Nitrogen subtraction on reported CO_2 emission using ultrasonic flare gas meter

Kjell-Eivind Frøysa, Christian Michelsen Research AS, Bergen, Norway
Henning Ekerhovd, StatoilHydro ASA, Kollsnes, Norway
Atle A. Johannessen, Fluenta AS, Bergen, Norway

1 INTRODUCTION

The CO_2 emission from flaring is typically measured by ultrasonic flare gas meters. In order to reduce the CO_2 emissions, nitrogen purging is often utilized in situations of low flow in the flare. At such purging conditions, a significant amount of the gas flow in the flare is nitrogen. The CO_2 emission data are to be reported to authorities. In order to get a realistic report of the CO_2 emissions, the nitrogen purging should be subtracted from the total combustible gas flow.

Ultrasonic flare gas meters measure primarily the flow velocity through the flow meter. From this, the volumetric flow rate at line conditions can be calculated using dimensions of the pipe, and by using measured pressure and temperature, the volumetric flow rate at a reference condition (for example 15 °C and 1.01325 bar) can be calculated. Such flow meters also measure the velocity of sound. From this measured velocity of sound, in combination with pressure and temperature, the density of the flare gas is estimated, and also the mass flow rate can thus be found. In the models relating the velocity of sound to the density, there are underlying assumptions regarding the gas composition. Typically, the assumption is that the gas contains hydrocarbons, in addition to up to some few percents of inert gases like nitrogen and carbon dioxide. Through the measured velocity of sound there is also a potential for estimation of nitrogen molar fraction in cases where nitrogen purging is a significant part of the flow. In the present paper, tests of such an algorithm in real flow tests at StatoilHydro's process plant at Kollsnes is reported.

At StatoilHydro's process plant at Kollsnes outside Bergen, Norway (see Fig. 1), wet components are separated from the natural gas from the fields Troll, Kvitebjørn and Visund. For the three flaring systems at Kollsnes, a nitrogen subtraction algorithm has been implemented based on the traditional measurements of the ultrasonic flare gas meter. In the present paper, flow tests addressing nitrogen subtraction will be reported. The flare gas meter is tested in series with a fiscal multipath ultrasonic gas flow meter, and the gas quality is monitored by gas chromatography and manual sampling and laboratory analysis. In addition, new functionality for nitrogen estimation has been implemented in the ultrasonic flare gas meter, and a new test with this new functionality has been carried out.

Section 2 of the paper gives some more background on the problem. Section 3 contains a closer description of the Kollsnes process plant, focused on issues of relevance for the present paper. In Section 4, the flow tests are described. Section 5 contains a general discussion of the problem, before the conclusions are made in Section 6.

Figure 1 Photo of StatoilHydro's process plant at Kollsnes.

2 BACKGROUND

CO_2 emission in flaring system has according to the MRG [1] to be reported as activity data (quantity of flare gas) and CO_2 emission factor. The CO_2 emission is then the product of these two quantities. There are two commonly used alternatives for these quantities. These are (i): activity data in mass and CO_2 emission factor in mass CO_2 per mass flare gas, and (ii): activity data in standard volume and CO_2 emission factor in mass CO_2 per standard volume flare gas.

In a nitrogen purging case, there are two ways of determining the CO_2 emission via the activity data and CO_2 emission factor. These are (i): to subtract the nitrogen purging from the activity data, and to use a CO_2 emission factor representative for the quality of the flare gas in the case of no extra nitrogen purging, or (ii): to include the nitrogen purging in the activity data and to apply a CO_2 emission factor that reflects the extra nitrogen content due to nitrogen purging (i.e. a smaller value for the CO_2 emission factor than in the first case).

The activity data in a flaring system is typically measured by an ultrasonic flare gas meter. This meter initially measures the flow velocity and thus the volumetric flow rate at line conditions. In order to convert to volume at standard pressure and temperature, measurement of pressure and temperature close to the flare gas meter have to be carried out. In order to convert to mass flow rate (when relevant due to activity data in mass), the density can be obtained from an internal algorithm in the flare gas meter that calculates the density from pressure, temperature and measured velocity of sound.

There are several methods for estimating the CO_2 emission factor for a flare gas system. These include:

- A standard value in order not to underestimate the value
- A value based on calculated gas composition from process simulations
- A value based on the gas composition of some few gas samples taken from the flare gas and analyzed in a laboratory
- A value based on the gas composition of regular gas samples on e.g. daily, weekly or monthly basis, taken from the flare gas and analyzed in a laboratory
- Online gas chromatography

All these methods have advantages and disadvantages, both in flaring systems with and without nitrogen purging. These issues will not be addressed in detail here. However, two of the issues related to online gas chromatography in flaring systems are the time response and the representativity of the sample. In a flaring system where rapid changes of gas quality may happen, the uncertainty of the average CO_2 emission factor over a time period may therefore be large.

As an alternative to installing online gas chromatography, a metering regime with the potential of subtraction of nitrogen purging from the activity data is tested out. This system estimates the amount of nitrogen in the flare gas, and carries out the subtraction. The system is based on the measured quantities like flow rate, velocity of sound, pressure and temperature. All these quantities are measured online and continuously in the flow.

3 PRESENT SITUATION AT KOLLSNES

At the StatoilHydro plant at Kollsnes, there are three flare gas lines, in addition to three export lines each equipped with gas chromatographs. This means that there is a good control over the typical natural gas that is present on the plant.

The flare gas lines include (i): the high pressure flaring system, (ii): the low pressure flaring system and (iii): the maintenance flaring system. Each of these lines is equipped with an ultrasonic flare gas meter, in addition to double pressure and double temperature sensors. The metering system is monitored according to condition-based maintenance scheme. This also includes the ultrasonic flare gas meter, where internal quality parameters are monitored. The ultrasonic flare gas meters have traditionally been set up to also provide the density of the flare gas. A typical flare gas metering station is illustrated in Fig. 2.

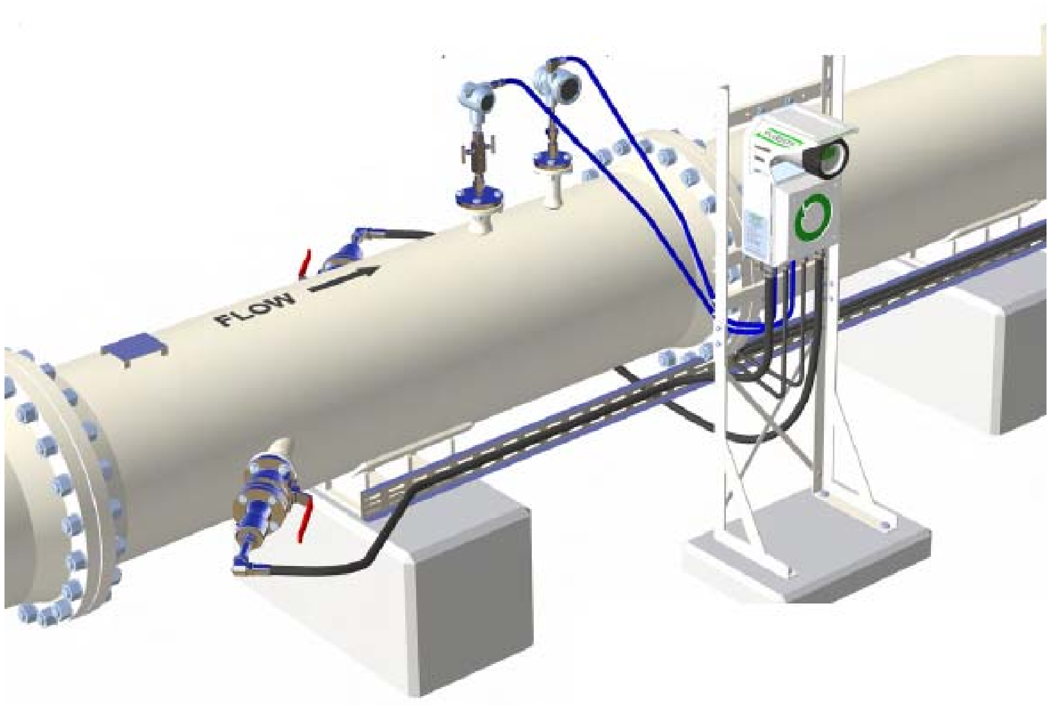

Figure 2 Typical set-up of an ultrasonic flare gas metering station.

From the gas density provided by the ultrasonic flare gas meter, the molar fraction of nitrogen is calculated in the flow computer. This calculation is based on an assumption that the flare gas consists of a natural gas part and nitrogen. In a normal set-up, the natural gas part of the flare gas is assumed to be equal to one of the export gases that are measured by online gas chromatography. The flow computer is set up and followed up by a fiscal metering system vendor. A typical example of an on-line report under nitrogen purging conditions is shown in Fig. 3.

The density algorithm, calculating the density from the measured velocity of sound, pressure and temperature is therefore a crucial part of the system. In 2009 this has been up-graded. There are at present two different options in the density algorithm. These are (i): flaring option and (ii): purging option.

Flaring option is typically used for high flow rates, where the flaring consists mainly of hydrocarbons. This option is similar to the traditional way of calculating the density in a flare gas meter. However, the measurements have been made more robust with respect to variations of gas composition. This is done by opening up for specification of a typical gas composition for the flaring at the specific plant. In particular, the specification of CO_2 and N_2 content can be relevant for the uncertainty of the estimated density. In cases where gas composition knowledge is not possible to provide, the algorithm uses default values and thereby works similar to the traditional density algorithms.

		Målt Gasskompossisjon			Brukt Gasskompossisjon		
					HP fakkel	LP fakkel	Vedl.fakkel
		Draupner	Sleipner	NGV	SLEIPNER	SLEIPNER	SLEIPNER
N2	(mol %)	1.05314	1.17447	1.20703	1.17447	1.17447	1.17447
CO2	(mol %)	1.83196	1.59735	1.54888	1.59735	1.59735	1.59735
C1	(mol %)	90.80219	91.06495	91.10398	91.06495	91.06495	91.06495
C2	(mol %)	5.26531	4.98032	4.92730	4.98032	4.98032	4.98032
C3	(mol %)	0.61399	0.65703	0.65983	0.65703	0.65703	0.65703
IC4	(mol %)	0.21362	0.25550	0.26683	0.25550	0.25550	0.25550
NC4	(mol %)	0.08676	0.10871	0.11441	0.10871	0.10871	0.10871
IC5	(mol %)	0.04311	0.05166	0.05263	0.05166	0.05166	0.05166
NC5	(mol %)	0.02553	0.03251	0.02941	0.03251	0.03251	0.03251
C6+	(mol %)	0.06439	0.07750	0.08969	0.07750	0.07750	0.07750

		Beregnet Gasskompossisjon		
		HP fakkel	LP fakkel	Vedl.fakkel
N2	(mol %)	92.75690	79.14800	81.30835
CO2	(mol %)	0.11707	0.33704	0.30212
C1	(mol %)	6.67431	19.21453	17.22384
C2	(mol %)	0.36502	1.05084	0.94197
C3	(mol %)	0.04815	0.13863	0.12427
IC4	(mol %)	0.01873	0.05391	0.04833
NC4	(mol %)	0.00797	0.02294	0.02056
IC5	(mol %)	0.00379	0.01090	0.00977
NC5	(mol %)	0.00238	0.00686	0.00615
C6+	(mol %)	0.00568	0.01635	0.01466

Figure 3 Snap-shot of the on-line report on estimated gas composition (Beregnet Gasskomposisjon) for the 3 flare gas lines at Kollsnes.

Purging option is typically used at low flow rates, where nitrogen may be a major part of the flare gas. In this option, the flare gas is assumed to consist of natural gas and nitrogen. The measured velocity of sound determines the fraction of each component. The natural gas composition has to be specified in order to use this option. The precision of this input is discussed in Section 5.

4 FLOW TESTS

The uncertainty of activity data and CO_2 emission factor in a flaring system with ultrasonic flare gas meter and subtraction of nitrogen has several contributions. Among these are the uncertainty of the measured flow rate, the uncertainty of the calculated density (in purging or flaring mode) and the uncertainty of the estimated nitrogen fraction (in purging mode). These three issues have been tested in dedicated flow tests at Kollsnes.

The flow test addressing flow rate had to be carried out before the test addressing density and nitrogen fraction. This was because there was only a short time window where the flow test could be carried out (explained below). At that time, the upgraded density algorithms were not yet ready for installation.

4.1 Flow rate

In 2009, a new high pressure pipe line from Kollsnes to the oil refinery at Mongstad was set in operation. This pipe line will provide Mongstad with Troll gas for the new gas power plant that will soon be set in operation. At Kollsnes the pipe line is equipped with two 6-path ultrasonic fiscal flow meters installed in parallel. Before the pipe line was set in operation, but after the metering station was installed, there was a possibility to route gas through one of the 6-path ultrasonic flow meters and then further to the high pressure flare equipped with an ultrasonic flare gas meter. This means that the same amount of gas was measured by both the 6-path fiscal flow meter at about 75 bar pressure, and by the ultrasonic flare gas meter at about 1 bar pressure. The pipe distance between the two meters was about 250 metres. This is accounted for in the analysis. The composition of this gas was in addition measured by online gas chromatography. In addition, gas samples were taken from the flare gas. These were analyzed in the laboratory at Kollsnes to provide gas composition.

It should here be commented that in addition to the Troll gas through the fiscal flow meter, the flaring also consists of a more or less constant background flaring of about 400 Sm^3/h. This background flaring is related to nitrogen purging and it consists therefore of significant amounts of nitrogen. It was not possible to stop this background flaring during the flow test. Therefore it should be expected that the ultrasonic flare gas meter measures a flow rate about 400 Sm^3/h larger than the 6-path ultrasonic fiscal flow meter.

The flow test was carried out at a flow rate of about 7500 Sm^3/h. This flow rate was held for about 30 minutes in order to simultaneously stabilize the flow through both meters in series. The flow rates measured in each flow meter during the test period are shown in Figure 4. It can be seen from that figure that the flow through the 6-path fiscal flow meter was fairly stable over the entire flow test period, while the flare gas flow rate oscillated more in the first part of the flow test period. In the time period from 10:03 to 10:18 the flow through both flow meters was quite stable. Average flow rate measured by the 6-path fiscal flow meter in this period was found to be 7561 Sm^3/h. For the ultrasonic flare gas meter, the similar flow rate was found to be 7917 Sm^3/h. This last flow rate has to be corrected for the background flaring in order to be compared to the flow rate measured by the 6-path fiscal flow meter.

The background flaring can be estimated from the measured flow rate by the flare gas meter before the flow test. In principle also the time period just after the flow test could have been used. However, in this period, there is a possibility that there are still some remaining natural gas from the flow test left in the system, and therefore, the flow rate measured by the flare gas meter just after the flow test may therefore not be representative for the background flaring. It can be seen in Figure 4 that there is a stable background flaring in the initial data in the plot, from 09:31 to 09:37. The average background flaring in this period is 381 Sm^3/h. If the whole period from 09:31 to 09:46 (just before the flow test) is used, an estimate of 447 Sm^3/h is found for the background flaring. It is thus expected that the background flaring is between 381 and 447 Sm^3/h. This means that the measured flow rate by the flare gas meter during the stable flow period from 10:03 to 10:18 is between 7470 and 7536 Sm^3/h

after correction for the background flaring. This should be compared to the measured flow rate by the 6-path fiscal flow meter of 7561 Sm^3/h. This means that the deviation between the measured flow rate by the ultrasonic flare gas meter and the 6-path fiscal flow meter was between -0.3 % and -1.2 %, after correction for the background flaring.

The specifications of the ultrasonic flare gas meter are that the flow rate is measured with an uncertainty of 2.5 - 5 %. The fiscal 6-path flow meter was flow calibrated prior to installation at Kollsnes, and the uncertainty is therefore expected to be below 1 %. This means that the deviation between the meters (0.3 - 1.2 %) is well inside the expected deviations, when the uncertainty specifications of the flow meters are taken into consideration.

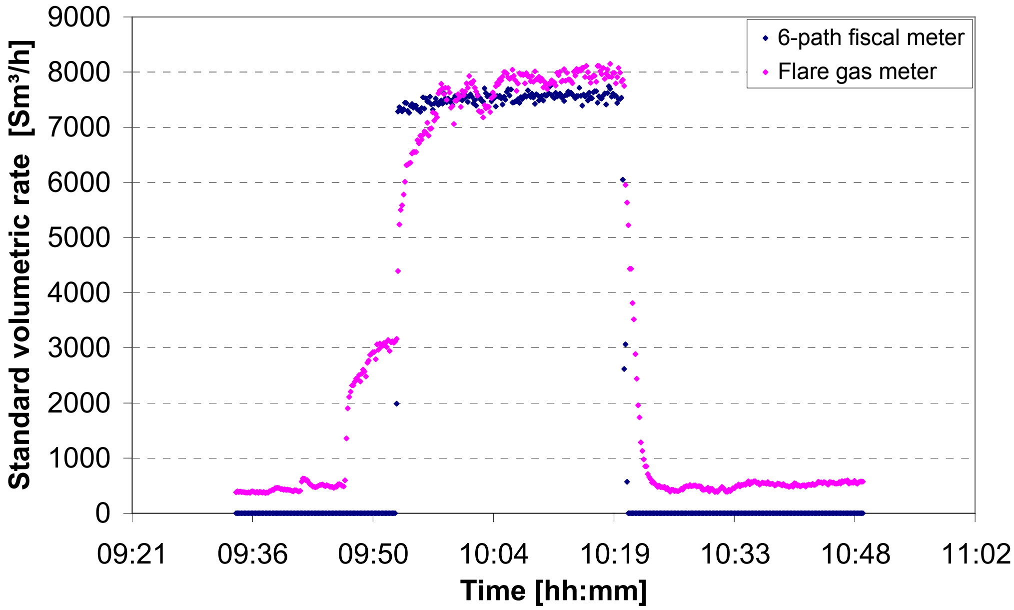

Figure 4 *Measured flow rates by the 6-path ultrasonic fiscal flow meter and the ultrasonic flare gas meter during the flow test. Background flaring is not accounted for, and thus the flare gas meter is expected to measure a higher flow rate than the fiscal meter.*

4.2 Density and nitrogen fraction, first test

In the flow test described in Section 4.1, also tests for measurement of the gas quality was carried out. As discussed in Section 4.1, the Troll gas was sent through the 6-path fiscal ultrasonic flow meter at high pressure. Thereafter, the same gas was sent through the flare gas meter at low pressure. When flowing through the flare gas meter, the Troll gas was mixed, about 7500 Sm³/h Troll gas and about 400 Sm^3/h background flaring with nitrogen-rich gas.

6-path fiscal flow meter:
The pressure was here about 75 bara and the temperature about 3 °C. The average axial flow velocity was about 0.5 m/s. Typical gas composition measured by on-line gas chromatography during the test was:

- C_1: 93.01 %
- C_2: 3.67 %
- C_3: 0.61 %
- C_4: 0.43 %
- C_5: 0.08 %
- C_{6+}: 0.12 %
- N_2: 1.67 %
- CO_2: 0.40 %

The fiscal flow meter measures the velocity of sound, in addition to the flow velocity. The velocity of sound measured on each of the 6 acoustics paths of the meter was reported. There was typically a span in velocity of sound (highest minus lowest velocity of sound measured by the 6 paths simultaneously) of about 0.9 m/s. The calculated velocity of sound agrees with the measured (averaged over the 6 paths) within +/- 0.7 m/s.

Flare gas meter:
As mentioned above, the gas is here a mixture of about 7500 Sm^3/h Troll gas and 400 Sm^3/h nitrogen rich background flaring.

Before the Troll gas was led through the flare gas meter, the flare gas meter measured the background flaring only (see Section 4.1). At that time, the flare gas meter measured a velocity of sound of about 342 – 343 m/s, typically about 3 m/s larger than the velocity of sound in pure nitrogen. This indicates that there are small amounts of hydrocarbons mixed into the background flaring. For example, a gas of 95 % nitrogen and 5 % methane will have about the same velocity of sound as measured by the ultrasonic flare gas meter.

During the flow test, with Troll gas through the two flow meters, the flow velocity through the flare gas meter was about 3 m/s. The pressure was here about 1 bara and the temperature about 3 °C. During the test, a gas sample was taken of the flare gas. This was analyzed in the laboratory, and the following gas composition was then found:

- C_1: 87.61 %
- C_2: 3.44 %
- C_3: 0.61 %
- C_4: 0.45 %
- C_5: 0.09 %
- C_{6+}: 0.39 %
- N_2: 6.98 %
- CO_2: 0.38 %

The velocity of sound is calculated to be 405.96 m/s from this composition and the pressure and temperature (about 1 bara and 4°C) measured at the time of the gas sampling. At that time the flare gas meter measured 405.59 m/s. This means that the deviation between measured and calculated velocity of sound was about 0.4 m/s.

The flare gas meter also estimated the density of the flare gas. It should be emphasized that this was the traditional density algorithm in that type of flare gas meter, where no assumption of gas composition had been made. The algorithm is optimized for low molar fractions of nitrogen and carbon dioxide. From this estimate, a nitrogen fraction was calculated from the assumption that the gas consisted of a mixture of Troll gas and pure nitrogen. It was then estimated a nitrogen molar fraction in the flare gas of 7.8 %. This has to be compared to the measured nitrogen fraction (of 7.0 %). It can thus be seen that the flare gas meter predicted the nitrogen molar fraction with a deviation from reference of 0.8 % (abs).

4.3 Density and nitrogen fraction, second test

After the first test (described in Sections 4.1 and 4.2), the ultrasonic flare gas meter was upgraded with new density algorithm. As described in Section 3, the new algorithm has two options:

- Flaring option
- Purging option

The flaring option is similar to the traditional density algorithms of ultrasonic flare gas meters, where the measured velocity of sound is used as basis for estimation of the density of the flare gas under the assumption that the gas to a large extent consists of hydrocarbons. The main difference from the previous versions is that it is now possible to specify a typical gas composition for the flare gas when available, including nitrogen and carbon dioxide, in order to reduce the uncertainty of the density estimate.

The purging option can be used in nitrogen purging conditions with large nitrogen content. In this case, the flare gas is assumed to be a combination of a specified natural gas and nitrogen. From the measured velocity of sound, the density and the molar fraction of nitrogen is estimated.

For both the flaring and the purging options the typical natural gas composition for this test was specified as the Troll gas composition measured 6 months earlier (see section 4.2).

The flow test was carried out during a planned event on the high pressure flare, where a compressor had to be de-pressurized, and therefore a high-flare situation took place. As in earlier flow tests, there was a nitrogen rich background flaring in addition. During the high-flaring situation and in the low-flaring situation after the high-flaring, gas samples were taken and analyzed on the laboratory. For the flow rate, there was no reference instrumentation during this test.

In the low flaring conditions before the depressurizing, a background flaring of about 370 Sm^3/h was measured. This number is taken as an average over a period of 2 minutes of stable flaring shortly before the high flaring case took place. The measured flow velocity during this background flaring was about 0.16 m/s. As discussed above, the background flaring has high nitrogen content. By using the new purging algorithm, the nitrogen fraction was calculated to be 95.2 %. This is in good agreement with similar estimates half a year earlier (see Section 4.2).

During the high flaring period, a sample of the flow was taken and analyzed at the laboratory. At this time, the ultrasonic flare gas meter gave the following parameters:

• Line pressure:	1.6100 bara
• Line temperature:	15.9744 °C
• Measured velocity of sound:	412.2596 m/s
• Volumetric flow rate at standard ref. cond.:	24192.98 Sm^3/h
• Measured flow velocity:	6.73 m/s
• Estimated line density, old model:	1.2087 kg/m^3
• Estimated line density, new flaring model:	1.2203 kg/m^3
• Estimated line density, new purging model:	1.1753 kg/m^3.
• Estimated molecular weight, old model:	18.0466 g/mole
• Estimated molecular weight, new model flaring:	18.2198 g/mole
• Estimated nitrogen fraction:	3.1165 %

The laboratory analysis of the gas sample gave the following results:

• Methane:	89.137 %
• Ethane:	6.247 %
• Propane:	0.243 %
• I-Butane:	0.083 %
• N-Butane:	0.032 %
• I-Pentane:	0.015 %
• N-Pentane:	0.008 %
• Hexane+:	0.032 %
• Nitrogen:	1.316 %
• Carbon dioxide:	2.859 %
• Argon/oxygen:	0.019 %

From the results of the laboratory analysis in addition to the pressure and temperature, the velocity of sound can be calculated as 414.7 m/s. This is 2.5 m/s above the measured value. Similarly, the density can be calculated from the gas composition as 1.2121 kg/m^3. The flare gas meter (new flaring algorithm) estimated the density as 1.2203 kg/m^3. This means that there is a deviation of 0.7 % between the two densities. In the interpretation of these deviations (in velocity of sound and in density), one should bear in mind that also the gas sample and laboratory analysis contain challenges and therefore also uncertainties.

After the high flaring period, there is a period that is dominated by nitrogen flaring. However, there are still small residues of the high flaring gas. This means that the molar fraction of nitrogen is expected to be somewhat lower than the 95 % that was found before the high flaring period. In this period, a sample of the flare gas was taken and thereafter analyzed on the laboratory.

The laboratory analysis of the gas sample gave the following results:

- Methane: 18.732 %
- Ethane: 2.300 %
- Propane: 0.395 %
- I-Butane: 0.067 %
- N-Butane: 0.088 %
- I-Pentane: 0.031 %
- N.Pentane: 0.029 %
- Hexane+: 0.074 %
- Nitrogen: 76.847 %
- Carbon dioxide: 0.754 %
- Argon/oxygen: 0.679 %

At the time of the gas sampling, the following data were read from the flare gas meter:

- Line pressure: 1.0210 bara
- Line temperature: 17.8482 °C
- Measured velocity of sound: 354.8365 m/s
- Volumetric flow rate at standard ref. cond.: 463.24 Sm^3/h
- Measured flow velocity: 0.2045 m/s
- Estimated line density, old model: 0.9976 kg/m^3
- Estimated line density, new flaring model: 0.9990 kg/m^3
- Estimated line density, new purging model: 1.1037 kg/m^3.
- Estimated molecular weight, old model: 23.6384 g/mole
- Estimated molecular weight, new model flaring: 23.6718 g/mole
- Estimated molecular weight, new model purging: 26.6503 g/mole
- Estimated nitrogen fraction: 87.4278 %

Note that at this time, the flow rate was down to 463.24 Sm^3/h and the flow velocity down to 0.20 m/s. With such a low flow rate (and flow velocity), the purging model is expected to be describing the gas quality better than the flaring algorithm.

From the gas composition measured at the laboratory from the gas sample, in addition to the pressure and the temperature, the velocity of sound was calculated to 355.0 m/s. This agrees within 0.2 m/s with the measured velocity of sound. Similarly, the density was calculated from the gas composition, pressure and temperature to be 1.1041 kg/m^3. This agrees well with the value estimated from the purging algorithm of the flare gas meter (1.1037 kg/m^3).

With respect to estimation of the nitrogen molar fraction, the agreement between the purging model of the flare gas meter and the gas analysis is not as good as for the velocity of sound and density. Here, the gas analysis indicates 76.8 %, while the purging model indicates 87.4 % nitrogen. One explanation for this deviation can be related to the model where the gas is expected to be a mix of the Troll gas and pure nitrogen. It can easily be seen that the gas sample cannot be such a mixture. For example, the molar fraction of CO_2 is larger than for Troll gas. Also the molar fraction of ethane in the gas sample is much higher than expected. The explanation of these deviations has not been found, but they should anyway be kept in mind when interpreting the estimated nitrogen molar fraction.

5 DISCUSSION AND PERSPECTIVES

The flow results presented in Chapter 4 are valuable input to the more general discussion related to flare gas metering, and in particular the nitrogen subtraction prior to CO_2 emission reports. In the nitrogen purging situations, the flow rates are generally low, and the nitrogen content can be quite high. If this purging gas is measured and interpreted as basically hydrocarbons, the CO_2 report will overestimate the emissions. How large this over-estimation is depends on how much of the total accumulated flaring during the reporting period that is carried out as purging. This will vary from installation to installation, and possibly also from period to period.

In general there are today no industrially accepted solutions for on-line composition measurements, and thus for nitrogen subtraction today. The methods that have been tried may have large uncertainties. On this back-ground, the possibility of using the on-line measurements carried out in the flare gas meter itself, which follow the changing flow rates and gas compositions in the flare is seen as an interesting alternative.

The requirements from the authorities depend on the quantity of flare gas and thereby the total CO_2 emission from the flaring system. Under the strictest requirements, the activity data (accumulated mass or standard volume of the flare gas) shall be determined with a documented relative expanded uncertainty of 7.5 % with 95 % confidence interval. Depending on the installation, and following the specifications of the flare gas meters, there is a potential for determining the activity data when no nitrogen subtraction is addressed, with relative expanded uncertainty of between 3 and 6 %, depending on the actual installation. This uncertainty is to be combined in an un-correlated way with the uncertainty contribution related to nitrogen subtraction, in order to obtain the total uncertainty budget for the activity data after nitrogen subtraction.

To be formal, the activity data after the nitrogen subtraction, A_{tot}, can be written in the following way:

$$A_{tot} = A_{measured} - A_{N2\,subtraction}$$

where $A_{measured}$ is the activity data as measured by the flare gas meter (without nitrogen subtraction) and $A_{N2\ subtraction}$ is the nitrogen subtraction. By assuming uncorrelated uncertainties, the uncertainty model for A_{tot} can be written as follows:

$$u(A_{tot})^2 = u(A_{measured})^2 + u(A_{N2\,subtraction})^2$$

$$\left(\frac{u(A_{tot})}{A_{tot}}\right)^2 = \left(\frac{A_{measured}}{A_{tot}}\frac{u(A_{measured})}{A_{measured}}\right)^2 + \left(\frac{A_{N2subtraction}}{A_{tot}}\frac{u(A_{N2subtraction})}{A_{N2subtraction}}\right)^2$$

where *u* denotes standard uncertainty. In table 1, the relative expanded uncertainty (95 % confidence level) that can be tolerated on the nitrogen subtraction before the relative expanded uncertainty of the activity data after nitrogen subtraction becomes as high as 7.5 % is shown. Numbers are given for four different relative expanded uncertainties of the activity data as measured by the flare gas meter (before nitrogen subtraction), 3 %, 4 %, 5 % and 6 %, and for four different fractions of the accumulated nitrogen purging relative to the total flaring (including the nitrogen flaring), 10 %, 20 %, 40 % and 60 %. When "Not possible" is stated in the table, even 0 % uncertainty of the nitrogen subtraction will lead to an uncertainty higher than 7.5 % for A_{tot}. However, in many cases, with an uncertainty of the nitrogen subtraction of 10 – 20 %, the relative expanded uncertainty of the activity data, A_{tot}, will still be below 7.5 %. It should also be commented that also in cases where the relative expanded uncertainty of A_{tot} is above 7.5 %, the method is still of interest. In such cases the method must be evaluated against other possible on-line methods for nitrogen subtraction.

Table 1 Uncertainty that can be tolerated on the nitrogen subtraction for keeping the total uncertainty of the activity data below 7.5 %, as a function of uncertainty of measured activity data by the flare gas meter, and the fraction of N_2-purging of the total flaring. All uncertainties are relative expanded uncertainties with 95 % confidence level.

Quantity of nitrogen purging in percent of total flaring	**Uncertainty of measured activity data, before nitrogen subtraction**			
	3 %	**4 %**	**5 %**	**6 %**
10 %	60 %	54 %	45 %	30 %
20 %	26 %	22 %	16 %	0 %
40 %	8.3 %	5 %	Not possible	Not possible
60 %	0 %	Not possible	Not possible	Not possible

The uncertainty of the estimated molar fraction of nitrogen depends on several effects, including:

- Specified natural gas in the purging situation
- Value of molar fraction of nitrogen
- Measured velocity of sound
- Measured temperature and pressure

For the flow test described above in Section 4.3, the natural gas is specified as Troll gas. This is reasonable for the Kollsnes plant. However, as part of a more general discussion, the effect of specifying non-optimal natural gases is briefly discussed. For illustration of this issue, two other gases are selected in addition to the Troll gas. These are methane, and a more heavy gas that is purely theoretical. The gas composition of this “heavy gas” is as follows

- C_1: 85 %
- C_2: 5 %
- C_3: 1 %
- C_4: 0.5 %
- C_5: 0.3 %
- C_{6+}: 0.2 %
- N_2: 4.0 %
- CO_2: 4.0 %

This means that the three gases in question have the following molar masses:

- Methane: 16.0 g/mole
- Troll: 17.4 g/mole
- Heavy: 19.1 g/mole

In Fig 5, the molar fraction of nitrogen as a function of velocity of sound is shown for mixtures of nitrogen and each of the three natural gases, for a pressure of 1 bar and a temperature of 20 °C. As expected, for smaller nitrogen molar fractions, the spread between the curves is large. For example, for a measured velocity of sound of 400 m/s, predicted molar fraction of nitrogen is from 10 % to 35 %, depending on which gas that is specified. However, the purging method is developed primarily for high nitrogen molar fractions. In Fig 6, a close-up of Fig. 5 is shown, for the more typical purging conditions. It can there be seen that for example for a measured velocity of sound of 360 m/s, the estimated molar fraction of nitrogen is from 74 % to 83 %. It should here be kept in mind that the span in quality between the three gases selected here may be larger than what is the case in practice. It can also be seen that at high nitrogen fractions, typically a change in velocity of sound of 1 m/s causes a change in predicted nitrogen molar fraction of about 2 % (abs), for the gases considered here. This means that the uncertainty of the measured velocity of sound is important to keep control of in order to use such an approach.

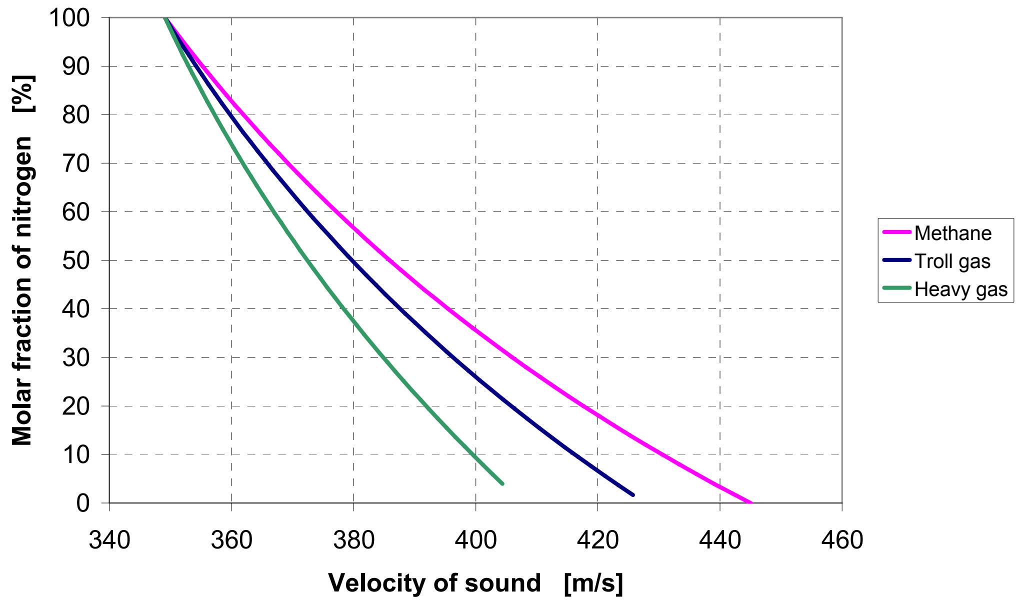

Figure 5 *Calculated data for molar fraction of nitrogen as a function of velocity of sound for a mixture of nitrogen and each of three natural gases. Pressure: 1 bara, temperature 20 °C.*

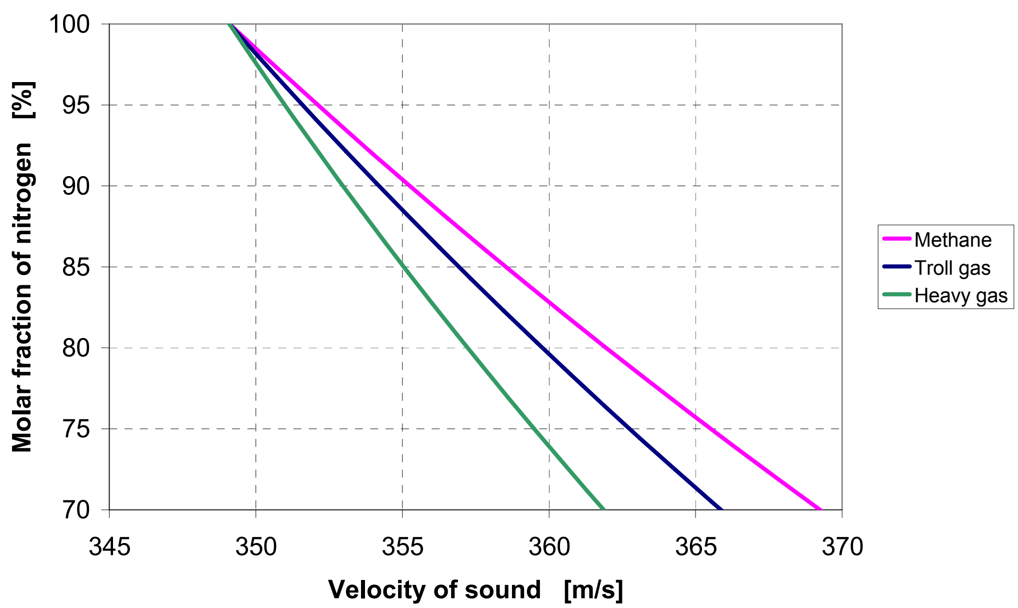

Figure 6 *Same as Fig. 5, but here a blow-up of the high nitrogen range.*

6 CONCLUSIONS

Nitrogen purging under low flaring conditions is increasingly taken into operation. In such situations, the nitrogen purging should be subtracted from the total amount of flare gas (activity data) that is reported to the authorities as part of the CO_2 emission report. In this paper, nitrogen subtraction based on the measurements carried out by an ultrasonic flare gas meter is discussed.

The ultrasonic flare gas meter has two options of operation, with respect to the estimation of the flare gas quality: (i) purging option and (ii) flaring option. Purging option is typically used under low flow conditions. The molar fraction of nitrogen is then estimated, in addition to the gas density. The nitrogen molar fraction can be high. Flaring option is typically used under high flow conditions. This is the traditional option, where the meter estimates a gas density under the assumption that the flare gas to a large extent consists of hydrocarbons.

The verification of a system for nitrogen molar fraction estimation and thereafter nitrogen subtraction based on ultrasonic flare gas meters, is here considered to be based on gas samples and laboratory analyses. Such a verification leans on a representative manual point for gas sampling. This is not trivial, but will here just be addressed as an issue that must be considered.

Flow tests have been carried out at StatoilHydro's gas processing plant at Kollsnes outside Bergen, Norway. Under these tests, both purging and flaring conditions have been tested. The flare gas was measured by the ultrasonic flare gas meter, and at the same time also sampled and thereafter analyzed at the laboratory. Under purging conditions, the nitrogen molar fraction has been estimated by the purging method of the flare gas meter with a deviation of about 10 % or less from a reference based on laboratory analysis of a gas sample. The uncertainty of the nitrogen subtraction depends on the actual site. However, the results are promising with respect to applying this methodology for nitrogen subtraction in flaring systems with nitrogen purging.

7 ACKNOWLEDGEMENT

Useful help on set-up and follow up of the fiscal metering system by Oussama Tlili and Reidar Høgvoll, FMC Technologies, is greatly acknowledged.

8 REFERENCES

[1] Guidelines for the monitoring and reporting of greenhouse gas emissions pursuant to Directive 2003/87/EC of the European Parliament and of the Council, 2006.