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Formation and suppression of foam in biogas plants – practical experiences

Foam formation during the anaerobic digestion may have negative impact on the economics of a biogas plant. This problem concerns especially those biogas plants, which utilize biogenic waste for biogas production. Eighteen operators of waste treating biogas plants from Saxony, Saxony-Anhalt and Thuringia have been surveyed. The aim of the enquiry was collecting experience about the foam formation in biogas reactors and about the foam fighting tasks in practice.

Keywords
Biogas, foam, anaerobic digestion, operational problems, biogas plants for treatment of biogenic wastes

Abstract
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Biogas production now has an established position in the mix of renewable energies. This is reflected in the high number of biogas plants in Germany. For 2011, the German Biogas Association estimated that there were a total of 7,100 biogas plants and 2,780 MW of total installed electric output. This represents an increase of 20 % compared to 2010. The construction of a further 370 biogas plants is expected for the year 2012 [1]. There is considerable potential for the generation of electricity from biomass.

Problems occurring in the process of anaerobic fermentation such as excessive foam formation [2] may have severe consequences for the operator of a biogas plant. So far, it has not been entirely possible to find the causes for this. Foam formation occurs primarily in plants with a changing substrate quality and quantity. This applies in particular to biogas plants where waste and residues are utilized. In order to evaluate the extent of the problem of foam formation in biogas reactors, a survey of operators of waste-based biogas plants in the German federal states of Saxony, Saxony-Anhalt and Thuringia was carried out. Eighteen biogas plant operators have been contacted, fifteen of which were willing to supply information on foam formation in their biogas reactors. Only one operator stated that problems with foam had never occurred. Two other operators reported foam formation in the process of the biological desulfurization step. Over the course of the service life of their biogas plant, twelve operators had had to deal with problems of foam formation in the biogas reactor with varying frequency: in two plants, foam occurred only once, while seven operators complained of regularly occurring foam formation. In the case of three biogas plants that had initial difficulties with foam, the problem was solved by modifying operation policies.

The experiences of the plant operators with regard to possible causes of foam formation and measures for the suppression of foam are summarized in this article. Moreover, observations of operators of three waste-based biogas plants in Bavaria, Brandenburg and Mecklenburg-Vorpommern and of five plants in Brandenburg, Mecklenburg-Vorpommern, North Rhine-Westphalia and Saxony-Anhalt (2 x) that utilize renewable resources were evaluated. At the time of the survey, problems with foam formation in the biogas reactor were occurring in all plants.

Foam formation in waste-based biogas plants

The causes of foam formation in biogas reactors are often not identified. Only careful observation and long-term experience can help to isolate factors that clearly induce foam formation.

The operators generally identified two types of foam. The foam differs in terms of the size of the gas bubbles and the amount of effort that is necessary to suppress the foam. Foam with large-sized bubbles is relatively easy to remove using conventional measures such as diet and stirring. Foam defined by small-sized bubbles causes greater difficulties as it is more stable. The mechanism behind foam formation and the causes for the different bubble sizes are not yet known.

The substrates are the most common causes for excessive foam formation. Apart from the use of unsuitable substrates, an excessive proportion of easily degradable substances also leads to a capacity overload of the biogas producing microorganisms. The risk of excessive foam formation increases when a biogas plant is fed with large amounts of animal protein. Fish waste has been identified as being particularly problematic for anaerobic fermentation. One plant operator reported the formation of foam with small-sized bubbles during the changeover of the biogas plant to the use of slaughterhouse waste. It can be assumed that the contained proteins were denatured through prior hygienization and partly or completely hydrolyzed. This process led to protein enrichment on the surface and the foam was thus stabilized. Clarke and Reid [3] described the same mechanism for proteins originating from plants. According to the operator, the biogas reactor content rose "like yeast dough" within a short period of time and blocked the gas pipe. This only happened after the first batch of slaughterhouse waste was fed to the plant. After the stabilization of the process, no foam formation was observed.

Other possible causes for foam formation in biogas plants are surface active agents which are contained in substrates such as the contents of grease separators, residues from bioethanol production and dairy wastewater. These substances lead to a reduction in the surface tension of the biogas reactor contents, with the result that the produced biogas cannot escape and is encapsulated in the form of bubbles on the surface of the liquid. If the foam is further stabilized due to other factors, these substrates can be problematic. This situation was observed in the digestion tower of a wastewater treatment plant where the contents of grease separators were used as co-substrates. During the winter months, foam formation was observed in the biogas reactor. Microscopic analysis showed the presence of filamentous microorganisms. It is known that bacteria such as *Microthrix parvicella* contribute to a stabilization of foam due to their filamentous structure [4].

The survey also identified waste from a paper mill – pulp – as a cause of foam formation. This material is characterized by a very high viscosity and a dry matter fraction of about 15 %, and it contributes to the formation of foam with large bubbles. According to the operator, this type of foam can easily be dealt with.

The addition of diatomaceous earth in biogas plants had different effects. Diatomaceous earth is a naturally occurring sedimentary rock (silicon dioxide) which mainly consists of fossilized remains of diatoms [5]. Due to the porosity of this substance, it is used as a filtering material in food technology (e. g. in breweries). While one operator described diatomaceous earth as promoting foam formation, another operator observed its foam-suppressing effect. In the latter case, the recurring foam formation as a result of the addition of dairy wastewater was reported which only did not happen when diatomaceous earth was contained in the substrate mix.

Thus, in most cases, foam formation is the result of the addition of unsuitable substrates or of the substrate amount being too high. Apart from that, two operators reported foam formation that occurred as a result of nutrient deficiency. The daily addition of a micronutrient solution adapted to the plant conditions provided a sustainable solution to the problem.

Process upsets may also lead to foam formation. In one case, a sudden rise of the temperature from 35 °C to 38 °C led to the formation of foam. As the composition of the added substrate had remained constant over a longer period of time, it can be assumed that the sensitive microbial community inside the biogas reactor was disturbed by the temperature difference. The sudden change of the ambient conditions presumably led to an increased die-off of microorganisms which caused the release of mucilage and storage substances. These are polysaccharides which either serve as storage substances inside the cell or externally as cell protection. The mechanism behind the effect of these substances on foam formation is not yet known. It is assumed that the release of these substances increases the viscosity of the reactor content, which leads to the encapsulation of gas bubbles in the liquid [6].

Foam formation in biogas plants utilizing renewable resources

Statistically, biogas plants that are fed with renewable resources have fewer problems with excessive foam formation since the substrate composition is less variable than in a waste-based biogas plant. Nevertheless, there are critical substrates which can cause process instabilities.

One of the most common foam-inducing substrates is chicken manure, which contains high amounts of nitrogen. Excessive N concentrations in the fermentation substrate inhibit the microbial community in the biogas reactor so that the content produces foam [7]. However, there are biogas plants where the microorganisms seem to have adapted to high ammonium concentrations. Operators still recommend the use of a neutralizing co-substrate in addition to chicken manure.

The addition of sugar beet also causes severe problems. Foam formation due to this substrate is supported by two factors. On the one hand, sugar beet contains up to 16 % (w/w) sugar (sucrose) in the dry matter. This is very quickly transformed into biogas in a biogas plant. The presence of this easily utilizable substrate leads to rapid reproduction of the microorganisms and to an overload of the plant. On the other hand, the cell walls of the sugar beet contain high amounts of pectin, which increases the viscosity of the fermentation substrate and gas bubbles are encapsulated in the matrix. This resulted in the expansion of the entire biogas reactor content after a plant was overfed with sugar beet due to a technical defect in the dosing system. Foam formation was so massive that the downstream systems were damaged and needed extensive repair.

Fermentation also responds with foam formation when humid, decomposed or moldy maize silage is fed to the plant. In one case in a biogas plant in Saxony-Anhalt, CCM silage (corn cob mix) was identified as foam-inducing. Maize kernels contain a lot of starch, which increases the viscosity of the biogas reactor content and has a similar effect on gas bubbles as pectin from sugar beet chips.

In another biogas plant that utilizes liquid manure and maize, a persistent foam layer was observed over several months which could only be controlled by daily addition of several liters of anti-foaming agent. The addition of rye groats (1–2 % (w/w) of the total substrate) was identified as the cause. After reduction of the groat amount to 0.25 %, the foam layer was considerably reduced. An analysis of the feeding protocols of other plants with foam formation showed that apart from rye other types of grain also promote foam formation, for example, millet and barley, both as groats and in the form of whole plant silage. The reason for the excessive foam formation is a too rapid utilization of the substrate, as was the case for the sugar beet. Finely ground groats also cause bloating in the rumen of cattle, as research from veterinary medicine shows [6]. The tiny particles offer more surface area for the microorganisms than coarsely ground grain, with the result that microbes reproduce more quickly and produce more proteins and polysaccharides (mucilage). When the cells die, these substances are released and promote foam formation. Furthermore, starch and proteins from rye groats have a stabilizing effect on the foam. In food technology, rye flour is known to readily form a particularly stable foam [8].

Easily degradable substances, such as sugar beet and grain groats, should be fed to a biogas plant with extreme caution. The art of composing a substrate mix lies in finding the right proportion of substrates. Thus, it is indeed possible to benefit from easily degradable substances without having to deal with problems such as acidification and foam formation [9].

Measures for the suppression of foam

Biogas plant operators have applied several measures to reduce excessive foam formation. In most cases, the first step against excessive foaming was a strict diet – the so-called "starvation diet". Substrate feeding is reduced to the minimum for two to three days so that microorganisms have sufficient time to adapt to the operating conditions.

Operators also recommend pumping down a part of the biogas reactor content in order to provide space for the foam and to allow for stirring of the foam using agitators. Some operators add water to the fermentation substrate in order to dilute the foaming mass. For this reason, it is advisable to plan a container for collecting cost-saving rainwater during the construction phase of the biogas plant.

The use of anti-foaming agents is a controversial issue. A general observation is that there is not one single anti-foaming agent for all types of foam – different anti-foaming agents work for different foams. Anti-foaming agents destroy the foam by replacing the foam-inducing surface film with a completely different type of film [10]. Plant oil is recommended as a cheap anti-foaming agent. Its advantages are not only its easy availability but also the fact that it is a natural substance which is completely metabolized in the biogas plant. For some types of foam, it has been observed that even small amounts of rape seed oil showed a good effect with regard to foam reduction. In a biogas plant where the formation of foam due to the addition of dairy wastewater is a regular occurrence, the addition of only three litres of oil removed the entire foam layer. According to the operators' experience, only those oils should be used where mucilage, such as phosphoglycerides, has been removed.

Success in foam suppression has also been observed after the adaptation of operation policies – an optimum stirring cycle is just as important as an adapted feeding regime in order to prevent foam formation. However, it is not possible to specify a general rule here. The stirring cycle should not be too short in order to prevent swimming layers. On the other hand, the reactor content must not be stirred constantly so that microorganism agglomerates are not destroyed. Experience from operators of plants utilizing renewable resources shows that ten minutes of stirring per hour is sufficient. Nevertheless, this value needs to be adapted for each biogas plant.

The same applies for the feeding frequency. As a generalization, it can be stated that more frequent feeding is preferable. However, frequent feeding is only possible using automation and exact dosage of the amounts added. This is reflected in the investment costs. One waste-based biogas plant in Saxony managed to find a sustainable solution to its problems with foam by dividing the daily feeding amounts into 72 batches, which means one dosage every 20 minutes.

A further prophylactic measure is the careful application of critical substrates. If it is not possible to entirely exclude critical substrates, they should be added to the biogas reactor in small doses, allowing long adaptation times. One experienced biogas plant operator recommends the following rule of thumb for the start-up of a new biogas reactor: at a filling volume of greater than 70 %, only 1–2 m^3 of fresh substrate should be added per day. This way, the formation of foam during the start-up process can be prevented.

Consequences of excessive foam formation

The extent of foam formation and its effect differ. In the case of moderate foam formation, the costs may be limited to the anti-foaming agent used and the increased deployment of staff. According to one plant operator from Bavaria, the costs are estimated to be € 500–€ 600 for each foaming event.

However, uncontrolled foam formation may also cause severe damage, ranging from blocking of gas pipes and problems with stirring technology to damage to equipment. One operator of a waste-based plant from Saxony reported a foaming event in which the entire reactor content was transformed into foam. This damaged the roof of the biogas reactor. The operator estimated the total damage to amount to € 500,000.

Conclusions

Although the biogas sector is experiencing a boom, there are still problems with regard to the process of biogas generation which have not yet been solved. One significant problem here is the excessive formation of foam inside the biogas reactor. This phenomenon applies to many plants and often leads to financial losses. For this reason, it is necessary to understand the causes of excessive foam formation. The exact mechanisms behind foam formation in the process of biogas generation are currently a focus of our research.

Literature

[1] Biogas Branchenzahlen 2011: Entwicklung der Anzahl Biogasanlagen und der gesamten installierten elektrischen Leistung in Megawatt [MW] (Stand: 11/2011), http://www.biogas.org/edcom/webfvb.nsf/id/DE_Branchenzahlen, Zugriff am 15.2.2012

[2] Moeller, L.; Herbes, C.; Müller, R.; Zehnsdorf, A. (2010): Schaumbildung und -bekämpfung im Prozess der anaeroben Gärung. Landtechnik 65(3), S. 204–207

[3] Clarke, R. T. J.; Reid, C. S. W. (1973): Foamy Bloat of Cattle. A Review. J. Dairy Sci. 57(7), pp. 753–785

[4] Kunst, S.; Knoop, S. (1996): Schaum in Faulbehältern, In: Ökologie der Abwasserorganismen, Springer Verlag, Heidelberg, S. 273–289

[5] Tsai, W. T.; Hsien, K. J.; Yang, J. M. (2004): Silica adsorbent prepared from spent diatomaceous earth and its application to removal of dye from aqueous solution. J. Colloid Interface Sci. 275, pp. 428–433

[6] Majak, W.; McAllister, T. A.; McCartney, D.; Stanford, K.; Cheng, K.-J. (2008): Bloat in Cattle. Alberta Agriculture and Rural Development, Agriculture and Agri-Food Canada, www.agriculture.alberta.ca, Zugriff am 15.2.2012

[7] Schumann, W.; Gurgel, A. (2007): Schwachstellenanalyse an ausgewählten Biogasanlagen in Mecklenburg-Vorpommern. In: 1. Rostocker Bioenergieforum. Bioenergieland Mecklenburg-Vorpommern, Universität Rostock, S. 155-169

[8] Zehle, F. (2009): Die Entstehung von Schaumstrukturen in Backwaren und deren Vorprodukten. Informationsmaterial der IGV GmbH zur iba 2009. http://www.igv-gmbh.de/aktuelles/projekte/entstehung-von-schaumstrukturen-in-backwaren.html, Zugriff am 15.2.2012

[9] Eder, B.; Schulz, H. (2007): Der Biogas-Prozess. In: Biogas Praxis, Ökobuch Verlag, Staufen, S. 17–40

[10] Mollet, H.; Grubenmann, A. (2000): Schaum. In: Formulierungstechnik: Emulsionen, Suspensionen, Feste Formen, Wiley-VCH, Weinheim, S. 125–132

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