Temperature compensation of a gas sensor for binary mixtures based on the permselectivity of polymeric membranes

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Abstract

A new concentration sensor for binary gas mixtures based on the permselectivity of polymeric membranes has been recently developed. The sensor responds to temperature changes. This work describes a simple way to compensate most of the temperature effect on the sensor’s response. Different membrane materials and gas mixtures were tested. The present approach proved to be especially beneficial for a PDMS based sensor when analyzing oxygen/nitrogen gas mixtures.

Keywords: Membrane-based sensor; Temperature compensation

1. Introduction

Sensor technology is a rapidly growing area with new applications being reported every year in the several journals covering this topic\cite{1,2}. Polymeric membranes are widely used in sensors applications either participating in the sensing mechanisms or immobilizing the component responsible for the sensing\cite{3–5}.

Polymeric membranes have been used in the development of low cost sensors for analyzing binary gas mixtures. By using inexpensive gas sensors it is possible to design relatively cheap, small and rugged analyzers capable of continuous on-line analysis of gas streams.

The concentration sensor is made of a membrane module, a pressure sensor and a needle valve. The needle valve is placed at the permeate outlet. The pressure sensor reads the pressure of the permeate chamber\cite{6}. At a given temperature and when the sample is being fed at a constant pressure, the permeate chamber pressure relates to the sample composition\cite{7–10}.

The calibration curves obtained with this sensor, for some gas mixtures at different temperatures, differ from each other mostly by a translation, see Fig. 2a. In some cases the response of the sensor is directly proportional to the absolute temperature variation, as happens with the pressure of an ideal gas,

\begin{equation}
P_{\text{translate}} = \left( \frac{T_{\text{translate}}}{T_{\text{input}}} \right) P_{\text{input}}
\end{equation}

where $P_{\text{translate}}$ is the absolute permeate pressure read at temperature $T_{\text{translate}}$, when the sensor reads $P_{\text{input}}$ at temperature $T_{\text{input}}$.

The response of the sensor can then be easily corrected if a differential pressure sensor is used; one of the pressure sensor’s terminal can be connected to a small container filled with an ideal gas (e.g., nitrogen), while the other can be connected to the permeate chamber, Fig. 1. If the temperature increases, the permeate pressure increases approximately proportionally to the absolute temperature variation, exactly in the same way as the gas in the container. This way most of the temperature effect on the concentration sensor’s response is cancelled.

To increase the precision of the response, the pressure sensor range should be only slightly larger than the permeate pressure range of the concentration sensor; the pressure in the container should be, e.g., equal to the lowest permeate pressure, see Fig. 3a. However, when at rest, the permeate pressure should be the ambient pressure and a high pressure difference might occur.
For this reason, the pressure sensor should stand at a high over pressure, as is the case of the Honeywell-143PC05D (pressure range, ±5 psi; maximum overpressure, 30 psi; repeatability, ±0.15%).

This improvement was tested with three gas mixtures, oxygen/nitrogen, carbon dioxide/helium and hydrogen/methane and two membrane materials. Two membrane modules of hollow fibers were considered, one using poly(dimethylsiloxane) (PDMS) composite membrane (with a poly(etherimide) (PEI) support) and the other using PEI integral asymmetric membrane. Both membranes were supplied by GKSS, Geesthacht, Germany.

2. Results and discussion

The experimental data presented below, Figs. 2–4, were obtained previously [7–9]. Three gas mixtures and two polymers were studied: oxygen/nitrogen with PDMS membranes, PDMS\(\text{O}_2/\text{N}_2\); carbon dioxide/helium with PDMS membranes, PDMS\(\text{CO}_2/\text{He}\), and hydrogen/methane with PEI membranes, PEI\(\text{H}_2/\text{CH}_4\).

The response of the sensor’s permeate pressure depends both on the membrane and needle valve bi-component permeabilities. The temperature has different effects on these permeabilities. The combined result is hard to forecast but in some cases it follows a simple pattern.

Fig. 2 shows the concentration sensor response to three temperatures, 283, 298 and 313 K. The response of each sensor, permeate pressure, increases with the temperature. However, sensor PDMS\(\text{O}_2/\text{N}_2\) shows a behavior with the temperature that is different from the others.

In Fig. 3, the previous response curves obtained at 283 and 313 K were translated to 298 K using Eq. (1). This correction corresponds to the use of a differential pressure sensor instead of an absolute one.

From this figure it is possible to see that for the PDMS\(\text{O}_2/\text{N}_2\) sensor the correction is quite good when \(x(\text{O}_2) \leq 0.6\). The absolute error on the oxygen feed molar fraction ranges from \(5.7 \times 10^{-4}\) to \(5.0 \times 10^{-2}\), oxygen molar fractions, respectively, 0.25 and 1.0, and 283.45 K, and from \(8.0 \times 10^{-4}\) to \(6.4 \times 10^{-2}\), oxygen molar fractions, respectively, 0.30 and 1.0 and, 313.15 K.

Fig. 4 shows the permeate pressure \(P^P\) as a function of temperature \(T\) for the PDMS\(\text{O}_2/\text{N}_2\) sensor when the oxygen feed molar fraction was 0.128, temperature ranges from 278.65 to 322.98 K. The solid symbols are experimental data [7] and the solid line was obtained using Eq. (1). It can be seen that Eq. (1) fits quite well the experimental data for \(x(\text{O}_2) = 0.128\).

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Sensor PDMS/O₂/N₂ shows a qualitatively similar response to the previous sensor but here the deviations are slightly higher, especially for x(O₂) ≥ 0.7. The absolute error on the carbon dioxide feed molar fraction ranges from 3.2 × 10⁻³ to 9.2 × 10⁻², carbon dioxide molar fractions, respectively, 0.60 and 1.0, and 283.25 K, and from 3.8 × 10⁻³ to 7.5 × 10⁻², carbon dioxide molar fractions, respectively, 0.05 and 0.05, and 312.15 K.

Sensor PEI/H₂/CH₄ functions differently and the errors are higher than for the previous systems. The absolute error on the hydrogen feed molar fraction ranges from 1.5 × 10⁻³ to 1.2 × 10⁻¹, hydrogen molar fractions, respectively, 0.45 and 0 and 283.45 K, and from 2.3 × 10⁻³ to 9.9 × 10⁻², hydrogen molar fractions, respectively, 0.40 and 0 and 314.45 K.

3. Conclusions

A simple method to compensate the temperature dependence of the concentration sensor is described and evaluated for different membrane materials and gas mixtures. This method corrects most of the temperature effects of sensor PDMS/O₂/N₂ for oxygen molar fractions below 0.60, absolute error smaller than 5.7 × 10⁻⁴, when temperature is changed to ±15 K around 298 K. For molar fractions above 0.60, the maximum absolute error obtained was about 5.0 × 10⁻². For sensors PDMS/O₂/N₂ and PDMS/CO₂/He, the proposed method corrects most of the temperature effects and reduces the need for sophisticated algorithms to correct the response of the sensor to temperature variations.

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