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Grey water treatment by a continuous process of an electrocoagulation unit and a submerged membrane bioreactor system

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HIGHLIGHTS

- ▶ Electrocoagulation (EC) was integrated with submerged membrane bioreactor (SMBR) to treat grey water.
- ▶ The EC-SMBR process achieved up to 13% reduction in membrane fouling.
- ▶ High average percent removals were obtained for most wastewater parameters.

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ABSTRACT

This paper presents the performance of an integrated process consisting of an electro-coagulation (EC) unit and a submerged membrane bioreactor (SMBR) technology for grey water treatment. For comparison purposes, another SMBR process without electrocoagulation (EC) was operated in parallel with both processes operated under constant transmembrane pressure for 24 days in continuous operation mode. It was found that integrating EC process with SMBR (EC-SMBR) was not only an effective method for grey water treatment but also for improving the overall performance of the membrane filtration process. EC-SMBR process achieved up to 13% reduction in membrane fouling compared to SMBR without electrocoagulation. High average percent removals were attained by both processes for most wastewater parameters studied. The results demonstrated that EC-SMBR performance slightly exceeded that of SMBR for COD, turbidity, and colour. Both processes produced effluent free of suspended solids, and faecal coliforms were nearly (100%) removed in both processes. A substantial improvement was achieved in removal of phosphate in the EC-SMBR process. However, ammonia nitrogen was removed more effectively by the SMBR only. Accordingly, the electrolysis condition in the EC-SMBR process should be optimized so as not to impede biological treatment.

1. Introduction

Recent decades have witnessed a growing disparity between readily available sources of clean water and the growing demand associated with population growth and economic development. Water stress due to climate change and pollution from industrial processes and urbanization affects developed as well as developing countries. Therefore, a sustainable water management strategy requires that decision-makers recognize treated wastewater as a vital asset in the overall water resources budget instead of a waste medium for costly disposal. An evidence of movement in this direction is the increasing attention given to the utilization of grey water (GW) in wastewater reclamation and reuse projects [1,2].

However, GW should be treated effectively in order to ensure its safe and sustainable reuse. A wide range of physical [3,4], chemical [5,6] and biological [7–10] processes have been applied for grey water treatment and recycling. While physical–chemical processes can effectively remove suspended solids, organic materials and surfactants, they are not cost-effective for removing the full array of dissolved components in wastewater. Physical processes alone are not sufficient to guarantee an adequate reduction of dissolved organic or inorganic pollutants from grey water [1]. Aerobic biological processes in combination with physical or physical–chemical processes have been found to be efficient for grey water treatment. In this regard, membrane bioreactor (MBR) technology has exhibited promise as a very attractive method for grey water recycling specifically the submerged membrane bioreactor (SMBR) configuration [1].

The operational efficiency of SMBR processes, however, is still inhibited by the membrane fouling problem [11,12]. Therefore,

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further research and development is required to decrease membrane fouling to make the SMBR commercially competitive with other treatment processes. Various methods have been applied to reduce membrane fouling in SMBR technology. These can be grouped into the following distinct approaches: cleaning the membrane unit by backwashing [12]; optimizing process operating parameters [13]; developing a new configuration of membrane modules such as helical module [14]; applying ultrasonic technique [15]; modifying the characteristics of the activated sludge in the reactor by adding chemical coagulants such as alum and iron salts [16,17] or the addition of adsorptive materials such as powdered activated carbon [18,19] and zeolite [17].

Among the above approaches, improving the characteristics of the activated sludge in the bioreactor by adding chemical salts has exhibited potential for reducing the fouling in SMBR applications. However, the addition of chemicals to the wastewater may result in production of undesirable chemical by-products or increase the volume of sludge in the reactor [20]. Alternatively, applying direct current (DC) field on the activated sludge has been shown as a promising and novel approach in SMBR applications [21–25]. This approach can be implemented by integrating electrocoagulation (EC) technology in the same reactor with the SMBR [21,22] or using the membrane as a cathode [23,24]. However, applying a DC field directly in the activated sludge reactor may be harmful to microorganism activity [21,22]. An alternative strategy is to use the EC unit as a pre-treatment step before the SMBR system in order to prevent direct contact of the microbial community with the applied DC field. This latter alternative was utilized in this study; namely, an electrocoagulation unit served as pre-treatment to a SMBR to treat grey water with the two reactor systems in series in continuous flow mode (i.e. EC-SMBR process). Although the EC process has been applied as a sole treatment method for grey water [5], no previous research has been conducted on the integration of EC with SMBR process for grey water treatment. The main objective of this study is to compare the performance of the SMBR process for grey water treatment with and without integrating the EC process. In general, EC technique offers several advantages to chemical coagulation; namely, no chemical addition is required, alkalinity is not consumed, and the absence of coagulation agents results in less sludge production [26].

2. Materials and methods

2.1. Experimental set-up

A laboratory scale experimental set-up was used in this study (Fig. 1). Two SMBRs were operated in parallel with a working volume of 3.63 L each. The first was a stand-alone SMBR while the second was preceded by an electrocoagulation (EC) unit (1.43 L) where a direct current (DC) was applied on the grey water before entering the SMBR. Two electrodes (anode and cathode) made of aluminium sheets were used with a surface area of 158 cm^2 each. The distance between the electrodes was fixed at 5.8 cm. Electrodes were connected to a source of external DC power supply maintained constant at 12 V. The power supply was connected to a timer to regulate the intermittent DC at an operational mode of 15 min ON – 45 min OFF. Two hollow fibre, ultrafiltration (UF) membrane modules, ZeeWeed-1 (GE/Zenon Membrane Solutions, Canada) were used in this study. Each module consisted of 80 fibres with 0.2 m length and pore size of 0.04 μm with a total surface area of 0.047 m^2. The effluents from the membrane modules were withdrawn *via* two peristaltic pumps (E SERIES, Barnant Company, USA) operated at constant suction pressure. Level sensors were connected to the feed pumps *via* a level controller system to maintain constant volume in each bioreactor. Compressed air (4.2 L/min) was supplied through the air diffusers located at the bottom of each membrane module. The compressed air was used for different purposes: (i) to provide the required aeration in both processes (SMBR and EC-SMBR) for maintaining the required dissolved oxygen for the microorganisms, (ii) to create a shear stress for effective scouring of the membrane surfaces and (iii) to provide good mixing of the sludge suspension in the bioreactors.

2.2. Wastewater characteristics

Both bioreactors were fed with actual grey water which was collected from one of the facilities operations buildings on the campus of the American University in Cairo (AUC), Cairo, Egypt. The composition of the raw grey water varied according to the distribution of activities of building employees. The primary contributions to grey water at the site were from cleaning, sinks, and kitchen activities. Characteristics of the grey wastewater used in this study are given in Table 1. The sludge for inoculation was taken from the secondary clarifier in El-Jabal El-Asfar municipal wastewater treatment plant in Cairo. The sludge was acclimatized for 45 days prior to membrane filtration experiments.

2.3. Experimental procedure

The strategy of this study was to operate both systems (SMBR and EC-SMBR) at the same constant transmembrane pressure (TMP), which was achieved by withdrawing the respective effluents *via* separate peristaltic pumps operated at $\Delta P = 7.5$ kPa. Both processes were operated at room temperature in parallel for 24 days comprising four consecutive filtration–cleaning cycles. The fouling behaviour was evaluated phenomenalogically by measuring the decline of permeate flux with time. Subsequently, no backwashing of the membrane module was performed during the operation period. Each cycle was operated until the percentage reduction in membrane flux of the SMBR process exceeded 90%. Before starting each new cycle, and in order to restore most of the membrane's permeability, the membrane modules were removed from the bioreactors and physical and chemical cleaning were applied according to the protocol described by Meng et al. [27].

2.4. Analytical methods

Influent and effluents were sampled regularly and analyzed by Hach methods (Hach, DR 2000, USA) for COD, ammonia nitrogen (NH_3–N), nitrate nitrogen (NO_3–N), orthophosphate (PO_4^{3-}), anionic surfactants, total dissolved solids (TDS), conductivity, colour and turbidity. Total suspended solids (TSS), mixed liquor suspended solids (MLSS) and mixed liquor volatile suspended solids (MLVSS) were performed according to Standard Methods [28]. Total and faecal coliforms were determined by the membrane filtration procedure. The dissolved oxygen (DO) concentration was measured using a DO metre (SensIon 8, Hach, USA). The values of pH and temperature were measured using a pH metre model CG 842 (SCHOTT, Germany). Calibrations of pH and DO metres were conducted once a week before use. The average values presented in this study were calculated as an arithmetic mean of the collected data.

2.5. Short run experiment

In order to compare the fouling behaviour between EC-SMBR and SMBR processes, a short experiment was conducted at the same operating conditions performed in the long run cycles. The purpose of this experiment is to compare the impact of applying EC pre-treatment step on the variations of activated sludge