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Review

Wastewater disposal to landfill-sites: A synergistic solution for centralized management of olive mill wastewater and enhanced production of landfill gas

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ABSTRACT

The present paper focuses on a largely unexplored field of landfill-site valorization in combination with the construction and operation of a centralized olive mill wastewater (OMW) treatment facility. The latter consists of a wastewater storage lagoon, a compact anaerobic digester operated all year round and a landfill-based final disposal system. Key elements for process design, such as wastewater pre-treatment, application method and rate, and the potential effects on leachate quantity and quality, are discussed based on a comprehensive literature review. Furthermore, a case-study for eight (8) olive mill enterprises generating 8700 m^3 of wastewater per year, was conceptually designed in order to calculate the capital and operational costs of the facility (transportation, storage, treatment, final disposal). The proposed facility was found to be economically self-sufficient, as long as the transportation costs of the OMW were maintained at $\leq$4.0 €/m^3. Despite that EU Landfill Directive prohibits wastewater disposal to landfills, controlled application, based on appropriately designed pre-treatment system and specific loading rates, may provide improved landfill stabilization and a sustainable (environmentally and economically) solution for effluents generated by numerous small- and medium-size olive mill enterprises dispersed in the Mediterranean region.

1. Introduction

Landfills are the most common form of waste disposal and the final step of the waste management hierarchy. Landfills, being relatively cheaper than other treatment/disposal alternatives, are used not only by developing but also by industrialized countries, such as US, Australia, UK and Finland (Laner et al., 2012). While the use of landfills is decreasing in many parts of the world, there are thousands of closed facilities and others that will be closed over the next 10–30 years (Laner et al., 2012). Landfill mining has been recently proposed as an alternative for resource recovery (Krook et al., 2012). These sites are also used for sustainable sludge management, where the anaerobic sludge compost can be used as a landfill cover and thus help to biologically oxidize organic compounds as well as methane, in the landfill gas (Cukjati et al., 2012).

The landfill sites were usually abandoned after closure (Robinson and Handel, 1993). However, European Directives 1999/31/EC and 2008/98/EC imposed post-closure care (aftercare) of the closed landfills in order to protect human health and the environment. The aftercare strategies involve basically the monitoring of gas/leachate emissions, of the receiving bodies (groundwater, surface water, soil), and the maintenance of the cover and leachate/gas collection systems, which is reviewed in detailed by Laner et al. (2012). Although at least a 30-year aftercare period is required by European Landfill Directive (CEC, 1999), it is hard to determine when to finish this period (Laner et al., 2011). Leachate quality (BOD/COD ratio), gas production rate, cellulose plus hemicellulose to lignin (CH/L) ratio, physical stability (post-closure settlement), biological/chemical stability are among the suggested indicators for termination of aftercare, each of which, however, might have limitations (Laner et al., 2011).

Leachate production and management is one of the major problems related to the environmental-operation of sanitary landfills (Tatsi and Zouboulis, 2002). Landfill-leachate, due to its

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problematic nature (high COD, salinity and low biodegradability due to high COD/BOD ratio, etc.) needs to be treated before its discharge. The most common and cost effective treatment method is the activated sludge (sequencing batch reactor) coupled with necessary pretreatment (Renou et al., 2008).

Landfill sites were usually designed to minimize the amount of water entering the system in order to prevent the groundwater pollution (Benson et al., 2007). However, with the improvement in the landfill management by use of modern composite liners and leachate collection systems, entering water can be used as an advantage to improve the microbial activity, to enhance the rate of organic waste decomposition and eventually decrease the long-term monitoring and maintenance period. Municipal solid waste (MSW) landfills are often operated as bioreactors. This is accomplished with leachate recirculation through the waste body. The process enables enhanced waste and leachate stabilization, and optimized biogas production (Benson et al., 2007; Reinhart et al., 2002; Komilis et al., 1999). In landfill bioreactors, apart from leachate recirculation, external water may be added to enhance anaerobic breakdown of refuse (Sponza and Agdad, 2004; Reinhart and Al-Yousfi, 1996; Sanphoti et al., 2006). Accordingly, it is hypothesized that controlled wastewater application, based on appropriately designed pre-treatment system and specific loading rates, may provide improved landfill stabilization and a sustainable solution for difficult to treat wastewaters, such as Olive Mill Wastewater (OMW). Despite that EU Landfill Directive prohibits wastewater disposal to landfills, leachate recirculation is permitted under some circumstances, in small islands and decentralized areas (JMD, 2006), where many olive mill enterprises exist in the Mediterranean Regions.

In this paper a case study is presented, dealing with the design and application of a landfill-based centralized facility, treating Olive Mill Wastewater (OMW). A conceptual design was performed and the capital and the operational costs of the overall facility (transportation, storage, pre-treatment, disposal) were calculated. While treating OMW via landfills, there are key points to be considered such as wastewater pre-treatment, application method and rate, effects on leachate quantity and quality. These issues are discussed in the present paper based on a comprehensive literature review, highlighting also future research needs.

2. Centralized management of olive mill wastewater

Olive mill wastewater is an effluent with high organic load (COD = 40–100 g/L), generated during the 2–3 months campaign of olive oil producing factories. It is a complex acidic effluent (pH 4.0–5.5), mainly composed of water (83–96%), sugars (1–8%), nitrogenous compounds (0.5–2.4%), organic acids (0.5–1.5%), phenols, pectin and tannins (1.0–1.5%), lipids (0.02–1.0%) and inorganic substances (Hamdi, 1993; Sayadi et al., 2000). Different technologies are available for olive mill wastewater (OMW) treatment, based on combination of physical, chemical and biological processes (Azbar et al., 2004; Mantzavinos and Kalogerakis, 2005; Paraskeva and Diamandopoulos, 2006). Indeed, fully equipped treatment systems for olive mill wastewaters incur total costs of 5–22 €/m^3 treated (Azbar et al., 2004). This is the case for biological treatment (anaerobic, aerobic) combined with necessary pre-treatment (physicochemical or mechanical). In case of natural evaporation systems the total costs are in the order of 0.65–1.31 €/m^3 (Azbar et al., 2004).

The most common treatment and disposal method for small and dispersed olive mill enterprises is natural evaporation in lagoons (Kavvadias et al., 2010). Lagoon performance is, however, significantly affected by wastewater characteristics and increasing wastewater solids and organics will decrease the evaporation rate (Jarboui et al., 2009). Additionally, they are often designed with large depth, thus wastewater evaporation is difficult to achieve in the field. It is therefore common practice that OMW ends up illegally to neighboring soils, groundwater, surface water bodies and/or the ocean. Another important problem of conventional open evaporation ponds is the generation of offensive odors all year round (Lagoudianaki et al., 2003). Yet, in addition to the potential biodegradation mechanisms taking place in the ponds and further production of the greenhouse gases, the loss of useful energy that can be gained through anaerobic digestion should also be considered.

Centralized management of olive mill wastewater is of interest for small and dispersed olive mills enterprises, which cannot afford large, complex and O&M intensive wastewater treatment facilities (Kapellakis et al., 2006). Centralized management minimizes or diminishes the environmental impacts at the production site, since the wastewater is transported in a different location where it is appropriately treated (Fig. 1). Demoted land such as abandoned sites, historically polluted areas, (closed) landfills and dumping sites are excellent applicants for sitting a centralized OMW facility.

The proposed centralized OMW facility (Fig. 2) consists of a storage lagoon, where the wastewater generated during the campaign, is transported and disposed of. The wastewater inside the lagoon is subject to sedimentation and acidification. The lagoon is isolated at the bottom using a synthetic liner, to avoid wastewater percolation into the ground water, while a floating cover can also be installed to control odors and insects and decrease evaporation,

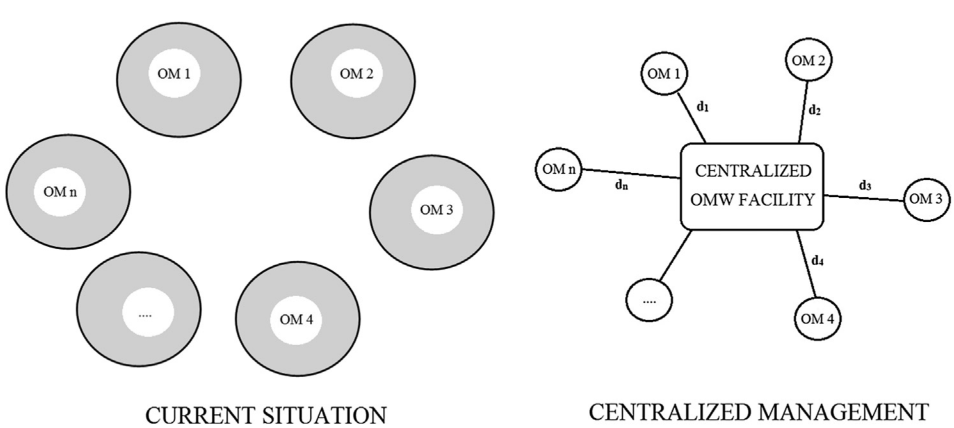

Fig. 1. System analysis of (a) small and dispersed olive mills (OM1, OM2, …n) and the environment affected by current OMW management practises (E1, E2, …n), and (b) the proposed solution of wastewater transport to a centralized facility ($d_{i..n}$ = distance of individual olive mill enterprise from the centralized facility).