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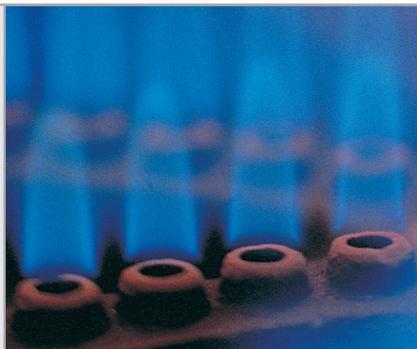
2-DAY TECHNICAL CONFERENCE

Natural Gas Quality, Energy Measurement, and Interchangeability

> December 5-6, 2005—Chicago

MONDAY, DECEMBER 5

> Registration and Continental Breakfast: 8:00 a.m.

> Welcome and Opening Remarks: 8:55 a.m.

Interchangeability Experience and Performance Specifications for a New Gas Sensor
Terry Williams, *Market Sector Leader, Advantica Technologies, Ltd.*

Online Gas Quality Measurement Technique Based on Optical and Thermal Gas Properties
Dr. Joachim F. Kastner, *Leitung Gasanalytik/ Head Gas Analysis, Elster-Instromet Systems, Germany*

> Refreshment Break

Ways and Means Related to Energy Measurement and Calculation
Dr. Thomas Bruno, *Project Leader, National Institute of Standards and Technology (NIST)*

Quality and Variability of Gaseous Fuels
Dr. Sherman S. Chao, *Principal, Analytical Solution, Inc.*

Panel Discussion

> Luncheon

Determining Accurate Gas Quality: An Essential Element of the Cash Register
Mark Keirs, *Regional Sales and Support, Welker Engineering Company*

The Application of MES Technology to On-Line Analysis of Natural Gas
Johan Bats, *Development Engineer, Instromet International*

> Refreshment Break

Extended Gas Analysis
Karen Crippen, *Manager, Chemical Research Services, GTI*

Panel Discussion

> Reception

TUESDAY, DECEMBER 6
> Continental Breakfast: 8:00 a.m.

Gas Sampling for Gas Quality
Thomas Welker, *Principal, Hydrocarbon Quality Associates*

Natural Gas Quality Standardization for Fuel Cells
Dr. Pinakin Patel, *Director, Special Systems & Research, FuelCell Energy, Inc.*

> Refreshment Break

The Impact of Gas Quality on LNG Manufacture and Use
Dr. John S. Roberts, *Principal Chemist, Materials & Chemicals Consultants, LLC*

Energy Measurement of LNG
Charles Cook, *Business Development Manager, Gas Chromatographs, Emerson Process Management*

Panel Discussion

> Luncheon

LNG Interchangeability: Options and Strategies from Importer to End User— *Individual Presentations by a Special Panel, Followed by a Q&A Session*

> Chair: Dr. Colleen Taylor Sen, *Senior Advisor, LNG, GTI*

> Ben Ho, *Technology Manager, BP*

> David Rue, *Manager, Industrial Combustion Processes, GTI*

> Kevin Shea, *Project Manager, San Diego Gas and Electric/Southern California Gas Co.*

> Ted Williams, *Director, Codes, Standards and Technical Support, American Gas Association*

> Representative of Power Generation Company

Conference ends: 3:30 p.m.

Online Gas Quality Measurement Technique based on Optical and Thermal Gas Properties

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I.   Abstract

The composition and hence the physical parameters of natural gas vary in space and time, depending on the gas source and by blending. The key parameters of natural gas are important to know for transportation and efficient consumption. Thus, gas quality measurement is required for technical and economic reasons. Liberalisation and unbundling of the gas markets will be another driver for the need of efficient gas quality measurement.

The article presents a novel correlative gas quality measurement technology based on optical and thermal gas properties. This technology enables accurate online gas quality analysis over a wide range of generic natural gases. The measurement device gas-lab Q1, based on this technique, only needs methane for calibration and is low on capital and operational costs. The new technology is successfully running in a wide range of applications in the natural gas industry.

II.   Introduction

Natural gas is an attractive fossil carrier of energy. As a natural product, its composition and hence its physical parameters vary in space and time, depending on its source and by blending. For gas production, transportation, trading and consumption, it is therefore of great economic and technical importance to have a knowledge of the gas properties.

The future gas market will be characterised by liberalisation and unbundling, all over the world. The number of gas trading partners and thus the number of interfaces between them will grow. On the other hand, the parameter variations of natural gas will increase due to international gas trading (e.g. import of LNG). Both trends are additional drivers for the need of fast, accurate and economic gas quality measurement technology.

Since gas trading is based on energy billing, the varying calorific value of natural gas is the key figure to know. The energy flow is the product of calorific value and volume flow at normal conditions. For this calculation, volume at flowing conditions must be converted to volume at normal conditions, which is usually done by calculating the gas law deviation factor on the basis of AGA8 or SGERG equation [1, 2]. These equations require as input data either the molar gas composition or key parameters like e.g. superior calorific value, normal density and CO_2 mole fraction.

Another critical gas property is the Wobbe index whose real-time measurement is often required in the control of sensitive processes in industrial gas applications.

Knock resistance is important if natural gas is used as a motor fuel. Its measure is the methane number (similar to the octane number for petrol). With a prompt methane number signal, engine control can be optimised, thereby improving efficiency and service life.

Power plants based on gas turbines profit from fast and accurate gas quality measurement for adjustment of the turbine parameters in the trade-off between high efficiency, low pollution and long service life.

This article presents a novel correlative gas quality measurement technology for generic natural gases. The new technique is based on optical and thermal gas properties. It has been implemented in the measurement device gas-lab Q1 to meet the requirements of the gas industry.

The gas-lab Q1 is a novel device for flameless fast and accurate in-situ-determination of natural gas quality. The technique is based on measurement of infrared absorption and heat conductivity combined with a correlation algorithm. There is no need for additional carrier gas and the device calibrates itself automatically with methane. The system was developed and tested for a wide variety of generic natural gases. The full measurement range can be covered with a single calibration data set.

The new technology is more accurate and lower in total costs than present calorimeters and Wobbe meters. The current online measurement technologies typically need extensive ambient conditioning. In comparison to process gas chromatography, the new

device is much faster and has lower operational costs, since it does not need carrier gas, multi-component calibration gas or pressurised air.

Present field applications range from billing measurement to control and regulation applications for fast industrial processes.

III.   Measurement Method

The presented method is based on the typical composition structure of generic natural gas. It consists mainly in hydrocarbons (abbreviated as "CH"), carbondioxide (CO_2) and nitrogen (N_2); these components typically make more than 99.9% of the total gas composition. Thus we approximate the molar composition of natural gas:

$$xCH + xN_2 + xCO_2 = 1,$$

with xCH, xN_2 and xCO_2 being the molar fractions of the total hydrocarbons (CH), nitrogen N_2 and carbondioxide CO_2, respectively. The hydrocarbons mainly consists of alkanes (C_nH_{2n+2}), of which the concentrations steadily decrease with increasing alkane order in generic natural gas.

The selection of the measurement values of the new technology corresponds to this typical composition pattern of natural gas. The measured values are:

Measurement Value		Correlating Gas Components
ACH	Infrared Absorbance of the Hydrocarbons	CH
ACO_2	Infrared Absorbance of Carbondioxide	CO_2
λ	Heat Conductivity	CH, N_2 CO_2

These physical data correlate directly with the molecular gas composition and thus make it possible to determine the key properties of natural gases. Figure 1 illustrates the measurement method: Hydrocarbons and carbondioxide absorb infrared light by excitation of the CH- and CO_2-molecules. The spectral intensity of this absorption is specific for the

component type and proportional to the component concentration. Infrared absorption is measured by sending white light through the gas and detecting the transmitted intensity in different spectral regions. In order to detect non-IR-absorbing gas components such as nitrogen, another sensor is used to measure the heat conductivity, that is (non-specific) sensitive to all gas components [3,4].

Light Absorption by Excitation of Molecule-Rotation-Vibrations
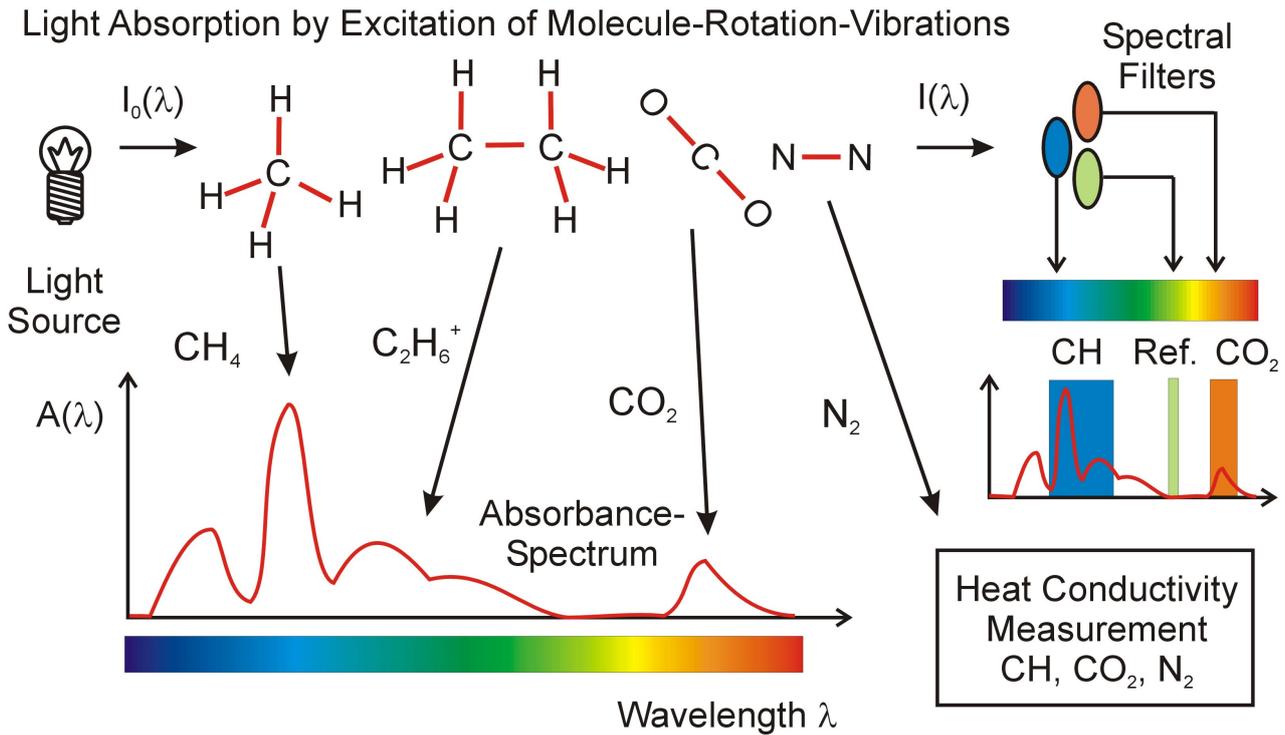
Figure 1: Measurement method: The absorption of infrared light correlates with the concentration and composition of the hydrocarbons and the concentration of carbondioxide. The heat conductivity correlates (non-specifically) with all gas components, also with nitrogen, that is invisible in the infrared spectrum.

Figure 2 shows the absorbance spectra of 3 typical natural gases in high spectral resolution. The displayed gases are methane (without CO_2), H-gas with low CO_2- and high CH-concentration, L-gas with high CO_2- and low CH-concentration. Since carbondioxide and the hydrocarbons absorb in well separated spectral ranges, they can be analysed independently. The absorbance ACO_2 in the spectral range 4200 - 4400 nm clearly shows the correlation with the CO_2-concentration. The absorbance ACH in the range 3100 –

3500 nm shows a more complex correlation with the composition of the hydrocarbons. Finally, analysis of the absorbance spectra results in information about the mole fraction of carbondioxide xCO_2 and the molar calorific value of the hydrocarbons HCHm.
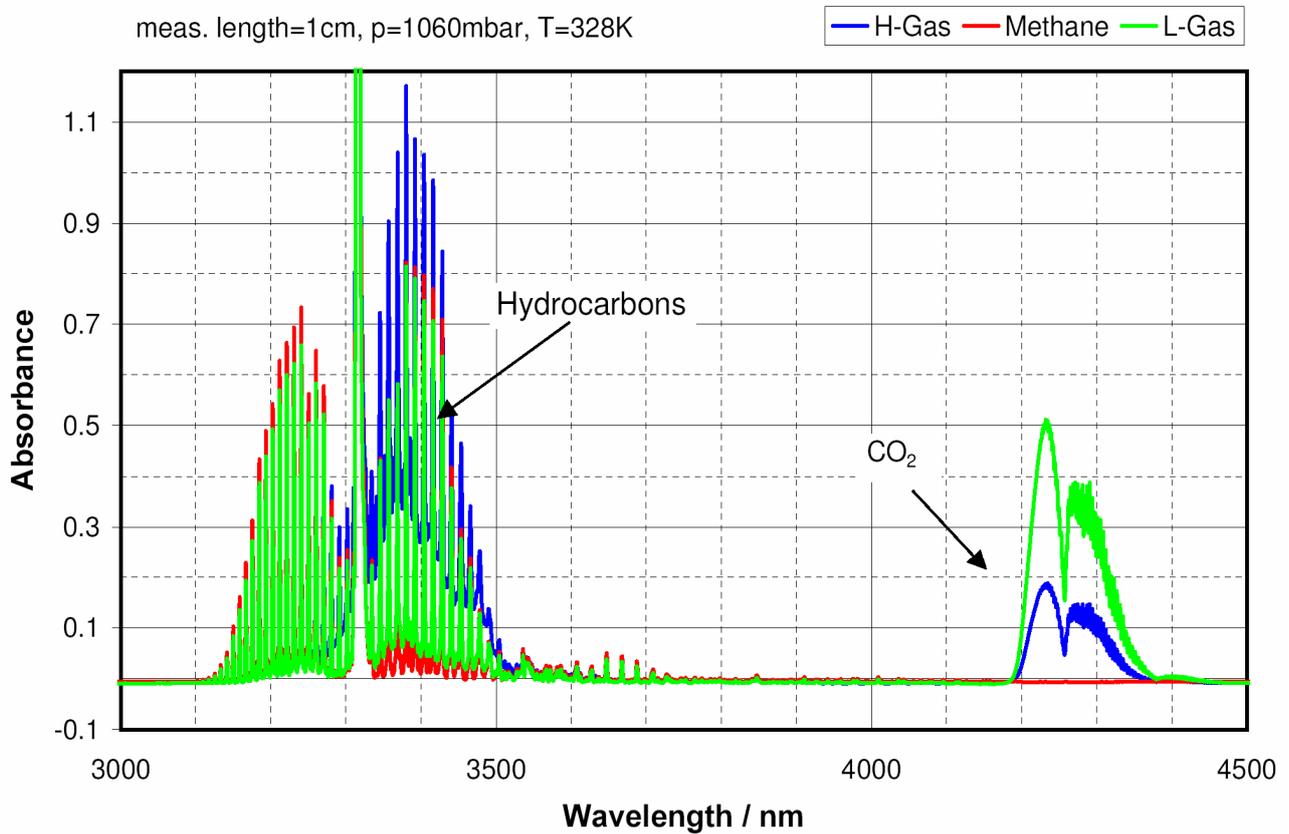
Figure 2: Absorbance spectra of typical gases: Methane (xCO_2=0), H-gas with low CO_2- and high CH-concentration, L-gas with high CO_2- and low CH-concentration.

The missing information of the hydrocarbons concentration xCH or of the complementary nitrogen concentration xN_2 can be determined by measurement of the heat conductivity λ. The evaluation algorithm is based on a correlation $\lambda = F(xCH, xN_2, xCO_2 \, HCHm)$ between mole fraction of the hydrocarbons xCH, mole fraction of the nitrogen N_2, mole fraction of carbondioxide xCO_2, molar calorific value of the hydrocarbons HCHm and heat conductivity λ. Figure 3 demonstrates this correlation for the special case xCO_2=0, as an example. The heat conductivity λ increases with decreasing molar calorific value HCHm and with increasing mole fraction xCH.
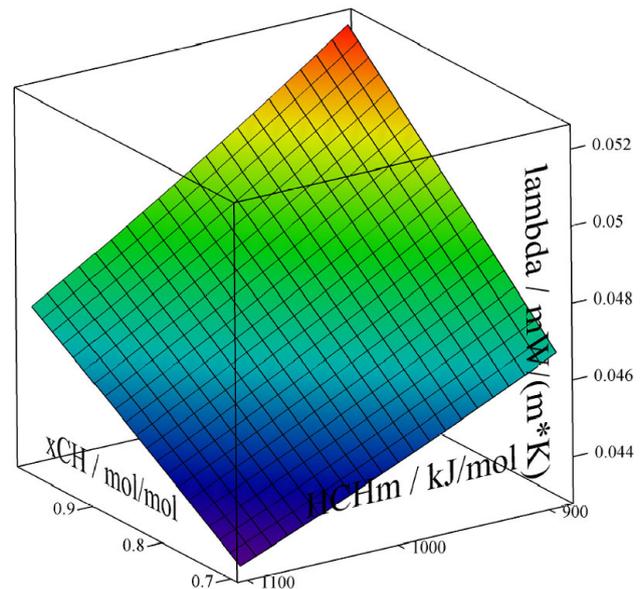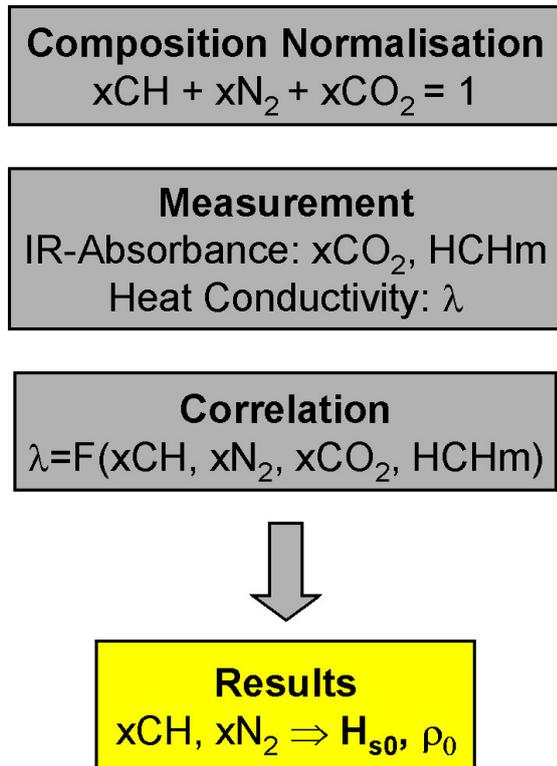
Graph of correlation F (xCO_2=0 as example)

Figure 3: Measurement of infrared absorbance results in mole fraction xCO_2 and molar calorific value of the hydrocarbons HCHm. Heat conductivity measurement delivers heat conductivity λ of the total gas mixture. Correlation λ=F(xCH, xN_2, xCO_2, HCHm) enables determination of xCH, xN_2 and thus results in calorific value H_{s0} and density ρ_0. The graph shows correlation λ=F(xCH, xN_2=1-xCH, xCO_2=0, HCHm) as an example.

Finally, the evaluation algorithm based on the measurement values and the mentioned correlation, results in the relevant gas parameters:

- calorific value H_{s0}
- normal density ρ_0

Further calculations based on fundamental laws and complex modelling of typical generic natural gases deliver further values such as:

- Wobbe index
- Methane number

- Modell analysis (CH_4, C_2H_6, C_3H_8, nC_4H_{10}.. nC_8H_{18}, N_2, CO_2)
- Net calorific value, specific density ....

Figure 4 shows the core set-up of the gas-lab Q1: The gas is running through the sensor bench, continuously. Sensors detect pressure, temperature, total heat conductivity and infrared absorption of the hydrocarbons and of carbondioxide.
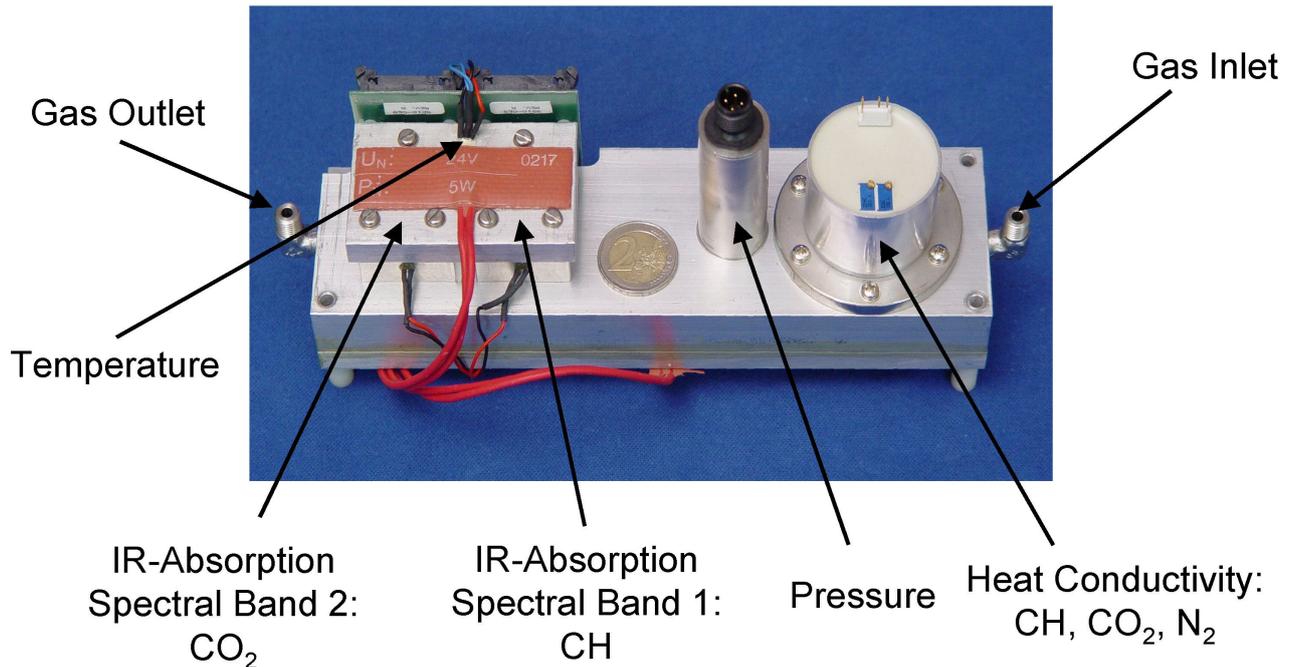
Figure 4: Sensor system of the gas-lab Q1

IV. Laboratory and Field Tests

The technical and mathematical parameters of the method were developed in comprehensive laboratory tests with a wide range of generic natural gases (figure 5). The relative deviations of the calorific value and density measurement of the gas-lab Q1 in comparison to laboratory gas chromatographs are displayed in figure 6. The systematic uncertainty of the calorific value was less than ±0.3 %, the uncertainty of the density measurement was less than ±0.6 % compared to the reference method. This result was achieved with a single set of calibration data over a wide range of typical generic natural gases.
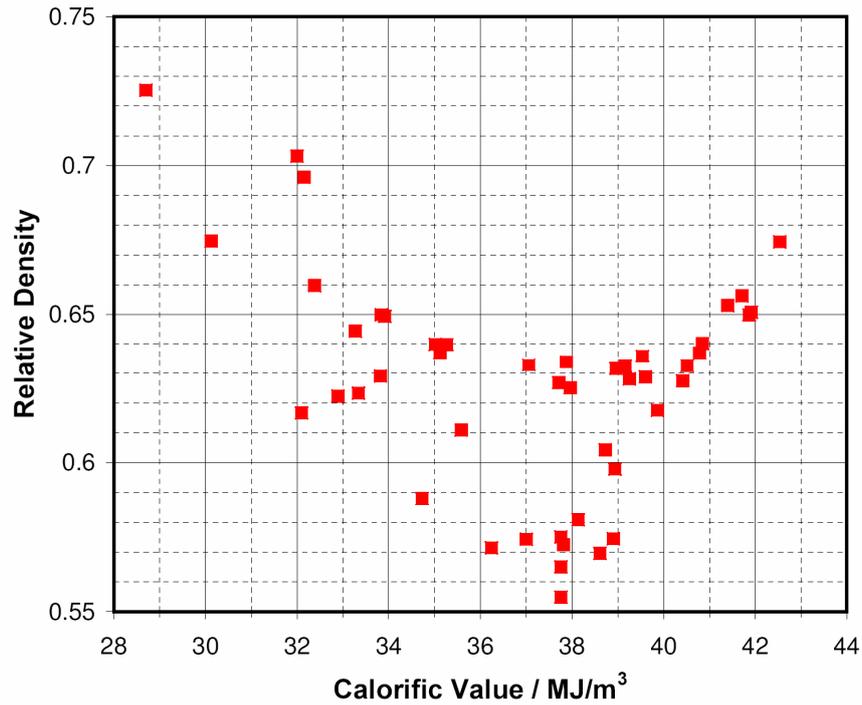
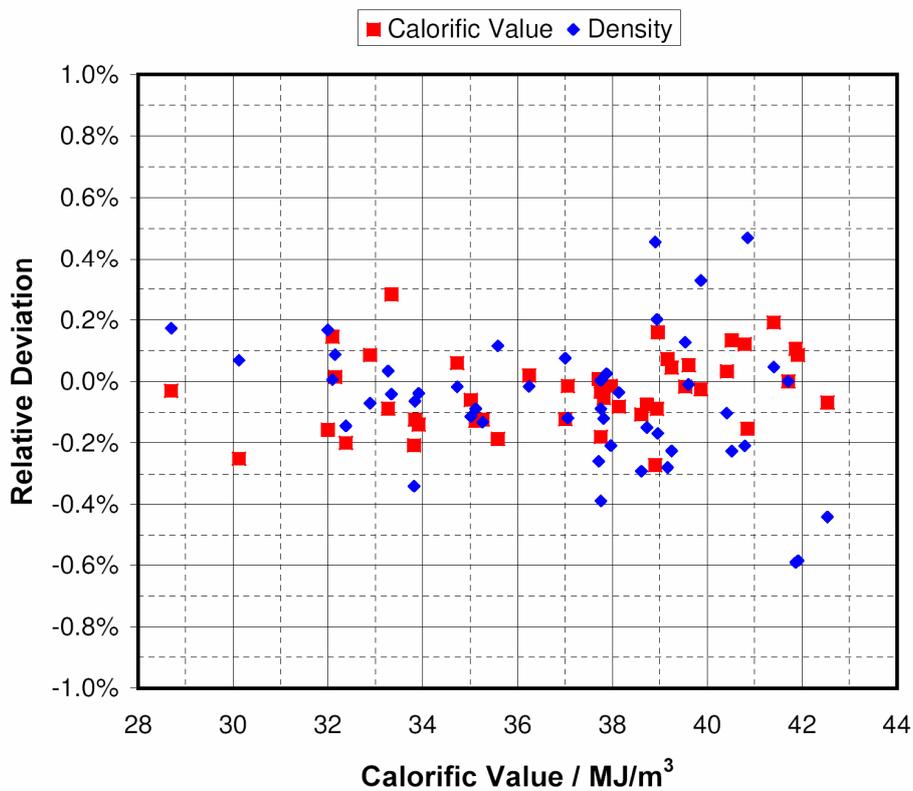**Figure 5: Test set with a wide range of generic natural gases.**


Figure 6: Accuracy of the calorific value and density measurement with a wide range of generic natural gases (single calibration data set for full range).

As mentioned above, industrial gas applications like gas motors and gas turbines profit from fast and accurate online analysis of the gas parameters. The presented technology is based on a continuos measurement and evaluation procedure and hence has the potential to meet these requirements. We investigated the dynamics of the device by switching the process gas from H-gas to methane and back. Figure 7 shows the response of the calorific value signal, normalised to step height. The response time t_{90} nominates the time for the signal to reach 90 % of the signal step height. The t_{90} of the core measurement system was about 20 - 25 s in our investigations. The total response time of a measurement system also includes the sampling time from the pipeline. The sampling time can be minimised towards the response time of the core system by installing a bypass.
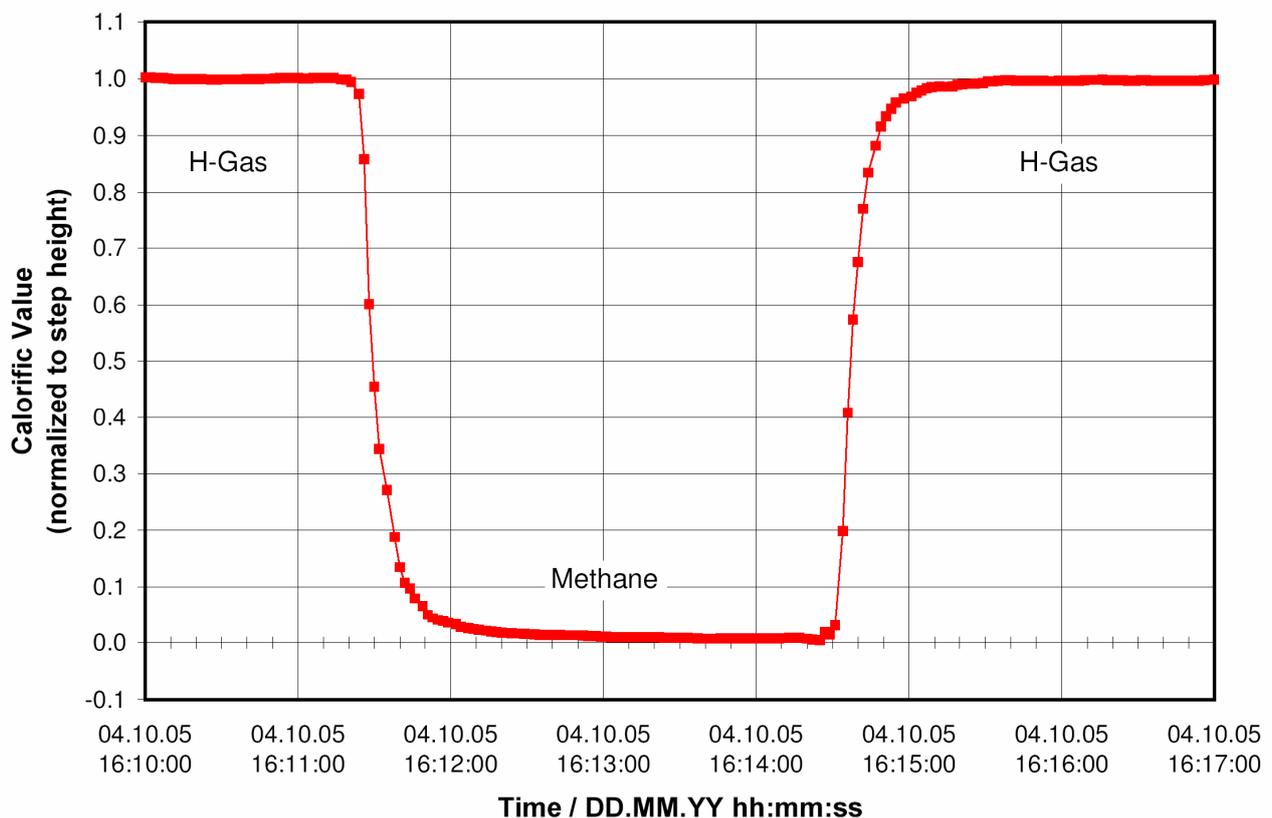
Figure 7: Response of the calorific value signal to a sharp change from H-gas to methane and back. The calorific value has been normalised to step height.

The gas-lab Q1 was installed in numerous field applications since 2002. As an example, Figure 8 displays the result of a field experiment. Task of this extensive experiment was to investigate the performance of a gas turbine at fast varying gas parameters. Therefore, the supply gas of a power plant under full load was varied by gas blending. The gas parameters were observed with the gas-lab Q1 and with an established process gas chromatograph as reference. While the gas chromatograph made discontinuous measurements with a period of several 10 minutes, the gas-lab Q1 delivered a continuous flow of data with a rate of approximately 1/s. The calorific value of the blended gas varied up to 8 %. The deviation of the calorific value measurement between the gas-lab Q1 and the reference chromatograph was within ±0.25 %.
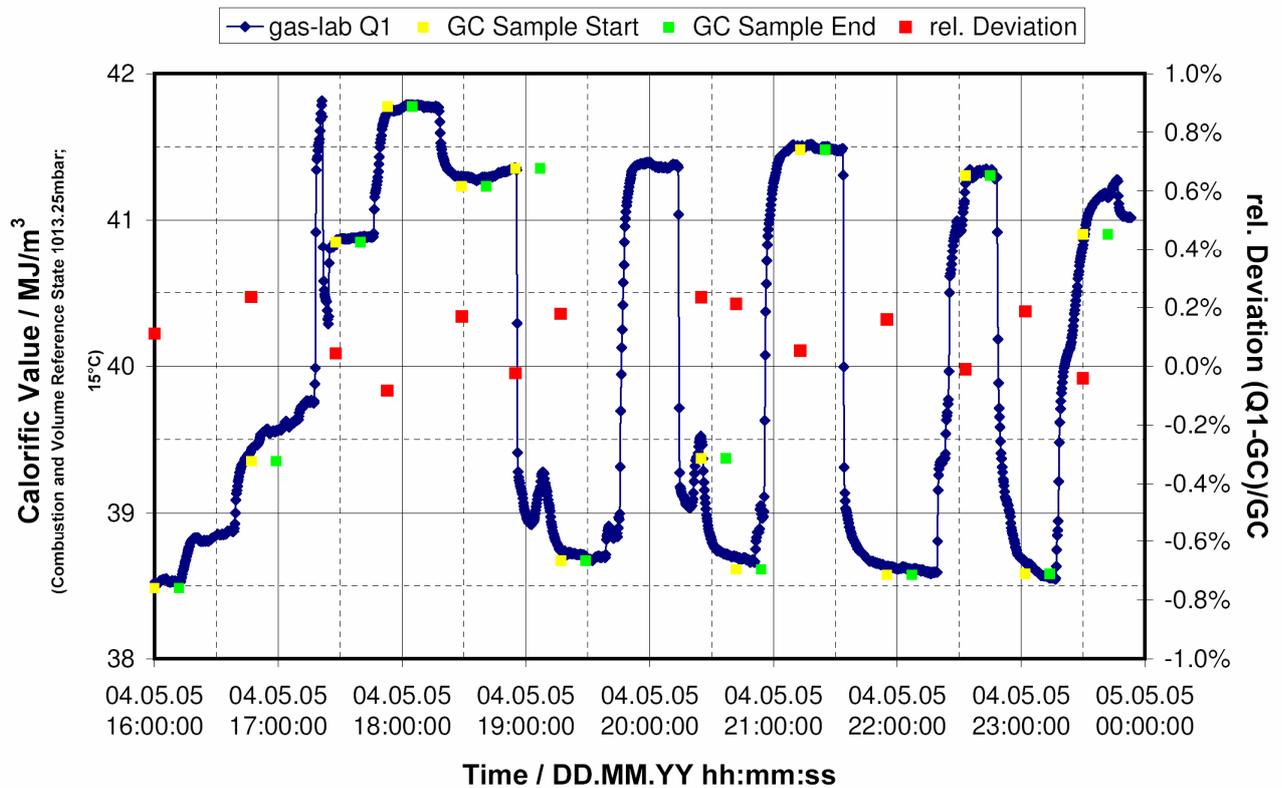
Figure 8: Field test to investigate the performance of a gas turbine under fast varying gas properties. Continuos calorific value measurement of gas-lab Q1 in comparison to a reference process gas chromatograph as a function of time.

V.   gas-lab Q1 Measurement Instrument

The measurement equipment gas-lab Q1 consists of two components (Figure 9):

The Q1 sensor unit has an Ex-proved housing (ATEX) comprising the sensor bench, electronics and three-way double block & bleed valve block. The measurement section features connections for pipeline gas, methane for calibration, an optional test gas and for venting. During operation, the unit is calibrated automatically with methane. A methane cylinder with a volume of 10 litres is sufficient for an operating period of more than one year. The standard system is mounted on a metal support also carrying the devices for pressure and flow conditioning as well as safety devices (safety relief valve, manual reset valve). The gas connection interface requires an upstream pressure of 200 mbar to 5 bar at a flow rate of 30 normal litres/h. A bypass line helps to accelerate sample taking and enables a response time of the sensor system of approx. 20 - 25 s.

The Q1 controller (1/3 width in 19" technology) communicates with the sensor system via a digital interface and is installed in a non-hazardous area, up to 1000 m remote. The computer provides the man-machine interface of the measurement equipment for control, evaluation, display, logging and communication. The interfaces are:

- 3 digital outputs, 4 analogue outputs
- serial interface for Modbus
- serial interface for parameter setting and local readout
- serial interface for Modem

The interfaces can be expanded by further I/O boards.

Communication via Modem and telephone line enables remote control and data retrieval from the logging archives. The logging archives comprise measurement data as current and mean values, as well as internal and external status and events.
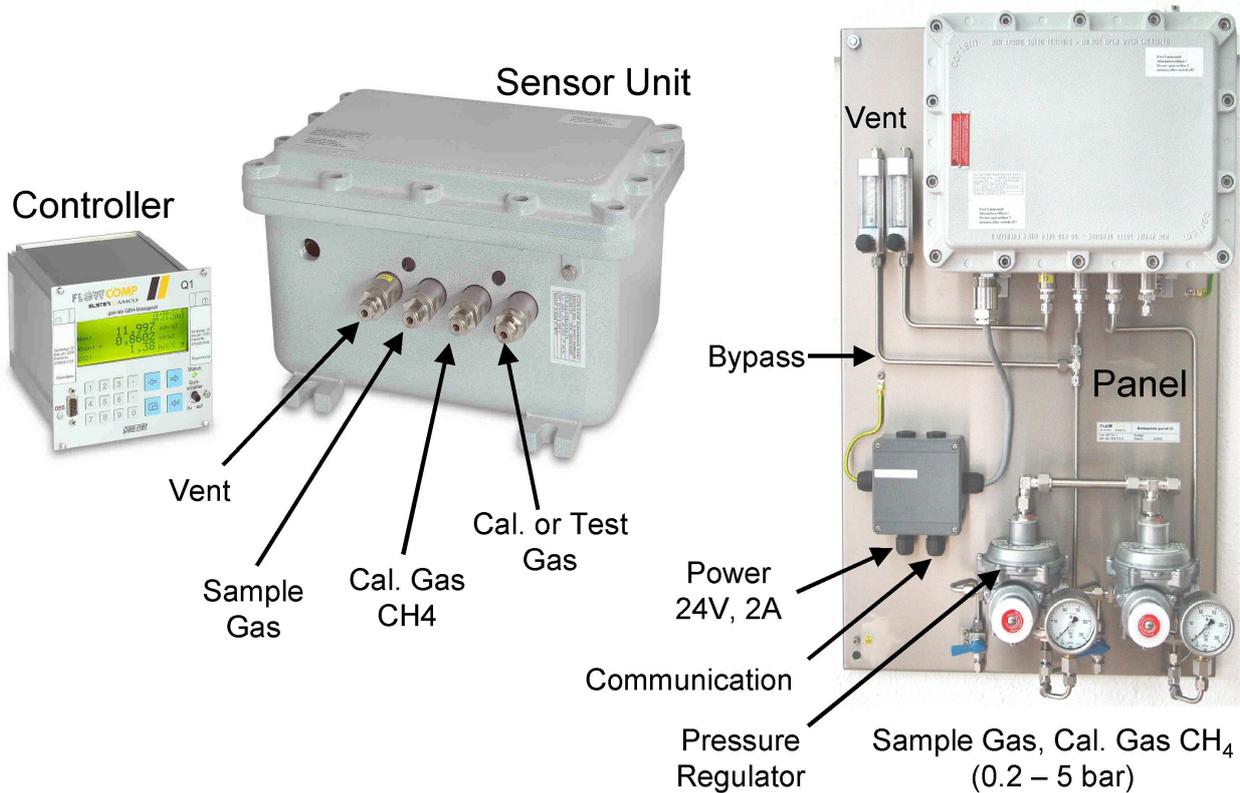
Figure 9: gas-lab Q1 controller, sensor unit and installation on mounting panel

VI.   Summary

Future natural gas market will be characterised by emerging liberalisation, a manifold of participants will take part in world wide gas trading. For technical and economic reasons, this market will ask for efficient gas quality measurement equipment.

In this article, we present a correlative gas quality measurement technique for a wide range of generic natural gases. The procedure is based on optical and thermal gas parameters, key measurement values are infrared absorbance and heat conductivity.

The new technique was implemented in the measurement device gas-lab Q1, a flameless, fast and accurate online gas quality analyser. The article shows laboratory and field results in order to demonstrate the accuracy and dynamics of the system for a wide measurement range with a single calibration data set. The presented equipment needs no extensive environmental conditioning, carrier gas or multi-component calibration gas. Hence it has technical and economic advantages in comparison to established gas quality measurement techniques.

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The gas-lab Q1 is applied for a variety of measurement tasks in the whole gas industry ranging from production, storage, transportation, distribution, up to gross consumption. The applications comprise operational and fiscal metering, backup measurement, control and regulation for gas blending stations, gas turbine management and protection

References

[1] ISO 12213: Natural Gas - Calculation of Compression Factor. Part1: Introduction and Guidelines; Part 2: Calculation Using a Molar Composition Analysis; Part 3: Calculation Using Physical Properties. International Standard ISO 12213, First edition (1997).

[2] AGA 8: Transmission and Measurement Committee Report No. 8, "Compressibilty Factors of Natural Gas and other related Hydrocarbon Gases"

[3] Kastner J., Schley P.: „Novel Optical Techniques for Process Analysis of Natural Gas Quality"
Proceedings of the Conference „Applications and Trends in Optical Analysis Technology", Frankfurt, Germany, February 26 – 27, 2002
Verein Deutscher Ingenieure: Kompetenzfeld Optische Technologien, VDI-Berichte: 1667, VDI-Verlag Düsseldorf, 2002

[4] Schley, P.: Microsensors to Determine Superior Calorific Value and Wobbe Number. Proceedings of the "2001 International Gas Research Conference", October 2001, Amsterdam, The Netherlands.