Ross, Fabian; Maack, Christian; Haas, Torsten; Buescher, Wolfgang and Boeker, Peter

Rating of silage quality using chemosensor-system

Quality of silage is not only an important factor concerning economic feeding of cattle, but also related to consumer protection considering the European Regulation of feed hygiene. The evaluation of silage quality contains currently additional to analytic methods the rating of crop characteristics by human sense. Actually the Institute of Agricultural Engineering, Bonn University, works at experiments to evaluate silage quality in a technical and objective way by using chemosensors. First measurements at samples of corn silage were carried out.

Keywords

Appraisal of silage, silage, fodder quality, electronic nose

Abstract

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Conservation of fresh forage material through ensiling is aimed at long-term protection of the feed material from spoilage as well as optimum retention of feed nutritional characteristics. It should also offer hygienic safety from harvesting through to feeding as well as consumer protection [1]. Normally, silage quality (success of the ensiling process) is assessed at opening of the silo or clamp. In most cases a points system is applied when assessing quality based on nutrient content, presence of fermentation products butyric and formic acids and the targeted pH level [2]. [3] recommends complementing such assessments with sensory evaluation. Using the human senses for silage classification according to smell, colour and structure with quality points subtracted where necessary. Increased content of undesirable „noxious fermentation“ products such as butyric and acetic acids can also be identified without analysis by smell alone.

During the fermentation process various volatile components are created that can be identified as odorous substances [4]. Along with fermentation acids, various aldehydes such as propanal, butanal, pentanal and hexanal can, in particular, be involved. A further substance group with odour influence features the alcohols ethanol, propanol and butanol and another group is that comprising alcanols. Various ester compounds also influence the smell of a silage whereby this smell is always the result of a mix of many odour-influencing substances that can be present in a sample in very different concentrations with differing dominance within the overall odour presentation. However, especially the evaluation of odour parameters is still strongly dependant on individual subjective sensory perceptions, making comparability more difficult. Measurement of gaseous compounds is also possible analytically via gas chromatography and mass spectrometry and through the coupling of the two approaches. The measurement input involved is, however, high and requires trained personnel as well as experience in analysing the data produced. For application on location this method is therefore unsuitable. A sampling system suitable for practical application should be as easily applicable as possible and additionally produce gas-chemical data rapidly.

As alternative to sensory and chemical analytical measurement, gas composition can also be determined via electronic sensor systems. An online odour measurement process has been developed for specific applications at the Agricultural Engineering Institute, University of Bonn [5].

Hereby were applied a number of sensors using the same measurement principles in the form of sensor arrays that were different in sensitivity to various substances. The concept of sensor arrays was derived methodically from the way the sense of smell functions, i.e. evaluating data from a limited number of smell sensing cells and applying the result to achieve complex odour impressions.

Objectives

In the described project the following objectives were targeted:

- Evaluating quality objectively
- Developing an alternative to microbiological and chemical analysis, as well as to livestock feeding trials
- Reducing quality losses
- Increasing reliability of production and product safety

A number of steps has been planned in order to achieve the above targets. First of all a method for efficient collection of silage gases must be found. This means, on the one hand, that the volatile molecules present in the silage gases must not be allowed to escape into the atmosphere. On the other, that the surrounding atmosphere must not influence the recording. For collecting suitable data it is also necessary that the chemosensor system be optimally adjusted during the various investigation phases.

A practicable method should be applied for analysing results and then the suitability of the chemosensor system for judging silage quality subsequently assessed.

Investigation preparation

To analyse the silage, precleaned air is sucked through the activated charcoal filter (**figure 1, right**). The air is then drawn through the sample glass containing the silage sample and thus suffused with the silage gases. Subsequently the suffused air is cleaned in a gas-conditioning blend of water and particles and further conveyed into the chemosensor system where the silage gases are measured (**figure 1, left**).

Certain silages have a strong smell of their own which can contaminate sampling and measuring equipment. However, the sampling apparatus must not be rinsed with water (with exception of the sampling glass). Instead, the gas conditioning and the chemosensor system as well as connecting pipes are cleaned with air. For this, „pure air“ from the active charcoal filter can be channelled via a bypass pipeline that avoids the sample glass and goes direct to the gas conditioning and chemosensor system. Alternatively, it is possible to rinse out the gas conditioning and chemosensor system separately. This variant has the advantage that larger amounts of air flow through the gas conditioning station and this increases cleaning efficacy.

Operating mode of the quartz crystal microbalance

The actual measurement of the molecules in the silage gas takes place via so-called oscillating quartz technology (**figure 2**). For this, the inverse piezo effect is used to encourage oscillation of a quartz platelet. The molecules are absorbed in the sensor layer and the change in mass of the quartz caused by this leads to a change in the frequency of the quartz oscillation. To increase measurement sensitivity the analyte molecules are first of all enriched in an adsorbent before being thermally desorbed and channelled in concentrated form to the quartz sensors.

Measurements with pure acids

In order to identify suitable settings for the enrichment units of the chemosensor system various measurement series were carried out with pure organic acids. In **figure 3** the measurement series with acetic acid is presented. It demonstrates the association of signal strength and desorption temperature. The enrichment units collect the gases and odour substances emitted by the silage during a low temperature adsorption phase. In the (up to three) desorption phases the gases are re-released at increased temperatures. Through a longer period of enrichment in the adsorption phase with high throughflow, and rapid heating at low throughflow, the required increase in gas concentration for the sensors is achieved, i.e. the gas enrichment. Gases are released successively at various temperature levels. In this way highly volatile gases can be measured in desorption phase 1, medium and less volatile gases in desorption phases 2 and 3. The measurements presented in **figure 3** show the increase in signals in association with increasing temperature. At 110 °C complete desorption and, with that, maximum signal value is reached for acetic acid. Measurements of this type are also applied for verifying the measurement characteristics of the chemosensor system during longer trial periods.

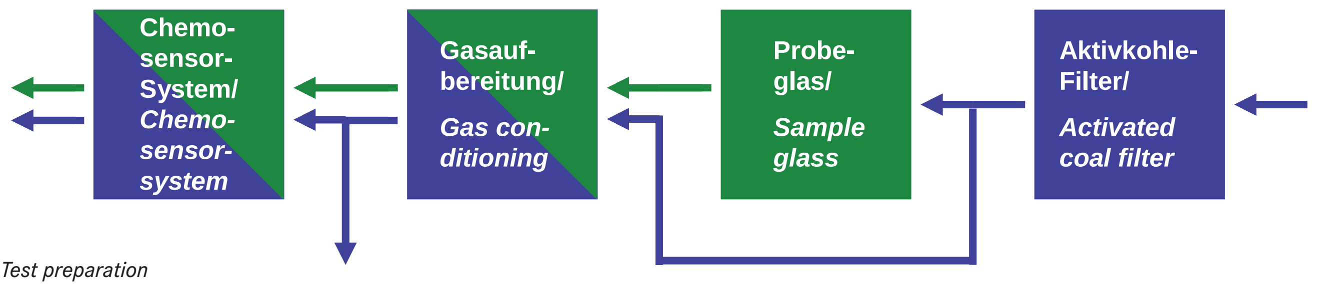
Measurements with silage

The silage gas trial was designed according to the appropriate DLG guideline [2]. While one part of the sample was always stored under anaerobic conditions, spoilage was encouraged in the other portion through opening to the air twice for twelve hours and then storing under aerobic conditions thus initiating secondary heating of the substrate. The substrate was then stored in a climate cabinet at 25 °C. Using insulated boxes prevented the surrounding air cooling down the samples. Samples were taken for testing when the temperature had increased by 3 K compared with the surrounding air. In this way it was possible to produce silage of differing quality out of the same initial substrate. The silages thus produced were evaluated according to the DLG sensory table [3] and tested using the chemosensor system.

The silage spoilage process differed greatly. Despite the same initial substrate, handling procedure and storage, the time within which a 3 K heat increase over the surrounding air occurred was very different. The same applied to the smells of the silages which also varied strongly.

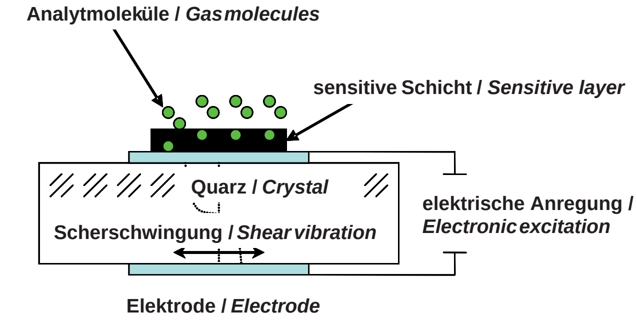
In **figure 4** are presented the recorded results from a good maize silage (aromatic odour) and a maize silage wherein secondary heating took place (alcohol odour). The recorded data shows two effects characteristic of chemosensor system measurements. The relative relationship of the sensor signal (the

Fig. 1



Test preparation

Fig. 2



Operating mode of a quartz crystal microbalance [6]

order) represents a pattern dependant on the composition of the silage gases. Different patterns indicate different compositions. Additionally, the height of the sensor signal strength reflects the concentration of the measured gases. Both results can be used for differentiation and evaluation of silages. The research project also investigated which parts of the data, singularly or in combination, permitted a prognosis of silage qualities. The results differed through the signals for silage with alcohol odour being higher than those for the aromatic silage. Additionally, the relationship of the sensors to one another, or the ranking of the sensors (sensor pattern), is important. In the „good" silage, sensor 4 has the highest strength of signal. With the alcohol-odour silage its signal level is in the middle area.

Conclusions

The experiment design allowed an efficient collection of silage gases. For the selection of suitable settings measurements with pure acids were necessary, but not sufficient on their own. In fact, investigations had to be carried out with silages of different qualities. Where measurements had to be repeated with different settings there occurred the difficulty of ensuring available identical material over a longer period of time. Results so far indicate that silage as product of a biological process can develop very differently despite the conditions being apparently the same. Another difficulty is that it is not possible to halt the spoilage process in order to create a particular spoilage status. Further investigations should clarify whether silage quality ranking via chemosensor system is possible.

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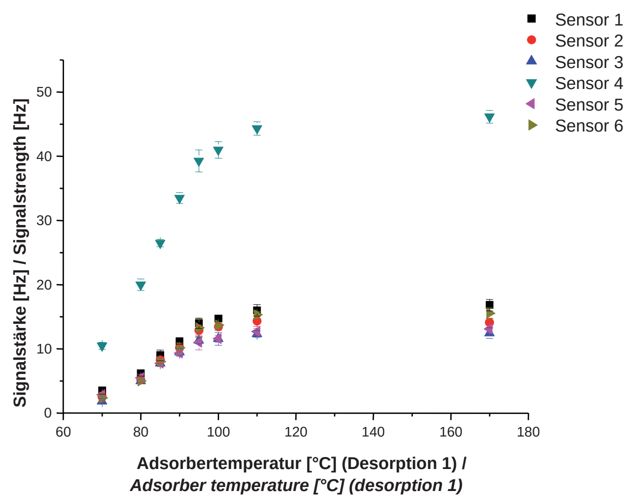
Authors

Fabian Ross and **Dr. agr. Christian Maack** are members of the scientific staff within the Department of Livestock Technology (director: **Prof. Dr. Wolfgang Buescher**) at the Agricultural Engineering Institute, University of Bonn, Nussallee 5, 53115 Bonn, E-Mail: ross@uni-bonn.de

Dr. rer. nat. Torsten Haas is a member of the scientific staff within the Department for Technology of Crop Farming at the Agricultural Engineering Institute, University of Bonn.

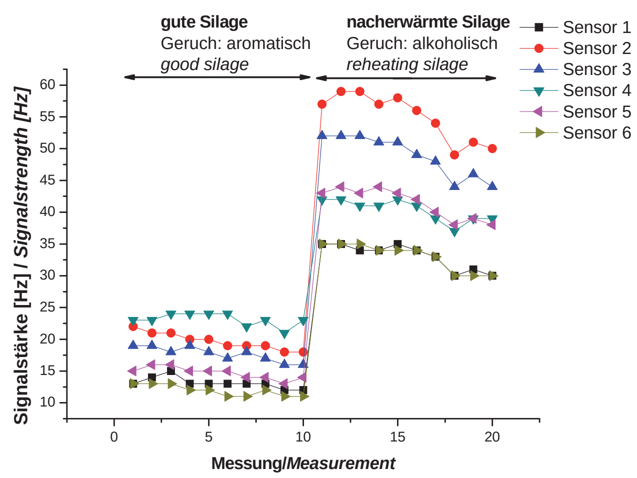
Dr. rer. nat. Peter Boeker is lecturer (Privatdozent) at the Agricultural Engineering Institute, University of Bonn.

Fig. 3



Acetic acid, signal level in reference to adsorber temperature

Fig. 4



Examples of signal patterns