Potential energy recovery and environmental pollution from the storage of the liquid fraction of co-digested pig slurry

Balsari Paolo[1], Dinuccio Elio[1], Gioelli Fabrizio[1]
(1) Depart. of Agriculture, Forest and Food Science, University of Turin – 10095, Grugliasco -Italy
*Corresponding author: paolo.balsari@unito.it

Abstract

The study main purpose was to evaluate the methane emission to the atmosphere during the liquid fraction of co-digested pig slurry storage. The trial was performed at a 0.5MWel. anaerobic digestion plant (ADP) operating in the Piemonte region (north western Italy). The residual biogas yield of digested liquid fraction was quantified during 200 days of storage in spring-summer conditions. Measurements were carried out by means of a floating recovery system. According to the study results, the recovering of the residual biogas from the digested liquid fraction storage tank of the investigated ADP could avoid the emission of up to 400 kgCO_2eq. per produced MWhel. and to increase the methane yield of the installation by approximately 7%.

Introduction

In recent years, the combination of the increasing demand of renewable energy and of the Italian price of electric energy (0.28€ kWhel.$^{-1}$) produced by anaerobic digestion plant (ADP) has generated more and more interest in anaerobic digestion of feedstocks and animal manures. In Piemonte region (northwest Italy), 37 agricultural ADP have been realized in the last five years and 58 more are waiting for approval or are in a start-up phase. ADP require digestate storage prior to its field application. Tank storage capacity must be able to allow at least 120-180 days of digestate storage [1] to guarantee a correct agronomic disposal of the slurry. A previous study [2] has shown that residual biogas production may occur during digestate storage as it retains significant undigested organic matter. This could causes loss of potential revenue for the ADP and significant environmental pollution as methane (CH_4), the main components of biogas, is a greenhouse gas (GHG) affecting the global environment and climate [3]. In spite of the large number (approximately 750) of agricultural ADP in operation in Italy, limited investigations on this topic have been carried out so far. This study was carried out within the ''Multi-regional Solutions to improve the Environmental and Economic Sustainability of PIG manure management in the Regions of the Po and Veneto basin (SEESPIG)'' project (http://www.seespig.unimi.it) to narrow the gap in knowledge by assessing, in a pilot scale experiment, the residual biogas yield from the storage of the liquid fraction of co-digested pig slurry.

Material and Methods

The experiment was carried out at a 0.5MWel. mesophilic AD plant operating in the Piemonte region made up of two continuously stirred tank reactors (CSTR) operating serially, with a capacity of 2,300m^3 and 2,700m^3, respectively. Within each fermenter, two horizontal axis mixer operate 20 min per hour. Each reactor is heated to 40 °C by stainless steel heating pipes. The main operating parameters of the AD plant are reported in Table 1.

Table 1. The main operating parameters of the anaerobic digestion plant during the monitoring period

Feedstock composition (%)	Temperature (°C)	OLR[a] (kg VS m^{-3} digester day^{-1})	HRT[b] (days)
Pig slurry from sows (67) Dairy cattle slurry (7) Farmyard manure (2) Maize silage (14) Sorghum silage (10)	40	2.20	40

[a] OLR: organic loading rate; [b] HRT: hydraulic retention time.

During the investigation period the plant was fed with animal manures and energy crops. Specifically, an average amount of 90 tons per day of pig slurry from sows was used, representing up to 70% of the feedstock loaded to the plant. The average electric energy daily produced by the plant was of about 11 MWh, corresponding to 92% of the installed electric capacity. Digested slurry (approximately 120 m^3 per day) is separated prior to storage by means of a one stage rotating (Rota mod. SEP 97) separator. Approximately 40% of the produced digested solid fraction is stored in heaps for at least 90 days and used as fertilizer on the farm, while the remaining 60% is sold to other farmers. The digested liquid fraction (approximately 110 m^3 day^{-1}) is stored in a 14000 m^3 (diameter 60m, walls height 5m) above ground open storage tank and applied to grasslands and arable crops during three seasons of the year: spring (about 40%), summer (30%), and autumn (30%). The residual biogas yield of digested liquid fraction was quantified during almost 7 month (200 days) of storage in spring-summer conditions. Measurements were carried out by means of a floating recovery system described in detail by [2]. Briefly, the system is made up of a squared floating polyethylene and stainless steel inox frame (2.5 m X 2.5 m: total surface 6.25m^2) covered by a PVC two sides coated polyester fiber membrane. In order to avoid gas leakings from the structure, the membrane is refolded under the frame and tied to it by means of ropes. The device is floated over the slurry surface so that the released biogas can be collected under the membrane. The collected biogas flows through a PVC tube and it is stored within a 2m^3 gasometer made of the same material of the covering membrane. The experiment started at the beginning of March, after emptying approximately 60% 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. Probes and data loggers (Onset® Hobo U12) were placed next to the recovery device to track the surface, middle, and bottom temperatures of the slurry; they were also installed to monitor the temperature and pressure of the biogas within the gasometer. On the first working day of each month, representative samples of digested liquid fraction were collected at the outlet of the mechanical separator in front of the storage tank entrance, and tested for pH, total solids (TS) and volatile solids (VS) content. Total solids and VS were determined after drying at 105°C for 24 hours; VS were measured in accordance with standard methods (VDI 4630, 2006),); and pH was determined by pH-meter HI 9026 (Hanna Instruments, Italia). Daily recordings of recovered biogas volumes were completed according to [2]. Methane and carbon dioxide (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 [4]. 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 [3].

Results

The chemical characteristics of fresh digested liquid fraction recorded during the monitoring period are shown in Table 2. Total solids content ranged from 2.26% to 3.09%; VS and TS ratio resulted to be always higher than 60%.

Table 2. Chemical characteristics of the digested liquid fraction during the monitoring period

Month	pH	TS (% wet basis)	VS (%wet basis)	VS/TS
March	7.79	2.39	1.50	62.8
April	7.74	2.26	1.43	63.3
May	7.70	2.27	1.38	61.0
June	7.96	3.09	1.94	60.8
July	7.98	2.99	1.77	60.1
August	7.70	2.78	1.68	61.6
September	7.81	2.36	1.40	60.5

During the experimental period, the daily recorded environmental temperatures (Table 3) ranged from 5.60 to 30.5°C (average 19.6°C), while the digested liquid fraction ones ranged from 14.8 to 29.5°C (average 23.2°C). Other studies [2] [5] also reported ambient air temperatures remarkable lower than those of stored digested slurries, due to the continuous flux of heated effluent from the biogas reactors.

Table 3. Environmental and digested liquid fraction temperatures recorded during the monitoring period

Month	Environmental Temp. (°C)	Slurry Temp. (°C)
March	13.6 (5.60-16.3)	20.1 (15.9-21.6)
April	17.9 (9.50-21.0)	20.8 (14.8-23.6)
May	18.7 (6.20-22.7)	21.9 (16.3-24.7)
June	20.9 (13.8-32.9)	23.8 (16.8-26.1)
July	25.7 (19.1-30.5)	26.9 (15.1-29.5)
August	23.2 (14.2-29.6)	25.0 (15.7-28.4)
September	17.3 (8.70-24.5)	24.2 (14.9-27.8)

The measured methane production (Figure 1) ranged from 66.1 to 117.2 L_NCH_4 m^{-2} surface day^{-1} (average 90.8 L_NCH_4 m^{-2} surface day^{-1}). The average methane concentration of the biogas was 77.5% (range 75.5–78.2%).

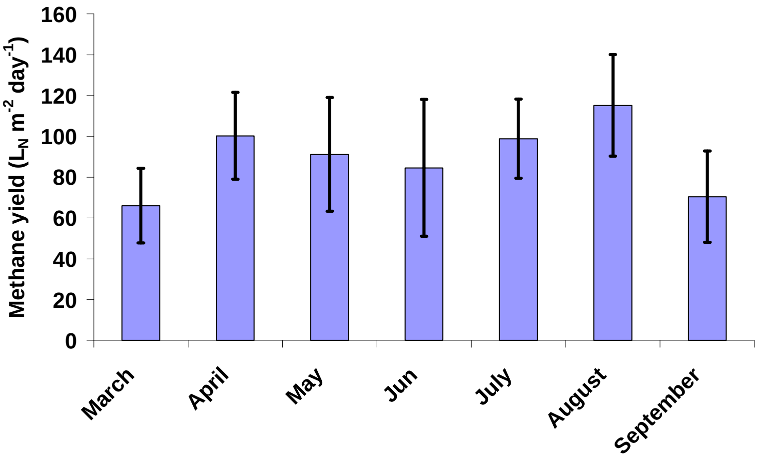

Figure 1. Average daily biogas yield recorded from the digested liquid fraction storage tank.

The average amount of recovered methane peaked in April (101 L_NCH_4 m^{-2} day^{-1}) and August (117 L_NCH_4 m^{-2} day^{-1}), just prior to the digested liquid fraction collection for agronomic utilization. In general, the average methane production per unit surface area increased with increasing the volume of slurry within the storage tank (Figure 2). However there is no statistically significant relationship ($p>0.05$) between the above mentioned variables, due to the high heterogeneity of the observed data. Assuming homogeneous methane production per unit surface area, it can be estimated that on average, over 200 days of monitoring, 253 Nm^3 (range 187–326 Nm^3) of residual CH_4 was emitted daily from the storage tank, which corresponds to a daily production of 2.30 Nm^3CH_4 m^{-3} of fresh digested liquid fraction loaded into the tank. A previous pilot scale study by [2] estimated 1.33 Nm^3 CH_4 emitted day^{-1} from digested liquid fraction over a five-month timeframe. The data from [2], however, referenced a digested liquid fraction from an agricultural biogas plant characterized by a longer retention time (130 days versus 40 days). The residual biogas emitted from digestate storage mainly depend on the operating conditions of the A.D. plant. According to [6], the higher the hydraulic retention time of the plant, the lower the amount of undigested organic matter to be digested during storage. The study results and the guidelines of the CH_4 and CO_2 Global Warming Power Working Group 1 [3] suggest that the collection of the residual biogas from the digested liquid fraction storage tank of the investigated ADP could avoid the emission of as much as 400 kg CO_2eq. per produced MWhel. Aside from environmental benefits, there are economic benefits to the cover of the slurry storage tank. During the monitoring period, the ADP yields averaged 3100 Nm^3 CH_4 day^{-1}. According to experimental results, the residual CH_4 (253 Nm^3 day^{-1}) collected from the storage of the digested liquid fraction accounts for approximately 7% of the total daily methane yield of the ADP. Considering the average hourly methane consumption (approximately 130 Nm^3 h^{-1}) of the combined heat and power (CHP) system of the plant, the latter value (253 Nm^3 day^{-1}) allows the production of approximately 0.90 additional MWhel per day (approximately 320 MWhel per year).

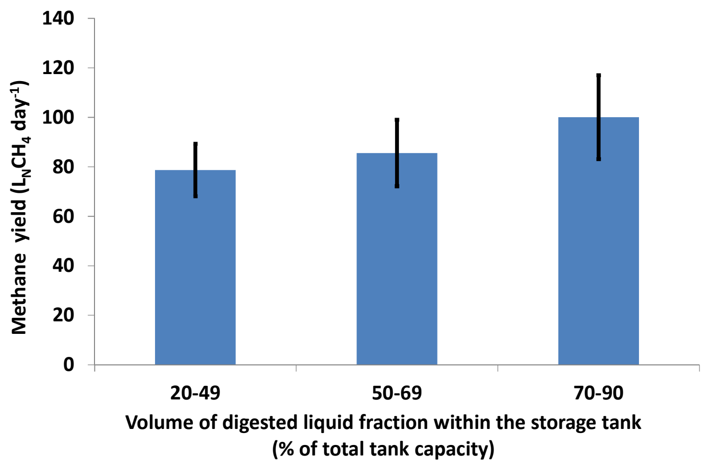

Figure 2. Average daily biogas yield with different volume of digested liquid fraction within the storage tank

Conclusion and perspectives

During the pilot experiment, a remarkable biogas potential was identified and measured from the digested liquid fraction. In general, the biogas yields showed high variability, fluctuated with manure temperature, and were affected by the volume of slurry within the storage tank. Additional methane yields, as much as 7% of the total methane yield of the AD have been measured. Therefore, covering the storage tank by gas-tight structures is strongly recommended as this offers an opportunity to reduce gaseous emissions to the atmosphere and to improve the ADP methane yield.

References (Times New Roman, bold, size 11)

[1] Regione Piemonte, 2007. Regolamento 10/R Disciplina generale dell’utilizzazione agronomica degli effluenti zootecnici e delle acque reflue e programma di azione per le ZVN di origine agricola

[2] Gioelli F, Dinuccio E, Balsari P, 2011. Residual biogas potential from the storage tanks of non-separated digestate and digested liquid fraction. Bioresource Technology 102, 10248-10251

[3] IPCC, 2007. Climate change 2007: the physical science basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

[4] VDI 4630, 2006. Fermentation of organic materials. Characterisation of the substrate, sampling, collection of material data, fermentation tests, Düsseldorf

[5] Hansen TL, Sommer SG, Gabriel S, Christensen TH, 2006. Methane production during storage of anaerobically digested municipal organic waste. J. Environ. Qual. 35, 830–836

[6] Lindorfer H, Pérez López C, Resch C, Braun R, Kirchmayr R, 2007. The impact of increasing energy crop addition on process performance and residual methane potential in anaerobic digestion. Water Sci. Technol. 56, 55–63

Acknowledgements

This study is part of the large research project “Multi-regional Solutions to improve the Environmental and Economic Sustainability of PIG manure management in the Regions of the Po and Veneto basin (SEES-PIG,) - grant n° 2010-2220, funded by Ager Project in the framework of the pig supply chain.