Global Flow Measurement Workshop
24-26 October 2023

Technical Paper

Uncertainty evaluation of non-stabilized oil sample compositional analysis evaluated using Monte Carlo methodology

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1. INTRODUCTION

In hydrocarbon allocation, the uncertainties of both flow measurements and compositions contribute to the uncertainties in allocated hydrocarbon volume, mass or monetary value, in particular for component-based allocation. Uncertainty analysis of single-phase flow measurements and of gas compositional analysis is considered well understood. The national measurement regulations in Norway states uncertainty requirements for these measurements. Oil compositional analysis, on the other hand, is more complex, and exhibits more challenges when the uncertainty is evaluated. This paper presents a Monte Carlo methodology for evaluating the measurement uncertainty of compositional analysis of non-stabilized oil samples, typically taken from a test separator or a first stage separator.

Compositional analysis of non-stabilized oil involves several procedures and measurements for the composition of the sample to be determined. Analysis results included in this work is obtained mainly from accredited laboratories where the ISO/IEC 17025:2017 standard requirements are followed. Typically, the sample is flashed to atmospheric conditions by single flash separation. The compositions of the resulting single flash gas (SFG) and single flash oil (SFL) is measured separately using dedicated gas chromatographs and procedures with following recombination back to separator fluid. Measured weight, density, molecular weight and calculated Gas to Oil Ratio (GOR) of the flashed oil is used to find the composition of the single flash oil sample. Moreover, in order to determine the mass (and molar) fraction of the heavy end of the flashed oil, a known (i.e., measured) amount of a pure component is added to the flashed oil before it is injected to the gas chromatograph for measurement. This pure component is normally referred to as the internal standard. Further, the labs typically make assumptions on the molecular weight of the flashed oil pseudo-components, hence they are not measured. The density of the flashed gas is also needed for recombination and is calculated from the measured flashed gas composition.

The different measurements, handling routines, calculations and assumptions that are needed to determine the composition of the original non-stabilized oil sample are all associated with an uncertainty. These input uncertainties propagate to the combined uncertainty of the sample composition. In this paper, the different input uncertainties are first discussed and evaluated. The evaluation is based on relevant standards typically used by the labs, as well as collected data and experience. The combined uncertainty of the oil sample composition is then evaluated using a Monte

Carlo methodology. The Monte Carlo methodology identifies which input uncertainties that dominate the combined sample composition uncertainty. Implications for hydrocarbon allocation uncertainty are discussed.

2. PROCEDURE FOR ANALYSIS

This paper focuses on compositional analysis of a non-stabilized oil sample conducted by laboratories accredited according to ISO/IEC 17025:2017 [1], referring to procedures and calculations based on relevant ASTM standards and equipment manuals. The procedures may differ between the laboratories. The procedure assumed for the uncertainty analysis documented in this paper is described in the following sub-sections, and is probably simplified compared with what is used in practice in the laboratories. This paper does not intend to fully describe the different steps in the procedure.

Figure 1 gives a schematic view of the analysis process from the sample is received in the laboratory, until the recombined composition is reported. Table 1 gives an overview of the different parameters which are obtained from the laboratory analysis.

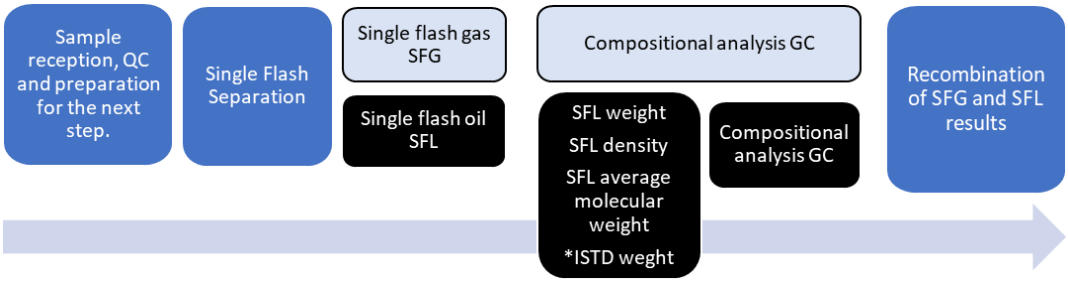


Figure 1 – Schematic illustration of a laboratory process for measuring the composition of a non-stabilized oil sample.

Table 1 – List of parameters

Process/ Analysis	Parameter	Method for determination
Single flash gas	Volume of flashed gas	Measured
Single flash oil	Weight of flashed oil	Measured
	Density of flashed oil	Measured
	Average molecular weight of flashed oil	Measured
Compositional analysis of flashed gas GC	Composition (mass fractions) of flashed gas	Measured
	Density of flashed gas	Calculated from the measured flashed gas composition, ISO 6976:2016
Compositional analysis of flashed oil	Weight of internal standard added to flashed oil	Measured
	Composition (mass fractions) of flashed oil (components up to and included C9)	Measured
	Mass fraction of C10+ in flashed oil	Calculated by difference from the measured composition up to C9
Recombined fluid	Gas Oil Ratio (GOR)	Calculated from flashed gas volume, density and flashed oil mass.
	Mass fractions of flashed gas and oil	Calculated from flashed gas volume, density and flashed oil mass.
	Composition (mass fractions)	Calculated from mass fractions and compositions of flashed gas and oil
	Molecular weight of C6-C9 pseudocomponents	Calculated from the measured distribution of paraffinic, naphthenic and aromatic components
	Molecular weight of C10+	Calculated from the average molecular weight of the flashed oil and the molecular weights of components <C10+.
	Composition (molar fractions)	Calculated from mass fractions and molecular weights of pseudocomponents

2.1 Sample reception, quality assurance and preparation

A pressurized oil sample in a Transportable Pressure Equipment Directive (TPED) approved cylinder is received and registered. Quality check upon receival is done

to ensure that the sampling pressure is maintained before starting and throughout the flash separation to avoid separation into two phases in the sample cylinder.

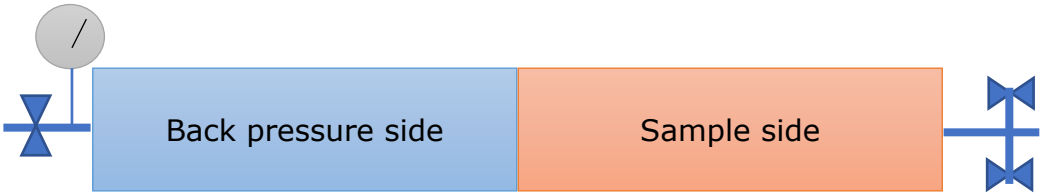


Figure 2 - Schematic illustration of a sampling cylinder.

2.2 Single Flash separation

The main scope of the Flash separation is to determine the GOR and perform the compositional analysis with Gas Chromatographs (GC). The calculated GOR is used during recombination of the Flashed Gas and Flashed oil results.

The oil sample under pressure is flashed to the atmospheric pressure and room temperature. The oil will then release some gas. The two fluids are now referred to as the (single) flashed gas and the (single) flashed oil which are collected in a gas container and in a pycnometer.

The volume of flashed gas, weight, density and average molecular weight of the flashed oil are then measured as described in the following sub-sections, and the GOR is calculated as the ratio of volume of the flashed gas (V_{gas}) and oil (V_{oil}), both at standard conditions:

$$GOR = \frac{V_{gas}}{V_{oil}} \quad (1)$$

2.2.2 Weight of flashed oil

The weight of flashed oil collected in a pycnometer is measured by weighing the pycnometer before starting and after completing the flash separation. The weight has traceable calibration.

2.2.3 Density of flashed oil

The density of the flashed oil can be measured using a test method based on the ASTM 5002-19 standard [2]. Approximately 1 mL to 2 mL of sample is introduced into an oscillating U-tube and the change in oscillating frequency caused by the change in the mass of the tube is used to determine the density of the sample. The sample is analyzed at atmospheric pressure and at 15 °C temperature.

2.2.4 Volume of Flashed gas

The volume of the flashed gas is measured from the flash separation equipment, as shown schematically in Figure 3.

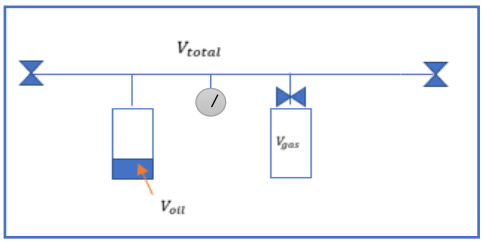


Figure 3 - Illustration of laboratory set-up for measuring flashed gas volume.

The gas volume is calculated using Boyle's law for an ideal gas ($PV = nRT$):

$$P_{atm}(V_{total} - V_{oil}) = nRT_{atm}$$

$$P_{gas}V_{gas} = nRT_{gas}$$

$$V_{gas} = \frac{(V_{total} - V_{oil}) \cdot P_{atm} \cdot T_{gas}}{P_{gas} \cdot T_{atm}} \quad (2)$$

Here:

P_{atm}	Atmospheric pressure is monitored out from the controlled gauge in the lab prior process start
P_{gas}	Pressure monitored with controlled gauge on the flash unit at the end of the completed flash separation
V_{total}	Precontrolled volume of the flash system included the gas container and buffers (buffers are used when the gas content is very high which is more applicable for condensate samples with high GOR)
V_{oil}	Volume of the flashed oil
V_{gas}	Volume of the flashed gas collected in a gas container
T_{atm}	Atmospheric temperature of 15°C is being used as a standard temperature, which aligns with the temperature used for density measurement of flashed oil in accordance with ASTM standard
T_{gas}	Actual gas temperature or the temperature of the implemented flash separation
n	Number of moles
R	Universal gas constant

The oil volume that is input to this calculation is found from the measured oil mass m_{oil} and oil density ρ_{oil}:

$$V_{oil} = \frac{m_{oil}}{\rho_{oil}} \quad (3)$$

2.2.5 Average molecular weight of flashed oil

The average molecular weight of the flashed oil can be measured by using a Cryometer based on freezing point depression and a method established internally based on the instrument manual [3]. The equipment is calibrated using a calibration solution. The measuring principle is based on measuring the molal concentration due to comparison of freezing point depression of pure benzene and benzene solutions made by flashed oil sample. The measured molal concentration is used to calculate the average molecular weight of the sample.

$$MW_{sample} = \frac{\nu \times G_{sample} \times 1000 \times 1000}{m_{sample} \times G_0} \quad (4)$$

Here MW_{sample} is the molecular weight of the sample (g/mole), ν is a constant correlating to the total number of ions (= 1 if totally undissociated, like benzene), G_{sample} is the weight of the sample (g), m_{sample} is the measured molality of the sample (mmole) and G_0 is the weight of the solvent benzene (g).

2.3 Compositional analysis of Single Flash Gas

The composition of the flashed gas is measured with a gas chromatograph (GC) using a test method based on ASTM 1945-14 standard [4]. With this test method the hydrocarbon components up to n-C9 are separated by gas chromatography and compared to the calibration data obtained under identical operating conditions from a reference standard mixture of known composition.

2.3.1 Composition as mass fractions of flashed gas

A representative and conditioned gas sample is injected into the gas chromatograph, which is separated to individual components based on their chemical properties, such as volatility and polarity and transported with a carrier gas through the capillary column. Eluted[1] components from the column generates signals at detectors, which in turn are processed by an integrating computer.

- **Peak Identification:** Each peak in a chromatogram corresponds to a specific gas component that can be identified by comparing the retention time of each peak to known standards (or reference compounds).
- **Peak Integration:** The area of each peak is measured and integrated automatically by the chromatography software. Peaks eluting after *n*-nonane are summed and reported as C10+.
- **Peak Quantification:** The area of a peak in the chromatogram is proportional to the mass fraction of the respective component. The mass concentration of each component is determined by area normalization,

[1] In chemistry the term *elute* is used when an absorbed substance is removed by a solvent.

with response factors established using calibration standards with known concentrations.

2.3.2 Density of flashed gas

The density of the flashed gas can be calculated from the measured flashed gas composition according to algorithms specified in ISO 6976 [5].

2.4 Compositional analysis of Single Flash Oil

The composition of the flashed oil is measured with a gas chromatograph (GC) using a test method based on ASTM 5134 standard [6] and covers the determination of the paraffins, naphthene's, and monoaromatics (PNA) of petroleum naphtha's. Components eluting after n-nonane are determined by-difference as a single group. Components that are present at the 0.05 % by mass level or greater can be determined.

A known weight fraction of a pure component, referred to as the internal standard ISTD, is added to the flashed oil and the mixture is homogenized before it is injected to the GC. In the GC, the sample is heated to a set temperature, typically 400 °C. A large fraction of the sample will evaporate, but the heavier components will remain in liquid phase and are backflushed to avoid contaminating the column. The evaporated components are transported through the GC column(s) by a carrier gas. Eluted components from the column are sensed by a flame ionization detector. The detector signal is processed by the integrating computer. The analysis is stopped after a predefined component reaches the detector. Thus, it is only the components that are lighter than this predefined component that are measured directly by the detector. In this study it is assumed that the analysis stops at nC10.

Each eluting peak is identified by comparing its retention index to a table of retention indices (times) and by visual matching with a standard chromatogram. The mass concentration of each component is determined by area normalization with response factors.

This process is illustrated schematically in the Figure 4.

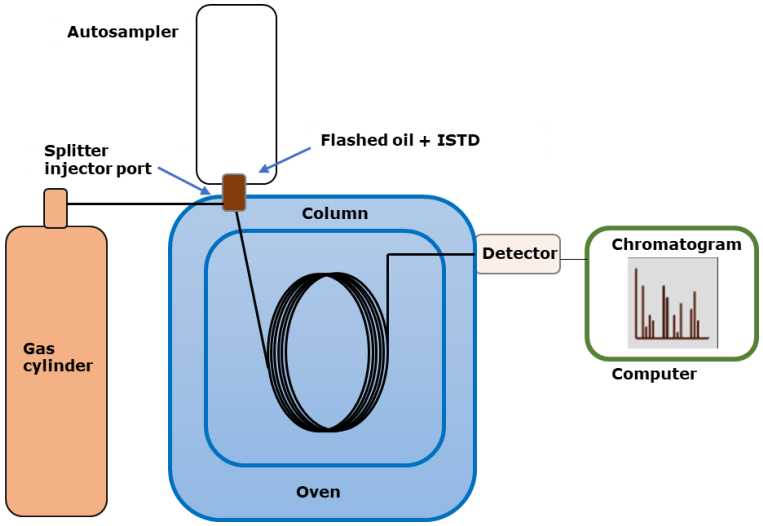


Figure 4 – Schematic illustration of a compositional analysis of single flash oil with Gas Chromatograph.

2.4.1 Composition as mass fractions of flashed oil up to C9

A known amount of an internal standard is added to a flashed oil in order to calculate the mass fraction of each component.

The peak areas are proportional with mass fractions, hence the mass fraction C_i of component i is given by

$$C_i = \frac{A_i}{A_{ISTD}} \cdot C_{ISTD} \tag{5}$$

where A_i is the peak area for component i, A_{ISTD} is the peak area for the internal standard and C_{ISTD} is the mass fraction of the internal standard.

2.4.2 Composition as mass fractions of flashed oil, C10+

The calculated mass fraction of C_{10+}, hence the non-measured part of the sample is then given by-difference:

$$C_{C10+,calc} = 1 - \sum_{i}^{n} C_{i,calc} \tag{6}$$

Table 2 summarizes how the molecular weights of the different components are obtained.

Table 2 – Component list and methods for determination of molecular weights.

Component	Type of component	Determination of molecular weight
N2, nitrogen	Defined	Literature
CO2, carbon dioxide	Defined	Literature
C1, methane	Defined	Literature
C2, ethane	Defined	Literature
C3, propane	Defined	Literature
iC4, isobutane	Defined	Literature
nC4, normalbutane	Defined	Literature
iC5, isopentane	Defined	Literature
nC5, neopentane	Defined	Literature
C6, hexanes	Pseudo-component	Calculated based on measured PNA distribution
C7, heptanes	Pseudo-component	
C8, octanes	Pseudo-component	
C9, nonanes	Pseudo-component	
C10+, plus fraction	Pseudo-component	Calculated based on the calculated C6-C9 molecular weights and the measured flashed oil molecular weight

2.5 Composition of recombined fluid

The composition of the oil sample can then be found by recombining the measured composition of the flashed gas and the flashed oil using the mass fractions of the phases.

2.5.1 Mass fraction of flashed gas and oil

The mass fraction φ_{gas} of flashed gas is given by:

$$\varphi_{gas} = \frac{V_{gas} \cdot \rho_{gas}}{V_{gas} \cdot \rho_{gas} + M_{oil}} \tag{7}$$

where V_{gas} is the (measured) volume of flashed gas, ρ_{gas} is the (calculated) density of the flashed gas and M_{oil} is the (measured) mass of flashed oil.

The mass fraction of flashed gas can also be expressed by a combination of the gas oil ratio GOR and flashed gas and oil densities, using:

$$GOR = \frac{V_{gas}}{V_{oil}}$$

$$\varphi_{gas} = \frac{GOR \cdot V_{oil} \cdot \rho_{gas}}{GOR \cdot V_{oil} \cdot \rho_{gas} + M_{oil}} = \frac{GOR \cdot \rho_{gas}}{GOR \cdot \rho_{gas} + \rho_{oil}} \tag{8}$$

The mass fraction φ_{oil} of flashed oil can then be calculated as:

$$\varphi_{oil} = 1 - \varphi_{gas} \tag{9}$$

2.5.2 Composition as mass fractions of recombined fluid

The composition of the recombined fluid, in terms of mass fraction per component i (C_i), can be calculated based on the mass fractions of gas φ_{gas} and oil φ_{oil}, combined with the composition of the flashed gas and flashed oil, in terms of mass fractions per component ($C_{gas,i}$ and $C_{oil,i}$):

$$C_i = C_{gas,i} \cdot \varphi_{gas} + C_{oil,i} \cdot \varphi_{oil} \tag{5}$$

2.5.3 Molecular weights of pseudocomponents

In order to convert the composition from mass fractions to mole fractions, the molecular weight of each component must be known. The molecular weight of the light defined components is known from literature with high accuracy. For the pseudo-components in the range C6-C9, the molecular weight is determined from the measured distribution of paraffinic, naphthenic and aromatic components in the flashed oil. The molecular weight of the C_{10+} component can be found from the measured average molecular weight of the flashed oil, and the composition:

$$m_{C10+} = \frac{C_{C10+}}{\frac{1}{m_{oil}} - \sum_i^{C9}\left(\frac{C_i}{m_i}\right)} \tag{6}$$

Where m_{C10+} is the molecular weight of the C_{10+} component group, m_{oil} is the measured average molecular weight of the flashed oil and m_i is the molecular weight of component i. C_{C10+} is the mass fraction of the C_{10+} component group.

2.5.4 Composition as molar fractions of recombined fluid

The molar fractions of the recombined fluid (X_i) for each component i can then be calculated as:

$$X_i = \frac{\frac{C_i}{m_i}}{\sum_i^{C10+}\left(\frac{C_i}{m_i}\right)} \tag{7}$$

3. FLUID USED IN THE ANALYSIS

The uncertainty analysis has been carried out for an unstablized oil sample taken from a separator outlet at K-lab Technology Centre multiphase flow loop 31.05.23, at 60 °C and 69.3 bar. The sample was sent to 4 different laboratories, and the average compositions and fluid properties was calculated from the analysis results. These averages are shown in Table 3 and used as the true composition of the K-lab sample in the uncertainty analysis.

Table 3 - Composition and properties of K-lab sample

	Oil sample		Flashed gas		Flashed oil	
	mol%	mass%	mol%	mass%	mol%	mass%
N2	0.13	0.03	0.47	0.45	0.00	0.00
CO2	0.83	0.35	2.87	4.58	0.00	0.00
C1	16.68	2.55	57.55	33.36	0.08	0.01
C2	8.02	2.29	26.45	28.78	0.53	0.11
C3	1.01	0.42	2.84	4.58	0.26	0.08
iC4	0.19	0.11	0.42	0.89	0.10	0.04
nC4	0.96	0.52	1.68	3.56	0.67	0.27
iC5	1.79	1.20	1.73	4.58	1.82	0.92
nC5	2.88	1.92	2.11	5.60	3.20	1.62
C6	6.21	4.81	1.80	5.64	8.01	4.74
C7	11.55	9.49	1.41	4.87	15.68	9.87
C8	13.30	12.36	0.56	2.44	18.50	13.18
C9	7.98	8.41	0.10	0.53	11.19	9.06
C10+	28.45	55.54	0.02	0.15	39.95	60.10

GOR of flash [Sm3/Sm3]	52.6
Flashed gas density [kg/Sm3]	1.17
Flashed oil density [kg/Sm3]	802.9
C6 molecular weight [g/mol]	85.1
C7 molecular weight [g/mol]	90.7
C8 molecular weight [g/mol]	102.6
C9 molecular weight [g/mol]	116.4
Flashed oil molecular weight [g/mol]	145.7

4. METHODS FOR DETERMINING INPUT UNCERTAINTIES

In this paper we have evaluated three different approaches for estimating the input uncertainties associated with the individual measurements that are used to determine the recombined oil sample composition.

4.1 Uncertainty requirements or reproducibility limits from standards

For some of the input measurements, it is possible to base the uncertainty evaluation on requirements or limits given by standards and best practice manuals or guidelines. Examples of this are reproducibility limits found in relevant ASTM standards. According to ASTM1945 [4], *the difference between two results obtained by different operators in different laboratories on identical test materials should be considered suspect if they differ by more than* (..) some given reproducibility limits.

In this paper, the reproducibility limits given in the ASTM standards have been interpreted as absolute expanded uncertainties with 95 % confidence level, based

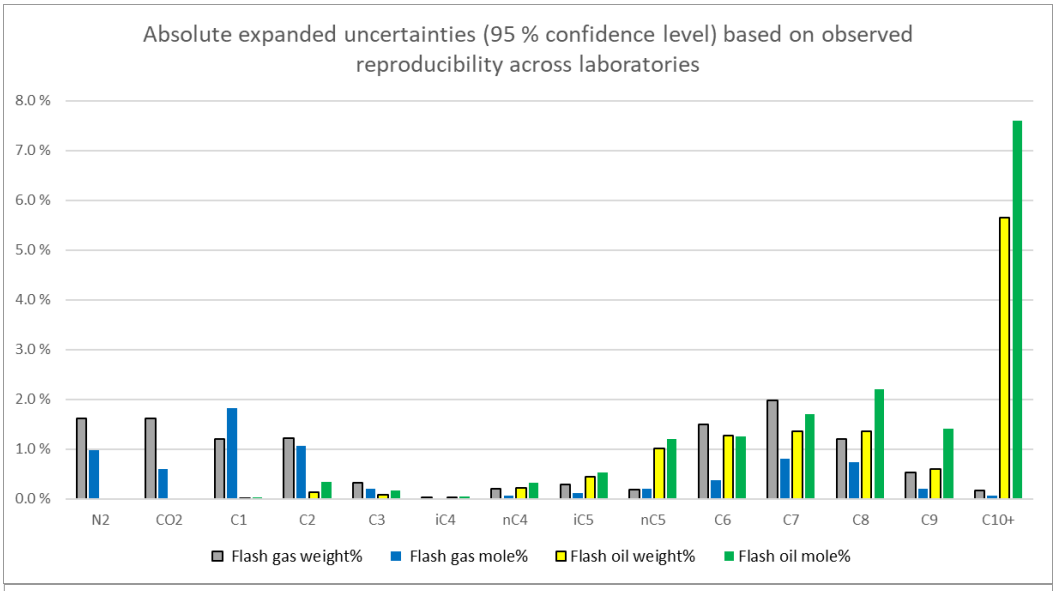
on the formulation "should be considered suspect", which corresponds well with a 95 % confidence level. The use of reproducibility limits for estimating uncertainty is also discussed in [8]: *if the demand on uncertainty is low, it may be possible to directly use the* s_R reproducibility between laboratories *as an approximation of* u_c. It is however not clear from [8] which level of confidence one can interpret for the reproducibility limits.

Note that the bias in the measurements cannot be determined due to a lack of reference, and that it is possible that the estimation of measurement uncertainty based on reproducibility limits may not include all potential sources of uncertainty.

4.2 From comparing different lab analysis of the same sample

One method of evaluating the measurement uncertainties can be by comparing the analysis results from different laboratories analysing the same sample. The K-lab oil sample described in chapter 3 was sent to four different laboratories, and the measurement results were then compared. We have estimated the relative expanded uncertainty (U*) at 95 % confidence level by multiplying the standard deviation of the samples with the student t-factor, in order to account for the small number of laboratories involved.

Note that using this approach the uncertainties associated with the flash operation is taken into account, as the deviations in the different measured compositions and fluid properties are both affected by variations in the separation into oil and gas phases in different laboratories, in addition to analysis uncertainties. This may result in an overestimation of some of the input uncertainties, as the interlaboratory differences may be dominated by differences in the flash operation, and not by the measurement process itself.



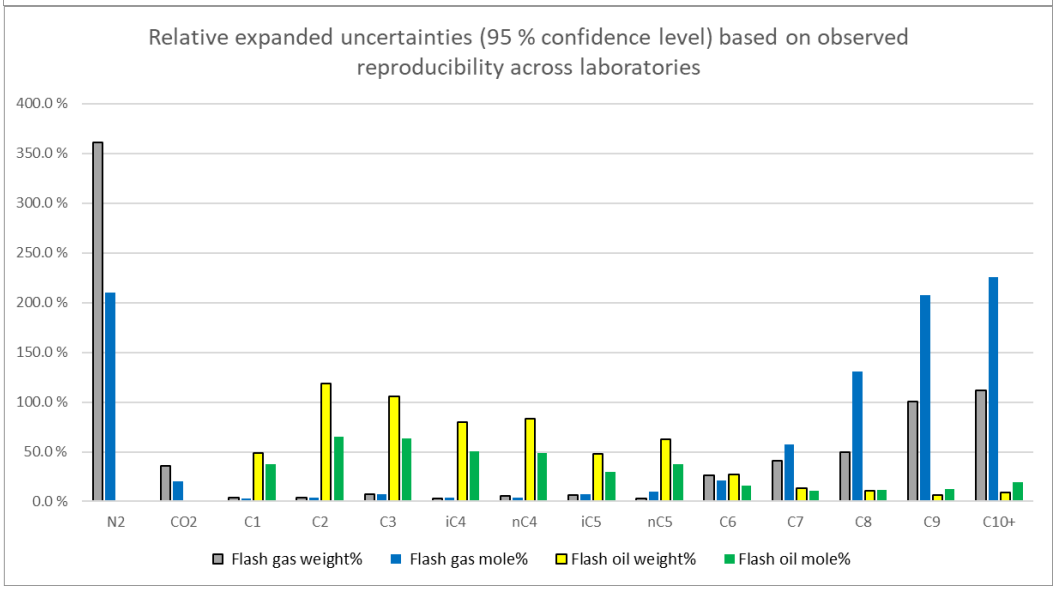


Figure 5 – Absolute (above) and relative (below) expanded uncertainties (95 % confidence level) of the weight and mole fractions of flashed gas and flashed oil, based on a comparison of results from 4 different laboratories. A student t-factor has been applied to account for the low number of samples.

Table 4 - Absolute (left) and relative (right) expanded uncertainties (95 % confidence level) of different properties of the flashed gas, flashed oil and the oil sample, based on a comparison of results from 4 different laboratories. A student t-factor has been applied to account for the low number of samples.

Estimated U	Flash Gas	Flash Oil	Oil sample	Estimtated U*	Flash Gas	Flash Oil	Oil sample
Density (kg/Sm3)	0.11	1.33	3.30	Density (kg/Sm3)	9.2 %	0.2 %	0.4 %
Gas Gravity	0.09			Gas Gravity	9.7 %		
GOR, Sm3/Sm3			23.00	GOR, Sm3/Sm3			44 %
Mole.wt (g/mol)				**Mole.wt (g/mol)**			
Total	1.64	9.73	7.63	Total	6.0 %	6.7 %	6.8 %
C6		0.40	0.18	C6		0.5 %	0.2 %
C7		3.37	0.49	C7		3.7 %	0.5 %
C8		3.34	0.59	C8		3.2 %	0.6 %
C9		3.21	2.09	C9		2.7 %	1.8 %
C10+		45.20	34.56	C10+		20.0 %	15.6 %

4.3 Detailed evaluation based on laboratory internal procedures, internal control and laboratory performance in ring-tests

In an ISO/IEC 17025:2017 [1] certified accredited laboratory, there is a thorough internal quality control from the sample enters the laboratory until the analysis report is issued.

Intra laboratory, interlaboratory comparison and proficiency testing of predefined test material is tested, and results are used to evaluate the measurement uncertainty. All the analysis equipment is controlled with a test material prior to testing the real samples. The control frequency varies for different instruments [7].

4.3.1 Control chart (Intra laboratory comparison)

Prior to the real sample analysis, each equipment is verified with internal control samples to ensure the validity of results. The results are controlled with control charts [7]. These charts are pre prepared based on measurement results carried out over several days, by different analysts, on the same equipment and with a same internal control sample that belongs to appropriate equipment. Based on these results, mean value, standard deviation, alarm limits and action limits are calculated, and a control chart is prepared. If the results of the analysis of data from monitoring activities are found to be outside pre-defined criteria, appropriate action is taken.

4.3.2 Proficiency testing (Interlaboratory comparison)

Proficiency testing of predefined test material is conducted in different laboratories to verify and validate the accuracy of each laboratories testing results. It compares the laboratories performances, ensuring that the laboratories meet regulatory standards, and identifies areas for improvement. This process helps manage risks associated with inaccurate results.

4.3.3 Laboratory “claimed uncertainty”

Control chart measurement results and proficiency testing results are used as a basis for calculating the measurement uncertainties in the laboratories. Handbooks

prepared by Nordtest [7] and [8] give more information on how intra and interlaboratory comparisons can be used as a basis for estimating measurement uncertainties.

For a specific analysis result, the laboratory may share its "claimed uncertainty" with the client ordering the analysis. However, as documentation regarding the different lab procedures, internal control results, and results from ring tests is not openly available or shared by the laboratories, it was not possible to base the input uncertainty estimates in this paper on such a detailed evaluation.

5. INPUT UNCERTAINTIES USED IN THE UNCERTAINTY ANALYSIS

In the following sections, the input uncertainties for the different measurements used for calculating the recombined oil sample composition are discussed, with basis in the different method for evaluating input uncertainties as described in the previous chapter. Note that any uncertainties resulting from a non-representative gas and oil due to errors in the flash operation are not included here.

5.1 Single Flash separation

5.1.1 Gas Oil Ratio

As detailed in chapter 2, the Gas Oil Ratio is not measured directly but calculated based on flashed gas volume, flashed oil density and flashed oil weight. Relevant standards are ISO 8655 [9] for flashed gas volume and *Norsk Akkreditering D00859* [10] for oil weight.

The comparison between laboratory results (standard deviation multiplied by a student t-factor, as described in chapter 4.3) results in an estimated expanded GOR relative uncertainty of 44 % (from Table 4). As the high discrepancy in GOR between laboratories may be explained by different flash procedures, and not by the *measurement/calculation* of the GOR itself, we are reluctant to use the comparison as a basis for estimating the GOR input uncertainty. Each lab may measure/calculate the GOR with a low uncertainty, but the results may differ because the flash operation itself has resulted in different separations between the oil and gas phase in different laboratories, as discussed in chaper 4.3.

In this paper we have chosen to set an overall relative expanded uncertainty (95 % confidence level) for the calculated GOR to an example **10 %**, but we point out that this uncertainty should be subject to a more thorough evaluation.

5.1.2 Flashed oil density

The relative expanded uncertainty (95 % confidence level) is in this analysis set to **0.412%** based on the reproducibility limit in ASTM D5002-19 [2] (note withdrawn). The relative expanded uncertainty (95 % confidence level) based on the comparison between laboratories is estimated to 0.2 %, well within the ASTM reproducibility limit.

5.1.3 Flashed oil average molecular weight

The relative expanded uncertainty (95 % confidence level) based on the comparison between laboratories is estimated to **6.7 %** based on comparison between laboratories. It is possible that using the interlaboratory comparison as a

basis will overestimate the measurement uncertainty, as some of the deviations between laboratories may be explained by different flashing procedures.

5.1.4 Molecular weight of pseudocomponents C6-C9

It is assumed that the molecular weight of the pseudo-components in the range C6-C9 is calculated from the measured distribution of paraffinic, naphthenic and aromatic components as described in chapter 2. Paraffinic components are heavier than the naphthenic, which in turn are heavier than the aromatic. The uncertainty in the measured PNA distribution increases with increasing carbon number, leading to a higher uncertainty in the molecular weight. In this paper we have estimated the uncertainties in molecular weights based on the comparison between laboratories analysing the same sample, as detailed in chapter 4.3. The resulting relative expanded uncertainties are shown in Table 5.

Table 5 - Relative expanded uncertainty of molecular weight, based on comparison between laboratories.

Component	Relative expanded uncertainty of molecular weight
C6	**0.2 %**
C7	**0.5 %**
C8	**0.6 %**
C9	**1.8 %**

5.2 Compositional analysis of Single Flash Gas

5.2.1 Composition as mass fractions of Single Flash Gas

The NORSOK I-106 [11] uncertainty requirements for fiscal gas composition is used in this paper for estimating the flash gas composition uncertainty.

Table 6 – NORSOK I-106 [11] uncertainty requirements for gas composition.

12.2.6.2.8 Fiscal gas composition

For the purpose of gas composition used for allocation of mass per component, the resulting uncertainty of each component, U_{Xi}, shall be so that the uncertainty of the components or group of components being part of the allocation procedure shall not exceed the following limits for the working range of X_i, unless there are project specific requirements:

Table 4 – Component uncertainty

Component range [mass %]	U_{Xi} (mol%) (k = 2)
0,5 to 20	0,15 x M/M_i
20 to 50	0,30 x M/M_i
50 to 100	0,60 x M/M_i

where
M is the molar mass for the composition in question.
M_i is the molar mass for component i.

Working range of X_i shall be specified by the project.

For the purpose of determination of the concentration of a specified component, the required uncertainty of this component is project specific.

5.2.2 Flashed Gas density

It is assumed that the density is calculated from the measured flashed gas composition is according to ISO 6976 [5]. Hence, the uncertainty of the measured composition contributes to the uncertainty in calculated gas density. In addition, there will be an uncertainty contribution associated with the model used in ISO 6976.

Using the NFOGM Fiscal Gas Metering Station Uncertainty calculator [12] with GC analysis uncertainties according to NORSOK I-106 [11] and ISO 6976:2016 used for density calculation, the uncertainty in density due to model, line conditions and gas composition is estimated to **1 %** for the K-lab sample.

The observed variation in the analysis from different laboratories indicate an uncertainty of 0.5 %.

5.3 Compositional analysis of Single Flash Oil

For estimating the uncertainties in measured mass fraction of the flashed oil, one needs to determine the measurement uncertainty of the mass fraction of the internal standard mixed with the flashed oil and the measured area fractions for each component excluding C10+, as described by the calculations given in 2.4. It has been very challenging to obtain good estimates for these input uncertainties, and in this paper we have therefore chosen to use an example uncertainty for the mass% of added internal standard of **1 %**. Moreover, we have chosen to base the area fraction uncertainties on ASTM reproducibility limits.

The ASTM D-5134 [6] reproducibility limits are given only from components with carbon numbers between 3 and 9, and are therefore here used for components C4-C9. For lighter components the ASTM1945 [4] reproducibility limits are used, in lack of a more adequate source (since the ASTM 1945 specifically targets gas and not oil analysis).

As the ASTM D-5134 reproducibility limits are given for many unique components, and the analysis results include several pseudocomponents (C6, C7, C8, C9), it was difficult to choose which limit should apply. Pragmatically we have considered the reproducibilities that fitted well with an overall trend of increasing reproducibility limits for components with higher fractions, as illustrated in Figure 6. The absolute uncertainties in area fraction have been set for each component based on the reproducibility limits, as introduced in chapter 4.1.

For the uncertainty of measured concentration of the internal standard after mixing and excluding C10+: If 5 mass% of an internal standard is mixed with 95 mass% of the flashed oil from the K-lab sample, we assume that the uncertainty calculated based on reproducibility for C6 (4.7 mass% before mixing) can be used as an approximation.

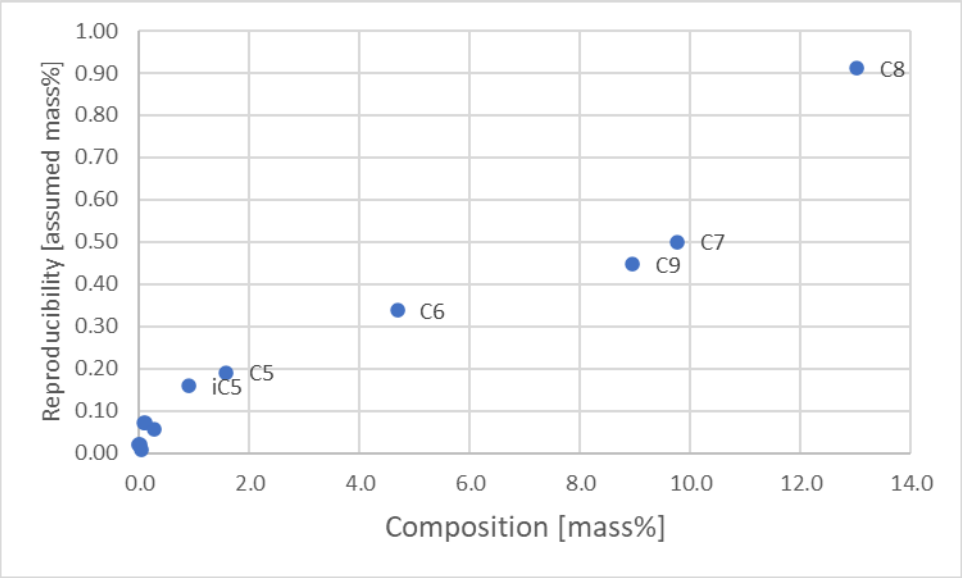


Figure 6 – Calculated reproducibility limits based on formulas given in ASTM D-5134.

6. METHODOLOGY FOR UNCERTAINTY AND SENSITIVITY ANALYSIS

The uncertainty analysis is carried out numerically using Monte Carlo simulations (5000 runs) compliant with ISO-GUM [13], [14]. The Monte Carlo results have been verified against numerically calculated sensitivity coefficients.

An outline of the Monte Carlo method for uncertainty propagation through a measurement function:

Set-up

- Define measurement function, $Y=f(x1, x2, x3...)$: This corresponds to the equations in chapter 2 relying the laboratory measurements and the recombined composition. For this study, the equations were implemented in an excel workbook.
- Find probability distribution for each input quantity: The uncertainties and distributions associated with each of the laboratory measurements and procedures, as evaluated in chapter 3.
- Give number, M, of Monte Carlo trials: In this study, M=5000 trials or runs was found to be adequate for the results to converge.

Monte Carlo simulation

- M draws of the input quantities from the corresponding distribution function: Generate M sets of input values drawn randomly from the input uncertainty distributions
- M measurement function values corresponding to these draws: Calculate the M recombined compositions corresponding to the M different sets of input values.

Evaluate results

Estimate y and associated standard uncertainty $u(y)$:

- From sorted measurement function values: determine discrete distribution function:
- From the M measurement function values: determine coverage interval for Y from desired probability (e.g. 95 %)

The recombined composition is found as the average of all M simulation results. Assuming normal distributions, the standard uncertainty is estimated as the standard deviation of the recombined composition distributions. The expanded uncertainty (at 95 % confidence level) is found by multiplying the standard deviations with a coverage factor k=1.96.

The Monte Carlo method is illustrated schematically in Figure 7.

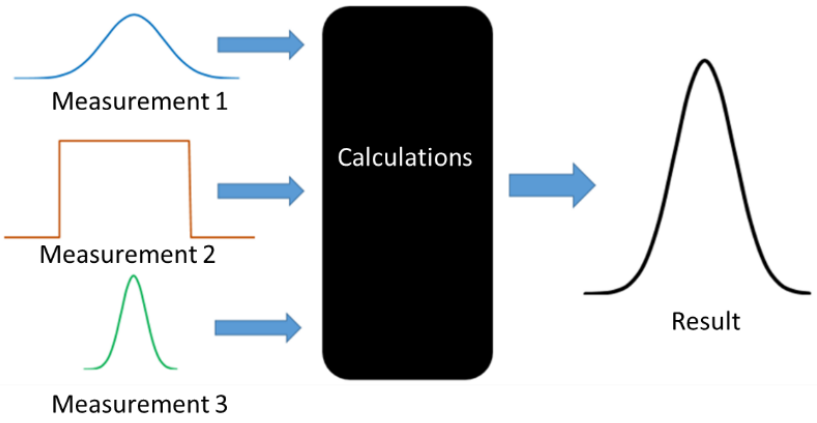


Figure 7 - Schematic illustration of the Monte Carlo method for uncertainty evaluation. The illustration shows probability distributions for 3 different input measurements which are combined using "calculations" into a probability distribution of the result.

7. RESULTS AND DISCUSSION

Figure 8 shows relative and absolute expanded uncertainties in the recombined fluid composition, both in terms of mass fraction and molar fraction. As described in chapters 4 and 6, the two bar plots compared in the figure are based upon the following:

- Orange bar plot ("Comparison method"): Based upon comparing the analysis results from the four different laboratories analysing the same sample. Relative expanded uncertainty at 95 % confidence level is estimated by multiplying the standard deviation of the samples with the student t-factor to account for the small number of laboratories involved.
- Blue bar plot ("MC method"): Uncertainty analysis carried out numerically using Monte Carlo simulations (5000 runs) compliant with ISO-GUM [13], [14]. For more details on this, see chapter 6.

As we can see from Figure 8 the results from the two methodologies differ significantly. For relative uncertainty in mass fraction, the Comparison methodology results in higher uncertainties for all components compared to the MC

method, particularly components C4 – C7 are exposed to large differences (up to five times larger for nC5). For relative uncertainty in molar fraction, the Comparison methodology results in much higher uncertainties particularly for the lighter components (C1 to C5) but also for C10+ compared to the MC method.

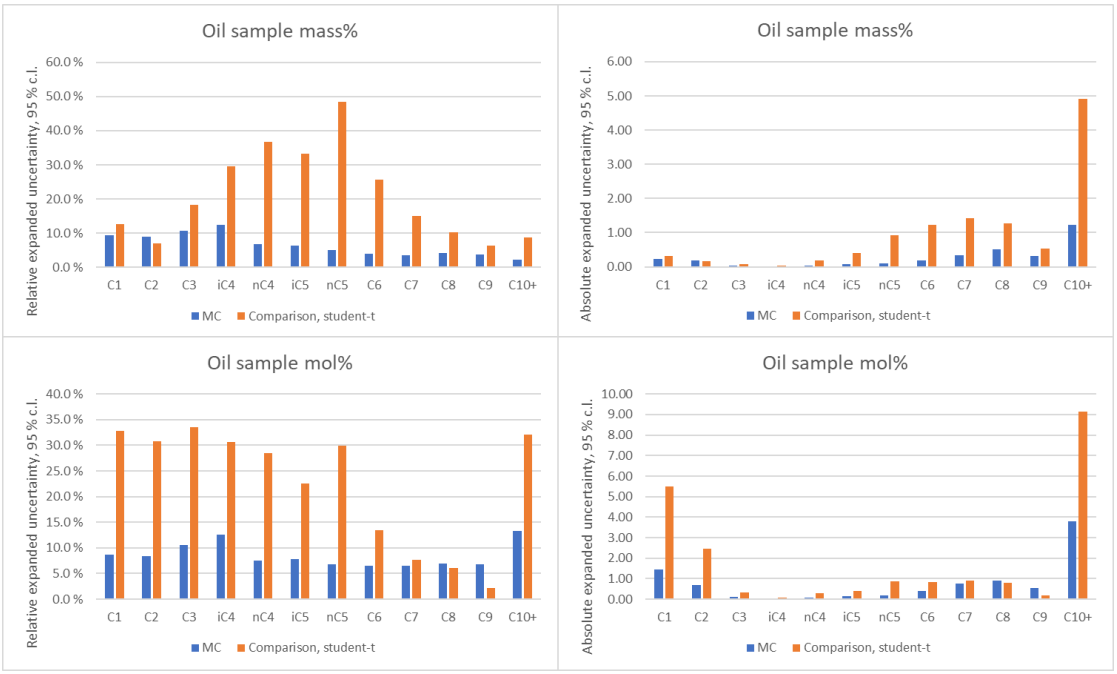


Figure 8 - Relative expanded uncertainty of recombined oil sample in mass% (top left) and mol% (bottom left), absolute expanded uncertainty of recombined oil sample in mass% (top right) and mol% (bottom right)

The observed discrepancy between the estimated uncertainties from the Monte Carlo analyse and the comparison between laboratories may be explained by the low number of analysis results that were compared. Only results from four laboratories were included for estimating the uncertainties based on laboratory comparison. Even though the student t-factor is applied to account for the small number of laboratories, it would still be desirable to have more analysis results, preferably from different laboratories, to get better uncertainty estimates. Ideally multiple samples should have been issued to a higher number of laboratories, or anonymized data from ring-tests can be reanalyzed to estimate the uncertainties with higher confidence. **The authors would hereby like to invite organisations or companies with access to such data to participate in this discussion, notably by publishing statistical analysis of such anonymized data.**

Another explanation for the large deviations in results between the Comparison method and the MC method proposed in this paper, could be that input uncertainties discussed in chapter 5 are underestimated, or that not all uncertainty contributions are taken into account. For instance, **uncertainties related to sample handling, flash operation, representativity of subsamples etc. have not been addressed explicitly**. If the laboratory procedures and calculations differ from what is described in chapter 2, this will affect how input measurement uncertainties propagate through the calculations.

For the MC method, the input uncertainties are given in chapter 5.
The input uncertainties are set based on available information, and for many of the input measurements, we have relied heavily on reproducibility limits from ASTM standards. However, as discussed in chapter 4.2 and chapter 5, the use of such reproducibility limits may be a simplification, and it is not clear from the standards which confidence levels applies to the limits. Furthermore, more detailed information regarding the laboratory procedure and is neccessary to evaluate the GOR, and internal standard composition example uncertainties used in this paper.

As this discussion illustrates, **more information on the different input uncertainties would be very useful.**

In the ever-increasing focus on uncertainty requirements in flow measurements, it may seem as if quality measurements have been somewhat forgotten. For flow measurements there exists several standards, regulations and guidelines. When it comes to quality measurements there are some informative handbooks such as [7] and [8] available, but information on procedures and detailed, transparent uncertainty calculations from the different laboratories is largely proprietary and not open. It is not transparent how the claimed uncertainties are estimated by the different laboratories.

For allocation uncertainty, this is particularly problematic as compositional information is direct input to the allocation equations in many cases. The potential high uncertainty in the compositional measurements will thus propagate through the system and lead to higher allocation uncertainties.

8. CONCLUSION

This paper focus on oil compositional analysis of non-stabilized oil samples, typically taken from a test separator or a first stage separator. We present a Monte Carlo methodology for evaluating the measurement uncertainty, and show that this is a complex task, and that the evaluation of input uncertainties is challenging.

Comparing the uncertainty of analysis results from four different laboratories analysing the same sample to the uncertainty evaluated using the proposed Monte Carlo methodology in this paper shows large deviations. There may be different reason for this, notably the low number of results that are compared, limited information available for evaluating input uncertainties, and that all uncertainty contributions have not been identified and evaluated. To close this knowledge gap, the authors of this paper encourage to more openness on how the uncertainty in the quality measurements, notably composition, are estimated and combined. The different laboratories accompany their test results with an uncertainty upon request, but the procedure for how the claimed uncertainties are calculated is not transparent.

With the high focus on uncertainty requirements in flow measurements, it is strongly desirable to strive for this also in quality measurements. The lack of open, well-documented and transparent uncertainty estimations of composition analysis is particularly problematic for allocation uncertainties as compositional information may be direct input to the allocation equations. As no part of an uncertainty chain

is stronger than the weakest link, it is crucial to ensure more transparency and traceability in the uncertainty evaluation of quality measurements. **We hope this paper will ignite a vivid discussion and inspire more publications regarding the uncertainties associated with compositional sampling and analysis.**

9. ACKNOWLEDGMENTS

We extend our sincere gratitude to Wenche Knutsen, Operations Manager, and John Andre Gjerde, HSEQ Advisor at Expro Petrotech AS, for their useful input and insightful discussions.

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APPENDIX A – RELATIVE SENSITIVITY COEFFICIENTS AND UNCERTIANTY BUDGETS

Relative sensitivity coefficients

Klabsample		Unc	Oil sample mass %													
			N2	CO2	C1	C2	C3	iC4	nC4	iC5	nC5	C6	C7	C8	C9	C10+
Molecular weights	C6 molecular weight	0.2 %	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	C7 molecular weight	0.5 %	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	C8 molecular weight	0.6 %	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	C9 molecular weight	1.8 %	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Flashed oil molecular weight	6.7 %	-	-	-	-	-	-	-	-	-	-	-	-	-	-
GC flashed oil	N2	500.0 %	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	CO2	500.0 %	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	C1	103.5 %	-	-	0.00	-	-	-	-	-	-	-	-	-	-	0.00
	C2	28.6 %	-	-	-	0.05	-	-	-	0.00	-	-	-	-	-	0.00
	C3	39.3 %	-	-	-	-	0.18	-	-	0.00	-	-	-	-	-	0.00
	iC4	9.4 %	-	-	-	-	-	0.38	-	-	-	0.00	-	-	-	0.00
	nC4	9.3 %	-	-	-	-	-	-	0.49	-	-	-	-	-	-	0.00
	iC5	7.9 %	-	-	-	-	-	-	-	0.72	-	-	-	-	0.00	0.01
	nC5	5.4 %	-	-	-	-	-	-	-	-	0.79	-	-	-	-	0.03
	C6	3.2 %	-	-	-	-	-	-	-	-	0.00	0.92	-	-	-	0.08
	C7	2.3 %	-	-	-	-	-	-	-	-	0.00	-	0.96	-	0.00	0.16
	C8	3.1 %	-	-	-	-	-	-	-	-	0.00	-	-	0.99	-	0.21
	C9	2.2 %	-	-	-	-	-	-	-	-	0.00	0.00	-	-	1.00	0.15
	Internal standard	2.9 %	-	-	0.00	0.05	0.18	0.38	0.49	0.72	0.79	0.92	0.96	0.99	1.00	0.65
	Mass% internal standard	1.0 %	-	-	0.00	0.05	0.19	0.40	0.52	0.76	0.83	0.96	1.02	1.04	1.05	0.68
GC flashed gas	N2	31.5 %	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	CO2	3.2 %	0.05	0.95	0.05	0.04	0.04	0.03	0.02	0.01	0.01	0.00	0.00	0.00	0.00	0.00
	C1	0.9 %	0.34	0.34	0.66	0.32	0.28	0.21	0.17	0.09	0.07	0.03	0.01	0.00	0.00	0.00
	C2	1.0 %	0.29	0.29	0.29	0.68	0.24	0.18	0.15	0.08	0.06	0.02	0.01	0.00	0.00	0.00
	C3	3.3 %	0.05	0.05	0.05	0.04	0.78	0.03	0.02	0.01	0.01	0.00	0.00	0.00	0.00	0.00
	iC4	16.9 %	0.01	0.01	0.01	0.01	0.01	0.62	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	nC4	4.2 %	0.04	0.04	0.04	0.03	0.03	0.02	0.49	0.01	0.01	0.00	0.00	0.00	0.00	0.00
	iC5	3.3 %	0.05	0.05	0.05	0.04	0.04	0.03	0.02	0.27	0.01	0.00	0.00	0.00	0.00	0.00
	nC5	2.7 %	0.06	0.06	0.06	0.05	0.05	0.03	0.03	0.02	0.20	0.00	0.00	0.00	0.00	0.00
	C6	2.7 %	0.06	0.06	0.06	0.05	0.05	0.03	0.03	0.02	0.01	0.08	0.00	0.00	0.00	0.00
	C7	3.2 %	0.05	0.05	0.05	0.04	0.04	0.03	0.02	0.01	0.01	0.00	0.03	0.00	0.00	0.00
	C8	7.2 %	0.02	0.02	0.02	0.02	0.02	0.01	0.01	0.01	0.00	0.00	0.00	0.01	0.00	0.00
	C9	36.4 %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	C10+	77.6 %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Flashed gas density	1.0 %	0.93	0.93	0.93	0.88	0.74	0.55	0.44	0.21	0.14	0.01	0.04	0.06	0.07	0.07
	Flashed oil density	0.4 %	0.93	0.93	0.93	0.88	0.74	0.55	0.44	0.21	0.14	0.01	0.04	0.06	0.07	0.07
	GOR of flash	10.0 %	0.93	0.93	0.93	0.88	0.74	0.55	0.44	0.21	0.14	0.01	0.04	0.06	0.07	0.07

Uncertainty budget

Klabsample		Unc	Oil sample mass %													
			N2	CO2	C1	C2	C3	iC4	nC4	iC5	nC5	C6	C7	C8	C9	C10+
Molecular weights	C6 molecular weight	0.21 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %
	C7 molecular weight	0.54 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %
	C8 molecular weight	0.58 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %
	C9 molecular weight	1.80 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %
	Flashed oil molecular weight	6.70 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %
GC flashed oil	N2	500 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %
	CO2	500 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %
	C1	103 %	0.0 %	0.0 %	0.3 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %
	C2	29 %	0.0 %	0.0 %	0.0 %	1.3 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.1 %
	C3	39 %	0.0 %	0.0 %	0.0 %	0.0 %	7.2 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.1 %
	iC4	9 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	3.5 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %
	nC4	9 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	4.6 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %
	iC5	7.9 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	5.7 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.1 %
	nC5	5.4 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	4.2 %	0.0 %	0.0 %	0.0 %	0.0 %	0.1 %
	C6	3.2 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	2.9 %	0.0 %	0.0 %	0.0 %	0.2 %
	C7	2.3 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	2.2 %	0.0 %	0.0 %	0.4 %
	C8	3.1 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	3.1 %	0.0 %	0.7 %
	C9	2.2 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	2.2 %	0.3 %
	Internal standard	2.9 %	0.0 %	0.0 %	0.0 %	0.1 %	0.5 %	1.1 %	1.4 %	2.1 %	2.3 %	2.6 %	2.8 %	2.8 %	2.9 %	1.9 %
	Mass% internal standard	1.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.2 %	0.4 %	0.5 %	0.8 %	0.8 %	1.0 %	1.0 %	1.0 %	1.0 %	0.7 %
GC flashed gas	N2	31.5 %	31.4 %	0.1 %	0.1 %	0.1 %	0.1 %	0.1 %	0.1 %	0.1 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %
	CO2	3.2 %	0.1 %	3.1 %	0.1 %	0.1 %	0.1 %	0.1 %	0.1 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %
	C1	0.9 %	0.3 %	0.3 %	0.6 %	0.3 %	0.2 %	0.2 %	0.2 %	0.1 %	0.1 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %
	C2	1.0 %	0.3 %	0.3 %	0.3 %	0.7 %	0.2 %	0.2 %	0.2 %	0.1 %	0.1 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %
	C3	3.3 %	0.1 %	0.1 %	0.1 %	0.1 %	2.6 %	0.1 %	0.1 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %
	iC4	16.9 %	0.1 %	0.1 %	0.1 %	0.1 %	0.1 %	10.4 %	0.1 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %
	nC4	4.2 %	0.1 %	0.1 %	0.1 %	0.1 %	0.1 %	0.1 %	2.1 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %
	iC5	3.3 %	0.1 %	0.1 %	0.1 %	0.1 %	0.1 %	0.1 %	0.1 %	0.9 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %
	nC5	2.7 %	0.1 %	0.1 %	0.1 %	0.1 %	0.1 %	0.1 %	0.1 %	0.0 %	0.5 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %
	C6	2.7 %	0.1 %	0.1 %	0.1 %	0.1 %	0.1 %	0.1 %	0.1 %	0.0 %	0.0 %	0.2 %	0.0 %	0.0 %	0.0 %	0.0 %
	C7	3.2 %	0.1 %	0.1 %	0.1 %	0.1 %	0.1 %	0.1 %	0.1 %	0.0 %	0.0 %	0.0 %	0.1 %	0.0 %	0.0 %	0.0 %
	C8	7.2 %	0.1 %	0.1 %	0.1 %	0.1 %	0.1 %	0.1 %	0.1 %	0.0 %	0.0 %	0.0 %	0.0 %	0.1 %	0.0 %	0.0 %
	C9	36.4 %	0.1 %	0.1 %	0.1 %	0.1 %	0.1 %	0.1 %	0.1 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.1 %	0.0 %
	C10+	77.6 %	0.1 %	0.1 %	0.1 %	0.1 %	0.1 %	0.1 %	0.1 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %
	Flashed gas density	1.0 %	0.9 %	0.9 %	0.9 %	0.9 %	0.7 %	0.6 %	0.4 %	0.2 %	0.1 %	0.0 %	0.0 %	0.1 %	0.1 %	0.1 %
	Flashed oil density	0.4 %	0.4 %	0.4 %	0.4 %	0.4 %	0.3 %	0.2 %	0.2 %	0.1 %	0.1 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %
	GOR of flash	10.00 %	9.3 %	9.3 %	9.3 %	8.8 %	7.4 %	5.5 %	4.4 %	2.1 %	1.4 %	0.1 %	0.4 %	0.6 %	0.7 %	0.7 %
	Total uncertainty from budget		32.7 %	9.9 %	9.4 %	9.0 %	10.8 %	12.4 %	6.8 %	6.5 %	5.1 %	4.1 %	3.7 %	4.4 %	3.8 %	2.3 %
	Uncertainty evaluated by Monte Carlo		32.5 %	9.8 %	9.4 %	9.0 %	10.8 %	12.5 %	6.7 %	6.4 %	5.0 %	3.9 %	3.6 %	4.2 %	3.7 %	2.2 %

Relative expanded uncertainties, 95 % confidence level.

Relative sensitivity coefficients

Klabsample		Unc	Oil sample mol % N2	CO2	C1	C2	C3	iC4	nC4	iC5	nC5	C6	C7	C8	C9	C10+
Molecular weights	C6 molecular weight	0.2 %	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.99	0.01	0.01	0.01	0.20
	C7 molecular weight	0.5 %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.39
	C8 molecular weight	0.6 %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.46
	C9 molecular weight	1.8 %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.28
	Flashed oil molecular weight	6.7 %	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71	1.78
GC flashed oil	N2	500.0 %	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	CO2	500.0 %	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	C1	103.5 %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	C2	28.6 %	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
	C3	39.3 %	0.00	0.00	0.00	0.00	0.18	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
	iC4	9.4 %	0.00	0.00	0.00	0.00	0.00	0.38	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	nC4	9.3 %	0.00	0.00	0.00	0.00	0.00	0.00	0.49	0.00	0.00	0.00	0.00	0.00	0.00	0.02
	iC5	7.9 %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.72	0.00	0.00	0.00	0.00	0.00	0.05
	nC5	5.4 %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.79	0.00	0.00	0.00	0.00	0.08
	C6	3.2 %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.92	0.00	0.00	0.00	0.20
	C7	2.3 %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.96	0.00	0.00	0.39
	C8	3.1 %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.99	0.00	0.46
	C9	2.2 %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.28
	Internal standard	2.9 %	0.00	0.00	0.00	0.05	0.18	0.38	0.49	0.72	0.79	0.92	0.96	0.99	1.00	1.49
	Mass% internal standard	1.0 %	0.00	0.00	0.00	0.05	0.19	0.40	0.52	0.76	0.83	0.96	1.02	1.04	1.05	1.57
GC flashed gas	N2	31.5 %	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	CO2	3.2 %	0.04	0.96	0.04	0.04	0.03	0.02	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.01
	C1	0.9 %	0.41	0.41	0.59	0.39	0.34	0.28	0.24	0.16	0.14	0.10	0.08	0.07	0.07	0.07
	C2	1.0 %	0.28	0.28	0.28	0.68	0.23	0.17	0.14	0.07	0.05	0.02	0.00	0.00	0.01	0.01
	C3	3.3 %	0.04	0.04	0.04	0.04	0.78	0.02	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.01
	iC4	16.9 %	0.01	0.01	0.01	0.01	0.01	0.62	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	nC4	4.2 %	0.03	0.03	0.03	0.03	0.02	0.02	0.50	0.00	0.00	0.00	0.00	0.00	0.01	0.01
	iC5	3.3 %	0.04	0.04	0.04	0.04	0.03	0.02	0.01	0.28	0.00	0.00	0.01	0.01	0.01	0.01
	nC5	2.7 %	0.05	0.05	0.05	0.04	0.04	0.02	0.02	0.01	0.21	0.01	0.01	0.01	0.01	0.01
	C6	2.7 %	0.04	0.04	0.04	0.04	0.03	0.02	0.02	0.00	0.00	0.09	0.01	0.01	0.01	0.01
	C7	3.2 %	0.04	0.04	0.04	0.04	0.03	0.02	0.01	0.00	0.00	0.01	0.04	0.01	0.01	0.01
	C8	7.2 %	0.02	0.02	0.02	0.02	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.02	0.00	0.00
	C9	36.4 %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	C10+	77.6 %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Flashed gas density	1.0 %	0.71	0.71	0.71	0.66	0.53	0.33	0.22	0.01	0.08	0.21	0.25	0.28	0.29	0.29
	Flashed oil density	0.4 %	0.71	0.71	0.71	0.66	0.53	0.33	0.22	0.01	0.08	0.21	0.25	0.28	0.29	0.29
	GOR of flash	10.0 %	0.71	0.71	0.71	0.66	0.53	0.33	0.22	0.01	0.08	0.21	0.25	0.28	0.29	0.29

Uncertainty budget

Klabsample		Unc	Oil sample mol % N2	CO2	C1	C2	C3	iC4	nC4	iC5	nC5	C6	C7	C8	C9	C10+
Molecular weights	C6 molecular weight	0.21 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.2 %	0.0 %	0.0 %	0.0 %	0.0 %
	C7 molecular weight	0.54 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.5 %	0.0 %	0.0 %	0.2 %
	C8 molecular weight	0.58 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.6 %	0.0 %	0.3 %
	C9 molecular weight	1.80 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	1.8 %	0.5 %
	Flashed oil molecular weight	6.70 %	4.8 %	4.8 %	4.8 %	4.8 %	4.8 %	4.8 %	4.8 %	4.8 %	4.8 %	4.8 %	4.8 %	4.8 %	4.8 %	11.9 %
GC flashed oil	N2	500 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %
	CO2	500 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %
	C1	103 %	0.0 %	0.0 %	0.3 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.2 %
	C2	29 %	0.0 %	0.0 %	0.0 %	1.3 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.4 %
	C3	39 %	0.0 %	0.0 %	0.0 %	0.0 %	7.2 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.3 %
	iC4	9 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	3.5 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %
	nC4	9 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	4.6 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.2 %
	iC5	7.9 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	5.7 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.4 %
	nC5	5.4 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	4.2 %	0.0 %	0.0 %	0.0 %	0.0 %	0.4 %
	C6	3.2 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	2.9 %	0.0 %	0.0 %	0.0 %	0.6 %
	C7	2.3 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	2.2 %	0.0 %	0.0 %	0.9 %
	C8	3.1 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	3.1 %	0.0 %	1.4 %
	C9	2.2 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	2.2 %	0.6 %
	Internal standard	2.9 %	0.0 %	0.0 %	0.0 %	0.1 %	0.5 %	1.1 %	1.4 %	2.1 %	2.3 %	2.6 %	2.8 %	2.8 %	2.9 %	4.3 %
	Mass% internal standard	1.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.2 %	0.4 %	0.5 %	0.8 %	0.8 %	1.0 %	1.0 %	1.0 %	1.0 %	1.6 %
GC flashed gas	N2	31.5 %	31.4 %	0.1 %	0.1 %	0.1 %	0.1 %	0.1 %	0.1 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %
	CO2	3.2 %	0.1 %	3.1 %	0.1 %	0.1 %	0.1 %	0.1 %	0.1 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %
	C1	0.9 %	0.4 %	0.4 %	0.5 %	0.3 %	0.3 %	0.2 %	0.2 %	0.1 %	0.1 %	0.1 %	0.1 %	0.1 %	0.1 %	0.1 %
	C2	1.0 %	0.3 %	0.3 %	0.3 %	0.7 %	0.2 %	0.2 %	0.1 %	0.1 %	0.1 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %
	C3	3.3 %	0.1 %	0.1 %	0.1 %	0.1 %	2.6 %	0.1 %	0.1 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %
	iC4	16.9 %	0.1 %	0.1 %	0.1 %	0.1 %	0.1 %	10.5 %	0.1 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %
	nC4	4.2 %	0.1 %	0.1 %	0.1 %	0.1 %	0.1 %	0.1 %	2.1 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %
	iC5	3.3 %	0.1 %	0.1 %	0.1 %	0.1 %	0.1 %	0.1 %	0.0 %	0.9 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %
	nC5	2.7 %	0.1 %	0.1 %	0.1 %	0.1 %	0.1 %	0.1 %	0.0 %	0.0 %	0.6 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %
	C6	2.7 %	0.1 %	0.1 %	0.1 %	0.1 %	0.1 %	0.1 %	0.0 %	0.0 %	0.0 %	0.2 %	0.0 %	0.0 %	0.0 %	0.0 %
	C7	3.2 %	0.1 %	0.1 %	0.1 %	0.1 %	0.1 %	0.1 %	0.0 %	0.0 %	0.0 %	0.0 %	0.1 %	0.0 %	0.0 %	0.0 %
	C8	7.2 %	0.1 %	0.1 %	0.1 %	0.1 %	0.1 %	0.1 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.1 %	0.0 %	0.0 %
	C9	36.4 %	0.1 %	0.1 %	0.1 %	0.1 %	0.1 %	0.1 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.2 %	0.0 %
	C10+	77.6 %	0.1 %	0.1 %	0.1 %	0.1 %	0.1 %	0.1 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.1 %
	Flashed gas density	1.0 %	0.7 %	0.7 %	0.7 %	0.7 %	0.5 %	0.3 %	0.2 %	0.0 %	0.1 %	0.2 %	0.3 %	0.3 %	0.3 %	0.3 %
	Flashed oil density	0.4 %	0.3 %	0.3 %	0.3 %	0.3 %	0.2 %	0.1 %	0.1 %	0.0 %	0.0 %	0.1 %	0.1 %	0.1 %	0.1 %	0.1 %
	GOR of flash	10.00 %	7.1 %	7.1 %	7.1 %	6.6 %	5.3 %	3.3 %	2.2 %	0.1 %	0.8 %	2.1 %	2.5 %	2.8 %	2.9 %	2.9 %
	Total uncertainty from budget		32.5 %	9.1 %	8.6 %	8.3 %	10.5 %	12.5 %	7.4 %	7.8 %	6.9 %	6.6 %	6.6 %	7.0 %	7.0 %	13.3 %
	Uncertainty evaluated by Monte Carlo		32.2 %	9.2 %	8.7 %	8.4 %	10.5 %	12.6 %	7.5 %	7.7 %	6.8 %	6.4 %	6.5 %	6.9 %	6.8 %	13.3 %

Relative expanded uncertainties, 95 % confidence level.