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Evaporation–condensation of olive mill wastewater: Evaluation of condensate treatability through SBR and constructed Wetlands

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ABSTRACT

In this study, a novel strategy for olive mill wastewater (OMW) treatment, which combines an evaporation–condensation step followed by the biological treatment of the condensate, was evaluated. Different solutions were evaluated as biological step, through a experimental tests, by operating for three weeks: two bench scale sequencing batch reactor (SBR), with and without media for attached growth, and two pilot scale constructed wetlands, a vertical (VF) and a horizontal (HF) submerged flow beds. When treating an influent OMW with a COD concentration in the range from 130 to 150 g L^{-1}, the evaporation/condensation process allowed to achieve up to 98.7% of COD removal (2.4 g COD L^{-1} in average in the condensate); moreover, the condensate showed a large biodegradable fraction, allowing the further treatment of the residual COD by simple biological reactors like SBRs or constructed wetlands (CWs). The CWs, either in HF or VF configuration, showed more stable and barely higher performances in comparison with the SBR, especially during the first week of operation and allowed to obtain an effluent with a pH close to neutrality without alkalinity dosing. The overall COD removal was about 99.8% and less than two weeks were needed for the start-up of the biological system, which is of pivotal importance given the olive mill process cycle. The evaporation process also generated a concentrate containing a high concentration of valuable chemicals, including polyphenols.

1. Introduction

Olive mills wastewater (OMW) management represents, traditionally, a big concern for the olive oil industry, being particularly difficult to be treated. The olive oil industry is widespread in Mediterranean countries and relevant for the economies of Spain, Italy, Greece, Turkey, Syria and Tunisia. Also other countries, including Argentina, Australia and South Africa are becoming emergent producers, covering about 25% of the total worldwide production. Just to cite some olive oil extraction basics, 100 kg of olives are producing, in average, 18 kg of virgin and extra-virgin oil, 50 kg of pomace and 60 kg of water, including vegetation water, contained inside the drupe, and water used to wash the olives and the machineries.

OMWs are usually showing a low pH, in the range of 4 to 5, a very high organic content ranging from 50 to 180 g L^{-1}, a high content in phosphorus, from 20 to 1100 mg $L^{-1}$and nitrogen compounds, from 600 to 900 mg L^{-1}, and, in general, a quite low biodegradability mainly generated by several phytotoxic compounds such as polyphenols, lipids and organic acids (Filidei et al., 2003; Roig et al., 2006). All these characteristics of OMWs play a role in the challenge of treatment, together with another main factor, that is, the seasonality: in fact, the production phase is commonly limited to 2–3 months, with a world's total production of more than 10^7 m^3 per year (Yalcuk et al., 2010; Benitez et al., 1997).

Several different OMW disposal or treatment methods have been adopted and developed, including filtration by membranes, thermal treatments by incineration or concentration, electrochemical oxidation, stabilization ponds, chemical precipitation by coagulants and flocculants, aerobic and anaerobic biological treatments, or direct disposal to agricultural soils.

Due to the spread character, to the small size of most of the mills and to the current lack of appropriate technologies to treat OMW, especially due to the related high investment and management cost, a high amount of the OMW in the Mediterranean area is discharged directly into rivers and sea. A common practice is the storage in evaporation ponds, where the anaerobic conditions are leading to diffusion of smells, breading of mosquitoes and risks of groundwater contamination (Benitez et al., 1997).

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Table 1
OMW common treatment issues.

Treatment/disposal	Main issues	Advantages
Chemical–physical treatments	Relevant costs Troubles in managing chemical sludge Limited COD removal (down to 50 g L^{-1})	No need for start-up and flexibility towards flow rate fluctuations Small size
Biological treatments	Complex management Commonly severe problems for inhibiting substances, i.e. polyphenols Still limited COD removal (down to 20 g L^{-1})	Potential biogas production through anaerobic digestion Low operational cost
Fertirrigation	Need of appropriate land availability High environmental impact potential: Groundwater, Superficial runoff, Underlying rigid regulations. Demanding management and transport	Reuse of organic matter in to agriculture Potential benefits for the soil quality (when correctly managed) and reduction of use of alternative fertilizers
Membrane filtration	High cost, complex operation and maintenance	Potentially high effluent quality (depending on the membrane) Small size and flexibility

In the following Table 1 the main treatment or disposal approaches are shown, linked to their prevalent issues (Panagiota and Diamadopoulos, 2006; Turano et al., 2002).

The still current need of a new technology for a technically and economically sustainable treatment of OMW must consider the following constrains: it should represent a valid and easily replicable solution to the OMW disposal issue, the need of expertise should be very low, as well as very low must be the overall environmental impact; finally, the process has to be very tolerant to the seasonality. For instance, the typical operation of olive mill undergo a very long stop and biological processes that require a minimum of feeding for the maintenance of biomass activity or a long start up (such as anaerobic digestion) are not suitable. Keeping in mind all these aspects, the Department of Civil and Environmental Engineering of the University of Florence has proposed a novel treatment scheme consisting in evaporation/condensation of the fresh OMW that is generating 2 fractions, a condensate and a concentrate; the condensate is then treated through biological processes.

A full scale evaporator/condenser was installed and tested for research purposes at an olive oil mill facility in Central Italy (Reggello–Province of Florence), followed by four parallel pilot scale plants: two Sequencing Batch Reactors (SBR), an Horizontal Subsurface Flow (HF) and a Vertical Subsurface Flow (VF) Constructed Wetlands (CWs).

The evaporation/condensation process strongly reduced the strength of the OMWs and produced a highly biodegradable condensate; this effluent could therefore be treated by biological secondary treatment reactors, such as SBR or CWs, in order to meet the quality target for discharge.

Based on the Italian limits on effluent discharge, we considered the following options:

a Collection of the condensate to the public sewer (when present) after the issue of a waiver and payment of a fee proportional to the load; in this case, no treatment would be required, even though the biodegradability of the condensate is a very important parameter to be evaluated; the suitability of this option, in fact, depends on the residual capacity of the downstream wastewater treatment plant and on the characteristics of the condensate; the full scale evaporation/condensation system actually installed, is following this option, on the basis of a specific waiver obtained from the authorities and under the payment of a fee, since the COD concentration is higher than the Italian limit for discharge in to the public sewage system (500 mg L^{-1}); in this case the easily biodegradable COD of the condensate is a useful contribution for the denitrification process and potentially contribute to the carbon to nutrient balance in the centralised wastewater treatment plant; this fact, in turn, represents also an indirect advantage for the downstream anaerobic digestion of sludge;

b collection of the condensate after a treatment aimed at achieving the specific Italian limit for discharge into public sewer (500 mg L^{-1}); this option presents the advantage of not requiring specific waiver issued by the designated authorities; however, it requires the presence of a public sewer and, based on preliminary batch test, a stable biological process to achieve COD removal;

c as alternative solution, we considered the treatment of the condensate to achieve the limit for discharge into surface water body (160 mg L^{-1}); this option requires the operation of a stable COD removal and, based on preliminary investigation carried out through batch test, the implementation of a supplementary treatment phase (after biological processes) based on physical chemical processes.

Only few experiments have been done for the OMW treatment by CWs (Herouvim et al., 2011), in some cases treating directly the raw OMW or diluted one, in other cases making use of hybrid systems, combining the CWs with different primary treatments (Del Bubba et al., 2004; Grafias et al., 2010; Herouvim et al., 2011).

This study is presenting the first results for the treatment of the OMW's condensate as evaporation/condensation by-product by CWs and SBR. This treatment scheme, even though surely more energy demanding in comparison with more passive or extensive treatment schemes, can ensure really high performances; eventually, appropriate concentrations of the pollutants for the discharge in fresh water or for reuse purposes can be achieved, with the result of recovering the above mentioned millions of m^3 per year of water.

The objective of this study was to demonstrate that with biological process it is possible to achieve the Italian limit for discharge into the sewage system (500 mg L^{-1}) and to identify the most suitable technology to ensure, at the same time, a stable COD removal and an easy operation and management.

2. Methods

The evaporator–condenser (EC) used for the pilot scale test (produced by Alfalaval, model Alfa Flash) was designed and operated to process up to 48 m^3 d^{-1} of olive mill wastewater, that is, approximately the entire effluent of the end-user olive mill. The EC was operated in order to produce about 80% of the influent flow as condensate and the remaining 20% as concentrate; while the concentrate was mixed with the olive mill pomace before further conventional collection to centralised treatment plants (usually operating further oil extraction and combustion to produce energy), the condensate was used for further biological processes