this work) should be carried out. The results from the post processing approach that has been used here is equivalent to the on-line implementation. However, an on-line test will be more flexible (more data can be produced) and is of course considered as the final proof of a method. Furthermore tests with data from more fields, including a wide variation in pressure, temperature and gas composition, should be carried out.

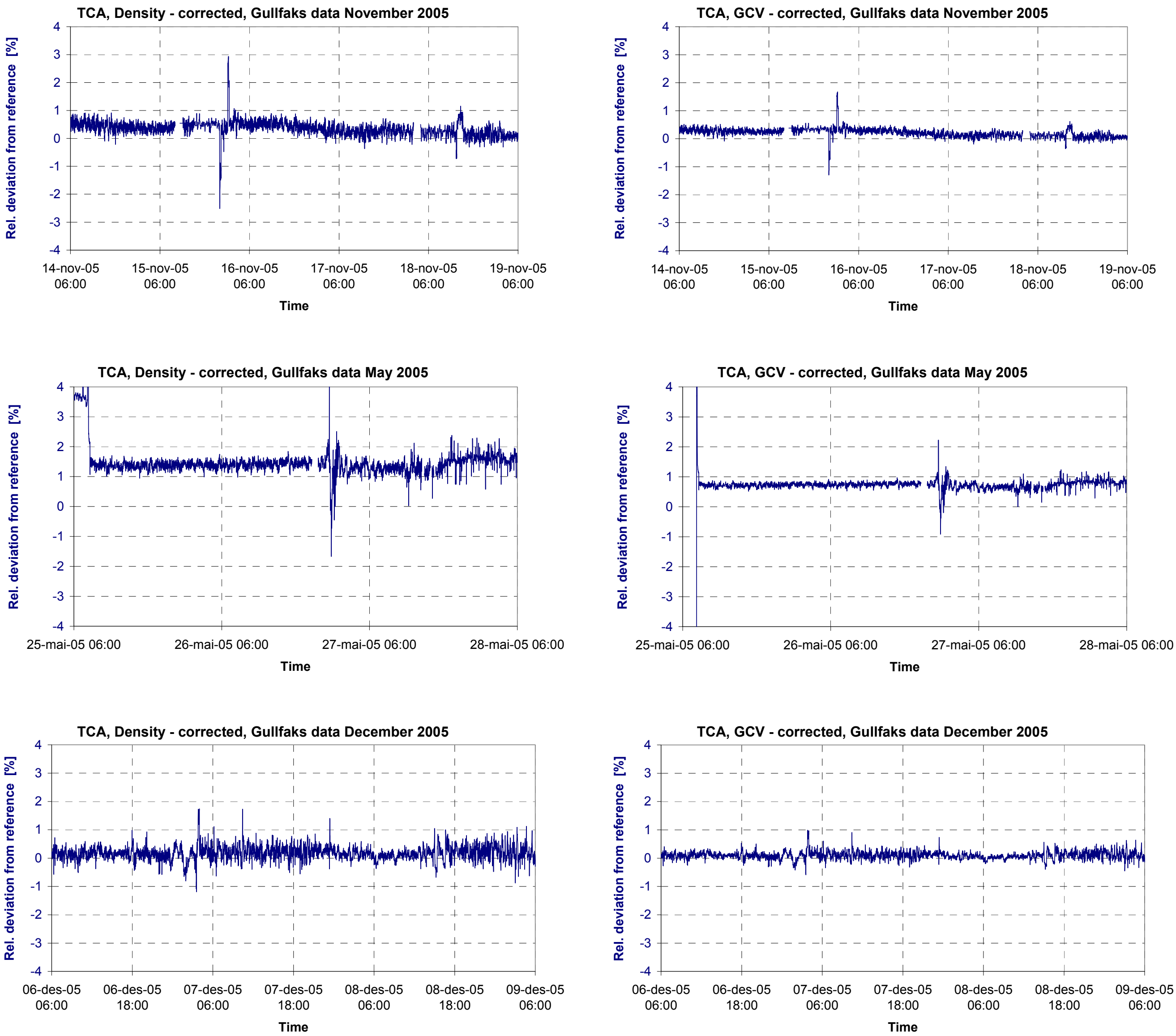

Figure 17 Deviation from reference for the calculated density (left) and GCV (right) from the measured velocity of sound, for the TCA-scheme. The results are corrected for the algorithm uncertainty. The data are taken from the Gullfaks C metering station (USM1, November 14 – 19, 2005 (upper), USM2, May 25 – 28, 2005 (in the middle) and USM1, December 6 – 9, 2005 (lower).

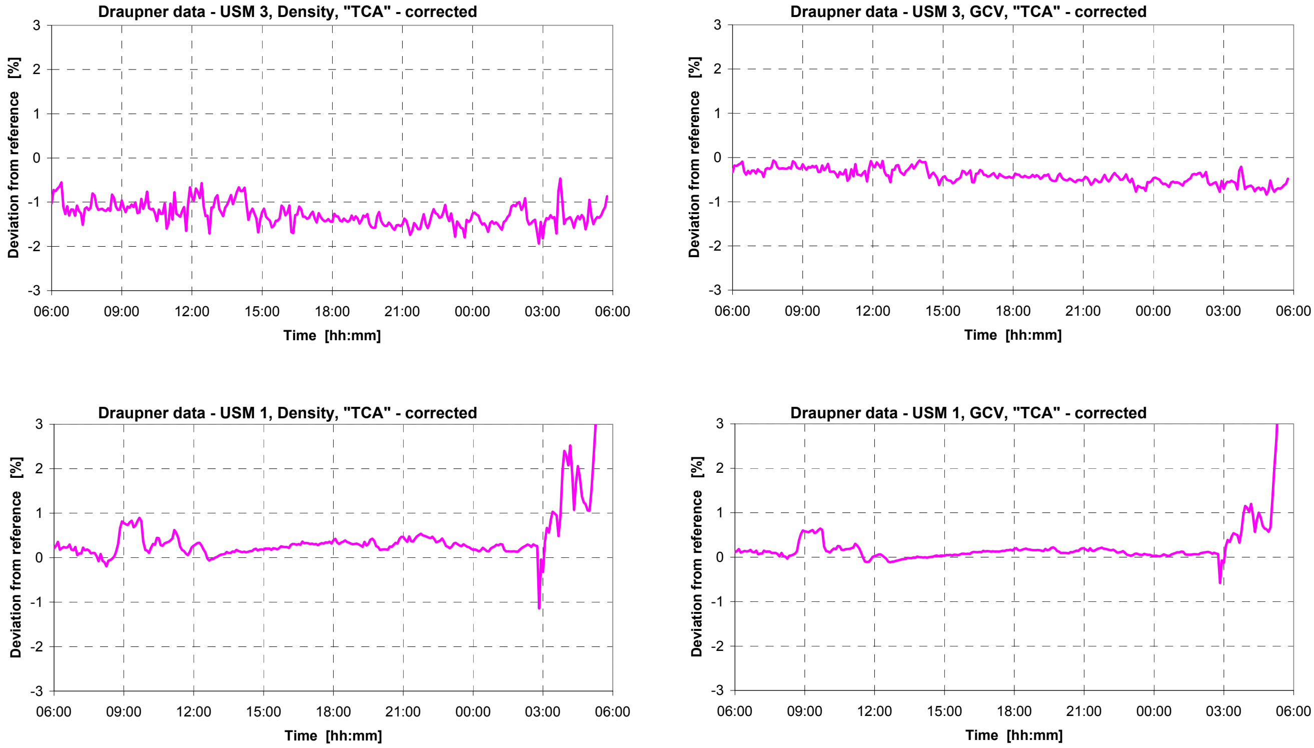

Figure 18 Deviation from reference for the calculated density (left) and GCV (right) from the measured velocity of sound, for the TCA-scheme. The results are corrected for the algorithm uncertainty. The data are taken from the 24-hour measurement period at Draupner. Upper figures: USM3. Lower figures: USM1.

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7 REFERENCES

[1] Frøysa, K.-E. and Lunde, P., "Density and calorific value measurement in natural gas using ultrasonic flow meters", Proc. of 23rd International North Sea Flow Measurement Workshop, Tønsberg, Norway, 18-21 October 2005.