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The Optimization of a Photoacoustic Refrigerant Sensor System Using a Three-Chamber Concept

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Summary:
Ever since the ban of the refrigerant R134a in 2017 for all newly manufactured vehicles, due to its high global warming potential, the necessity of low-cost, reliable and precise refrigerant measuring devices has arisen. We present a photoacoustic gas detector for the refrigerants R134a and the environmentally-friendly alternative R1234yf. The sensor consists of a detection, an absorption and a filter chamber. The influence of the filter chamber length on the sensor signal was evaluated and a signal drift, originating from filter chamber leakage, was successfully eliminated and validated by FTIR measurements.

Keywords: Photoacoustic detector, photometer, refrigerants, R1234yf, R134a

Background, Motivation and Objective

Carbon-fluorine based refrigerants are classified as greenhouse gases due to the high global warming potentials (GWP) [1]. The refrigerant R134a has a GWP value of 1300 (according to the fifth assessment of the IPCCC from 2013) when compared to carbon dioxide. This led to a, since 2017 effective, European ban on R134a air conditionings for all newly manufactured vehicles [2]. The hydrofluoroolefin R1234yf is considered an environmentally less harmful alternative (GWP of 4) and shows similarities in the thermodynamic properties [1]. R1234yf is far more expensive than R134a. To prevent illegal refillings of cheaper gas mixtures containing both refrigerants, low-cost refrigerant gas analyzers are required. We present a newly developed photoacoustic (PA) R134a and R1234yf detection method, with special focus on the optimization of the filter chamber geometry and the reduction of sensor signal drifts.

The Three-Chamber Photoacoustic Detector

An IR broadband light source and a commercially available MEMS microphone were used. The large main absorption bands of R134a and R1234yf coincide, which makes it difficult to identify a quantitative gas mixture, that consists of both refrigerants [3]. A separated detection of the individual gases in a gas mixture was achieved with the three-chamber concept. The PA cell (Fig. 1) consists of a detection (DC), an absorption (AC) and a filter chamber (FC).

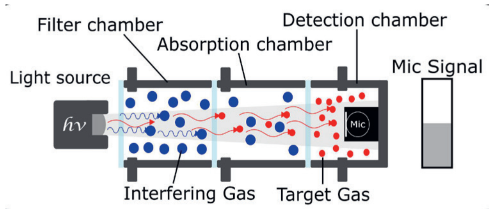

Fig. 1: The three chamber based PA detector. The filter chamber is filled with the intruding gas, while the detection chamber consists of the microphone and the target gas. The examined gas mixture is introduced into the absorption chamber.

The MEMS microphone and the target gas are hermetically sealed into the DC. The AC is filled with the analyzed gas sample. Additionally, the FC is filled with the known intruding gas, to manipulate the spectrum of the IR light source, removing the spectra of non-target gases. An ideal FC would absorb all photons of the intruding gas before reaching the AC and by that, reducing the cross sensitivity of the detector towards the interfering gas. The leftover photons are absorbed afterwards by the introduced target gas in the AC, reducing the light intensity reaching the DC. The detected microphone signal in the DC drops, depending only on the target gas concentration in the AC and independent of the interfering gas.

Influences of the Filter Chamber Length

Three filter chambers with variating lengths (20, 50 and 80 mm) were manufactured (by SIMEK GmbH) for an experimental determination of the

FC geometry influences on the detected signal. The following experiments were carried out with a R1234yf detector. Therefore, the DC is filled with R1234yf and gets hermetically sealed. The filter chambers were filled through silicone tubes with the interfering gas R134a. The silicone tube were mechanically shut with a clamp during the following experiments. To test the efficiency of the FC, the two refrigerants were separately introduced into the AC, while variating the concentrations of the respective gases (Fig. 2). The respective refrigerant concentrations were set to 40, 60 and 80 vol.-% at a flow velocity of 50 ml/min.

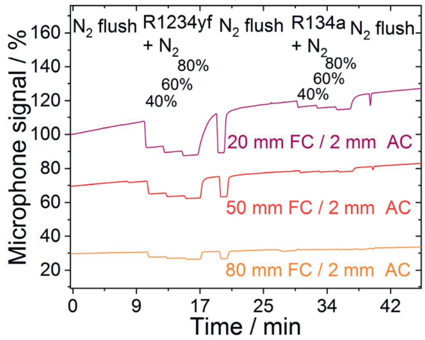

Fig. 2: R1234yf detector: Influence of the filter chamber length on the cross sensitivity and absolute signal strength.

The measurement results show a reduction of the cross sensitivity with increasing FC lengths, while the absolute signal strength and therefore the signal-to-noise ratio is reduced with increasing length (Fig. 2). The functionality and importance of the FC were verified by these measurements. The drift in the plots is resulted by the escaping R134a out of the not gas-tight filter chambers.

Optimizing the Filter Chamber

To assure a complete hermetic closure of the FC, metallized silicon windows were soldered to the respective window openings of the 50 mm long FC. In a second step, the tested FC was filled with R134a. Subsequently, the filling tubes of the chamber were mechanically crimped and soldered afterwards, resulting in a gas tight sealing (Fig. 3).

Fig. 3: a) The gas filled filter chamber after a hermetic sealing with soldered silicon windows. b) The crimped and solder sealed filling tubes.

The experimental results in Fig. 4 include measurements before (red) and after (black) the solder sealing of the gas filled filter chamber. The respective measurements were executed for about 18 hours to check the long-term stability of the detected R1234yf sensor signal. The AC was filled with N_2 during the measurements. It can be observed in Fig. 4, that the black curve of the gas filled FC with an additional solder sealing is a perfect straight line with no observable drift effect occurring, while the red curve shows an exponential increase of the sensor signal and reaches a plateau after 13 hours. The signal of the mechanically sealed FC (red curve) increased by 75% from its original value due to the loss of R134a from the not gas tight FC.

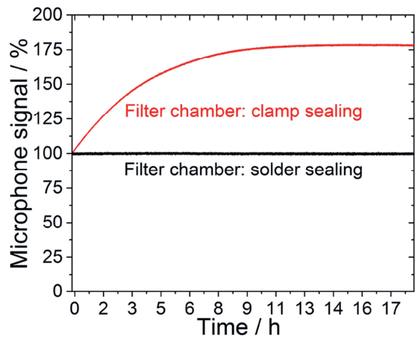

Fig. 4: Comparison of the R1234yf sensor signal long-term stability before and after a soldered sealing of a 50 mm long filter chamber (filled with R134a).

Conclusion

The experiments with the different gas filled filter chamber lengths showed, that an increase in the FC length reduces the cross sensitivity and the signal strength of the sensor system simultaneously. The measurements showed strong drifting of the sensor signal, which was eliminated after hermetically sealing the FC. A solder sealing of the gas filled measurement system chambers showed long term sensor signal stability.

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