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Monitoring Food Aging in a Refrigerator with GC/MS and Gas Sensor Systems

Julian Joppich[1], *My Sa Marschibois*[1], *Tobias Baur*[1], *Oliver Brieger*[1], *Caroline Schultealbert*[1], *Martin Leidinger*[2], *Thorsten Conrad*[2], *Andreas Schütze*[1]
[1] Saarland University, Lab for Measurement Technology, Saarbrücken, Germany
[2] 3S GmbH – Sensors, Signal Processing, Systems, Saarbrücken, Germany
j.joppich@lmt.uni-saarland.de, m.marschibois@lmt.uni-saarland.de

Summary:
We are targeting novel smart gas sensor systems to reduce food waste mainly from end consumers. To identify characteristic components and adequate sensors and sensor operation modes suitable for determination of these gas patterns during storage and aging, studies with different foods have been conducted. Besides a GC/MS, the test setup consists of several gas sensors, located both behind the chromatography column and parallel to the GC/MS, i.e. without separation of the compounds. First results show that emissions of aging food can be detected both by the GC/MS and by the gas sensors.

Keywords: food aging, food waste, gas chromatography/mass spectrometry (GC/MS), metal oxide semiconductor sensor, smart gas sensor

Background, Motivation

Approximately a third of the global food production is wasted while approx. one billion people worldwide are suffering hunger. In Europe, mostly fruit and vegetables go to waste or are discarded during production. Around 50 % of overall food waste is due to consumer behaviour, and more than 50 % of that waste is avoidable [1]. Since food waste accounts for 3.3 billion tons of CO_2 emissions, it is also a huge burden for the environment [2]. Against the backdrop of today's climate crisis, this is another reason to minimize food waste.

Low-cost gas sensor systems could help consumers reduce food waste. Different solutions seem possible, i.e. handheld devices for immediate analysis of dairy products after opening instead of relying on the "best before" date or continuous monitoring of the inside of a refrigerator. Specific gas emissions could, e.g., help determine when specific foods should be consumed. These sensor solutions could therefore prevent disposing of edible food or spoilage of food during storage.

Materials and Methods

To be as realistic as possible, a large commercial refrigerator is used and modified to our needs, see also Fig. 1: it is equipped with 32 closed storage boxes, containing different food samples. The storage boxes are connected to a valve block, which allows sampling the headspace of each box individually. At defined intervals, gas samples are automatically drawn from the sample boxes by a pump. Pump and valves are controlled by a multi gas sensor system supplied by the company 3S GmbH (D); the device contains two metal oxide semiconductor (MOS) gas sensors. The sample air is also passed through an additional, custom-built sensor system [4], equipped with a SGP30 (Sensirion AG, CH), a BME680 (Bosch Sensortec GmbH, D) and a ZMOD4410 (Renesas Electronics Corporation, JPN); all are operated using TCO (temperature cycled operation, [3]).

Parallel to these sensor systems, the gas composition is analysed by a GC/MS (Thermo Fisher Scientific, Trace 1300 Gas Chromatograph, ISQ 7000 Single Quadrupole Mass Spectrometer; TG-624 60 m/0.25 mm/1.4 µm column, temperature program, S/SL injector, headspace injection). To ensure a reliable synchronisation of the GC/MS with the valve operation, a trigger is provided by a custom-built controller. In addition, further MOS gas sensors (an AS-MLV-P2 (ScioSense, NL, former ams AG), a SGP30 and a ZMOD4450) are located parallel to the MS behind the GC column and run at constant temperature, i.e. they are supposed to detect separated compounds. The split between sensors and MS is approximately between 8:10 and 9:10.

The food to be tested, including different fruits (banana, citrus fruits), meat and fish, was stored in the storage boxes for up to 14 days, the box headspace was analysed at least once a day. The temperature of the refrigerator is set to 6 °C.

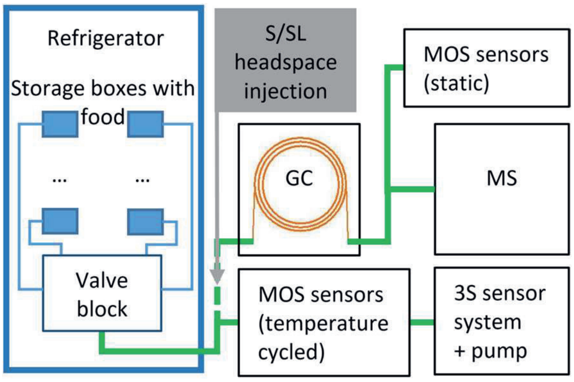

Fig. 1: Sketch of the measurement setup including storage boxes in the refrigerator, valve block, GC/MS and gas sensor systems.

Results

The exemplary results from the banana boxes (day 10) show that the chromatogram of the GC/MS and the peaks of the MOS sensor (AS-MLV-P2) correspond very well (see Fig 2).

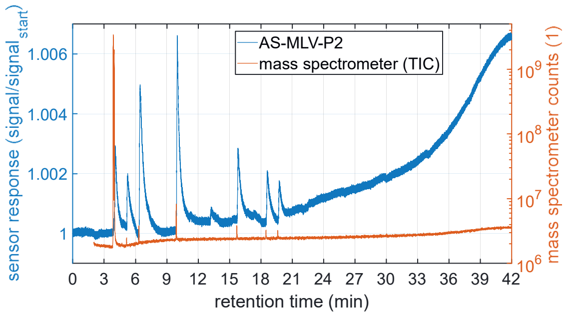

Fig 2: Chromatogram of a banana box after 9 days of storage and corresponding MOS sensor signal.

In fact, the MOS sensor has a higher sensitivity and detects additional peaks that are not visible in the MS signal (e.g. at about 13 minutes), although the split between the MS and the MOX sensors provides a higher flow to the MS. However, the sensor shows tailed peaks, which might originate from effects of the sensor chamber or from the sensitive layer. The ascending baseline might be ascribed to increasing column bleeding with increasing column temperature and flow. Moreover, while the first two peaks (the peaks of the permanent gases) do not grow over the course of the days, almost all other peaks grow or occur as the food (banana) ages. The assignment of peaks to substances is summarized in Tab. 1.

The temperature cycled sensors show a distinct response during exposure to the atmospheres of the boxes, and different foods and degrees of aging result in different patterns.

Tab. 1: Identified peaks in the chromatogram of Fig. 2.

Retention time (min)	most probable substance(s)
3.85 - 3.88	O_2, N_2, Ar
3.96	CO_2
5.14	acetaldehyde
6.32	ethanol
9.90	ethyl acetate
13.12	presumably pentanone (only MOS sensor)
15.70	isobutyl acetate
18.49	2-pentanol acetate
19.61	1-butanol-3-methyl acetate

Summary and Outlook

The results of the first measurements with the complete setup indicate that the sensors are suitable to detect components emitted by aging food that can be assigned to spoilage. GC peaks were successfully detected by the MOS gas sensors, further work on improving the peak shape and quantification abilities are foreseen. Data of the temperature cycled gas sensors have to be evaluated by means of pattern recognition. Finally, the ongoing systematic measurements will give an insight in the compounds and patterns of the emissions of various types of food needed to determine the degree of aging over a longer time. An additional challenge in the future will be the reliable recognition of these gas patterns in presence of a variety of cross influences inside a normal refrigerator.

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