Bioresource Technology 247 (2018) 419–425

Contents lists available at ScienceDirect

Bioresource Technology

journal homepage: www.elsevier.com/locate/biortech

Ammonia and methane emissions during drying of dewatered biogas digestate in a two-belt conveyor dryer

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ARTICLE INFO

Keywords:
Digestate
Drying
Ammonia scrubber
Greenhouse gas emissions
Fourier transform infrared spectroscopy

ABSTRACT

Aim of the present study was to identify type and amount of emissions during the drying of biogas digestate in a two-belt conveyor dryer at different temperature settings and to investigate the effect on its nutrient content. Furthermore, the possibility of recovering nitrogen from the exhaust air was investigated. Emissions of CH_4, CO_2 and NH_3 were measured by Fourier transform infrared spectroscopy. Biogas is mainly composed of CH_4 and CO_2, hence gas release from the digestate during drying was expected to increase the concentration of these components. Although CO_2 concentration was elevated above the background concentration, CH_4 did not exceed the background concentration. Maximum NH_3 concentration of 183.3 $mg{\cdot}m^{-3}$ was detected during drying. A NH_3 concentration of 10.8 $mg{\cdot}m^{-3}$ was measured in the exhaust air of the ammonia scrubber, which is equal to a NH_3 reduction rate of 94%.

1. Introduction

The generation of electrical energy derived from anaerobic digestion is a well-established technology. In Germany, about 8000 biogas plants are currently operated with an overall installed power of more than 4.2 GW (FNR, 2017). Thus, Germany holds the leading position within the European Union regarding the number of operating anaerobic digestion plants and installed power (EBA, 2017; Le Seigneur, 2017). The German Renewable Energy Act (EEG, 2014) supports the generation of renewable energy by guaranteeing fixed feed-in tariffs and bonuses for ecologically worthwhile applied heat from combined heat and power plants (CHP). Energy generated by anaerobic digestion can contribute to an environmentally friendly energy mix if a sustainable land-, crop- and facility management is ensured including the utilization of biogas digestate.

Biogas digestate contains various plant nutrients while the composition depends on the used substrates. The co-digestion of animal manure and energy crops becomes more and more important due to the increased biogas yield and improved nutrient balance of the digestate (Hrad et al., 2015; Mata-Alvarez et al., 2014). Using the digestate as fertilizer contributes to closing the nutrient cycle and hence to preserve natural resources. Fertilizing properties of digestate are addressed in various studies. When digestate is applied to rice fields a 23% increase in grain yield, compared to multi compound mineral fertilizers (N; P; K), was observed (Gnanamani and Kasturi Bai, 1992). Also a higher lettuce yield was reported by Wenke et al. (2009) when digestate was applied compared to using mineral nitrogen fertilizer. Other studies state that the yields of crops are equal or even lower, when digestate is used for fertilization instead of mineral fertilizers (Ghoneim, 2008; Lošák et al., 2011). Also, nitrogen losses during storage under aerobic conditions reduce the plant available nitrogen content of digestate and therefore, the fertilizing value (Möller and Müller, 2012; Petersen and Sørensen, 2008). In addition, a net nitrogen immobilization caused by the solid fraction of the digestate was reported by (Peters and Jensen, 2011), while liquid fractions can be characterized as N-K fertilizers similar to accordant mineral fertilizers (Möller and Müller, 2012).

Application of digestate to agricultural fields is regulated by law to avoid undesired nutrient accumulation (Maurer and Müller, 2012). Therefore, in regions with high livestock density, the digestate has to be transported over longer distances to regions with nutrient demand. However, transporting untreated digestate is not economically feasible due to the high water content concomitant with a low nutrient concentration (Döhler and Schliebner, 2006). Therefore, biogas digestate is often separated into liquid and solid fractions before field application.

Biogas CHPs deliver electrical energy that can be easily distributed through network supply. However, the co-generated heat has to be used locally. In Germany, the use of heat is limited because biogas power plants are located in rural areas with well-established heat supply systems and there are only a few potential heat consumers for bulk consumption (Bühle et al., 2011). The development of local heating grids is encouraged to deliver heat to households, agricultural facilities or public buildings. Furthermore, the heat can be used for processing

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http://dx.doi.org/10.1016/j.biortech.2017.09.099
Received 14 June 2017; Received in revised form 13 September 2017; Accepted 15 September 2017
Available online 19 September 2017

technologies like drying digestate or other agricultural products.

Drying of digestate reduces the volume of the material to be stored and increases the transportation value. In addition, material degradation due to microbiological processes can be avoided if digestate is dried. Although no final dry matter content for the safe storage of digestate is reported in literature, target values of 85%–90% are common in commercial drying.

Dewatered digestate can be dried with different techniques by using different methods of heat transfer. In the case of convection drying heat is transferred from hot air or exhaust gas (CHP) to the digestate. In addition, techniques where heat is transferred by direct contact of the digestate to hot surfaces are available. Commonly applied for digestate are feed-and-turn dryers, belt dryers, and drum dryers. Recently, the use of solar flat-bed dryers has also been reported (Maurer and Müller, 2012). To compare the primary energy demand and the global warming potential of different technologies, life cycle assessment studies were carried out like that presented by Rehl and Müller (2011). The study stated that hot air convective belt drying was the application with the highest primary energy demand compared to convective hot air solar drying and contact drying of digestate in a heated drum, depending on the kind of fuel used for heat supply. Environmental impact of digestate processing technologies heavily depends on the energy source used for treatment as well as on the allocation methods used. Compared to a burden-free use of heat provided by the CHP, environmental burdens considerably increase when heat generation is taken into account. (Rehl and Müller, 2011).

Although drying technologies are commercially available, application has been rather limited until now (Möller and Müller, 2012). In 2009, only six out of 441 biogas plant operators indicated that they use drying techniques for digestate treatment (Witt et al., 2010). In general, information about drying of digestate and gaseous emissions during drying in particular is rare. Although it is known that methane, a highly active greenhouse gas, and ammonia, affecting the environment by its eutrophication and acidification potential, is released from digestate storage tanks (Boulamanti et al., 2013; Groth et al., 2015; Oonk et al., 2015) only few studies focus on the emission potential of digestate during drying. Pantelopoulos et al. (2016) stated that drying of digestate is prone to NH_3 volatilisation, which can be minimised by acidifying the slurry before drying. A further study investigated emissions during solar drying of digestate in a flat bet dryer (Maurer and Müller, 2012). This study showed that the highest emission rates occurred at the beginning of the drying cycle in the batch-wise process. In contrast, continuous drying of digestate in a multi-layer belt dryer combines the advantages of a compact construction with the mixing of the material and cracking of the dried surface, while being discharged onto the next lower belt. In addition, using a hot airflow in through flow mode ensures efficient and uniform drying. However, to our knowledge, studies about gaseous emissions during continuous hot air convective through flow drying of biogas digestate in a two-belt conveyor dryer have not been published yet.

Aim of the present study was to identify type and amount of emissions during convective hot air drying of dewatered biogas digestate in a two-belt conveyor dryer at different drying temperatures and to investigate the effect on its nutrient content. Furthermore, the possibility of recovering nitrogen from the exhaust air should be investigated.

2. Material & methods

The digestate used for the drying experiments was taken from a 200 $kW_{el.}$ biogas plant that was fed daily with 15,000 kg of a mixture containing 19% corn silage, 53% manure, 21.4 % grass silage and 6.8% grain (Lindner et al., 2015). The hydraulic retention time of the substrate was 150 days. A scheme of the power plant is given in Fig. 1, More detailed technical descriptions of the biogas plant are to be found in further studies (Lemmer et al., 2013; Naegele et al., 2013). After anaerobic fermentation, the digestate was dewatered by two screw press separators to a dry matter content (DM) of 25% and fed to the dryer via a screw conveyor (Fig. 1)

2.1. Two-belt conveyor dryer

For drying the dewatered digestate, a prototype two-belt conveyor dryer (Huber SE, Berching, Germany) was used, Fig. 2.

The thermal capacity of the dryer was 150 kW and it was connected to the heating grid of the biogas power plant. Since the heating grid supplies various other facilities on the experimental farm, only 34 kW of thermal energy was available for drying. To represent normal farm conditions, where the major part of waste heat would be available for drying, a supplementary heating unit of 150 $kW_{th.}$ was employed for drying experiments at temperatures above 70 °C.

After feeding the substrate via a vertical screw conveyor (Himel, Melchingen, Germany), the bulk height of 80 mm was adjusted by a bifilar screw, also distributing the material evenly on the belt. After passing the upper drying belt, the digestate falls down a height of 850 mm onto the lower belt. Finally, the dried product is removed by a horizontal screw conveyor.

For nitrogen recovery, the exhaust air from the dryer is led through an ammonia scrubber (Fig. 3). Here, a sulphuric acid solution is sprayed on a 800 mm thick packed bed by a centrifugal pump NH_3 is converted into $(NH_4)_2SO_4$ and dissolved in the solution while purified air is leaving the system. To ensure an effective dissolving process, the pH-value of the solution is controlled by a pH-controller (Type 202530, Jumo, Fulda, Germany). When the pH-level rises, H_2SO_4 is added automatically to maintain pH 3.0. To prevent $(NH_4)_2SO_4$ precipitation, the solution is changed when electrical conductivity (EC) reaches 120 $mS{\cdot}cm^{-1}$, measured with an electrical conductivity meter (Type 202540, Jumo, Fulda, Germany).

2.2. Measurement of air condition

Temperature and rel. humidity was measured at the inlet and outlet of the drying zone with PT100 sensors (accuracy ± 0.3 °C) and humidity sensors (HMT 330, Vaisala, Helsinki, Finland) with an accuracy of ± 2.5% RH. Pressure was measured before and after the recirculation fan with ± 0.2% accuracy (VEGABAR 52, VEGA, Schiltach, Germany), Fig. 2.

$NH_{3,}$ CH_4 and CO_2, concentration was measured by Fourier transform infrared spectroscopy (FTIR) (GASMET DX4000, Ansyco, Karlsruhe, Germany) in the circulating air and in the exhaust air of the ammonia scrubber. Air was sucked through stainless steel tubes placed in two axis orientation from inside the dryer to the FTIR sensor.

Gas concentrations were measured in $mg{\cdot}m^{-3}$ and corrected to standard conditions (T_N = 273.15 K; P_N = 1013.25 hPa) and dry gas basis by the software CALCMET™ based on actual temperature, pressure and water content as measured in the FTIR detector.

2.3. Experimental design

The dewatered digestate was homogenized before feeding. To supply the amount of homogenous substrate for one complete test series, freshly separated material was mixed with material already stored for some hours at the drying site.

Drying experiments were performed at drying air temperatures of 45 °C, 70 °C and 80 °C, measured at the inlet of the drying area with three replications per temperature. The required drying time was determined in pre-tests to ensure a final moisture content of less than 10%. For 45 °C, a drying time of 50 min on the upper belt and additionally 35 min on the lower belt delivered appropriate results. For 70 °C and 80 °C, 25 min on the upper belt and 20 min on the lower belt were sufficient. Digestate flow rates, as a result of chosen belt speed, are presented in Table 1.

Measurements of NH_3, CH_4 and CO_2 concentration in the circulating