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DOI:10.1016/j.biortech.2011.08.076

Residual biogas potential from the storage tanks of non-separated digestate and digested liquid fraction

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Abstract

Biogas plants daily produce enormous volumes of digestate that can be handled in its raw form or after mechanical separation. In Italy, effluents are usually stored within aboveground, uncovered tanks, which make them potential emitters of biogas into the atmosphere. The purpose of this study was to estimate the amount of biogas emitted to the atmosphere during the storage phase of non-separated digestate and digested liquid fraction. The trials were performed at two northwest Italy 1MWel. biogas plants. A floating system for the residual biogas recovery, and a set of three wind tunnels for NH_3 emission measurement were used. The experiment demonstrated significant loss to the atmosphere for each of the gases; specifically, on average, 19.5 and 7.90 Nm^3biogas MWhel.$^{-1}$were emitted daily from the storage tanks of non-separated digestate and digested liquid fraction, respectively.

Keywords: anaerobic digestion; digestate; digested liquid fraction; digested slurry storage; biogas emissions.

1. Introduction

Anaerobic digestion (AD) of organic substrates converts organic matter to biogas, a mixture of methane (CH_4), carbon dioxide (CO_2), and other trace gases, which can serve as a fuel source for heat and electricity production (Ward et al., 2008). The combination of increasing demand for energy from renewable sources and increasing Italian market prices for biogas-produced electric energy (0.28€ $kWhel.^{-1}$ for an AD plant with installed electric power up to 1MW) has caused interest in anaerobic digestion as a revenue source to spread rapidly throughout Europe.

The growth has been stunning. In Italy alone, a current survey (Fabbri et al., 2010), found approximately 230 agricultural AD plants to be operating throughout the nation, 87% of which are fed with a mixture of animal manures, energy crops, and agro-industrial by-products. Plant size and production have also grown; several recently-built farm-scale installations produce nearly 1MW of electric power. While these statistics are impressive, further opportunity remains in the secondary products of AD.

The typical final product of anaerobic digestion is digested slurry that is handled “as is” or after mechanical separation. In both cases, the digested slurry and the digested liquid fraction are stored within aboveground, uncovered tanks. While energy crops and agricultural by-products as input biomasses ensure high biogas yields relative to those produced from animal manures (Amon et al., 2007), they require long hydraulic retention times (HRT) (Amon et al., 2002; Scherer et al., 2002) for optimal degradation of their organic matter. During retention lies the opportunity for residual gas production and therefore, additional revenue.

Previous studies have documented that residual biogas production (Hansen et al., 2006; Lindorfer et al., 2008; Resch et al., 2008; Menardo et al., 2011) are likely to occur during digestate storage as it retains significant undigested organic matter. As these authors suggest, abandoning the potential that remains within the digestate may lead to two critical downsides—additional environmental pollution and lost plant revenue. Pollution results from methane and CO_2, the main components of biogas, which are also greenhouse gases (GHG) that affect the global environment and climate (IPCC, 2007). Thus, gaseous loss abatement during the digestate storage phase will likely make environmental sustainability of anaerobic digestion even more attractive.

Döhler et al. (2009) estimated the digestate storage phase accounts for approximately 27% of global $CO_{2eq.}$ emissions generated throughout the AD process. On the other hand, residual biogas potentials of anaerobic digested slurry can vary widely (Hansen et al., 2006) according to AD plant operating parameters (feedstock type and quality, organic loading rate, hydraulic retention time) and storage parameters (environmental and digestate temperature). Unfortunately, and in spite of the large number of agricultural biogas plants operating in Italy, limited investigations have yet to be conducted on this topic. Therefore, this study aims to estimate the residual biogas yield during the storage of non-separated digestate and digested liquid fraction at two representative Italian agricultural biogas plants.

2. Materials and Methods

Measurements were taken of residual biogas yields during storage of non-separated digestate and digested liquid fraction at two 1MWel. AD plants operating in northwest Italy.

AD Plant 1 has two identical 6000m^3 double-chamber concentric fermenters heated to 41°C by stainless steel heating pipes positioned on the chamber inner walls. Within each fermenter, three mixing units (one long axis, one horizontal axis, and one vertical axis mixer) operate 20 minutes per hour. During the investigation period the plant was fed with animal manures, energy crops, and agricultural by-products. The main technical parameters of the plant are reported in Table 2. Solid feedstocks are loaded to fermenters by means of a mixing wagon running 20 hours per day, whereas the liquid one is fed by a pumping station. Digestate is stored within a 6000 m^3 aboveground storage tank (diameter 36 m, height 6 m) without a gas tight covering system. No mixing system is installed on the storage tank. Approximately 100 m^3 of fresh digestate is loaded daily into the storage tank by overflow of the second fermenter.

AD Plant 2 is made up of two 6000 m^3 fermenters. The first unit is a double-chamber concentric fermenter, whereas the second one is a 6000 m^3 single-chamber reactor tank covered by a gasometer. Both fermenters are heated to 41°C by stainless steel heating pipes installed on the inner walls of the tanks. Mixing of the first fermenter is provided by a set of four mixing units (one long axis, two vertical, and one horizontal axis) operating 20 minutes per hour. The second fermenter is equipped with three long axis mixers. The main process parameters of Plant 2 during the experimental period are reported in Table 2. Solid feedstocks are loaded into fermenter 1 by a mixing wagon while a pumping station loads liquid manures. Digested slurry (approximately 90 m^3 per day) is separated prior to storage by means of a screw-press mechanical separator (Sepcom® mod.065) working 24 hours a day. The digested solid fraction is stored in a static heap on an uncovered concrete platform as opposed to the liquid fraction which is stored within a 6000 m^3 aboveground tank (diameter 36m, walls height 6m) without a gas tight covering system. No mixing system is installed on the storage tank.

At both examined biogas plants, stored slurries are applied to arable crops three times during the year: spring (about 40%), summer (30%), and autumn (30%). The solid fraction produced at biogas plant 2 is stored in a static heap for a period of at least 90 days and used as fertilizer by application on the farm or transported to outside farmlands. During the experimental period (150 days) both biogas plants were monitored by DEIAFA within the national research project PROBIO-biogas funded by Piemonte Region. The study showed that both biogas and electric energy production were nearly steady and that no process failures arose.

2.1 Measurement of residual biogas potential from non-separated digestate and digested liquid fraction

The residual biogas potential during storage of non-separated digestate (Experiment 1) and digested liquid fraction (Experiment 2) was measured by means of a recovery system that was designed by DEIAFA (University of Torino).

The device (Fig. 1) is made up of a squared floating polyethylene and stainless steel frame (2.5m X 2.5m: total surface 6.25m^2) covered by a PVC two side-coated polyester fiber membrane. To avoid gas leaks from the structure, the membrane is folded again under the frame and fastened to it with rope.

Once the device is floated over the digested slurry surface, any released biogas is collected beneath the membrane. Thereafter, biogas flowed through PVC tubing to a 2m^3 gasometer made of the same material as the membrane covering.

The biogas collected by the pilot system is quantified by the following means:

- a pressure probe that detects a slight overpressure within the gasometer;
- a vacuum pump, activated by the pressure sensor, that collects the biogas from the gasometer;
- a timer that curtails power to the pump after two minutes of operation to avoid gasometer failure;
- a gas meter (SamGas, mod. G2.5 – flow rate: min 0.025 m^{3}h^{-1}; max 4.0 m^{3}h^{-1});
- a vacuum pump (ASF Thomas mod. 107) connected to the gas meter.

The residual biogas potential of non-separated digestate and digested liquid fraction was quantified during spring-summer conditions for a number of days (150) close to the requirements of Italian regulations. Each experiment started at the end of March, after emptying approximately 80% of tank capacity. The biogas recovery system was placed on the surface of the slurry and fixed in the middle of the tank for the entire storage period.

Both experiments utilized probes and data loggers (Onset® Hobo U12) placed next to the recovery device to track the digested slurry temperatures during measurement; they were also installed to monitor the temperature and pressure of the biogas within the gasometer. Newly-digested manures were sampled and tested monthly for pH, total solids (TS) content, and volatile solids (VS) content. At each sampling, one 2 L sample, comprised of four to six sub-samples taken from the inlet of the storage tank, was analyzed. Total solids and VS were determined in accordance with standard methods (AOAC, 1990); pH was determined by pH-meter HI 9026 (Hanna Instruments, Italia). Daily recordings of recovered biogas volumes were completed by reading the volume meter display on the pump. Methane and CO_2 biogas concentrations were measured and recorded weekly by means of a portable gas analyzer (Draeger X-AM 7000). Recorded data were normalized to normal litres (L_N) (dry gas, T= 0 °C, P= 1013 hPa) according to VDI 4630 (2006). Daily biogas yields from whole digested slurry storage tanks were estimated afterward while assuming a homogeneous biogas production per unit surface area. Emissions of GHG expresses as CO_2 equivalents were estimated considering a global warming potential of 25 and 1 for CH_4 and CO_2, respectively (IPCC, 2007).

2.2 Statistical analyses

Significant differences in results were investigated using the ANOVA procedure. Before analysis some data were log transformed in order to fit a normal distribution. For all the statistics, a significance level of P= 0.05 was applied.

3. Results and discussion

The chemical characteristics of non-separated digestate in experiment 1 and of digested liquid fraction during experiment 2 are shown in Table 3. Total solids content of non-separated digestate resulted to be always higher than 8.7%, VS and TS ratio ranged from 0.75 to 0.82. On average, the concentration of TS in the digested liquid fraction was approximately 45% less than the concentration in the non-separated digestate, while the VS and TS ratio remained lower than 0.70 the entire time. During the pilot experiments, a remarkable biogas potential was identified and measured from non-separated digestate and digested liquid fraction (Figs 2 and 3). In general, a wide variability was detected in daily biogas yields from both slurries throughout the trials. This effect is probably due to a discontinuous CH_4 release via ebullition (Husted, 1994). The measured biogas production from non-separated digestate (Fig. 2) ranged from 119 and 776 L_N biogas m^{-2} surface day^{-1} (average 468 L_N biogas m^{-2} surface day^{-1}). Average methane concentration was 56% (51%÷61%). Despite the average environmental temperature of 16.6°C (min. 5.35°C, max 24.4°C), the digestate ones ranged from 22.0 to 34.2°C (average 29.2°C). Assuming homogeneous biogas production per unit surface area, it can be estimated that on average 476 Nm^3 biogas day^{-1}were emitted from the storage tank, corresponding to approximately 4.30 Nm^3 biogas m^{-3} non-separated digestate daily loaded into the tank.

In experiment 2 (Fig. 3), the recorded average temperature of the liquid fraction was 25.9°C (range 17.9-33.5°C). An average biogas production of 190 L_N biogas m^{-2} surface day^{-1} (range 83-319 L_N biogas m^{-2} surface day^{-1}) was measured. This latter value corresponds to approximately 2.32 Nm^3 biogas per m^3 of fresh digested liquid fraction daily loaded into the tank. Methane concentration in the biogas was in the range of 56%-61% (average 57.5%). Biogas yields measured from the digested liquid fraction were remarkably lower than the residual biogas potential of non-separated digestate. This difference is largely due to the significantly ($P<0.05$) lower VS content (Table 2) of the liquid fraction relative to the non-separated digestate (Menardo et al., 2011). Fig. 4 shows the relationship between biogas yields and manure temperature. Specifically, our results showed that the higher the digestate temperature, the higher the amount of recovered biogas per square meter of covered surface—a consistent finding with previous results by Kaparaju et al. (2003) and Sommer et al. (2007*).* Furthermore, throughout the trials, the ambient air temperatures were always significantly ($P< 0.05$) lower than those of stored slurries (Figs. 2 and 3) due to the continuous flux of heated effluent from the biogas reactors (Hansen et al., 2006).

Both our study results and the guidelines of the CH_4 and CO_2 Global Warming Power Working Group 1 (IPCC, 2007) suggest that covering the digestate or digested liquid fraction stored in the tank of a 1MWel. AD plant could avoid emission to the air of as much as 205 kgCO_2eq. and 85kgCO_2eq. per produced MWhel., respectively. While our estimates assume the daily amount of biogas produced in the middle of the storage tanks to be representative of the entire storage surface, an even higher residual biogas production would be expected from the area close to the digestate inlet given the daily flux of “fresh” effluent that would help to maintain a constant level of undigested organic matter and a higher digestate temperature.

4 Conclusions

This study demonstrated that the storage phase of the AD process is fundamental to its environmental sustainability. Considerable amount of biogas is indeed lost to the air during non-separated digestate and digested liquid fraction storage. Thus, gas-tight covering of AD plant storage structures is strongly recommended. According to the study results, the coverage of the non-separated digestate or digested liquid fraction storage tank of a 1MWel. AD plant could prevent emission to the atmosphere of as much as 205 kgCO_2eq. and 85kgCO_2eq. per produced MWhel.

Acknowledgements

This study is part of the large research project "EU-AGRO-BIOGAS," the European biogas initiative to improve the yield of agricultural biogas plants established by the European Union under the 6th Framework Programme.

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Figure captions

Fig. 1. Main components of the pilot biogas recovery system

Fig. 2. Air temperature, slurry temperature, and daily biogas yields measured from the non-separated digestate storage tank at AD Plant 1 (experiment 1)

Fig. 3. Air temperature, slurry temperature, and daily biogas yields measured from the digested liquid fraction storage tank at AD Plant 2 (experiment 2)

Fig. 4. Relationship between average daily slurry temperature and biogas production rates as measured from non-separated digestate and digested liquid fraction

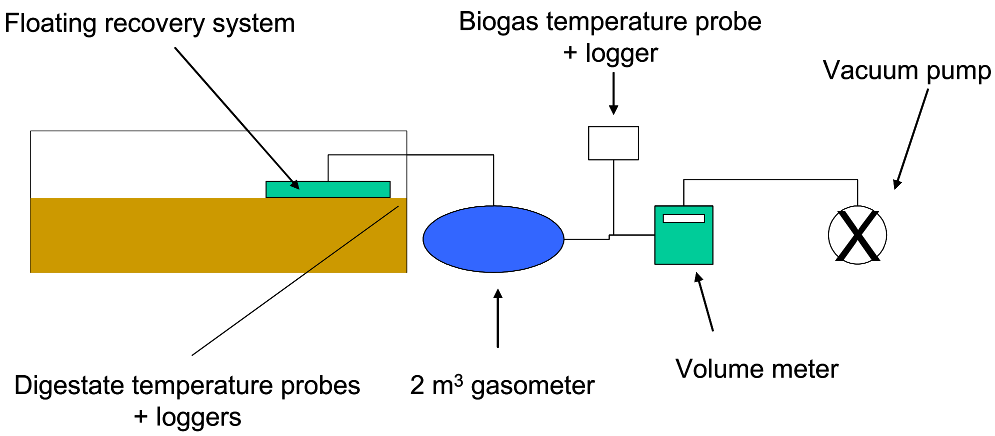

Fig. 1

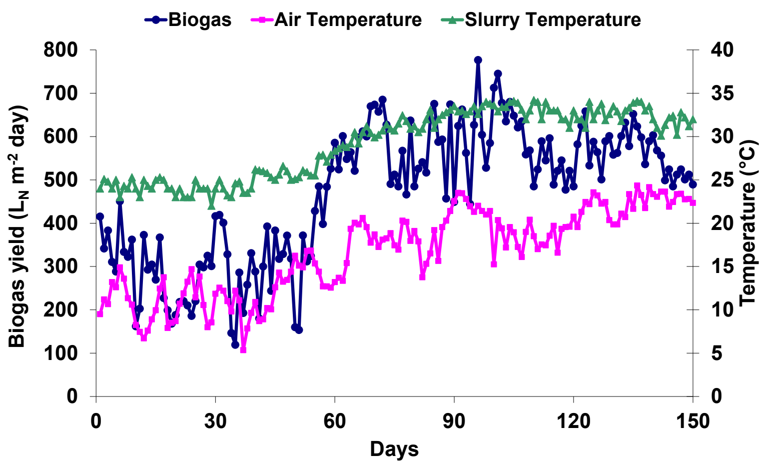

Fig. 2.

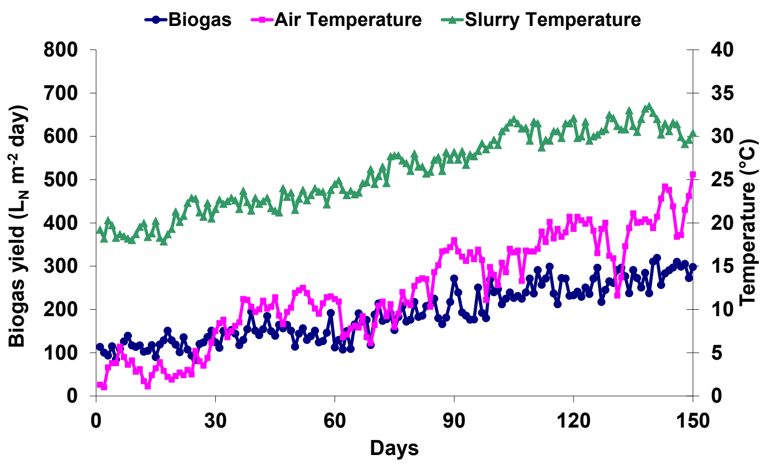

Fig. 3.

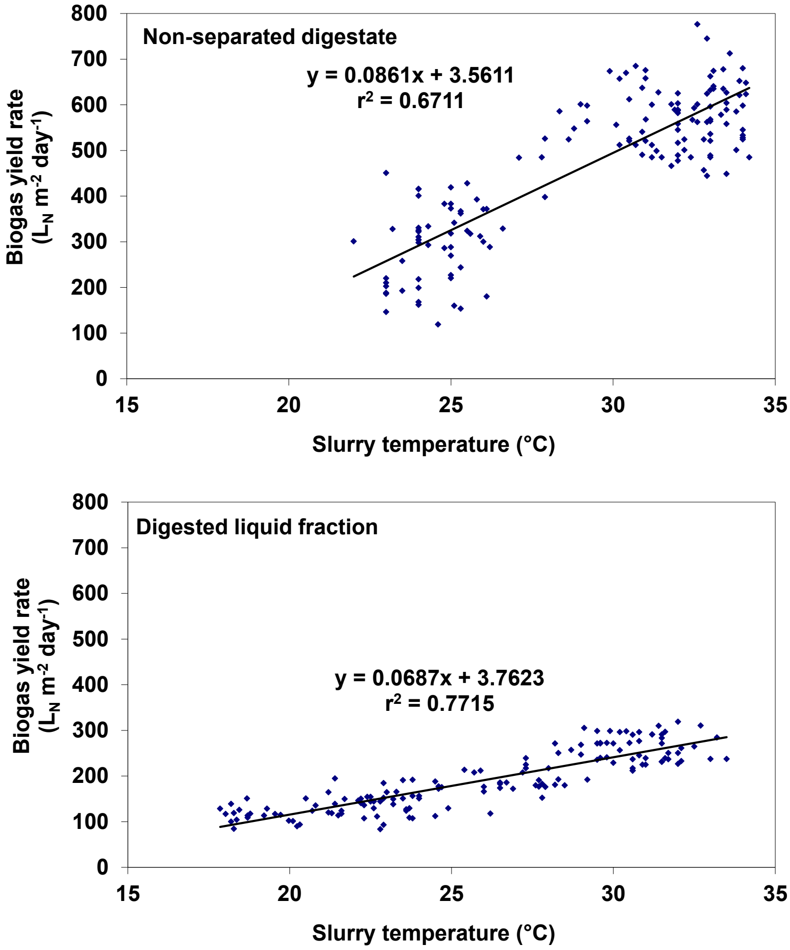
Non-separated digestate
y = 0.0861x + 3.5611
r2 = 0.6711
Biogas yield rate
(LN m-2 day-1)
Slurry temperature (°C)
Digested liquid fraction
y = 0.0687x + 3.7623
r2 = 0.7715
Biogas yield rate
(LN m-2 day-1)
Slurry temperature (°C)
0
100
200
300
400
500
600
700
800
15
20
25
30
35

Fig. 4.

Table captions

Table 1. The main operating parameters of the anaerobic digestion plants during the investigation

Table 2. Chemical characteristics of non-separated digestate (experiment 1) and digested liquid fraction (experiment 2)

Biogas Plant	Feedstock Composition	Temperature (°C)	OLR† (kgVS m^{-3} digester day^{-1})	HRT‡ (days)
1	Cattle slurry (12%) Farmyard manure (31%) Poultry manure (8) Maize silage (27%) Drying maize residue (21%) Rice chaffs (1%)	41	1.40	105
2	Cattle slurry (33%) Farmyard manure (24%) Maize silage (26%) Triticale silage (11%) Drying maize residue (3%) Kiwi (3%)	41	1.10	130

†OLR: organic loading rate. ‡HRT: hydraulic retention time.

Table 1

Month	pH	TS (%)	VS (% wet basis)	VS/TS
	Experiment 1			
1	7.9	9.56	7.55	0.79
2	7.9	8.79	6.68	0.76
3	8.1	8.92	6.96	0.78
4	8.0	9.12	6.84	0.75
5	7.9	9.03	7.40	0.82
	Experiment 2			
1	7.9	4.62	3.19	0.69
2	8.0	5.24	3.30	0.63
3	8.1	5.29	3.60	0.68
4	7.9	5.41	3.68	0.68
5	7.9	5.15	3.55	0.69

Table 2