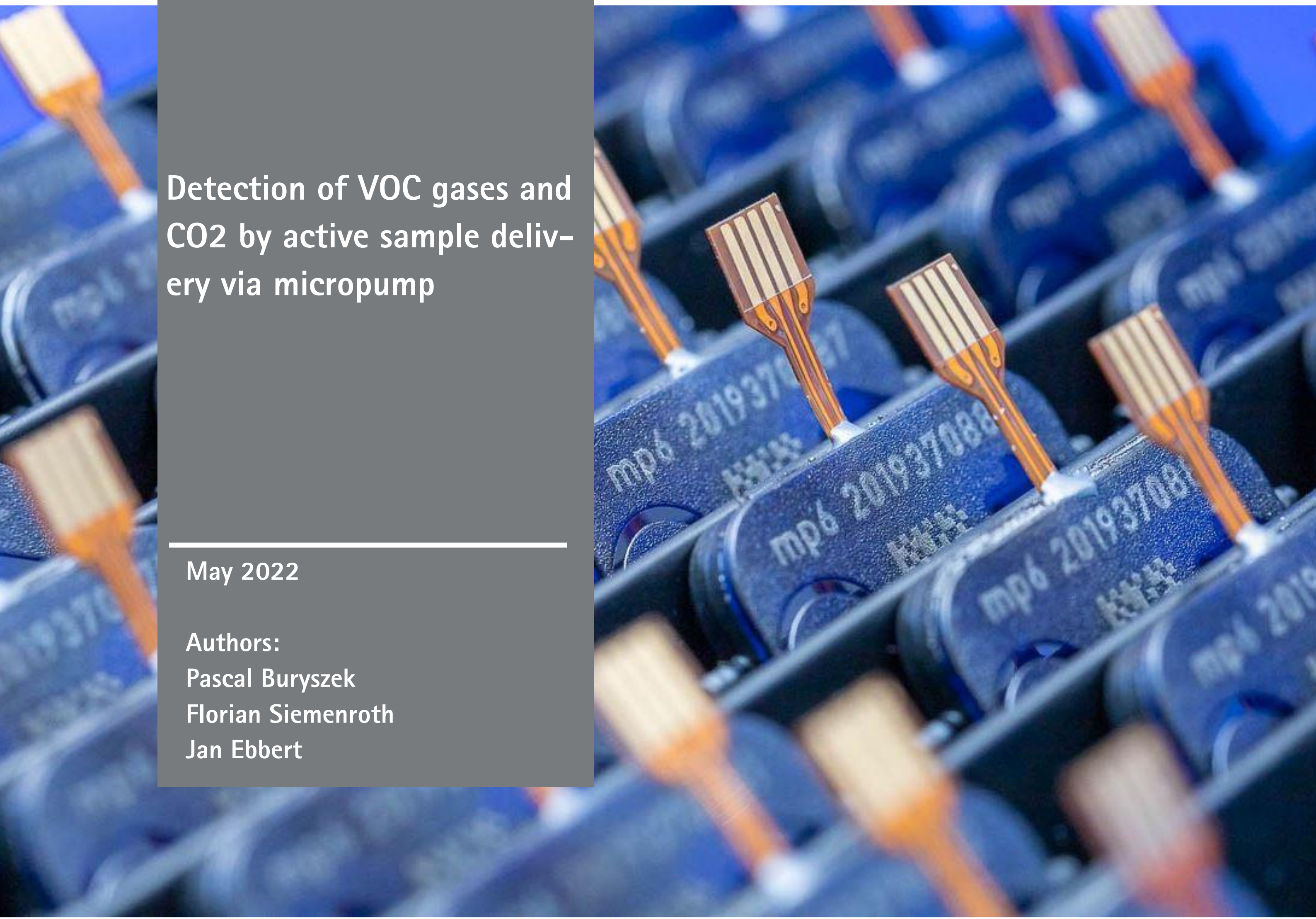
CASE STUDY

Bartels mikrotechnik

with passion for microfluidics



Detection of VOC gases and CO2 by active sample delivery via micropump

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Non-invasive and active measuring of gases

Increased reaction time

Process and quality monitoring

Sensing ambient gas phase compositions is a crucial task in today's everyday life. Be it for containing stable conditions or for supervising potential toxic concentrations, in many circumstances gas phase analysis has become a powerful tool.

When analysing cell growth, it is essential to observe carbon dioxide levels. Additionally, when ambient pollution has to be measured, volatile organic compound (VOC) sensors are used.

In the following experiment, it will be shown how via the mp6 micropump by Bartels Mikrotechnik GmbH it has become possible to transport gas phases in microliter proportions to such sensors. It is of great importance to understand whether and how the procedure is functioning. Thus, the gas phase biological experiment within a closed reservoir will be analysed.

For quantitative results, the gas will be conveyed to a VOC and a CO_2 sensor at different fermentation stages and the development of both concentrations is going to be displayed and analysed.

What is microfluidics?

Microfluidics is the fine art of creation and manipulation of small portions of fluids, often realized by flow within small, sub-millimeter-scale channels. These small dimensions allow the fluid flow to be controlled with exquisite precision (Seifert, S. and Thiele, J. "Microfluidics: Theory and Practice for Beginners" (2020)).

Microfluidic systems are used in many applications, including medical testing, drug delivery, chemical analysis, chip cooling etc. These systems have the advantages of small volume, low cost and high throughput analysis (Gidde; 2020).

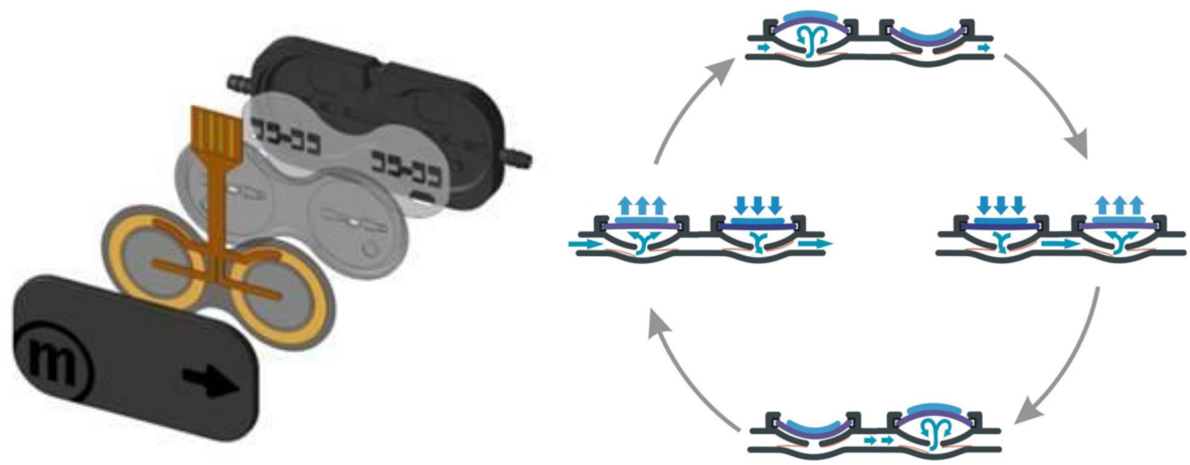
Further use of this method in the realm beyond academic research, such as that of commercial fine-chemical production, sensor development, or encapsulation of active substances, is presently being explored. Microfluidics, though, is a demanding field and working area that requires both profound theoretical understanding and experimental skills as there is no standard in education and training on this method in many fields of study that actually can benefit most from this technique (Seifert, Thiele).

Micropumps are essential components in the microfluidic systems. They are used to manipulate, transport and control the precise quantity of fluid in terms of microlitre and millilitre (Gidde; 2020). Compared to conventional syringe pumps, microfluidic pumps have the capability to be combined with other on-chip functional units to realize portable micro total analysis systems (µTAS) (Gao, Y. "Trapping and control of bubbles in various microfluidic applications". Lab on a chip 24 (2020)). Micropumps have been developed on various principles for many different applications viz. drug delivery and biomedical assays (Gidde; 2020).

About the mp6 micropump

The available, industrialized and commercialized example is the mp6 micropump by Bartels Mikrotechnik GmbH. This micropump is a positive displacement membrane pump utilizing piezo buzzers. With a volume of 2250 mm^3 (30 mm x 15 mm x 5 mm) it is, as a micro pump, dimensionally very beneficial.

It is built up in a „sandwich“ (stack) setup and combined and sealed in a laser welding process.



The laser melts single segments, so that the melted mass unites the parts. There is no glue in contact with the fluid, but only the material the micropump is made from. Standard materials are PPSU (Polyphenylsulfone), PI (Polyimide) and PP (Polypropylene). Due to the unibody and the fact that the pump does not contain any moving parts, it is sterilizable, robust and reliable with a lifetime of more than 5000 hours. The micropump possesses two membrane stages in a series setup running with an 180° phase shift.

These two stages behave like two seperate micropumps connected in series causing pressure to double. Besides, this principle makes it much more tolerant regarding gas bubbles. The mp6 is running at high voltages which regulate the bending of the piezo membranes and the frequencies which define the number of displacements per second. The peak-to-peak voltage amplitude ranges from 0-250 V_{pp}. Additionally, the mp6 operates at frequencies between 1-600 Hz. These electronic parameters applied to the piezo membranes lead to the following typical fluidic values of the pump:

- Liquids ($\eta \cong 1$ mPas): q = 5 - 8000 µl/min in free flow and p > 600 mbar
- Gas: q > 25 ml/min in free flow and p > 150 mbar

The flow rate depends on the pressure. In addition, the performance of the mp6 is dependent on the viscosity of the liquids.

The mp6 micropump is made in Dortmund, Germany and leaves the factory after a 100% OQC (Outgoing Quality Control).

Technologies for sensing VOC-gases and CO2

The SCD40 CO_2- and SGP40 VOC-sensors by Sensirion function around metal oxide (MOx) films.

MOx-films, e.g. SnO_2, are placed between two electrodes. The SGP40 identifies electrical resitivity changes ΔR of the MOx-film. These fluctuations are induced by heating the material underneath the coating, causing oxygen particles to dissociate from their bond with the metal. Because of the negative charge of the oxygen particles as well as their high reactivity, the ions react with the ambient gases that flow through the tube attached to the sensors. Subsequently, electrons are released and diffuse inside the MOx-film.

It is evident, that this variation of the charge carrier density brings along resistivity fluctuations that highly depend on the number of reactions between gas and oxygen particles. Therefore, the sensor is able to accurately measure and evaluate the ambient VOC-concentration (Zakrzewska, A. “Mixed oxides as gas sensors”. Thin Solid Films (2001)).

Comparison of the MOx-technology and conductive polymers

MOx-technology holds many advantages that couple with some deficiencies. To accurately display the importance of MOx-films, its convenient to compare these techniques to other approaches, e.g. conductive polymers (CP).

Most importantly, MOx-structures are characterized by excellent sensitivities detecting far into the ppm or even ppb regions. Due to the occuring chemical reactions, respond times are also superior. Since single particles are involved into the process, MOx-lifetimes are comparably long as well. Naturally, this comes along with comparably low expenses (Chiu, S.-W. "Towards a Chemiresistive Sensor-Intergrated Electronic Nose: A Review". Sensors (2013) ; Tomić, M. "VOCs Sensing by Metal Oxides, Conductive Polymers and Carbon-based materials". Nanomaterials (2021)).

However, the constant electron flow is accompanied by pretty high energy consumptions. Additionally, since every electron dispensed has an influence on the resisitivity change, MOx-technologies serve very little selectivites. Thus, usage as a sensor for whole groups of elements or molecules such as VOCs is advised.

The advantage of conductive polymers compared to metal oxides lies within their low energy consumption as well as an improved selectivity. It is also worth noting that CPs are commonly working at room temperatures. Additional improvement in comparison to MOx-films is the resilience against acidic damaging. Nonetheless, its high affectibility towards humidity and temperature makes handling outside lab environments difficult. Even though subtraction of these factors is possible, the additional installments are what make CPs less conventient (Chiu, S.-W. "Towards a Chemiresistive Sensor-Intergrated Electronic Nose: A Review". Sensors (2013) ; Tomić, M. "VOCs Sensing by Metal Oxides, Conductive Polymers and Carbon-based materials". Nanomaterials (2021)).

Sensing VOC- and CO2-gases with the mp6 micropump

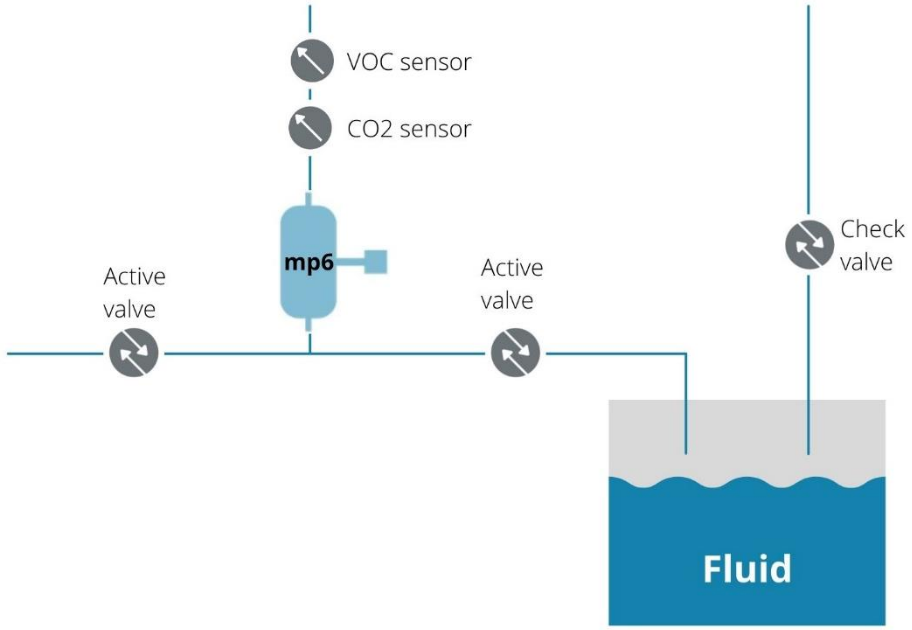
Due to the request for higher safety and efficiency in industrial processes, the use of sensors increases continuously. Since various sensors can not be used with completely passive feeding, the mp6 micropump from Bartels Mikrotechnik GmbH opens up new fields of application. Due to their simple setup, they can be produced at a low cost level. Additionally, thanks to their particle tolerance, they prove efficient under ambient conditions.

With its small dimensions, the mp6 micropump can either be used as a subassembly together with the sensor or as an OEM (original equipment manufacturer) component to be integrated into a more complex unit. Especially for portable instruments, where miniaturization plays an important role, the low energy consumption comes into play. Battery operation may be easily realized. Depending on the customers needs, the driving electronics are either integrated into the main PCB (printed circuit board) of the unit or even inside an enlarged pump housing.

The use of an inert polymer in combination with an optimized placement of the pump inside the system enables operation under the most demanding conditions.

The micropump mp6 provides a minimum flow rate of 6 ml/min for liquids (with dynamic viscosities of $\eta \cong 1\ \mathrm{mPas}$ and 18 ml/min for gases. By using the available evaluation kit, the pump performance can be tested in the target application and the driving parameters can be defined.

For once the CO_2 concentration gives information about the grown cellcultures. The higher the emitted amopunt of CO_2 the higher the number of individual cell already developed.



To verify whether differences in gas concentrations can be detected after passing through the mp6 micropumps, a reservoir including a sealed lid with four ports is utilized.

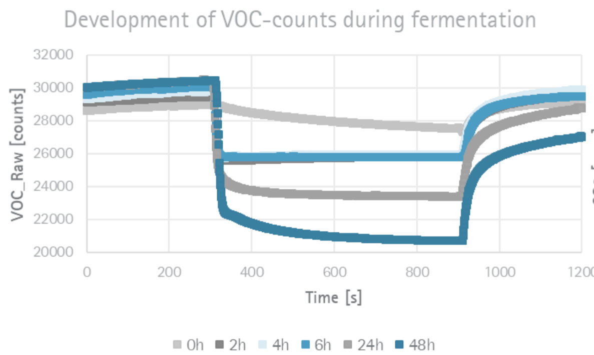
One port is connected to a pressure sensor by Honeywell to monitor the pressure inside the reservoir. Additionally, two valves which are connected antiparallel to each other can regulate pressure differences within a margin of their opening pressure (40 mbar).

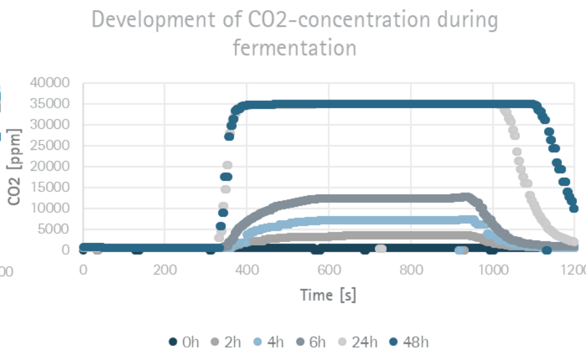
For the Sensor setup, two ports are reserved in order to transport produced gases via a closed-loop. The VOC-Sensor SGP40 by Sensirion is connected to a breadboard while the electrical supply for the CO_2-Sensor SCD40, which is also manufactured by Sensirion, is assured by the mp-Multiboard2 by Bartels Mikrotechnik GmbH. To prevent fresh oxgen flowing into the reservoir, active valves are implemented that also ensure clean tubes.

If needed, a fourth port for fluid transportation into or out of the reservoir is available.

Results

Functional CO_2- and VOC-sensing has been observed. By filling the reservoir with yeast and a nutrient medium the fermentation of beer has been observed and could be verified by sensor results.

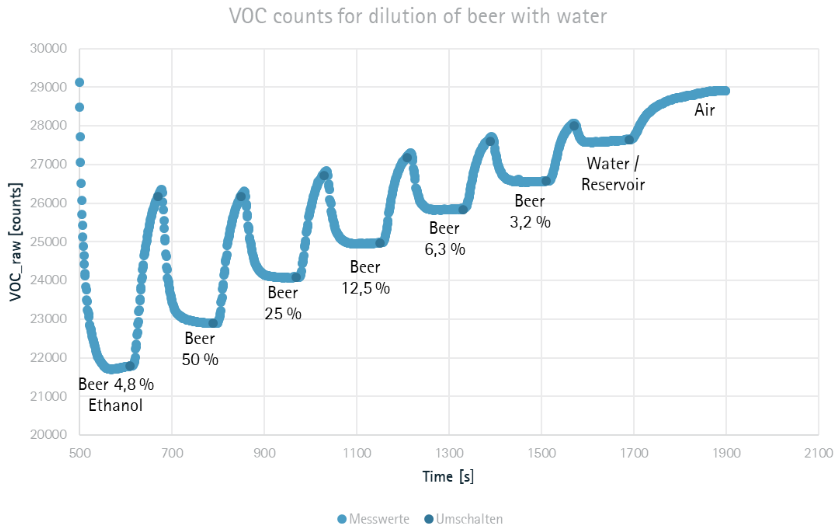




It shall be noted that high VOC-concentrations correspond to low count rates by the SGP40 sensor because the sensor is observing the degree of air quality, hence the inverse of pollution levels. Moreover, the CO_2 concentration is directly given in ppm while the VOC-sensor only provides count rates, whose quantitative concentrations were not calculated yet. The most probable main component accountable for VOC-counts is ethanol (C_2H_5OH).

It is logical that by letting the mixture ferment more cells are produced. Thus the carbon dioxide concentration rises with developed fermentation processes to a point beyond the sensors sensing limits.

Furthermore, by observing the amount of VOC counts it is possible to determine the ethanol content within the reservoir. Via mentioned setup, the dilution of beer is traced. As can be seen, the lower the ethanol concentration the higher the detected VOC counts. Following these findings, the ethanol concentration is obtained and monitored through gas phase analysis without any contamination.



In conclusion, CO_2 as well as VOC concentrations rise with advanced fermentation. That way, by simply assigning a reference (e.g. beer with 4.8% C_2H_5OH), the fermentation process of yeast into beer can be protocolled industrially with very little space and resources needed. Since all data can be obtained via gas phase analysis, contaminants are mostly excluded from the measurement.

Components and systems used:

- mp6 micropump by Bartels Mikrotechnik
- mp-Multiboard2 by Bartels Mikrotechnik
- SCD41 (CO_2) development board by Sensirion
- SGP40 (VOC) sensor by Sensirion
- Active SMV valve by Takasago

Acknowledgement:

Our partner, Sensirion from Stäfa, Switzerland, was instrumental in defining our research path, whereby we were able to develop a great solution for a microfluidic system that can measure VOC and CO_2 values by feeding MOX sensors actively. For that, we are extremely grateful and we are looking forward to our close collaboration.

In case you are interested in the above-described microfluidic componenents or if you are interested in getting in touch with either one of us, Sensirion or Bartels Mikrotechnik, please feel free to contact us. You can find the contact details below.

Bartels mikrotechnik

Bartels Mikrotechnik is a globally active manufacturer and development service provider in the field of microfluidics. In the microEngineering division, the company supports industrial customers in the modification, adaptation and new development of high-performance and market-oriented product solutions through the innovative means of microsystems technology. The second division, microComponents, produces and distributes microfluidic products and systems, especially for miniaturized and portable applications. Our key products are micro-pumps that convey smallest quantities of gases or liquids and are used in a variety of ways in biotechnology, pharmaceuticals, medical technology and numerous other applications.

Bartels Mikrotechnik with passion for microfluidics!

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