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Greywater treatment in a submerged membrane bioreactor with gravitational filtration

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ABSTRACT

This study examined the practical performance of a submerged membrane bioreactor treating low-load greywater. A 17 L laboratory-scale bioreactor with a flat-plate microfiltration membrane (polyethylene; pore size 0.4 μm) was operated to treat the effluent from the showers of the student housing complex at the Tunis Agriculture University (Tunisia). Permeate was intermittently withdrawn at constant transmembrane pressure induced by water level difference. The Pollutant removal and membrane behaviour were monitored. The treatment obtained a stable output with an excellent effluent quality in terms of chemical oxygen demand, suspended solids and anionic surfactant levels (20, <0.1 and 0.025 mg/L, respectively); in addition, faecal coliforms in the permeate were undetectable. The average power consumption by the experimental plant was 3.3 kWh per 1 m^3 of treated water.

Keywords: Greywater; Gravitational filtration; Membrane bioreactor; Microfiltration

1. Introduction

Greywater reuse is becoming an increasingly important factor for saving potable water in many countries. Greywater is defined as the domestic wastewater from laundries, showers, bathtubs, hand basins and kitchens, excluding streams from toilets [1–3]. Some authors exclude kitchen wastewater from the other greywater streams [4–7]. The elimination of the toilet stream from domestic wastewater generates effluents with reduced levels of nitrogen, solids and organic matter (especially the barely degradable fraction), but that often contains elevated levels of surfactants, oils and pathogens.

Greywater treatment and reuse offers the potential to substantially reduce demand of domestic potable water, but care must be taken to ensure that this is achieved without endangering public health and the environment.

Several wastewater treatment methods, such as soil filtration, constructed wetlands, rotating biological contactors and sequencing batch reactors (SBRs) have been extensively tested for greywater treatment [8,9].

The membrane bioreactor (MBR) has recently been regarded as an innovative technology for greywater treatment due to its process stability and its ability to remove pathogens. The MBR technology combines a biological degradation process utilising activated sludge with a direct solid–liquid separation by membrane filtration. Using micro- or ultrafiltration membrane technology (with pore sizes ranging from 0.05 to 0.4 μm), MBR systems allow for the complete physical retention of bacterial flocs and virtually all suspended solids (SS) within the bioreactor. As a result, the MBR has many advantages over conventional wastewater treatment processes, including small

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footprint and reactor volume requirements, high effluent quality, good disinfection capability, higher volumetric loading and reduced sludge production [10].

Submerged MBR has been successfully employed in Japan for greywater recycling in office blocks and residential buildings, because of its compact structure and lower power costs [11]. Two types of submerged membrane reactors have been developed to date, classified by the membrane separation principle involved: suction filtration and gravitational filtration (see Fig. 1) [12]. In the former type, permeate is removed by a suction pump from the effluent side. In the latter type, permeate is pushed from the bulk-solution side by the pressure head of the mixed liquor over the membrane modules. The latter type, therefore, requires no suction pump for membrane separation, thereby simplifying the structure and saving energy and so reducing costs.

Tunisia is arid and semi-arid country with a high population growth rate and severe water scarcity. A research project was approved to reduce fresh water consumption in a student housing complex at the Tunis Agriculture University, by reusing greywater in applications that do not require potable water quality.

Here, we present the results of our investigation on the application of a gravitational-filtration MBR to the treatment of greywater effluent from the showers of the student housing complex. The pollutant removal and membrane behaviour were monitored.

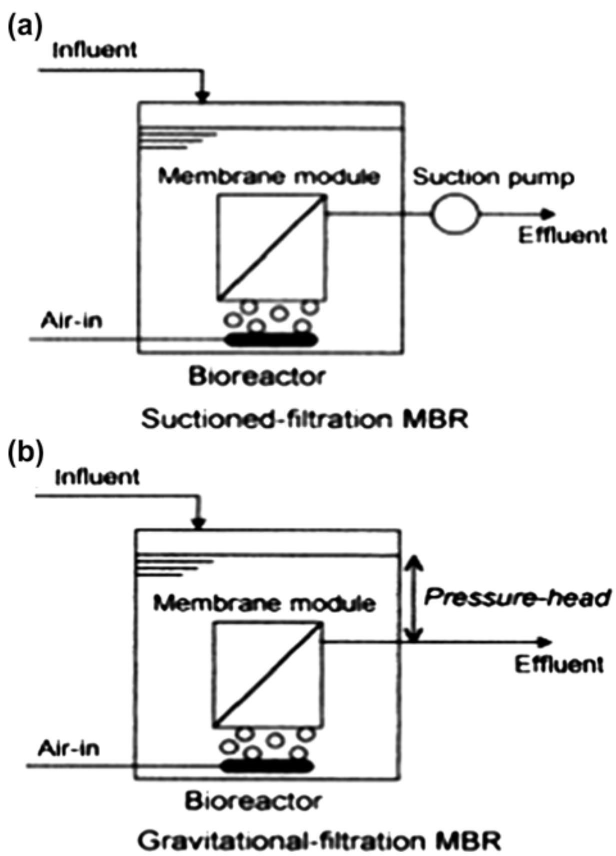

Fig. 1. Suction-filtration and gravitational-filtration membrane bioreactors [12].

2. Materials and methods

2.1. Greywater source

The greywater was collected at the outlet of the bathing area in the student housing unit at Tunis University (Tunisia). The house is a public building, with three floors for female engineering students and a capacity of 212 people. The bathing area is equipped with 18 showers and is situated on the ground floor. Greywater was collected once per week in polystyrene tanks. Coarse and fine particles were removed by filtration through a 0.9 mm stainless steel screen.

2.2. Description of the pilot plant

The MBR used consisted of a single tank with an effective volume of 17 L, in which was housed a submerged microfiltration plate and frame filter module (A3 with Kubota membrane) made of polyethylene with a total membrane area of 0.15 m^2 and a pore size of 0.4 μm (Fig. 2). Permeate was intermittently withdrawn at constant transmembrane pressure (0.46 kPa) due solely to the water level difference, i.e. without a pump. To operate the filtration unit, a solenoid valve was placed in the effluent pipe. Coarse and fine membrane bubble diffusers, connected to a compressor through solenoid valves, were used to supply air to the system at a flow rate of 20 L/min; the diffusers were placed at the bottom of the reactor and also under the membrane modules, so that an uplifting two-phase flow of bubbling air and mixed liquor would remove any cake layer deposited on the membrane (Fig. 3).

2.3. Operating conditions

In the start-up process, activated sludge obtained from a domestic wastewater treatment plant was used after filtration with a 0.9 mm stainless steel screen. The mixed liquor suspended solids (MLSS) content in the activated sludge was initially 4 g/L. During the operation, no sludge was discharged from the reactor except when sampling for the MLSS (25 mL per

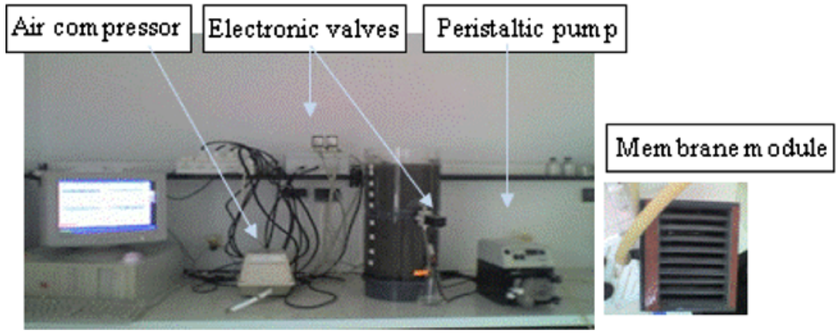

Fig. 2. Experimental MBR set-up.

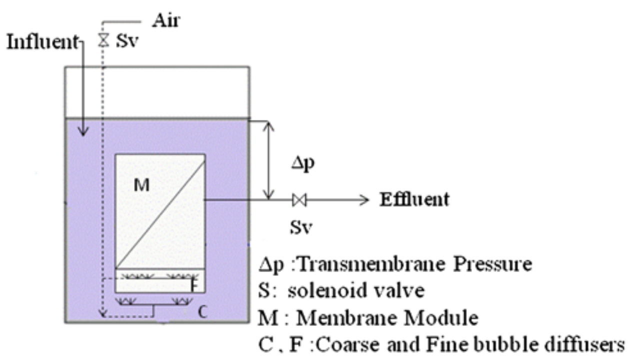

Fig. 3. Schematic diagram of the submerged MBR.

Table 1
Operating parameters for the laboratory-scale MBR

Operating parameters	Average	Minimum	Maximum
Hydraulic retention time (h)	13.0	8.9	14.3
Organic loading rate (kg_{COD}/m^3 d)	0.318	0.200	0.432
Feed/biomass (kg_{COD}/kg_{MLSS} d)	0.09	0.05	0.123

10 days). Table 1 shows the main operating parameters of the pilot plant.

The system was operated as a SBR at eight cycles per day. Each cycle (3 h) began with a filling phase, which took no more than 5 min. The reactor volume was controlled by a level controller. After the reaction phase (an aeration period of 30 min), the permeate was intermittently withdrawn (5 min on and 1 min off).The permeate withdrawal period took only 20 min, and the cycle ended with the idle phase, as shown in Fig. 4. The operating conditions were controlled by a programmable logic controller connected to a laptop computer.

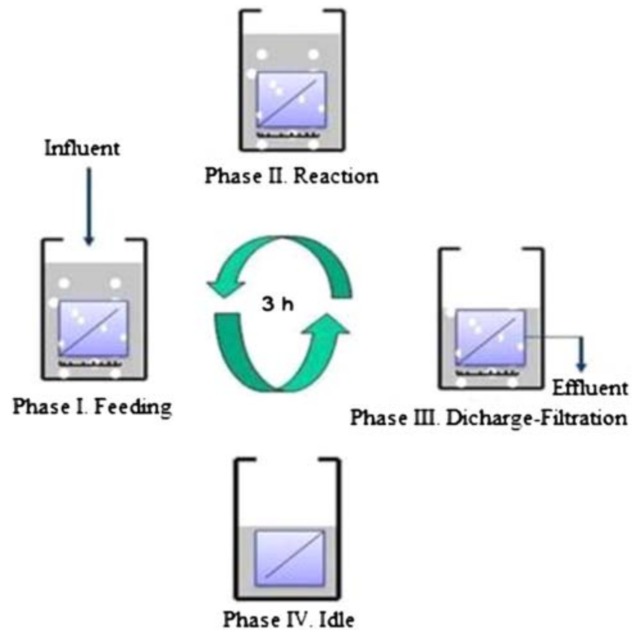

Fig. 4. Schematic diagram of the phases in the MBR reactor cycle.

2.4. Analyses and methods

All parameters related to the quality of the influent, supernatant and effluent, and mixtures thereof were measured according to the standard methods [13]. Nitrates (NO_3) and nitrites (NO_2) were analysed with an ion chromatograph (waters). The analysis of anionic surfactants (AS), reported as methylene blue active substances, utilised a colorimetric method using linear alkylbenzene sulfonate as the reference substance [13].

3. Results and discussion

3.1. Overall performance of the MBR

Qualities of the influent and effluent including chemical oxygen demand (COD), biological oxygen

Table 2
Characteristics of the greywater influent and the permeate

Parameter	Greywater (mean ± SD)	Permeate (mean ± SD)
SS (mg/L)	33 ± 16	ND
COD (mg/L)	164 ± 59	20.8 ± 5.8
BOD_5 (mg/L)	97.3 ± 32.1	12.3 ± 2.5
NH_4–N (mg/L)	6.8 ± 5.6	0 .2 ± 0.1
NO_2–N (mg/L)	0.04 ± 0.02	0.16 ± 0.02
NO_3–N (mg/L)	0.2 ± 0.1	9.85 ± 4.30
AS (mg/L)	6.00 ± 2.00	0.025 ± 0.020
Feacal coliforms (CFU/100 mL)	$0.5 \times 10^5 \pm 10^4$	ND
Total coliforms (CFU/100 mL)	$1.1 \times 10^5 \pm 10^5$	ND

Data shown are mean values with standard deviation (SD); ND, not detected.

demand over a 5-day (BOD_5), ammonia nitrogen (NH_4) and coliforms were measured, and the values are shown in Table 2. The influent had an average COD concentration of 164 mg/L. The average ratio COD/BOD_5 was very low with a value of 1.6 indicating high biodegradability [14]. Similar values were reported for the shower effluent of a sports and leisure club in Morocco, where the COD/BOD_5 ratio was very low with values between 1.1 and 2.0 [15].

COD was reduced from the influent value of 100–225 mg/L to less than 30 mg/L in the permeate. The NH_4–N concentration decreased from 1.2–12.0 mg/L to less than 0.5 mg/L. Whereas NO_3 increased in effluent to 9.0 mg/L, indicating that the nitrification of ammonia nitrogen to nitrate occurred and was not inhibited. As expected, SS were not detected in the effluent; the pore size of the flat membranes in this study was less than 0.4 μm.

The concentration of AS in the influent was measured and found to be approximately 6 mg/L. This concentration is similar to that observed in municipal wastewater plants dealing only with domestic wastewater range of 1–15 mg/L [16].

AS were reduced from 3.50 to 8.90 mg/L in the influent to less than 0.02 mg/L in the effluent. Removal rates of up to >99% were observed throughout the study. This high removal rate was attributed to the characteristics of the MBR system, including the retention and the biodegradation of AS. Similar removal rates were observed in prior study with a greywater influent [17], indicating that there was no inhibition of AS biodegradation in the range of influent concentrations up to 30 mg/L.

The influent contained at least 10^5 CFU/100 mL of potentially pathogenic micro-organisms similar to previously reported daily values of microbiological pollution in shower greywater [18]. Total coliforms in the effluent were undetectable.

3.2. Sludge concentration

The MLSS level in the activated sludge was initially 4 g/L, but the occurrence of foaming at the beginning of the operation led to a loss of MLSS; the concentration later stabilised at 3.5 g/L. A slight increase of MLSS was observed in conjunction with very low microbial growth (Fig. 5), likely due to the composition of the greywater, which contained a variety of bactericidal substances found in shampoo, body soap and other cleaning agents. Some surfactants also inhibit microbial growth [19].

3.3. Membrane flux

The permeate was withdrawn due to the pressure caused by a water level difference between the reactor and the permeate, eliminating the need for a pump and hence, reducing system energy requirements. The Δp, therefore increased as the water level rose in the reactor.

Here, Δp was calculated using Eq. (1) as an approximation of the pressure head of mixed liquor over the membrane modules [19]:

$$\Delta p = (H - H_0) \times 9.80665 \quad (1)$$

where Δp is the transmembrane pressure (kPa), H is the surface level of the mixed liquor (m), H_0 is the level of the effluent outlet (m) and 9.80665 is a conversion factor (1 m of pressure head of water ≅ 0.1 kgf/cm^2 = 9.80665 kPa). The difference in densities between mixed liquor and pure water is neglected in this calculation. The available pressure in this system was accordingly confined to less than 0.46 kPa, equivalent

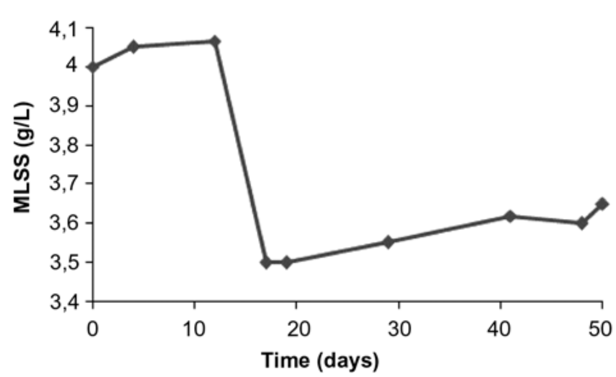

Fig. 5. Sludge concentration profile.

to a pressure head of 47 cm, corresponding to the maximum water level allowed by the reactor design.

The reactor was continuously operated for 50 days, and the membrane flux was periodically monitored. During the operation, a stable flux of 7 L/m^{2}h was observed at the highest Δp (Fig. 6). The authors of a previous study on treating greywater with a Kubota microfiltration membrane reported membrane flux values were higher than 16 L/m^{2}h [20]. The lower flux observed in our system was due to the operation at low Δp. Increasing the Δp applied is expected to increase the flux. The membrane flux was maintained for a long time without membrane cleaning (i.e. no physical or chemical washing of the membranes was employed) and the total amount of greywater effluent produced per day was as almost constant at 28 L.

3.4. Energy consumption

In MBR systems, energy consumption generally arises from power requirements for pumping feed water, recycling retentate, permeate suction (occasionally) and aeration [21]. In this work, permeate was withdrawn by gravity pressure, which did not require a pump; hence, the energy needs were mainly for aeration (the energy required for feeding the influent can be neglected). The average power consumption by the MBR reactor was 3.3 kWh per 1 m^3 of treated water (Fig. 7). Other studies have reported lower energy consumption (2.4 kWh) with higher pressure, when the permeate was withdrawn using an induced water level difference of 1.69 m [20]. Thus, the low Δp applied to our MBR reactor resulted in an increased energy consumption. In fact, the withdrawal of permeate must be coupled with aeration to prevent the depositing of sludge on the membrane. The rise in Δp induces an increase in permeate flux, then the aeration time reduces and also the energy demand decreases. However, it is known that high permeate flux can cause membrane clogging and directly increase energy consumption [22]. Therefore, methods to prevent membrane fouling and reduce energy consumption should be further investigated.

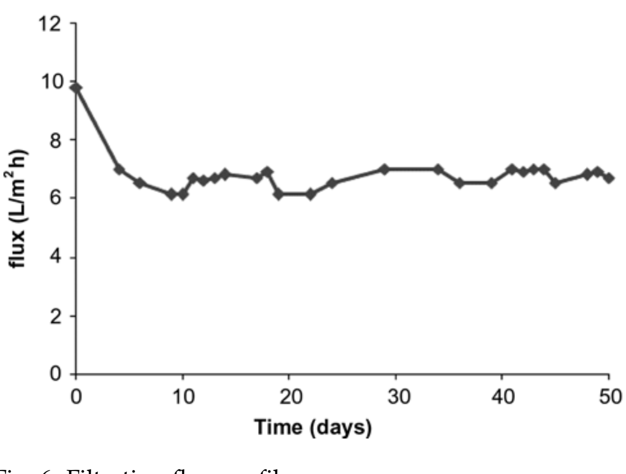

Fig. 6. Filtration flux profile.

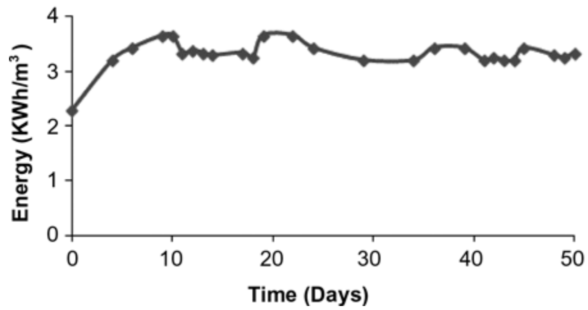

Fig. 7. Energy consumption profile.

4. Conclusions

The submerged MBR was feasible and effective in treating shower greywater. The quality of treated water indicated that the removal of organic matter and SS was quite successful. The nitrification of ammonia nitrogen to nitrate occurred and was not inhibited. A significant decrease in the AS was also observed. An effluent amount of 28 L/d was withdrawn by gravitational filtration at a flux has not exceeded a 7 L/m^{2}h.

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