Waste Management 56 (2016) 125–136

Contents lists available at ScienceDirect

Waste Management

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

On the value of electrical resistivity tomography for monitoring leachate injection in solid state anaerobic digestion plants at farm scale

Axelle Degueurce [a,c], Rémi Clément [a,b,*], Sylvain Moreau [a,b], Pascal Peu [a,c]

[a] Irstea, UR GERE, 17 av. de Cucillé, CS 64427, F-35044 Rennes, France
[b] Irstea, 1 rue Pierre-Gilles de Gennes, CS 10030, F-92761 Antony cedex, France
[c] Université Européenne de Bretagne, F-35044 Rennes, France

ARTICLE INFO

Article history:
Received 9 February 2016
Revised 16 June 2016
Accepted 22 June 2016
Available online 6 July 2016

Keywords:
Leachate injection
Agricultural waste
Moisture content
Electrical resistivity tomography

ABSTRACT

Agricultural waste is a valuable resource for solid state anaerobic digestion (SSAD) thanks to its high solid content (>15%). Batch mode SSAD with leachate recirculation is particularly appropriate for such substrates. However, for successful degradation, the leachate must be evenly distributed through the substrate to improve its moisture content. To study the distribution of leachate in agricultural waste, electrical resistivity tomography (ERT) was performed. First, laboratory-scale experiments were conducted to check the reliability of this method to monitor infiltration of the leachate throughout the solid. Two representative mixtures of agricultural wastes were prepared: a "winter" mixture, with cattle manure, and a "summer" mixture, with cattle manure, wheat straw and hay. The influence of density and water content on electrical resistivity variations was assessed in the two mixtures. An increase in density was found to lead to a decrease in electrical resistivity: at the initial water content, resistivity decreased from 109.7 to 19.5 Ω·m in the summer mixture and from 9.8 to 2.7 Ω·m in the "winter" mixture with a respective increased in density of 0.134–0.269, and 0.311–0.577. Similarly, resistivity decreased with an increase in water content: for low densities, resistivity dropped from 109.7 to 7.1 Ω·m and 9.8 to 4.0 Ω·m with an increase in water content from 64 to 90 w% and 74 to 93 w% for "summer" and "winter" mixtures respectively. Second, a time-lapse ERT was performed in a farm-scale SSAD plant to monitor leachate infiltration. Results revealed very heterogeneous distribution of the leachate in the waste, with two particularly moist areas around the leachate injection holes. However, ERT was successfully applied in the SSAD plant, and produced a reliable 3D map of leachate infiltration.

1. Introduction

The potential of anaerobic digestion is increasing worldwide (Guo et al., 2015) due to its combined environmental benefits i.e., reducing greenhouse gas emissions, producing renewable energy, organic amendment and fertilizer. Germany had 6800 biogas plants in 2012, accounting for 76% of all such installations in Europe (Guo et al., 2015). In France, only 400 plants were recorded in 2015 and mainly handle agricultural residues using both liquid and solid state processes (ADEME, 2015).

The total solid (TS) contents of the agricultural feedstock determine the choice of the most appropriate anaerobic technology used to produce biogas. A solid state anaerobic digestion (SSAD) plant can handle substrates with TS content over 15% (kg/kg) (Mata-Alvarez et al., 2000). Several SSAD technologies, continuous one stage or two stage systems and sequenced batch systems, are available (Vandevivere et al., 2002). Batch mode SSAD is particularly useful for treating the effluents resulting from agricultural activity like livestock manure and crop residues and has the advantages of being simple to run, robust and cheap.

The successful efficient degradation of organic matter in anaerobic digestion requires balanced physical-chemical conditions to enable the development of the necessary microbial activity (Yang et al., 2015). Moisture content in the media was found to be the most important determining factor (Chugh et al., 1998). In batch solid-state digesters, sprinklers or perforated pipes are usually used to spread the liquid phase, the leachate, over the top surface of the substrate to reach the required moisture content in the solid medium. However, to date, information on the hydrodynamics of recirculation of the leachate through the cattle manure or other agricultural residues has been limited. Moreover, agricultural residues and mixtures are particularly porous and heterogeneous and

* Corresponding author at: Irstea, 1 rue Pierre-Gilles de Gennes, CS 10030, F-92761 Antony cedex, France.
E-mail address: remi.clement@irstea.fr (R. Clément).

http://dx.doi.org/10.1016/j.wasman.2016.06.028
0956-053X/

there is no data available on the ability of the systems to homogeneously moisten such substrates.

Knowing the flow characteristics and transfer time of the leachate through solid medium is a precondition to designing an optimal liquid injection system, i.e. the number of perforated pipes, the size and number of perforations, etc. to achieve uniform TS within the solid media. However, current knowledge of TS profile in a solid-state anaerobic digester is limited. Several techniques and sensors are used to measure water content (or TS) in landfills, including neutron probes, electrical resistance (impedance) sensors, time domain reflectometry (TDR) sensors, electrical resistivity tomography (ERT), the partitioning gas tracer technique, and fiber optic sensors (Imhoff et al., 2007; Kumar et al., 2009). Neutron probes, electrical resistance sensors or TDR sensors are not convenient because the measurements are made locally and are not representative of the heterogeneous porous media concerned here (Yuen et al., 2000; Gawande et al., 2003; Imhoff et al., 2007).

Among all geophysical methods, ERT may be the most suitable method to study the distribution of electrical resistivity (2D or 3D) (Binley et al., 1996; Bernstone et al., 2000; Buselli and Lu, 2001; Clement et al., 2009; Lillo et al., 2009; Clément et al., 2010; Audebert et al., 2014b). ERT is a non-destructive method as the measurement is performed on the top surface of the media through several staked down electrodes. A current I (known value) is injected in the media between two electrodes while another sets of electrodes measures the resulting electrical potential. A low electrical potential indicates a high resistant media. This method is becoming a widely-used tool to study infiltration in several porous media (Depountis et al., 2005; Massuel et al., 2006; Brunet et al., 2010; Clément et al., 2011). During the injection of water into porous media, ERT can be used with a time-lapse approach. Time-lapse monitoring repeats the same ERT measurement several times at the same location (Loke, 1999), namely, before, during and after injection of the leachate. ERT time-lapse monitoring is useful because variations in water content can be considered as the parameter with the most influence on electrical resistivity, if the temperature and the porosity are constant during leachate injection (Loke, 1999). In most cases, according to the previous hypotheses (Clement et al., 2009; Descloitres et al., 2003; Rosqvist et al., 2005), an increase in electrical resistivity indicates a decrease in water content and a decrease in electrical resistivity indicates infiltration of a liquid.

Already applied in landfills for in-situ characterization of the flow of leachates through municipal solid waste (MSW), the results of ERT led to the enhancement of the design of the leachate injection systems and enriched knowledge of MSW behavior (Ogilvy et al., 2002; Lillo et al., 2009; Clément et al., 2011; Audebert et al., 2014b). The non-intrusive, non-destructive and 3-dimensional response of the ERT method thus appears to be suitable for the study of the propagation of a leachate through agricultural effluents in a SSAD plant.

According to the literature, ERT has been applied to locate the agricultural waste pollution on soil and groundwater. Sainato et al. (2010) tested the performance of ERT to detect anomalies of resistivity and to identify the relative impact, on physicochemical properties of soil and groundwater, produced by the spreading of different effluents (Sainato et al., 2010). Sainato et al. also studied the mobility of some contaminants from animal wastes in sol by ERT (Sainato et al., 2012). Recent publications demonstrate the opportunity of used ERT, to monitor ground contamination (Papadopoulos et al., 2015; Sainato et al., 2010; Seferou et al., 2012) but ERT has never been applied to study leachate injection in SSAD. The purpose of the present study was thus to assess the relevance of using the ERT method to monitor the leachate infiltration through agricultural wastes and residues. This was done by using standard geophysics approaches based on the combination of laboratory and full scale experimentations.

As electrical resistivity was found to be mostly influenced by the type of medium, its density, and its water content (Yoon et al., 2002; Grellier et al., 2007; Clement et al., 2011), only these three parameters were studied at laboratory scale. Next, the ERT method was applied in a farm scale anaerobic digester. The objective was to monitor the infiltration and drainage of the leachate, and to determine whether or not infiltration could be detected and located. The efficiency of the existing injection system of the leachate was then analyzed and discussed with respect to the ERT data recorded on the field.

2. Materials and methods

This section is divided in two distinct parts. The first part is dedicated to laboratory tests. These tests were built paying particular attention to reproduce conditions to which substrates are really exposed at full scale, with the objective to conclude on the sensitivity of using electrical resistivity method on agricultural residues. The second part presents field tests that were performed to study leachate infiltration through specific agricultural wastes in a particular SSAD plant.

2.1. Laboratory tests

To study variations in and the sensitivity of electrical resistivity in agricultural waste, laboratory scale experiments were conducted under controlled conditions. Two mixtures of waste with different moisture content and densities were used.

2.1.1. Characteristics of the substrates

2.1.1.1. Preparation of mixtures. Agricultural residue with TS content higher than 15% (kg/kg) typically consisted of solid manure, straw, chaff, lawn cuttings, cover crops, etc. that can be used for farm-scale SSAD (Simon et al., 2010; Weiland, 2006). The residue composition differs considerably depending on the location of the plant and the season. However, in most cases in France, solid animal manure (recovered in stalls) is the main substrate used in winter. In summer, less manure is available because farm animals are outside grazing pastures. To balance the lack of solid manure, digesters are loaded with co-substrates (lawn cuttings, straw, etc.). Based on this observation, two typical combinations of substrates and co-substrates with different physical-chemical characteristics were selected: a "winter" mixture and a "summer" mixture.

"Winter" and "summer" mixtures were defined according to the standard inputs used at a dairy farm located in Troyes (Aube, France) over a whole year. The "winter" mixture was composed of 48 w% of solid dairy cow manure and 52 w% of solid beef cattle manure. The "summer" mixture was composed of 30 w% of dairy cow manure, 32 w% of beef cattle manure, 19 w% of wheat straw and 19 w% of hay. Solid manure consisted in a mixture of cattle faeces and wheat straw used as animal bedding in stalls. Dairy manure, beef cattle manure and hay were collected from the same farm (Troyes, France). Wheat straw was fresh and came from a farm located in Rennes (Brittany, France). All these fractions are representative of the agricultural waste used in SSAD in France. 50 kg of each mixture were available for the experiments. No further pretreatment was performed: mixtures were not ground and therefore had the same physical properties as substrates used in the field.

Fig. 1 shows the physical appearance of the "winter" and "summer" mixtures. Both mixtures were very heterogeneous, with more aggregated faeces in the "winter" mixture. The "summer" mixture looked more like wheat straw, and had a lower density and a higher porosity than the "winter" mixture.