Northern Gas Networks

Northern Gas Networks Limited
Unit 9, Temple Point
Bullerthorpe Lane
Leeds
LS15 9JQ

@NGNgas
Find us on Facebook

29th July 2016

Steve Brown
Senior Manager Smarter Markets
The Office of Gas and Electricity Markets OFGEM
9 Millbank
London SW1P 3GE

Dear Steve

NGN would like to formally propose the relaxation of the prevailing standard MPE (Maximum Permissible Error) in line with the CV open letter proposal from Rob Church Ofgem dated 21/08/14 for CVDD (see Appendix 1), which would facilitate the introduction of new CVDD reducing costs for DN's and other parties. NGN believe in the immediate future this provides a path forward for approving the GasPT2 for use on all directed sites including Biomethane and have compiled the attached report to support this case.

At present in the UK the MPE requirement for a "directed" instrument is +/- 0.14 MJ/m3 or around +/- 0.35%. In Europe the widely accepted MPE for Calorific Value determination in fiscal use is +/- 0.2 MJ/m3 or 0.5%. This is supported in documents such as OIML R 140 (2007 Ed) "Class A" instrument. The overall uncertainty requirement for a correctly designed flow measurement system (+/- 1.1%) can be achieved when using a CVDD with a MPE of +/- 0.2 MJ/m3. A typical uncertainty calculation, (see attached Kelton report), takes into account each Instrument, Calibration & other influencing factors such ADC's, Power supply etc. and devises a total uncertainty, each contribute to the overall energy uncertainty calculation with the CVDD being one of many. The combined uncertainty is calculated using GUM and ISO5168, systems delivering an overall energy uncertainty of better than +/-1.1% using these methods are accepted for fiscal use.

Orbital gas have commissioned Kelton Engineering to carry out an independent performance evaluation of a typical measurement system using a GasPT2 to determine the impact on Overall uncertainties (see attached report). NGN believe that the attached report demonstrates that devices with a slightly higher MPE can still form part of a fully compliant measurement system and meet the required total uncertainty requirements.

NGN believe this demonstrates that devices capable of meeting the OIML R140 specification for a "Class A" device can be used in the UK for fiscal metering (+/- 1.1%) and would ask that this be considered as an appropriate standard.

Even though it is recommended in BS EN ISO 5168 to factor in the amount a fuel source will vary in quality (i.e. CV) when determining the uncertainty of a fiscal metering system, typically this is ignored when determining the overall uncertainty. As discussed at our meeting in 2015, NGN believe that inferential analysers with a higher frequency of measurement, such as GasPT2, will by default reduce the uncertainty of instantaneous physical property calculations, resulting in a lower average error than that of a slower unit such as those currently used on directed offtakes and entry points. Evidence of this can be seen in the attached DNV GL documents (GasPT2 Performance & Measurement Model with Time) this along with the relaxation of MPE would mean that fast acting inferential devices can reduce the overall measurement system uncertainty with changing gas composition and maintain compliance when stable.

Currently Gas Chromatograph technology is utilised due to the accuracy requirements, the a good GC will typically perform in a lab test with an MPE of better than 0.1 MJ/m3 and an acceptable field MPE of better than 0.14 MJ/m3. One of the reasons for the high accuracy is the daily calibration it undergoes, which is automatically carried out across the UK fleet at the start of the gas day, 5 am, using a Type 4 calibration gas. In addition a 35 day test is carried out using a natural gas taken from the distribution or transmission system and certified by an approved body. The Ofgem 35 day test gas must be run through the GC at least every 35 days to confirm performance using a natural gas rather than a calibration gas that does not contain all the species that are in a normal natural gas, but also confirming the calibration is good.

The GasPT2 is an inferential device and does not require field calibration, the instrument is not complex and very stable. Although the CO2 sensor used in the GasPT2 uses the NDIR principle of measurement, which can drift due to the apparent absorption of IR light by the contamination. The effect of this drift on the physical property calculation is negligible as the purpose of the sensor is to determine the concentration of Carbon Dioxide with the balance of inert assumed to be Nitrogen, the TCD measures the total inerts.

We propose, as per the GC solution, a 35 day test is carried out on the GasPT2 using the appropriate test gas, the operation being controlled by GasPTGO invoking 35DAY. GasPTGO was developed by DNV GL to replicate DANGO and has been implemented on many Tracker sites throughout the UK. Although the Tracker sites are not the regulated measurement, the software and hardware are identical to that of an FWACV regulated site using a Gas Chromatograph.

Inferential analysers are typically a smaller footprint and lower purchase price than the presently used CVDD's. They also do not require carrier gas and highly skilled maintenance activities thereby reducing operational costs, they also offer Reduced Natural Gas Emissions, Reduced Civil Works, Reduced Technician Visits (Transport Pollution), Reduced Power Consumption, Reduced Calibration Gas

Emissions. Devices that can meet the proposed MPE will result in significant savings for DN's, Biomethane producers and other future sources of gas. As an example it is estimated that over a ten year period GasPT2 could deliver a Totex saving of over £100k per unit when compared with traditional GC solutions.

NGN believe that an inferential analyser such as the Gas PT2 is fit for purpose if we consider MPE statements above and could offer significant advantages when we consider the other points.
Since the UK networks are required to innovate under the RIIO model and use equipment that has lower OPEX and CAPEX, we propose that the MPE requirement for CVDD be changed from the prevailing standard +/- 0.14 MJ/m3 can be changed to +/- 0.2 MJ/m3 for any entry flow, therefore allowing the use of inferential analysers which will result in the above benefits.

I would be very grateful if you could advise NGN and SGS regarding a potential relaxation to allow NGN to use OIML R140 approved Class A devices to realise the above mentioned benefits
During this price control period NGN has committed to updating its CVDD and is looking to innovative products like GasPT2 to enable NGN to meet its RIIO targets.

NGN would welcome an industry wide consultation on this matter to fully explore the opportunities and challenges this may create.

Yours sincerely

Ben Hanley
Lead Electrical & Instrumentation Engineer
Northern Gas Networks

Supporting Information to the Request for Relaxation of the Maximum Permissible Error (MPE) of Ofgem Regulated

Calorific Value Determination Devices (CVDD)

Contents

Executive Summary

Following an independent report commissioned by Ofgem covering gas energy measurement in consumer billing, for which the outcome was published on 21st August 2014 (see appendix 1), a request is made by Northern Gas Networks (NGN) to relax the prevailing Maximum Permissible Error (MPE) of 0.1 MJ/m^3 to 0.2 MJ/m^3.

The MPE prescribed by Ofgem and enforced by SGS results in the use of complex pieces of equipment (Gas Chromatographs) plus the additional operational support infrastructure. Complexity and Higher Cost generally go hand in hand, this is certainly the case for Calorific Value Determination Devices (CVDD) that comply with this performance requirement, not only in terms of CAPEX but also OPEX.

NGN have formally requested the relaxation of the prevailing MPE, which would facilitate the introduction of new CVDD's reducing costs for Distribution Networks and other parties. NGN believe in the immediate future this provides a path forward for approving the GasPT2 for use on all directed sites, with no limitation on flow, including Biomethane and Shale Gas connections.

In addition it is proposed that the OIML R 140 Ed. 2007 (E) International Recommendation for Measuring Systems for Gaseous Fuels be adopted as the criteria for the suitability for regulated CVDD's moving forward.

This document shows that;

- Inferential fast acting devices, such as GasPT2, will improve the uncertainty of a metering system to that of a slower Gas Chromatograph with changing gas quality (which is the norm in the UK) – Illustrated by the Independent DNV – GL Report Appendix 2

- Relaxing the MPE to 0.2 MJ/m^3 will allow the defacto uncertainty for energy metering of +/- 1.1% to be maintained – Illustrated by the Independent Kelton Report Appendix 3 & DNV GL Report Appendix 2 " Performance of GasPT2"

- CAPEX and OPEX Savings – Illustrated by typical figures within Section 3 "Cost Benefits"

1. Definition of Acronyms

CAPEX	Capital Expenditure
CV	Calorific Value
CVDD	Calorific Value Determination Device
DN	Distribution Network
E&I	Electrical and Instrumentation
EMMUA	Engineering Equipment Materials Users Association
GasPT	Gas Properties Transmitter
GC	Gas Chromatograph
GUM	Guide to the Expression of Uncertainty in Measurement
ISO	International Standards Organisation
LNG	Liquefied Natural Gas
MPE	Maximum Permissible Error
MTBF	Mean Time Between Failures
MTTR	Mean Time To Repair
NDIR	Non Dispersive Infra-Red
NGN	Northern Gas Networks
Nmi	Netherlands Measurement Institute
OIML	International Organisation of Legal Metrology
OPEX	Operational Expenditure
P	Pressure
RD	Relative Density
RIIO	Revenue = Incentives + Innovation + Outputs
SOS	Speed of Sound
T	Temperature
TCD	Thermal Conductivity Detector

2. Consideration of the use of Inferential Devices

Introduction - CV Determination in the UK

A number of Transmission and Distribution companies have looked for alternative instruments to the Gas Chromatograph (GC) for Calorific Value determination in accordance with ISO 6976. The calculated CV being part of the energy flow calculation typically required to produce an uncertainty of better than +/- 1.1%.

Their main objectives and incentives are:

1) Reduce Capital Expense
2) Reduce Operational Expense
3) Reduce Maintenance Complexity

In recent years there has been much development of inferential instruments. In Europe some devices have obtained approval to OIML R140 as a "Class A" instrument. (i.e. a device with a MPE of 0.5% for a defined range of gases). A number of gas companies in Europe are therefore adopting inferential devices for CV determination to reduce costs and complexity of maintenance.

Within the UK current regulations for CV determination requires an MPE of 0.1 MJ/m^3 (This equates approximately to 0.25%). The use of inferential devices has therefore typically not been considered in the UK.

Suitability of Inferential Instruments

Presently CVDD's that are evaluated do not include any consideration of the frequency of measurement within the stated MPE. Many studies have demonstrated that as Natural Gas quality varies at a higher frequency an inferential device with a near continuous measurement has typically an equivalent if not improved performance when compared with a gas chromatograph measuring once every 3.5 minutes. (See Section 4 "Specifying the Frequency of Calorific Value Measurements in Natural Gas Applications.")

In consideration of the variability of gas sources within the UK and the objectives stated above, the use of near real time inferential devices within the UK is appropriate.

Cost Benefits

1) Capital

Depending on the site conditions, customer specifications and other factors the cost of systems vary. For the purpose of comparison minimal “fit for purpose” installed values for both types of Instruments will be considered.

Table 1

Aspect	Typical GC Cost	Typical Inferential Cost
Civil Works	£4,000 - £8,000	£500 - £1,000
E+I Installation	£4,000	£1,000
Instrument and Equipment Fitted into Enclosure	£60,000	£25,000
Commissioning	£3,500	£800
Total	**£71,500**	**£27,300**

2) Operational

For the operational expense routine maintenance requirements per annum only are included.

Table 2

Aspect	Typical GC Cost	Typical Inferential Cost
Carrier Gas / yr	£220	£0
Calibration Gas / yr	£1200	£0
Routine Maintenance / Yr	£2,200	£800
Totals	**£3,620**	**£800**

3) Maintenance Complexity

The reduction in maintenance complexity represents a significant improvement in hidden or unplanned costs. Repairing a GC involves skilled staff and can result in many hours of down time. Inferential instruments are much like modern Pressure or Temperature Transmitters; they will typically operate for up to 10 years without intervention and are simply exchanged in the event of an issue.

This methodology results in much lower MTTR’s and MTBF’s.

Ofgem & Nmi Test Ranges

Ofgem instrument test/alarm ranges are detailed in Table 3, these standard ranges are used for evaluation of CVDD’s in the UK which result in a calculated Maximum Permissible Error for Calorific Value.

The Nmi (Netherland Measurement Institute) is a globally recognised independent specialist for testing, certifying and training in the field of metrology and gaming. The test ranges used by the Nmi, also detailed in Table 3, are in line with the requirements of a European operator whom use OIML R140 (2007) for guidance and certification of CVDD’s, which also produces a calculated MPE.

As can be seen the majority of the ranges either equal or exceed that traditionally required by Ofgem, with exception of C_2 (Ethane) and nC_4 (normal Butane).

Typically Natural Gas within the UK Transmission and Distribution systems do not exceed the levels used within the Nmi test, however the Ofgem test ranges for nC_4 (normal Butane) has a marginal difference and C_2 (Ethane) is significantly higher. The previous maximum Ofgem ranges for Ethane was 12% and normal Butane 1%. With regards to Ethane the range increased due to the influx of vaporised LNG into the transmission system within the regional proximity of strategic LNG storage sites.

These strategic LNG storage sites liquefy natural gas from the transmission system which provided a peak gas supply to shippers and supplement network capacity, also provided contingency against the risk of supply emergencies. The emergence of LNG import terminals in South Wales (2005) resulted in the distinct possibility that Vaporised LNG may be reprocessed at the LNG storage sites thereby increasing the potential of exporting higher Ethane gas into the transmission system in the infrequent cases mentioned above. The LNG storage sites have since been deemed superfluous and closed.

Table 3

Component	Ofgem - Alarm Range (mol%)		NMI Evaluation Range (mol %)	
	Min	Max	Min	Max
N2	0	10	0	10
CO2	0	7	0	7
C1	78	100	65	100
C2	0	18	0.5	12
C3	0	7	0.03	7
IC4	0	1	0	1.5
NC4	0	1.6	0	1.5
NEOC5	0	0.35	0	0.5
IC5	0	0.35	0	0.5
NC5	0	0.35	0	0.5
C6/C6+	0	0.35	0	0.6

On-site Performance Testing

When a Gas Chromatograph is installed for fiscal applications whether this be for Ofgem regulated or other non-regulated sites a performance evaluation of the CVDD is typically carried in accordance with ISO 10723 Natural Gas - Performance Evaluation for Analytical Systems.

This International Standard specifies a method of determining whether an analytical system for natural gas analysis is fit for purpose. This standard is written around instruments that determine a range of actual gas compositions or calculate properties from actual gas composition. Since the instrument proposed is an inferential devise, GasPT2, and does not provide measurement of individual component amount fractions, therefore the international standard in this form cannot be applied.

However in the spirit of the ISO 10723 standard, a defined range of certified reference gases covering the ranges required by Ofgem can be applied to an inferential device upon initial installation and record the measured Calorific Value over a specified period. The data can then be used in a simple calculation to ensure the calculated CV's are within the required limits i.e. error of no more than the proposed relaxation figure of +/- 0.2 MJ/m^3 of that stated on the certified reference gas certificate.

In the short term a standard test method can be used, in the longer term a proposal should be made to either amend ISO 10723 (2012) to include inferential CVDD's or a new standard written specifically for inferential CVDD's.

Standard Test Method for Inferential Devises

A defined range of certified reference gases applied to the inferential device upon initial installation and log the measured Calorific Value over a specified period. The data then being used to calculate the Maximum Permissible Error by comparing the measured Calorific Value to that of the reference Calorific Value.

Other Published Guidelines

Also considered is the International Standard ISO 15971:2008 - Natural Gas -- Measurement of Properties -- Calorific value and Wobbe Index

ISO 15971:2008 concerns the measurement of calorific value of natural gas and natural gas substitutes by non-separative methods, i.e. methods that do not involve the determination of the gas composition, nor calculations from it. ISO 15971:2008 describes the principles of operation of a variety of instruments in use for this purpose, and provides guidelines for the selection, evaluation, performance assessment, installation and operation of these.

Within the standard it discusses inferential devises, which the GasPT2 is, however since the standard was written inferential technology has significantly moved on and therefore the bias detailed within the guidance document or the classification is no longer applicable.

3. Specifying the Frequency of Calorific Value Measurements in Natural Gas Applications

Introduction

Throughout the Natural Gas Industry many different types of instruments and analysers are used to determine Gas Quality. One of the most common measurements is the Calorific Value (CV) of Natural Gas. When selecting a system or analyser (CVDD) to determine the CV of the gas it is normal to specify a maximum permissible error (MPE) for obvious reasons. However, traditionally in many Networks the Gas Quality has been relatively stable, and the frequency of the measurement has not been a concern and often not specified. In recent years diverse sources of Natural Gas are commonly seen throughout the transmission and distribution networks, therefore stable gas quality is the exception rather than the rule (Appendix 2 - ii. “DNV GL - GasPT2 Performance” Pg. 8/9/10)

In light of the variability of CV within Networks more attention to specifying the frequency of measurement is needed.

Standards and Guidance

International standards and Engineering guidance documents do not adequately address this topic. For example ISO 6974/6976 along with ISO 5168 and GUM together should enable an Engineer to determine the uncertainty of measurement of a system using a gas chromatograph. The frequency of measurement though is ignored.

EMMUA 138 makes a definition of analysis time lag and advocates the use of single stream instruments but does not address the topic sufficiently.

ISO 10715 provides some guidance on how to determine an appropriate sampling frequency however it unfortunately states: “Sampling frequency is a matter of common sense” and then adds: “the statistical approach – is only intended to support the common sense approach”.

OIML R 140 2007 (E) provides the most specific guidance, section 7.4.1 time interval for determination of CV states: “in principle, the energy to be determined should be the sum of the instantaneous energies delivered”. The document recognises the practicalities of this statement and therefore defines that for “Class A” accuracy the maximum time interval should be 15 minutes or less but then adds: “depending on CV stability”.

It is clear that the frequency of measurement and sample transit time should be included when specifying a CVDD and associated system.

Bias and MPE’s including frequency of measurement.

Research has shown that the variability of CV has a significant effect on metering errors. One paper dealing with the “Uncertainty associated with the energy content in flow measurement of natural gas” concluded “The work also suggests that the chemical analysis-sampling rate plays an important role in the overall uncertainty budget.”

DNV GL have provided a method of evaluating the effects of the variability of CV on the overall error of measurement. (Appendix 2 - ii “DNV GL - GasPT2 Performance”). It can be seen from the simulations that the typical variations in CV, as seen in UK gases, increases the errors associated with GC measurements such that the overall average error can become equal to or worse than 0.2 MJ/m^3 (Based on a 3.5 minute cycle time).

Recommendation

In determining the suitability, specification, and selection of CVDD’s for applications in the UK the measurement frequency should be included in the calculation of MPE’s.

Appendix 1

To: Gas shippers, gas suppliers,
network companies, consumers,
consumer representatives, investors
and other interested parties

Making a positive difference
for energy consumers

Direct Dial: 020 7901 7034
Email: rob.church@ofgem.gov.uk

Date: 21 August 2014

Dear colleague

Open letter: Gas energy measurement in consumer billing

Earlier this year we commissioned an independent report covering two key aspects of gas measurement, as follows:

- calculating thermal energy and its impact on domestic consumers
- technical standards for calculating calorific value (CV) at biomethane injection sites.

We have published the report in full on our website.[1] This letter summarises the report's findings and our conclusions that:

- the prescribed method for converting metered volumes of gas into thermal energy remains appropriate
- the technical standards for CV determination devices at bio-methane injection sites should be proportionate to the size of such sites and the effect on downstream gas.

Background

Unlike electricity meters which measure in energy units (kWh), gas meters in Great Britain measure the volume of gas that is being used. However, volume for a given mass of gas is variable, ie the gas may expand with increased temperature or reduced atmospheric pressure, and vice versa. So, to ensure that the consumer is accurately billed for the amount of energy consumed, rather than simply the volume of gas, it is necessary to both correct for the volume changes using a volume correction factor (VCF) and determine the energy content of the gas supplied, known as the CV of the gas. CV is measured in MJ/m^3.

Volume Conversion Factor

The Gas (Calculation of Thermal Energy) Regulations 1996, as amended (the 'Regulations'), prescribe the conversion of volume to energy for temperature and pressure. There is currently a single volume conversion factor for all GB supply points with an annual consumption of less than 732,000 kWh, which covers the vast majority of domestic households[2] and smaller commercial premises. This volume conversion factor is applied by gas suppliers to their volumetric meter readings in order to bill the consumer.

Our objective for the gas conversion arrangements is to ensure consumers have accurate bills for the energy they consume, without imposing excessive costs on suppliers to operate these rules which are then reflected in consumer bills.

---

[1] www.ofgem.gov.uk/gas/distribution-networks/charging-arrangements
[2] Typical domestic consumption is 13,500 kWh per year.

As part of our efforts to ensure the regulatory framework continues to act in the interests of consumers, we recently commissioned work to identify the impacts on consumer bills of using a location-specific volume conversion factor. This was to take account of variations in pressure and temperature across the country. The analysis examined the effect of the prevailing volume conversion factor using national temperature and pressure data from 2011.

The analysis demonstrates that energy calculation under the prevailing volume conversion factor is accurate to within -1.48% to +1% for 95% or more of the population. Even at the extremes, the energy calculation is accurate to within -1.569% to +2.477%, which is broadly in line with the maximum permissible error for gas meters themselves.[3]

Based on the analysis, we do not think that introducing a location-specific volume conversion factor would be in the overall consumer interest because:

- the existing arrangements are already accurate and a location-specific factor would have a very limited impact on reducing overall error
- the costs of implementation within suppliers' systems is likely to impose additional costs on consumers that outweigh the benefits
- we know that data quality[4] is a problem in the industry, and are concerned that it would create further risk of mistakes that result in less accurate consumer bills
- it would create additional complexity and make bills less understandable for consumers.

While we recognise that there are always options for increasing accuracy, it is not the case that it will always be in consumers' interests to mandate such approaches, as doing so may incur disproportionate additional costs. So, we do not propose to act now to amend the Regulations.

Calculation of Calorific Value of biomethane

As the traditional sources of GB gas (such as the North Sea) decline, alternative sources of gas will become increasingly important to the GB energy mix. For instance, in addition to providing an environmentally sound option for waste management, anaerobic digestion[5] can offer a sustainable source of biomethane gas.

The Energy Market Issues for Biomethane ('EMIB') work programme was established by Ofgem to address the costs and complexity of injecting biomethane into the gas grid. This included creating a review group, consisting of each of the gas distribution network operators and facilitated by the Joint Office of Gas Transporters. The review group came up with recommendations in each of these five areas:

1. Gas Distribution Network connection policies
2. Network capacity availability
3. Gas quality regulation
4. Data requirements and transmission and third party ownership of CV equipment
5. Technical standards for CV

In March 2014 we issued an open letter[6] confirming that the first three of these issues had been, or were in the process of being, dealt with. We also confirmed that we thought the issue of third party ownership could be addressed by interpreting the Regulations flexibly,

---

[3] Domestic gas meters are accurate if they measure gas volume to within +/-2%. See the Gas (Meter) Regulations 1983 (SI 684) and the Measuring Instruments (Gas Meters) Regulations 2006 (SI 2647).

[4] For instance, in June 2014 we wrote to industry parties requiring that they produce a report on how data quality issues which impact upon customers' transfers could be addressed. Metering and address data is of particular concern. The letter is published at: https://www.ofgem.gov.uk/ofgem-publications/88308/industrydataqualityownershipandgovernance.pdf

[5] anaerobic digestion is a natural process in which micro-organisms break down organic matter in the absence of oxygen

[6] www.ofgem.gov.uk/ofgem-publications/86979/emibopenletterfinal.pdf

and so we do not intend to do anything else on this. On the issue of data requirements and data transmission, we said that we would work with stakeholders to consider more detailed proposals. This work is ongoing.

Technical standards

This letter addresses the last of the five EMIB review group's report and recommendations for the technical standards for CV determination devices (CVDD).[7] The recommendation was to reduce the required accuracy of CVDDs from the prevailing standard for Maximum Permissable Error (MPE) from +/- 0.1 MJ/m^3 to +/- 0.5 MJ/m^3 for entry flows up to 2.5 million m^3/day. The principal driver for this was to reduce the obstacles to the uptake of use of renewable gas supplies such as biomethane. However, it was noted that this approach could be applicable and benefit the network entry of any small volumes of gas.

The analysis we commissioned determined that the impact of biomethane injection on CV for billing purposes depends on relative volumes of both the injected biomethane and the flow weighed average CV of the network. As the size of such injection sites is generally expected to be small, ie <100,000 m^3/day as compared to >1 million m^3/day at conventional system entry points, the impact on the CV of downstream gas is likely to be negligible. As biomethane injection sites are likely to be several orders of magnitude smaller than existing entry points, the analysis supported the view of the EMIB group that the specification for CV determination devices at such sites needn't be as stringent and therefore as expensive as currently required.

Rather than the single additional tier put forward by the EMIB group, the analysis we commissioned considered the implications of wider MPE values, but limited to much smaller sites, given the likely size of biomethane injection sites, as follows:

- ± 1.0 MJ/m^3 for sites <100,000m^3/day
- ± 0.7 MJ/m^3 for sites 100,000 to 250,000 m^3/day

We have considered the report and agree that the existing MPE tolerances for CV determination devices at system entry points should be proportionate to the impact they have on flow weighted average CV. The EMIB group report said its recommended relaxation of MPE tolerances could lead to cost savings of £25,000 - £50,000 per CVDD installation.

The prevailing MPE tolerances are not prescribed in the Regulations, but have become custom and practice through Letters of Direction issued by the Authority, according to the Regulations. We therefore do not consider that that the Regulations need amending to give effect to revised technical standards. However, we will have regard to proportionate standards and the recommendations mentioned above as part of any future work on the testing and approving CVDDs.

We also consider that these principles regarding CV determination devices should apply equally to other sources of unconventional gas, such as shale and coal-bed methane.

Yours faithfully

Rob Church
Associate Partner, Retail Markets & Research

---

[7] www.gasgovernance.co.uk/emib/report

Appendix 2

Technical Note Number: 15896
Issue: 1
Date: 27/10/2014

GasPT Measurement Error Dependence on Measurement Frequency

Prepared for:	**Prepared by:**
Discussion	Nigel Bryant, Andrew Laughton

GL Industrial Services UK Ltd trading as DNV GL
Holywell Park
Ashby Road
Loughborough Leicestershire
LE11 3GR
United Kingdom
Tel: 01509 282133
E-mail: nigel.bryant@dnvgl.com
Website: www.dnvgl.com

Customer Reference: GasPT Ofgem Approval

DNV GL is the trading name of GL Industrial Services UK Ltd

Registered in England and Wales No. 3294136 Registered Office: Holywell Park, Ashby Road, Loughborough, Leicestershire, LE11 3GR UK.

"If you cannot see it, how do you know what it is?"

Impact on calorific value measurement

The Danalyzer injects a small sample of line gas every 4 minutes and provides a calculated CV with a maximum error of 0.1 MJ/m^3 for UK distributed gases (0.14 MJ/m^3 error allowable on 35 day test). This is an accurate determination of the quality of that gas sample but provides no information on the quality of gas passing the sample point during the remainder of the 4 minutes.

Figure 1: Plot showing actual CV of natural gas versus value reported by Danalyzer

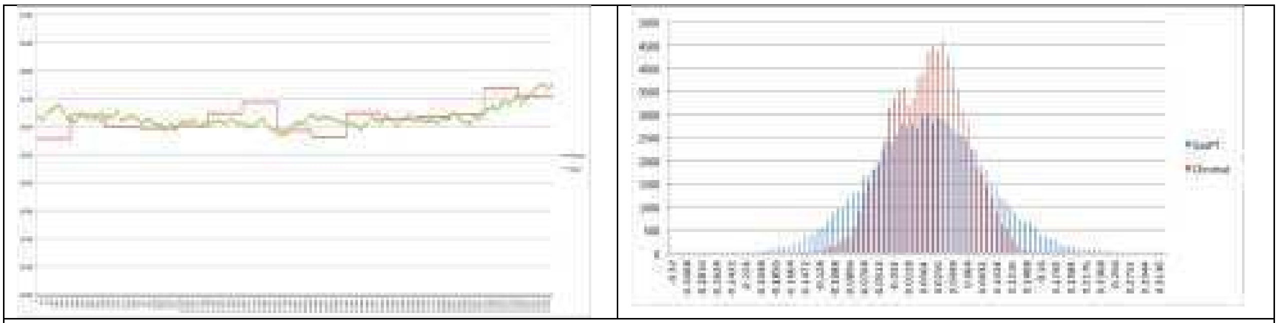
Ideally the analysis time for the Danalyzer, or other process GC, would be reduced whilst maintaining the same level of accuracy. Unfortunately this is not possible, at the present time, due to the physical constraints of chromatography.

The GasPT provides a near continuous [every 8 seconds] determination of CV and other gas properties. An evaluation of the GasPT by the Polish Oil and Gas Company reported[1] that the error in CV did not exceed 0.07 MJ/m^3[0.2%] for a set of evaluation gases representative of Polish pipeline gas. These test gases were not as extreme in composition as the Ofgem evaluation gases, for which initial tests suggest that a maximum error of 0.2 MJ/m^3 [0.5%] could be achievable. Whilst this is greater than the maximum error in CV for a Danalyzer [0.25%] the GasPT can provide 55 results in the time that a Danalyzer provides a single result.

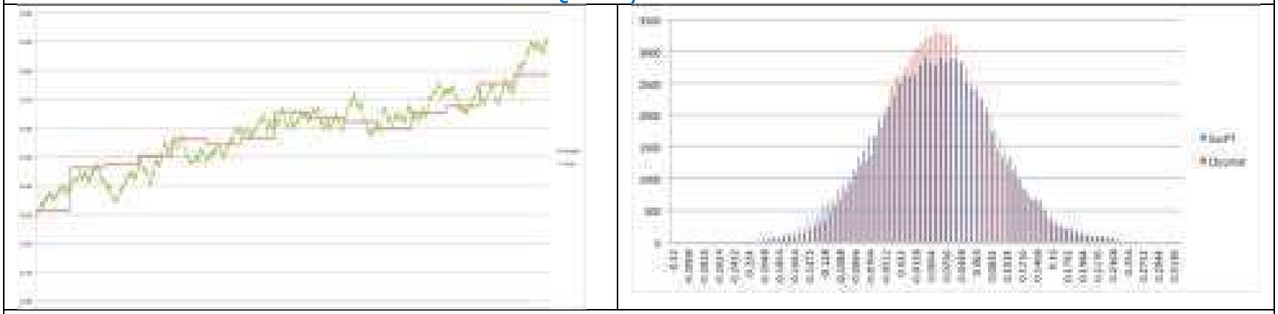
---

[1] Polish Oil and Gas Company, Evaluation of correlative device GasPT used to determine parameters of natural gases properties, Ref: 320/B/PFC/2012/A, 16TH November 2012

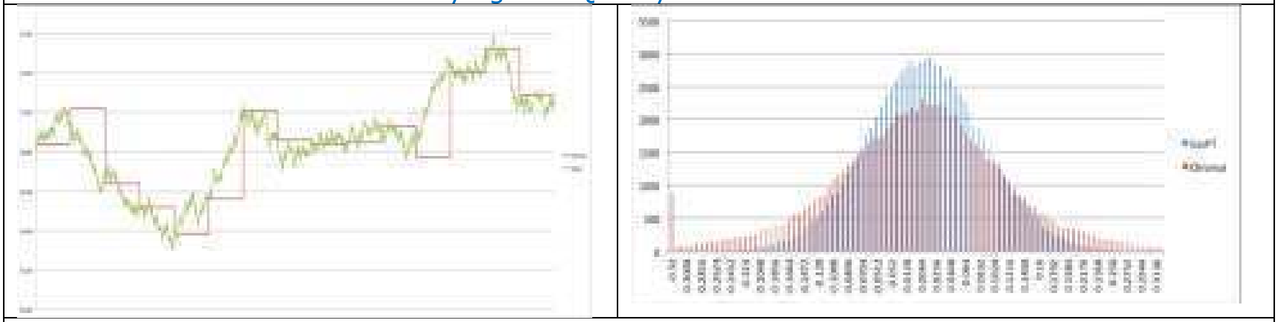
Where the CV of the gas does not change by more than 0.2 MJ/m^3 between Danalyzer analyses the frequent measurements made by the GasPT do not offer an advantage. However, if the CV of the gas changes by more than 0.2 MJ/m^3 during this time then the more frequent, and now comparatively more accurate GasPT results do offer a benefit over the Danalyzer's less frequent results. The plots in Figure 2[2] show the impact on error when the variation in natural gas quality varies by differing amounts. Where the variation is limited the GC provides the CV with the lower error. However, as variation increases the GasPT tracks the changes closely and provides a CV with a lower error than that provided by the GC.   This is more noticeable where the CV consistently increases or decreases during the day.



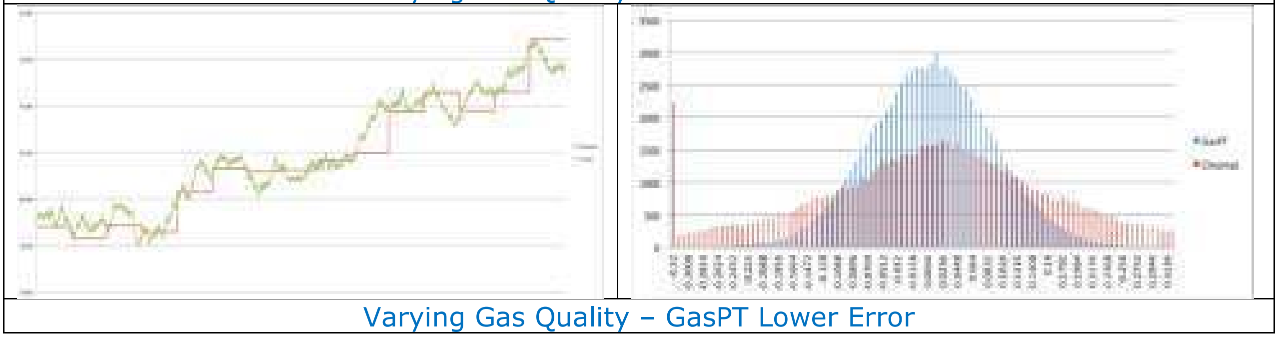
Stable Gas Quality – GC Lower Error



Varying Gas Quality – Similar Error



Varying Gas Quality – GasPT Lower Error



Varying Gas Quality – GasPT Lower Error

Figure 2: Plot showing impact of frequency of measurement on error

---

[2] Plots provided by Orbital Gas Systems

An analysis of real data has been carried out to further demonstrate the comparable accuracy of the GasPT with a Danalyzer. Four minute (approximate) Danalyzer data has been extracted for the period April 2002 to July 2002. During this period the CV is variable as shown in Figure 3.

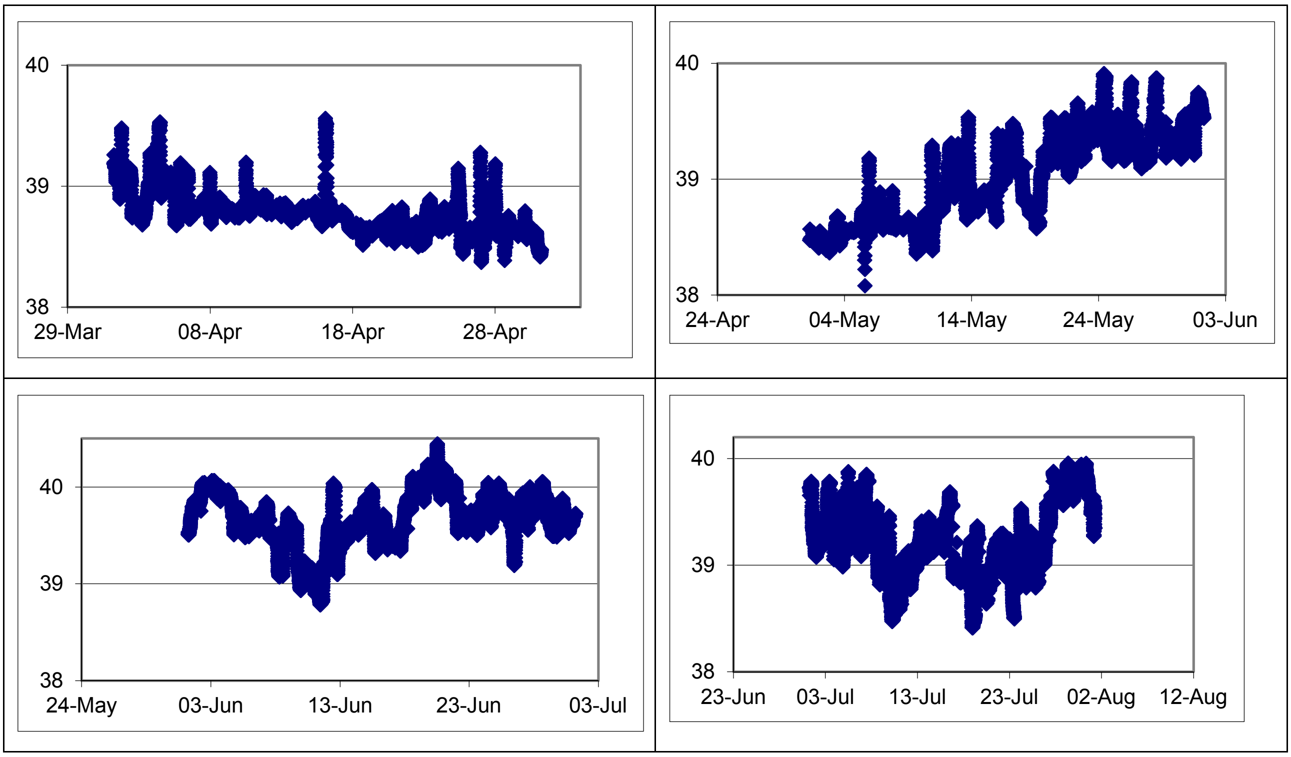


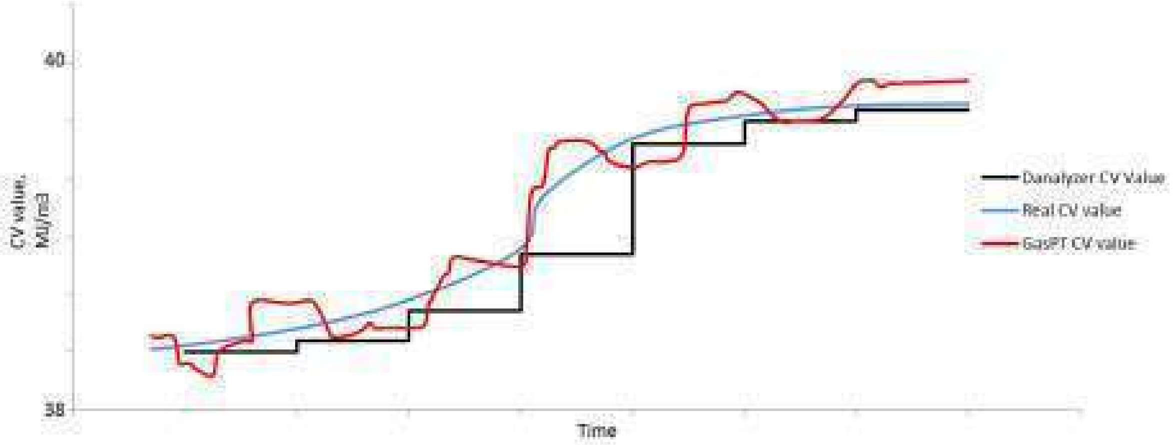
Figure 3: Plot of Calorific Value between May 2002 and July 2002

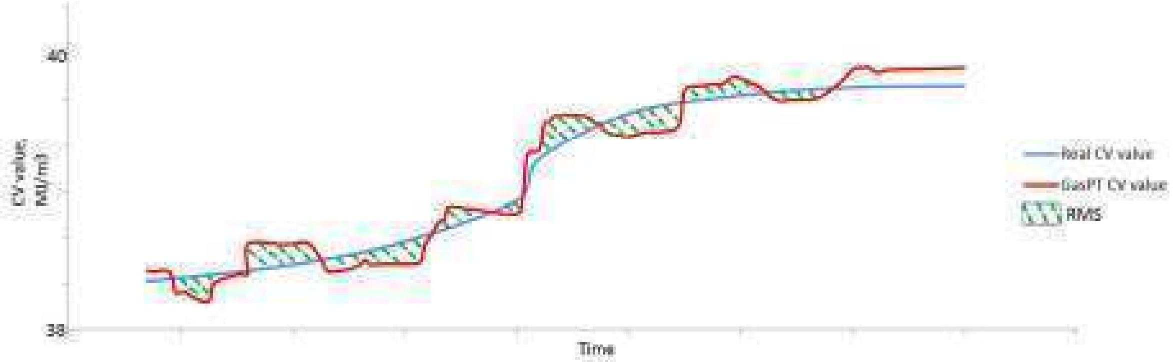
The site Danalyzer results have been used as a basis for the 'real' continuous CV – using a cubic spline as necessary. These 'real' values were compared with a Danalyzer, having an analysis time of 240 seconds and a maximum error of 0.05 MJ/m^3 and a GasPT, having an analysis time of 10 seconds and a maximum error of 0.2 MJ/m^3. The variation between subsequent Danalyzer analyses has been assumed to have a correlation coefficient of 0.95, and for the GasPT 0.995, to prevent extreme changes in CV due to the random uncertainty. The results are presented in Table 1 and show that the determination of a monthly average CV is the same by Danalyzer or GasPT with the more frequent GasPT analysis rate compensating for the higher error on each individual measurement.

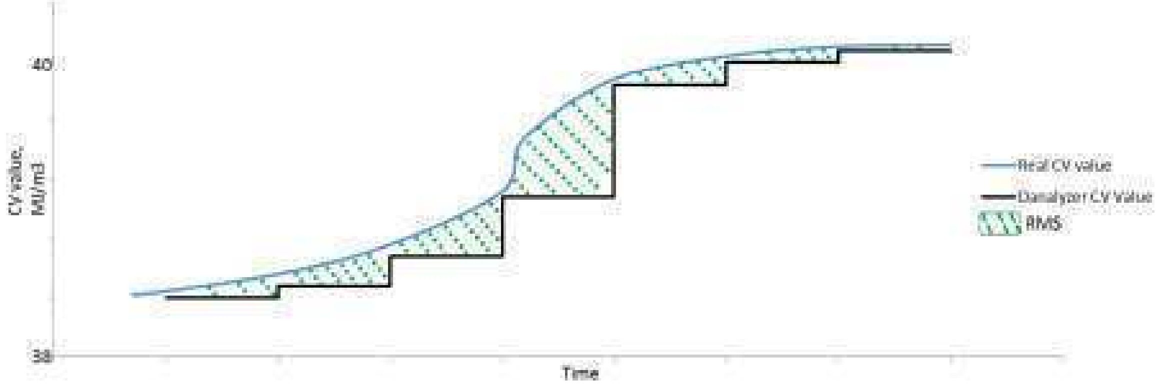
	April		**May**		**June**		**July**	
	Danalyzer	**GasPT**	**Danalyzer**	**GasPT**	**Danalyzer**	**GasPT**	**Danalyzer**	**GasPT**
Sample Time	240	2	240	2	240	2	240	2
Analysis Time	240	8	240	8	240	8	240	8
Error	0.05	0.2	0.05	0.2	0.05	0.2	0.05	0.2
Average CV	38.774	38.772	38.980	38.981	39.682	39.681	39.237	39.237
Average Error	0.001	-0.001	-0.001	0.000	0.001	0.000	0.000	0.000
Max Error	0.26	-0.09	0.77	0.19	0.18	-0.16	0.51	-0.16
Root Mean Square	0.021	0.010	0.033	0.011	0.017	0.011	0.026	0.009

Table 1: Determination of CV by a Danalyzer and GasPT

The root mean square, RMS, provides an estimate of the overall error between the real true CV and the measured CV, taking into account the delay in the reported result, (a combination of sampling time and analysis time). The RMS for the GasPT is smaller than the Danalyzer, this is shown schematically below:







The frequency of measurement has a significant effect over a shorter time frame. The GasPT generates the same daily average as a Danalyzer, as shown below.

	2nd July 2002	
	Danalyzer	GasPT
Sample Time	240	2
Analysis Time	240	8
Error	0.05	0.2
Average CV	39.237	39.237
Average Error	0.000	0.000
Max Error	0.51	
Root Mean Square	0.026	0.012

Impact on metered volume

Providing the flow computer with frequent gas quality data compensates for the higher uncertainty and overall has no detrimental impact on the determined volume. The GasPT would provide the flow computer with CV, relative density and carbon dioxide concentration values that would be configured to use the AGA8 Gross Characterisation method to calculate compression factor and correct the metered volume.

Impact on Energy Flow Calculation

CV data in near real-time from GasPT will produce more accurate Energy Flow data than mismatched instantaneous flow vs delayed CV data from a GC.

Conclusion

1. A GasPT with a maximum error in measurement of 0.2 MJ/m^3 will provide the same daily averaged CV as a Danalyzer.
2. Near real-time monitoring of CV will improve the calculation/correction of metered volume.
3. Near real-time monitoring of CV will improve the accuracy of energy flow data.
4. GasPT delivers the opportunity to have real time management of the network.
5. GasPT eliminates the risk that temporary excursions could be completely unnoticed
6. GasPT delivers a significant cost of ownership reduction by eliminating carrier gas.
7. Significant reduction in ‘down time’ compared to a GC
8. Reduced footprint, weight and ancillary equipment allows reduction in civil/mechanical installation work
9. Broad temperature and pressure operating range of GasPT gives a much more robust installation

Performance of the GasPT2

Nigel Bryant

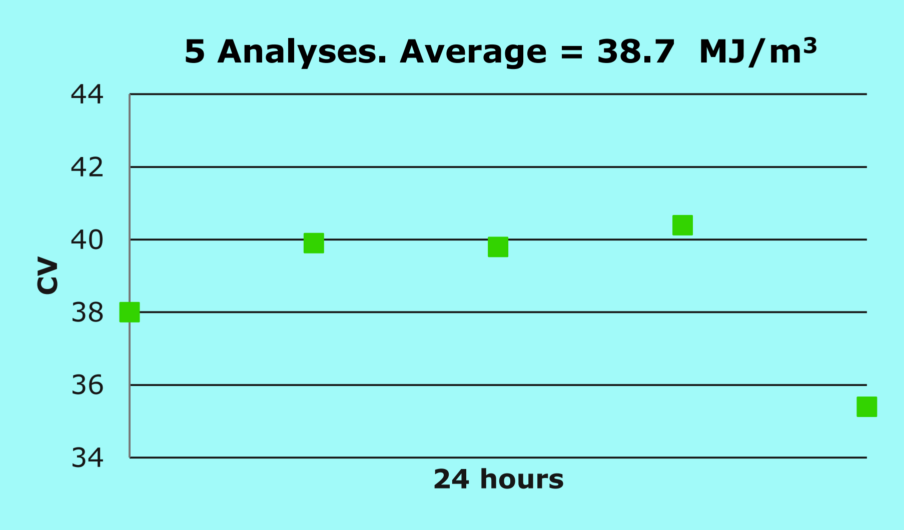
"If you cannot see it how do you know what it is"

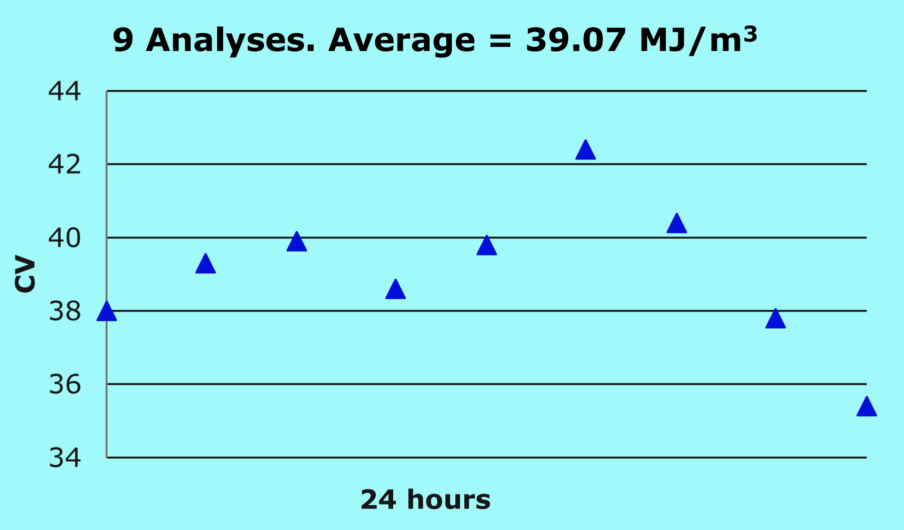
"There are known knowns ...

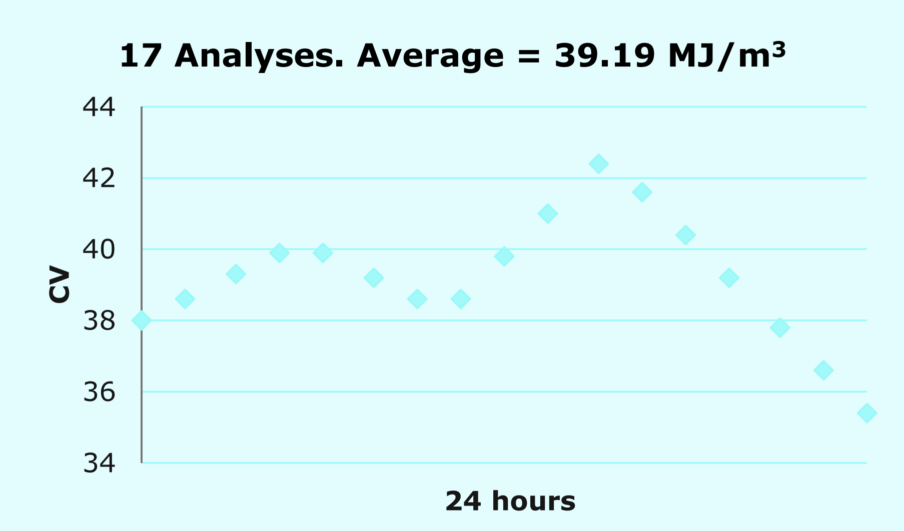
There are known unknowns ...

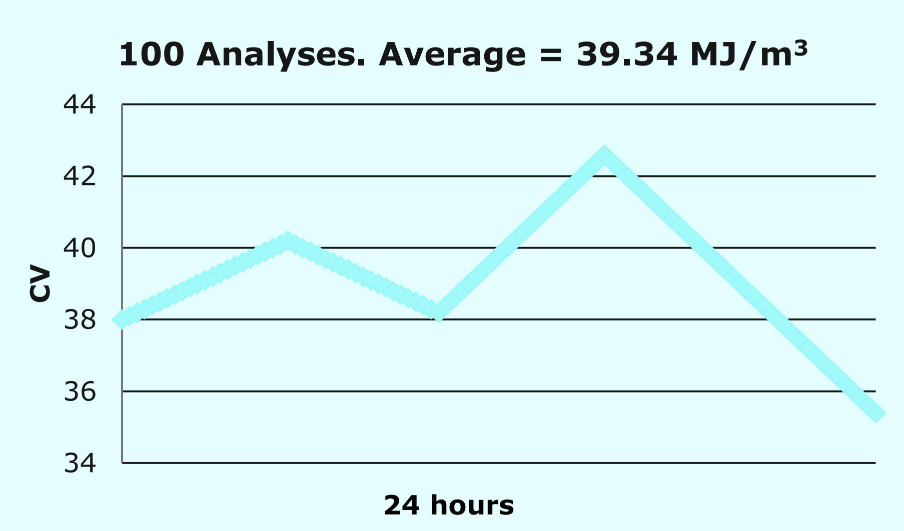
But there are also unknown unknowns ..."

Increased frequency of measurement proves more accurate result

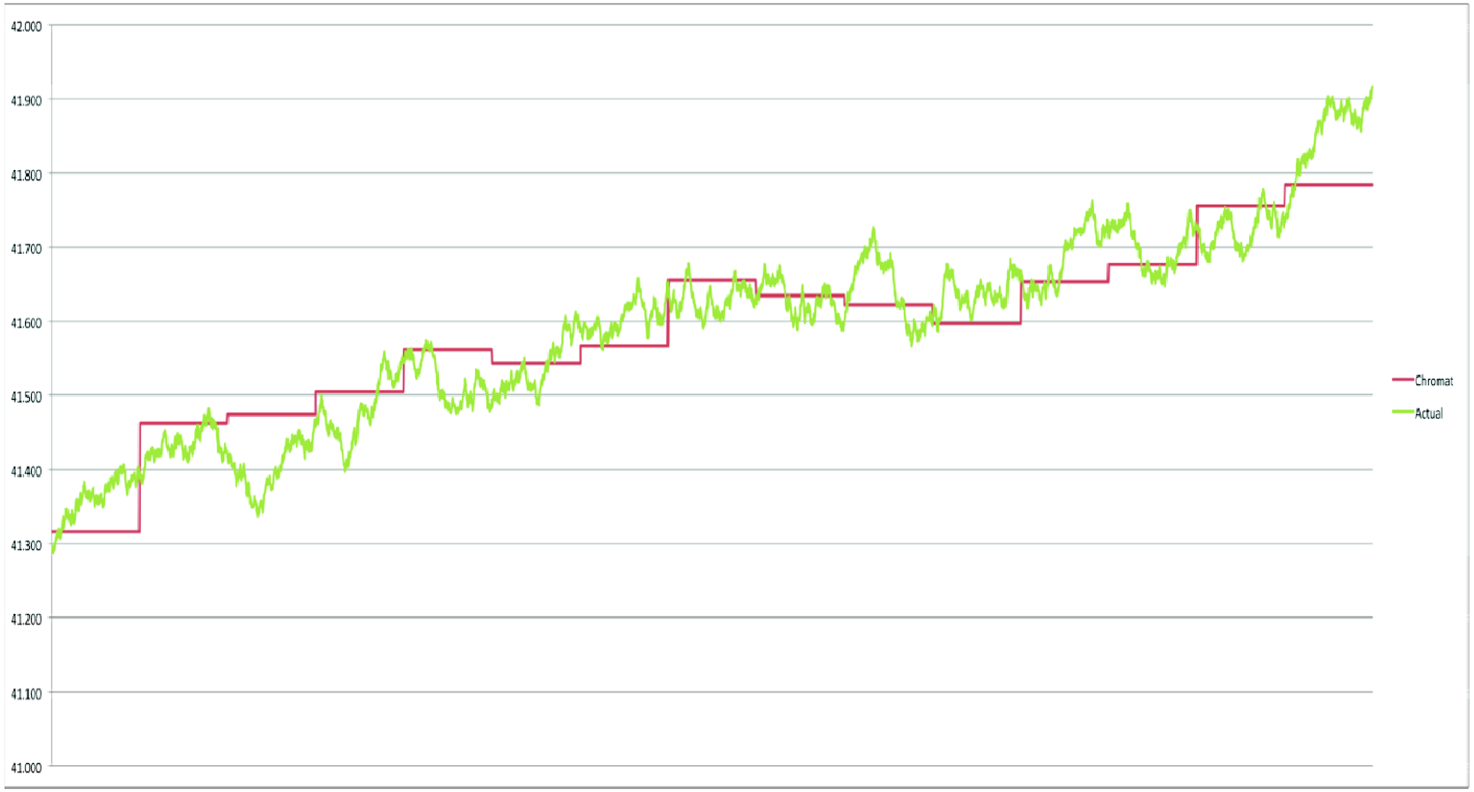

5 Analyses. Average = 38.7 MJ/m³


9 Analyses. Average = 39.07 MJ/m³


17 Analyses. Average = 39.19 MJ/m³


100 Analyses. Average = 39.34 MJ/m³

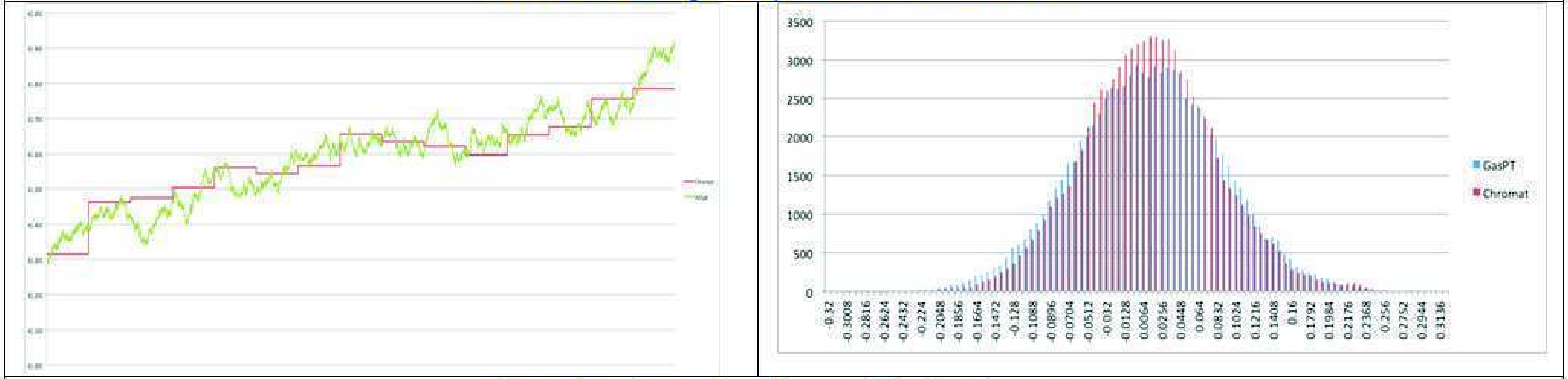
Process gas chromatograph provides intermittent measurements



- The Danalyzer injects a sample of line gas every 4 minutes and provides a calculated CV with a maximum error of 0.14 MJ/m^3 for UK distributed gases.

GasPT provides near continuous measurement

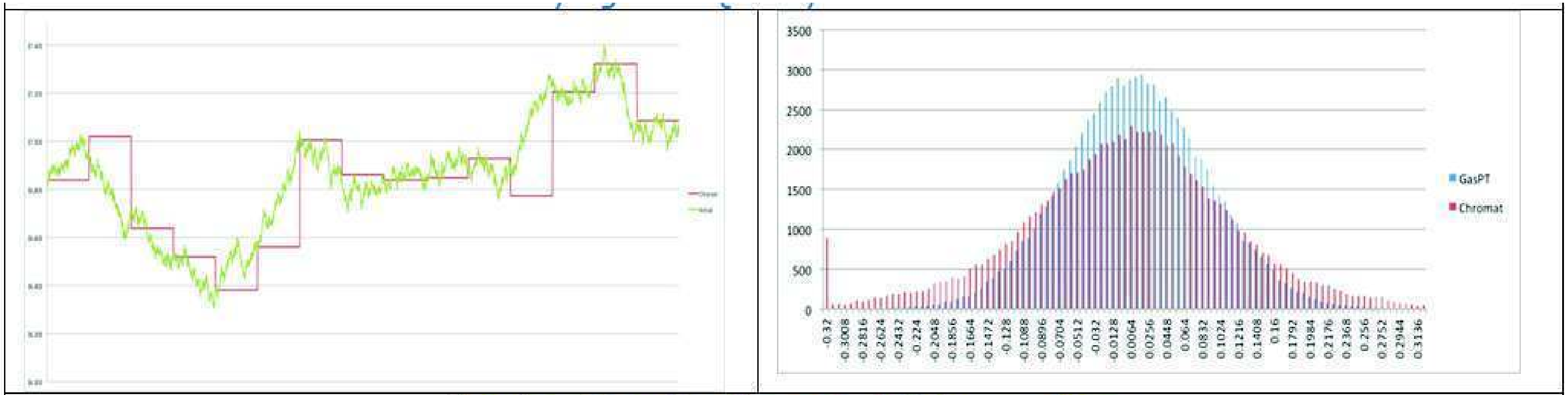
Stable Gas Quality – GC Lower Error



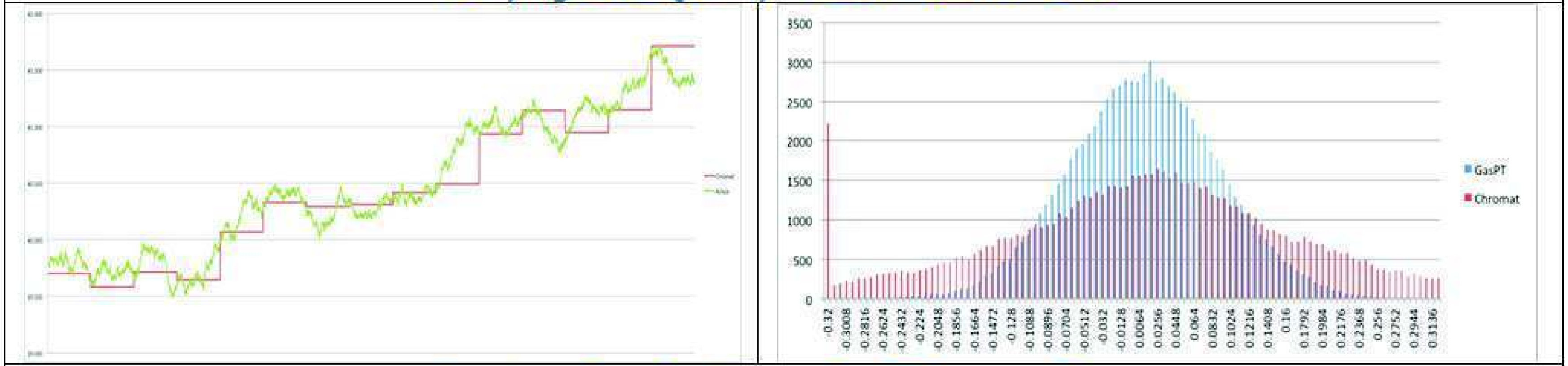
Varying Gas Quality – Similar Error

- The GasPT provides a calculated CV every 8 seconds with a Uncertainty of about 0.25 MJ/m^3 for UK distributed gases

As gas quality varies the frequency of measurement has greater influence



Varying Gas Quality – GasPT Lower Error



Varying Gas Quality – GasPT Lower Error

- When the frequency of analysis is taken into account the overall error in measurement of a gas stream of changing gas quality is the same or better than that achieved by the Danalyzer.

A more accurate CV

- It can be shown that when the CV changes linearly for a stated period of time the error is:

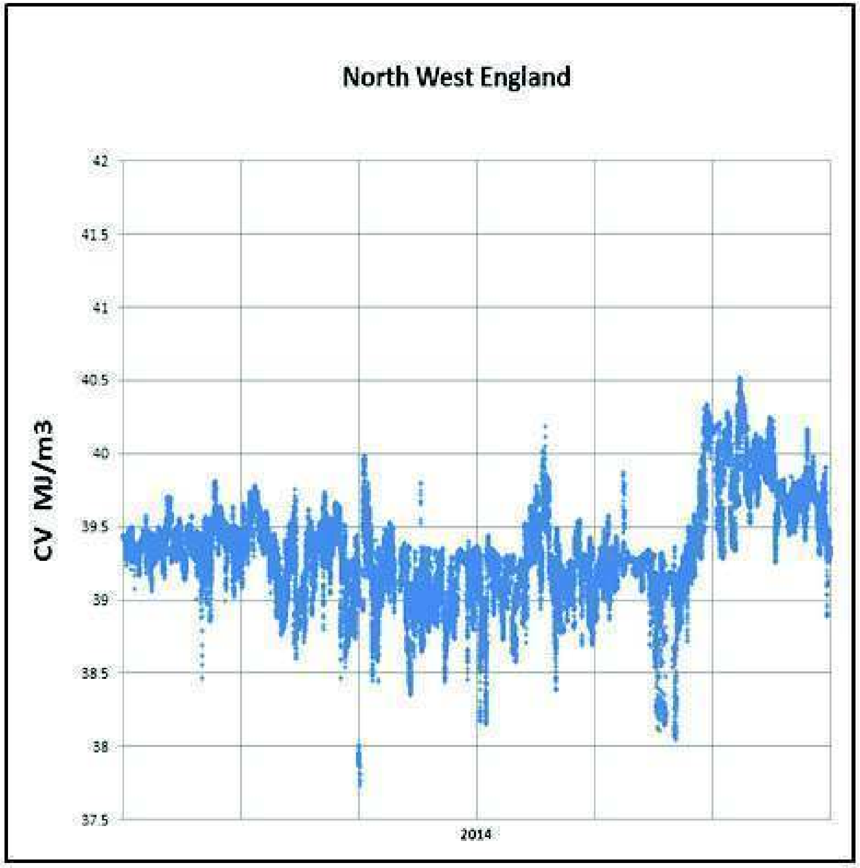
$$(1/N)\times B\times(T/2) + b + u$$

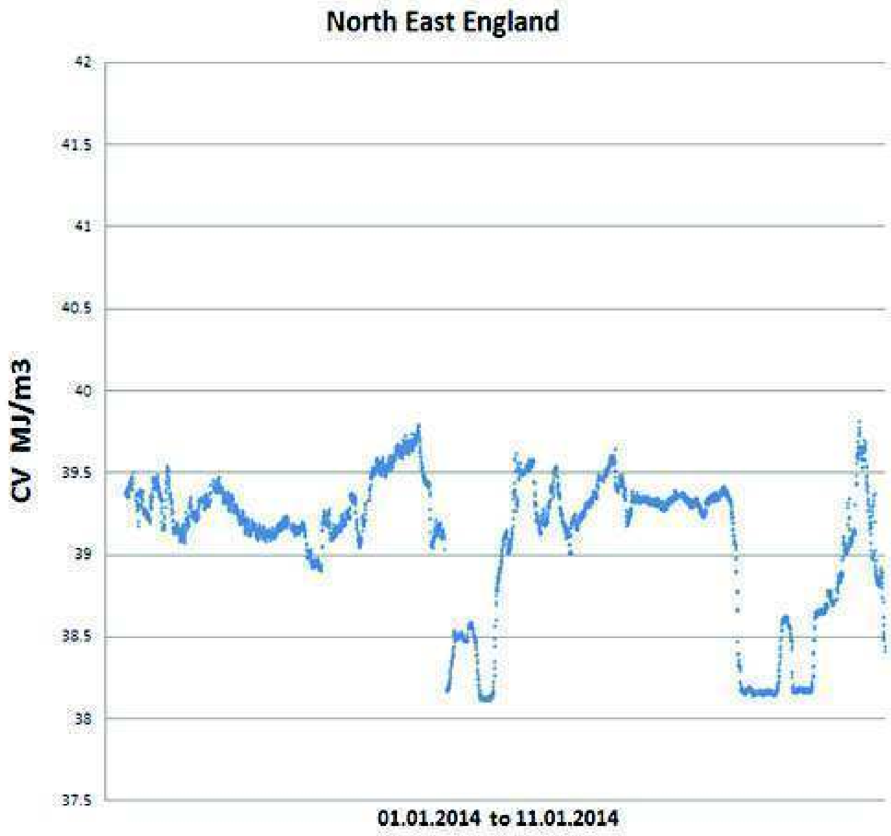
N = No of samples, B = change in measured value, T = time, b = error, u = uncertainty.

Since u should average over (long enough) time to zero this parameter can be ignored.

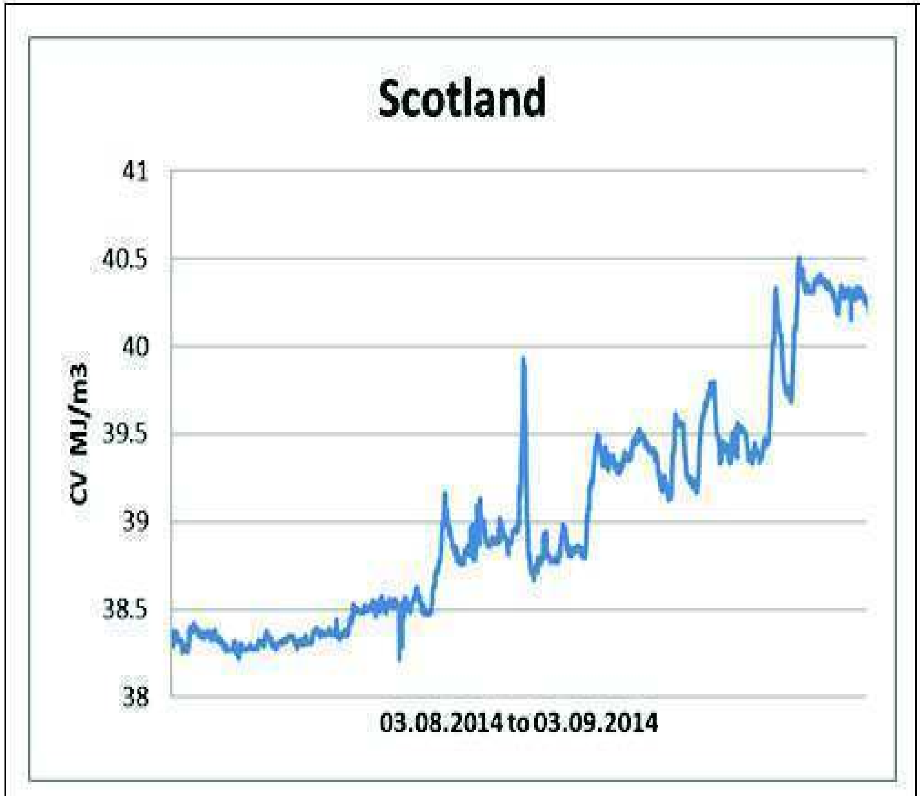
- Assuming one hour monitoring of natural gas changing by 1.5 MJ/m^3 using a Danalyzer (MPE is 0.14 MJ/m^3 but assume typically 0.05 MJ/m^3) with 3.5 min cycle time, and a GasPT (MPE is 0.25 MJ/m^3) operating with an 8 second cycle time the calculated errors are:
  - Danalyzer error = $(1/17)\times 1.5\times(60/2)+0.05 = 2.69$
  - GasPT error = $(1/450)\times 1.5\times(60/2)+0.25 = 0.35$
- The increased frequency in measurement provides the opportunity to reduce the measurement error and provide a more accurate CV.

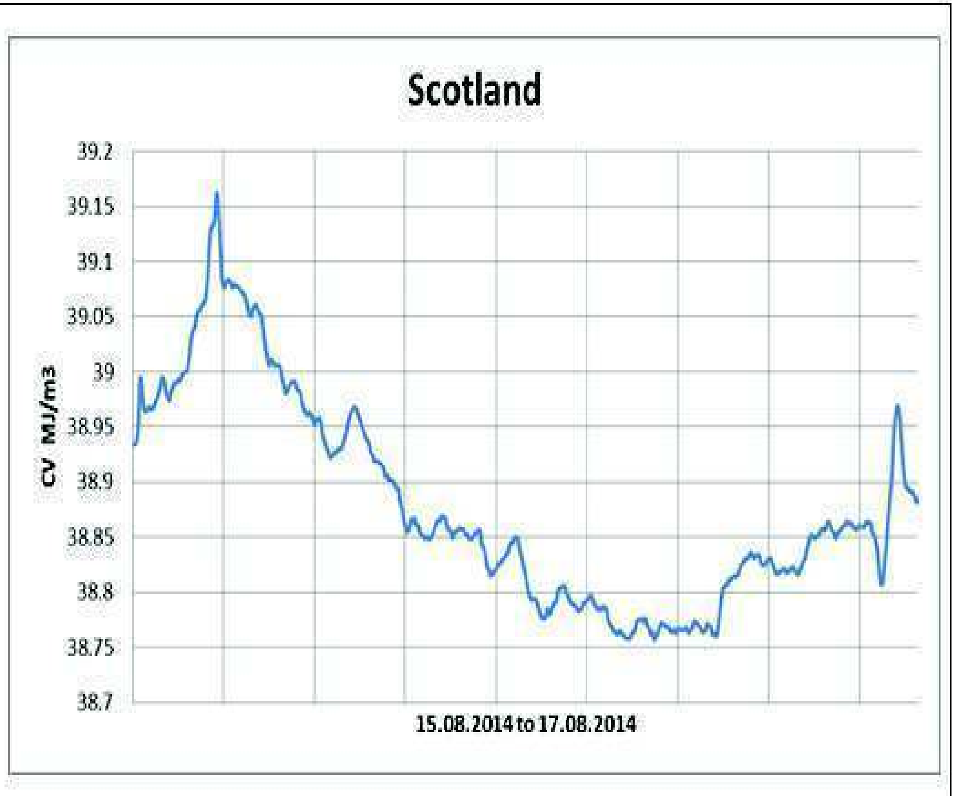
Network gas quality does change



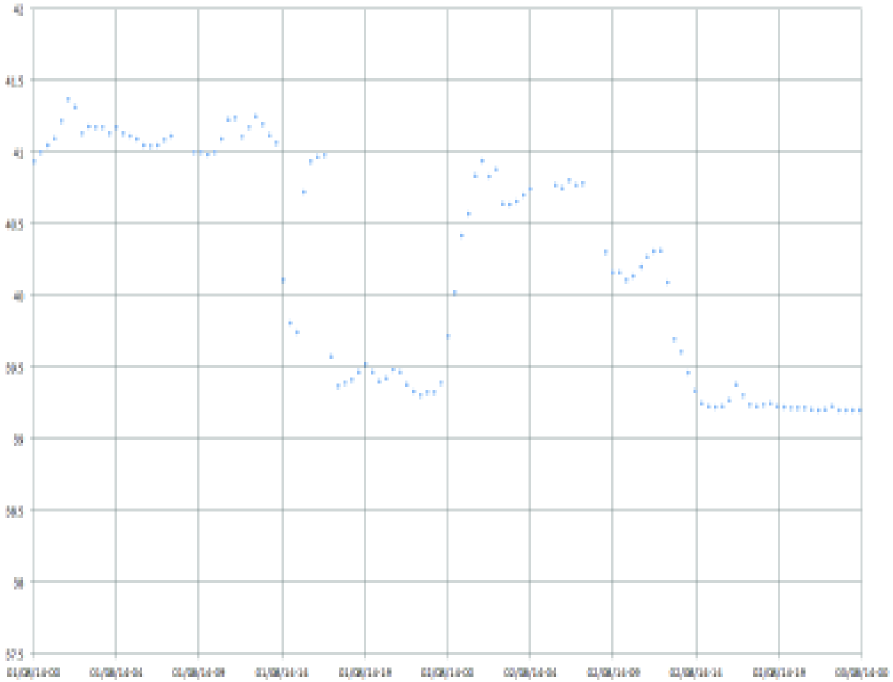


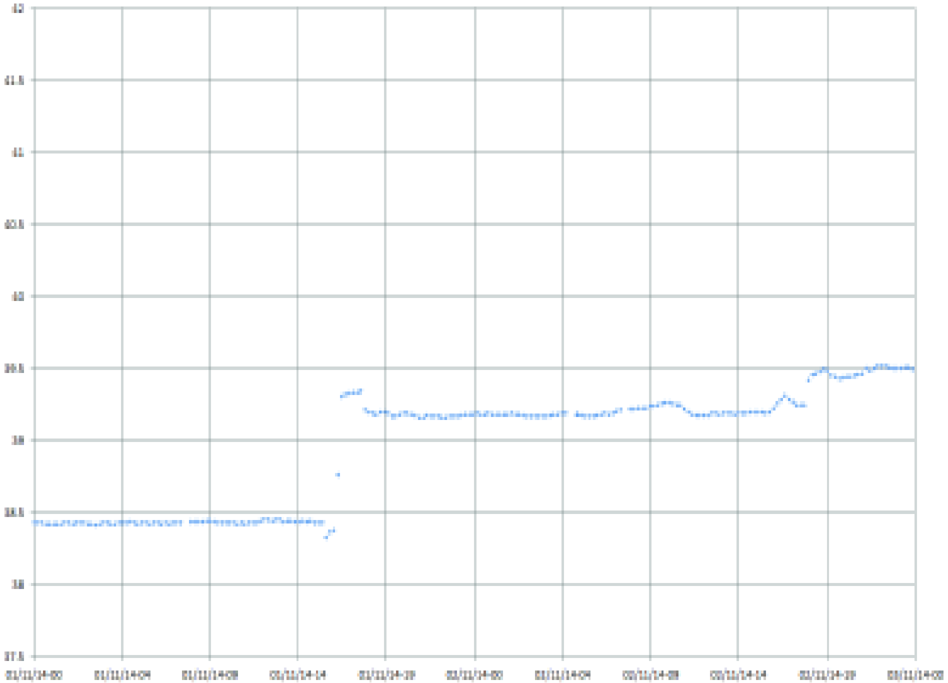
Single source supplies show significant variation





Single source supplies show significant variation





GasPTi – Rapid Sampling and Fast Analysis.

Can GasPT replace a GC in a typical metering system

- The uncertainty requirements for a fiscal metering system are
  - 1% for standard volume flow
  - 1.1% for energy.

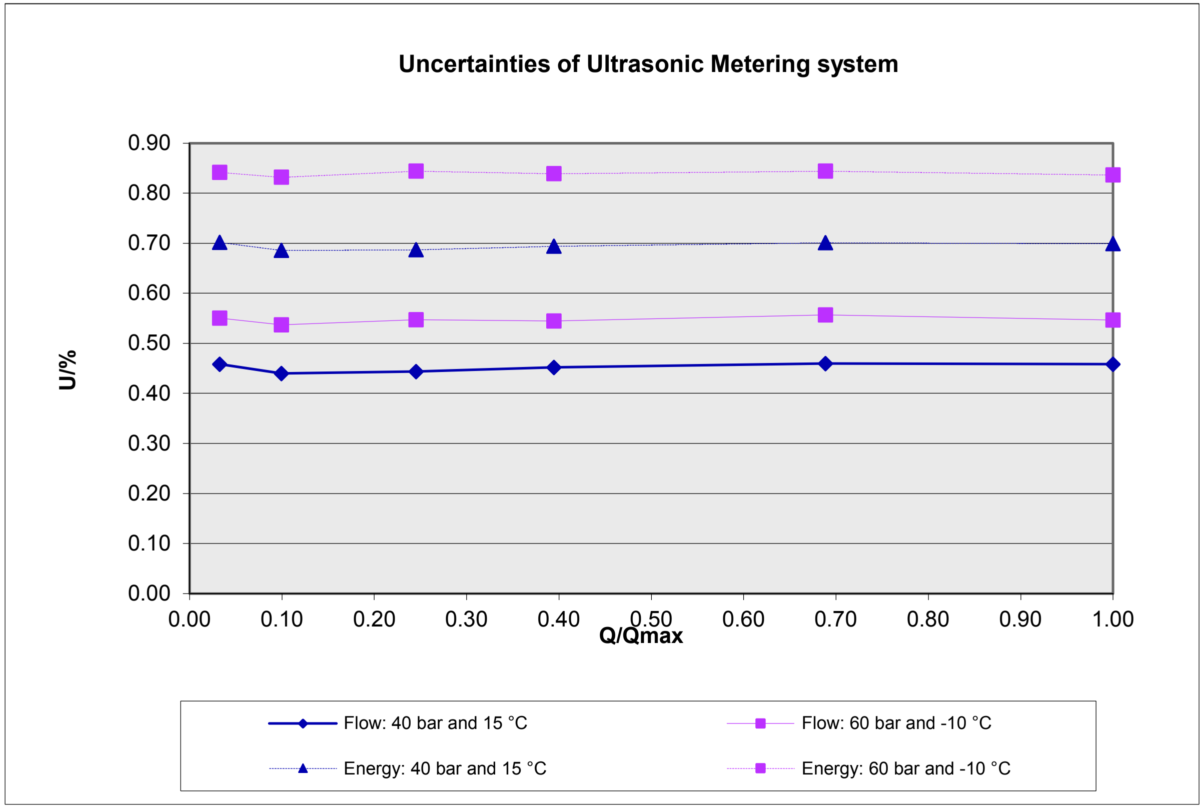
- Report assesses the calculated uncertainties of a typical ultrasonic meter and orifice plate metering system with a GasPT2 analyser.

- The expanded uncertainties in CV (0.18), N2 (0.37), CO_2 (0.17) and RD (0.0021) are based on the GasPT2 uncertainties from DNV GL Technical Note 14149: Estimation of GasPT2 Property Measurement. Andrew Laughton 16.07.2013

- The gas composition used was the mean 2013 East Midlands gas composition

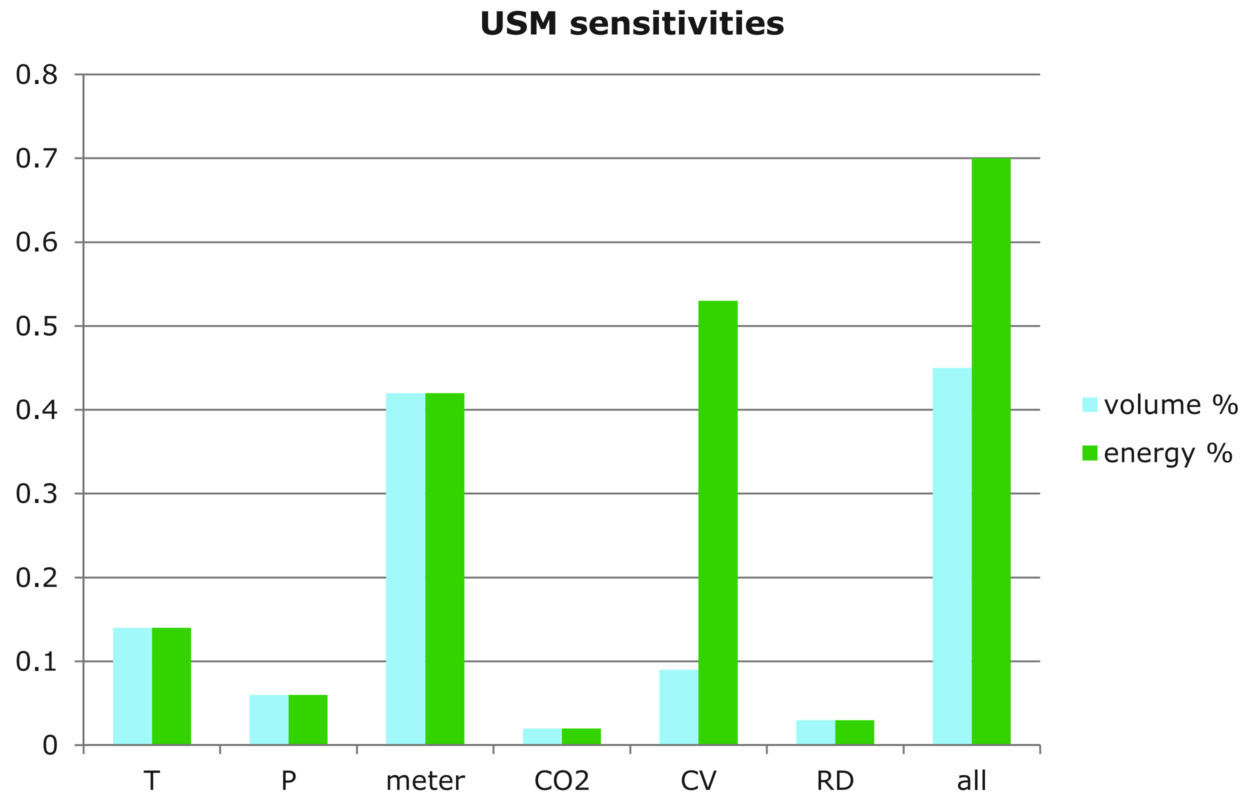
The uncertainties in flow and energy have been calculated using a Monte Carlo method in accordance with ISO 5168. The overall uncertainties are quoted for the flow and energy at standard UK metering conditions of 15 °C and 1.01325 bar

Ultrasonic Metering System



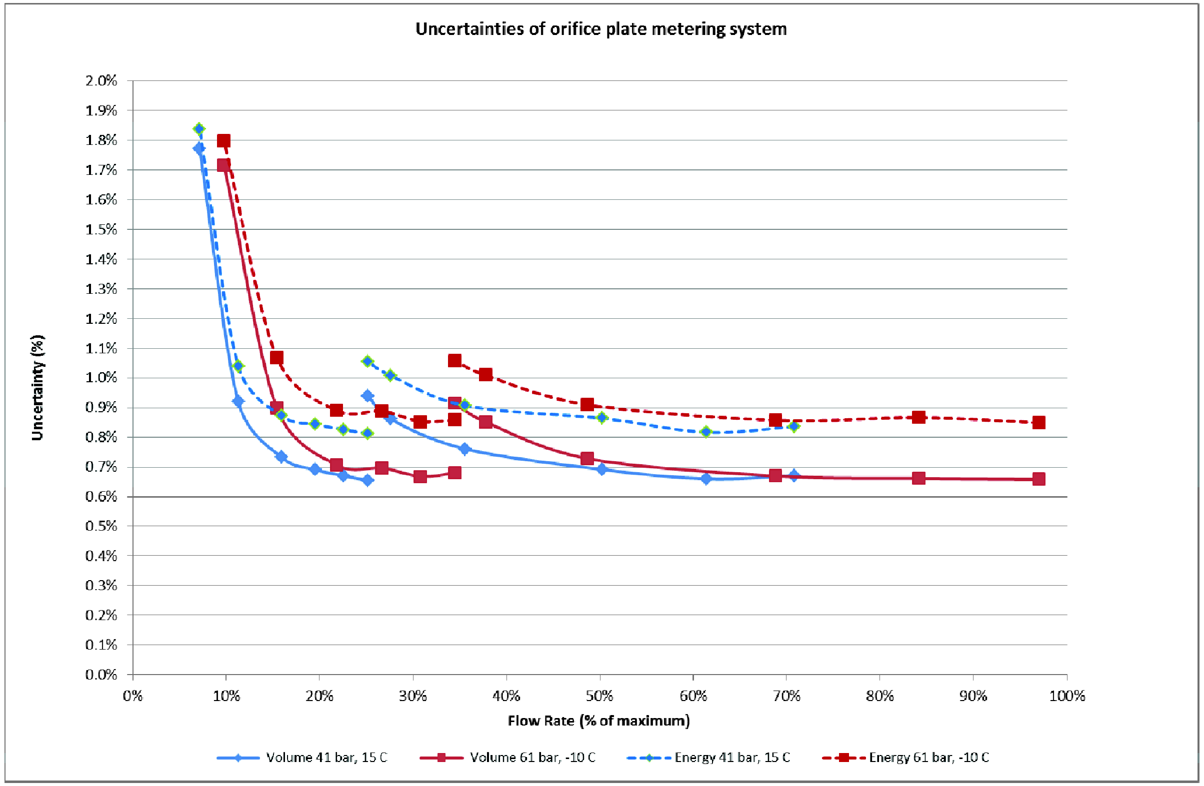
- The maximum uncertainties for a typical ultrasonic metering system with a GasPT are 0.56% for volume and 0.84% for energy.

Sensitivities of USM System



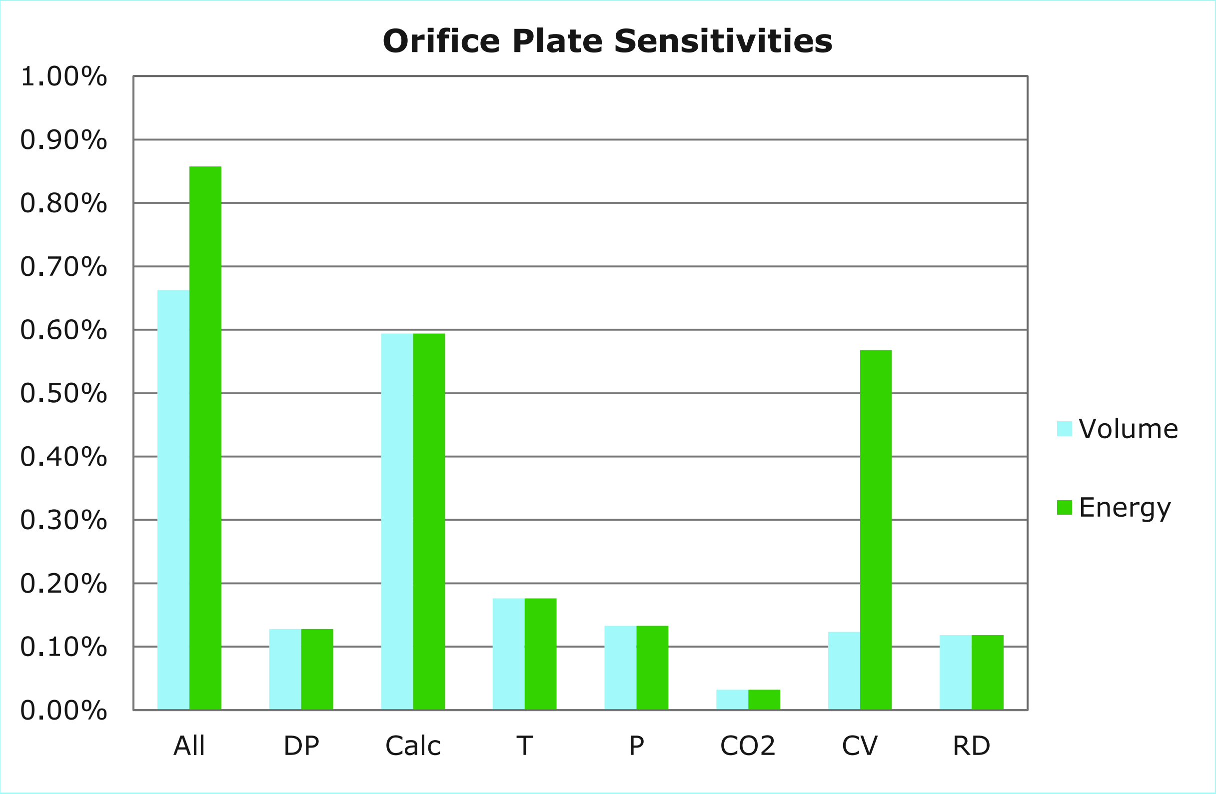
Volume	the dominant uncertainty is the meter
Energy	the dominant uncertainty is the CV measurement (and meter)

Orifice plate metering system



- The maximum uncertainties for a typical orifice plate metering system with a GasPT are up to 0.91% for volume and 1.06 % for energy above 30% Qmax at typical operating conditions.

Orifice plate metering system sensitivities



- The ISO 5167 calculation (including pipe and orifice plate diameters) is the dominant uncertainty measurement in the calculation of volume and energy uncertainty.
- CV measurement is the next dominant measurement in the energy uncertainty.

To conclude

- Where the variation in calorific value is limited the GasPT cannot offer any advantage over a Danalyzer.

- Where there is significant variation in calorific value then the GasPT can provide a robust and more accurate measurement of calorific value, comparable to, or better than a Danalyzer.

- It has been shown that the overall ultrasonic and orifice plate metering system uncertainties using a GasPT are within the custody transfer metering limits of 1% for standard volume flow and 1.1% for energy.

The GasPT offers a lower cost alternative to the traditional gas chromatograph without compromising accuracy.

End

Nigel Bryant
nigel.bryant@dnvgl.com
+44 (0)1509 282133

www.dnvgl.com

SAFER, SMARTER, GREENER

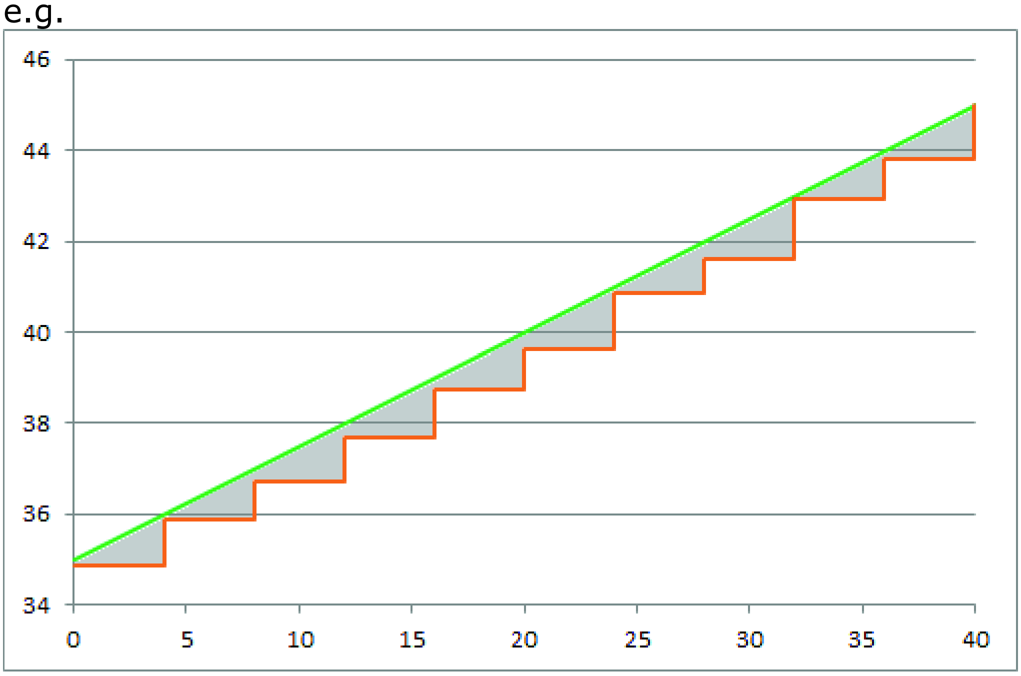
Measurement Model with Time

Measured value = true value + bias + uncertainty
$m = q + b + u \times rand$

where rand is the appropriate random distribution variable,
$\langle rand \rangle = 0$, $\langle rand^2 \rangle = 1$ e.g. normal with mean=0 & stdev=1
where <X> denotes expectation value of X, i.e. average value of X

The bias, b, is the average error of the measuring instrument for a specified set of compositions. The absolute value of b, |b|, is compared to the specified MPB (Maximum Permissible Bias) to decide whether the instrument's performance is acceptable.
The uncertainty, u, can be estimated as the standard deviation of the errors for a specified set of compositions. The value of $|b|+2\times u$ is compared to the specified MPE (Maximum Permissible Error) to decide whether the instrument's performance is acceptable. The value represents the range within which at least 95% of measurement errors are expected to be.

Assume q varies with time as $A + B\times t$ from t=0 to t=T
e.g.



The true value is the straight green line going from 35 at t=0 to 45 at t=40 (mins), i.e. $q = 35 + 0.25\times t$

The orange stepped line represents the measured value, with a measurement every 4 (mins). The bias, b, is -0.2 and the uncertainty, u, is 0.1

The total quantity is the area under the respective line.
The grey shaded area is the difference (error) between the measured and true value.

The total true value, Q, (the area under the green line) is $(A+B\times T/2)\times T$

Assume N measurements in the time period T, i.e. every $dt = T/N$
The total measured value, M, (the area under the stepped orange line) is the sum of the N measurements (multiplied by the time interval), i.e. for time $t = i\times dt$ for $i=0$ to $N-1$:-

$$M = \text{sum}\{ A + B\times i\times dt + b + u\times rand_i \}\times dt$$

where $rand_i$ is the random variable for measurement i
Performing the summations :-

$$M = A\times N\times dt + B\times N\times (N-1)\times dt^2/2 + b\times N\times dt + u\times N\times dt\times \langle rand\rangle$$

Or, since $T = N\times dt$:-

$$M = A\times T + B\times (1-1/N)\times T^2/2 + b\times T + u\times T\times \langle rand\rangle$$

Thus, the error $(M-Q) = -(1/N)\times B\times T^2/2 + b\times T + u\times T\times \langle rand\rangle$

The average error, i.e. divided by the total time T, is

$$(M-Q)/T = -(1/N)\times B\times T/2 + b + u\times \langle rand\rangle$$

For large T, the average random variable $\langle rand\rangle$ is zero.

Thus, the overall error depends on the measurement bias, b, and the number of measurements, N, and not on the measurement uncertainty, u.

It is shown above that the average error for a stated period of time (assuming a linear change in the value) is given by

$$(1/N)\times B\times (T/2) + b + u$$

where N is the number of measurements, B is the change in the value, T is the total time, b is the measurement error and u is the uncertainty. Since u should average over time to zero this parameter can be ignored.

Assuming 60 mins of measurements of natural gas changing by 1.5 MJ/m^3 , i.e. a 3.8 % change
e.g. $CV = 39 + (1.5/60)\times t$ (t in mins), i.e. $B=0.025\ MJ/(m^3.min)$

Assuming a constant flowrate of F m^3/min
Assuming b is zero and $u\times rand$ averages to zero for all instruments.

The true energy is 39.75×60×F = 2385×F MJ
For a Danalyzer with a 225 sec cycle time (i.e. N=16) the error is
(1/16)×0.025×(60/2)×60×F = 2.8125×F MJ   or 0.12 %
For a GasPT2 with an 8 sec cycle time (i.e. N=450) then error is
(1/450)×0.025×(60/2)×60×F = 0.1×F MJ   or 0.004 %

The MPE for a Danalyzer is 0.14 MJ/m^3 (0.35 %), with a typically achievable maximum error value of 0.05 MJ/m^3 (0.13 %).
The MPE for a GasPT2 is 0.25 MJ/m^3 (0.63 %).

The increased frequency in measurement provides the opportunity to reduce the measurement error and provide a more accurate energy measurement.

Appendix 3

331

KELTON®

Client : **ORBITAL GAS SYSTEMS LTD**

Client Contact : **NEIL STUCHBURY**

Project Title : **GASPT2 UNCERTAINTY EFFECT**

Document Title : **UNCERTAINTY EFFECT OF GASPT2 REPLACING GAS CHROMATOGRAPH**

Document Ref. : **NK3214 – 001**

Client Ref. : **PO 160926**

REV	ISSUE DATE	DESCRIPTION	PREP. BY	APP. BY
1	22/04/2016	Draft for Comment	BK	KV
1.1	22/04/2016	Client Contact Added	BK	KV
2	04/05/2016	Final	BK	KV

Kelton Engineering Ltd, 2nd Floor, Oakland Court, 26 Market Square, South Woodham Ferrers, Essex CM3 5XA
t: +44(0)1245 327707, f: +44(0)1245 327708, w: www.kelton.co.uk, e: info@kelton.co.uk

CONTENTS

1.0 EXECUTIVE SUMMARY

2.0 INTRODUCTION

3.0 UNCERTAINTY INPUTS

4.0 UNCERTAINTY RESULTS

5.0 REFERENCES

APPENDIX A - UNCERTAINTY MODULES

APPENDIX B - GASPT2 EVALUATION CERTIFICATE

1.0 EXECUTIVE SUMMARY

GasPT2 is an online transducer that provides information regarding the physical properties of natural gas. GasPT2 measures a number of physical properties of a sample of gas from which it infers a composition. From the inferred composition GasPT2 uses ISO 6976[1] to calculate Calorific Value, Relative Density and Wobbe index. The GasPT2 has achieved NMi approval (Certificate TC8670 rev 0; refer to Appendix B) for use as a class A Calorific Value Determination Device in accordance with OIML R140[3].

In the United Kingdom, new metering systems connecting the National Transmission System to Local Distribution Zones must measure gas flows within uncertainty limits of ±1.0 % on volume measurement (at Standard reference conditions) and ±1.1 % on energy measurement[4].

This report aims to demonstrate the impact on the overall measurement uncertainty of using a GasPT2 instead of a gas chromatograph (GC).

For the purpose of determining the impact of using a GasPT2 instead of a gas chromatograph, two analyses are presented. The analyses, both based on a typical new 6" orifice plate installation, differ in the calculation of the gas properties (i.e. density, CV, RD) and the associated uncertainties of these and subsequent terms in the calculation of mass, Standard volume and energy.

The impact of using a GasPT2 on the mass and standard volume flow rates are minimal in this uncertainty analysis but may become slightly more significant for higher densities. For orifice plate systems the density has an impact twice (once in the mass flow rate calculation and once in the volume conversion) however for volume devices, such as turbine or ultrasonic meters, there would only be the single effect on the volume conversion.

The impact of using a GasPT2 on the energy flow rate is more significant due to the higher CV uncertainty, but the analyses show that typical metering systems would still operate well within the uncertainty limits for NTS to LDZ metering.

2.0 INTRODUCTION

2.1 Background

GasPT2 is an online transducer that provides information regarding the physical properties of natural gas. GasPT2 measures a number of physical properties of a sample of gas from which it infers a composition. From the inferred composition GasPT2 uses ISO 6976[1] to calculate Calorific Value, Relative Density and Wobbe index. The GasPT2 has achieved NMi approval (Certificate TC8670 rev 0; refer to Appendix B) for use as a class A Calorific Value Determination Device (CVDD) in accordance with OIML R140[3].

In the United Kingdom, new metering systems connecting the National Transmission System to Local Distribution Zones (NTS-LDZ) must measure gas flows within uncertainty limits of ±1.0 % on volume measurement (at Standard reference conditions) and ±1.1 % on energy measurement[4].

This report aims to demonstrate the impact on the overall measurement uncertainty of using a GasPT2 instead of a gas chromatograph.

2.2 Typical Orifice Plate Measurement System Description

The report is based on a typical new 6″ orifice plate installation using two differential pressure (DP) transmitters in a low/high arrangement. The uncertainty associated with the equipment is detailed in Appendix A. The metering run equipment used in this analysis consists of:

- 6″ (Sch40) meter tube
    - D = 154.2 mm
- Orifice plate
    - d = 92.5 mm
    - β = 0.6
- Typical DP transmitters
    - Low Range 0 to 200 mbar
    - High Range 0 to 1000 mbar
    - Yokogawa EJX110A (M capsule)
- Typical pressure transmitter
    - Range 0 to 80 barg
    - Yokogawa EJX430A (B capsule)
- ISO/IEC 60751 Class A 4-wire Pt100 PRT
- Typical flow computer
    - ADC accuracy 0.03 % span

For the purpose of determining the impact of using a GasPT2 instead of a gas chromatograph, two analyses are presented. In both cases the mass flow rate was calculated in accordance with ISO 5167-2:2003[5]. The uncertainty calculations were performed over the DP range at a pressure of 30 barg and temperature of 15 °C. The composition used in the analyses is detailed in Table 1.

Component	mol%
Nitrogen	6.01
Carbon Dioxide	2.00
Methane	78.20
Ethane	7.93
Propane	5.01
n-Butane	0.01
i-Butane	0.30
n-Pentane	0.10
i-Pentane	0.05
neo-Pentane	0.05
n-Hexane	0.34
CV	40.83 MJ/Sm^3
RD	0.7033

Table 1 - Gas Properties

2.2.1 Gas Chromatograph

The reference case uses a typical gas chromatograph providing a full gas composition up to C6+. This composition was used to calculate meter density in accordance with AGA 8:1994[6] (detailed characterisation method) and calorific value and relative density in accordance with ISO 6976:1995[1]. The uncertainty associated with a typical gas chromatograph is detailed in Appendix A.

2.2.2 GasPT2

For the GasPT2 case, CV, RD and CO_2 (determined by the GasPT2) were used to calculate meter density in accordance with AGA 8:1994[6] (Gross characterisation method). The uncertainty associated with the GasPT2 is derived as detailed in Appendix A from the NMi type evaluation report[2].

2.3 Uncertainty Analysis Method

The calculations were carried out using KELTON® UNCERTAINTYPLUS™.net and conducted in accordance with the GUM[7] and ISO 5168[8].

Quantities such as flow rate, density and calorific value are derived from knowledge of the relationship between measured input values; this may be expressed in the form:

$$y = f(x1, x2, x3\dots xi)$$

Where the output y (for example density) is a function of a number of inputs x (composition, temperature and pressure values).

The standard uncertainty a measured or calculated quantity is found by combining the uncertainty associated with each input quantity following the methods outlined in the GUM[7] and ISO TR 5168[8].

$$u_c(y) = \sqrt{\sum_{i=1}^{n} \left(c_i \cdot u(x_i)\right)^2}$$

The sensitivity coefficients c_i show the change in output y in relation to the change in each input, for simple equations these can be calculated using traditional partial differentiation $\partial f/\partial x_i$.

A more practical solution (and the method used within UNCERTAINTYPLUS™.net) is to approximate the sensitivity coefficients numerically as described in section 5 of the GUM[7]. The sensitivity for each input is calculated by sequentially increasing then reducing the estimated value by a finite increment δ_i, holding all other values constant and recording the effect this has on the output.

$$\frac{\partial y}{\partial x} \cong \frac{f(x_i + \delta_i) - f(x_i - \delta_i)}{2\delta_i}$$

This method is consistent with Section 8.3 of ISO 5168[8] on *Propagation of measurement uncertainties* where the sensitivity coefficients are calculated numerically.

Section 5.1.3 of the GUM[7] suggests using the uncertainty value as the finite increment so that $\delta_i = u(x_i)$.

Unless otherwise stated the calculations show quantities expressed using SI units. All input and output units on the 'InputOutput' sheet of the UNCERTAINTYPLUS™.net

Module are given in customary units, and these are converted to/from SI units in the calculation. All flow and uncertainty calculations within the UNCERTAINTYPLUS™.net Module are performed in SI units.

Except where explicitly stated the measurement uncertainties quoted in this document are expanded uncertainties. The expanded uncertainty is estimated by multiplying the standard uncertainty by the coverage factor *k*=2 providing a level of confidence of approximately 95%.

3.1 Pressure Measurement

The line pressure measurement is based on a Yokogawa EJX430A gauge pressure transmitter which is ranged 0 to 80 barg.

The combined standard uncertainty in pressure is estimated by combining inputs derived from the calibration of the transmitter and the manufacturer's specification[9].

The sources of uncertainty are:

U_{ac} = Reference accuracy
U_d = Drift (Stability)
U_{ps} = Power supply effect
U_{temp} = Ambient temperature effect
U_{cal} = Transmitter calibration reference uncertainty
U_{tol} = Transmitter calibration tolerance
U_{adc} = ADC tolerance
U_{amb} = Ambient pressure effect

3.1.1 Reference Accuracy, U_{ac}

The reference accuracy is taken from the product data sheet[9] for the Yokogawa EJX430A gauge pressure transmitter and includes hysteresis, terminal based linearity and repeatability.

$U_{ac} = \pm 0.04$ % of the calibrated span

When calculating the standard uncertainty a normal distribution is assumed.

3.1.2 Transmitter Drift, U_d

The contribution due to drift in transmitter output is calculated from the value for stability taken from the product data sheet[9] and the calibration interval. It is assumed that routine calibrations are performed every 12 months.

$U_d = \pm 0.05$% URL/5 years

When calculating the standard uncertainty, a normal distribution is assumed.

3.1.3 Power Supply Effect, U_{ps}

A contribution is made to the uncertainty budget for variations in power supply, including the variation between the power supply during the calibration of the transmitter and that during operation. The estimated uncertainty for this is taken from the product data sheet[9].

Power supply effect = < ±0.005% of calibrated span per volt

The tolerance for the maximum power supply deviation is assumed to be ±5 volts.

When calculating the standard uncertainty, a normal distribution is assumed.

3.1.4 Ambient Temperature Effect, U_{temp}

A contribution is made to the uncertainty budget for variations in ambient temperature, including the variation between the temperature during the calibration of the transmitter and the operating temperature, assumed to be up to 10 °C. The estimated uncertainty for this is taken from the product data sheet[9].

$U_{temp} = \pm(0.009\ \%URL + 0.040\ \%span)/28°C$

When calculating the standard uncertainty a normal distribution is assumed.

3.1.5 Transmitter Calibration Reference Uncertainty, U_{cal}

The uncertainty for the equipment used to calibrate the pressure transmitter has been estimated to be ±0.025% of reading.

When calculating the standard uncertainty a normal distribution is assumed.

3.1.6 Transmitter Calibration Tolerance, U_{tol}

The tolerance for calibration of the pressure transmitter is assumed to be ±0.20 % of the calibrated span. Calibrations are assumed to be performed on a 12 monthly basis.

When calculating the standard uncertainty, a rectangular distribution is assumed.

3.1.7 ADC Tolerance, U_{adc}

A contribution is made to the uncertainty budget for field signal conversion to the flow computer.

U_{adc} = ±0.03 %span

When calculating the standard uncertainty a rectangular distribution is assumed.

3.1.8 Ambient Pressure Uncertainty, U_{amb}

For gauge pressure transmitters allowance is made for typical variations in ambient pressure.

U_{amb} = ±24 mbar

When calculating the standard uncertainty, a rectangular distribution is assumed.

3.1.9 Combined Uncertainty in Pressure

The estimated uncertainty for the pressure transmitter is therefore calculated to be 0.12 bar.

The combined expanded uncertainty is calculated by multiplying the standard uncertainty by the coverage factor k=2.

3.2 Temperature Measurement

The RTD element is assumed to be installed downstream of the orifice plate within a thermowell and connected directly to the flow computer. The combined standard uncertainty in temperature is estimated by combining inputs derived from the calibration of the temperature loop and the RTD element specification.

The sources of uncertainty are:

U_{rtd} = RTD accuracy
U_{cal} = Loop calibration
U_{tol} = Loop calibration tolerance
U_{inst} = Installation Effects

3.2.1 RTD Accuracy, U_{rtd}

The uncertainty of the temperature element is referenced & detailed within IEC / BS EN 60751[10] for the Class A platinum resistance thermometer. The uncertainty of temperature measurement is ±0.18 °C at 15 °C.

When calculating the standard uncertainty a normal distribution is assumed.

3.2.2 Loop Calibration U_{cal}

The uncertainty for the equipment used to calibrate the temperature loop has been estimated to be ±0.125 °C (typical for a certified decade resistance box).

U_{cal} = ± 0.125 °C

When calculating the standard uncertainty a normal distribution is assumed.

3.2.3 Loop Calibration Tolerance, U_{tol}

The tolerance for the calibration of the temperature loop is assumed to be ±0.2 °C.

When calculating the standard uncertainty a rectangular distribution is assumed.

3.2.4 Installation Effects, U_{inst}

A contribution to the uncertainty budget is made for installation effects due to thermal gradients. An uncertainty of ±0.1 °C has been included for installation effects.

When calculating the standard uncertainty a normal distribution is assumed.

3.2.5 Combined Uncertainty in Temperature

The estimated uncertainty for the temperature measurement is calculated to be 0.33 °C.

The combined expanded uncertainty is calculated by multiplying the standard uncertainty by the coverage factor k=2.

3.3 Differential Pressure Measurement

The DP is measured using two Yokogawa EJX110A DP transmitters (URL 1000 mbar; Low Span 0 to 200 mbar; High Span 0 to 1000 mbar). The flow computer will automatically switch the in use DP transmitter from low to high at 95 mbar and from high to low at 90 mbar. The uncertainty in DP measurement is made up of contributions from the following sources:

U_{ac} = Reference accuracy
U_{d} = Drift (Stability)
U_{ps} = Power supply effect
U_{temp} = Ambient temperature effect
U_{stat} = Static pressure effect
U_{cal} = Transmitter calibration reference uncertainty
U_{tol} = Transmitter calibration tolerance
U_{adc} = ADC tolerance

3.3.1 Reference Accuracy, U_{ac}

The reference accuracy is taken from the data sheet[11] for the Yokogawa EJX110A transmitter and includes hysteresis, terminal based linearity and repeatability.

U(ac) = ± 0.04 %span

When calculating the standard uncertainty a normal distribution is assumed.

3.3.2 Drift, U_{d}

The contribution due to drift in transmitter output is calculated from the value for stability taken from the data sheet[11] for the Yokogawa EJX110A transmitter and the calibration interval. It is assumed that routine validations will be performed on an annual basis.

Stability = ± 0.05 %URL/5 years

When calculating the standard uncertainty a normal distribution is assumed.

3.3.3 Power Supply Effect, U_{ps}

A contribution is made to the uncertainty budget for variations in power supply, including the variation between the power supply during the calibration of the transmitter and that during operation. The uncertainty for this is taken from the data sheet[11] for the Yokogawa EJX110A transmitter. The tolerance for the maximum power supply deviation is assumed to be ±5 volt.

Power supply effect = < ±0.005 %span per volt

When calculating the standard uncertainty a normal distribution is assumed.

3.3.4 Ambient Temperature Effect, U_{temp}

A contribution is made to the uncertainty budget for variations in ambient temperature, including the variation between the temperature during the calibration of the transmitter and the operating temperature. The uncertainty for this is taken from the data sheet[11] for the Yokogawa EJX110A transmitter. The estimated maximum temperature deviation between calibration and operation is assumed to be ±10 °C.

U_{temp} = ± (0.009 %URL + 0.040 %span) per 28°C

When calculating the standard uncertainty a normal distribution is assumed.

3.3.5 Static Pressure Effect, U_{stat}

A contribution is made to the uncertainty budget for the variation between the (static) pressure during the calibration of the transmitter and the operating (static) pressure. The uncertainty for this is taken from the data sheet[11] for the Yokogawa EJX110A transmitter. The estimated maximum pressure deviation between calibration and operation is assumed to be ±10 bar.

U_{stat} = ± (0.020 %URL + 0.075 %span) per 69 bar

When calculating the standard uncertainty a normal distribution is assumed.

3.3.6 Transmitter Calibration Reference Uncertainty, U_{cal}

The uncertainty for the equipment used to calibrate the DP transmitters has been estimated to be ±0.050% of reading.

When calculating the standard uncertainty a normal distribution is assumed.

3.3.7 Transmitter Calibration Tolerance, U_{tol}

The tolerance for the calibration of the DP transmitters is assumed to be ±0.20 %span. Calibrations are assumed to be performed on a 12 monthly basis.

When calculating the standard uncertainty, a rectangular distribution is assumed.

3.3.8 ADC Tolerance, U_{adc}

A contribution is made to the uncertainty budget for field signal conversion to the flow computer.

$U_{adc} = \pm 0.03$ %span

When calculating the standard uncertainty a rectangular distribution is assumed.

3.4 Density

The calculation of mass flow rate is carried out in accordance with ISO 5167-2:2003[5]. This calculation uses meter density as an input. The meter density is calculated within the flow computer in accordance with AGA8:1994[6]. RD is used to convert the mass flow rate into volume flow rate at Standard conditions. CV is used to convert the volume flow rate into energy flow rate.

3.4.1 Gas Chromatograph

Where a full composition is available from the gas chromatograph the meter density is calculated using the AGA8:1994[6] Detailed Characterisation method. The combined uncertainty in meter density at operating conditions is considered to be a function of gas composition, the equation of state, temperature and pressure. Relative density is calculated within the flow computer in accordance with ISO 6976:1995[1] from the full gas composition.

The uncertainty in gas composition is calculated by combining typical calibration gas uncertainty, calibration uncertainty and gas chromatograph repeatability.

A contribution of ±0.1 % is made for uncertainty in the AGA 8:1994[6] Detail Characterization calculation method and basic data. For RD and CV calculated in accordance with ISO 6976:1995[1] this is also ±0.1 %.

When calculating the standard uncertainty a normal distribution is assumed.

The combined expanded uncertainty for the meter density, RD and CV are calculated to be ±0.48 %, ±0.13 % and ±0.15 % respectively.

The expanded uncertainties have been calculated by multiplying the standard uncertainties by the coverage factor k=2 assuming a normal distribution.

3.4.2 GasPT2

In this report it has been assumed that the GasPT2 determines the CV and RD and measures the CO_2 content, which are then used to calculate the meter density using the AGA8:1994[6] Gross Characterisation method. The combined uncertainty in meter density at operating conditions is considered to be a function of CV, RD, CO_2, the equation of state, temperature and pressure.

The uncertainty in the GasPT2 (CV, RD and CO_2) has been derived from the NMi type evaluation report[2]. The accuracy and repeatability of the GasPT2 against a known reference has been calculated from the 'accuracy under reference conditions' test results and 'repeatability' test results respectively. These were calculated for reference gases 2 to 6◊ taking the root sum square combination of the maximum result and two times the standard deviation in results as a worst case. The drift was taken from the 'adjustment interval and drift' test on reference gas 6◊. The results are presented in Table 2.

◊ *Reference gases 1 and 7 have been excluded as they are outside the specification of GSMR.*

The combined uncertainties in CV, RD and CO_2 were calculated from the root sum square of the accuracy, repeatability and stability. When calculating the standard uncertainty a normal distribution is assumed.

	CV	RD	CO_2
Accuracy	0.29 %	0.05 %	0.08 %mol/mol
Repeatability	0.03 %	0.01 %	0.03 %mol/mol
Stability	0.14 %	0.16 %	0.07 %mol/mol
Total Uncertainty	±0.33 %	±0.17 %	±0.11 %mol/mol

Table 2 - Uncertainty Derived from NMi Type Evaluation Report

Further testing of the GasPT2 was carried out by NOVA Chemicals[12] which compared the GasPT2 performance directly with a gas chromatograph measuring the same gas sample. The results of the 24 tests largely substantiate the uncertainty values used above with the majority of values lying within these bounds.

A contribution of ±0.1 % is made for uncertainty in the AGA 8:1994[6] Gross Characterization calculation method and basic data.

The combined expanded uncertainty for the meter density is calculated to be ±0.52 % by multiplying the standard uncertainty by the coverage factor k=2 assuming a normal distribution.

3.5 Mass Flow Rate

The mass flow rate is calculated in accordance with ISO 5167-2:2003[5].

$$q_m = C_d E \varepsilon A_t \sqrt{2 \Delta p \rho}$$

where

$$E = \frac{1}{\sqrt{1-\beta^4}}$$

$$A_t = \frac{\pi d^2}{4}$$

and

q_m = mass flowrate [kg/s]
C_d = discharge coefficient [-]
E = velocity of approach factor [-]
ε = expansibility factor [-]
A_t = area of orifice bore [m^2]
Δp = differential pressure [Pa]
ρ = upstream density [kg/m^3]

Note: β is the ratio of orifice bore to upstream pipe diameter (d/D = 0.6)

The uncertainty in mass flow rate is made up of contributions from the following sources:

U(Cd) = Discharge coefficient
U(ε) = Expansibility factor
U(d) = Orifice diameter
U(D) = Pipe diameter
U(Δp) = Differential pressure (refer to A.6)
U(ρ) = Density (refer to A.7)
U(comp) = Computation

3.5.1 Discharge Coefficient, U_{Cd}

The relative uncertainty (in %) in the discharge coefficient is taken from ISO 5167-2:2003[5], Section 5.3.3.1.

$U(Cd) = \pm 0.5\ \%$ for $0.2 \leq \beta \leq 0.6$

The uncertainty in Cd is therefore U(Cd) = ±0.5%.

When calculating the standard uncertainty a rectangular distribution is assumed.

3.5.2 Expansibility Factor, U_{ε}

The relative uncertainty (in %) in the expansion factor is taken from
ISO 5167-2:2003[5], Section 5.3.3.2.

$$U(\varepsilon) = 3.5\left(\frac{\Delta p}{\kappa p}\right)$$

where Δp is the differential pressure and p is the upstream static pressure.

When calculating the standard uncertainty a rectangular distribution is assumed.

3.5.3 Orifice diameter, U_d

ISO 5167-1:2003[13], Section 8.2.2.4 states that the maximum uncertainty in d that can occur whilst conforming to the standard's requirements is 0.1%. In practice it is likely that the measurements will show a lower uncertainty than this, however in order to be conservative and permit some allowance for in-situ changes to the orifice diameter this value will be used.

U(d) = ±0.1%

When calculating the standard uncertainty a normal distribution is assumed.

3.5.4 Pipe diameter, U_D

ISO 5167-1:2003[13], Section 8.2.2.4 states that the maximum uncertainty in D that can occur whilst conforming to the standard's requirements is 0.4%. In practice it is likely that the measurements will show a lower uncertainty than this, however in order to be conservative and permit some allowance for in-situ changes to the pipe diameter this value will be used.

U(D) = ±0.40%

When calculating the standard uncertainty a normal distribution is assumed.

3.5.5 Computation, U_{comp}

A contributor to the uncertainty budget has been included for computation errors associated with calculations in the flow computer.

U(comp) = ±0.01 %

When calculating the standard uncertainty a normal distribution is assumed.

3.6 Standard Volume Flow Rate

The uncertainty in standard volumetric flow rate is obtained by combining (root sum square) the uncertainty in the mass flow rate with the uncertainty in the RD.

3.7 Energy Flow Rate

The uncertainty in energy flow rate is obtained by combining (root sum square) the uncertainty in the Standard volume flow rate with the uncertainty in the CV.

4.1 Uncertainty Results using Gas Chromatograph

High range		Mass flowrate		Std volume flowrate		Energy flowrate	
% Span	Δp (mbar)	Qm (kg/s)	Uncert (%)	Qvs (Sm^3/s)	Uncert (%)	Qe (MJ/s)	Uncert (%)
20	200.0	4.67	0.85	5.41	0.86	221.0	0.87
25	250.0	5.21	0.77	6.05	0.79	246.9	0.80
30	300.0	5.71	0.73	6.62	0.74	270.3	0.76
40	400.0	6.58	0.68	7.64	0.69	311.8	0.71
50	500.0	7.35	0.66	8.53	0.67	348.2	0.69
60	600.0	8.04	0.65	9.33	0.66	381.0	0.68
70	700.0	8.68	0.64	10.07	0.65	411.1	0.67
80	800.0	9.27	0.63	10.75	0.65	439.0	0.66
90	900.0	9.82	0.63	11.39	0.65	465.1	0.66
100	1000.0	10.34	0.63	11.99	0.64	489.7	0.66

Low range		Mass flowrate		Std volume flowrate		Energy flowrate	
% Span	Δp (mbar)	Qm (kg/s)	Uncert (%)	Qvs (Sm^3/s)	Uncert (%)	Qe (MJ/s)	Uncert (%)
20	40.0	2.09	0.86	2.43	0.87	99.1	0.88
25	50.0	2.34	0.78	2.71	0.79	110.8	0.80
30	60.0	2.56	0.73	2.97	0.74	121.3	0.76
40	80.0	2.96	0.68	3.43	0.70	140.0	0.71
50	100.0	3.30	0.66	3.83	0.67	156.5	0.69
60	120.0	3.62	0.64	4.20	0.66	171.4	0.67
70	140.0	3.91	0.64	4.53	0.65	185.1	0.67
80	160.0	4.18	0.63	4.84	0.65	197.8	0.66
90	180.0	4.43	0.63	5.14	0.64	209.7	0.66
100	200.0	4.67	0.62	5.41	0.64	221.0	0.66

Table 3 - Uncertainty Results using Gas Chromatograph

4.2 Uncertainty Results using GasPT2

High range		Mass flowrate		Std volume flowrate		Energy flowrate	
% Span	Δp (mbar)	Qm (kg/s)	Uncert (%)	Qvs (Sm^3/s)	Uncert (%)	Qe (MJ/s)	Uncert (%)
20	200.0	4.67	0.86	5.41	0.87	221.0	0.93
25	250.0	5.21	0.78	6.05	0.80	246.9	0.87
30	300.0	5.71	0.74	6.62	0.76	270.3	0.82
40	400.0	6.58	0.69	7.64	0.71	311.8	0.78
50	500.0	7.35	0.67	8.53	0.69	348.2	0.76
60	600.0	8.04	0.65	9.33	0.68	381.0	0.75
70	700.0	8.68	0.65	10.07	0.67	411.1	0.75
80	800.0	9.27	0.64	10.75	0.67	439.0	0.74
90	900.0	9.82	0.64	11.39	0.66	465.1	0.74
100	1000.0	10.34	0.64	12.00	0.66	489.7	0.74

Low range		Mass flowrate		Std volume flowrate		Energy flowrate	
% Span	Δp (mbar)	Qm (kg/s)	Uncert (%)	Qvs (Sm^3/s)	Uncert (%)	Qe (MJ/s)	Uncert (%)
20	40.0	2.09	0.86	2.43	0.88	99.1	0.94
25	50.0	2.34	0.79	2.71	0.80	110.8	0.87
30	60.0	2.56	0.74	2.97	0.76	121.3	0.83
40	80.0	2.96	0.69	3.43	0.71	140.0	0.78
50	100.0	3.30	0.67	3.83	0.69	156.5	0.76
60	120.0	3.62	0.65	4.20	0.68	171.4	0.75
70	140.0	3.91	0.65	4.53	0.67	185.1	0.74
80	160.0	4.18	0.64	4.84	0.66	197.8	0.74
90	180.0	4.43	0.64	5.14	0.66	209.7	0.74
100	200.0	4.67	0.63	5.41	0.66	221.0	0.73

Table 4 - Uncertainty Results using GasPT2

4.3 Uncertainty Comparison Graphs

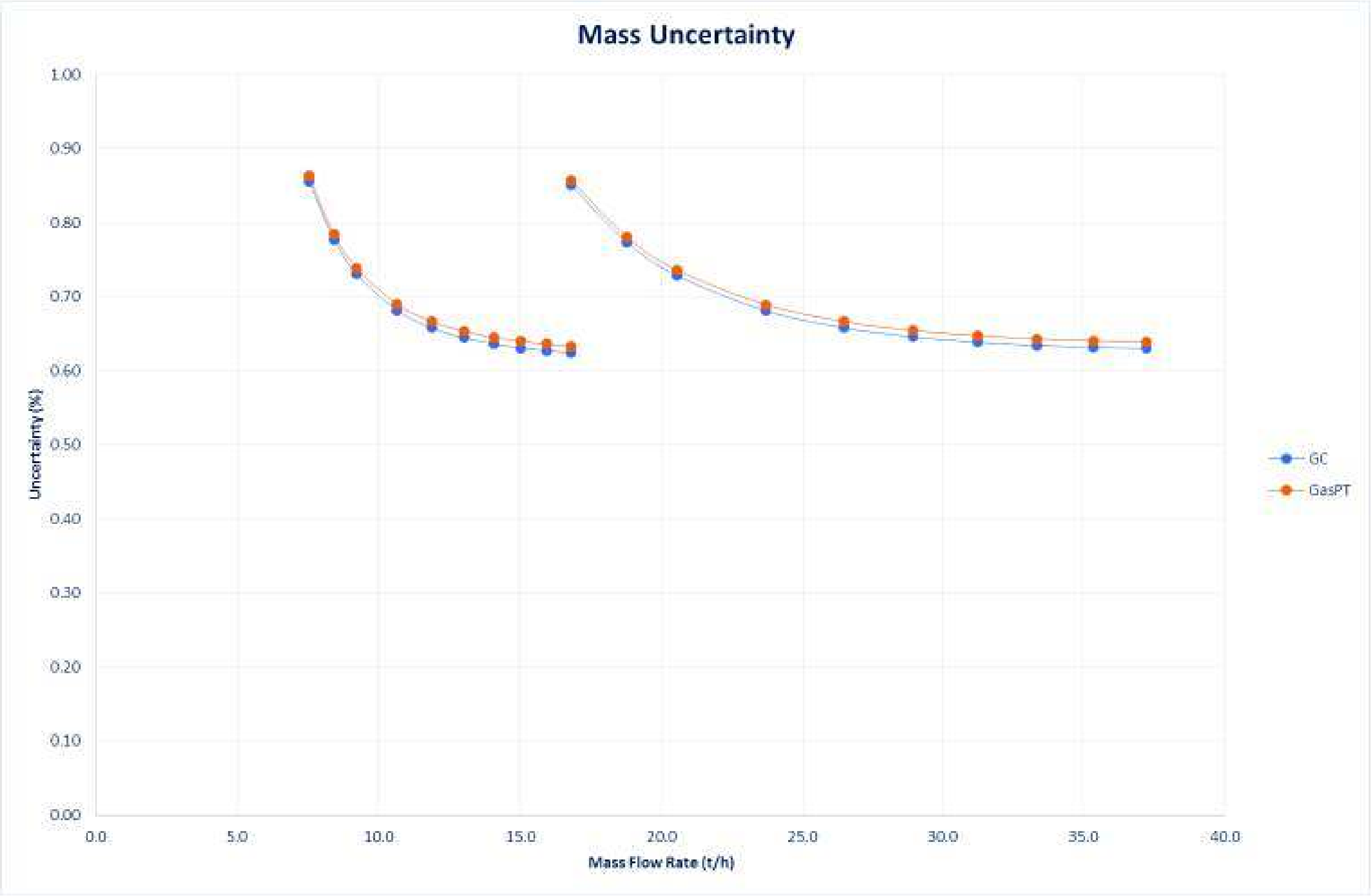


Figure 1 - Mass Uncertainty Comparison

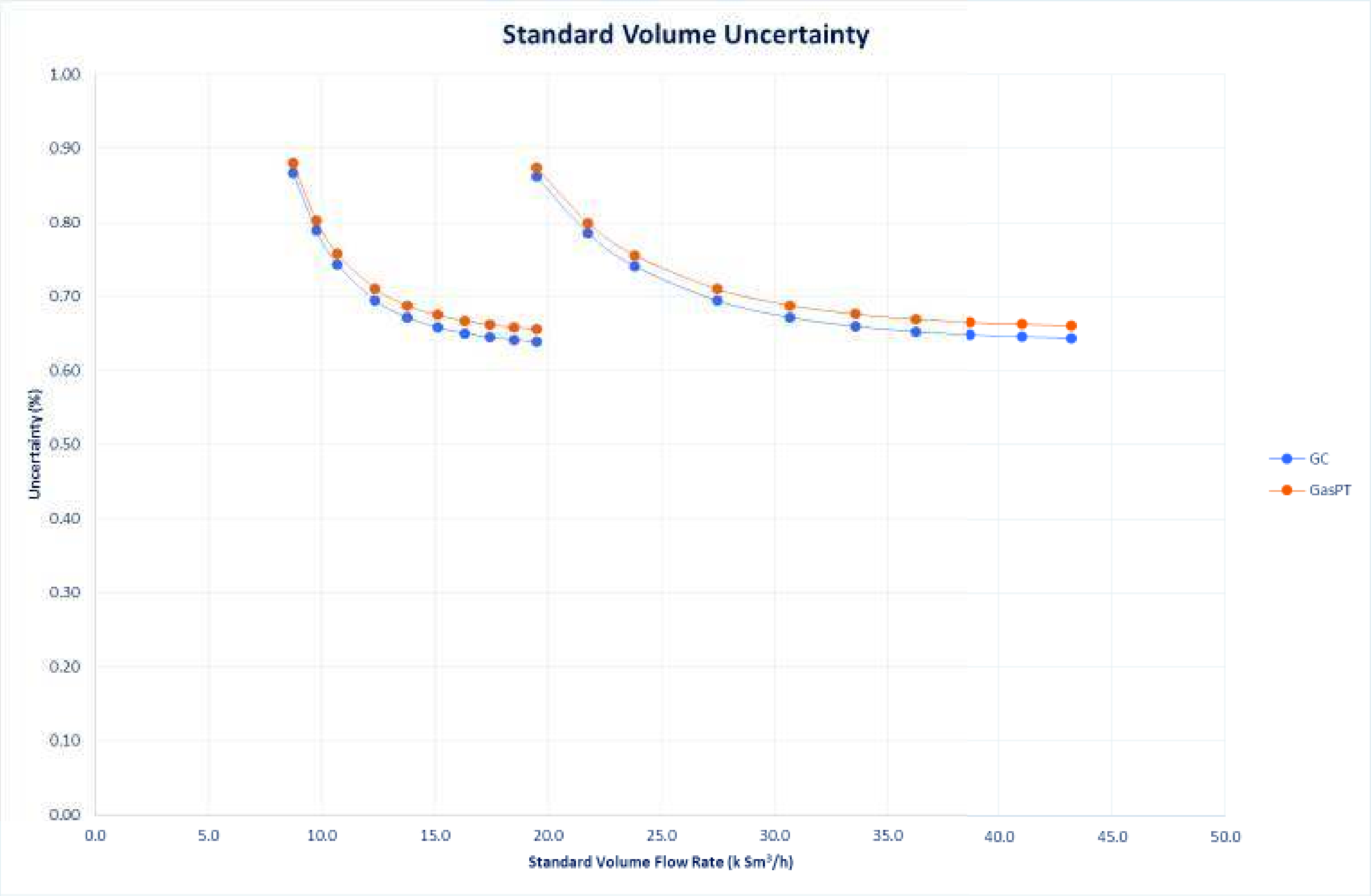


Figure 2 - Standard Volume Uncertainty Comparison

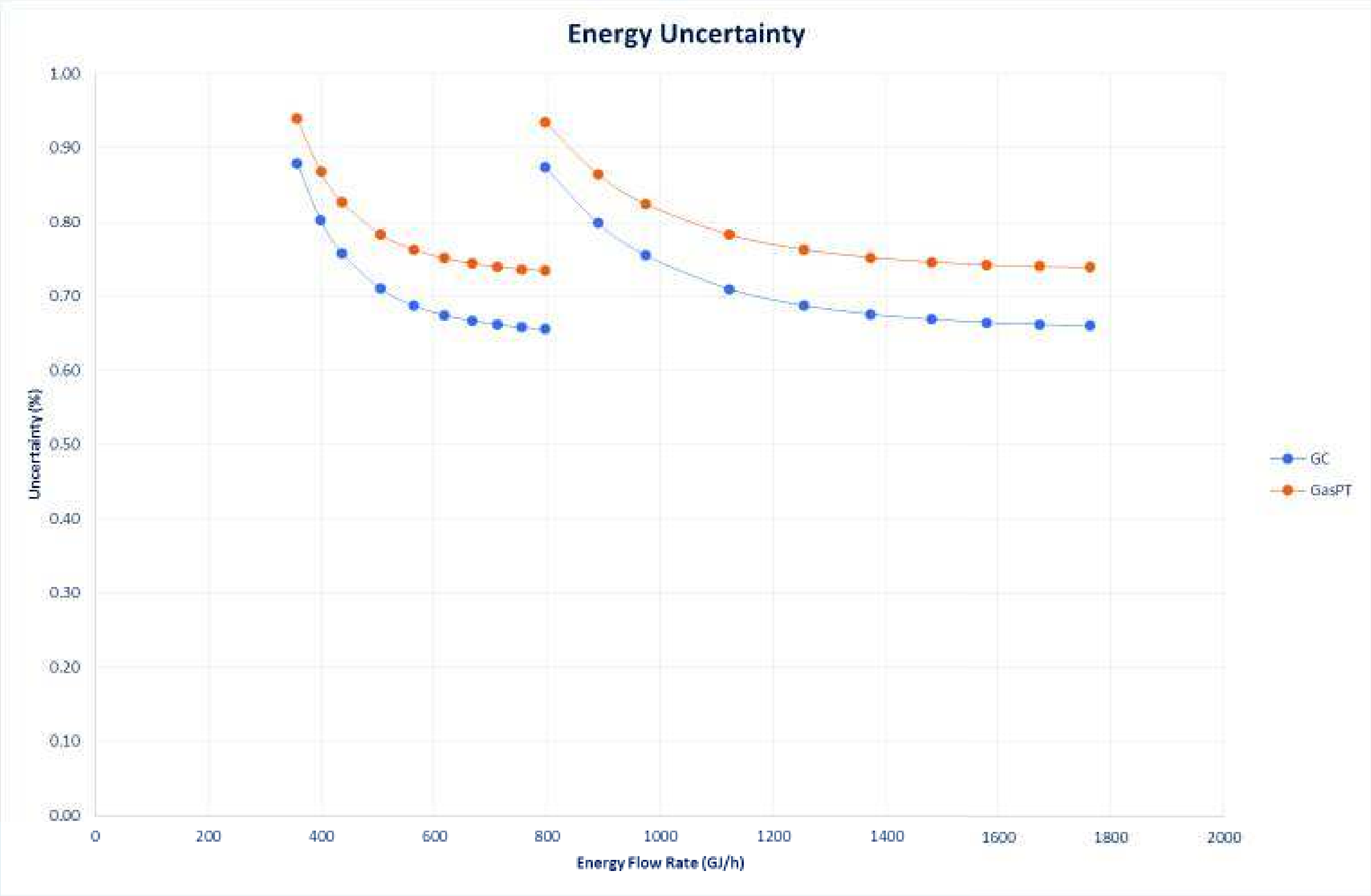


Figure 3 - Energy Uncertainty Comparison

4.4 Conclusions

The effect of using a GasPT2 (as opposed to a GC) on the mass (Figure 1) and Standard volume (Figure 2) flow rates are minimal in this uncertainty analysis. The effect is expected to become slightly more significant for higher densities. For orifice plate systems the density has an impact twice (once in the mass flow rate calculation and once in the volume conversion) however for volume devices, such as turbine or ultrasonic meters, there would only be the single effect on the volume conversion.

The effect of using a GasPT2 (as opposed to a GC) on the energy flow rate (Figure 3) is more significant due to the higher CV uncertainty, but the analyses show that typical metering systems would still operate well within the uncertainty limits for NTS to LDZ metering of ±1.0 % on Standard volume and +1.1 % on energy[4].

5.0 REFERENCES

[1] ISO 6976:1995 Natural Gas - Calculation of Calorific Values, Density, Relative Density and Wobbe Index from Composition.

[2] Type Evaluation Report NMi – 14200680-01, NMi Certin B.V., 28th September 2015.

[3] OIML R 140:2007 Measuring systems for gaseous fuel.

[4] Uniform Network Code – Offtake Arrangements Document – Section D: Measurements. Joint Office of Gas Transporters, Version 2.81, 01 September 2008.

[5] ISO 5167-2:2003 Measurement of fluid flow by means of pressure differential devices inserted in circular cross-section conduits running full – Part 2: Orifice Plates.

[6] AGA Report No. 8:1994, Compressibility Factor of Natural Gas and Other Related Hydrocarbon Gases.

[7] ISO/IEC Guide 98-3:2008 Uncertainty of Measurement – Part 3. Guide to the Expression of Uncertainty in Measurement (GUM:1995).

Note: Also known as 'JCGM 100:2008 Guide to the Expression of Uncertainty in Measurement' and 'BS PD 6461-3:1995 General Metrology. Guide to the Expression of Uncertainty in Measurement (GUM)'

[8] BS ISO 5168:2005 Measurement of fluid flow - Procedures for the Evaluation of Uncertainties.

[9] General Specifications – Yokogawa EJX430A Gauge Pressure Transmitter, GS 01C25E01-01EN, Yokogawa Electric Corporation, 21st Edition July 2015.

[10] IEC / BS EN 60751:2008 Industrial Platinum Resistance Thermometers and Platinum Temperature Sensors.

[11] General Specifications – Yokogawa EJX110A Differential Pressure Transmitter, GS 01C25B01-01EN, Yokogawa Electric Corporation, 23rd Edition July 2015.

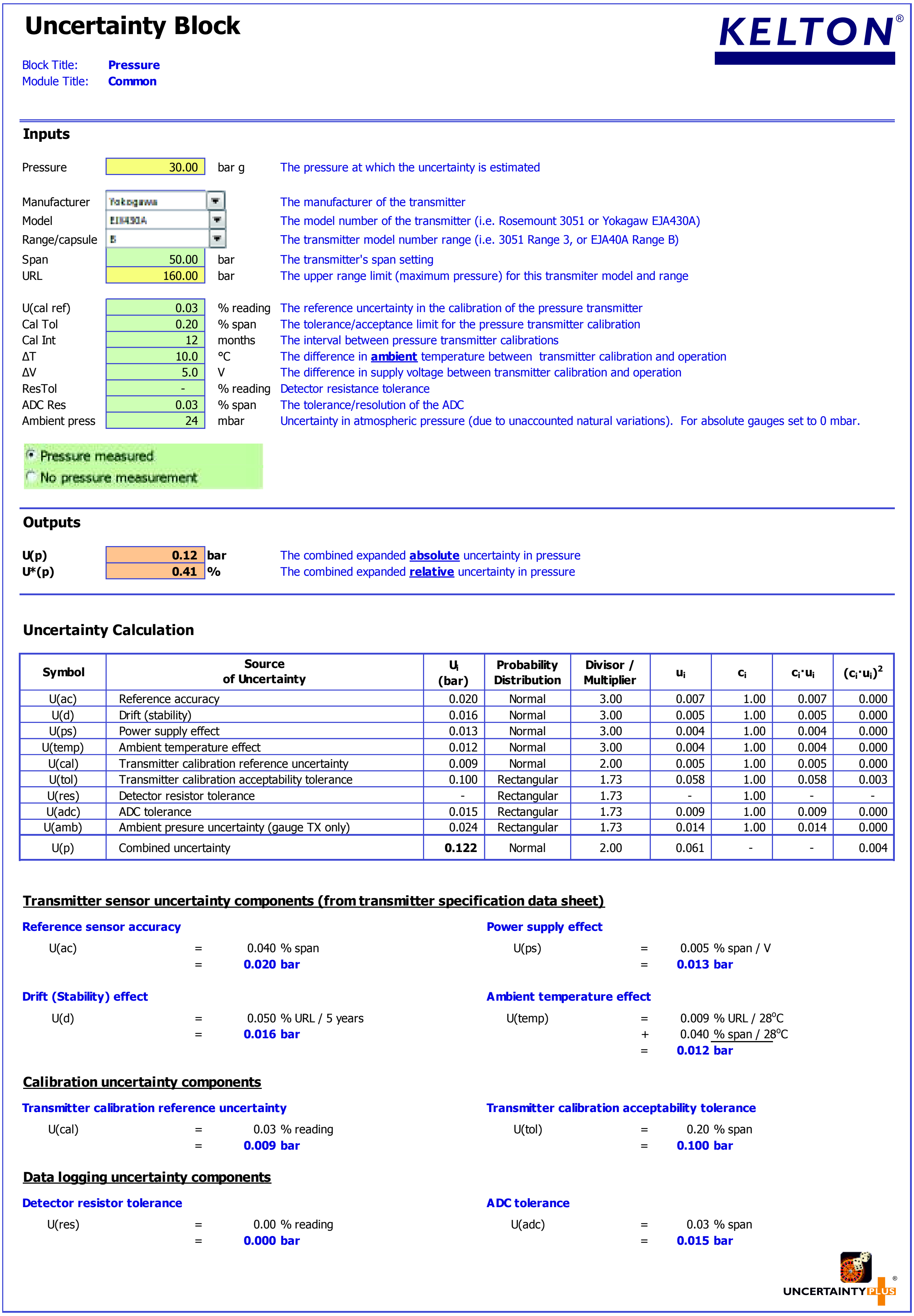
[12] In-Situ Calorimeter/Specific Gravity (Wobbe Device), Technical Report ####, NOVA Chemicals, 2012.

[13] ISO 5167-1:2003 Measurement of fluid flow by means of pressure differential devices inserted in circular cross-section conduits running full – Part 1: General principles and requirements.

APPENDIX A

UNCERTAINTY MODULES – COMMON

APPENDIX A



Uncertainty Block

Block Title: **Pressure**
Module Title: **Common**

Inputs

Pressure	30.00	bar g	The pressure at which the uncertainty is estimated
Manufacturer	Yokogawa		The manufacturer of the transmitter
Model	EJA430A		The model number of the transmitter (i.e. Rosemount 3051 or Yokagaw EJA430A)
Range/capsule	B		The transmitter model number range (i.e. 3051 Range 3, or EJA40A Range B)
Span	50.00	bar	The transmitter's span setting
URL	160.00	bar	The upper range limit (maximum pressure) for this transmiter model and range
U(cal ref)	0.03	% reading	The reference uncertainty in the calibration of the pressure transmitter
Cal Tol	0.20	% span	The tolerance/acceptance limit for the pressure transmitter calibration
Cal Int	12	months	The interval between pressure transmitter calibrations
ΔT	10.0	°C	The difference in **ambient** temperature between transmitter calibration and operation
ΔV	5.0	V	The difference in supply voltage between transmitter calibration and operation
ResTol	-	% reading	Detector resistance tolerance
ADC Res	0.03	% span	The tolerance/resolution of the ADC
Ambient press	24	mbar	Uncertainty in atmospheric pressure (due to unaccounted natural variations). For absolute gauges set to 0 mbar.

● Pressure measured
○ No pressure measurement

Outputs

U(p)	**0.12**	**bar**	The combined expanded **absolute** uncertainty in pressure
U*(p)	**0.41**	**%**	The combined expanded **relative** uncertainty in pressure

Uncertainty Calculation

Symbol	Source of Uncertainty	U_i (bar)	Probability Distribution	Divisor / Multiplier	u_i	c_i	$c_i \cdot u_i$	$(c_i \cdot u_i)^2$
U(ac)	Reference accuracy	0.020	Normal	3.00	0.007	1.00	0.007	0.000
U(d)	Drift (stability)	0.016	Normal	3.00	0.005	1.00	0.005	0.000
U(ps)	Power supply effect	0.013	Normal	3.00	0.004	1.00	0.004	0.000
U(temp)	Ambient temperature effect	0.012	Normal	3.00	0.004	1.00	0.004	0.000
U(cal)	Transmitter calibration reference uncertainty	0.009	Normal	2.00	0.005	1.00	0.005	0.000
U(tol)	Transmitter calibration acceptability tolerance	0.100	Rectangular	1.73	0.058	1.00	0.058	0.003
U(res)	Detector resistor tolerance	-	Rectangular	1.73	-	1.00	-	-
U(adc)	ADC tolerance	0.015	Rectangular	1.73	0.009	1.00	0.009	0.000
U(amb)	Ambient presure uncertainty (gauge TX only)	0.024	Rectangular	1.73	0.014	1.00	0.014	0.000
U(p)	Combined uncertainty	**0.122**	Normal	2.00	0.061	-	-	0.004

Transmitter sensor uncertainty components (from transmitter specification data sheet)

Reference sensor accuracy

U(ac) = 0.040 % span
= **0.020 bar**

Power supply effect

U(ps) = 0.005 % span / V
= **0.013 bar**

Drift (Stability) effect

U(d) = 0.050 % URL / 5 years
= **0.016 bar**

Ambient temperature effect

U(temp) = 0.009 % URL / 28°C
\+ 0.040 % span / 28°C
= **0.012 bar**

Calibration uncertainty components

Transmitter calibration reference uncertainty

U(cal) = 0.03 % reading
= **0.009 bar**

Transmitter calibration acceptability tolerance

U(tol) = 0.20 % span
= **0.100 bar**

Data logging uncertainty components

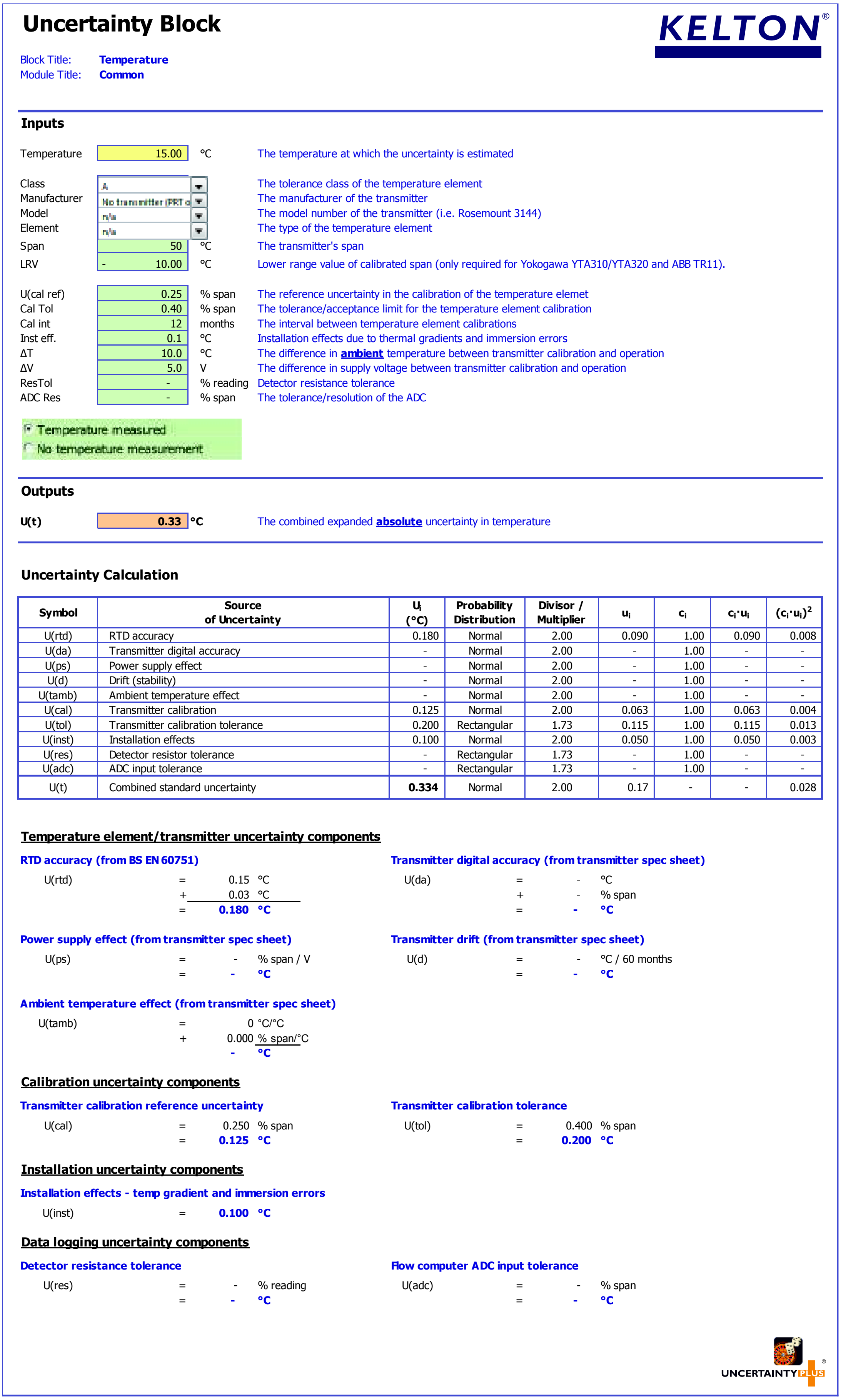
Detector resistor tolerance

U(res) = 0.00 % reading
= **0.000 bar**

ADC tolerance

U(adc) = 0.03 % span
= **0.015 bar**

APPENDIX A



Uncertainty Block

KELTON®

Block Title: **Temperature**
Module Title: **Common**

Inputs

Temperature	15.00	°C	The temperature at which the uncertainty is estimated
Class	A		The tolerance class of the temperature element
Manufacturer	No transmitter (PRT o		The manufacturer of the transmitter
Model	n/a		The model number of the transmitter (i.e. Rosemount 3144)
Element	n/a		The type of the temperature element
Span	50	°C	The transmitter's span
LRV	- 10.00	°C	Lower range value of calibrated span (only required for Yokogawa YTA310/YTA320 and ABB TR11).
U(cal ref)	0.25	% span	The reference uncertainty in the calibration of the temperature elemet
Cal Tol	0.40	% span	The tolerance/acceptance limit for the temperature element calibration
Cal int	12	months	The interval between temperature element calibrations
Inst eff.	0.1	°C	Installation effects due to thermal gradients and immersion errors
ΔT	10.0	°C	The difference in **ambient** temperature between transmitter calibration and operation
ΔV	5.0	V	The difference in supply voltage between transmitter calibration and operation
ResTol	-	% reading	Detector resistance tolerance
ADC Res	-	% span	The tolerance/resolution of the ADC

● Temperature measured
○ No temperature measurement

Outputs

U(t)	**0.33**	**°C**	The combined expanded **absolute** uncertainty in temperature

Uncertainty Calculation

Symbol	Source of Uncertainty	U_i (°C)	Probability Distribution	Divisor / Multiplier	u_i	c_i	$c_i \cdot u_i$	$(c_i \cdot u_i)^2$
U(rtd)	RTD accuracy	0.180	Normal	2.00	0.090	1.00	0.090	0.008
U(da)	Transmitter digital accuracy	-	Normal	2.00	-	1.00	-	-
U(ps)	Power supply effect	-	Normal	2.00	-	1.00	-	-
U(d)	Drift (stability)	-	Normal	2.00	-	1.00	-	-
U(tamb)	Ambient temperature effect	-	Normal	2.00	-	1.00	-	-
U(cal)	Transmitter calibration	0.125	Normal	2.00	0.063	1.00	0.063	0.004
U(tol)	Transmitter calibration tolerance	0.200	Rectangular	1.73	0.115	1.00	0.115	0.013
U(inst)	Installation effects	0.100	Normal	2.00	0.050	1.00	0.050	0.003
U(res)	Detector resistor tolerance	-	Rectangular	1.73	-	1.00	-	-
U(adc)	ADC input tolerance	-	Rectangular	1.73	-	1.00	-	-
U(t)	Combined standard uncertainty	**0.334**	Normal	2.00	0.17	-	-	0.028

Temperature element/transmitter uncertainty components

RTD accuracy (from BS EN 60751)

U(rtd) = 0.15 °C
\+ 0.03 °C
= **0.180 °C**

Transmitter digital accuracy (from transmitter spec sheet)

U(da) = - °C
\+ - % span
= **- °C**

Power supply effect (from transmitter spec sheet)

U(ps) = - % span / V
= **- °C**

Transmitter drift (from transmitter spec sheet)

U(d) = - °C / 60 months
= **- °C**

Ambient temperature effect (from transmitter spec sheet)

U(tamb) = 0 °C/°C
\+ 0.000 % span/°C
- °C

Calibration uncertainty components

Transmitter calibration reference uncertainty

U(cal) = 0.250 % span
= **0.125 °C**

Transmitter calibration tolerance

U(tol) = 0.400 % span
= **0.200 °C**

Installation uncertainty components

Installation effects - temp gradient and immersion errors

U(inst) = **0.100 °C**

Data logging uncertainty components

Detector resistance tolerance

U(res) = - % reading
= **- °C**

Flow computer ADC input tolerance

U(adc) = - % span
= **- °C**

UNCERTAINTY PLUS®

APPENDIX A

Uncertainty Block

KELTON®

Block Title: **Differential pressure (high)**
Module Title: **Common**

Inputs

∆p	1,000.00	mbar	The pressure at which the uncertainty is estimated
Manufacturer	Yokogawa		The manufacturer of the transmitter
Model	EJX110A		The model number of the transmitter (i.e. Rosemount 3051 or Yokagaw EJA430A)
Range/capsule	M		The transmitter model number range (i.e. 3051 Range 3, or EJA40A Range B)
Span	1,000	mbar	The transmitter's span setting
URL	1,000	mbar	The upper range limit (maximum pressure) for this transmiter model and range
P	30	bar	Line pressure
U(cal ref)	0.05	% reading	The reference uncertainty in the calibration of the pressure transmitter
Cal Tol	0.20	% span	The tolerance/acceptance limit for the pressure transmitter calibration
Cal Int	12	months	The interval between pressure transmitter calibrations
ΔP static	10	bar	The difference in **static (line)** pressure between ∆p transmitter calibration and operation
ΔT	10.0	°C	The difference in **ambient** temperature between transmitter calibration and operation
ΔV	5.0	V	The difference in supply voltage between transmitter calibration and operation
ResTol	-	% reading	Detector resistance tolerance
ADC Res	0.03	% span	The tolerance/resolution of the ADC

Outputs

U(∆p)	**2.41**	**mbar**	The combined expanded **absolute** uncertainty in pressure
U*(∆p)	**0.24**	**%**	The combined expanded **relative** uncertainty in pressure

Uncertainty Calculation

Symbol	Source of Uncertainty	U_i (mbar)	Probability Distribution	Divisor / Multiplier	u_i	c_i	$c_i \cdot u_i$	$(c_i \cdot u_i)^2$
U(ac)	Reference accuracy	0.400	Normal	3.00	0.133	1.00	0.133	0.018
U(d)	Drift (stability)	0.100	Normal	3.00	0.033	1.00	0.033	0.001
U(ps)	Power supply effect	0.250	Normal	3.00	0.083	1.00	0.083	0.007
U(temp)	Ambient temperature effect	0.175	Normal	3.00	0.058	1.00	0.058	0.003
U(stat)	Static pressure effect	0.138	Normal	3.00	0.046	1.00	0.046	0.002
U(cal)	Transmitter calibration reference uncertainty	0.500	Normal	2.00	0.250	1.00	0.250	0.063
U(tol)	Transmitter calibration acceptability tolerance	2.000	Rectangular	1.73	1.155	1.00	1.155	1.333
U(res)	Detector resistor tolerance	-	Rectangular	1.73	-	1.00	-	-
U(adc)	ADC tolerance	0.300	Rectangular	1.73	0.173	1.00	0.173	0.030
U(∆p)	Combined uncertainty	**2.414**	Normal	2.00	1.207	-	-	1.457

Transmitter sensor uncertainty components (From transmitter specification data sheet)

Reference sensor accuracy

U(ac) = 0.040 % span 0.040
= **0.400 mbar** 0.040

Power supply effect

U(ps) = 0.005 % span / V
= **0.250 mbar**

Drift (Stability) effect

U(d) = 0.050 % URL / 5 years
= **0.100 mbar**

Ambient temperature effect

U(temp) = 0.009 % URL / 28°C 0.0400
+ 0.040 % span / 28°C 0.0400
= **0.175 mbar**

Static pressure effect

U(stat) = 0.020 % URL / 69 bar
+ 0.075 % span / 69 bar
= **0.138 mbar**

Calibration uncertainty components

Transmitter calibration reference uncertainty

U(cal) = 0.050 % reading
= **0.500 mbar**

Transmitter calibration acceptability tolerance

U(tol) = 0.200 % span
= **2.000 mbar**

Data logging uncertainty components

Detector resistor tolerance

U(res) = 0.000 % reading
= **0.000 mbar**

ADC tolerance

U(adc) = 0.030 % span
= **0.300 mbar**

UNCERTAINTY PLUS®

Uncertainty Block

Block Title: **Differential pressure (low)**
Module Title: **Common**

Inputs

Δp	200.00	mbar	The pressure at which the uncertainty is estimated
Manufacturer	Yokogawa		The manufacturer of the transmitter
Model	EJX110A		The model number of the transmitter (i.e. Rosemount 3051 or Yokagaw EJA430A)
Range/capsule	M		The transmitter model number range (i.e. 3051 Range 3, or EJA40A Range B)
Span	200	mbar	The transmitter's span setting
URL	1,000	mbar	The upper range limit (maximum pressure) for this transmiter model and range
P	30	bar	Line pressure
U(cal ref)	0.05	% reading	The reference uncertainty in the calibration of the pressure transmitter
Cal Tol	0.20	% span	The tolerance/acceptance limit for the pressure transmitter calibration
Cal Int	12	months	The interval between pressure transmitter calibrations
ΔP static	10	bar	The difference in **static (line)** pressure between Δp transmitter calibration and operation
ΔT	10.0	°C	The difference in **ambient** temperature between transmitter calibration and operation
ΔV	5.0	V	The difference in supply voltage between transmitter calibration and operation
ResTol	-	% reading	Detector resistance tolerance
ADC Res	0.03	% span	The tolerance/resolution of the ADC

Outputs

U(Δp)	**0.49**	**mbar**	The combined expanded **absolute** uncertainty in pressure
U*(Δp)	**0.24**	**%**	The combined expanded **relative** uncertainty in pressure

Uncertainty Calculation

Symbol	Source of Uncertainty	U_i (mbar)	Probability Distribution	Divisor / Multiplier	u_i	c_i	$c_i \cdot u_i$	$(c_i \cdot u_i)^2$
U(ac)	Reference accuracy	0.080	Normal	3.00	0.027	1.00	0.027	0.001
U(d)	Drift (stability)	0.100	Normal	3.00	0.033	1.00	0.033	0.001
U(ps)	Power supply effect	0.050	Normal	3.00	0.017	1.00	0.017	0.000
U(temp)	Ambient temperature effect	0.061	Normal	3.00	0.020	1.00	0.020	0.000
U(stat)	Static pressure effect	0.051	Normal	3.00	0.017	1.00	0.017	0.000
U(cal)	Transmitter calibration reference uncertainty	0.100	Normal	2.00	0.050	1.00	0.050	0.003
U(tol)	Transmitter calibration acceptability tolerance	0.400	Rectangular	1.73	0.231	1.00	0.231	0.053
U(res)	Detector resistor tolerance	-	Rectangular	1.73	-	1.00	-	-
U(adc)	ADC tolerance	0.060	Rectangular	1.73	0.035	1.00	0.035	0.001
U(Δp)	Combined uncertainty	**0.489**	Normal	2.00	0.245	-	-	0.060

Transmitter sensor uncertainty components (From transmitter specification data sheet)

Reference sensor accuracy

U(ac) = 0.040 % span 0.040
= **0.080 mbar** 0.040

Drift (Stability) effect

U(d) = 0.050 % URL / 5 years
= **0.100 mbar**

Static pressure effect

U(stat) = 0.020 % URL / 69 bar
+ 0.075 % span / 69 bar
= **0.051 mbar**

Power supply effect

U(ps) = 0.005 % span / V
= **0.050 mbar**

Ambient temperature effect

U(temp) = 0.009 % URL / 28°C 0.0400
+ 0.040 % span / 28°C 0.0400
= **0.061 mbar**

Calibration uncertainty components

Transmitter calibration reference uncertainty

U(cal) = 0.050 % reading
= **0.100 mbar**

Transmitter calibration acceptability tolerance

U(tol) = 0.200 % span
= **0.400 mbar**

Data logging uncertainty components

Detector resistor tolerance

U(res) = 0.000 % reading
= **0.000 mbar**

ADC tolerance

U(adc) = 0.030 % span
= **0.060 mbar**

APPENDIX A

UNCERTAINTY MODULES – GAS CHROMATOGRAPH ANALYSIS

APPENDIX A

Uncertainty Block

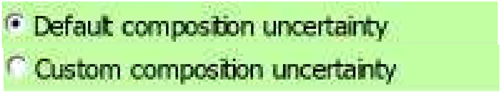
KELTON®

Block Title: **Composition**
Module Title: **GC ANALYSIS**

Gas Composition Input

Symbol	Source of Uncertainty	component value mole %	Cal Gas Uncertainty mole %	Calibration Tolerance mole %	Repeatability mole %	U(mol) %
N2	Nitrogen	6.01	0.030	0.030	0.030	0.052
CO2	Carbon Dioxide	2.00	0.010	0.010	0.010	0.017
C1	Methane	78.20	0.050	0.050	0.050	0.087
C2	Ethane	7.93	0.030	0.030	0.030	0.052
C3	Propane	5.01	0.030	0.030	0.030	0.052
nC4	nButane	0.01	0.002	0.002	0.002	0.003
iC4	iButane	0.30	0.005	0.005	0.005	0.009
nC5	nPentane	0.10	0.002	0.002	0.002	0.003
iC5	iPentane	0.05	0.002	0.002	0.002	0.003
neoC5	neoPentane	0.05	0.002	0.002	0.002	0.003
nC6	nHexane	0.34	0.005	0.005	0.005	0.009
nC7	nHeptane	-	0.002	0.002	0.002	0.003
nC8	nOctane	-	0.002	0.002	0.002	0.003
nC9	nNonane	-	0.002	0.002	0.002	0.003
nC10	nDecane	-	0.002	0.002	0.002	0.003
H2	Hydrogen	-	0.002	0.002	0.002	0.003
H2O	Water	-	0.002	0.002	0.002	0.003
H2S	Hydrogen sulphide	-	0.002	0.002	0.002	0.003
He	Helium	-	0.002	0.002	0.002	0.003
Ar	Argon	-	0.002	0.002	0.002	0.003
CO	Carbon Monoxide	-	0.002	0.002	0.002	0.003
O2	Oxygen	-	0.002	0.002	0.002	0.003

Total Composition 100.0000



● Default composition uncertainty
○ Custom composition uncertainty

UNCERTAINTY PLUS®

Uncertainty Block

Block Title: **AGA8 Line Density**
Module Title: **GC ANALYSIS**

Calculation Inputs (shown for information only)

Density calculation

AGA8:1994 / ISO 12213-1:1997 ▼

	Value	Uncertainty		
P	30.00	0.122	bar g	The pressure at which the density is calculated
T	15.00	0.334	°C	The temperature at which the density is calculated
U(EOS)		0.10	%	Uncertainty in equation of state. Consult relevant standard.

Outputs

ρ_l	28.8472	kg/m³	The calculated line (flowing) density
$U(\rho_l)$	0.14	kg/m³	The combined expanded **absolute** uncertainty in line (flowing) density
$U^*(\rho_l)$	0.48	%	The combined expanded **relative** uncertainty in line (flowing) density

Uncertainty Calculation

Symbol	Source of Uncertainty	Component value	Uncertainty	Probability Distribution	Divisor / Multiplier	u_i	c_i	$c_i \cdot u_i$	$(c_i \cdot u_i)^2$
N2	Nitrogen (mol %)	6.010	0.052	Normal	2.00	2.598E-02	7.117E-02	0.002	0.000
CO2	Carbon Dioxide (mol %)	2.000	0.017	Normal	2.00	8.660E-03	3.521E-01	0.003	0.000
C1	Methane (mol %)	78.200	0.087	Normal	2.00	4.330E-02	-7.084E-02	- 0.003	0.000
C2	Ethane (mol %)	7.930	0.052	Normal	2.00	2.598E-02	1.838E-01	0.005	0.000
C3	Propane (mol %)	5.010	0.052	Normal	2.00	2.598E-02	4.289E-01	0.011	0.000
nC4	nButane (mol %)	0.010	0.003	Normal	2.00	1.732E-03	6.722E-01	0.001	0.000
iC4	iButane (mol %)	0.300	0.009	Normal	2.00	4.330E-03	6.732E-01	0.003	0.000
nC5	nPentane (mol %)	0.100	0.003	Normal	2.00	1.732E-03	9.218E-01	0.002	0.000
iC5	iPentane (mol %)	0.050	0.003	Normal	2.00	1.732E-03	9.126E-01	0.002	0.000
neoC5	neoPentane (mol %)	0.050	0.003	Normal	2.00	1.732E-03	9.126E-01	0.002	0.000
nC6	nHexane (mol %)	0.340	0.009	Normal	2.00	4.330E-03	1.203E+00	0.005	0.000
nC7	nHeptane (mol %)	-	0.003	Normal	2.00	1.732E-03	6.718E-01	0.001	0.000
nC8	nOctane (mol %)	-	0.003	Normal	2.00	1.732E-03	7.893E-01	0.001	0.000
nC9	nNonane (mol %)	-	0.003	Normal	2.00	1.732E-03	9.069E-01	0.002	0.000
nC10	nDecane (mol %)	-	0.003	Normal	2.00	1.732E-03	1.025E+00	0.002	0.000
H2	Hydrogen (mol %)	-	0.003	Normal	2.00	1.732E-03	-1.632E-01	- 0.000	0.000
H2O	Water (mol %)	-	0.003	Normal	2.00	1.732E-03	-1.389E-02	- 0.000	0.000
H2S	Hydrogen sulphide (mol %)	-	0.003	Normal	2.00	1.732E-03	1.156E-01	0.000	0.000
He	Helium (mol %)	-	0.003	Normal	2.00	1.732E-03	-1.575E-01	- 0.000	0.000
Ar	Argon (mol %)	-	0.003	Normal	2.00	1.732E-03	1.252E-01	0.000	0.000
CO	Carbon Monozide (mol %)	-	0.003	Normal	2.00	1.732E-03	3.875E-02	0.000	0.000
O2	Oxygen (mol %)	-	0.003	Normal	2.00	1.732E-03	6.910E-02	0.000	0.000
P	Line pressure (barg)	30.000	0.122	Normal	2.00	6.105E-02	1.020E+00	0.062	0.004
T	Line temperature (°C)	15.000	0.334	Normal	2.00	1.669E-01	-1.361E-01	- 0.023	0.001
	Equation of state (kg/m³)		0.029	Normal	2.00	1.442E-02	1.000E+00	0.014	0.000
U(ρ)	Combined standard uncertainty (kg/m³)		**0.139**	Normal	2.00	0.069467882	-	-	0.005

Sensitivity calculation

c_i (the partial derivative ∂y/∂x) for each input is determined using the finite difference method where the input quantities are successively varied by the magnitude of their uncertainty

Uncertainty Block

Block Title: **Calculated standard density**
Module Title: **GC ANALYSIS**

Calculation Inputs (shown for information only)

Std density calculation
ISO 6976:1995

ISO 6976 reference temperature
15 degC

	Value	Uncertainty		
P_b	1.01325	n/a	bara	Pressure at base/standard conditions.
T_b	15.00	n/a	°C	Temperature at base/standard conditions.
U(EOS)		0.10	%	Equation of state uncertainty. Consult relevant standard.

Outputs

ρ_{std}	0.8619	kg/Sm³	The calculated standard (base) density
$U(\rho_{std})$	0.001	kg/Sm³	The combined expanded **absolute** uncertainty in standard (base) density
$U^*(\rho_{std})$	0.13	%	The combined expanded **relative** uncertainty in standard (base) density

Uncertainty Calculation

Symbol	Source of Uncertainty	Component value	Uncertainty	Probability Distribution	Divisor / Multiplier	u_i	c_i	$c_i \cdot u_i$	$(c_i \cdot u_i)^2$
N2	Nitrogen (mol %)	6.010	0.052	Normal	2.00	2.598E-02	3.229E-03	0.000	0.000
CO2	Carbon Dioxide (mol %)	2.000	0.017	Normal	2.00	8.660E-03	1.007E-02	0.000	0.000
C1	Methane (mol %)	78.200	0.087	Normal	2.00	4.330E-02	-1.823E-03	- 0.000	0.000
C2	Ethane (mol %)	7.930	0.052	Normal	2.00	2.598E-02	4.171E-03	0.000	0.000
C3	Propane (mol %)	5.010	0.052	Normal	2.00	2.598E-02	1.016E-02	0.000	0.000
nC4	nButane (mol %)	0.010	0.003	Normal	2.00	1.732E-03	1.616E-02	0.000	0.000
iC4	iButane (mol %)	0.300	0.009	Normal	2.00	4.330E-03	1.615E-02	0.000	0.000
nC5	nPentane (mol %)	0.100	0.003	Normal	2.00	1.732E-03	2.217E-02	0.000	0.000
iC5	iPentane (mol %)	0.050	0.003	Normal	2.00	1.732E-03	2.214E-02	0.000	0.000
neoC5	neoPentane (mol %)	0.050	0.003	Normal	2.00	1.732E-03	2.213E-02	0.000	0.000
nC6	nHexane (mol %)	0.340	0.009	Normal	2.00	4.330E-03	2.816E-02	0.000	0.000
nC7	nHeptane (mol %)	-	0.003	Normal	2.00	1.732E-03	3.417E-02	0.000	0.000
nC8	nOctane (mol %)	-	0.003	Normal	2.00	1.732E-03	4.019E-02	0.000	0.000
nC9	nNonane (mol %)	-	0.003	Normal	2.00	1.732E-03	4.623E-02	0.000	0.000
nC10	nDecane (mol %)	-	0.003	Normal	2.00	1.732E-03	5.228E-02	0.000	0.000
H2	Hydrogen (mol %)	-	0.003	Normal	2.00	1.732E-03	-7.818E-03	- 0.000	0.000
H2O	Water (mol %)	-	0.003	Normal	2.00	1.732E-03	-8.103E-04	- 0.000	0.000
H2S	Hydrogen sulphide (mol %)	-	0.003	Normal	2.00	1.732E-03	5.880E-03	0.000	0.000
He	Helium (mol %)	-	0.003	Normal	2.00	1.732E-03	-6.970E-03	- 0.000	0.000
Ar	Argon (mol %)	-	0.003	Normal	2.00	1.732E-03	8.301E-03	0.000	0.000
CO	Carbon Monozide (mol %)	-	0.003	Normal	2.00	1.732E-03	3.233E-03	0.000	0.000
O2	Oxygen (mol %)	-	0.003	Normal	2.00	1.732E-03	4.930E-03	0.000	0.000
P	Line pressure (barg)	30.000	0.122	Normal	2.00	6.105E-02	0.000E+00	-	-
T	Line temperature (°C)	15.000	0.334	Normal	2.00	1.669E-01	0.000E+00	-	-
	Equation of state (kg/Sm³)		0.001	Normal	2.00	4.309E-04	1.000E+00	0.000	0.000
$U(\rho_{,std})$	Combined standard uncertainty (kg/Sm³)		**0.001**	Normal	2.00	0.000580199	-	-	0.000

Sensitivity calculation

c_i (the partial derivative ∂y/∂x) for each input is determined using the finite difference method where the input quantities are successively varied by the magnitude of their uncertainty

APPENDIX A

Uncertainty Block

Block Title: **Calculated Cv**
Module Title: **GC ANALYSIS**

Calculation Inputs (shown for information only)

	Value	Uncertainty		
P_b	1.01325	n/a	bar g	Pressure at base/standard conditions.
T_b	15_15	n/a	°C	Temperature at base/standard conditions.
U(EOS)		0.10	%	Equation of state uncertainty. Consult relevant standard.

Calorific value calculation

ISO 6976:1995

ISO 6976 ref temp (combustion/metering)

15_15

Outputs

Cv	40.83	MJ/Sm³	The real superior calorific value (volumetric basis)
U(Cv)	0.060	MJ/Sm³	The combined expanded **absolute** uncertainty in the calorific value
U*(Cv)	0.15	%	The combined expanded **relative** uncertainty in the calorific value

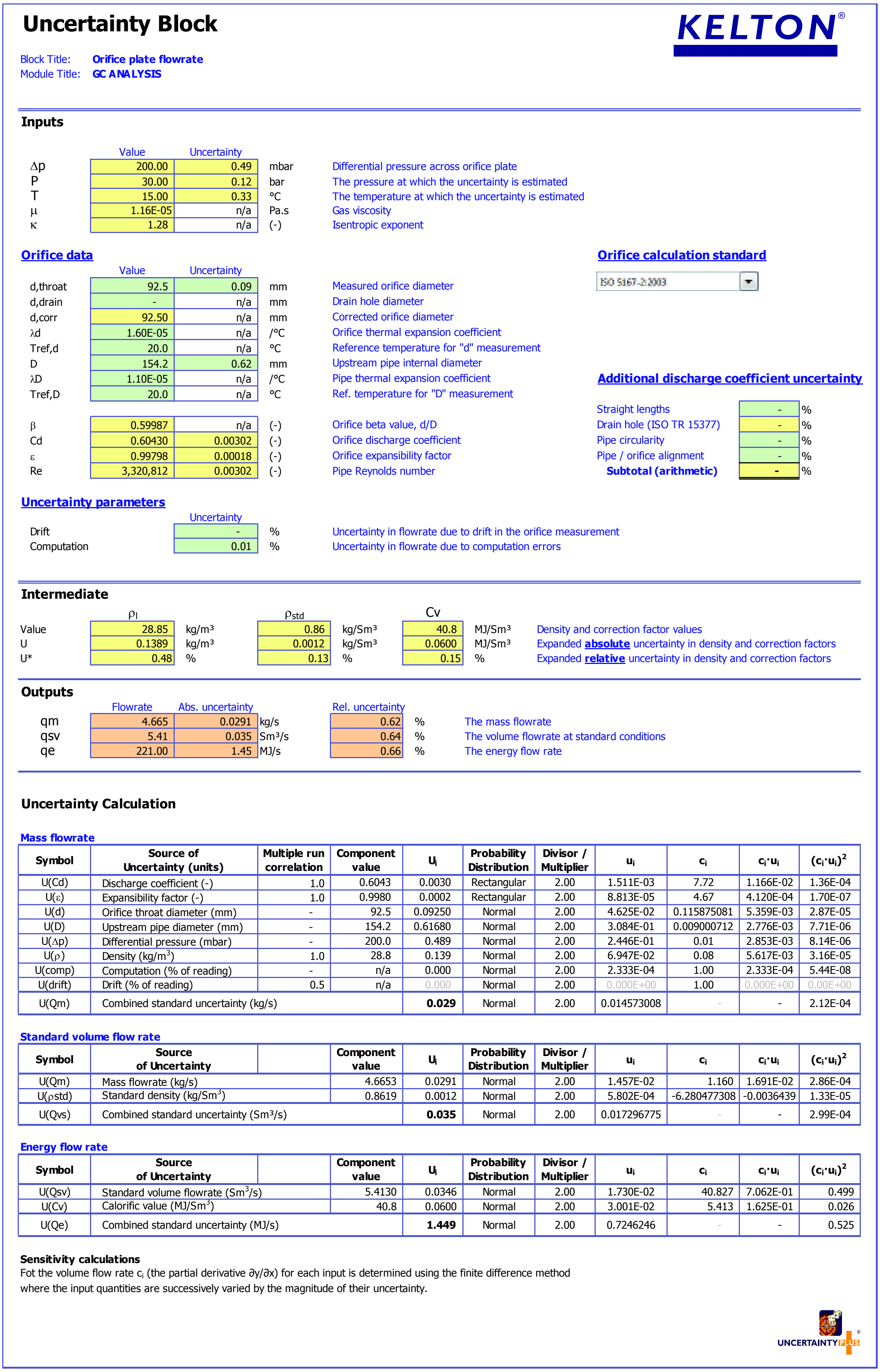
Uncertainty Calculation

Symbol	Source of Uncertainty	Component value	Uncertainty	Probability Distribution	Divisor / Multiplier	u_i	c_i	$c_i \cdot u_i$	$(c_i \cdot u_i)^2$
N2	Nitrogen (mol %)	6.010	0.052	Normal	2.00	2.598E-02	-4.099E-01	- 0.011	0.000
CO2	Carbon Dioxide (mol %)	2.000	0.017	Normal	2.00	8.660E-03	-4.073E-01	- 0.004	0.000
C1	Methane (mol %)	78.200	0.087	Normal	2.00	4.330E-02	-3.051E-02	- 0.001	0.000
C2	Ethane (mol %)	7.930	0.052	Normal	2.00	2.598E-02	2.560E-01	0.007	0.000
C3	Propane (mol %)	5.010	0.052	Normal	2.00	2.598E-02	5.373E-01	0.014	0.000
nC4	nButane (mol %)	0.010	0.003	Normal	2.00	1.732E-03	8.190E-01	0.001	0.000
iC4	iButane (mol %)	0.300	0.009	Normal	2.00	4.330E-03	8.147E-01	0.004	0.000
nC5	nPentane (mol %)	0.100	0.003	Normal	2.00	1.732E-03	1.101E+00	0.002	0.000
iC5	iPentane (mol %)	0.050	0.003	Normal	2.00	1.732E-03	1.097E+00	0.002	0.000
neoC5	neoPentane (mol %)	0.050	0.003	Normal	2.00	1.732E-03	1.091E+00	0.002	0.000
nC6	nHexane (mol %)	0.340	0.009	Normal	2.00	4.330E-03	1.383E+00	0.006	0.000
nC7	nHeptane (mol %)	-	0.003	Normal	2.00	1.732E-03	1.666E+00	0.003	0.000
nC8	nOctane (mol %)	-	0.003	Normal	2.00	1.732E-03	1.948E+00	0.003	0.000
nC9	nNonane (mol %)	-	0.003	Normal	2.00	1.732E-03	2.232E+00	0.004	0.000
nC10	nDecane (mol %)	-	0.003	Normal	2.00	1.732E-03	2.517E+00	0.004	0.000
H2	Hydrogen (mol %)	-	0.003	Normal	2.00	1.732E-03	-2.895E-01	- 0.001	0.000
H2O	Water (mol %)	-	0.003	Normal	2.00	1.732E-03	-3.815E-01	- 0.001	0.000
H2S	Hydrogen sulphide (mol %)	-	0.003	Normal	2.00	1.732E-03	-1.677E-01	- 0.000	0.000
He	Helium (mol %)	-	0.003	Normal	2.00	1.732E-03	-4.106E-01	- 0.001	0.000
Ar	Argon (mol %)	-	0.003	Normal	2.00	1.732E-03	-4.094E-01	- 0.001	0.000
CO	Carbon Monozide (mol %)	-	0.003	Normal	2.00	1.732E-03	-2.896E-01	- 0.001	0.000
O2	Oxygen (mol %)	-	0.003	Normal	2.00	1.732E-03	-4.094E-01	- 0.001	0.000
P	Line pressure (barg)	30.000	0.122	Normal	2.00	6.105E-02	0.000E+00	-	-
T	Line temperature (°C)	15.000	0.334	Normal	2.00	1.669E-01	0.000E+00	-	-
	Equation of state (MJ/Sm³)		0.041	Normal	2.00	0.02	1.000E+00	0.020	0.000
U(Cv)	Combined standard uncertainty (MJ/Sm³)		**0.060**	Normal	2.00	0.030012176	-	-	0.001

Sensitivity calculation

c_i (the partial derivative ∂y/∂x) for each input is determined using the finite difference method where the input quantities are successively varied by the magnitude of their uncertainty

APPENDIX A



Uncertainty Block

Block Title: **Orifice plate flowrate**
Module Title: **GC ANALYSIS**

Inputs

	Value	Uncertainty		
Δp	200.00	0.49	mbar	Differential pressure across orifice plate
P	30.00	0.12	bar	The pressure at which the uncertainty is estimated
T	15.00	0.33	°C	The temperature at which the uncertainty is estimated
μ	1.16E-05	n/a	Pa.s	Gas viscosity
κ	1.28	n/a	(-)	Isentropic exponent

Orifice data

	Value	Uncertainty		
d,throat	92.5	0.09	mm	Measured orifice diameter
d,drain	-	n/a	mm	Drain hole diameter
d,corr	92.50	n/a	mm	Corrected orifice diameter
λd	1.60E-05	n/a	/°C	Orifice thermal expansion coefficient
Tref,d	20.0	n/a	°C	Reference temperature for "d" measurement
D	154.2	0.62	mm	Upstream pipe internal diameter
λD	1.10E-05	n/a	/°C	Pipe thermal expansion coefficient
Tref,D	20.0	n/a	°C	Ref. temperature for "D" measurement
β	0.59987	n/a	(-)	Orifice beta value, d/D
Cd	0.60430	0.00302	(-)	Orifice discharge coefficient
ε	0.99798	0.00018	(-)	Orifice expansibility factor
Re	3,320,812	0.00302	(-)	Pipe Reynolds number

Orifice calculation standard

ISO 5167-2:2003

Additional discharge coefficient uncertainty

Straight lengths	-	%
Drain hole (ISO TR 15377)	-	%
Pipe circularity	-	%
Pipe / orifice alignment	-	%
Subtotal (arithmetic)	**-**	%

Uncertainty parameters

	Uncertainty		
Drift	-	%	Uncertainty in flowrate due to drift in the orifice measurement
Computation	0.01	%	Uncertainty in flowrate due to computation errors

Intermediate

	ρ_l		ρ_{std}		Cv		
Value	28.85	kg/m^3	0.86	kg/Sm^3	40.8	MJ/Sm^3	Density and correction factor values
U	0.1389	kg/m^3	0.0012	kg/Sm^3	0.0600	MJ/Sm^3	Expanded **absolute** uncertainty in density and correction factors
U*	0.48	%	0.13	%	0.15	%	Expanded **relative** uncertainty in density and correction factors

Outputs

	Flowrate	Abs. uncertainty		Rel. uncertainty		
qm	4.665	0.0291	kg/s	0.62	%	The mass flowrate
qsv	5.41	0.035	Sm^3/s	0.64	%	The volume flowrate at standard conditions
qe	221.00	1.45	MJ/s	0.66	%	The energy flow rate

Uncertainty Calculation

Mass flowrate

Symbol	Source of Uncertainty (units)	Multiple run correlation	Component value	U_i	Probability Distribution	Divisor / Multiplier	u_i	c_i	$c_i \cdot u_i$	$(c_i \cdot u_i)^2$
U(Cd)	Discharge coefficient (-)	1.0	0.6043	0.0030	Rectangular	2.00	1.511E-03	7.72	1.166E-02	1.36E-04
U(ε)	Expansibility factor (-)	1.0	0.9980	0.0002	Rectangular	2.00	8.813E-05	4.67	4.120E-04	1.70E-07
U(d)	Orifice throat diameter (mm)	-	92.5	0.09250	Normal	2.00	4.625E-02	0.115875081	5.359E-03	2.87E-05
U(D)	Upstream pipe diameter (mm)	-	154.2	0.61680	Normal	2.00	3.084E-01	0.009000712	2.776E-03	7.71E-06
U(Δp)	Differential pressure (mbar)	-	200.0	0.489	Normal	2.00	2.446E-01	0.01	2.853E-03	8.14E-06
U(ρ)	Density (kg/m^3)	1.0	28.8	0.139	Normal	2.00	6.947E-02	0.08	5.617E-03	3.16E-05
U(comp)	Computation (% of reading)	-	n/a	0.000	Normal	2.00	2.333E-04	1.00	2.333E-04	5.44E-08
U(drift)	Drift (% of reading)	0.5	n/a	0.000	Normal	2.00	0.000E+00	1.00	0.000E+00	0.00E+00
U(Qm)	Combined standard uncertainty (kg/s)			**0.029**	Normal	2.00	0.014573008	-	-	2.12E-04

Standard volume flow rate

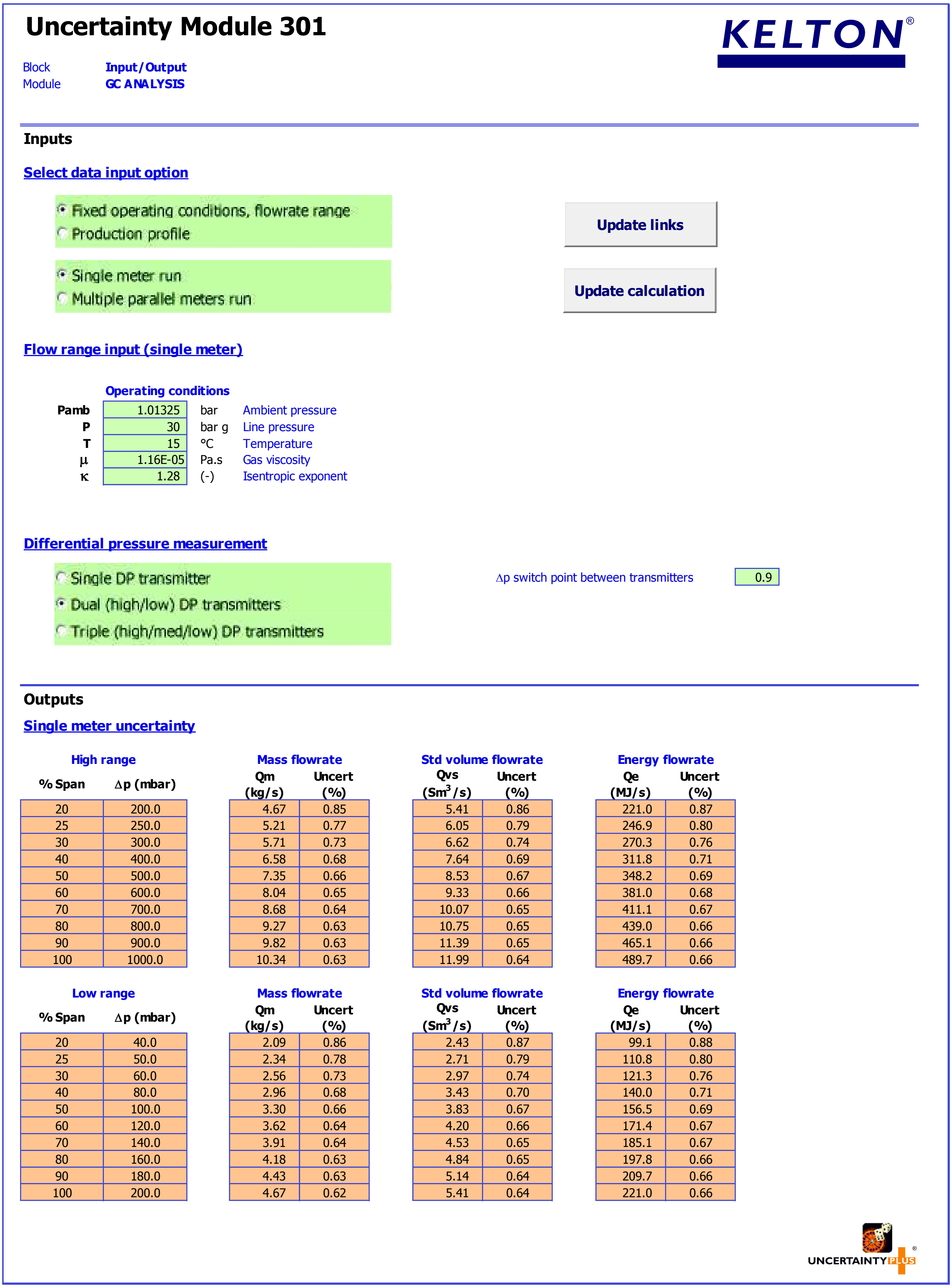
Symbol	Source of Uncertainty		Component value	U_i	Probability Distribution	Divisor / Multiplier	u_i	c_i	$c_i \cdot u_i$	$(c_i \cdot u_i)^2$
U(Qm)	Mass flowrate (kg/s)		4.6653	0.0291	Normal	2.00	1.457E-02	1.160	1.691E-02	2.86E-04
U(ρstd)	Standard density (kg/Sm^3)		0.8619	0.0012	Normal	2.00	5.802E-04	-6.280477308	-0.0036439	1.33E-05
U(Qvs)	Combined standard uncertainty (Sm^3/s)			**0.035**	Normal	2.00	0.017296775	-	-	2.99E-04

Energy flow rate

Symbol	Source of Uncertainty		Component value	U_i	Probability Distribution	Divisor / Multiplier	u_i	c_i	$c_i \cdot u_i$	$(c_i \cdot u_i)^2$
U(Qsv)	Standard volume flowrate (Sm^3/s)		5.4130	0.0346	Normal	2.00	1.730E-02	40.827	7.062E-01	0.499
U(Cv)	Calorific value (MJ/Sm^3)		40.8	0.0600	Normal	2.00	3.001E-02	5.413	1.625E-01	0.026
U(Qe)	Combined standard uncertainty (MJ/s)			**1.449**	Normal	2.00	0.7246246	-	-	0.525

Sensitivity calculations

Fot the volume flow rate c_i (the partial derivative $\partial y/\partial x$) for each input is determined using the finite difference method where the input quantities are successively varied by the magnitude of their uncertainty.



Uncertainty Module 301

Block	**Input/Output**
Module	**GC ANALYSIS**

Inputs

Select data input option

● Fixed operating conditions, flowrate range
○ Production profile

● Single meter run
○ Multiple parallel meters run

Flow range input (single meter)

	Operating conditions		
Pamb	1.01325	bar	Ambient pressure
P	30	bar g	Line pressure
T	15	°C	Temperature
μ	1.16E-05	Pa.s	Gas viscosity
κ	1.28	(-)	Isentropic exponent

Differential pressure measurement

○ Single DP transmitter
● Dual (high/low) DP transmitters
○ Triple (high/med/low) DP transmitters

Δp switch point between transmitters 0.9

Outputs

Single meter uncertainty

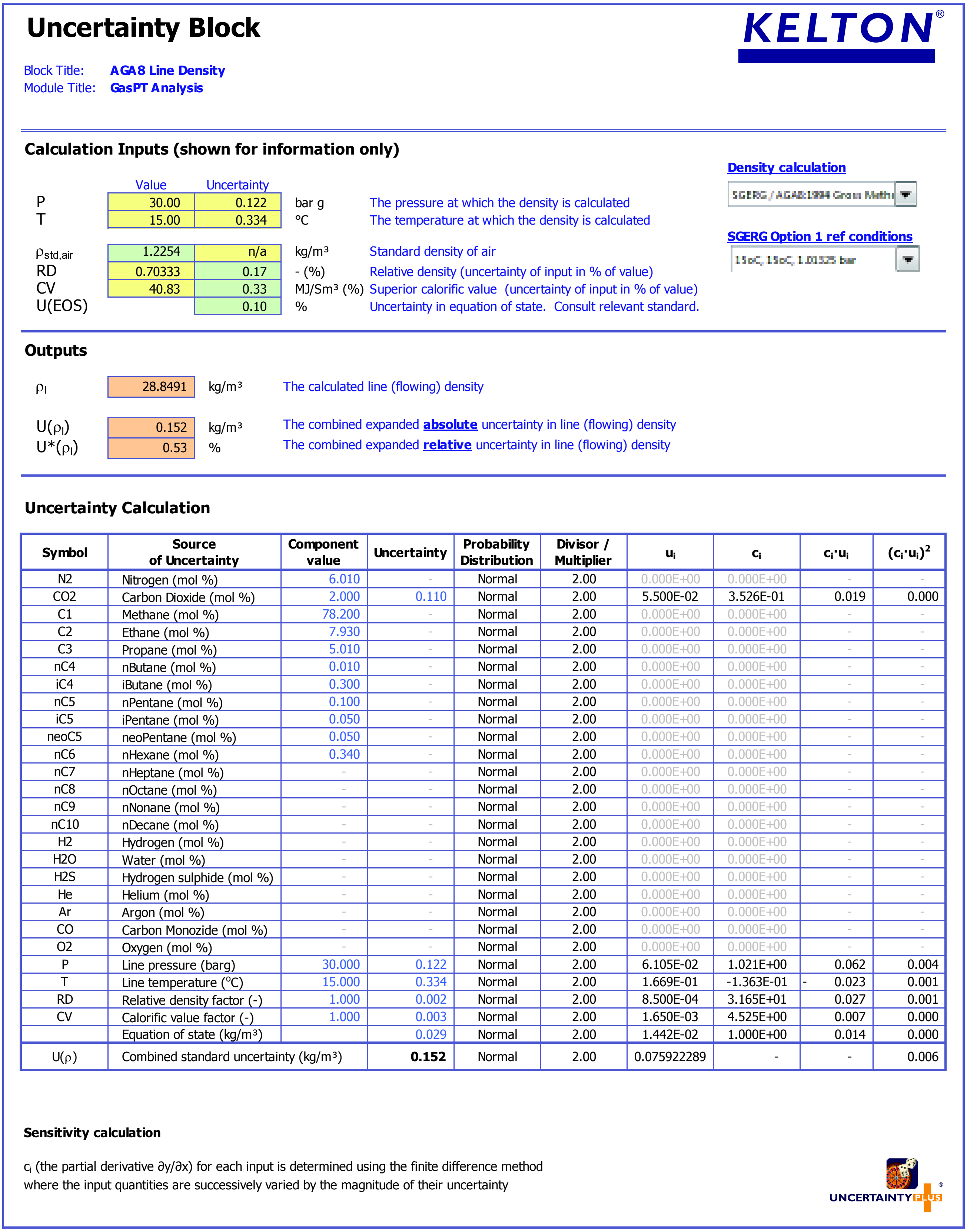
High range		Mass flowrate		Std volume flowrate		Energy flowrate	
% Span	Δp (mbar)	Qm (kg/s)	Uncert (%)	Qvs (Sm^3/s)	Uncert (%)	Qe (MJ/s)	Uncert (%)
20	200.0	4.67	0.85	5.41	0.86	221.0	0.87
25	250.0	5.21	0.77	6.05	0.79	246.9	0.80
30	300.0	5.71	0.73	6.62	0.74	270.3	0.76
40	400.0	6.58	0.68	7.64	0.69	311.8	0.71
50	500.0	7.35	0.66	8.53	0.67	348.2	0.69
60	600.0	8.04	0.65	9.33	0.66	381.0	0.68
70	700.0	8.68	0.64	10.07	0.65	411.1	0.67
80	800.0	9.27	0.63	10.75	0.65	439.0	0.66
90	900.0	9.82	0.63	11.39	0.65	465.1	0.66
100	1000.0	10.34	0.63	11.99	0.64	489.7	0.66

Low range		Mass flowrate		Std volume flowrate		Energy flowrate	
% Span	Δp (mbar)	Qm (kg/s)	Uncert (%)	Qvs (Sm^3/s)	Uncert (%)	Qe (MJ/s)	Uncert (%)
20	40.0	2.09	0.86	2.43	0.87	99.1	0.88
25	50.0	2.34	0.78	2.71	0.79	110.8	0.80
30	60.0	2.56	0.73	2.97	0.74	121.3	0.76
40	80.0	2.96	0.68	3.43	0.70	140.0	0.71
50	100.0	3.30	0.66	3.83	0.67	156.5	0.69
60	120.0	3.62	0.64	4.20	0.66	171.4	0.67
70	140.0	3.91	0.64	4.53	0.65	185.1	0.67
80	160.0	4.18	0.63	4.84	0.65	197.8	0.66
90	180.0	4.43	0.63	5.14	0.64	209.7	0.66
100	200.0	4.67	0.62	5.41	0.64	221.0	0.66

APPENDIX A

UNCERTAINTY MODULES – GasPT2 ANALYSIS

APPENDIX A



Uncertainty Block

Block Title: **AGA8 Line Density**
Module Title: **GasPT Analysis**

Calculation Inputs (shown for information only)

	Value	Uncertainty		
P	30.00	0.122	bar g	The pressure at which the density is calculated
T	15.00	0.334	°C	The temperature at which the density is calculated
$\rho_{std,air}$	1.2254	n/a	kg/m³	Standard density of air
RD	0.70333	0.17	- (%)	Relative density (uncertainty of input in % of value)
CV	40.83	0.33	MJ/Sm³ (%)	Superior calorific value (uncertainty of input in % of value)
U(EOS)		0.10	%	Uncertainty in equation of state. Consult relevant standard.

Density calculation

SGERG / AGA8:1994 Gross Meth ▼

SGERG Option 1 ref conditions

15oC, 15oC, 1.01325 bar ▼

Outputs

ρ_l	28.8491	kg/m³	The calculated line (flowing) density
$U(\rho_l)$	0.152	kg/m³	The combined expanded **absolute** uncertainty in line (flowing) density
$U^*(\rho_l)$	0.53	%	The combined expanded **relative** uncertainty in line (flowing) density

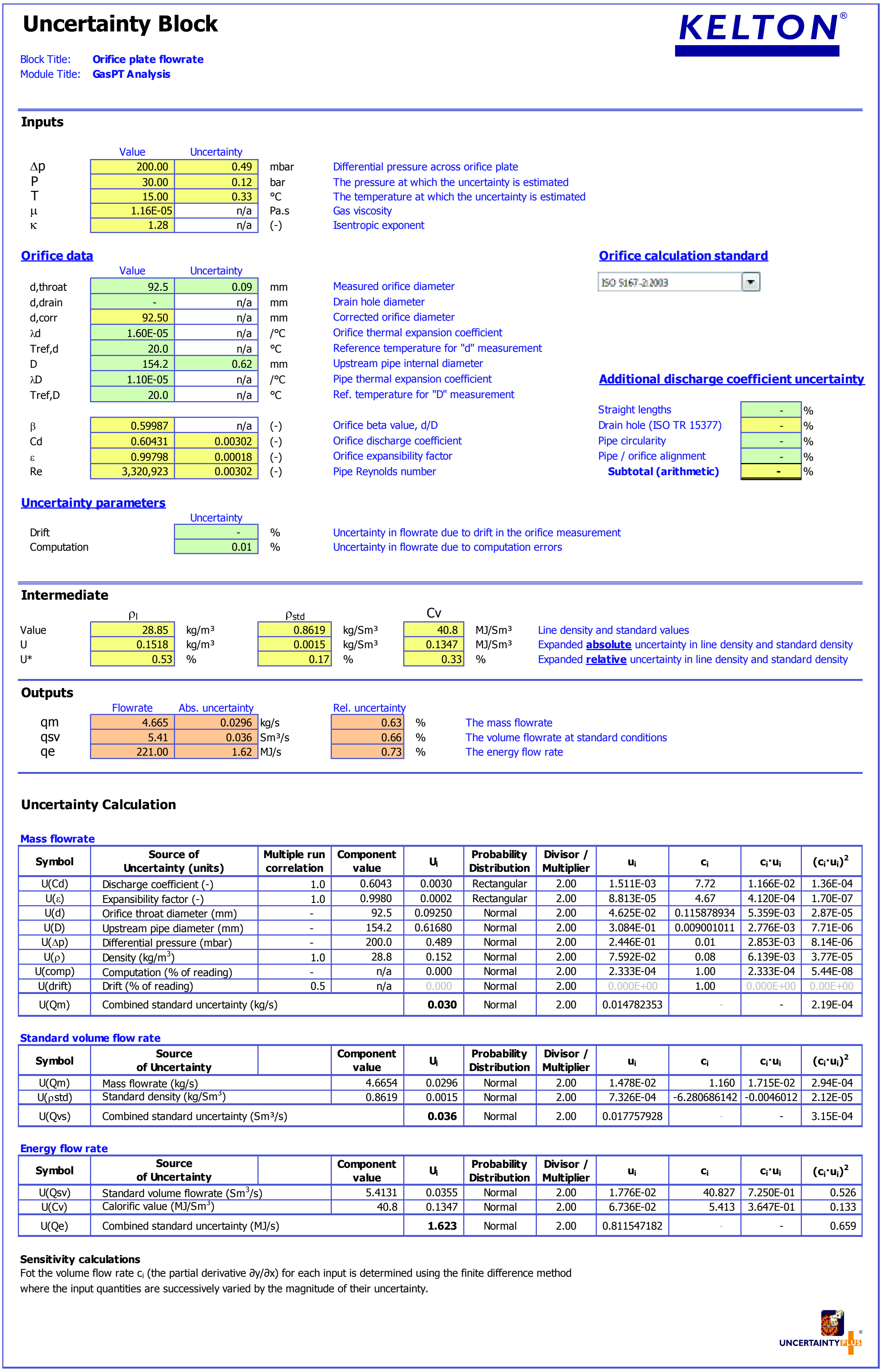
Uncertainty Calculation

Symbol	Source of Uncertainty	Component value	Uncertainty	Probability Distribution	Divisor / Multiplier	u_i	c_i	$c_i \cdot u_i$	$(c_i \cdot u_i)^2$
N2	Nitrogen (mol %)	6.010	-	Normal	2.00	0.000E+00	0.000E+00	-	-
CO2	Carbon Dioxide (mol %)	2.000	0.110	Normal	2.00	5.500E-02	3.526E-01	0.019	0.000
C1	Methane (mol %)	78.200	-	Normal	2.00	0.000E+00	0.000E+00	-	-
C2	Ethane (mol %)	7.930	-	Normal	2.00	0.000E+00	0.000E+00	-	-
C3	Propane (mol %)	5.010	-	Normal	2.00	0.000E+00	0.000E+00	-	-
nC4	nButane (mol %)	0.010	-	Normal	2.00	0.000E+00	0.000E+00	-	-
iC4	iButane (mol %)	0.300	-	Normal	2.00	0.000E+00	0.000E+00	-	-
nC5	nPentane (mol %)	0.100	-	Normal	2.00	0.000E+00	0.000E+00	-	-
iC5	iPentane (mol %)	0.050	-	Normal	2.00	0.000E+00	0.000E+00	-	-
neoC5	neoPentane (mol %)	0.050	-	Normal	2.00	0.000E+00	0.000E+00	-	-
nC6	nHexane (mol %)	0.340	-	Normal	2.00	0.000E+00	0.000E+00	-	-
nC7	nHeptane (mol %)	-	-	Normal	2.00	0.000E+00	0.000E+00	-	-
nC8	nOctane (mol %)	-	-	Normal	2.00	0.000E+00	0.000E+00	-	-
nC9	nNonane (mol %)	-	-	Normal	2.00	0.000E+00	0.000E+00	-	-
nC10	nDecane (mol %)	-	-	Normal	2.00	0.000E+00	0.000E+00	-	-
H2	Hydrogen (mol %)	-	-	Normal	2.00	0.000E+00	0.000E+00	-	-
H2O	Water (mol %)	-	-	Normal	2.00	0.000E+00	0.000E+00	-	-
H2S	Hydrogen sulphide (mol %)	-	-	Normal	2.00	0.000E+00	0.000E+00	-	-
He	Helium (mol %)	-	-	Normal	2.00	0.000E+00	0.000E+00	-	-
Ar	Argon (mol %)	-	-	Normal	2.00	0.000E+00	0.000E+00	-	-
CO	Carbon Monozide (mol %)	-	-	Normal	2.00	0.000E+00	0.000E+00	-	-
O2	Oxygen (mol %)	-	-	Normal	2.00	0.000E+00	0.000E+00	-	-
P	Line pressure (barg)	30.000	0.122	Normal	2.00	6.105E-02	1.021E+00	0.062	0.004
T	Line temperature (°C)	15.000	0.334	Normal	2.00	1.669E-01	-1.363E-01	- 0.023	0.001
RD	Relative density factor (-)	1.000	0.002	Normal	2.00	8.500E-04	3.165E+01	0.027	0.001
CV	Calorific value factor (-)	1.000	0.003	Normal	2.00	1.650E-03	4.525E+00	0.007	0.000
	Equation of state (kg/m³)		0.029	Normal	2.00	1.442E-02	1.000E+00	0.014	0.000
U(ρ)	Combined standard uncertainty (kg/m³)		**0.152**	Normal	2.00	0.075922289	-	-	0.006

Sensitivity calculation

c_i (the partial derivative ∂y/∂x) for each input is determined using the finite difference method where the input quantities are successively varied by the magnitude of their uncertainty

APPENDIX A



Uncertainty Block

KELTON®

Block Title: **Orifice plate flowrate**
Module Title: **GasPT Analysis**

Inputs

	Value	Uncertainty		
Δp	200.00	0.49	mbar	Differential pressure across orifice plate
P	30.00	0.12	bar	The pressure at which the uncertainty is estimated
T	15.00	0.33	°C	The temperature at which the uncertainty is estimated
μ	1.16E-05	n/a	Pa.s	Gas viscosity
κ	1.28	n/a	(-)	Isentropic exponent

Orifice data

	Value	Uncertainty		
d,throat	92.5	0.09	mm	Measured orifice diameter
d,drain	-	n/a	mm	Drain hole diameter
d,corr	92.50	n/a	mm	Corrected orifice diameter
λd	1.60E-05	n/a	/°C	Orifice thermal expansion coefficient
Tref,d	20.0	n/a	°C	Reference temperature for "d" measurement
D	154.2	0.62	mm	Upstream pipe internal diameter
λD	1.10E-05	n/a	/°C	Pipe thermal expansion coefficient
Tref,D	20.0	n/a	°C	Ref. temperature for "D" measurement
β	0.59987	n/a	(-)	Orifice beta value, d/D
Cd	0.60431	0.00302	(-)	Orifice discharge coefficient
ε	0.99798	0.00018	(-)	Orifice expansibility factor
Re	3,320,923	0.00302	(-)	Pipe Reynolds number

Orifice calculation standard

ISO 5167-2:2003 ▾

Additional discharge coefficient uncertainty

Straight lengths	-	%
Drain hole (ISO TR 15377)	-	%
Pipe circularity	-	%
Pipe / orifice alignment	-	%
Subtotal (arithmetic)	**-**	%

Uncertainty parameters

	Uncertainty		
Drift	-	%	Uncertainty in flowrate due to drift in the orifice measurement
Computation	0.01	%	Uncertainty in flowrate due to computation errors

Intermediate

	ρ_l		ρ_{std}		Cv		
Value	28.85	kg/m³	0.8619	kg/Sm³	40.8	MJ/Sm³	Line density and standard values
U	0.1518	kg/m³	0.0015	kg/Sm³	0.1347	MJ/Sm³	Expanded **absolute** uncertainty in line density and standard density
U*	0.53	%	0.17	%	0.33	%	Expanded **relative** uncertainty in line density and standard density

Outputs

	Flowrate	Abs. uncertainty		Rel. uncertainty		
qm	4.665	0.0296	kg/s	0.63	%	The mass flowrate
qsv	5.41	0.036	Sm³/s	0.66	%	The volume flowrate at standard conditions
qe	221.00	1.62	MJ/s	0.73	%	The energy flow rate

Uncertainty Calculation

Mass flowrate

Symbol	Source of Uncertainty (units)	Multiple run correlation	Component value	U_i	Probability Distribution	Divisor / Multiplier	u_i	c_i	$c_i \cdot u_i$	$(c_i \cdot u_i)^2$
U(Cd)	Discharge coefficient (-)	1.0	0.6043	0.0030	Rectangular	2.00	1.511E-03	7.72	1.166E-02	1.36E-04
U(ε)	Expansibility factor (-)	1.0	0.9980	0.0002	Rectangular	2.00	8.813E-05	4.67	4.120E-04	1.70E-07
U(d)	Orifice throat diameter (mm)	-	92.5	0.09250	Normal	2.00	4.625E-02	0.115878934	5.359E-03	2.87E-05
U(D)	Upstream pipe diameter (mm)	-	154.2	0.61680	Normal	2.00	3.084E-01	0.009001011	2.776E-03	7.71E-06
U(Δp)	Differential pressure (mbar)	-	200.0	0.489	Normal	2.00	2.446E-01	0.01	2.853E-03	8.14E-06
U(ρ)	Density (kg/m³)	1.0	28.8	0.152	Normal	2.00	7.592E-02	0.08	6.139E-03	3.77E-05
U(comp)	Computation (% of reading)	-	n/a	0.000	Normal	2.00	2.333E-04	1.00	2.333E-04	5.44E-08
U(drift)	Drift (% of reading)	0.5	n/a	0.000	Normal	2.00	0.000E+00	1.00	0.000E+00	0.00E+00
U(Qm)	Combined standard uncertainty (kg/s)			**0.030**	Normal	2.00	0.014782353	-	-	2.19E-04

Standard volume flow rate

Symbol	Source of Uncertainty		Component value	U_i	Probability Distribution	Divisor / Multiplier	u_i	c_i	$c_i \cdot u_i$	$(c_i \cdot u_i)^2$
U(Qm)	Mass flowrate (kg/s)		4.6654	0.0296	Normal	2.00	1.478E-02	1.160	1.715E-02	2.94E-04
U(ρstd)	Standard density (kg/Sm³)		0.8619	0.0015	Normal	2.00	7.326E-04	-6.280686142	-0.0046012	2.12E-05
U(Qvs)	Combined standard uncertainty (Sm³/s)			**0.036**	Normal	2.00	0.017757928	-	-	3.15E-04

Energy flow rate

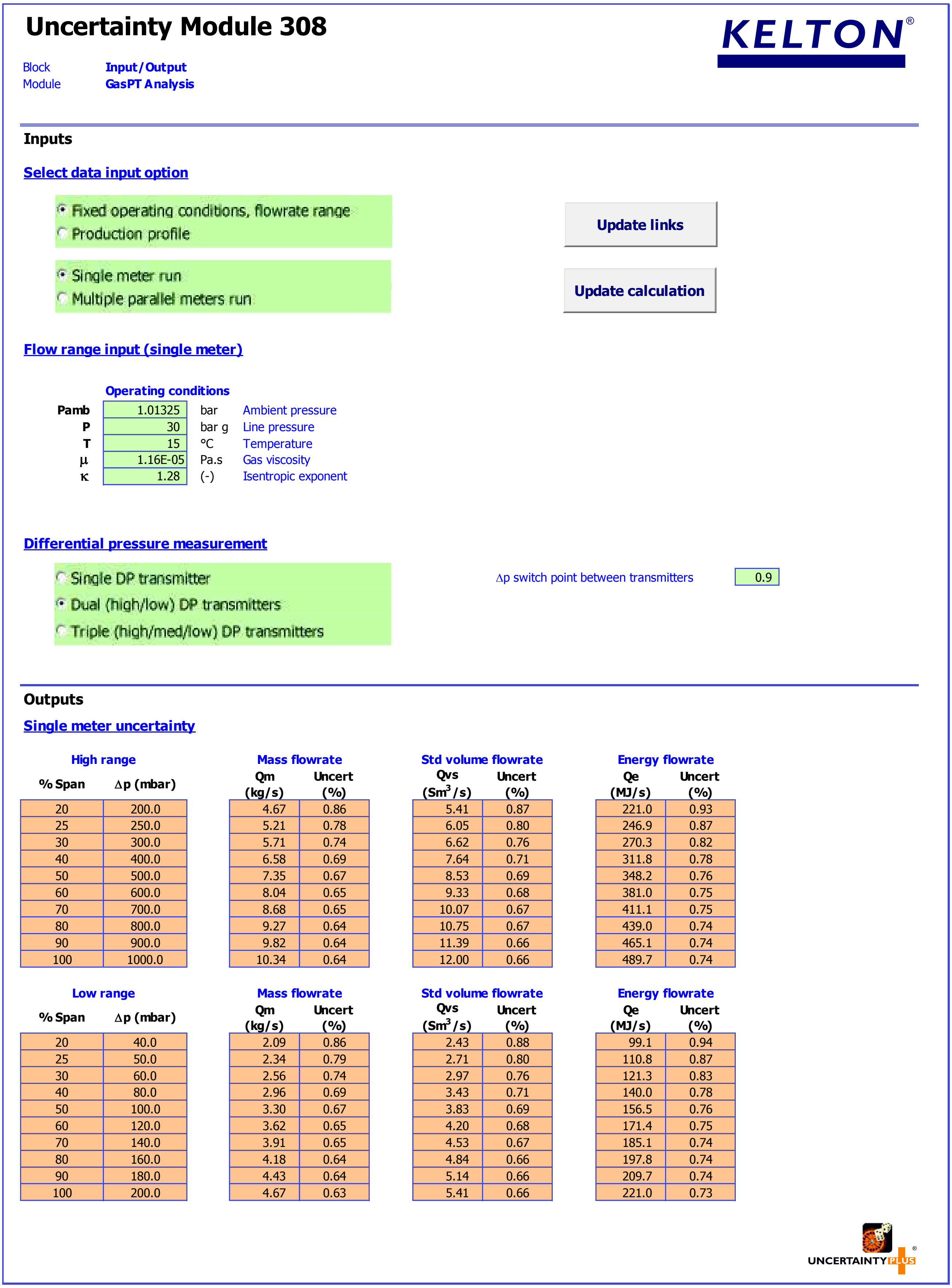
Symbol	Source of Uncertainty		Component value	U_i	Probability Distribution	Divisor / Multiplier	u_i	c_i	$c_i \cdot u_i$	$(c_i \cdot u_i)^2$
U(Qsv)	Standard volume flowrate (Sm³/s)		5.4131	0.0355	Normal	2.00	1.776E-02	40.827	7.250E-01	0.526
U(Cv)	Calorific value (MJ/Sm³)		40.8	0.1347	Normal	2.00	6.736E-02	5.413	3.647E-01	0.133
U(Qe)	Combined standard uncertainty (MJ/s)			**1.623**	Normal	2.00	0.811547182	-	-	0.659

Sensitivity calculations

Fot the volume flow rate c_i (the partial derivative ∂y/∂x) for each input is determined using the finite difference method where the input quantities are successively varied by the magnitude of their uncertainty.

UNCERTAINTY PLUS®

APPENDIX A



Uncertainty Module 308

Block	**Input/Output**
Module	**GasPT Analysis**

Inputs

Select data input option

● Fixed operating conditions, flowrate range
○ Production profile

● Single meter run
○ Multiple parallel meters run

Flow range input (single meter)

Operating conditions

Pamb	1.01325	bar	Ambient pressure
P	30	bar g	Line pressure
T	15	°C	Temperature
μ	1.16E-05	Pa.s	Gas viscosity
κ	1.28	(-)	Isentropic exponent

Differential pressure measurement

○ Single DP transmitter
● Dual (high/low) DP transmitters
○ Triple (high/med/low) DP transmitters

Δp switch point between transmitters 0.9

Outputs

Single meter uncertainty

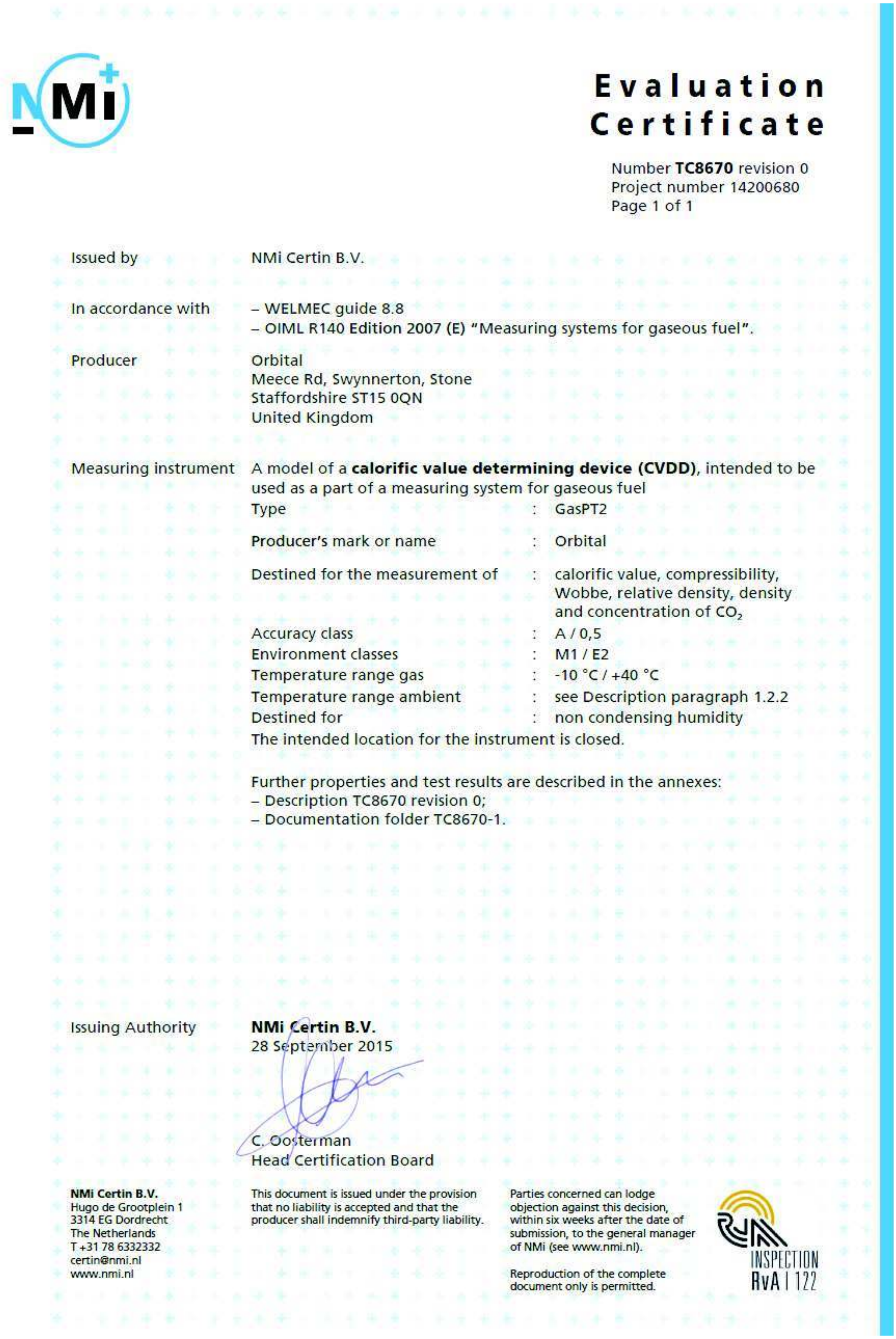
High range		**Mass flowrate**		**Std volume flowrate**		**Energy flowrate**	
% Span	**Δp (mbar)**	**Qm (kg/s)**	**Uncert (%)**	**Qvs (Sm^3/s)**	**Uncert (%)**	**Qe (MJ/s)**	**Uncert (%)**
20	200.0	4.67	0.86	5.41	0.87	221.0	0.93
25	250.0	5.21	0.78	6.05	0.80	246.9	0.87
30	300.0	5.71	0.74	6.62	0.76	270.3	0.82
40	400.0	6.58	0.69	7.64	0.71	311.8	0.78
50	500.0	7.35	0.67	8.53	0.69	348.2	0.76
60	600.0	8.04	0.65	9.33	0.68	381.0	0.75
70	700.0	8.68	0.65	10.07	0.67	411.1	0.75
80	800.0	9.27	0.64	10.75	0.67	439.0	0.74
90	900.0	9.82	0.64	11.39	0.66	465.1	0.74
100	1000.0	10.34	0.64	12.00	0.66	489.7	0.74

Low range		**Mass flowrate**		**Std volume flowrate**		**Energy flowrate**	
% Span	**Δp (mbar)**	**Qm (kg/s)**	**Uncert (%)**	**Qvs (Sm^3/s)**	**Uncert (%)**	**Qe (MJ/s)**	**Uncert (%)**
20	40.0	2.09	0.86	2.43	0.88	99.1	0.94
25	50.0	2.34	0.79	2.71	0.80	110.8	0.87
30	60.0	2.56	0.74	2.97	0.76	121.3	0.83
40	80.0	2.96	0.69	3.43	0.71	140.0	0.78
50	100.0	3.30	0.67	3.83	0.69	156.5	0.76
60	120.0	3.62	0.65	4.20	0.68	171.4	0.75
70	140.0	3.91	0.65	4.53	0.67	185.1	0.74
80	160.0	4.18	0.64	4.84	0.66	197.8	0.74
90	180.0	4.43	0.64	5.14	0.66	209.7	0.74
100	200.0	4.67	0.63	5.41	0.66	221.0	0.73

APPENDIX B

GASPT2 EVALUATION CERTIFICATE

APPENDIX B



Evaluation Certificate

Number **TC8670** revision 0
Project number 14200680
Page 1 of 1

Issued by: NMi Certin B.V.

In accordance with:
- WELMEC guide 8.8
- OIML R140 Edition 2007 (E) "Measuring systems for gaseous fuel".

Producer:
Orbital
Meece Rd, Swynnerton, Stone
Staffordshire ST15 0QN
United Kingdom

Measuring instrument: A model of a **calorific value determining device (CVDD)**, intended to be used as a part of a measuring system for gaseous fuel

Type : GasPT2

Producer's mark or name : Orbital

Destined for the measurement of : calorific value, compressibility, Wobbe, relative density, density and concentration of CO_2

Accuracy class : A / 0,5
Environment classes : M1 / E2
Temperature range gas : -10 °C / +40 °C
Temperature range ambient : see Description paragraph 1.2.2
Destined for : non condensing humidity
The intended location for the instrument is closed.

Further properties and test results are described in the annexes:
- Description TC8670 revision 0;
- Documentation folder TC8670-1.

Issuing Authority: **NMi Certin B.V.**
28 September 2015

C. Oosterman
Head Certification Board

NMi Certin B.V.
Hugo de Grootplein 1
3314 EG Dordrecht
The Netherlands
T +31 78 6332332
certin@nmi.nl
www.nmi.nl

This document is issued under the provision that no liability is accepted and that the producer shall indemnify third-party liability.

Parties concerned can lodge objection against this decision, within six weeks after the date of submission, to the general manager of NMi (see www.nmi.nl).

Reproduction of the complete document only is permitted.

INSPECTION
RvA I 122

Appendix 4

Technical Note to Energy Regulators

GasPT2

Measurement of Natural Gas Quality

A submission to support product approval
on behalf of Orbital Gas Systems, UK

Contents

Technical Note to Energy Regulators

GasPT2 - Measurement of Natural Gas Quality

Submission to support product approval on behalf of Orbital Gas Systems, UK

Introduction

The purpose of this note is to demonstrate how GasPT2, an inferential gas properties transmitter, can meet international standards in the measurement of the quality of natural gas.

Worldwide, the expanding market for natural gas is generating the need for improved monitoring and energy accounting, as natural gas is traded across international boundaries through pipeline interconnectors or shipped liquefied natural gas (LNG) before delivery to new customers. Increased international trading and new unconventional gas sources (shale gas, biomethane) are resulting in downstream users seeing greater variation in natural gas quality. This has triggered the development of the GasPT2 which provides gas quality information in real time, so that control and fiscal metering of natural gas can be performed to a level previously unachievable.

Although it is not a gas chromatograph (GC), and does not work in the same way as a GC, the GasPT2 instrument provides fast and accurate information on the key physical properties of natural gas such as calorific value (CV), relative density (RD) and Wobbe Index (WI).

GasPT2 was originally designed by British Gas R&D (UK) and it is now licensed from DNV GL worldwide and exclusively to Orbital Gas Systems Ltd. In addition, a unique gas sampling and gas conditioning system has been developed and integrated with the GasPT2 instrument to give accurate and rapid gas quality monitoring (named GasPTi). The advantages of GasPT2 over GC's in speed of response, near-zero maintenance and cost are leading to a wide application of GasPT2 across the production, supply and end-use of natural gas with an overall improvement in energy accounting.

An international network of distributors for GasPT2 has been organised in order to provide knowledgeable and immediate local support to customers worldwide.

This note provides a description of how the GasPT2 instrument operates and details the international regulatory approvals and safety certification gained to date, together with some examples demonstrating the range of applications of the GasPTi system worldwide.

At Orbital Gas Systems we believe the information provided in our note gives a compelling argument for the approval of GasPT2 for both process control and fiscal metering applications as it has met the international standards all our current customers have requested. We would be very pleased to provide a GasPT2 system complete with gas conditioning for further testing either in the laboratory or in the field, as required by government agencies.

Description of Operation

The GasPT2 employs the concept of the “effective composition.” This is the idea that a gas composed of hydrocarbons, nitrogen and carbon dioxide can be represented by a simpler gas mixture employing fewer hydrocarbons. GasPT2 uses correlative techniques to infer an equivalent five-component gas mixture (methane, ethane, propane and nitrogen plus direct measurement of carbon dioxide). All of the hydrocarbons (including C4+) are resolved into the three “effective” hydrocarbons by using a simple process that balances the hydrogen and carbon atoms. The physical measurements made by GasPT2 are speed of sound, thermal conductivity and carbon dioxide. The speed of sound measurement is made via use of a unique acoustic resonator and speed of sound has a good correlation with relative density. Thermal conductivity is measured at ambient and an elevated temperatures with good correlation to calorific value.

Carbon dioxide is measured by an NDIR sensor and this is done because the molecular weights of carbon dioxide (CO_2) and propane (C_3H_8) are equivalent. In an earlier version of the instrument, this equivalency required additional calibration to suit an expected set of gas compositions. GasPT2 now has CO_2 measurement, thereby improving its accuracy and giving the widest application to all natural gases without customised calibration.

From the inferred effective gas mixture of methane, ethane, propane, nitrogen, and measured carbon dioxide, the GasPT2 uses ISO 6976 to calculate the gas quality characteristics of calorific value (CV), relative density (RD), Wobbe index (WI), compression factor (Z), motor octane number (MON) and methane number (MN).

The instrument does not provide a full compositional analysis of the gas sample, as a gas chromatograph would; however, test results show the GasPT2 measurements of CV and Wobbe are better than ±0.5% error (OIML R140 Class A instrument).

See Appendix A for a description of the GasPT2 components.

See Appendix B: GasPT2 Specification for details on operational range and performance.

Certification

GasPT2 has been certificated by Baseefa, the UK approvals service, as flameproof equipment suitable for safe use in Zone 1 and Zone 2 hazardous areas.

Certification has been gained demonstrating compliance with ATEX, IECEx and CSA regulations.

The ATEX Directive requires certified products to be marked with the CE mark (confirms compliance with mandatory European Commission Electro Mechanical Compatibility regulations and the Low Voltage Directive for equipment containing mains voltages). GasPT2 has all these approvals and is marked accordingly with ATEX, CE, IECEx and CSA marks.

The CE mark for GasPT2 is CE 1180 which represents Baseefa as our notified approvals body.

GasPT2 Safety Interface

10 ATEX 0157 Ex II(1)G [Ex ia Ga] IIB (-20°C ≤ Ta ≤+50°C)
EN 60079-0 : 2009 EN 60079-11: 2007
IECEx BAS 10.0084 Ex ia Ga IIB (-20°C ≤ Ta ≤+50°C)
IEC 60079-0:2004 Ed 4.0 IEC 60079-0:2007-10 Ed 5 IEC 60079-11:2006 Ed 5
CSA Certificate No. 2429362 Ex ia Ga Iib

GasPT2 MU Probe

10 ATEX 0176 Ex II(2)G [Ex d ia Gb] IIB T4 (-20°C ≤ Ta ≤+55°C)
EN 60079-0 : 2009 EN 60079-1 : 2007EN 60079-11:2007
IECEx BAS 09.0093 Ex d ia IIB T4 Gb (-20°C ≤ Ta ≤+50°C)
IEC 60079-0:2004 Ed 4.0 IEC 60079-0:2007-10 Ed 5 IEC 60079-1:2007-04 Ed 6
IEC 60079-11:2006 Ed 5
CSA Certificate No. 2429362 Ex d IIb T4 Gb

GasPT2 AU Probe

02 ATEX 0139X Eex ia IIB T4 (-40°C ≤ Ta ≤+70°C)
EN 50014:1997 Am1/2 EN 50020:2002 EN50284:1999
IECEx BAS 12.0008X Ex ia IIB T4 Gb (-40°C ≤ Ta ≤+70°C)
IEC 60079-0:2004 Ed 4.0 IEC 60079-0:2007-10 Ed 5 IEC 60079-1:2007-04 Ed 6
IEC 60079-11:2006 Ed 5
CSA Certificate No. 2429362 EX ia IIb

American Bureau of Shipping: ABS approval has been gained for GasPT2 applications aboard LNG tankers. Certificate No. 13-LD1105876-PDA

Copies of certificates are shown in Appendix C: GasPT2 Certificates.

Baseefa, ATEX, IECEx and CSA test reports can be provided if required.

An independent laboratory report confirming satisfactory electromagnetic compatibility (EMC) with tolerance to cable and air-borne interference can also be provided if required

Countries with GasPT2 Installations

Europe: UK, Eire, France, Belgium, Netherlands, Denmark, Germany, Poland, Italy, Spain, Portugal, Turkey

Americas: USA, Canada, Columbia, Chile, Mexico

Far East: Thailand, S. Korea, Japan, China

Types of Application

There is a wide range of diverse applications where GasPT2 systems have been installed, reflecting the many benefits of GasPT2 over conventional technology in rapid response, accuracy, cost and low maintenance.

Gas Transmission Networks

National Grid	UK
Snam Retegas	Italy
Fluxys	Belgium
PTT	Thailand
Alliance Pipelines	USA
Xcel	USA

Applications: Control of mixing and blending gas streams to obtain required gas specifications for transmission pipeline gas. Fuel gas Fiscal Metering and Custody transfer between networks.

Gas Distribution Networks

GdF Suez	France
SoCal Sempra	USA
Shizuoka Gas	Japan
NGD	UK
W&W	UK
NGN	UK
SGN	UK

Applications: Custody transfer and fiscal metering on grid off-takes to gas distribution networks or large commercial and industrial customers. Fast Gas Quality control for gas supply to networks.

Gas Production and Process Plant

BP	UK
Perenco	UK
Air Products	UK

Applications: Monitor the export gas CV and Wobbe from gas production plants prior to injection into the high pressure gas transmission grid.

OEM Instrumentation

Emerson Daniels	USA
Hydrafact	Germany
Flonidan	Denmark
Vestas Controls	Denmark
Amlorit	UK
4C Measurement	UK
Anatrol	UK

Applications: GasPT2 used in parallel backup operation to gas chromatographs to record CV and Wobbe if GC fails and monitor peaks in CV which cannot be recorded by GCs because of slower response time.

Glass Production

Pilkington	UK
Owens Corning	UK
PPG	China
Santos Barosa	Portugal

Applications: Control combustion air/fuel ratio in response to changing gas supply quality to ensure consistent burner flame shape and temperature on glass production process.

Steel Manufacture and Metal Heating

Corus	UK
PPG	China

Applications: Control air/fuel ratio on large industrial burners for metal reheating furnaces on steel production process.

Industrial Research

NationalInstitute AIST	Japan
Applied Technology	Japan

Applications: Study combustion control in response to gas quality variations.

Gas Turbines

GE Power & Water	Italy
IHI Corporation	Japan
KBK Chitose Airport	Japan
Mitsubishi Power	Japan
EoN	Netherlands
AFC Energy	UK

Applications: Fast reporting of gas quality variation and adjustment of multiple fuel injection points on large gas turbines.

Combined Heat & Power Gas Engines

Yanmar	Japan
Niigata Power	Japan
Rapid Flame	UK

Applications: Control ignition timing on large CHP gas engines where ignition requirements will vary with gas quality.

LNG Importation Terminals

Tokyo Gas	Japan
Osaka Gas	Japan
POSCO	S. Korea
Shell	UK
South Hook	UK
National Grid IOG	UK
Dragon LNG	UK

Applications: Monitor CV and Wobbe of boil-off gas from LNG tanks and to control CV and Wobbe of terminal export gas into the medium pressure distribution network.

Marine LNG Tanker Transportation

CNOOC	China

Applications: Monitor CV of boil-off gas from ship LNG tanks and control of gas Wobbe prior to supply to ship power generation system. This is a very harsh environment where GCs are unable to be installed. American Bureau of Shipping ABS approval was gained for these applications (see Appendix C).

Bio-Methane Production

National Grid	UK
SGN	UK
NGN	UK
W&W	UK
Severn Trent	UK
GTS	NL

Applications: Monitor and control export gas quality from Biomethane to grid production plants, LPG enrichment, CV and Wobbe.

Gas Compressors

Dominion	USA
Centrica	UK

Applications: Monitor CV and calculate molar mass for compressor control on high pressure gas transmission pipelines.

Key Benefits

Fast Scan and Response Time:

- GasPTi response time T90 from the sample point to the analysis output is approximately 10 seconds (T90 is 90% of final value in response to a step change).
- The GasPT2 scan time can be as fast as one reading every 2 seconds and this compares typically with more than 5 minutes for the Gas Chromatograph.

The impact of this is significant in terms of energy accounting on gas transmission systems. Flow measurement is instantaneous but GCs are generally measuring CV of gas which, over 5 minutes, has travelled considerable distance down the pipeline. Therefore, energy metering has traditionally mismatched flow and CV measurement. This may not have been an issue when energy sources and CV were generally stable but as gas quality variations increase, speed of measurement to ensure accurate energy accounting becomes more important. The delayed CV measurement from GCs may also result in errors in the calculation of compressibility (z) and speed of sound for ultrasonic meter calibration.

The speed of response is also critical for process control applications where product quality can be affected by variations in gas heating value. Typical examples are float glass, glass bottle and glass fibre production, ceramics and metal heating plants where flame shape and flame temperature will change with gas quality variations.

Low/zero maintenance:

- Typically GasPT2 undergoes one validation check with a known sample gas taking less than one hour every year. This compares with the considerable effort required to keep a GC in calibration with skilled labour (works chemist) and use of carrier gases and reference gases.

Easy to Install, Configure and Use:

- Typically GasPT2 systems are installed and configured in about one hour. All communications and operational parameters can be changed on line via laptop PC and setup is very simple. The communications with modems, supervisory computers and datalogging systems is via RS485 serial interface using the international industry standard MODBUS protocol. Ethernet or analogue I/O signals can be provided.

Integrated System with Sample Probe and Gas Conditioning Enclosure:

- GasPTi-F (integrated with Fixed VE sample probe) is mounted directly on the pipeline. A unique vortex eliminating sample probe is provided which gives fast response, small sample and zero probe vibration. This can be seen as having operational, environmental and safety benefits over traditional GC installations.
- There is no requirement for gas sample lines, additional housings or gas cylinder storage as with GCs. This eliminates the need for civil engineering works (foundations for housings) and means the amount of gas flowing through GasPT2 and vented is typically 10 to 20 times less than a GC system.

Low cost:

- Initial purchase cost and installation cost of GasPT2 are considerably less than GCs and in addition, the overall lifetime cost of ownership is further reduced by the GasPT2 advantages over GCs in significantly lower operational and maintenance costs.

See Appendix D: Cost of Ownership

Laboratory Tests and Field Trials

GasPT2 has undergone numerous laboratory tests and field trials across the world as gas transmission companies and government regulatory authorities prove the performance of our instrument. All tests have produced results of better than +/- 0.5% over the range of gases requested.

Country	**Gas Company**	**Tested by**
Canada	TransCanada	NovaChem
Columbia	TGI	CDT de Gas
France	GRTgaz	Engie R&D
Italy	Snam Retegas	Nmi
Mexico	Tejas Gas	Fermaca
Netherlands	Gasunie	Kema
Poland	GazSystem	Polish Oil & Gas Institute
Spain	Enagas	Enagas
Spain	Repsol	Repsol
Thailand	PTT	PTT
UK	National Grid	SGS
USA	Pipeline Research Council PRCI	Colorado State University
USA	Energy Transfer Partners	Energy Transfer Partners
USA	GE Gas Turbines	GE Gas Turbines
Future Testing		
Czech Republic	Net4Gas	
Germany	EON	
Turkey	IGDAS	

Reports for each test are available upon request.

Regulatory Approvals

Europe

Within the European Union, the Directives of the European Commission generally take precedence over national legislation and regulations. The existence of a Directive on Gas Quality Measurement would therefore set the standard for GasPT2 performance testing and approvals.

The Measuring Instruments Directive (MID) 2004/22/EC includes gas metering (volume) accuracy requirements but does not include gas quality measuring accuracy.

The European Commission required the specification of a set of standards on Gas Quality in order to create a competitive single European gas market according to the Directive 2003/55/EC. The technical group CEN were given a mandate (M/400 EN) to create a common standard for European gas quality but this has focused on Wobbe and CV high and low limits and it does not define the accuracy of measurement for either parameter.

So, in the absence of a European standard, most European countries are using the recommendations of the International Organisation of Legal Metrology (OIML).

This is text from OIML R 140: 2007 (E) Measuring Systems for Gaseous Fuel prepared by the OIML Technical Subcommittee TC 8/SC 7 *Gas metering* 2007

Section 8.8.1 Types of calorific value determining devices (CVDD):

“The calorific value of natural gas can be determined using different techniques which fall into the following categories:

- *Direct measurement, i.e. direct combustion, catalytic combustion,*
- *Indirect measurement, i.e. stoichiometric combustion,*
- *Inferential determination, i.e. correlation with other measured properties, composition based calculation.”*

This section demonstrates that inferential techniques such as GasPT2 are acceptable to OIML.

Section 7.4.1 Time interval for determination of CV:

“In principle, the energy to be determined should be the sum of the instantaneous energies delivered. However, in practice this is not possible and it is acceptable not to associate the instantaneous calorific value to the instantaneous corresponding volume…”

Until now, it has not been possible to determine instantaneous energy flow but with near real-time CV measurement GasPT2 provides the opportunity to improve overall energy measurement enabling volume, energy and other physical properties to be reported to flow computers within seconds of each other.

Section 6.3.1 Maximum permissible errors (CV Measurement - only CVDD): Table 2:

Class A ± 0.50 %
Class B ± 1.00 %
Class C ± 1.00 %

Comprehensive laboratory tests and field trial results from different countries have shown GasPT2 to be much better than ±0.5%, the requirement for Class A instruments.

North America

International regulatory bodies such as the American Gas Association (AGA) recognize inferential techniques as a valid alternative to gas chromatograph analysis for heating value measurement in relation to gas custody transfer.

This is the text from AGA Report No.5: Natural Gas Energy Measurement:
Prepared by the Transmission Measurement Committee March 2009:

Section 5.3: Heating Value from Inferential (Correlative) Methods

"Inferential methods can provide cost savings over the traditional gas chromatograph installation and near real-time gas property determination at locations where spot or composite sample analyses are traditionally used…..Although this (inferential method) is a relatively new technology, it is considered to be fundamentally sound and capable of providing accuracies acceptable for custody transfer measurement."

Section 4.1: Uncertainty – Acceptance Criteria

AGA Report No.5 requires that in custody transfer applications the estimated uncertainty including error in heating value determination should be less than ±0.5%.

Conclusions

1. GasPT2 has undergone comprehensive laboratory testing and field trials on gas transmission pipelines to show accuracy of CV and Wobbe measurement better than ±0.5%.

2. GasPT2 meets the performance recommendations of OIML R 140: 2007 (E): Measuring Systems for Gaseous Fuel as a Class A instrument for CV measurement.

3. GasPT2 complies with the performance requirements of AGA Report No.5 Natural Gas Energy Measurement for CV determination.

4. Both OIML R140: 2007 (E) and AGA Report No.5 specifically state that inferential techniques *(such as GasPT2)* are capable of providing accurate CV measurement and as such can be considered for use as custody transfer measurement and fiscal metering devices.

5. GasPT2 has safety approval from ATEX, IECEx and CSA for use in hazardous areas (Zone 1 and Zone 2).

6. As a lower cost solution than gas chromatographs to on-line gas quality measurement, GasPT2 can be employed much wider across gas transmission and distribution networks together with end-user application and a resulting improvement in overall network monitoring, control and energy accounting.

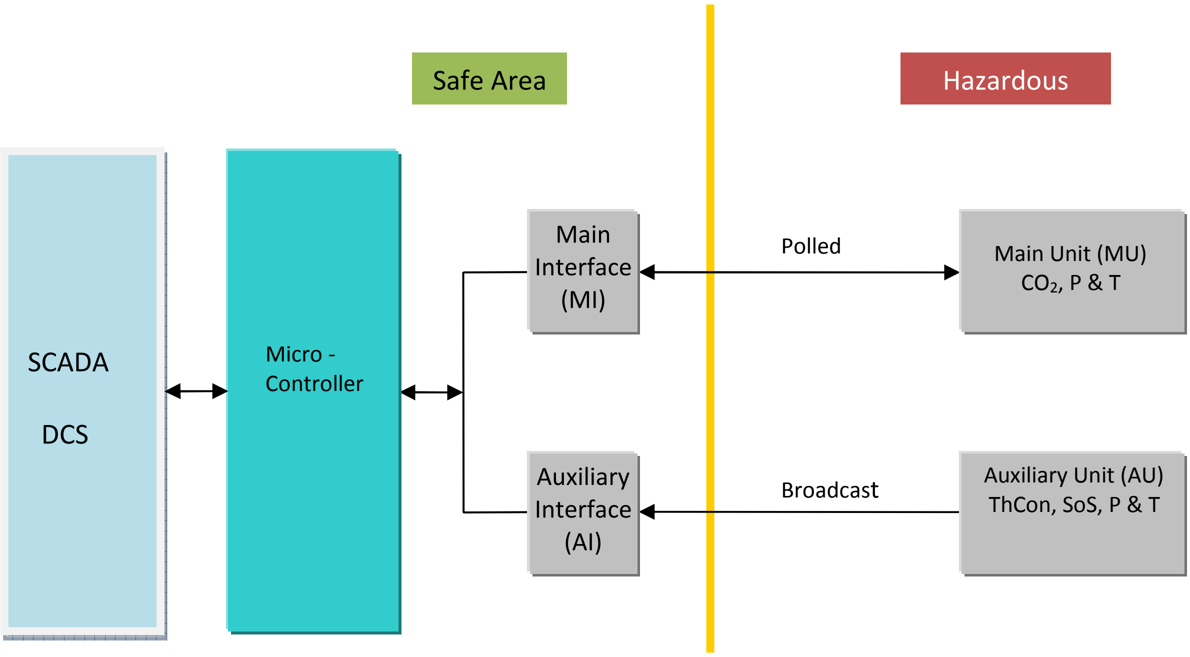
At Orbital Gas Systems Ltd we believe the information provided in our memorandum gives a compelling argument for the approval of GasPT2 for both process control and fiscal metering applications as it has met the international standards all our current customers have requested. We would be very pleased to provide a GasPT2 system complete with gas conditioning for further testing either in the laboratory or in the field, as required by government agencies.

Appendix A: Description of Components

The **Main Unit (MU)** contains the main processor along with sensors for CO_2, temperature and pressure. This is the unit in which the values for the gas properties are calculated and it is the one that communicates with the user via laptop, DCS or SCADA system.

The **Ancillary Unit (AU)** contains speed of sound, thermal conductivity, temperature and pressure sensors. This unit sends information to its associated Main Unit.

Purpose-designed and certificated safety interfaces provide galvanic isolation for the sensor units. The power supply section of the interface uses a transformer as the isolating element and the serial communication signals are opto-isolated. In addition, each interface limits the voltages, currents and power supplied to its sensor unit. By limiting these parameters, the sensor units can be operated in a hazardous area as they do not represent a source of ignition.



The figure above shows the manner in which the various elements of a GasPT2 system relate to each other. The connections between the elements are all two-wire RS485 using a MODBUS® message protocol.

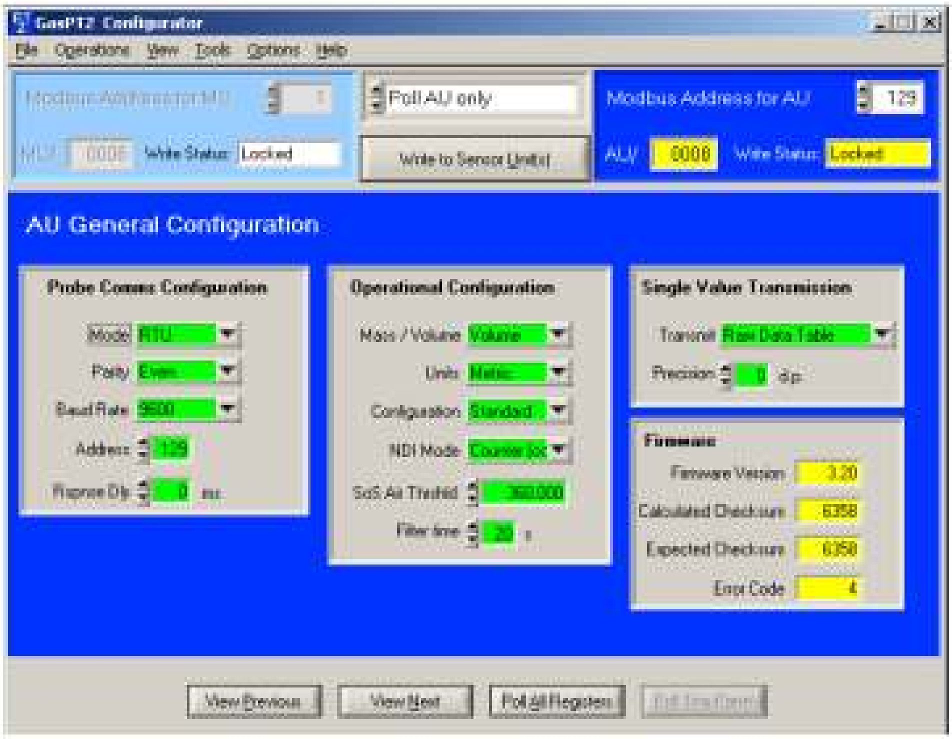
The output from the Microcontroller can be Ethernet (TCP/IP), Serial (RS485 or RS232) or analogue (4-20mA, 1-5Vdc).

GasPT2 is provided with configuration and display software such that setup can be completed within one hour and all parameters can be viewed and recorded as necessary with scan rates down to readings once every two seconds if needed.

Modbus Address for MU: 1
Poll MU only
Modbus Address for AU: 129
MU/ 0008 Write Status: Locked
AU/ 0001 Write Status: Locked

MU Gas Properties

Temperature: 16.60 °C
Pressure (Absolute): 101.87 kPa
Speed of Sound: 419.33 m/s
CO2 Temperature: 16.71 °C
CO2 Pressure: 101.82 kPa
CV (Superior): 41.13 special
CV (Inferior): 37.11 special
Wobbe Index: 52.58 special
Effective Methane: 91.11 %
Effective Ethane: 3.33 %
Effective Propane: 2.42 %
Carbon Dioxide: 0.78 %
Nitrogen: 2.37 %
Relative Density: 0.6119
Density (gas): 0.7913 special
Compressibility: 0.99730
MON: 128.03
Methane Number: 81.59



Modbus Address for MU: 1
Poll AU only
Modbus Address for AU: 129
MU/ 0008 Write Status: Locked
AU/ 0008 Write Status: Locked

AU General Configuration

Probe Comms Configuration

Mode: RTU
Parity: Even
Baud Rate: 9600
Address: 129
Rsponse Dly: 0 ms

Operational Configuration

Mass / Volume: Volume
Units: Metric
Configuration: Standard
NDI Mode: Counter (oc
SoS Air Thrshld: 360.000
Filter time: 20 s

Single Value Transmission

Transmit: Raw Data Table
Precision: 0 d.p.

Firmware

Firmware Version: 3.20
Calculated Checksum: 6358
Expected Checksum: 6358
Error Code: 4

The Microcontroller can be used as a data logging device storing either to permanent memory or to flash card. We have also used the Microcontroller to provide calculate and output parameters such as molar mass, carbon emission factor and specific heat ratio which are not standard GasPT2 outputs.

Appendix B: Specification

Operational Range

Sensor Units

Sample Gas Temperature	- 20 to +55 °C
Humidity	Non-condensing
Max Pressure (absolute)	1300 mbara (300 mbarg) 18.82 psia (4.3 psig)
Sample Gas Flowrate	0.1 l/min to 1.0 l/min 0.21ft3/hr to 2.1 ft3/hr
Hazardous Area Classification	Suitable Zone 1 and Zone 2 Hazardous Areas

Safety Interfaces

Ambient Temperature	-20 to +50 °C
Humidity	Non-condensing
Hazardous Area Classification	Non-hazardous (Safe) Area
Power Requirement	22 Vdc @ 200 mA

Performance

Calorific Value (over normal range)	
- Accuracy	Better than ± 0.5 %
- Repeatability	0.04 MJ/m^3
- Drift	Less than ± 0.1 MJ/m3 per year,
Relative Density	± 0.0016 (< 0.25% Error)
Sample Gas Temperature	± 0.3°C (< 0.54°F)
Sample Gas Pressure	± 2 mbar
Gas property update time	2 to 20 seconds (default 8 seconds)
Gas property averaging time constant	2 to 255 seconds (default 20 seconds)

Appendix C: Certificates of Approval

Available upon request

Please contact:

Orbital Gas Systems Limited
Tel: +44 (0) 1785 857000

Appendix D: Intentionally Blank

……………………………………………….

Appendix E: Example Test Results

Italy (Snam Rete Gas)

	Italy Gas	Algeria Gas	LNG
C1 Methane %	99.4034	86.6349	90.7398
C2 Ethane %	0.0909	7.5175	7.4648
C3 Propane %	0.0297	1.6335	1.0464
C4+ %	0.0389	0.5590	0.1198
CO2 %	0.0415	1.5987	0.0128
N2 %	0.3956	1.9823	0.6164
He %	0.0000	0.0672	0.0000
O2 %	0.0000	0.0069	0.0000
GC Gross CV (MJ/m3)	37.6832	40.0057	40.3253
GasPT22 GrossCV (MJ/m3)	37.6706	40.0204	40.2778
GasPT2 Gross CV Error	**- 0.033%**	**+ 0.037%**	**- 0.118%**

	Russia Gas	Dutch Gas	Calibration Gas
C1 Methane %	97.2081	90.5673	92.6315
C2 Ethane %	1.2683	4.6036	3.4635
C3 Propane %	0.3921	0.9034	0.8465
C4+ %	0.1724	0.3927	0.5303
CO2 %	0.1565	1.3357	0.5428
N2 %	0.7815	2.1705	1.9854
He %	0.0174	0.0225	0.0000
O2 %	0.0037	0.0043	0.0000
GC Gross CV (MJ/m3)	38.1744	38.6543	38.7481
GasPT2 GrossCV (MJ/m3)	38.1865	38.6622	38.6733
GasPT2 Gross CV Error	**+ 0.032%**	**+ 0.020**	**- 0.193%**

Test results from other shippers available upon request, Italy chosen as many different sources and highest variability of gas quality enters their network.