An Evaluation of Biological Treatment Methods Used in Olive Mill Wastewaters

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Abstract: Olive mill wastewater (OMW) is produced seasonally by a large number of small olive mills scattered in Mediterranean countries. It has a high environmental impact because of the concentration of its pollutant content and the quantity of waste water produced. OMW contains high amounts of organic, inorganic and polyphenols. It affects the water and soil quality, is toxic to plant life, and create odor nuisance when disposed into the environment. The main problem regarding the disposal of OMW is to find an environmentally friendly and economically viable solution. Among the various techniques proposed, biological treatment appears to be convenient from the economic point of view. The biological treatment of OMW is quite difficult since it contains many complex substances, mostly when more easily degradable carbon source is present in the medium. Several biological treatment systems have been examined for the treatment of OMW, resulting in considerable organic load and toxicity abatement. The present work aims to provide an updated review of the current biological methods used in OMW treatment.

Keywords: Olive mill wastewater, OMW, biological treatment, aerobik systems, anaerobic systems

Introduction

Mediterranean countries produce more than 98% of the world's olive oil, which is estimated at over 2.5 million metric tons per year. About 75% is produced in the European Union (EU) (McNamara et al., 2008). Olive oil mills are small agro-industrial units located mainly around the Mediterranean, Aegean and Marmara seas that account for approximately 95% of the worldwide olive oil production (Ergüder et al., 2000). In the olive growing countries of the Mediterranean area (Greece, Italy, Lebanon, Portugal, Spain, Syria, Tunisia and Turkey) olive oil mill effluent production is more than 30 million m^3 per year (Beccari et al., 1996). Olive mill wastes are a significant source of potential or existing environmental pollution in these countries (Bejarano et al., 1992). The difficulties of treatment of olive mill effluents are mainly related to high organic loading, seasonal operation, high territorial scattering, and the presence of organic compounds which are hard to biodegrade such as long-chain fatty acids and phenolic compounds.

Olive oil mill wastewater (OMW) is formed from the water content of the fruit and water used in washing and processes of olive oil extraction. The composition of OMW widely depends on the type of process involved in obtaining the oil. OMW are dark-colored wastes and contain high amounts of many complex substances that are not easily degradable (Borja et al., 1993; Sorlini et al. 1986). Generally, OMW can be treated by conventional biological treatment methods or can be utilized as fermentation raw material for the production of value added microbial products. However, this OMW also contains high concentrations of phenolic compounds which inhibit microbial activity. This makes biological treatment or microbial fermentation difficult (Massadeh and Modallal, 2008).

The uncontrolled disposal of OMW is becoming a serious environmental problem, due to its high organic COD concentration, and because of its high content of microbial growth-inhibiting compounds, such as phenolic compounds and tannins. The improper disposal of OMW to the environment or to domestic wastewater treatment plants is prohibited due to its toxicity to microorganisms, and also because of its potential threat to surface and groundwater (Ramos-Comenzana et al., 1996, Shaheen and Karim, 2007). When OMW are disposed into the environment, they create odor, color and increased oxygen demand in water bodies. They also affect the soil quality and plant life. Therefore, discharge of OMW into receiving media is not permissible unless treatment.

Olive oil production and wastewater generation

The basic steps in production of olive oil are always the same. Batch and continuous processes are the main methods used in the system. The first step in the oil production process is cleaning the olives and removing the stems, leaves, twigs, and other debris left with the olives. The second step is produced olive oil by crushing olives and extracting the oil by stone mills, metal tooth grinders, or various kinds of hammer mills or chemical means (Dalis et al. 1996). The olive paste generally stays under the stones for 30 to 40 minutes. The purpose of crushing is to tear the flesh cells to facilitate the release of the oil from the vacuoles. Mixing the paste for 20 to 45 minutes allows small oil droplets to combine into bigger ones. The paste can be heated or water added during this process to increase the yield, although this generally results in lowering the quality of the oil. The next step consists in separating the oil from the rest of the olive components (Azbar et al. 2004). This used to be done with presses and centrifugation except in old facilities. The oil is then left in tanks or barrels where a final separation. Sometimes the produced oil will be filtered to eliminate remaining solid particles that may reduce the shelf life of the product.

Finally, possible additional processing steps include refining the oil to reduce its acidity and improve flavor by alkali or steam processing; bleaching the oil to reduce chlorophyll, carotenoids, residual fatty acids, and pesticides using kieselguhr, activated carbon, or synthetic silica treatment, and deodorization to reduce odors with the use of activated carbon. The olive oil production processes are summarized in Figure 1.

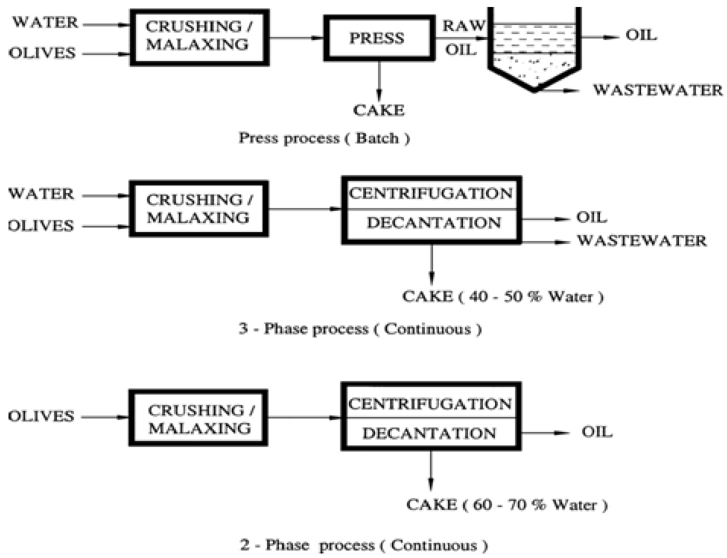

Figure 1. Olive oil production processes (Azbar et al., 2004).

The remaining paste still contains a small quantity (about 2-6%) of oil that cannot be extracted by further pressing, but only with chemical solvents. This is done in specialised chemical plants, not in the oil mills. Olive oil production processes mainly differ in the process water requirements. A two-phase plant involves two phases and much less additional water is used than in the three-phase process. Generally, one tone of olives yields one/two tones of OMW, according to the oil extraction process used. The continuous process uses about 2 L of water for kg of olives while the discontinuous one requires much less. Although the composition is dependent on the process used, the olive mill wastewater is a stable emulsion constituted by ''vegetation waters'' of the olives, water from the processing, olive pulp and oil.

Parameter	Conventional press process	Three-phase process
pH	4.5–5.0	4.7–5.2
Total solids, %	12	3
Volatile suspended solids, %	10.5	2.6
Mineral suspended solids, %	1.5	0.4
Suspended solids, %	0.1	0.9
Chemical oxygen demand, g/L	120–130	40
Biochemical oxygen demand, g/L	90–100	33
Sugars, %	2–8	1.0
Total nitrogen, %	5–2	0.28
Polyalcohols, %	1.0–1.5	1.0
Pectin, tannin, %	1	0.37
Polyphenols, %	1.0–2.4	0.5
Oil and grease, %	0.03–10	0.5–2.3

Table 1. Characteristics of Wastewaters (Azbar et al., 2004)

An estimated 10–30 million m^3 of OMW is generated every year from the production of olive oil. The organic fraction of OMW includes sugar, tannins, polyphenols, polyalcohols, pectins and lipids (Capasso et al., 1995). Most of the problems associated with OMW pollution can be attributed to the phenolic fraction. More than 30 different phenolic compounds have been identified in OMW and the types and concentrations of phenolics reported in OMW vary tremendously. In fact, phenolic compounds are responsible for several biological effects, including antibiosis and phytotoxicity (Dalis et al. 1996). The antimicrobial activity is principally due to phenolic compounds such as tyrosol and hydrotyrosol. Another negative property of OMW is its extremely high organic content. Generally OMW has BOD values ranging between 12,000 and 63,000 mg/L and COD values between 80,000 and 200,000 mg/L. These concentrations are approximately 400 times higher than municipal sewage (Al-Malah et al., 2000). As microorganisms present in the environment consume these materials, oxygen will be depleted from the water with adverse effects on the aquatic media. Common disposal practices for OMW include direct discharge into soils or streams and use of evaporation ponds or lagoons. (Al-Malah et al., 2000; Galli et al., 1997).

Biological treatment processes

Treatment processes must be efficient, allow for easy and economical operation in small-scale farm settings, and consider the seasonality and the distribution of olive oil production. Therefore, a variety of biological methods (e.g., aerobic or anaerobic bioreactors, composting) and microorganisms for treatment of OMW have been tested, and reviewed by many researchers to remove the dark coloration, reduce the organic load and remove phytotoxic compounds (Capasso et al. 1995).

Aerobic processes

Aerobic biological processes are commonly used in the treatment of organic wastewaters for achieving high degree of treatment efficiency, while in anaerobic treatment, considerable progress has been achieved in anaerobic biotechnology for waste treatment based on the concept of resource recovery and utilization while still achieving the objective of pollution control (Chan et al. 2009). Using a simple aerobic treatment for OMW is not effective because of the its characteristics. However, biological treatment is possible when a combination of aerobic and anaerobic methods is applied, especially when it is diluted with municipal wastewater.

A number of different aerobic microorganisms have been tested in aerobic processes to treat OMW, including *Bacillus pumilus*, *Arthrobacter* sp., *Azotobacter vinelandii*, *Pseudomonas putida* and *Ralstonia* sp. and various bacterial consortia (McNamar and et al., 2008). Several studies of aerobic degradation of OMW have focused on *A. vinelandii*. For example, Papadelli et al. (1996) isolated a strain of *A. vinelandii* from soil treated with OMW. Eventually, 490% removal of phytotoxic compounds from OMW was achieved using this strain (Ehaliotis et al., 1999; Piperidou et al. 2000).

A number of studies have also utilized bacterial consortia coming from activated sludge, commercial communities, soil, and wastewater. Bioremediation of OMW using aerobic consortia has been quite successful in these studies, achieving significant reductions in COD (up to 80%) and the concentration of phytotoxic compounds, and complete removal of some simple phenolics.

Aerobic treatment has been also carried out in the presence of various strains of fungi such as white rot fungi (including the edible mushrooms *Lentinula* and *Pleurotus*), *Basidiomycetes* sp. and *Aspergillus niger* and several different yeasts. In addition to reduction of COD and removal of simple phenolics, fungi are also effective at reducing coloration of OMW. The different biological treatments lead to very variable reductions in COD and polyphenol levels depending on the performance of the strains selected for use.

Anaerobic processes

The anaerobic digestion is a biological process in which a complex community of microorganisms work in a stable, self-regulating steady state converting waste organic matter into a mixture of carbon dioxide and methane gases (Kaspar and Wuhrmann, 1978; Zeikus, 1980; Gujer and Zehnder, 1983; Speece, 1983; Sterling et al., 2001). Anaerobic treatment is considered as a cost-effective alternative, if compared to aerobic treatment especially for high organic industrial wastewater. Anaerobic digestion has a great number of advantages: low nutrient requirements, energy savings, generation of low quantities of sludge, excellent waste stabilization, production of biogas (methane) without the requirement of pre-treatments of the residues (Kang and Weiland, 1992; Weiland, 1993; Yadvika et al., 2004).

OMW is an effluent of the olive oil extraction process. The large volumes involved, along with the high phenolic content and chemical oxygen demand, cause major environmental problems. However, the seasonal production and high organic loading of OMWs make anaerobic treatment a very attractive option for these wastes. Furthermore, production of much less biosolids (sludge) and biogas as a valuable end product, which may offset the associated treatment costs, further add to the positive aspects of anaerobic treatment (Ergüder et al., 2000). Anaerobic digestion processes produces useful energy and result in a net reduction in CO_2 emissions. Another advantage of anaerobic digestion is that a digester can be started up after more than eight months under non-feeding conditions (Tsonis and Grigoropoulos, 1993), and is thus suitable for the treatment of seasonal wastes such as OMW. The low rate anaerobic sludge blanket type reactor is considered as the most efficient anaerobic reactor for the treatment of OMW.

Anaerobic digestion is usually the basic biological process for OMW treatment since it has many advantages compared to aerobic treatment. These include no aeration requirements, lower sludge production, lower nutrient requirements, the production of methane gas, and the quick recovery of anaerobic systems that have been dormant for a long time (Droste, 1997). The last point is particularly important, as the treatment unit will be without wastewater for about 8-9 months.

In the last decade, most of the research conducted on OMW treatment has been focused on the use and development of anaerobic methods and bioreactors that can remove efficiently the high organic load (Boari et al., 1984; Borja et al., 1992; Hamdi, 1995; Andreozzi et al., 1998) as well as reduce the toxicity of microorganisms-inhibiting materials present in OMW (Paredes et al., 2001). It has been reported that anaerobic bacteria decompose organic materials in a three-stage process emman et al., 1997). In the first stage, anaerobic bacteria degrade complex organic materials into simpler compounds; namely, polysaccharides and polyphenols are converted to their monomers (monosaccharides and phenols, respectively). During the second stage, acetogenic bacteria convert the phenols and the monosaccharide into organic acids, such as acetic, lactic and formic acids and alcohol. Finally, in the third stage, methanogenic bacteria, which are characterized by their sensitivity to pH, convert the organic acids into biogas (a mixture of 60–80% methane and other gases, mainly carbon dioxide).

The presence of compounds toxic to methanogens in OMW appears to be a significant problem for anaerobic digestion of OMW. The presence of phenolics limits the effectiveness of aerobic or anaerobic treatment of this wastewater. Minimising the effects caused by high concentration of phenolics, OMW must be diluted prior to either aerobic or anaerobic processes. Although dilution decreases the concentration of the toxic compounds present in wastewater, making it easier to reach the required standards for the final effluent, it also causes an increase in waste volume, which is not desired (El-Gohary et al., 2009).

A lot of researches were made for the anaerobic treatment of OMW in the literature. Some of them was summarized in here: For example, Boari and Mancini (1990) studied the biological treatment of olive mill effluent wastewater. They studied the effect of sedimentation, coagulation, followed by aeration. They also studied BOD, COD, and suspended solids as main parameters and found that the removal percentage of organics was higher than 90%. Their results using anaerobic digesters showed 70% removal of COD, and more economical operation. Hayek et al. (1996) reduced the COD by 75% using upflow anaerobic sludge blanket (UASB) reactor.

Ergüder et al. (2000) reported that OMWW could be treated anaerobically with high efficiencies (85.4–93.4%) and treatment of 1 L OMWW by anaerobic methods resulted in production of 57.1±1.5 L of methane gas (i.e. 413 mL of methane gas was produced from degradation of 1 g of COD found in olive mill waste water). Authors concluded that olive mill wastes can be treated under anaerobic conditions leading to production of biogas in significant amounts.

Reductions in COD from 70% to 89% have been reported for anaerobic processes (Borja et al., 1996; Marques et al., 1997; Marques, 2001). In addition to a substantial reduction of COD, Dalis et al. (1996) reported large reductions (475%) in the concentrations of both toxic phenols and volatile fatty acids using a two stage anaerobic reactor with an inoculant obtained from a domestic wastewater facility. In contrast, other studies have reported that the build up of recalcitrant phenolics (e.g., condensed tannins, Zouari and Ellouz, 1996) as well as the presence of long-chain fatty acids (Hwu and Lettinga, 1997) in anaerobic reactors inhibited microbial activity.

Subuh (1999) has conducted anaerobic digestion of OMW using laboratory scale Up-flow Anaerobic Sludge Blanket (UASB) reactor. He proved that removal efficiency of the soluble fraction of COD reached 76% using the UASB. Sabbah et al (2001) have evaluated different techniques for the treatment of OMW including aerobic and anaerobic combined with physical treatment methods. Different types of reactors were checked such as stirred-tank reactor, fluidized-bed reactor, and UASB reactor. UASB has showed a promising technique for anaerobic treatment of OMW.

The anaerobic wastewater treatment processes have been tested for the treatment of olive mill effluents in pilot scales. They have been tested in large scales as well, but only in combination with aerobic processing. A multistage system with first an anaerobic stage and a sequential aerobic treatment stage has been investigated by Steegmans (Steegmans, 1987). Sabbah et al. (2001) found that removal of the phenolic compound and possibly other toxic materials that inhibit the growth of microorganisms using in the primary treatment step contributes significantly on increasing the efficiency of anaerobic digestion.

Anaerobic digestion of unmodified OMW have been concerned with problems such as high toxicity and low biodegradability and acidification of the reactor (Boari et al. 1984; Borja et al. 1992). However, the efficiency of anaerobic digestion was increased when preceded by a pretreatment step. Several treatment methods can be used as pretreatment of OMW such as physical (flotation, membrane seperation, gravitty settling, ultrafiltration, centrifugation, coagulation etc.) and chemical (such as fenton oxidation processes) and biological (aerobic, composting). For example, pretreatment of OMW by previously aerobic fermentation with Aspergillus niger (Martin et al., 1991) and Geotrichum candidum (Beccari et al., 1999) could reduce residence time required for anaerobic process. Selective preremoval of inhibitors such as lipids and poly phenols through lime or lime/bentonite addition followed by phase separation before anaerobic digestion as a chemophysical treatment has been studied (Box, 1983). Similarly, Azbar et al. (2008) compared the methane production in an anaerobic digester fed with either raw or chemically pretreated OMW. They found over 80% increase in biogas production when digesting OMW after chemical pretreatment. Accordingly, it has been concluded that, the anaerobic biodegradability of OMW could be significantly enhanced by chemical pretreatment. El-Gohary et al. (2009) reported that an integrated system consisting of catalytic oxidation using Fenton's in combination with a two stage anaerobic post-treatment (classical UASB followed by hybrid UASB) is recommended for treatment of olive mill wastewater. The use of Fenton's reaction as a primary treatment of OMW enhances the efficiency of anaerobic digestion.

Conclusion

Generation of OMW in the Mediterranean region has a significant environmental impact and the high organic polluted OMW affects the soil, groundwater and watercourses. Besides, the seasonal nature of olive oil production, the geographic dispersion of mills and economic limitations for cost effective treatment all present significant challenges in designing treatment options for OMW. However, OMWis not managed properly, due to the fact that there is at present no reliable management plan. Therefore, a shift in current management schemes is required that focuses on both the sustainable conservation of water resources in the Mediterranean region and on the development of a cost-effective management method for OMW. Overall, the incorporation of biological processes provides some of the most viable options for the treatment of OMW. Effective treatment methods will be resulted in significant reductions in COD, phenolics and color allows safe and economical disposal of OMW onto land or into surface waters.

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