Developing TDLAS Measurement Technologies for Energy Efficient and Responsible Exploitation of Shale Gas

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Introduction

Natural gas is the world's fastest growing fossil fuel, with global consumption expected to increase by 70% over the coming years, from around 4 trillion m^3 in 2014 to around 7 trillion m^3 by 2040. Typically gas processing costs are around 2.3 cents per m^3 which, taken in isolation, doesn't sound like much but when you factor in the huge amounts of gas being used it makes natural gas processing a €91 billion global industry now and potentially a €150 billion plus global industry in the future.

The majority of gas processing costs are related to energy and materials usage, some of which is in terms of natural gas that is consumed to process other natural gas. It follows that anything that can be done to increase the efficiency of natural gas processing has the potential to dramatically reduce energy usage, saving costs and reducing the associated environmental impact. In this article we explain why the emergence of shale gas complicates the issue, and increases the urgency for a solution, and then explain why more accurate measurements can be the key to unlocking process efficiency improvements of as much as 20%.

Background Information

All natural gas contains associated and undesirable impurities, such as water, carbon dioxide, nitrogen, and hydrogen sulphide. Although the composition of raw gas varies widely, the composition of gas delivered to transmission pipelines is tightly controlled. In order for the gas producers to meet gas quality specifications, all natural gas requires some treatment even if all that is done is to remove bulk water. Around 20% of all natural gas feedstock requires extensive, and considerably more expensive, treatment, before it can be delivered to the pipeline.

Changing Demographics

Raw natural gas varies substantially in composition from source to source, methane being the major component, typically comprising 60% to 98% of the total. Additionally, natural gas contains significant amounts of ethane, some propane and butane, and typically 1% to 3% of other heavier hydrocarbons. The table below illustrates a typical natural gas composition from a conventional source, and the likely range of each species.

Component	Typical Analysis (mol %)	Range (mol %)
Methane	94.9	65.0 – 98.0
Ethane	2.5	1.8 – 20.0
Propane	0.2	0.1 – 20.0
Butane	0.06	0.02 – 0.6
Pentane	0.01	trace – 0.18
Hexane plus	0.01	trace – 0.06
Nitrogen	1.6	1.3 – 5.6
Carbon Dioxide	0.7	0.1 – 8.0
Oxygen	0.02	0.01 – 0.1
Hydrogen	trace	trace – 0.02
Hydrogen Sulphide	trace	trace – 5.0

Table 1: Typical Conventional Source Natural Gas Composition

New factors are also coming in to play as increasing inclusion of LNG together with European government driven directives for bio-methane introduction to transmission networks present fresh measurement challenges. The industry in Europe is also starting to see increasing amounts of natural gas from unconventional sources coming into play. This has already happened in the USA, where gas from unconventional sources such as shale gas, or gas extracted by fracking from tight sandstone deposits, already accounts for more than 45% of total production.

Poland is currently leading the way in terms of natural gas production from unconventional sources in Europe, and is expected to have the biggest reserves, and there are many sites in Europe where shale gas exploration is taking place.

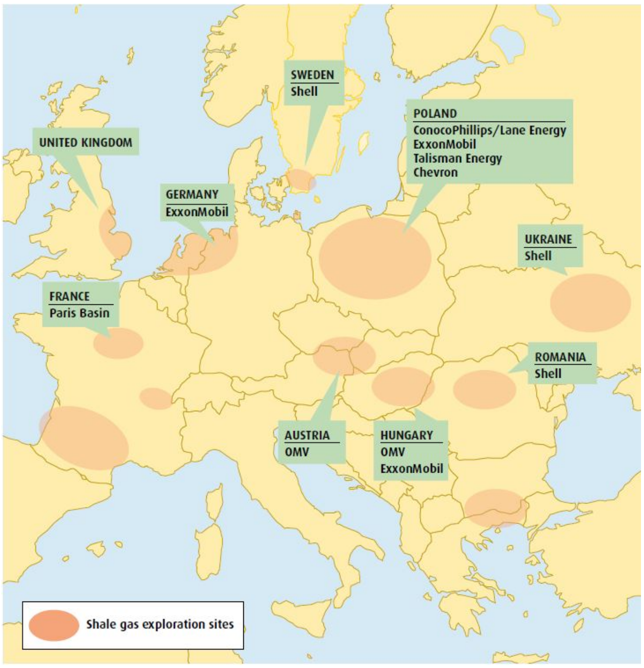

Figure 1: European Unconventional Gas Sources

What is interesting, and will be increasingly significant in natural gas production as time goes by, is that natural gas from unconventional sources has a far greater compositional variance than gas from conventional sources. Whereas conventional gas reserves lie in large subterranean pockets where the gas has had many millennia to homogenise, gas extracted from unconventional sources, particularly shale gas and fractured gas, is comprised of many small pockets of gas, each of which can be very different from its neighbours.

So, all shale gas is not the same in terms of its composition. This means that its processing requirements are also going to vary significantly. It’s worth noting that, as well as being markedly different from site to site, shale gas composition often varies significantly across the field. The exact composition of European natural gas extracted from unconventional sources will depend on the site, but an indication of the possible diversity can be gained by looking at some data from the USA.

	High mol %	Low mol %
CH_4	97.3	27.5
C_2H_6	16.1	0.1
C_3H_8	5.2	0.0
CO_2	30.4	0.0
N_2	65.0	0.1

Figure 2: Range of U.S. Shale Gas Composition

Figure 2 summarises this diversity, showing the range of compositional variation that is currently seen in US shale gas, and providing typical high and low percentage levels for the major constituents. It is clear that some plays are lean, whereas others are rich.

Some also show high levels of nitrogen, approaching 65%. This level is high enough to require treating, but blending with other gas in the area will often be used as the most economical solution. In other fields, typically where gas is predominately biogenic, methane is created as a bi-product of bacterial consumption of organic material in the shale. Significant associated water is produced, requiring central production facilities for dehydration, compression, and disposal. Carbon Dioxide is a naturally occurring by-product of shale gas produced by desorption so can also be present in significant concentration. Indeed, it is expected that the CO_2 levels in produced gas will themselves increase steadily over the productive life of a well, eventually exceeding 30% in some areas.

Efficient gas processing requires precise knowledge about both the dynamic quantity of contaminants present in the gas feedstock and residual in the resulting downstream transmission gas, as this facilitates closed-loop control and process optimisation. We know that shale gas can vary significantly from area to area and dynamically from one point in time to the next; therefore its processing requirements will also be changing. This clearly places new demands on the measurement equipment used by the industry as ideally the analyzers used need to be fast, accurate and immune to interference from background gas compositional variation. It is beyond the scope of this article to consider the implications for all measurements that are important to the efficient processing of natural gas but, as it is usually one of the biggest issues that need to be dealt with, we will illustrate the complexity of the issue by looking in detail at moisture measurement.

Measurement of Moisture Content

It is well known that strict control of moisture concentration is essential for safe and efficient operation of transmission networks, and also that significant commercial factors apply as fixed maximum contractual limits for water dew point are defined at custody transfer points throughout the supply chain. One example in Europe being EASEE Gas, which stipulates that water content must not exceed -8°C dp at 70 bar.

There are many technologies for the measurement of moisture in natural gas, including impedance and capacitive sensors, chilled mirror, quartz crystal micro-balance, and tuneable diode laser spectroscopy (TDLAS). Each measurement technique has its advantages and disadvantages, most of which are widely known. TDLAS is of particular interest and its use in the industry is increasing rapidly, but it is a technology that is not without potential for problems, so an understanding of its strengths and weaknesses is useful.

Although, due to their molecular selectivity, they can be considered immune to contamination effects, TDLAS analyzers can suffer from significant interference in complex mixtures such as natural gas. This is due to interaction with spectra of other species present in the gas composition. Although care will be taken to select the most appropriate wavelength to maximise selectivity, interference usually governs what can be achieved in terms of detection limits and accuracy in natural gas applications. For the majority of TDLAS analyzers interference occurs with methane, ethane, carbon dioxide and hydrogen sulphide – all of which are present in natural gas and all of which will vary significantly in concentration, particularly for shale gases.

To get around the problem some TDLAS analyzers are calibrated specifically for the gas composition on which they will be used. For laboratory use this approach is acceptable however, as has been demonstrated, natural gas composition can vary dramatically, either due to variation in field dynamics or due to blending / mixing during processing or transportation. So, although the specified accuracy of the current generation of field TDLAS analyzers is reasonable - typical claimed accuracy being the larger of +/-4ppm or 2% of measured value - any deviation from the gas composition that was used for calibration will result in measurement errors. These additional errors are not generally included in the manufacturer's performance claims, as those figures are often based on laboratory tests. As a result, real-World errors over the range of compositions that have been presented could become considerable. What's more this situation will be significantly more pronounced for shale gas as the range and frequency of compositional variations seen are going to be substantially larger than would be the case for gas from conventional sources.

Before we look at the measurement confidence limits resulting from these additional error components, it is first worth noting that TDLAS analyzers usually operate at atmospheric pressure. Therefore a calculation needs to be made of the equivalent transmission dew point temperature. The EASEE Gas limit of -8°C dp at 70 bar is equivalent to an atmospheric measurement of approximately 50ppm$_V$. The chart below illustrates the upper and lower confidence levels for the resulting measurement both with and without the real-World effects from compositional variation.

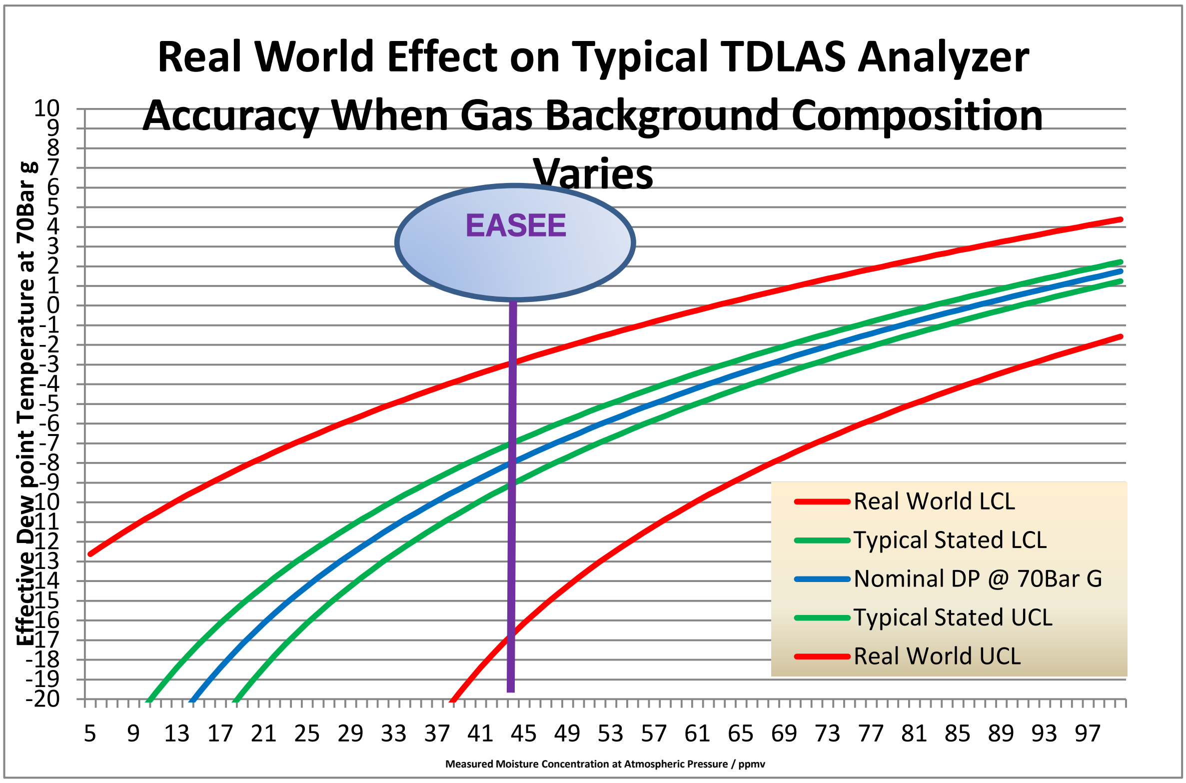

Figure 3: Confidence Limits for stated Accuracy and Real-World Variation

The green lines show the specified performance limits for a typical TDLAS at +/-4ppm, which suggest a confidence band of approximately 2°C dew point. However, if we factor in a 20ppm$_v$ error component, which typically would be seen due to the level of expected shale gas background compositional variation, this band increases dramatically to around 14°C dew point.

This could clearly result in two types of problem: If the analyzer is over reading a higher than representative moisture content then the gas processing will be increased, adding significant and unnecessary gas production costs; if the analyzer is under reading a lower moisture content than is actually truly the case then there is a very serious risk that the processes for moisture removal could be backed-off leading to liquid formation in the downstream transmission pipeline, with associated risk of hydrate formation, pipeline blockage or compressor damage. Although this doesn't affect gas processing costs or efficiency, the costs resulting from hydrate formation are significant and any breach of tariff limits can cause natural gas transmission to be shut-off unnecessarily, and/or fines being imposed on operators.

The Way Forward

With more than 40 years experience as an instrumentation manufacturer serving the natural gas industry, Michell Instruments believe that a holistic approach is needed to solve these challenges. What we believe the industry needs is a reliable and robust new generation TDLAS analyzer with class-leading ±1 ppm$_v$ accuracy that has been designed for Real-World applications and can therefore maintain its class-leading accuracy performance over the full range of compositional variations that can, and will, occur dynamically. The chart below shows some example data which cover the key current and emerging gas quality requirements.

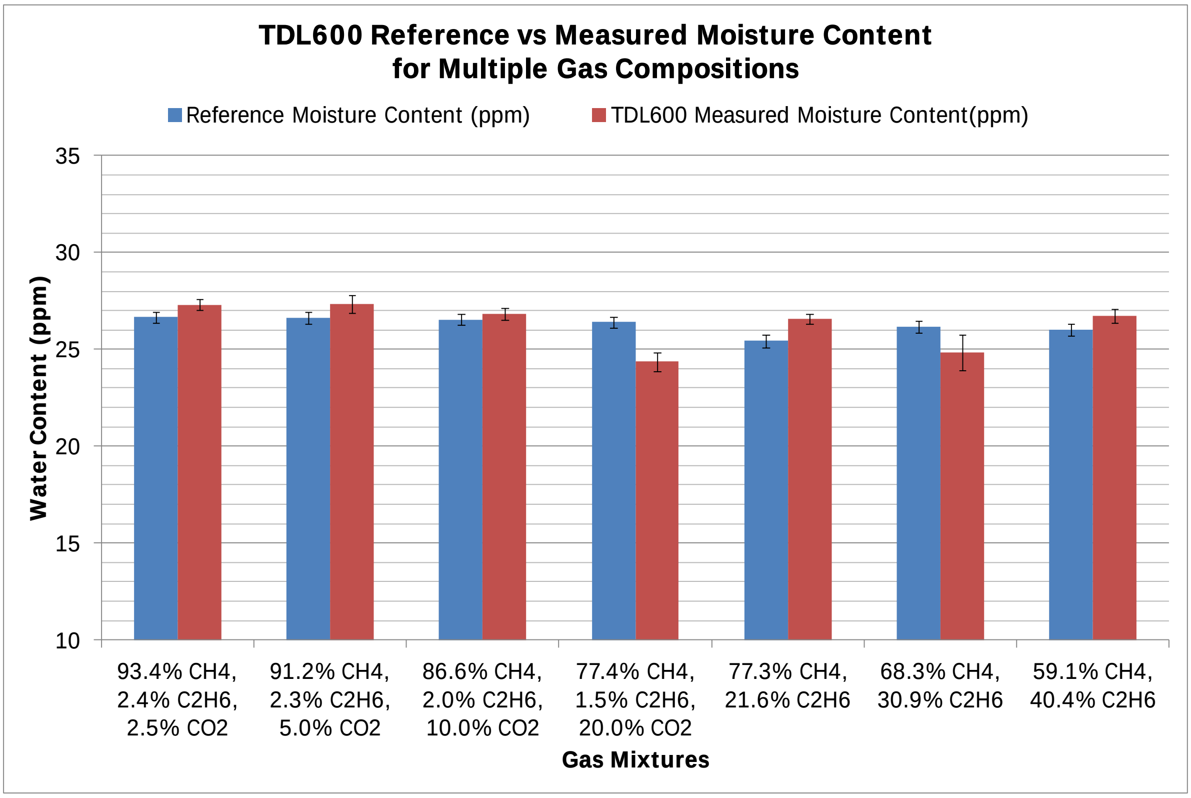

Figure 4: TDL600 Measurement Accuracy for a Range of Typical Shale Gas Compositions

The data above not only confirm that the TDL600 has achieved its targeted class-leading accuracy of +/- 1ppm$_v$, but also indicate that this performance is maintained over the full compositional range that is seen in real-World natural gas. Translating the performance of the TDL600 to assess its implications in the context of European gas quality, it is clear that the resulting confidence band at the EASEE Gas level of -8°C would equate to just +/- 0.25°C dp.

Compared to the current state of the art, the improved performance of the TDL600 is expected to offer significant benefits to gas producers and pipeline operators as on the one hand it should help to reduce the instances of gas transmission being shut-off unnecessarily, and on the other offers very significant energy cost saving opportunities in gas processing as there will be less requirement to over-dry gas to ensure adherence to gas quality specifications for moisture. Based on the worst case prior art error band shown in figure 3 and the data above, Michell estimate that these efficiency savings could be as high as 20%.

Conclusion

The natural gas industry is moving forwards and its needs are evolving as the market develops. Measurement technologies need to adapt and improve in step with the industry. There is an increasingly strong requirement to quantify natural gas contaminant concentrations such as moisture, carbon dioxide and hydrogen sulphide with single figure ppm$_v$ precision. Existing TDLAS analyzers appear to offer a solution but often fail to deliver in the real-World as, in situations where gas composition changes, background interference can result in significant errors. We have shown that recent technological advances in TDLAS analyzer design can unlock potential efficiency savings of up to 20% when applied to the processing and removal of moisture from natural gas. The challenge is now to roll-out that improved technology for all critical measurements as that could be the key to saving in the region of €20 billion globally per annum and result in dramatically increased energy efficiency, contributing considerably to the responsible exploitation of shale gas.