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DEVELOPMENT OF REAL-TIME GAS QUALITY MEASUREMENT

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1. INTRODUCTION

This paper maps the development of the GasPTi gas properties transmitter which has integrated gas sampling, gas conditioning and gas analysis into one product. This results in a rapid and accurate reading of natural gas properties such as Calorific Value (Heating Value or Btu), Relative Density, Wobbe and Compressibility.

The instrument has been designed in response to changing conditions within natural gas networks across the World. Increased trading in natural gas and transportation by pipeline interconnectors and LNG shipping, plus more unconventional gas injection into networks (via shale gas and biomethane), means gas transmission operators and downstream users are now seeing much more variation in gas quality. This leads to the need for new instrumentation that can respond quickly and accurately to such changes, with a preference for simple, low-cost installation, operation and maintenance.

2. TRADITIONAL GAS QUALITY MEASUREMENT

2.1 Mismatch

The calculation of total energy flow in gas pipelines requires accurate measurement of both gas volume and gas calorific value (CV). Ideally, these two measurements should be matched at the same time in the flow computer but in practice the flow data is almost instantaneous whereas the calorific value data is delayed by several minutes. This mismatch between instantaneous volumetric flow measurement of pipeline gas and delayed gas quality measurement has been recognised and accepted in international standards for many years (REF.1). If gas quality remains stable then this is not a problem but if CV is changing then there is an inherent error in the energy flow calculation as the delayed gas quality data offered to the flow computer relates to gas which is several miles down the pipeline. The error is compounded if the volumetric flow is also changing.

Until now, it has not been possible to determine instantaneous energy flow but with near real-time CV measurement GasPTi provides the opportunity to improve overall energy measurement with time-matched flow and heat content data.

2.2 Standards

In the absence of a European standard on natural gas quality, most European countries are using the recommendations of the International Organisation of Legal Metrology (OIML). Recommendation R140 (REF.1) identifies the types of calorific value determining devices (CVDD) as direct measurement (direct combustion, catalytic combustion), indirect measurement (stoichiometric combustion) and inferential determination (correlation with other measured properties, composition based calculation - such as GasPTi). This demonstrates that inferential techniques such as those employed in GasPTi are acceptable to OIML for CV measurement.

Similarly, in North America the American Gas Association (AGA) has recognised inferential techniques for CV measurement (REF.2).

Quoting directly from Report AGA 5 Natural Gas Energy Measurement: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.”*

2.3 Some Drawbacks of Traditional Equipment

The traditional gas chromatograph (GC) has been the workhorse of gas quality measurement for 50 years or more. Accepting that there are positive features of GCs such as complete composition analysis of complex mixtures and generally good accuracy, there are also drawbacks which are leading to further development work.

We have discussed the slow response of GCs and the mismatch between flow and gas quality data. This has led to the development of micro-GCs with reduced compositional range but faster response.

Generally a GC will require a skilled workforce to maintain the device, providing knowledge of the sampling science and chemistry of gas chromatography. Micro-GCs will have fewer components but may still require a trained workforce for calibration and maintenance.

The distance between the sample point on the pipeline and the GC housing can be 20m or more and this requires the installation of electric powered trace heated sample lines to ensure no liquid dropout. This also leads to slow response due to the volume of high pressure gas passing through the sample line. A preconditioning enclosure close to the pipeline would improve response but add to the installation time and cost.

Commissioning of GC systems can be time-consuming to ensure correct purging, pressure, flow and temperature control. Calibration and repeatability checks are run using calibration gas to verify peaks and timed events are properly set.

Due to the temperature sensitivity of GCs, they are normally installed in temperature controlled housings together with the peripheral controls, calibration gas and carrier gas cylinders. The ongoing costs of cylinder replacement and transportation can be significant. Helium carrier gas is becoming less available and costs are rising.

3. SPECIFIC REQUIREMENTS FOR A NEW INSTRUMENT

3.1 Performance

In order to apply the new instrument in the changing operating conditions of natural gas pipelines worldwide, the key performance criteria for the new gas properties transmitter were speed of response, accuracy and applicability across the increasing variability of natural gas types (particularly carbon dioxide content).

Speed of response was to consider all aspects of the sampling, conditioning and analysis process. A short sample line with small diameter tube would result in minimum high pressure gas volume and would enable best response time. This would also have the benefit of minimum vented gas. If the transmitter could respond in near-real-time then smaller variations in CV could be monitored and accounted for in overall energy flow metering.

The accuracy of the instrument would have to meet the standards normally applied to the traditional GC, with uncertainty in CV and Wobbe measurement being typically better than $\pm$0.5% of measured value. The overall uncertainty in energy flow measurement, including flow, temperature, pressure and heating value, is typically set at $\pm$1.5%.

Carbon dioxide (CO2) content varies considerably across different natural gas sources. Unconventional gases are being injected into gas grids and this might require measurement of higher levels of CO2 for example from biomethane or higher levels of ethane from shale gas.

3.2 Installation and Commissioning

GC installation and setup can be time consuming as previously detailed and so any new instrument should consider ease of installation, on-site configuration and rapid commissioning. Elimination of the need for carrier gas and calibration gases would lead to a more compact system with smaller footprint. Any reduction in the requirement for skilled staff to commission the system would be beneficial.

3.3 Operation and Maintenance

The intention to install the new instrument for gas quality monitoring on remote sites leads to the requirement for simple operation and low maintenance such that a less skilled workforce can be deployed rather than the 'works chemist' type of staff require to maintain GCs. An elimination of calibration gas and carrier gas would reduce transportation and ongoing operational costs.

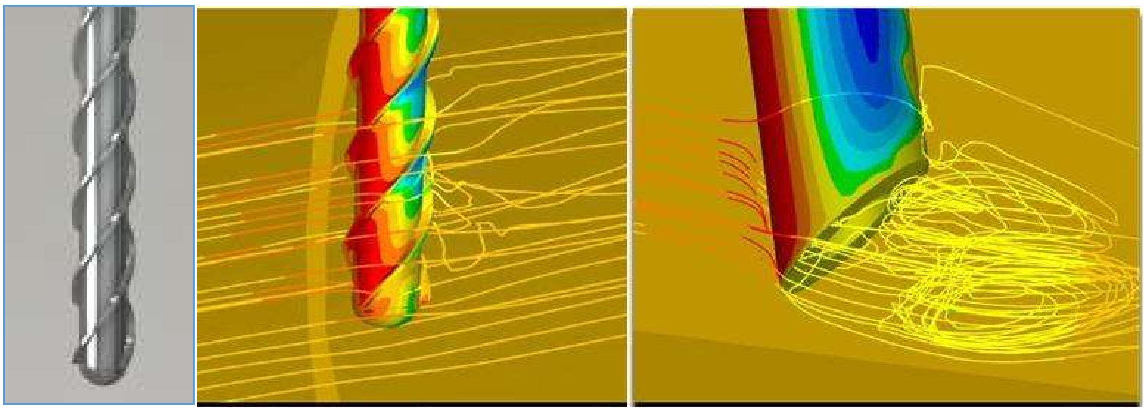
4. GAS SAMPLING, CONDITIONING AND ANALYSIS

The concept of the GasPTi system design is a fully integrated gas sampling, gas conditioning and gas analysis system that can be installed easily and quickly on a pipeline without the need for additional equipment, sample lines or cabling. The components of the system are described in the following sections.

4.1 Sample probe design

Conventional probes are known to suffer from vibration and potential breakage in high pressure, high gas velocity environments due to pressure pulsations caused by vortex shedding. The patented VE (Vortex Elimination) sample probe has a helical strake design which eliminates vortex shedding, and the need for wake calculations, allowing practically any length of probe to be used to ensure representative sampling 1/3 or more into the pipeline.

VE Technology Probe Conventional Probe



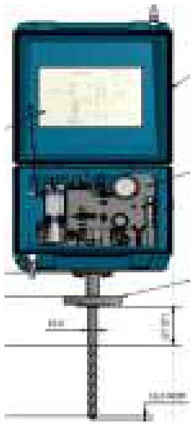
Whilst investigating the problems associated with vortex shedding, the development team also discovered that conventional probe tip design not only encouraged the up-take of particulates, but could also change the physical condition of the sample. To overcome these problems, the probe tip has been integrated into the VE Technology® sampling probe to provide an aerodynamic profile. The operation of the VE Technology probe tip and that of a standard probe have been modelled as seen above. Special attention should be given to the flow at the probe tip for the VE Technology sample probe which shows practically no disruption to the flow lines.

The aerodynamic tip, which actively rejects particulates, and the small diameter intake tube allow significantly reduced filtration (and improved accuracy). All sample wetted parts are stainless steel (no elastomers for seats or seals) and have specially treated electropolished surfaces as standard to ensure the absolute minimum of “hang up”.

4.2 Gas conditioning benefits

The overall response time of any gas analyser to a change in pipeline gas quality has to consider the sampling dead-time as well as the instrument response. The advantage of GasPTi in being an integrated system and pipeline mounted is that there is a very short sampling line, with pressure reduction at the head of the probe, resulting in a very fast response.

The GasPTi scan time can be as fast as one reading every 2 seconds and this compares typically with more than 10 minutes for the GC or 5 minutes for a micro-GC. We are therefore close to the energy accounting requirement for real-time measurement and matched volumetric flow and CV data.



GasPTi is normally mounted in a gas conditioning transmitter enclosure which sits on the pipeline. A VE 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. The gas conditioning components include an in-line filter, sample gas preheater to prevent liquid dropout on pressure let-down, pressure and flow controls, with no significant changes to internal volumes or flow paths which might alter the sample characteristics.

Typically GasPTi systems are installed on the pipeline 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.

There is no requirement for long gas sample lines, additional housings or gas cylinder storage as with GCs. This eliminates the need and expense for civil engineering works (foundations for housings) and means the amount of gas flowing through GasPTi and vented can be 30 times less than a GC system.

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

4.3 GasPT measurement principles

The GasPT instrument employs the concept of the “effective composition”. This is the idea that a natural gas composed of many hydrocarbons, nitrogen and carbon dioxide can be represented by a simpler gas mixture employing fewer hydrocarbons. GasPT uses correlative techniques to infer an equivalent five-component gas mixture (methane, ethane, propane, nitrogen and carbon dioxide). All of the hydrocarbons are resolved into the three “effective” hydrocarbons by using a simple process that balances the hydrogen and carbon atoms. The physical measurements made by GasPT 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 ($CO2$) and propane ($C3H8$) are equivalent. In an earlier version of the instrument this equivalency required additional calibration to suit an expected set of gas compositions. GasPT now has $CO2$ measurement, improving its accuracy and giving a wide application to all natural gases without customised calibration. From the inferred gas mixture of methane, ethane, propane, nitrogen, and measured carbon dioxide, the GasPT uses ISO6976 to calculate the gas properties 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 have shown the GasPT measurements of CV and Wobbe are typically better than $\pm$0.3% error against certificated gas samples.

The GasPT measurement system requires one annual validation check with a known sample gas taking less than one hour. This compares with the considerable effort required to keep a GC operational and in calibration with skilled labour (works chemist) which can be a day or more each month.

5. CERTIFICATION AND APPROVALS

5.1 Safety

The GasPT instrument has been certificated by Baseefa, the UK approvals service, as flameproof equipment suitable for safe use in Zone 1 hazardous areas. Certification has been gained demonstrating compliance with ATEX, IECEx and CSA regulations. Approval has also been gained from the American Bureau of Shipping for applications on LNG tankers. 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). GasPT has all these approvals and is marked accordingly with ATEX, CE, IECEx and CSA marks. The GasPTi gas conditioning heater also has ATEX and IECEx approval with further approvals being sought for FM (USA) and TIIS (Japan).

5.2 Performance

Performance testing by recognised test houses has resulted in GasPTi approvals for custody transfer applications worldwide: for example in the UK (National Grid), Italy (Snam Retegas), Poland (PGNiG) and North America (TransCanada). Typically in Europe, the OIML recommendation R140 and in N.America the AGA Report 5 both require CV error to be less than $\pm$0.5% and the GasPTi is comfortably within this limit. Calculations for CV, RD and Wobbe are performed to the international standard ISO 6976: (REF.3).

The VE sampling probe meets the requirements of the ISO 10715 (REF.4), API 14.1 (REF.5) and GPA 2166 (REF.6) sampling standards for natural gas.

6. CUSTOMER TESTING

GasPTi has undergone numerous laboratory tests and field trials across the world as gas transmission companies and government regulatory authorities prove the performance of the instrument.

United Kingdom

The test programme for this approval, carried out by independent laboratory SGS Ltd on behalf of the UK government agency Ofgem, was in three phases:

Phase 1: Assessing the accuracy, repeatability and response time of the GasPT with respect to its derivation of calorific value. The requirement was for CV measurement of 10 gas samples to 0.2MJ/m3 accuracy with repeatability between 2 gas samples and response time to within 0.2MJ/m3 within 4 minutes.

Phase 2: Testing the single-stream sampling system with particular reference to operational characteristics including alarms, sample flow variation, sample pressure variation, temperature dependence (-10 to +50 DegC), power loss, electromagnetic compatibility and an automated 35 day gas examiners test.

Phase 3: Inspecting the security and integrity of supply plus data and reporting procedures.

GasPT successfully passed the tests with CV error less than ±0.5% over a wide gas sample range (CV between 37.32 to 43.06 MJ/m3) and has been given limited fiscal metering approval by Ofgem for biogas applications in the UK.

Italy

These tests were performed at a metering and compressor site by the national transmission company and consisted of a 12 months trial comparing GasPT measurements with a gas chromatograph.

Over 12 months the GasPT was fully operational 100% of the time but the GC availability was less than 90%. Six gas samples were collected from various points on the transmission system and CV performance tests were repeated every 3 months with these samples. The results obtained from the tests of accuracy and durability, using daily data and hourly data show that the GasPT is considered to be a Class A instrument for CV determination according to the Recommendation OIML R140: 2007 (E) which provides an Maximum Permissible Error for CV of ±0.5%. Periodic tests to verify the accuracy of measurement and endurance tests showed no drifts outside calibration limits over the 12 months trial period.

Spain

Both gas transmission and gas production companies have completed laboratory tests and have forwarded the results to their respective operational departments. In both cases, the GasPT performance was less than ±0.5% error on CV measurement.

Poland

A gas transmission company arranged a field trial at a pipeline mixing point in Krakow. This provided the opportunity to compare GasPT with a gas chromatograph under pipeline conditions with 3 gas streams being switched continuously over a 2 week period. The GasPT performance was typically better than ±0.2% error on CV and as a result further laboratory testing was performed by second transmission company to demonstrate that GasPT complies with OIML R140: 2007 (E) recommendations in all aspects. These results have shown GasPT to be within errors of ±0.15% on

CV across a wide range of gas samples from CV of 26 to 40 MJ/m3. Satisfactory performance was also monitored with high nitrogen and helium levels.

Netherlands

Independent laboratory tests have been undertaken on GasPT on behalf of the gas transmission company. The tests successfully showed that GasPT meets the expected performance level of less than ±0.5% error on CV measurement. As a result a further set of field trials have been completed to test the operational configuration and durability of GasPTi in the field.

Canada

These tests have been performed by an independent R&D company on behalf of the gas transmission company at a compressor site. The results of testing some 18 different gas samples with CV between 36 and 42 MJ/m3 and with CO2 content between zero and 5% showed GasPT has a CV measurement with error typically less than ±0.2% compared with a traditional gas chromatograph.

Colombia

These tests were performed by an independent test laboratory on behalf of the national gas transmission company. The tests were based on the Standard ASTM D3764-09 REF.7) and the results obtained were then analyzed by following the Standards ASTM D6299 (REF.8) and ISO 10723 (REF.9). The results showed GasPTi acceptable repeatability, reproducibility and linearity with CV error less than ±0.5%.

Mexico

These test were carried out by a gas transmission operator on behalf of a gas transmission company at a gas pipeline metering station supplying Mexico City. The results showed a maximum error of ±0.18% in CV of the GasPTi sampling and analysis system compared with a traditional gas chromatograph.

USA (Colorado State University and PRCI)

Two test programmes have been carried out by an independent university test laboratory on behalf of a collaborative group of major international gas transmission companies. GasPT was tested against microGCs and other instruments and in both programmes GasPT was shown to give the best accuracy and response times in response to different samples gases. Wobbe error was less than 0.3% across the gas sample range. Colorado State University are now using GasPT in their laboratories for gas engine test experiments and a showcase GasPTi installation is to be sponsored by PRCI.

Future Trials

Test programmes are being developed with the gas transmission companies and Government Energy Regulators for Norway, Turkey, UAE, Japan and Thailand.

7. IMPLEMENTATION

An international network of more than 25 distributors for GasPTi has been organised in order to provide knowledgeable and immediate local support to customers worldwide. Training has been given to ensure commercial and technical competence in the products.

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

GasPTi has been used for control of mixing and blending gas streams to obtain required gas specifications for transmission pipeline gas. This includes several biomethane injection systems in the UK, with low cost GasPTi used to monitor the export gas from biogas production plants and the CV and Wobbe downstream of the mixing point with the national grid gas.

It has been used for custody transfer, fiscal metering and GC tracking on grid off-takes to gas distribution networks and large commercial and industrial customers.

GasPTi has provided very fast scanning (2 seconds) of gas quality variation and adjustment of multiple fuel injection points on gas turbines.

Motor Octane Number and Methane Number, calculated from GasPTi, are used to control ignition timing on large CHP gas engines where ignition requirements will vary with gas quality.

GasPTi has been used to control combustion air/fuel ratio in response to changing gas supply quality to ensure consistent burner flame shape and temperature on industrial processes such as glass production and steel heating. The carbon emissions factor for an industrial process can be calculated by GasPTi systems.

GasPT has been used to monitor CV and Wobbe of boil-off gas from LNG tanks, LNG recirculation and to control CV and Wobbe of terminal export gas into the medium pressure distribution network.

GasPTi is used in marine applications to monitor the CV of boil-off gas from ship LNG tanks and to control gas Wobbe prior to fuel gas supply to ship power generation systems. This is a very harsh environment where it is not possible to operate GCs.

8. CONCLUSIONS

a. A new integrated gas sampling, conditioning and analysis system GasPTi has been developed to provide fast and accurate monitoring of pipeline gas quality.

b. GasPTi meets or exceeds all relevant sampling and analysis standards and holds worldwide certification for use in hazardous areas.

c. GasPTi has undergone comprehensive laboratory testing and field trials on gas transmission pipelines to show accuracy of CV and Wobbe measurement typically better than $\pm$0.3% error and always much better than $\pm$0.5%.

d. GasPTi meets the performance recommendations of OIML R 140: 2007 (E): Measuring Systems for Gaseous Fuel as a Class A instrument for CV measurement and complies with the performance requirements of AGA Report No.5 Natural Gas Energy Measurement for CV determination.

e. As a lower cost solution than gas chromatographs for on-line gas quality measurement, GasPTi can be employed widely across gas transmission and distribution networks together with end-user applications with a resulting improvement in overall network monitoring, control and energy accounting.

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