Journal of Environmental Management xxx (2016) 1–8

Contents lists available at ScienceDirect

Journal of Environmental Management

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

Research article

Mesophilic and thermophilic anaerobic co-digestion of winery wastewater sludge and wine lees: An integrated approach for sustainable wine production

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A R T I C L E I N F O

Article history:
Received 28 November 2015
Received in revised form
13 March 2016
Accepted 19 March 2016
Available online xxx

Keywords:
Anaerobic digestion
Dewatering
Mesophilic
Thermophilic
Trace elements
Winery wastes

A B S T R A C T

In this work, winery wastes generated by a cellar producing approximately 300,000 hL of wine per year was monitored for a period of one year. On average, 196 L of wastewater, 0.1 kg of waste activated sludge (dry matter) and 1.6 kg of wine lees were produced per hectoliter of wine produced. Different winery wastes, deriving from different production steps, namely waste activated sludge from wastewater treatment and wine lees, were co-treated using an anaerobic digestion process. Testing was conducted on a pilot scale for both mesophilic and thermophilic conditions. The process was stable for a long period at 37 °C, with an average biogas production of 0.386 m^3/kg COD_{fed}. On the other hand, for thermophilic conditions, volatile fatty acids accumulated in the reactor and the process failed after one hydraulic retention time (23 days). In order to fix the biological process, trace elements (iron, cobalt and nickel) were added to the feed of the thermophilic reactor. Metals augmentation improved process stability and yields at 55 °C. The pH ranged between 7.8 and 8.0, and specific gas production was 0.450 m^3/kg COD_{fed}, which corresponded to dry matter and COD removals of 34% and 88%, respectively. Although the observed performances in terms of biogas production were good, the thermophilic process exhibited some limitations related to both the necessity of metals addition and the worse dewaterability properties. In fact, while the mesophilic digestates reached a good dewatering quality via the addition of 6.5 g of polymer per kg of dry matter, the required dosage for the thermophilic sludge was greater than 10 g/kg of dry matter.

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1. Introduction

The winemaking process produces large volumes of waste streams, including solid organic waste, wastewater, greenhouse gases, and packaging waste (Lucas et al., 2010). Winery wastewater is a major waste stream resulting from a number of activities that include tank, floor and equipment washing; barrel cleaning; wine and product losses; bottling facilities; filtration units; and rainwater captured in the wastewater management system (Ioannou et al., 2014). The quantification of the produced wastewater is difficult, and it depends on the cellar dimensions and the technologies applied. In general, wastewater production ranges from 0.7 to 14 L per liter of wine produced (Andreottola et al., 2009), but specific studies conducted in different countries demonstrated that typical values are approximately 2–6 L of wastewater per liter of wine produced (a short review of winery wastewater in the main production countries is available in Supplementary Material).

This effluents generally presents a considerable level of COD, the major part of which is soluble (Beck et al., 2005) and highly biodegradable (Andreottola et al., 2005) due to the presence of ethanol, sugars, and organic acids (Malandra et al., 2003; Mosteo et al., 2008; Petruccioli et al., 2000; Vlyssides et al., 2005).

Because of its characteristics, this stream is generally treated using either aerobic or anaerobic processes (Ioannou et al., 2014). Among biological processes, the activated sludge process is the most commonly employed because of its high efficiency and simplicity. It can remove 98% of COD and cope with large variations in the hydraulic and pollution load (Beck et al., 2005; Fumi et al., 1995; Petruccioli et al., 2000).

The removal of organic material generates considerable

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http://dx.doi.org/10.1016/j.jenvman.2016.03.029
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quantities of excess sludge, normally in the range 0.21–0.28 kg MLVSS (mixed liquor volatile suspended solids) per kg of COD removed (Brucculeri et al., 2005; Torrijos and Moletta, 1997). Ruggieri et al. (2009) estimated that dewatered wastewater sludge represents 12% of the total organic solid waste produced by wineries and that its management via external companies is expensive and often difficult. An alternative to valorize this waste stream could be the use of an anaerobic digestion process. Anaerobic digestion (AD) is a mature technology and it is applied to treat different types of organic wastes (municipal solid wastes, sewage and waste activated sludge, agro-industrial residues, livestock effluents, etc.) and to reduce their biodegradability while simultaneously recovering bio-energy. The combination of the conventional activated sludge process (CAS) and AD is a common practice in municipal wastewater treatment plants and limits the external management costs for sludge disposal thanks to a reduction in the sludge volume. Biogas is a renewable source of energy that is usable inside the same production process and/or wastewater treatment plant, which reduces the energy requirements (Shen et al., 2015). Moreover, digestate, the effluent from the anaerobic process, can be reused in agricultural fields because of the presence of nutrients such as N, P, and K together with stabilized C and humic substances. AD removes pathogens and polyphenolic compounds with different efficiencies based on the operating conditions used. Pathogen reduction is affected by temperature, retention time and fed substrates (Poudel et al., 2010; Sahlström et al., 2004), whereas the efficiency of polyphenol degradation is mainly determined by the operational temperature (Cavinato et al., 2014; Levén and Schnürer, 2005).

Once AD is implemented for winery wastewater WAS, other winemaking process residues (e.g., wine pomace, pressed cake, or lees) should be co-treated to increase the biogas production, to improve the reactor utilization and to make the anaerobic process more economically advantageous.

Wine lees (WL) in particular are an interesting co-substrate because of their biodegradability and availability throughout the year. Like wastewater, WL contain a high organic content and their disposal requires the appropriate treatment. The composition of WL depends on the winemaking technology, although, according to de Bustamante and Temiño (1994), the main characteristics are an acidic pH (between 3 and 6), a COD greater than 30,000 mg/L, potassium in concentrations greater than 2500 mg/L, and phenolic components in quantities up to 1000 mg/L.

This paper considers the production of winery waste activated sludge and lees and their anaerobic co-digestion under both mesophilic and thermophilic conditions. The study assesses the process feasibility at pilot scale and evaluates the effluent quality in terms of pollutant removal and dewatering capacity. The suggested approach is schematically represented in Fig. 1.

2. Materials and methods

2.1. Experimental set-up

2.1.1. Winery wastewater treatment plant

Waste activated sludge was collected in a cellar where a wastewater treatment plant was operating. The cellar was located in the northeast of Italy and produced approximately 300,000 hL of wine per year. It processed and bottled both self-produced and bought wines; therefore, the working period is not restricted to the grape harvest, but rather, it is distributed throughout the year. Therefore, there is no real seasonal variation in the output. Considering the wine production and winery wastewater flow in the monitored cellar during a one-year period, the specific wastewater generation was calculated to be 1.96 L of wastewater per liter of wine produced. Winery wastewater was treated in the internal WWTP. After pre-treatment (screening and primary sedimentation), the wastewater is sent to a 1400 m^3 aerobic bioreactor. In order to balance the nutrients ratio and improve the activated sludge activity, urea and ammonium phosphate were added to the biological reactor. The activated sludge process operated with average hydraulic and sludge retention times (HRT and SRT) of 6.7 d and 35 d, respectively. Considering the HRT and SRT values, the volume of biological reactor is oversized in order to withstand the load picks. The MLVSS was 3010 mg/L and the corresponding food to microorganisms ratio was 0.26 kg COD/kg MLVSS per day. The treated water and waste activated sludge are separated in a secondary sedimentation tank. The treated water is eventually disinfected and filtrated using quartz sand before discharging. The sludge treatment process consists of a thickening section followed by a filter press. The sludge is not stabilized. On average, 3858 kg of wet sludge, with a dry mass content between 15 and 20%, was produced per week. This corresponded to some 613 kg of dry matter per week, or 0.1 kg of dried sludge per hectoliter of wine produced. The dewatered sludge is usually managed by composting, which has an average cost of approximately 110 €/ton of fresh matter.

Influent and effluent streams for the wastewater treatment plant were monitored for one year to determine their characteristics (Table with winery wastewater and effluent characteristics is available as Supplementary Material). Additionally, dewatered sludge after filter pressing was collected and analyzed.

2.1.2. Pilot scale anaerobic reactors

Two parallel continuous stirred tank reactors (CSTRs) with working volumes of 230 L were employed for anaerobic co-

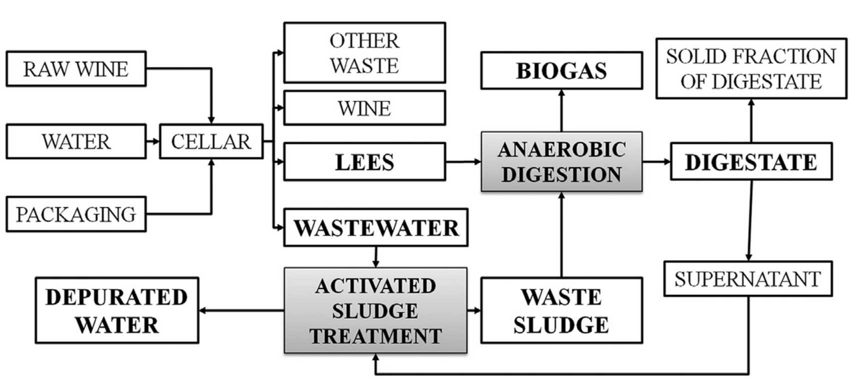

Fig. 1. Integration of anaerobic digestion in the wine-making process.

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