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Density of biogas digestate depending on temperature and composition

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HIGHLIGHTS

- Density of biogas digestate decreases with increasing temperature.
- Density of biogas digestate increases with increasing TS content.
- Density can be calculated depending on temperature and composition.
- Each equation shows relative deviations below 1%.

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ABSTRACT

Density is one of the most important physical properties of biogas digestate to ensure an optimal dimensioning and a precise design of biogas plant components like stirring devices, pumps and heat exchangers. In this study the density of biogas digestates with different compositions was measured using pycnometers at ambient pressure in a temperature range from 293.15 to 313.15 K. The biogas digestates were taken from semi-continuous experiments, in which the marine microalga *Nannochloropsis salina*, corn silage and a mixture of both were used as feedstocks. The results show an increase of density with increasing total solid content and a decrease with increasing temperature. Three equations to calculate the density of biogas digestate were set up depending on temperature as well as on the total solid content, organic composition and elemental composition, respectively. All correlations show a relative deviation below 1% compared to experimental data.

1. Introduction

Density is one of the most important thermophysical properties of biogas digestate (also called fermentation broth) to design and optimize stirring devices, pumps or heat exchangers of a biogas plant. Since biogas digestate contains water as well as several organic and inorganic compounds such as organic fibers, solids and mucilages (depending on the used input materials), the density is significantly different for every biogas plant and not equal to the density of water.

In the relevant literature, data regarding the density of biogas digestate depending on its composition and temperature are rarely. Pohn et al. (2011) determined the density of biogas digestate from two different biogas plants to develop an optimized stirring system. Each of the plants was fed with manure, corn silage and grass silage. Densities were measured at 313.15 and 323.15 K, whereby the density was lower for both biogas digestates at the higher temperature.

Regarding its consistency, biogas digestate is comparable to manure. The dependency of the density on the total solid (TS) content of manure has been investigated by several authors. For instance, Landry et al. (2004) analyzed different physical and rheological parameters of different manures (cattle, sheep, poultry and swine manure) with TS contents between 10% and 50%. Thirion et al. (1998) analyzed only cattle manure with TS contents between 16% and 53%. Both showed an increase of the density with a rising TS content – regardless of the origin of the manure. In addition, simple approaches of a linear regression can be found in the literature for a correlation describing the density of manure depending on the TS content (see Chen, 1983; Achkari-Begdouri and Goodrich, 1992; Houkom et al., 1974).

In the present study the density of different biogas digestates were determined depending on temperature and composition. Additionally, correlations between density, temperature and composition were developed. Using these correlations biogas plant components can be designed more accurately.

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2. Materials and methods

2.1. Biogas digestate

Three different biogas digestates were chosen for the experiments, which originated from anaerobic, semi-continuous experiments carried out by Schwede et al. (2013a), Schwede et al. (2013b). As inoculum biogas digestate from an agricultural biogas plant was used in both studies, which was operated with corn silage and cattle dung as feedstock. During the experiments of Schwede et al. (2013b) the fermenter was fed with biomass from the marine microalga *Nannochloropsis salina* (A). For the study of Schwede et al. (2013a) one fermenter was fed with corn silage (CS) and a second fermenter was fed with a mixture of algal biomass and corn silage in a ratio of 1:6 based on fresh matter (A + CS). Samples for the density measurements were taken after 245 days of the semi-continuous digestion. Further details on the set up and configuration of the fermenters, the feedstocks and the feeding intervals can be found at Schwede et al. (2013a, 2013b).

To represent a variety of moisture contents (MC) and in turn different TS contents, the biogas digestate was mixed with certain amounts of distilled water. The examined biogas digestates contained 0%, 10% and 20% distilled water additional to their original MC.

2.2. Density measurement

Density was measured with Gay-Lussac pycnometers according to DIN ISO 3507 with a sample volume of 100 ml, equipped with an integrated thermometer and adjusted to three decimal places by the manufacturer (Witeg Ltd., Germany). A water bath was used to heat the samples in a temperature range from 293.15 to 313.15 K in steps of 5 K. Each sample was measured nine times.

2.3. Analytical methods

The content of total solids (TS) and volatile solids (VS) of each biogas digestate was determined in triplicate according to DIN EN 12880 and DIN EN 12879, respectively. A Weender analysis of each biogas digestate was carried out in triplicate to determine the organic composition (crude protein, crude fat, crude ash, crude fiber, crude carbohydrate) by an external laboratory (Agrolab Ltd., Germany). The elemental composition (C, H, N, S) was determined twice for each biogas digestate by the Chair of Analytical Chemistry at Ruhr-Universität Bochum using quantitative elemental analysis (vario EL, Elementar Analysensysteme Ltd., Germany). Oxygen (O) was calculated assuming C, H, N, S and O form 100% of the organic composition.

3. Results and discussion

3.1. Composition of biogas digestates

The composition of the biogas digestates is given in Table 1. TS content of all samples (diluted and not diluted with distilled water) varies between 6.53% and 13.86%. The standard deviation of TS is very low for biogas digestates using A as feedstock due to a high homogeneity because of a maximum algal cell size of 5 μm for *N. salina* (Hibberd, 1981). Standard deviation for CS is higher due to a low homogeneity because maize was cut in 4 mm pieces using a straw cutter for ensiling before feeding.

In particular the organic composition differs between the biogas digestates. Biogas digestate with A as feedstock shows a high crude protein (26.93%) and crude fat (17.57%) content, whereas a very low crude fiber content (1.60%) was determined. In contrast CS has a ten times higher crude fiber content (17.03%) and a high Nfe content (49.00%). The differences in the organic composition of the biogas digestates were expected because of the used feedstocks and were wanted to get a high variety in the samples.

The elemental composition also show differences between the individual biogas digestates. Because of the lower crude protein content the C:N and the C:S ratio of CS (19 and 401, respectively) is higher compared to A (11 and 100, respectively). The ratios of A + CS are between A and CS (14 and 147, respectively). However, the differences in elemental composition are not as distinctive as for the organic composition. They only vary within the scope of a few percent.

3.2. Density of biogas digestates

The density of all biogas digestates with a dilution rate of 20% depending on its temperature is shown exemplarily in Fig. 1 on the left side. Independent of the used feedstock density decreases with rising temperature (the same effect occurred for undiluted samples and diluted samples with 10% dilution rate, data not shown), what agrees with the results found by Pohn et al. (2011).

The right side of Fig. 1 shows the density of all biogas digestates at 313.15 K depending on its total solid content. For all biogas digestates the density increases with rising TS content. For the mixture A + CS the increase is not as obvious as for the fermented algal biomass (A) and the corn silage (CS), but with regards to the standard deviation of the density values for A + CS a similar behavior seems reasonable. The increase due to a rising TS content can also be found at the other investigated temperatures (data not

Table 1
Composition of the biogas digestates: TS content with different rates of distilled water, as well as organic and elemental composition.

Feedstock		A	CS	A + CS
TS, 0% of distilled water	% of FM	13.86 ± 0.03	8.97 ± 0.15	8.91 ± 0.08
TS, 10% of distilled water	% of FM	11.41 ± 0.04	7.82 ± 0.15	7.85 ± 0.06
TS, 20% of distilled water	% of FM	9.49 ± 0.03	6.53 ± 0.25	7.01 ± 0.11
Crude protein	% of TS	26.93 ± 0.32	14.23 ± 1.19	18.03 ± 0.29
Crude fat	% of TS	17.57 ± 0.32	3.43 ± 0.21	4.27 ± 0.15
Crude fiber	% of TS	1.60 ± 0.17	17.03 ± 2.93	10.70 ± 3.32
Nfe	% of TS	30.23 ± 0.15	49.00 ± 0.61	40.70 ± 2.89
Crude ash	% of TS	23.67 ± 0.21	16.30 ± 1.08	26.30 ± 0.56
C	% of TS	50.12 ± 0.04	44.13 ± 0.10	42.52 ± 0.38
H	% of TS	7.64 ± 0.05	6.41 ± 0.01	6.15 ± 0.05
N	% of TS	4.71 ± 0.06	2.34 ± 0.10	2.95 ± 0.02
S	% of TS	0.50 ± 0.04	0.11 ± 0.02	0.29 ± 0.01
O	% of TS	13.36 ± 0.01	30.71 ± 0.21	21.80 ± 0.46

FM – fresh matter, TS – total solids.