Aspects of Process Measurement in the Natural Gas Industry

Joachim F. Kastner, Director, Head R&D, Division Gas Quality, Elster GmbH, Mainz-Kastel

1 Introduction

1.1 Natural Gas

Natural gas is an attractive carrier of fossil primary energy. It consists mainly in methane and a mixture of the alkane series, the main inert components are nitrogen and carbon dioxide, other components are typically far below 0.1mol% (Picture 1). The combustion of natural gas is very clean concerning exhaust gas pollution and particular matter. Compared to other fossil energy carriers, natural gas usage results in a relatively low emission of the climate gas CO₂ per provided energy. The reason is the relatively high hydrogen/carbon ratio in its molecular composition. Due to its gaseous phase and cleaness it is an ideal fuel for the high efficient gas turbine power plants with combined heat-power-cycle that can reach an energetic efficiency of 60% electrical. Furthermore natural gas has a wide application diversification ranging from domestic use for heating, industrial power generation, car fuel, feedstock for the chemical industry to fuel cells and absorber heat pumps.

![Natural Gas Features](image)

**Picture 1: Features and main components of natural gas**

The strategic factors of the natural gas industry are characterized by a steady volume growth of about 3 %/a since the 70ties of the last century. This did and still does require massive investments in the transport and distribution infrastructure. In addition to the construction of new pipelines, the transportation of liquefied natural gas (LNG) in tanker ships is also growing in importance. This also leads to a growing variety of gas parameters worldwide.
These variations must be taken into consideration for transport and distribution in ever more complex networks and also for gas utilisation. Furthermore the gas markets are characterized by liberalization and unbundling of the oligopoly market structures. The number of gas trading partners and thus the number of interfaces between them will grow.

Another strategic factor are global environmental and climate policy targets that started to gain importance in the recent years, with topics like CO₂-emission trade and new alternative gas resources like Biogas upgrading and injection into the natural gas transportation grid. Recent discussions even concern the injection of hydrogen with following background. Regenerative electricity production often depends on un-controllable natural factors, mainly the weather. Hence the power production does not always correlate well with the electricity consumption. In order to balance the power flow, the production could be reduced by switching of the power generation. A more efficient approach however would be to store the excessive energy. One solution could be to produce hydrogen by hydrolysis with regenerative electricity and to inject that hydrogen into the natural gas grid. This would introduce a new gas component into the transportation grid that is not specified with most established gas quality measurement equipment.

These trends are drivers for investments in the gas industry infrastructure, hence also in the gas measurement technology. There is a growing need for fast, accurate and economic gas quality measurement technology.

1.2 Process Measurement in the Natural Gas Industry

Gas trading is based on energy billing. The basic challenge for gas measurement is to determine the energy, since this is generally used as the utility value for the consumer and therefore provides a good basis for fiscal billing. 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 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 standard conditions. For this calculation, volume at flowing conditions must be converted to volume at standard conditions by pressure and temperature state conversion and regarding the non-ideal gas
property of the natural gas. The measuring task of energy billing is described in the equation in Picture 3.

\[ E = V_0 \cdot H_{s,0} = \frac{p \cdot T_0 \cdot T}{p_0 \cdot T \cdot K} \cdot V \cdot H_{s,0} \]

**Picture 3**: Energy is the fundamental quantity in gas industry. It is determined by measurement of the volume under operational conditions \( V \), calorific value at standard conditions \( H_{s,0} \), operational pressure \( p \) and temperature \( T \). Since natural gas is not an ideal gas, the compressibility factor \( K \) must be regarded. The picture also shows examples of typical measurement instrumentation.

\( V \) is the volume, \( T \) is the temperature and \( p \) is the pressure in operating conditions. The index 0 denotes the standard state, \( p_0 = 1013.25 \text{ mbar} \) and \( T_0 = 273.15 \text{ K} \). Natural gas is not an ideal gas which is described by the compressibility factor \( K \). This is calculated with the AGA8 or SGERG equation [2] dependent on the pressure and temperature and also on the quality of the gas. These equations require as input data either the molar gas composition or key gas parameters like e.g. superior calorific value, normal density and \( \text{CO}_2 \) mole fraction. Finally, \( H_{s,0} \) denotes the volumetric calorific value of the gas in the standard state. Picture 3 also shows some examples of gas measurement instrumentation. The leading gas analysis technology for billing is the process gas chromatograph. It supplies a detailed analysis based on substance quantities, relatively slow and discontinuously, but with very high accuracy and precision. Many gas parameters can then be calculated from this molar analysis [3].

In addition to the primary task of gas quality analysis to establish the energy values, there are other gas parameters which are important for ensuring that gas can be transported and consumed safely and efficiently. Such a critical gas property is the Wobbe index that correlates with the heat power of a burner nozzle. Its 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 optimized, 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. These tasks often require a higher measurement dynamics than provided by gaschromatographs. Alternative measurement technologies are based on sensor systems with various measurement principles like infrared absorption, thermal quantities etc. and determine the mentioned gas parameters via a correlative evaluation. Sensor systems typically deliver a less detailed and less accurate analysis than gaschromatographs, but they have the potential for lower costs and for faster and continuous analysis of the desired gas parameters.

Besides the key gas parameters, other measurement tasks are related to individual substances and substance groups such as oxygen O₂, hydrogen H₂, carbon dioxide CO₂, sulfur, particularly H₂S, and also the condensation of water and hydrocarbons. These extended gas parameters are often determined using specialist measuring instruments or by sampling and laboratory analysis. Current, high performance field gaschromatographs, however, now also make it possible to measure the parameters of an extended gas analysis in the process.

2 Process Gaschromatography

Process gaschromatographs for the natural gas industry have the following principal setup:

A carrier gas, typically Helium, is sequentially and continuously flowing through an injector, a thin tube, the so called column, and a detector, typically a heat conductivity or flame ionisation detector. A small amount of sample is injected as a pulse into the carrier gas stream and transported through the column and the detector. The internal of the column is packed or coated with an active material that interacts physically with the components of the gas sample. The different components interact with different intensity with the active material of the column and hence reach the detector at different delay times after injection; this time delay is called retention time. The peak intensity corresponds to the concentration of the corresponding sample component; this correlation is represented by the so-called response factor. The detector signal as a function of time and concentration is called chromatogram. It can be evaluated quantitatively by comparing the peak intensities of the sample chromatogram with the chromatogram of a calibration gas with known composition.
Modern process GCs are based on microsystems technology with micro-electro-mechanical systems (MEMS). The key functional blocks of a GC, injector, column, heating, detector are highly miniaturized and integrated, resulting in various advantages. Due to their small dimensions, injector and detector fit well to capillary columns. The separation performance of gaschromatographic columns increases with decreasing column diameter, hence these capillary columns achieve better analytical performance than classical columns. Furthermore, thermal conductivity detectors on MEMS technology achieve very high linearity and sensitivity. Finally, the consumption of consumables like carrier, calibration and sample gas is significantly lower and allows annual maintenance intervals, an important aspect for the total cost of ownership.

**Picture 4:** Principle set-up of a gaschromatograph

![Diagram of a gas chromatograph](image)

**Picture 5:** Modular setup of the gas chromatograph EnCal 3000 including 2 micro-GC channels

![Modular setup of the gas chromatograph EnCal 3000](image)
2.1 Natural Gas

Due to its genesis and further gas processing before transportation, natural gas is a clean and relatively well defined gas mixture, see also Picture 1. For standard billing requirements it is sufficient to quantify the main components methane, ethane, propane, i-butane, n-butane, neo-pentane (not always required), i-pentane, n-pentane. Furthermore all significant hydrocarbons with higher order than n-pentane must be quantified. However a summary value, the so called C6+, is sufficient. Some process gas chromatographs determine this sum by so-called backflush-to-detector mode. The carrier gas stream is switched to reverse flow, when n-pentane has passed the column, and all higher hydrocarbons are recombined to a summary peak and detected collectively. The evaluation of the calorific value suffers slightly from a small uncertainty, because the detailed distribution of the higher hydrocarbons is not known then. However the summary concentration of these components is in the range of some 100ppm and the effect on the calorific value can be neglected for standard billing purposes. In order to improve this approximation, a so-called brake-down calculation can be applied, that models a typical composition distribution, where the concentrations decrease with carbon order. Other types of process gas chromatograph have no back-flush operation, but make an extended detailed separation of the higher hydrocarbons, typically up to n-C9. This allows a more precise calculation of the gas properties, however the components above e.g. nC9 are then neglected or again modeled by a brake-down calculation.
Picture 7: Chromatogram of natural gas: Major components nitrogen, methane, CO₂, ethane.

Picture 8: Chromatogram of natural gas: Hydrocarbons n-propane, i-butane, n-butane, i-pentane, n-pentane
The measurement performance of a state-of-the-art process gas chromatographs for the calorific value achieves an accuracy of 0.2% for the full range of natural gases and a repeatability of about 0.02%. Modern devices based on micro-GC-technology have a very good linearity, but the residual non-linearity can still be improved by applying an elaborative multi-level-calibration of all significant components, reaching an accuracy well below 0.1%.

2.2 Biogas [4]

Biogas provides a valuable contribution to energy production from renewable sources. It is produced through the microbial decomposition (digestion/fermentation) of organic materials in a moist, anaerobic environment. Renewable primary products (energy plants, such as grain, maize, sunflowers, grass, …), animal excrement, biological waste and waste material from industry and agriculture all serve as raw materials. The composition of raw biogas varies depending on the feedstock with the main components methane and CO$_2$, minor components are N$_2$, H$_2$, O$_2$, H$_2$O, H$_2$S and further trace components.

In the simplest case, biogas can be burnt in a heating boiler and the heat may then be used directly. However, the most efficient utilization is on-site cogeneration of heat and power, where the gas is used in internal combustion engines to generate electricity and the waste heat is used directly, e.g. in local heat networks.

Often however, there is no reasonable possibility for using the waste heat from biogas plants in the surrounding area. In this case, it may be advantageous to upgrade the raw biogas to

**Picture 9:** Chromatogram of natural gas: Hydrocarbons n-propane, n-hexane, hexane-isomers, benzene, cyclohexane
the standard of natural gas and inject it into natural gas grids [5],[6]. Upgrading and injection into the public gas grid allows highly efficient combined heat and power generation anywhere in the supply grid.

For gas injection into the grid, the requirements of product quality and custody fiscal metering must be fulfilled. They are laid down in the DVGW Codes of Practice G 260 [7] and G 262 [8]. The main process of upgrading is a significant reduction of CO₂ below 6%, also the minor components must be reduced below certain limits.

Often the upgraded biogas must be adapted to the gas parameters in the gas grid before it is injected; conditioning may therefore take place, for example by mixing with LPG (Liquid Petroleum Gas) or air.

Custody energy measurement and operational product quality thus require extensive gas quality analysis with the following typical measured variables: CH₄, CO₂, N₂, H₂, O₂, C₃, iC₄, nC₄, and H₂S where applicable. Especially the need to measure O₂ and H₂ is a challenge for field devices. It requires a completely different gas chromatographic method than analysis of natural gas, with a damageable molesieve column and carrier gas argon.

![Chromatogram of upgraded biogas](image)

**Picture 10:** Chromatogram of upgraded biogas: Hydrogen and oxygen demands for a completely different method than for natural gas, with sensitive molesieve columns and argon carrier gas.
2.3 Odorants [9]

Natural gas is odorless. This was painfully experienced when in March 18, 1937 a major disaster struck the New London School in Texas. An enormous gas explosion destroyed the building in just a few seconds. Approximately 300 people got killed and about 200 were wounded. Later it turned out that the cause was a gas leakage that was not noticed because the used gas was odorless.

Although odorization of gas was already known and practiced it was on a voluntary basis. Shortly after this terrible accident it became obligatory to odorize the gas with ethanethiol, also referred to as mercaptane, which became the first odorants for natural gas. Since this time legislation worldwide adapted to this idea and nowadays odorization of natural gas still is common practice with safety of the users of natural gas as the one and only objective.

As indicated ethanethiol was the first odorant to be added to the natural gas.

Meanwhile for various reasons several different components have been used like TBM (tert-butyl-mercaptan), THT (tetrahydrothiophene) and more recently the so called sulfur-free odorants which are gaining popularity because of their environmental friendly features.
To guarantee that people with an average sense of smell will be able to notice the presence of natural gas for example in case of a leakage, concentration limits are defined for the various odorants. There is also a maximum concentration level to prevent unnecessary reporting of alleged gas leakages with harmless leak rates, but also to protect customers and environment against pollution by excessive odorants.

In order to achieve an odorant concentration in the proper bandwidth, gas flow dependent odorization systems are used. These systems get the gas flow information from the gas meter in the station and based on a ratio calculation the proper amount of odorant is injected into the gas stream. A quantitative check of the odorant levels will often be performed as discontinuous spot checks. To reduce the risk of odorization failures continuous measurement devices specialized in the analysis of various odorants are available on the market. Often these are gas chromatography based analyzers equipped with electrochemical detectors that are not maintenance free, may have a relatively short lifetime and are not suitable to measure the main components in natural gas required for the energy measurement itself.

Modern process gaschromatographs based on microsystems technology, like the EnCal 3000, are sensitive enough to detect the low levels of various odorants, like THT, with thermal conductivity detectors. The use of THT as a single component odorant is widely spread all over the world. The concentration ranges of the odorant vary per country but are typically above the detection limit of EnCal 3000 for THT (8 mg/m³ or 2 ppm). What makes the application even more interesting is that it can be combined with the heating value measurement which is the main application for the process gas chromatograph.

In Picture 13 the results of a field test are showing both heating value and THT measurement over a period of 14 days. The average THT concentration found in this test is 4.2 ppm where the odorization system was setup to inject 16-18 mg/m³ which is equivalent to 4-4.5 ppm.

![Picture 13](image)

**Picture 13:** Field test of the process micro-GC EnCal 3000. Simultaneous measurement of calorific value and concentration of the odorant THT.
2.4 Hydrocarbon Dewpoint Analysis [10]

Practical importance of hydrocarbon condensation

Hydrocarbon condensation is very important for safety when transporting gas. Condensate may adversely affect the function and integrity of gas equipment, particularly regulators, valves and measuring systems.

Hydrocarbon condensate can also cause problems when using gas, primarily when used in combustion gas turbines. Condensate can accumulate in the gas transport system and be transported in sudden surges. This can produce temporary overheating and result in the machine suffering damage. But even low, uniform concentrations of condensate can adversely affect the operation of a gas turbine by causing ignition delays or post-ignitions during the combustion process.

Therefore there are sufficient reasons for all parties in the production, transport and consumption chain to specify the potential for hydrocarbon condensation of the natural gas. The hydrocarbon dewpoint is thus often a major gas quality parameter in supply contracts.

For this reason, hydrocarbon condensation is also specified in a range of technical regulations. The DVGW regulations require that the condensation point of hydrocarbons at the relevant pipeline pressure is less than the ground temperature [7], [8]. The EASEE-gas Committee has specified a limit of -2°C for the pressure range from 1 to 70 bar for the hydrocarbon dewpoint [11].

However, specifications require to be checked by means of measurement. Elster has therefore developed an option for establishing the hydrocarbon dewpoint from an extended gas analysis for its process gas chromatograph EnCal 3000.

Hydrocarbon condensation and hydrocarbon dewpoint

Natural gas essentially consists of methane, higher hydrocarbons, nitrogen and carbon dioxide. The higher hydrocarbons, in particular, are prone to condense when exposed to the pressures and temperatures which are typically used in the process. The phase properties of a gas are shown in a so-called phase diagram as a function of temperature and pressure (Picture 14). The hydrocarbon dewpoint at a given pressure represents the temperature at which the hydrocarbons of the natural gas start to condense out of the gas phase. The maximum dewpoint temperature is known as the cricondentherm and for many typical natural gas types, it will typically be in a pressure range between around 25 and 45 bar.
Methods for measuring the hydrocarbon dewpoint

Direct method: Condensation on a cooled mirror
One fundamental method is to find the hydrocarbon dewpoint using a cooled mirror. The mirror is cooled until a film of condensate forms on the mirror surface at the dewpoint. The threshold point is detected in the reflected light so that the dewpoint can be identified. Mirror dewpoint meters have become established as the standard for hydrocarbon dewpoint measurements.

Indirect method: Calculation using the gas analysis
The dewpoint can also be calculated indirectly from the gas analysis using state equations. The benefits of this method compared to direct dewpoint measurements is the fact that it is possible to calculate the complete phase properties of the gas. This means that the dewpoint for a range of pressures or even for the current pipeline pressure can be found. The requirement for this method, however, is a very detailed and high precision analysis of the gas up to the high hydrocarbon orders. This means that the indirect method of finding the dewpoint from the gas analysis generally involves discontinuous sampling and analysis using laboratory gas chromatographs.

ISO 23874 [12] describes the requirements for the gas chromatograph analysis and the algorithm for preparing the chromatograph data for completing the calculation in the state equations. This standard describes the following main steps:

![Phase diagram of a typical natural gas](image-url)
- Standard analysis of the main components of natural gas: Nitrogen N₂, carbon dioxide CO₂ and hydrocarbons from C1 to nC5
- Analysis of the higher hydrocarbons over nC5 to nC12 using boiling point separation
- Individual analysis of the benzene, cyclohexane, methylcyclohexane and toluene components
- Analysis of the unidentified components, generally alkane isomers and modelling their substance properties such as boiling point, from the retention time
- Grouping the unidentified components with the corresponding n-alkane to form an equivalent fraction and modelling the effective substance properties of this fraction.

In a study by the National Physics Laboratory (UK), various direct and indirect methods for measuring the hydrocarbon dewpoint were investigated [13]. The study shows a distribution of the various measuring methods in a range of around 10°C. This means that, on the one hand, the study shows that the determination of the “true” dewpoint is technically demanding and that a specification of the dewpoint measurement should always also define the analytical method to be used. On the other hand, the study also shows, however, that the indirect determination of the hydrocarbon dewpoint using a GC analysis can be a real alternative to the established direct method using a dewpoint mirror.

**Hydrocarbon dewpoint measurement with the process micro-GC EnCal 3000**

Conventional process gas chromatographs for measuring calorific values typically do not supply a suitable analysis for calculating the dewpoint since the hydrocarbons above hexane cannot be determined with sufficient detail or accuracy. The process gas chromatograph EnCal 3000 now offers a detailed and high precision analysis up to n-nonane (nC9). An extended set-up with 3 micro-GC channels can even analyze hydrocarbons until n-dodecane (nC12) (Picture 15). The detection limit for the hydrocarbons in the range of C9 to C12 is about 1ppm. On the basis of this increased analytical performance of the EnCal 3000, Elster has developed an algorithm for calculating the dewpoint, which has been derived from ISO 23874 and to which additional data modeling has been assigned. The results of the dewpoint analysis are well within the distribution of results found by the study from National Physics Laboratory (UK).

The classical key parameters of the gas quality analysis, like calorific value etc. can be derived from the same measurement. Compared to a conventional measuring system consisting of a C6 gas chromatograph and a separate dewpoint measurement with a cooled mirror, the apparatus requirement and therefore the investment and maintenance costs are drastically reduced.
Picture 15: Chromatogram of a C12 calibration gas with a micro-GC with thermal conductivity detector.

Picture 16: Comparison of the dewpoint measurement with various methods on real gas samples: Direct measurements using manual and automatic mirror dewpoint meters. Indirect dewpoint measurement from the gas chromatograph analysis of the EnCal 3000 (internal measurements and study by the National Physics Laboratory [13])
3 Sensor Measurement System for Natural Gas Analysis [14]

This chapter presents a correlative gas quality measurement technology based on a sensor system for 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, has no need for additional carrier gas, 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 and multi-component calibration gas. Present field applications range from billing measurement to control and regulation applications for fast industrial processes.

Measurement Technology

The presented method is based on the typical composition structure of generic natural gas. It consists mainly in hydrocarbons (abbreviated as “CH”), carbondioxide (CO₂) and nitrogen (N₂); these components typically make more than 99.9% of the total gas composition. Thus we approximate the molar composition of natural gas:

\[ x_{CH} + x_{N_2} + x_{CO_2} = 1, \]

with \( x_{CH}, x_{N_2} \) and \( x_{CO_2} \) being the molar fractions of the total hydrocarbons (CH), nitrogen N₂ and carbondioxide CO₂, 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:

<table>
<thead>
<tr>
<th>Measurement Value</th>
<th>Correlating Gas Components</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACH</td>
<td>Infrared Absorbance of the Hydrocarbons</td>
</tr>
<tr>
<td>ACO₂</td>
<td>Infrared Absorbance of Carbondioxide</td>
</tr>
<tr>
<td>( \lambda )</td>
<td>Heat Conductivity</td>
</tr>
</tbody>
</table>

These physical data correlate directly with the molecular gas composition and thus make it possible to determine the key properties of natural gases. Picture 17 illustrates the
measurement method: Hydrocarbons and carbon dioxide 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.

**Picture 17:** Measurement method: The absorption of infrared light correlates with the concentration and composition of the hydrocarbons and the concentration of carbon dioxide. The heat conductivity correlates (non-specifically) with all gas components, also with nitrogen, that is invisible in the infrared spectrum.

The missing information of the hydrocarbons concentration $x_{CH}$, respectively of the complementary nitrogen concentration $x_{N_2}$ can be determined by measurement of the heat conductivity $\lambda$. Therefore a model for the thermal conductivity $\lambda_{\text{model}}$ is used as a function of the molar calorific value of the hydrocarbons $H_{CHm}$ and of the mole fraction of the hydrocarbons $x_{CH}$, nitrogen $N_2$ and carbon dioxide $x_{CO_2}$:

$$\lambda_{\text{model}} = F(x_{CH}, x_{N_2}, x_{CO_2}, H_{CHm})$$

The missing information $x_{CH}$, respectively $x_{N_2}$ is gained by an iterative evaluation algorithm: The unknown quantities are being varied iteratively until the measured thermal conductivity $\lambda$ fits with the model thermal conductivity $\lambda_{\text{model}}$. 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 $\rho_0$
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 (CH₄, C₂H₆, C₃H₈, nC₄H₁₀... nC₈H₁₈, N₂, CO₂)
- Net calorific value, specific density ....

Picture 18 shows the core set-up of the sensor system 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 carbon dioxide.

**Picture 18:** Sensor system for the analysis of natural gas, based on infrared absorption and heat conductivity measurement.

**Outlook**

As mentioned above, there is a discussion to produce hydrogen by hydrolysis with regenerative electricity and to inject that hydrogen into the natural gas grid. Currently there are no significant concentrations of hydrogen in the natural gas grid. Hence the established gas quality measurement instrumentation is not in general specified for hydrogen measurement. The presented sensor system could be extended to an additional gas component, like e.g. hydrogen, with the following approach:

An additional gas component introduces an additional degree of freedom into the set of correlation equations. Hence we need more information about the gas, preferably by additional measurements. This could be achieved by measuring the heat conductivity at an additional temperature, different from the first one. Correspondingly, there would be 2 model equations of the heat conductivity as a function of the composition:
The unknown concentrations could again be found by iterative numerical solution.

**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. The relative deviations of the calorific value and density measurement of the gas-lab Q1 in comparison to laboratory gas chromatographs are displayed in Picture 19. 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 (gaschromatographic analysis). This result was achieved with a single set of calibration data over a wide range of typical generic natural gases.

![Picture 19](image)

**Picture 19**: Left: Test set with a wide range of generic natural gases. Right: Accuracy of the calorific value and density measurement with that test set (single calibration 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 continuous 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. Picture 20 shows the response of the calorific value signal. The response time $t_{90}$ nominates the time for the signal to reach 90 % of the signal step height. The minimum $t_{90}$ of about 10 s was achieved for the core sensor system. The total response time of a measurement system also includes the sampling time from the
pipeline. The sampling time can be minimized towards the response time of the core system by installing a bypass.

Picture 20: Response of the calorific value signal to a sharp change from L-gas to H-gas and back.

The gas-lab Q1 was installed in numerous field applications since 2002. As an example, Picture 21 displays the result of a field experiment in the United States. 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 %.

Picture 21: Field test to investigate the performance of a gas turbine under fast varying gas properties. Continuous calorific value measurement of gas-lab Q1 in comparison to a reference process gas chromatograph as a function of time.
4 Summary

This paper demonstrates the meaning of gas quality measurement in the natural gas industry. The key measurement task is the determination of energy for billing the gas streams in all business processes like transportation, distribution and consumption. Various other measurement tasks and their motivation have been described. Technical solutions for these measurements were explained. The presented applications are mainly based on state-of-the-art micro-GC technology. Another presented instrumentation is based on a correlative sensor system with optical and thermal quantities. It also provides the key task of energy measurement and further key gas parameters, but with a very high sensor dynamics. Both technologies have the potential for further development to meet the requirements of the future gas industry.

5 References