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Research article

Performance investigation of a jet loop membrane bioreactor for the treatment of an actual olive mill wastewater

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ABSTRACT

In this study, following the pre-treatment of olive mill wastewater (OMW), its treatment in a jet loop membrane bioreactor (JLMBR) was investigated. Among the pre-treatment options, the configuration composed of physical settling, cartridge filter and ceramic membrane showed the best performance in terms of investigated parameters. For the JLMBR that was fed by pretreated OMW, up to 93 and 87% removal efficiencies were achieved for the chemical oxygen demand (COD) and total phenol, respectively, at volumetric organic load (VOL) of 17.8 kg COD/m^3 day. The calculated specific oxygen uptake rate (SOUR) values were in the range 7.7–34.7 g O_2/kg MLVSS h. When even hydraulic retention times (HRT) values decreased by a factor of 1:24, system performance in terms of COD and total phenol removal remained almost stable. Decreasing the sludge retention time (SRT) to three days made considerable perturbations for the system performance, increasing the effluent COD and total phenol values in 900 and 80 mg/L, respectively. The JLMBR showed a high overall performance for the treatment of an actual OMW under the evaluated operational conditions.

1. Introduction

Mediterranean countries are responsible for the 97% production of olive oil. The ranking of the countries by production are Spain (45.3%), Italy (14.3%), Greece (9.8%), Syria (5.8%), Turkey (5.2%), Morocco (4.2%), and Tunisia (3.9%) (IOC, 2015). Different processes such as batch or continuous 2 or 3-phase olive oil extraction are in use for olive oil production and two by products, namely OMW and solid cake, are formed. OMW are formed from the water content of the fruit itself and the water used to wash and process them. Discharge of OMW without treatment to the receiving water resources is a major problem due to its high organic and nutrient content (Table 1). The chemical composition of OMW is highly variable depending on factors such as; olive type, cultivation system, degree of maturity of the fruit, and type of oil extraction process. Typically, the weight composition of OMW is 83–96% water, 3.5–15% organics, and 0.5–2% mineral salts (Greco et al., 1999; Tziotzios et al., 2007; Michailides et al., 2011).

OMW shows phytotoxic and antimicrobial characteristics due to its aromatic content and high phenolic content of OMW makes it highly problematic wastewater. Also, OMW is an odorous, acidic and dark coloured wastewater and, has a high C/N ratio. Depending on the production method, 0.5–1.5 m^3 wastewater are released for each processed ton of olive. OMW has a high organic content; COD and BOD values could reach up to 220 g/L and 110 g/L, respectively. Considering these high values, OMW has 200–400 folds greater organic content than domestic wastewaters (Benitez et al., 1997; Borja et al., 1998; Fadil et al., 2003; Paraskeva and Diamadopoulos, 2006; Morillo et al., 2009).

OMW can be treated by physical, chemical, biological or combined processes. Evaporation (Jarboui et al., 2010), membrane filtration (Paraskeva et al., 2007), chemical settling (Aktas et al., 2001), electrocoagulation (Tezcan Ün et al., 2006), ozonation (Chedeville et al., 2009), electrochemical oxidation (Gotsi et al., 2005), anaerobic and aerobic degradation (Ammary, 2005; Eusébio et al., 2007) are among the above mentioned processes. Advanced oxidation processes (AOPs) are also an important process to be considered in olive oil wastewater treatment and other food and beverage effluents of high organics and nutrients content with overall treatment efficiencies of up to 99% when used in

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Table 1
Characterization results of raw OMW samples.

Parameters	Unit	OMW-I	OMW-II	OMW-III
COD	mg/L	55730	91550	67820
BOD_5	mg/L	29930	38600	33520
TOC	mg/L	–	23454	18620
TN	mg/L	–	338	230
Total phenol	mg/L	2439	4509	3672
Phenol	mg/L	197	–	–
SS	mg/L	14080	33500	25200
PO_4	mg/L	–	852	638
SO_4	mg/L	–	117	105
Toxicity	%	24.2	21.8	–
Conductivity	mS/cm	11.30	10.04	12.01
pH	–	4.85	4.28	4.54

combination with biological processes (Cañizares et al., 2007; Oller et al., 2011; Bustillo-Lecompte and Mehrvar, 2015). When these methods are used solely for OMW treatment, usually discharge limits can not be met. Thus combination of processes is needed. Integration membrane processes to biological treatment processes are preferred combination type in recent applications.

Membrane bioreactors (MBR) have evident advantages over conventional biological processes. These advantages are lower footprint, easiness of automation and operation, handling with higher organic loadings (Bouhabila et al., 2001; Xing et al., 2003). Moreover, due to the retention of whole microorganisms in MBRs, it is able to work with higher microorganism concentration and thus required reactor volume is lowered in order to remove the same amount of pollutant (Farizoglu and Uzuner, 2011).

Conventional aeration systems are deficient in order to meet the high oxygen requirement of OMW. Hence, it is inevitable to employ the innovative reactors to realize oxygen transfer rapidly, when the OMW is treated aerobically. Jet loop reactors (JLRs) have many advantages over classical reactors such as, simple construction, lower construction and operation costs, more circulation under the same energy input, no moving part in the reactor, easy transfer from pilot scale to industrial scale (Velan and Ramanujam, 1992; Fadavi and Chisti, 2005). The potential use of JLR for industrial wastewater treatment is increasing especially due to their extensive mixing properties and high mass transfer capabilities (Petruccioli et al., 2002; Yildiz et al., 2005).

Since OMW is highly complex and problematic wastewater, it is rather difficult to treat it with only one type of process. An efficient pre-treatment is always a necessity due to OMW's high organic content. Reactors as JLR, which are able to transfer high oxygen, have been gaining importance. Thus, in this study various experiments concerning with preparation of OMW to biological treatment by various pre-treatment options and then treatment of OMW in JLMBR using membrane filter were investigated.

2. Materials and methods

2.1. Jet loop membrane bioreactor system

The JLR consists of two concentric cylinders. The reactor (outer one) and draft-tube (inner one) have diameters of 10 cm and 4 cm, respectively and both of them have 2 mm of thickness. Wider compartment located at the top of the reactor is called as degassing tank and its internal diameter is 20 cm. Total height of the reactor is 110 cm. Draft tube, which is below the 35 cm from the top of the reactor and 10 cm from the bottom (impact plate) of the reactor was centered to the reactor through a support layer. Liquid is circulated by a circulation pump and air which is coming from another line pass through a nozzle and injected into the suction pipe. The liquid and the gas inside the draft tube move downwards and after reaching the bottom of the reactor they rise within the annulus between the wall of the reactor and the draft tube. Some part of fluid which is including bubbles and flowing through the same level of sucking pipe, recycled into the sucking pipe due to pressure difference and continues to the cycle. Nozzle consists of two concentric cylindrical pipes; outer cylinder, where liquid flows has internal diameter of 15.7 mm and inner cylinder, where air flows has internal diameter of 4 mm and thickness of 1.2 mm. Excessive heat produced by the working pumps was removed by heat exchanger which was installed at pump's sucking line. JLMBR, which was set up by jet loop reactor manufactured from stainless-steel and a ceramic membrane unit integrated into the JLR, has a total volume of 20 L including the reactors, pipes and pumps volume available for water. Controlled parameters for the JLMBR system are dissolved oxygen concentration (>4 mg/L), temperature (25 °C), circulation flow rate in JLR (40–55 L/min), circulation flowrate (20–65 L/min) and transmembrane pressure (0.8–2.8 bar). Schematics diagram of the tested system is given in Fig. 1.

2.2. Characterization of OMW

Wastewaters were taken from an olive mill (a three-phase production facility), located at the city of Balıkesir. Physicochemical characterization of raw wastewater samples, which was taken at three different periods is given in Table 1. Samples used in the experiments (OMW-I), were transported to laboratory in plastic barrels and kept at 4 °C.

2.3. Ceramic membrane filter unit

Specifications of the tested ceramic membrane filter are given in Table 2. Ceramic filter was backwashed by air of 4–5 bars in every 5 min for 1 min duration. For the circumstances of required flux is not met, ceramic membrane was washed by chemicals. The chemical washing procedure is as, soaking into sodium hydroxide solution (1%) for 1 h followed by rinsing with tap water for 0.5 h then soaking into Nitric acid (1%) solution for 1 h and finally rinsing with tap water for 0.5 h.

2.4. Operational parameters for JLMBR and used culture

Feed water organic content was kept constant and influent flowrate, hydraulic retention time (HRT), volumetric organic loading (VOL) and sludge retention time (SRT) were changed to assess their effect on system performance. In order to reach to the steady-state conditions, a feeding volume in the range 7–65 folds of system volume was introduced into the reactor. Changed parameters and their range are shown in Table 3.

Activated sludge samples taken from the settling tank of the Erzincan City wastewater treatment plant used as inoculum. Microbial cultures introduced into JLR and it was operated about 30 days until the microorganism acclimated to the reactor's internal conditions. Sludge has not been wasted during the acclimatization period of 30 days. 0.78 kg COD/m^3 day of constant volumetric loadings were applied for acclimatization period. The effluent COD concentrations showed a steady decrease after 25 days. Decreasing trend continued to 30th day (Fig. 2). Thus, we assured that the biomass was ready for the actual treatment.

It can be clearly seen from Table 1 that OMW is highly poor in terms of nitrogenous content. Thus, extra nitrogen ($NaNO_3$), which is required for microbial cells was added in order to ensure the ratio of C:N = 100:5.

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