The Different Thermophysical Properties of Natural Gas and Hydrogen and the Resulting Advantages.

The transition away from fossil natural gas to alternatives presents producers, distributors, and consumers with a whole new set of challenges. In many cases the planned transition involves a stepwise and gradual replacement of fossil gas with hydrogen, whilst making use of the existing infrastructure (distribution networks, metering systems, end-use equipment, etc.). However, the distributed nature of hydrogen injection systems and the very different thermophysical properties of hydrogen present a significant challenge for existing measurement and control systems.

In this article we will briefly discuss four significant topics in the transition to hydrogen: the differences in the thermophysical properties of hydrogen compared with natural gas, current hydrogen measurement technology, the impact of hydrogen blends on the efficiency of industrial processes and the importance of tracking hydrogen in the distribution network for fair billing of customers.

The reasons for measuring hydrogen content are manifold and stem from the large differences between the macroscopic properties of hydrogen compared with natural gas, which is primarily composed of methane. Some examples include safety monitoring (hydrogen is more prone to leakage and has a much higher upper explosive limit), power regulation (the volumetric energy density of hydrogen is around 1/3 of methane) and combustion properties (the flame speed and temperature of hydrogen are considerably higher).

Looking at the three gas properties displayed in Figure 1: thermal conductivity λ, heat capacity cp and speed of sound cs, hydrogen clearly stands out. Simplistically seen, hydrogen content can therefore be determined relatively accurately by measuring one or more of these properties. However, this only truly applies when the properties or composition of the "complementary gas" is known and remains constant over time. For these cases cost effective measuring instruments operating on the basis of thermal conductivity or speed of sound measurements are a popular choice. The gasQS static (Figure 4 on the right) is a high-quality example in this category and correlates the hydrogen content of a (quasi-)binary gas mixture from the measurement of thermal conductivity.

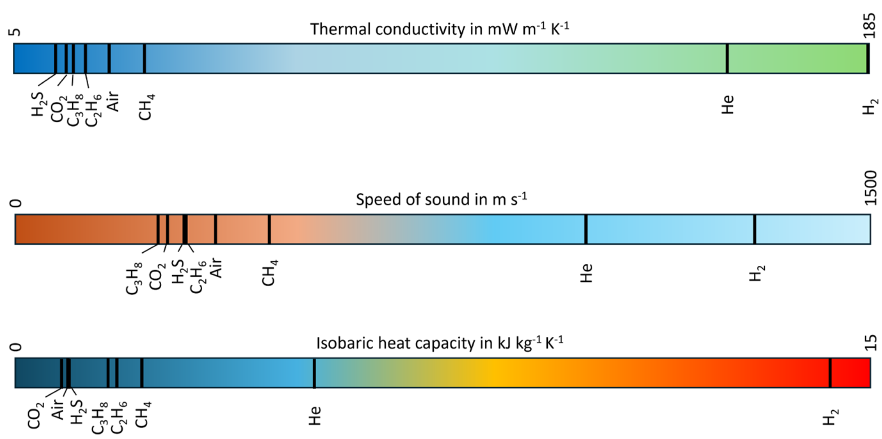


Figure 1: Thermal conductivity, speed of sound and isobaric heat capacity of different gases at 293.15 K and 1.01325 bar.

For more complex gas mixtures, more sophisticated measuring instruments are required, with the ideal instrumentation depending on the particulars of the measurement task. Gas chromatographs remain the gold standard, are however often too expensive or slow for specific applications. Correlative instruments that measure multiple physical properties of the gas mixture (see Figure 2) tend to be faster and lower maintenance and make very good choices, assuming the measurement technology is appropriate for the concentration of hydrogen required. The gasQS flonic (Figure 4) is a gas quality measuring instrument that operates on the basis of thermal conductivity, heat capacity and speed of sound measurements that is able to determine hydrogen concentrations up to 100% in virtually any gas mixture and is as such compatible with a wide range of applications.

Hydrogen tracking in the natural gas network

For blending applications in which the composition of the natural gas is known, the measurement of only one of these gas parameters is sufficient to determine the hydrogen content to high accuracy. Gas quality instrumentation based only on thermal conductivity measurements, such as the gasQS static, is particularly popular for the determination of hydrogen concentration as the underlying sensors are fast, robust, reliable and do not require a defined gas flow. In situations where the natural gas quality is unknown or is dominated by local sources (biogas plants etc.) with temporal variability, then the measurement of a single gas parameter is insufficient to accurately

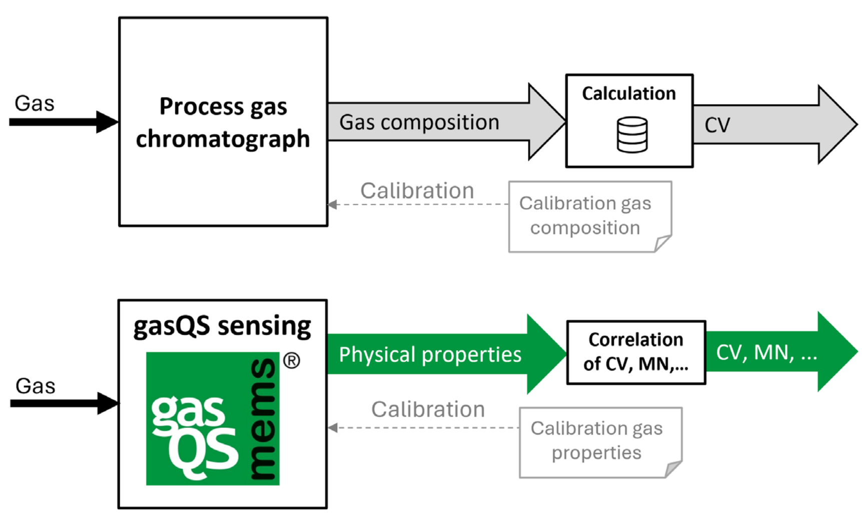


Figure 2: Two approaches to determine calorific value , process gas chromatography above, correlative devices.

determine hydrogen content. Correlative measuring instruments like the gasQS flonic can determine hydrogen content of complex and variable gas mixtures by measuring the thermal conductivity, heat capacity and density of the gas.

In very closely meshed and branched gas networks, such as urban networks, it is not sufficient to determine the gas quality (or hydrogen content) directly at the mixing plant and simulate the calorific value using volumetric flow meters; sensors (e.g. for measuring thermal conductivity) must also be distributed in the natural gas network to ensure fair billing and optimised operation of the end consumers. Initial analyses by the Physikalisch-Technische Bundesanstalt (PTB) show that with knowledge of the volume flow in parts of the network, it appears to be possible to correctly simulate the calorific value with hydrogen in the network in accordance with metrology regulations.

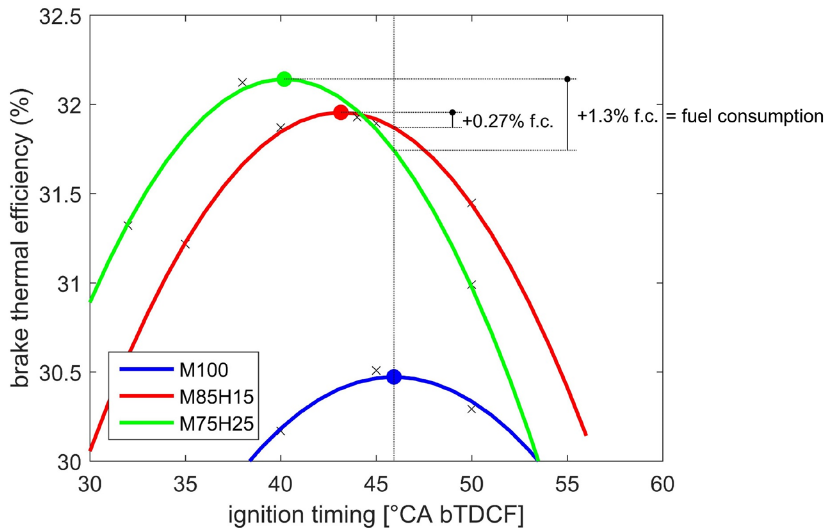
Knocking characteristics of gas engines

Today, CNG engines must be able to tolerate two per cent hydrogen by volume. In order to be equipped for the future, CHP plants in particular must be ready for much higher proportions. The addition of hydrogen to CNG engines appears to improve their thermal efficiency. However, the faster combustion rate at a constant ignition angle leads to higher combustion and end gas temperatures and pressures. As a result, the likelihood of engine knocking increases. [2] With the help of thermal conductivity measuring devices, such as the gasQS static, which collect information about the supplied gas mixture for the engine control system, the engine timing can be adjusted to changing mixtures (see Figure 3). A gas component analysis would be too slow and too expensive to purchase and maintain for many installations.

Hydrogen mixtures in furnaces

The transition to hydrogen and hydrogen blends is a major area of research in hard to abate industries such as the glass manufacturing industry. Due to limitations in the supply of hydrogen, and green hydrogen in particular, it is important that furnaces and associated systems are outfitted to handle a range of gas qualities.

Figure 3 : Ignition timing vs. brake thermal efficiency [5].



The differences in the thermophysical properties of hydrogen and typical natural gas are considerable: the volume flow must be approximately tripled for an equivalent power, and the air requirement reduced by a factor of 4 (V/V) for hydrogen compared to the combustion of a standard natural gas. The combustion characteristics of hydrogen such as flame temperature, flame speed and flame shape result in differences in heat transfer to the melt, production of NOx and conditions inside the furnace and in the exhaust gas. As such, the measurement of hydrogen content is paramount to process efficiency and to ensure the quality of glass production. [3]

Process monitoring in hydrogen production

In hydrogen production, a distinction is made between different degrees of purity for different applications. Purity grade A (industrial applications) [4] can be produced directly in some electrolysis plants. At this grade, the hydrogen produced in an electrolyser contains around 0.5% oxygen. In addition to the product gas measurement, the concentrations of hydrogen in oxygen and oxygen in hydrogen must also be monitored along the entire process chain for safety reasons. Therefore, measuring the hydrogen concentration is important both for ensuring the safety of the process and for quality control of the purity of the final product. Correlative measurement technology, as used in gasQS measuring devices, is very well suited for these applications. It is sufficiently sensitive due to the physical properties of hydrogen but does not drive up the capital and operating costs significantly, even with several measuring points.

Conclusion

All in all, it can be said that the different nature of hydrogen compared to natural gas places new demands on measurement technology, but also enables innovation in new measuring equipment due to its characteristics. •

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Figure 4: gasQS flonic and static.