Operation of a small scale SMBRe system for wastewater reuse

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Abstract

In this study, the operation of an intermittently aerated and periodically fed external submerged MBR system was investigated in order to assess the reuse potential of the permeate generated. The effluent characteristics were evaluated in relation to the Greek legislation (Joint Ministerial Decree 145116/11) for wastewater reuse. Experimental results showed that organic carbon, suspended solids, total nitrogen and *Escherichia coli* removal met the strict legislation limits for unrestricted use, while effluent ammonia nitrogen and turbidity should be improved. In respect to the total coliforms, chlorination was needed for unrestricted use.

Keywords

Wastewater reclamation; Water reuse; Membrane bioreactor; Ultrafiltration; Disinfection

INTRODUCTION

The South European countries are regularly confronted with water scarcity and water supply irregularities, particularly in the summer period. Wastewater reclamation and water reuse presents a favorable solution to the growing pressure on water resources, as a result of anthropogenic activities (Asano et al. 2005; Aggelakis and Bontoux, 2001; Aggelakis et al. 1999). The degree of treatment is mostly ascertained by the recommended use of the reclaimed water, which should be of high quality in order to meet the strict legislation limits for agricultural or landscape irrigation, supply of underground aquifers, urban and regional use and industrial reuse. In Greece, the Joint Ministerial Decree (JMD) 145116/11 indicates the physicochemical and microbiological requirements, concerning the reuse of treated effluents. According to the legislation, certain constituents of interest have to be monitored and controlled in reuse water. A sound operation of the secondary biological treatment system is needed in order to guarantee the required low limits of nutrients concentration and suspended solids in the treated water. Monitoring of *Escherichia coli* and *Total coliforms* is of great importance because waterborne pathogens can cause plethora of public health problems (Rose et al. 1996; Costan-Longares et al. 2008) and should be removed from reclaimed water before discharging. Membrane processes are considered as essentials for the production of high quality effluents, suitable for a wide range of reclamation and reuse purposes (Melin et al. 2006; Xing et al. 2000; Marti et al. 2011; Malamis et al. 2015). Even though, complete removal of microorganisms cannot be expected, especially if we consider the storage and distribution system facilities, which can be prone to re-growth. MBR effluents disinfected with residual chlorine will be adequate for many water reuse applications (Ottoson et al. 2006; Arévalo et al. 2009).

In this study, the operation of an intermittently aerated and periodically fed external submerged MBR system was investigated in order to assess the reuse potential of the permeate produced. The effluent characteristics were evaluated in comparison to the Greek legislation for the reuse of treated wastewater (Joint Ministerial Decree - JMD 145116/2011).

MATERIALS AND METHODS

SMBRe system

The SMBRe system contained an equalization tank, an aeration tank and a second external tank where the membrane was submerged. The membrane was a flat sheet type module (Microdyn Nadir), with total active area of 0.34 m^2. It was composed of hydrophilic polyether-sulfone (PES), with a pore size of 0.04 μm (150 kDa). The activated sludge was recirculated between the bioreactor and the membrane tank through the use of a pump. No sludge settling occurred in the membrane tank. A schematic layout of the system can be found in Fig. 1. Intermittent aeration in the bioreactor was implemented to achieve effective denitrification. The dissolved oxygen (DO) was kept between 2-4 mg/L in the aeration phase. The membrane module was operated using a filtration cycle consisting of a back-wash and a fine bubble aeration period (specific aeration capacity of 0.8 $m^3/m^2.h$, absolute value of 4.5 L/min). The following cycle program was implemented: 510 sec filtration phase, 30 sec relax phase I, 30 sec back-wash (<150 mbar) and 30 sec relax phase II. The BNR process and TMP were automatically controlled by a programmable logic controller.

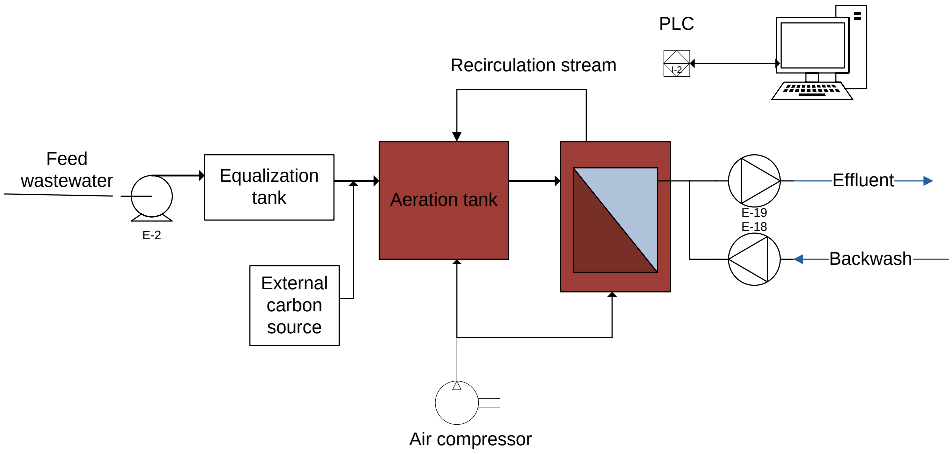

Figure 1. Schematic layout of the SMBR pilot plant.

Wastewater characteristics

The experimental period was 190 days and the domestic wastewater was received from the University Campus of Xanthi. The influent sewage characteristics were: BOD, 180 ± 63.9 mg/L; total COD, 388 ± 196 mg/L; total suspended solids (TSS), 201 ± 88.5 mg/L; total Kjeldahl nitrogen (TKN), 78.5 ± 22.1 mg/L; NH_4^+-N, 57.7 ± 17.2 mg/L; EC, 1229 ± 178 μS/cm and pH, 7.31 ± 0.23. The municipal sewage used was a low carbon/nitrogen ratio wastewater, where the organic carbon content was insufficient to achieve complete denitrification and external carbon source addition was needed. The influent wastewater was added in each cycle at the beginning of anoxic phase within a short time period of 3 min in order to facilitate denitrification. *Escherichia coli* and *Total coliforms* numbers were accounted for 64 ± 40 ($x10^4$) and 9.4 ± 5.7 ($x10^6$) cfu/100 mL, respectively.

Analytical methods

The sampling frequency was twice every week for measuring the input and output of the physicochemical parameters. Concentrations of NO_3^--N were determined through the use of ion chromatography (Dionex IC100), while NH_4^+-N concentrations were estimated by the steam distillation method, as described in the APHA manual. COD, BOD_5, TKN, SS, MLSS and MLVSS concentrations were measured according to APHA (Clesceri et al., 1998). Electrical conductivity (EC) and pH were determined using a CRISON CM35 and a METROHM 632 pH meter, respectively. Dissolved oxygen

(DO) concentration was determined by an oxygen measuring instrument (WTW Handheld meter Oxi340i). *Total coliforms* and *Escherichia coli* populations were estimated by placing the membrane filters on m-endo and Chromocult coliform agar plates and incubating these solid media for 22-24 h at 35 ± 0.5 ^oC and 44 ± 0.5^oC, respectively. Turbidity was determined by using the Hach 2100Q turbidity meter.

RESULTS AND DISCUSSION

SMBRe operation

Regarding the influent loading parameters, the unit was operated under a F/M ratio of 0.27 ± 0.1 $gBOD_5/gVSS.d$, an organic loading rate (L_{ORG}) of 0.9 ± 0.2 g BOD_5/L.d and a nitrogen loading rate ($L_{N,V}$) of 0.024 g TKN/L.d. During the whole experimental period, waste sludge was not removed and the corresponding sludge age (SRT) was equal to the operation day, while the hydraulic retention time was 5 d. Permeate flux was fluctuated between 4.2 and 13.8 L/m^2h, whereas MLSS content was between 4-6 g/L. The permeability was 56.6 ± 5.6 L/m^2.h.bar and the respective resistance was 9.4 ± 0.82 m^{-1}. During the experimental period, only a slight TMP increase was observed, with the latter being equal to 142 ± 51.6 mbar.

Organic carbon removal

According to the Joint Ministerial Decree 145116/11 for wastewater reuse, BOD is a main quality parameter characterizing the organic carbon content of the treated effluent. The permitted effluent BOD value is ≤25 mg/L for restricted irrigation and ≤10 mg/L for 80% of samples for unrestricted irrigation (agricultural and urban use, and groundwater recharge). The operation of the intermittently aerated and periodically fed SMBRe system resulted in low effluent BOD concentrations, varying between 1-7 mg/L BOD_5. The average BOD_5 value was 3.4 ± 1.5 mg/L, meeting, in any case, the legislation limits for unrestricted irrigation. Melin et al. (2006) also reported similar BOD concentrations in the permeate of an ultrafiltration unit.

Nitrogen removal

Influent organic and ammonia nitrogen were oxidized to nitrate in the aerobic phase and nitrate nitrogen was completely denitrified in the following anoxic phase through the utilization of the external carbon source added, resulting in NO_3^--N effluent concentration of 0.7 ± 0.7 mg/L. Regarding nitrogen removal, effluent TKN and NH_4^+-N concentrations were 9.81 ± 1.90 mg/L and 4.26 ± 0.61 mg/L, respectively. The effluent total and ammonia nitrogen concentrations determined met the legislation limit (lower than 15 mg/L TN) for restricted irrigation, industrial use and groundwater recharge for non-potable applications, as achieved by filtration via suitable soil layer for aquifers. In the cases of unrestricted irrigation, industrial use, urban and suburban green applications, and groundwater recharge with drilling, the legislation requirements were met, except for irrigation in nitrite vulnerable zones, due to the higher ammonia nitrogen concentration determined.

Suspended solids and Turbidity

In the case of total suspended solids, the limits specified by the Greek legislation for reclaimed water reuse are ≤10 mg/L for restricted use and ≤2 mg/L for unrestricted use (in 80% of samples analyzed). It is expected that ultrafiltration with a pore size of 0.04 μm should retain 100% of the suspended solids. In this study, TSS were negligible lower than the effluent quality limits enforced for unrestricted use (<2 mg/L). Based on turbidity measurements, effluent NTU (Nephelometric turbidity units) values varied between 1.2 and 3.6 and estimated to be equal with 3.26 ± 0.7. However, these values were higher than the recommended NTU limits, but lower than those reported in several analogous studies, where NTU values within 5 and 10 were determined (Xing, 2000; Jefferson, 2001). Exceptionally, these were higher than the values measured by Cote et al. (1997) and Arévalo et al. (2009).

Microbiological aspects

Based on the membrane pore size, someone can expect that the UF membrane should provide complete bacterial removal and the permeate should be free from *Total Coliforms* (TC) and *Escherichia coli* (EC). This goal was achieved for the *Escherichia coli* during the whole experimental period, counting 0-1 cfu/100 mL with an average of 0.1 cfu/100 mL. These EC numbers complies with the effluent quality standards of the Greek legislation (set limits ≤200 cfu EC/100 mL for restricted irrigation and ≤5 & ≤50 cfu EC/100 mL for 80% & 95% of the samples analyzed for unrestricted irrigation). Arévalo et al. (2012) presented similar results, showing EC effluent concentrations of 0.2 cfu/100 mL. In a full scale plant, Battistoni et al. (2006) also found an EC effluent concentration of 3.8 and 2.4 cfu/100 mL during the autumn and the summer period, respectively.

According to the Greek legislation, TC enumeration is required for unrestricted wastewater reuse. For unrestricted urban and suburban green applications, and groundwater recharge, the TC limits are 2 TC/100 mL and 20 TC/100 mL for 80% and 95% of the samples analyzed. At the initial stage of operation, TC removal efficiency was 99.7%, although TC effluent concentration was 6920 cfu/100 mL, which was much higher than the permitted limits. To control this problem, chemical cleaning of the membrane and systematic disinfection of the effluent pipes with sodium hypochloride were implemented. In the following operational period, a sharp reduction of the effluent TC concentration was observed and TC enumerated as 4 cfu/100 mL after a short period of time. Thus, the effluent concentration of TC was varied between 0 and 10, proving the effectiveness of chemical disinfection during ultrafiltration, which is in compliance with legislation limits of ≤ 20 cfu/100 mL for 95% of samples analyzed for unrestricted use. The TC reduction in the permeate was performed by two mechanisms, 1) by size exclusion (due to the pore size) and 2) sorption to membrane surface and/or cake layer (Le-Clech et al., 2006; Marti et al., 2011). TC cell retention mechanism was intensified by biofouling phenomena, contributing to a higher microbial rejection, since the membrane cut off was diminished (Wong et al., 2009; Da Silva et al., 2007; Judd, 2004). In order to comply with the second requirement of the legislation that sets a limit of 2 cfu TC/100 mL for 80% of the samples analyzed, chlorination of the permeate was implemented by using a NaOCl concentration of 2 mg /L. The results showed 100% TC reduction, with the effluent quality meeting the legislation limits for unrestricted use.

CONCLUSIONS

In this study, the operation of an intermittently aerated and periodically fed external submerged MBR system was investigated to assess the reuse potential of the permeate obtained. The effluent characteristics were evaluated in comparison to the Greek legislation for the reuse of the treated wastewater (Joint Ministerial Decree - JMD 145116/2011). The results showed a low effluent BOD concentration (3.4 ± 1.5 mg/L), which met the legislation limits for unrestricted use. The effluent total nitrogen (<15 mg TN/L) and ammonia concentrations met the legislation limits for restricted irrigation, industrial use and groundwater recharge for non-potable applications. In the cases of unrestricted irrigation, industrial use, urban and suburban green applications, and groundwater recharge with drilling, the legislation requirements were met, except for irrigation in nitrite vulnerable zones, due to the higher ammonia nitrogen concentration determined. The suspended solids concentration complied with the limits for unrestricted use. Permeate NTU values were slightly higher than the required limits for unrestricted use. *Escherichia coli* limits were within the limits for unrestricted use, while, to meet the legislation limits for total coliforms, additional measures, i.e. chlorination, were needed. In conclusion, modifications in MBR process are necessary to optimize the removal efficiency concerning ammonia and turbidity in order to meet the legislative requirements.

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