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A floating coverage system for digestate liquid fraction storage

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HIGHLIGHTS

- A low-cost floating covering system for digestate liquid fraction storage tanks was developed.
- The system allows to abate CO_2eq atmospheric emissions and to recover the residual biogas.
- The system was tested on a digestate liquid fraction storage tank of a 1 MWel AD plant.
- The system demonstrated to be a reliable solution to improve AD plant sustainability and biogas yield.

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ABSTRACT

Anaerobic digestion is booming in the nations of Europe. In fact, Italy alone has approximately 500 plants in operation or in some phase of start-up. Previous studies have made evident the potential that lies in digested manure residual biogas. Nevertheless, much of the potential goes unrealized when enormous amounts of digestate are produced, but are then stored in uncovered tanks. This research work designed, constructed, and tested a low-cost digestate storage tank cover system capable of abating CO_2eq atmospheric emissions and then recovering the biogas. The experiment, carried out at a 1 MW electric anaerobic digestion plant, demonstrated that collecting the residual biogas from the digested liquid fraction storage tank made it possible to avoid atmospheric emissions of up to 1260t CO_2eq annually and to increase the methane yield of the installation by 3%.

1. Introduction

In recent years, as a consequence of high renewable energy subsidies, anaerobic digestion (AD) of feedstocks and animal manures has spread throughout Europe and many installations have recently been constructed (EurObserv'ER, 2010). In the Piemonte region of northwest Italy alone, 37 AD plants have been constructed in the last five years and 58 more are awaiting approval or are in start-up. The average installed power of these plants is 0.5 MWel with an average daily digestate production of 100 m^3 per installed MWel (DEIAFA, 2012, unpublished data). Given these figures (installations and production capability), an estimated 1.8 million tons of digested slurry per year will require management during the coming years in the region.

Anaerobic digestion plants require that digestate be stored in tanks prior to field application; the storage capacity must be sufficient to meet the minimum requirement of 120–180 days of storage (Regione Piemonte, 2007) and to meet the application timing requirements of crop growth. Prior to storage, the anaerobically-digested slurry is generally separated mechanically to produce a solid fraction that is rich in nutrients and can be conveniently transported over long distances. The liquid fraction, that contains lower total solid (TS) concentrations than the original digested slurry, is more suitable for liquid manure handling equipment. In addition, a crust or sediment is less likely to form during storage, which reduces the need to mix the slurry prior to its collection for agronomic utilization. As reported by others (e.g., Sommer, 1997; Lindorfer et al., 2007), biogas and ammonia (NH_3) losses are expected from the stored digested slurry due to its large amount of undigested volatile solids (VS) and high ammonium nitrogen (NH_4-N) concentration. Menardo et al. (2011), in work carried out at the national level through batch trials, found that stored digested slurry contains significant residual biogas potential. In particular, Gioelli et al. (2011) have conducted pilot scale studies at two 1 MWel AD plants and reported average biogas emissions of 468 L_N m^{-2} surface day^{-1} and 190 L_N m^{-2} surface day^{-1} from uncovered, non-separated digestate and digested liquid fraction storage tanks, respectively. Moreover, Gioelli et al. (2009) found average daily NH_3 emission rates from stored non-separated digestate ranged between 2.06 and 4.44 g NH_3 m^{-2} surface and between 7.89 and 14.6 g NH_3 m^{-2} surface from digested liquid

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fraction. Biogas consists mainly of methane (CH_4) and carbon dioxide (CO_2), two of the main greenhouse gases (GHG) that affect the global environment and climate (IPCC, 2007). Atmospheric NH_3 also impacts the environment through particulate matter formation, aquatic eutrophication, and soil acidification (Goebes et al., 2003), which indicates that biogas and NH_3 losses from plant storage structures can represent an environmental hazard.

In terms of actual practice, our monitoring of regional AD plants has shown that digestate and digested liquid fraction are generally stored in uncovered tanks (Gioelli et al., 2012). Furthermore, although several natural (straw, peat, and light expanded clay aggregates) and synthetic (geotextile, plastic, and rubber) materials (VanderZaag et al., 2008; Balsari et al., 2006) are available to abate diffuse emissions, many have limitations. Nicholson et al. (2002) demonstrated that while simple storage covering results in reduced ammonia emissions, only a small reduction is attainable with methane due to its release during mixing at the end of the storage period. Rigid covers are another option, but as underlined by Hörnig et al. (1999), they are costly and impractical. Specifically, after such a cover is installed, parts of it may require removal for agitation and pumping when the manure is removed for application, which necessitates that a permanent opening be installed that can be sealed between pumping intervals (Nicolai et al., 2004). Inflated dome covers address this issue by an opening when the dome is deflated during manure agitation and removal (Stenglein et al., 2011). At biogas plants, CH_4 emission to the atmosphere from digestate can be avoided by connecting the storage tank to the gas bearing system (Moitzi et al., 2007), which offers the added potential to increase the AD plant biogas yield (Menardo et al., 2011). None of the above impermeable covers recover the complete residual biogas produced by the digestate because pumping and mixing operations allow air to enter the tank and dilute the biogas. The most common solution in Italy for digestate storage tank coverage is to use a pressurised double membrane cover system; however, this method also falls short. Specifically, it fails to meet the spring and autumn seasons demands when digestate is applied frequently and quickly and the digestate in the tank is never fully collected. Additionally, during these repeated pumpings, air must be collected from outside the cover to compensate for the depression created under the cover. To address the flaws of available technology, we designed, installed, and tested the efficacy of an innovative floating coverage system to store and collect the emitted residual biogas on a 6000 m^3 storage tank of a 1 MWel AD plant. The research was carried out within the "EU-Agro-Biogas Project" funded under the Sixth Framework Programme.

2. Methods

2.1. Description of the AD plant

The plant selected for installation of the floating cover is located in the Piemonte Region of northwest Italy. It is a completely stirred tank reactor (CSRT) with 1 MWel of installed power. Two 6000 m^3 double-chambered, air-tight fermenters are operated in series under mesophilic conditions (41 °C). The fermenters are fed with a mixture of cattle slurry (23%), farmyard manure (30%), energy crops (27%), and agricultural by-products (20%). Solid feedstocks are loaded to fermenters by means of a mixing wagon running 20 h per day, whereas the liquid one is fed by a pumping station. The organic load rate (OLR) of the plant is 1.55 kg volatile solids m^{-3} day^{-1}, and hydraulic retention time (HRT) is approximately 105 days.

Approximately 100 m^3 of fresh digestate is loaded daily into a 5 m^3 mixing pit by overflow from the second fermenter, and mechanically separated by a screw press (Sepcom, model 065). The digested solid fraction (approximately 20 t day^{-1}) is stored in a static heap for at least 90 days and used as applied fertilizer on the farm or transported to other farmlands. The digested liquid fraction (approximately 80 m^3 day^{-1}) is stored in a 6100 m^3 (Ø36 m, 6 m wall height) aboveground uncovered tank and applied to grasslands and arable crops during three seasons of the year: spring (about 40%), summer (30%), and autumn (30%). The storage capacity of digestate and the length of the storage period depend on factors such as biogas plant type, crop rotation and regional regulations. However, in most 1 MWhel agricultural biogas plants operating in northwest Italy the digestate is stored in tanks of about 6000 m^3 (Gioelli et al., 2011).

2.2. Design and concept of the floating cover

To enable collection of residual biogas from the digestate liquid fraction during frequent tank unloading (spring, autumn), a floating cover system was designed by DEIAFA in collaboration with Ecomembrane® Company (Cremona, Italy). The cover is floated over the slurry surface so that it can move up and down with the slurry level during loading and unloading operations. In this way, the volume occupied by the biogas beneath the structure remains constant, even during digestate collection events. Typically, during storage a natural crust forms on the surface of digested slurry, which can lift the structure and compromise the seal. A crust also requires that the slurry be mixed prior to collection and/or agronomic utilization, however, a floating cover makes stirring impossible because the cover needs rotation on its vertical axis during slurry mixing. To reduce the probability of crust formation beneath the cover, the newly designed floating cover was placed directly over the surface of digested liquid fraction in which the total solids content is lower compared to that of the unseparated digestate.

2.2.1. Coverage description

The following are components of the coverage system:

- peripheric floating frame (diameter 35.7 m) (Fig. 1) composed of 48 polypropylene and stainless steel modules linked by U stainless steel profiles. Each module is 2.3 m long, 0.56 m high, and 0.1 m thick. To provide structure buoyancy, four polypropylene panels are mounted on each module;
- central floating post (Fig. 2) fabricated from nine polypropylene blocks (1.1 m long × 1.1 m wide × 0.6 m high) that supports a 2.4 m high stainless steel frame. The post has a buoyancy capacity of approximately 4 t;

Fig. 1. Peripheric floating frame.