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DRYING CHARACTERISTICS AND NITROGEN LOSS OF BIOGAS DIGESTATE DURING DRYING PROCESS

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ABSTRACT Digestate occurring during the fermentation of biomass in biogas plants contains high content of major plant nutrients like phosphorus, potassium and nitrogen. Due to the high water content of biogas digestate (90 – 97%) it is not economically justified to transport the digestate over longer distances. Reducing water content of biogas digestate by drying is an option to reduce volume and therefore alleviate transportation costs. However, during drying the digestate emits volatile compounds due to decomposition which are not yet sufficiently known in quality and quantity. Therefore, the objective of this study was to investigate the drying behavior and the change of digestate composition. Drying was performed in a hybrid solar/waste-heat dryer, which uses solar energy besides waste heat of a combined heat and power unit (CHP) and the exhaust air of a micro turbine. In this experiments 60 t of liquid digestate were applied. Climatic data were measured inside and outside the drying hall. Dry matter (DM) and organic dry matter (ODM) were measured on a daily basis. Furthermore, energy consumption of waste and solar heat were recorded and related to the quantity of dried feedstock. Chemical analysis of total nitrogen, ammonium, phosphate, potassium oxide, magnesium oxide and calcium oxide was undertaken before and after the drying process and losses of nitrogen were calculated. Specific energy consumption depended on the climatic conditions and most of the energy consumption was covered by the waste heat of the CHP. During the drying process a significant loss of nitrogen was observed.

Keywords: Digestate, drying of digestate, nitrogen loss, hybrid solar/waste-heat dryer

INTRODUCTION

Germany has worldwide the highest number of installed biogas plants (Weiland 2009). In the year 2008 4,000 biogas plants were operating (FNR 2009) and about 500,000 ha of agricultural land was used to cultivate renewable feedstock (Schüssler 2009). This is equivalent to a theoretical biogas potential of 417 PJ/a, whereof 85 % arises from biogas production in the agricultural sector (FNR 2009). It is expected that no stagnation will take place in the near future. Therefore, the number of biogas plants should continue to increase as well as the amount of digestate that is a by-product of the fermentation process. Wet fermentation processes take the biggest part of the fermentation in the agricultural domain with a dry matter content of the digestate between 3 – 10 % (Döhler and Wulf 2009). In general, during the past few years digestate has been used as a liquid fertilizer in the agricultural sector.

In Germany there are regions with intensive livestock farming and also intensive biogas production on the same farm. Often, substrates directly from the farm such as manure and slurry are processed in the biogas plants.

The addition of co-substrates for instance harvest residues or residues from food processing industries enhances the dry matter content and leads to a higher biogas yield (Wulf, Jäger et al. 2006; Weiland 2009). Nevertheless, this enhancement of dry matter can also lead to an enhancement of digestate and plant nutrients like ammonia in the nutrient cycling of farms. In view of the limited quantity of nitrogen that can be applied on fields as regulated by the Fertilization Ordinance (Düngeverordnung) (Bundesministerium für Ernährung 2007) it is necessary to find a way to manage and transport the surplus of digestate out of the farm and the region, respectively. Döhler and Schliebner (2006) concluded that it is not economical feasible to transport the liquid digestate for distances further than 5 – 10 km. In view of this economical limitation drying of digestate to reduce the cost of transportation seems to be a viable alternative to deal with the surplus of nutrients and digestate on the farm's nutrients cycling.

However, the handling of the surplus is only one aspect of drying the digestate. Another aspect of drying the digestate is the outgassing of the volatile compounds. The liquid digestate of biogas plant contains among other compounds high amounts of nitrogen. The nitrogen in the digestate is in the form of ammonium and ammonia. Both forms of nitrogen are prone to volatilize and Whelan et al. (2009) have shown in their studies that the ammonia losses from digestate under laboratory conditions are linear with time. They also assume that the change of concentration rate due to volatilization is inversely proportional to depth (Whelan, Everitt et al. 2009).

Aim of this case study was to characterize the drying process with digestate from a biogas plant in Germany using a hybrid solar/waste-heat drying plant and to calculate the losses of nitrogen.

MATERIALS AND METHODS

The case study was conducted on a farm located in the German Federal Land of Baden-Württemberg. The farm has three main units, pig fattening, the biogas plant and the drying plant.

The biogas plant has a total fermentation volume of 2,200 m³ and the composition of the feedstock is shown in table 1. The biogas is combusted in a combined heat and power unit (CHP) with an electrical power of 320 kW and in two micro turbines with a total electrical power of 130 kW.

Table 1 Composition of the feedstock of the biogas plant

Substrate	Mass percentage (%)
Expired (spoiled) food and feeding stuffs	40
Cattle slurry	20
Energy plants	15
Pig slurry	15
Husk	5
Dried poultry dung	5

The biogas plant produces in total circa 10,000 t of digestate per year but just one third is used for drying in the hybrid solar/waste-heat dryer because of the limited drying capacity.

Batch drying test

The hybrid solar/waste-heat drying plant is covered with a transparent roof and transparent walls consisting of polyethylene bubble film with a U-value of 3.2 W m^{-2} K^{-1}. The drying hall has a drying area of 480 m² and is filled by means of a sub terrestrial pipeline whereby the digestate is pumped into the drying plant. The ambient air exchange is regulated with a controlled ventilation flap and four speed controlled exhaust fans. On the ceiling there are six fans, which circulate the air around the hall and guide the saturated air away from the drying surface, which accelerates the drying process. An electric mole™ mixes the digestate to achieve uniform water evaporation and to avoid crust forming on the surface of the digestate.

During the drying process all the drying relevant parameters for characterising the drying behaviour were saved by the data acquisition system such as global radiation, wind speed and temperature and relative humidity (RH) inside and outside the hall. Depending on the recorded parameters the programmable logic control system (PLC) controls all components of the drying plant automatically. Figure 1 shows the scheme of the drying hall.

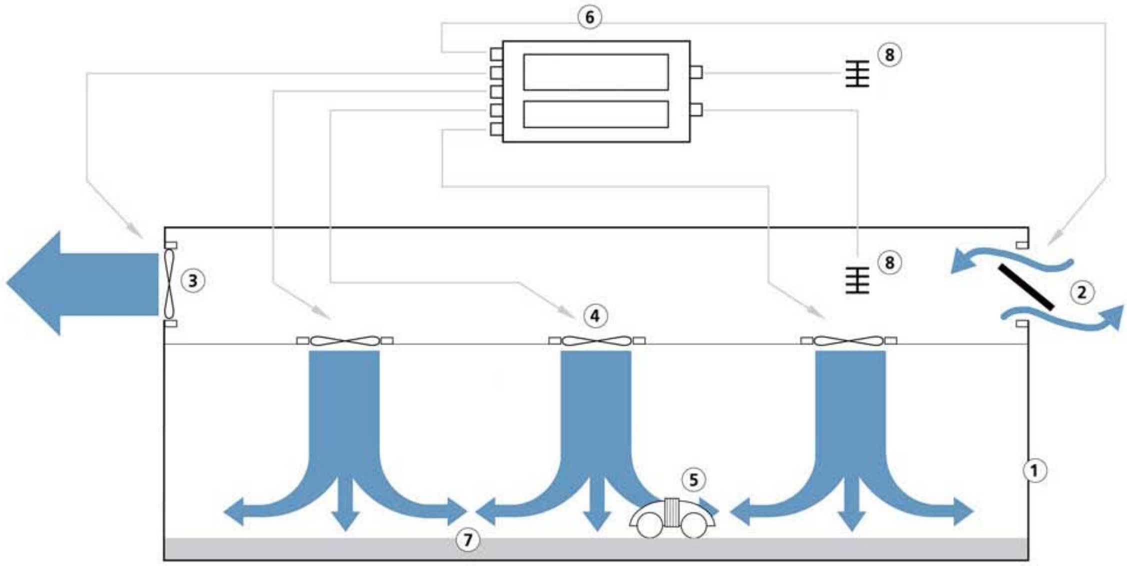

Figure 1 Scheme of the hybrid solar/waste-heat drying plant: 1) closed transparent hall, 2) ventilation flap, 3) exhaust fan. 4) ceiling fans 5) electric mole™ 6) PLC control system, 7) drying area, 8) sensors for temperature, relative humidity wind and global radiation (Starcevic 2003)

Digestate

The digestate originates from the biogas plant described above with the feedstock mentioned in table 1. The liquid digestate has a moisture content of 94 % when it is filled in the drying plant. To determine the composition of the digestate in terms of P_2O_5, K_2O, CaO and MgO it was analyzed in the laboratory according standard methods.

Experimental procedure

The drying plant was filled with 60 t of liquid digestate. The climatic data were collected every four minutes during drying time. The energy input needed for drying was measured by a heat meter. Once a day samples of the digestate were collected according to a grid pattern across the drying area. Three replicates were collected and analyzed in the laboratory. Analysis of the dry matter (DM) was performed by drying the digestate at 105°C in a drying oven (DIN-EN-12880), while the organic dry matter (ODM) was determined subsequently at 550°C in a muffle furnace (DIN-EN-12879). Equation 1 shows the calculation of the DM.

$$DM = \frac{DM_1}{DM_0} \cdot 100(\%) \qquad \textbf{(1)}$$

DM_0 = weight of the fresh digestate

DM_1 = weight of the digestate dried at 105°C

Chemical analyzes to determine the content of N_{tot} was done according DIN ISO 11261, NH_4-N, P_2O_5, K_2O, CaO and MgO (according DIN 38406) were done with the fresh and dried digestate. As a result of these analyzes the nitrogen loss could be calculated as a mass balance.

RESULTS AND DISCUSSION

Drying characteristics

As shown in figure 2, the digestate in experiment 1 was dried from an initial dry matter content of 5.4 % to final dry matter content of 89.1 %. In experiment 2 the dry matter content was initially 6.13 % and at the end 90.0 %. At the early stages of drying for both experiments the standard deviation was low. But when the dry matter content rose to a content of about 25 % the standard deviation was high and indicated a very uneven drying across the drying area. For a dry matter content of more than 85 % the standard deviation became lower, which showed that the digestate dried homogeneously at the end of drying.

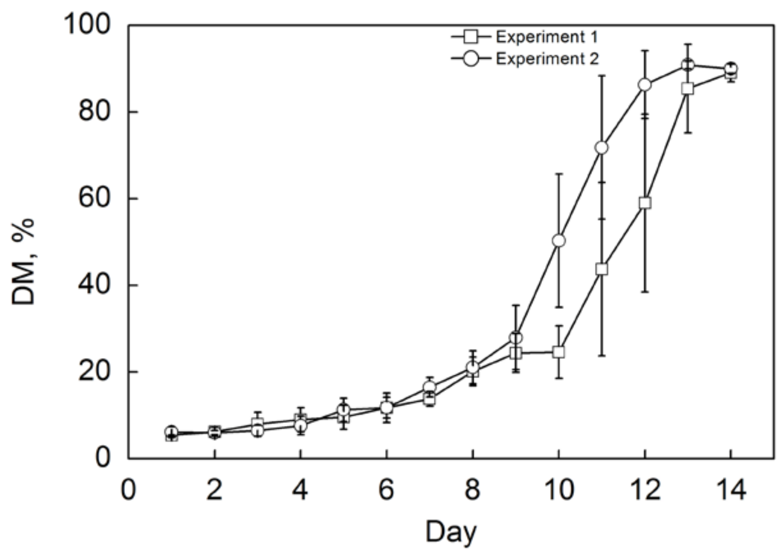

Figure 2 Changes in the dry matter content (DM) during drying (error bars indicate standard deviation).

In table 2 the main parameters of the experiments are shown. Due to the prevailing conditions there will be different influences and the experiments will not be comparable for all parameters. For example the micro turbine was not working during run 1. Also the temperature and the relative humidity were not exactly the same. Regarding the chemical composition of the liquid digestate there are also differences due to the composition of the feedstock of the biogas plant. The feedstock is not constant throughout the year, due to seasonal variations.

Table 2 Comparison of the main parameters of two drying experiments

Parameters		Run 1	Run 2
Drying time (days)		13	13
Initial mass digestate (t)		60	60
Final mass digestate (t)		4.1	4.1
Initial water content (%)		94	94
Final water content (%)		11	10
Mean temperature ambient (°C)		17.0	19.4
Mean RH ambient (%)		71.8	72.5
Mean temperature inside (°C)		30.1	32.9
Mean RH inside (%)		50.2	42.3
Mean temperature digestate (°C)		31.6	35.0
Energy consumption	CHP (MWh)	89	94
	Solar (MWh)	18.4	11.9
	Micro turbine (MWh)	-	24.3
Energy (MJ/kg H_2O evaporated)		7.3	8.4

In terms of the chemical analyzes of the fresh and dried digestate there were losses of total nitrogen and ammonium so that at the end of experiment one 0,028 g/g DM of total nitrogen and 0,024 g/g DM of ammonium were volatilized. In experiment two 0,042 g/g DM ammonium volatilized and in total 0,058 g/g DM of nitrogen were lost. Regarding other nutrients (P_2O_5, K_2O, CaO and MgO) there was an accumulation during drying. Furthermore this accumulation to the total mass of dry matter is insignificant and can be considered as being a consequence of the water loss or an insignificant decomposition of dry matter. Figure 3 shows the changes of nutrients during the drying process.

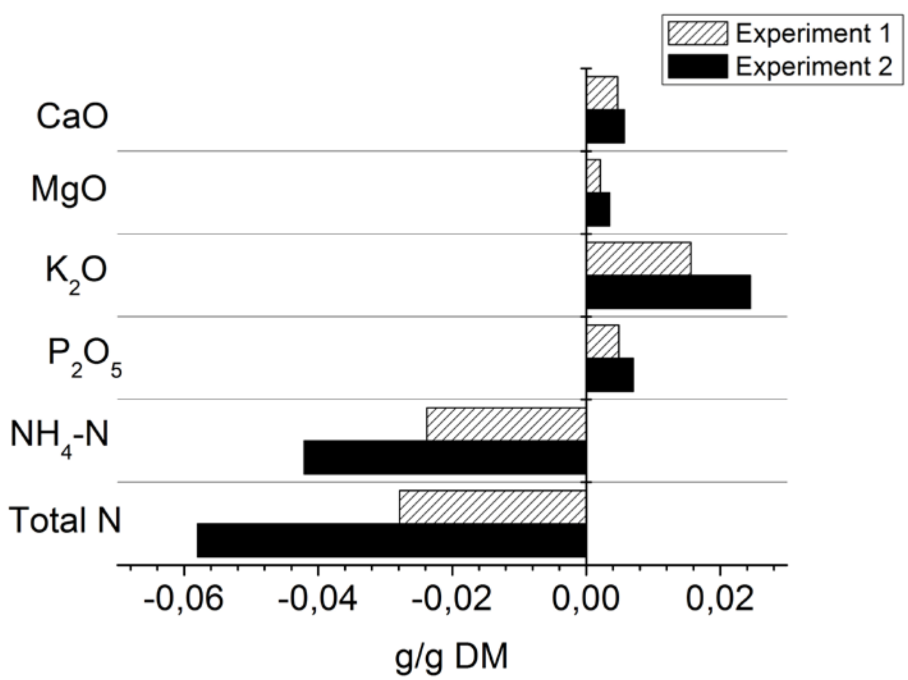

Figure 3 Changes of nutrient contents

CONCLUSION

Referring to the water evaporation and energy input from the CHP, micro turbine and solar irradiance, the power consumption was for the first experiment 7.3 MJ/kg water evaporated and for the second experiment 8.4 MJ/kg water evaporated. These experiments were performed during the summer time in Germany. During the cooler seasons more energy would be needed to dry the digestate.

The composition of the dried digestate has to be considered critically. There is a decrease of nitrogen in the digestate during the drying process. It can be assumed that the nitrogen is emitted to the air as volatile nitrogen (Whelan, Everitt et al. 2009). To know what kind of nitrogen is emitted, it is necessary to measure the discharged air and to determine the gas emissions of the digestate in the dryer.

The low nitrogen content implies that there is a low content of ammonium, which is easily available for plants, but raises the question if it is reasonable to dry the digestate in spite of the decrease in fertilizer value. At the moment drying of digestate and the subsequent use as fertilizer is stipulated by the government (Bundesministerium für Umwelt 2008). To break-even for the drying procedure with and without governmental subsidies has to be identified.

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