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Innovative gas property sensing utilizing breakthrough MEMS µ-sampling

White paper

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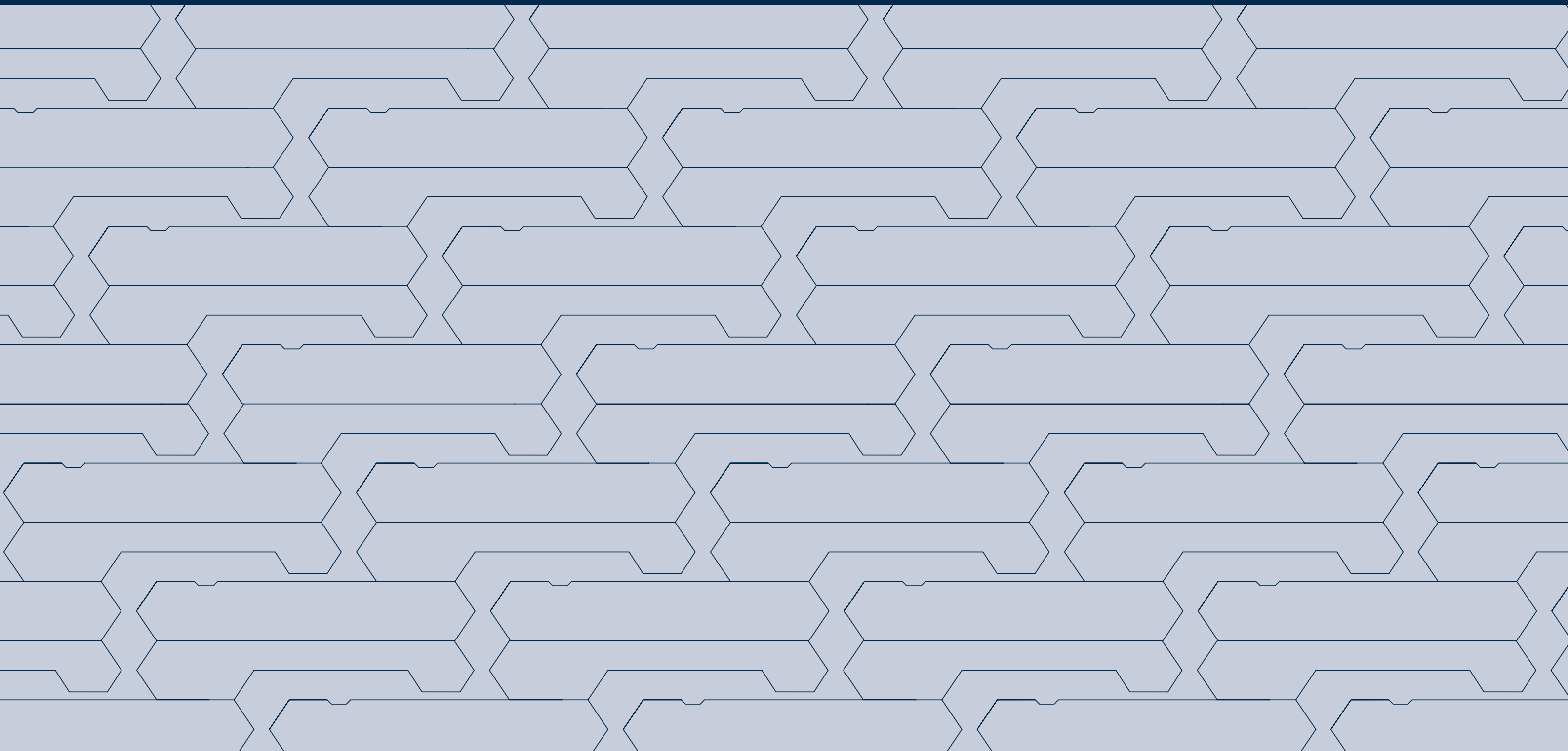

Innovative gas property sensing utilizing breakthrough MEMS µ-sampling

Determination of viscosity and density of gases and gas mixtures

Background and introduction

With a growing sensor market, the interest in and need to measure physical properties of gas and gas compositions continues to climb. The strategic importance of mass flow sensors benefits from this development and they are often preferred in a growing range of applications due to their high accuracy and reliability. MEMS (micro-electro-mechanical system) based thermal flow sensors further enable miniaturization and multifunctionality and thus cost-effective and integrated solutions.

First Sensor is going one step further in terms of multifunctionality. Along with the micro thermal flow sensor, our integrated solution can offer pressure and temperature sensing and also a sensor for determining the gas properties.

Examples of MEMS sensors are thermal flow sensors and micro hot plates. Thermal flow sensors are usually calibrated to the mass flow [kg/s] and depend heavily on physical parameters of the gas such as thermal conductivity and thermal capacity. Because of this, unknown gases or mixtures lead to large errors.

Hot plates are used to estimate thermal properties of gases and allow the estimation of concentration of binary gas mixes . Hot plates with reactive coatings are used for low concentration measurement but require a great deal of heating energy and are consumptive.

Due to the high dependency of thermal flow sensors on thermal parameters, it is beneficial to measure additional properties of gases and mixtures. This paper introduces an innovative sensor principle that allows the determination of additional viscosity and density.

Features and benefits

Thermal conductivity and thermal capacity are typically used to obtain more information about the gas. The measurement of additional gas properties allows improved characterization and thus provides a significantly more accurate flow measurement, especially with changing gas compositions.

For example, O_2 and N_2 are almost indistinguishable in terms of thermal conductivity. However, they show a more differentiated behavior by utilizing viscosity (Figure 1).

The determination of the concentration of gas mixtures consisting of more than binary gases can be accomplished by combining several properties. Figure 2 shows the separation of random gas concentration of a trinary gas composition using two gas properties, in this case density and viscosity. More complex gas mixtures can be resolved by using even more properties, e.g. thermal conductivity.

References

1. Depending on gas mixture and measuring principle. For example, more than two gases are possible using FFT.

Innovative gas property sensing utilizing breakthrough MEMS µ-sampling

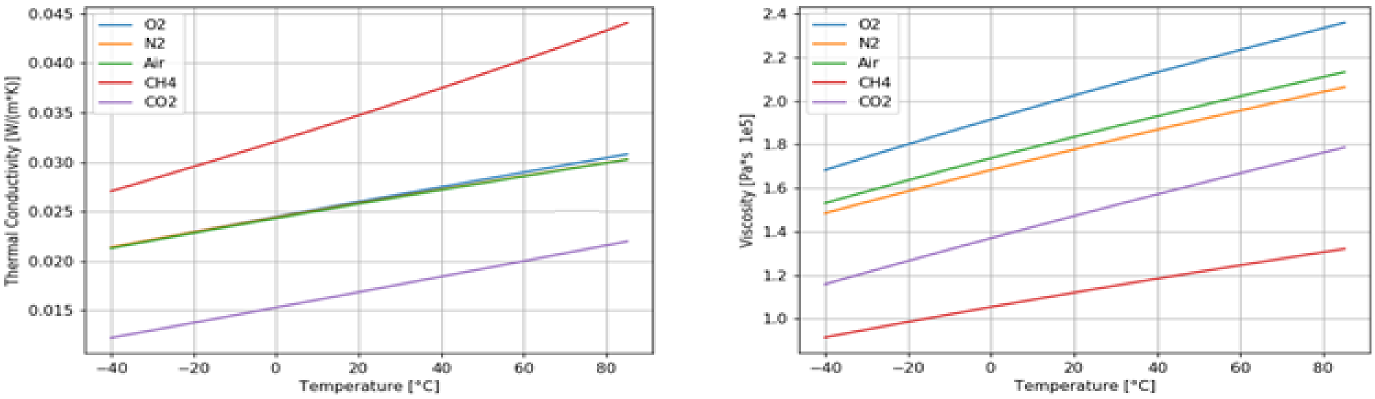

Figure 1: Properties of typical gases

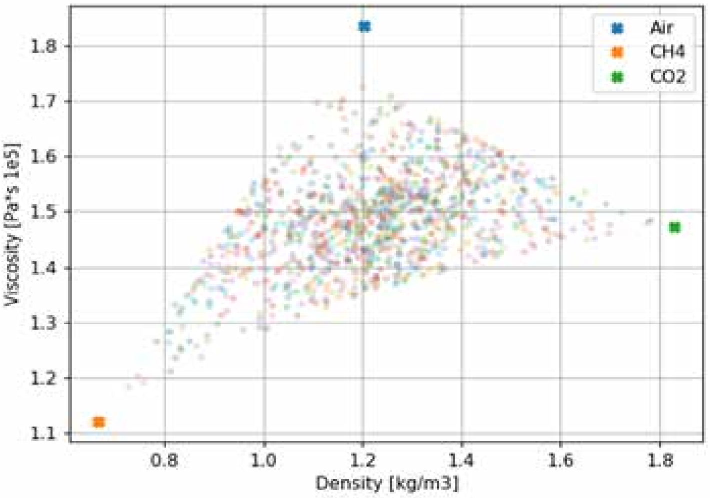

Figure 2: Distinction of a trinary gas composition by using density and viscosity

Thus, by using the published patent gas property sensor (GPS) to determine viscosity and density in addition to thermal conductivity and thermal capacity, a wider range of gas compositions can be detected and compensated, which is of high interest for various applications.

The miniaturized GPS is integrated directly on the thermal flow sensor die and can thus be easily implemented in the application. Due to its innovative design and non-consuming technology, the GPS provides very fast, reliable, and long-term stable results. Its functional principle is shown in Figure 3.

Functional principle

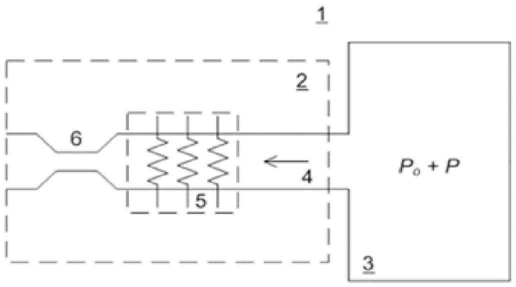

Figure 3: Setup of the gas property sensor

The underlying function is the displacement of a known volume within a MEMS µ-chamber [Figure 3, (3)]. This leads to an overpressure, P, which causes an outflow through the channel (4). This flow is guided over a mass flow sensor (5). Through this, the density of the gas can be calculated with known volume and mass:

$$\rho = \frac{m}{V}$$

Furthermore, the outflow is restricted by the resistance (6). The curve shape of the outflow rate depends i.a. on the viscosity η_a of the gas and can be estimated as follows:

$$\dot{\gamma}_{\mathrm{a}} = \frac{6Q}{wh^2},$$

$$\sigma = \frac{wh}{2(w+h)}\,\frac{\Delta P}{l},$$

$$\eta_{\mathrm{a}} = \frac{\sigma}{\dot{\gamma}_{\mathrm{a}}},$$

$\dot{\gamma}$ is the apparent shear rate (s^{-1}),
σ is the shear stress (Pa),
η_a is the apparent viscosity (Pa·s),
ΔP is the pressure difference between the leading pressure sensor and the last pressure sensor (Pa),
Q is the flow rate (ml/s),
w is the width of the flow channel (mm),
h is the depth of the flow channel (mm),
l is the distance between the leading pressure sensor and the last pressure sensor (mm).

With these characteristics the gas type gets a unique fingerprint and can be identified via an algorithm that's runs on the sensors front-end electronic.

Innovative gas property sensing utilizing breakthrough MEMS µ-sampling

Simulations

In the following simulations, only one physical parameter was changed at a time with a virtual gas mixture. The figures show the mass flow at the mass flow sensor depending on density and viscosity.

Changing the density (Figure 4) for typical gases shows significant change of amplitude and area of the mass flow sensor signal. The shape of the curve does not change.

In case of changing viscosity (Figure 5), the curve shape changes significantly, the area under the curve remains constant.

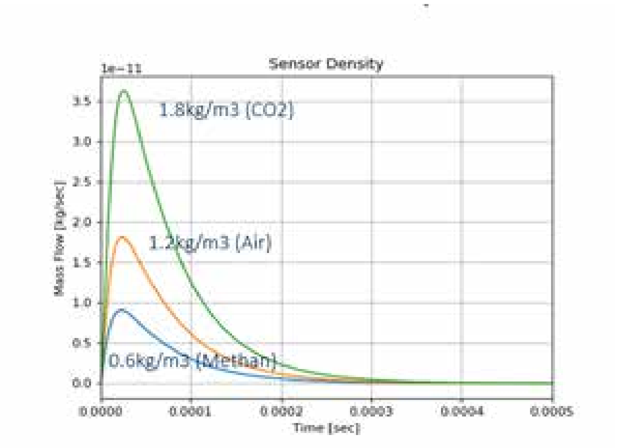

Figure 4: : Density-driven amplitude changes

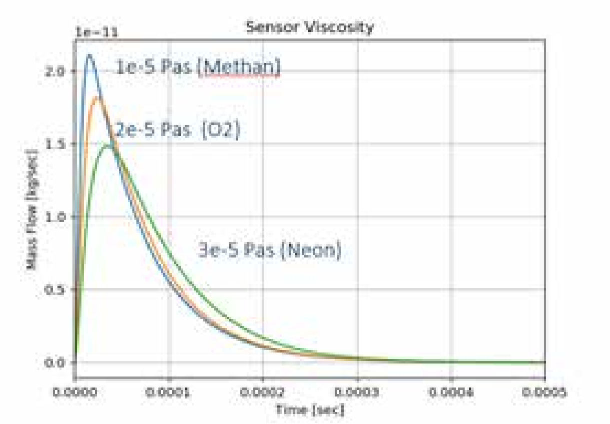

Figure 5: Viscosity-related changes of the curve shape

Conclusion

The innovative sensor-principle with the combination of measuring the thermal volume expansion and the mass flow measurement allows the determination of additional gas parameters such as density and viscosity. Together with standard parameters such as thermal conductivity and specific thermal capacity, the GPS can therefore be used to measure several properties of gas mixtures. This makes it possible to determine gas concentrations of difficult binary or higher-order gas mixtures. Furthermore, it can be used to compensate errors of thermal mass flow sensors by detecting gas properties for an unknown composition of gas mixtures, resulting in more accurate flow measurements.

The GPS provides very fast (~20ms per measurement), reliable, and long-term stable results by consuming very low power in the range of only a few milliwatts. The published patent GPS can be customized and calibrated to many different gas mixtures and is well-suited for all applications where gases have to be differentiated. Multidimensional parameter determination also provides cost-effective alternatives to very complex gas analysis and gas mixture identification methods for various applications, such as within the natural gas, industrial, and medical areas.