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Formation and removal of foam in the process of anaerobic digestion

Process upsets in biogas production which are induced by unregulated foam formation can have a negative impact on the efficiency of biogas plants. However, the causes of excessive foam formation in the biogas production process have not yet been researched in detail. A new research project on the controlled avoidance of foaming was started, which investigates the causes of foam formation in biogas plants.

Keywords

Biogas, foam, anaerobic digestion, operational problems

Abstract

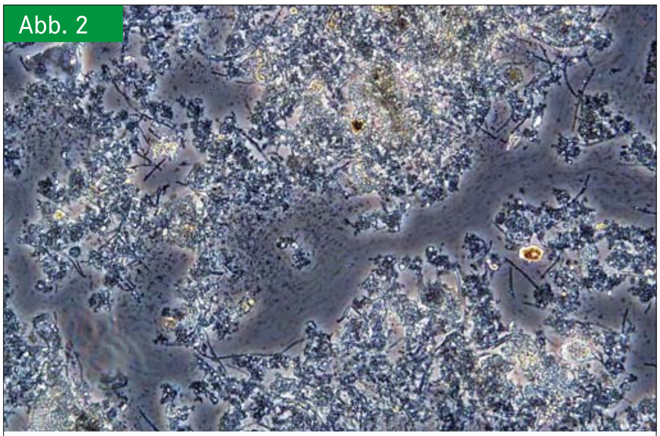
Landtechnik 65 (2010), no. 3, pp. 204-207, 2 figures, 24 references

A great number of biogas plants have been commissioned in Germany in the last decade as part of the promotion of renewable energies. Biogas can be utilized in many different ways. It is a very suitable component in the energy mix of renewable energy sources. After being processed, it may be used as a fuel or for the generation of heat. Considering that biogas plants often operate at the limit of efficiency, technical problems and process upsets that involve long downtimes and repair costs can have serious economic consequences for the operator of a biogas plant. An investigation of ten selected plants in the German state of Mecklenburg-Vorpommern showed that the formation of foam (**Figures 1** and **2**) in the reactor is one of the major causes of process upsets in biogas plants [1]. The American Society of Civil Engineers also reports that the formation of foam in digestion towers is a persistent problem for the operators of wastewater treatment plants [2]. The German federal research program (Bundesmessprogramm) for the evaluation of biogas plants has also reported on problems due to foam formation [3]. Hence, it is important to investigate the reasons for the formation of foam and to find suitable measures to prevent and counteract foam formation in biogas plants.

Fig. 1

Foam can be a problem in biogas plants.
Photo: A. Künzelmann, UFZ

Abb. 2



Microscope image of foam in a biogas plant.
Photo: L. Moeller, UFZ

Reasons for the formation of foam in the anaerobic digestion process

The experience of the operators of biogas plants shows that problems with foam formation are often caused by using inadequate substrates, and also occur during the start-up process or when the addition of grain is increased suddenly. Heavy foam formation may also indicate suboptimal operating conditions or an unsuitable operation policy.

Proteins play a major role in the formation of foam. They are present in the fermentation liquid from the outset, either as microbial product or in the form of extra-cellular polymers that are bound to solids [4]. Proteins also enter the digestion process with the substrates. Substrates with a high protein content include grain, clover grass and poultry manure [5]. During the degradation of proteins in the anaerobic digester, ammonium is produced which can have an inhibiting effect on biogas production and thus facilitates foam formation. Ammonium is in dissociation equilibrium with ammonia, which is a strong cell toxin. The shift of the equilibrium in favor of ammonia depends on the increase of the temperature and/or the pH value, among other factors [5].

In plants that recirculate substrate for mashing fresh substrate, high nitrogen concentrations have been observed to contribute to the formation of foam. Nitrogen compounds accumulate due to the constant recirculation of digestate into the process [1].

Carbohydrates and lipids have less influence than proteins on foam formation. One reason is that they are more easily degradable. Due to their hydrophobic nature, lipids tend to rise to the surface. There they separate from the water and contribute to the stabilization of the foam by clinging to solids [4]. In the fermentation liquid, the lipids, which are often present as oil or fat, are hydrolyzed into their components: glycerine and fatty acids. Fatty acids are further degraded and transformed into methane. Intermediate products include volatile organic acids, which are also associated with foam formation [6]. The major fraction of the acids produced is generally acetic acid (acetate), which, compared to other organic acids, is most frequently mentioned in connection with foam formation in literature [2]. Current results show that the concentration of volatile fatty acids seems to depend on the biogas plant itself and on its mode of operation. While high-performance reactors for wastewater treatment typically show low acetate concentrations, preparations with maize silage as the sole feedstock exhibited acetic acid concentrations of up to 3 g/L [7]. Although volatile fatty acids are surface-active, there is disagreement as to whether their presence in the biogas reactor is the reason for or a consequence of the imbalance in the fermentation process that becomes evident in foaming. Their accumulation in the fermentation liquid reflects the kinetic decoupling of acid producers and acid consumers and is typical of a stress situation [2]. The reasons for this are manifold, e.g. organic overload of the system or excessive dosage of easily degradable co-substrates (e.g. fruit and vegetable matter) [8].

Mycotoxins, the metabolic product of some molds, which may occur in maize silage due to insufficient ensiling, may also contribute to foam formation and the instability of the fermentation process [9]. However, it was shown that fusarium spores are rendered innocuous in biogas plants and that they have no negative effect on the process of anaerobic digestion [10].

In contrast, the presence of filamentous microorganisms is often linked with foaming, in particular, in the anaerobic stabilization of sludge in wastewater treatment. The main foam producers include the bacteria species *Microthrix parvicella* and *Nostocoida limicola*. Hydrophobicity of the cell surface promotes foam formation, as gas bubbles are incorporated into the filamentous structures and make the sludge float [11]. The dominant filamentous microorganisms found in the sludge of digestion tanks are also present in the activated sludge and in the foam in the aerobic step of the treatment process. This means that the digestion of secondary sludge from the aerobic step of treatment plants leads to an accumulation of filamentous microorganisms in sludge digesters [12]. Herzberg and Houy [13] report on a treatment plant in Meldorf (Schleswig-Holstein, Germany) where the occurrence of these microorganisms led to several cases of foaming over of the digestion tank and to problems of gas utilization. The production of foam was occasionally so heavy that up to a third of the content of the digestion tank escaped and spread over the building and the grounds of the treatment plant.

Digestion tanks with thermophilic operation show a lower risk of foam formation caused by the presence of filamentous microorganisms. Microbiological investigations showed more efficient destruction of filaments in thermophilic treatment and thus a lower potential for foam formation [14].

Alongside the substrate-related factors, the mode of operation also plays a major role in foam formation. If the feeding intervals are very long, for example, the amounts of substrate to be added are higher. High feeding rates of more than 4 kg of organic dry substance/m^3 cause heavy overloading of the process [15]. As a consequence, by-products and degradation products with hydrophobic and surface-active properties may be accumulated, e.g. volatile organic acids, which puts a strain on the microorganisms. This may lead to excessive foam formation [4; 16]. It is recommended to feed mainly easily degradable material in more frequent, smaller batches and to combine the material with co-substrates or to stabilize it by adding alkaline buffers [5; 17].

Problems with foaming are often observed during the start-up process. The reasons for this are not clear yet.

Foaming is also linked with unsuitable heating and circulation equipment. If the heating system is not properly sized and operated, insufficient heat transfer combined with insufficient mixing of the reactor contents may also lead to foaming [18]. Heavy stirring may also produce foam, as sinking layers are stirred up and the upsetting of microbial structures destabilizes the process [8; 19].

Foam formation thus may have a number of causes. Because only a few plants are fitted with extensive measurement technology for process monitoring, the causes of foaming are often unknown [1].

Consequences of excessive foam formation

Foam-related problems in biogas reactors range from crust formation on the reactor wall, failure of pushers, dirt and blockage of gas and condensate pipes and recirculation pump due to the retention of foam solids, to over-foaming and a complete standstill of the plant [4; 18; 20]. Furthermore, there may be process control problems in the fermenter and the sensors can be disrupted. Foaming may lead to an inverted solids profile with higher concentrations of solids in the upper part of the reactor and a reduction of the active volume of the fermenter, causing a reduction of the digestion time [4; 21]. Heavy foaming also has a negative effect on the quality of mixing in the medium. The microorganisms in the foam phase are not sufficiently supplied with nutrients, leading to a decrease in the efficiency of biogas production [22].

The economic consequences due to energy losses, additional working hours and costs for cleaning are a serious burden for the operator of a biogas plant [6; 20; 23]. Westlund et al. [6] describe a foaming event in the anaerobic digestion step in a Swedish treatment plant that produces 2 000 m^3 biogas/d, which lasted for ten weeks in spring 1996. Foaming led to a reduction in the gas production of 40 %. Because of the reduced energy production, additional costs for staff, increased oil consumption and use of polymers in the dewatering phase, the total losses amounted to $150 000.

Moreover, additional expensive plant components and measurement technology, such as foam sensors, foam traps and dosing systems for anti-foaming agents, become necessary to protect against the consequences of foam formation.

Measures for the prevention and control of foam

The prevention and control of foam should already be considered when planning a biogas plant. Various engineering measures can help to minimize the likelihood of foam production. Measures for the prevention of foam include considering the flow scheme in the plant and avoiding reactor parts that impair the movement of the medium and cause currents and turbulence at the surface of the reactor. Furthermore, rotating components may be installed which apply shear stress to the foam. However, the installation of these components in the fermentation tank will also increase investment costs. Moreover, these devices alone are not sufficient; their effectiveness can be enhanced by the simultaneous application of chemical anti-foaming agents, preferably at low concentrations [22].

Especially during the start-up phase and during the entire operation, overfeeding should be avoided by appropriate dosing of the substrate in order to prevent process problems. Sufficient time should be planned for the commissioning and maintenance of a biogas plant in order to allow for a slow start-up phase and to avoid process upsets. If foam has already formed, reducing or suspending substrate feeding and minimizing the stirring intensity may help to stabilize the process.

The methods of foam removal applied in biotechnology can be subdivided into physical (thermal and mechanical) and chemical procedures. These methods are generally applied to minimize the effect of foaming and do not combat the actual causes [21].

Thermal foam removal is achieved by heating the medium by means of contact with heating surfaces or steam. However, this universal method is not very suitable for application in biogas plants due to the associated high energy requirement.

Foam may be removed mechanically by means of rotating components, as mentioned above. Ultrasonic disintegration has been applied successfully for the removal of filamentous microorganisms [11; 13]. The filaments that cause the foam are broken down. In the course of cell disruption, the sludge is liquidized so that it is more easily available for the sludge-degrading microorganisms [13]. Additionally, ultrasound treatment can help to break down persistent structural matter and make it more easily degradable for bacteria [5]. Thus, anaerobic degradation and bacteria performance is enhanced.

Barjenbruch et al. [23] investigated the effect of mechanical and thermal pre-treatment of excess sludge on the foam formation potential in the digestion tank. While mechanic disintegration of the sludge by means of a high pressure homogenizer produced only a minimal reduction of the foam phase, thermal pre-treatment of the sludge at 121 °C helped to effectively prevent foaming in the digestion tank. The efficiency and profitability of these measures must be verified on a case-by-case basis.

Chemical foam removal involves the addition of chemicals to the reactor content. This method is very effective; however, the anti-foam agent must be selected with care. It is well known that the application of certain anti-foaming agents disrupts the biology of the process of anaerobic digestion. It must be ensured that the applied defoamer is free of silicone so that there is no formation of siloxane in the biogas. This may lead to wear in the engine during gas combustion due to silicium precipitation [24].

Westlund et al. [6] have successfully applied poly aluminium salts (PAX-21) against microbial (*M. parvicella*) foam in digestion tanks in a wastewater treatment plant near Stockholm. Natural oils, organic substances consisting of triglycerides and free fatty acids, have also been used successfully as anti-foaming agents. The advantage of these substances compared to other chemical anti-foaming agents is that they are readily available, they can be degraded by microbes and thus increase the biogas yield [22].

Before applying an anti-foaming agent in an anaerobic digestion process, the economic aspects of its use must be evaluated. The applied amounts and the efficiency with regard to foam removal need to be considered here. It must also be ensured that the anti-foaming agent is used in an appropriate concentration, as concentrations that are too low or too high can contribute to the stabilization of the existing foam [22].

Conclusions

Many questions still need to be answered regarding the formation and removal of foam in biogas plants. For this purpose, a project was started to investigate the causes of foam formation in biogas plants. One focus of the project is to gain a better understanding of the process with the objective of determining when and why a biological process tends to foam formation and what are the early signs of foam formation. The aim is the targeted prevention of foam formation. On this basis, strategies for the prevention of foaming are to be developed and implemented in practice.

Literature Books are signed with ●

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Acknowledgement

The project was funded by the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety.