

Impact of Water on the Temperature Homogeneity in a High-Temperature Gas Sensor

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Summary:

The study investigates the impact of water in the exhaust gas on the temperature homogeneity of high-temperature gas sensors. The sensors are equipped with a rear-side platinum heater and five front-side thermocouple junctions to monitor the temperature distribution. Experimental results show that increasing water content has a cooling effect, requiring higher heating power to maintain the target temperature. It also leads to local temperature variations across the sensor substrate. These temperature inhomogeneities may lead to significant measurement errors in temperature-sensitive gas sensors.

Keywords: high-temperature, gas sensor, impact, water, temperature homogeneity

Introduction

In many exhaust gas applications, such as in the automotive sector or biomass combustion, gas sensors are exposed to harsh environmental conditions. This includes, on the one hand, very high flow velocities, particle-loaden exhaust gases, and high exhaust temperatures. To withstand these conditions, high-temperature gas sensors are employed [1-4]. An example of such a high-temperature gas sensor is a thermoelectric hydrocarbon sensor. This sensor utilizes the thermoelectric voltage as the measurement signal. Here however, a temperature variation of 2 °C can correspond to a propene concentration of 1000 ppm [1, 5]. Therefore, a precise temperature control is of great importance for these sensors, as temperature fluctuations can lead to erroneous measurement signals [1-3]. For this reason, the cooling effect of water (H₂O) in the gas atmosphere plays a significant role.

Methods and Setup

Typical high-temperature gas sensors are fabricated on ceramic substrates. The dimensions of these sensors are 50.8 mm in length, 6.35 mm in width, and 0.63 mm in height. To maintain the sensors at their operating temperature, a screen-printed platinum heater structure is located on the rear side of the sensor. It enables heating to the desired operating temperature of 600 °C and allows temperature control via a four-wire resistance measurement and subsequent heater control. On the front side, thermocouples made of gold (Au) and platinum (Pt) conductors are printed, providing five thermocouple junctions (see Fig. 1). These measurement points are positioned in a way that they represent the temperature distribution in a region relevant to gas

sensing. The temperature at the measurement points can be calculated from the measured thermoelectric voltage using the Seebeck coefficient for Pt/Au [2].

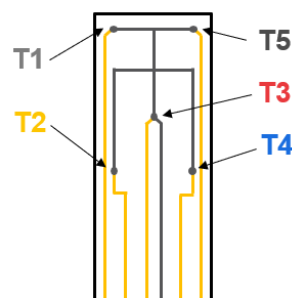


Fig. 1: Schematic representation of a sensor with five thermocouple junctions

Results and Discussion

To investigate the influence of water on the temperature homogeneity of the sensor substrate, the sensor was mounted horizontally (with the thermocouple junctions facing upwards) in an exhaust gas pipe. At a constant total flow rate, the H₂O-content was increased from 0 to 10 vol.% in steps of 2.5 % and subsequently decreased again. The base gas consists of 10 % oxygen (O₂) in nitrogen (N₂). Fig. 2 a) shows the measured temperatures (T1–T5, corresponding to the thermocouple junctions shown in Fig. 1) on the front side of the sensor, the dosing of the water content (see Fig. 2 b).

The heater was operated at a constant voltage, resulting in a temperature of 600 °C at the central temperature measurement point T3 under exposure to the base gas (see red curve in Fig. 2 within the first 300 s).

When examining the temperature measurements, it is immediately apparent that the temperature at all measurement points decreases significantly with increasing water content. The temperature at the central measurement point (T3) decreases by 5 °C when the water content is increased from 0 to 10 %. While the temperatures at the sensor tip (T1 and T5) show a stronger cooling of 7 °C, the temperature decrease at the more inward measurement points T2 and T4 is lowest, amounting to 4 °C.

In addition, the cooling behavior reveals that the lateral temperature decrease at the left edge of the sensor (T1 and T2) is comparable to that at the right edge (T4 and T5). This behavior is expected, as the water content changes uniformly within the surrounding gas. Furthermore, the diagram shows a uniform cooling behavior both during an increase and a decrease in water content, indicating a linear relationship between cooling and water concentration.

It can also be observed that the absolute temperature on the left side of the sensor (T1 and T2) is higher than the corresponding values on the right side (T5 and T4). Possible reasons for this include a slightly tilted installation of the sensor relative to the horizontal orientation. Another potential cause could be a slightly off-centered, asymmetric printed heater structure on the rear side of the sensor.

Despite these inaccuracies, the cooling effect of water on the sensor temperature is clearly evident.

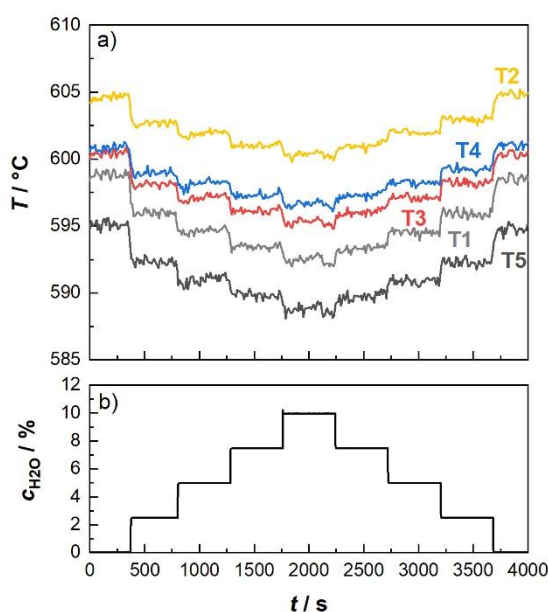


Fig. 2: a) Measurement of the temperature at five thermocouple junctions, b) concentration of H_2O

Conclusion and Outlook

The results show that increasing water content in the exhaust gas causes a clear and nearly linear cooling of the sensor, affecting all measurement points. Temperature reductions of several degrees Celsius, especially at the sensor tip, are critical for thermoelectric hydrocarbon sensors due to their high temperature sensitivity. Consequently, water-induced cooling effects must be considered in sensor operation and calibration to ensure reliable measurements under realistic exhaust gas conditions.

In further steps, the cooling influence of the water content will be investigated for a heater operated under constant temperature control. Here, the heating power of the platinum heater applied to the tip of the rear side, can serve as an additional signal to correct the sensor signal with respect to the cooling effect of water. It has to be considered that an increasing heater power might lead to additional individual temperature inhomogeneities due to installation or production anomalies.

References

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