International Biodeterioration & Biodegradation 119 (2017) 552–564

Contents lists available at ScienceDirect

International Biodeterioration & Biodegradation

journal homepage: www.elsevier.com/locate/ibiod

Evaluation of a membrane bioreactor on dairy wastewater treatment and reuse in Uruguay

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ARTICLE INFO

Article history:
Received 11 July 2016
Received in revised form
21 November 2016
Accepted 21 November 2016
Available online 8 December 2016

Keywords:
Nutrients removal
Membrane bioreactor
Dairy industry
Wastewater treatment
Water reuse
Uruguay

ABSTRACT

Eutrophication episodes have been recently observed in the Santa Lucia river basin (SLRB) in Uruguay, the main drinking water source for approximately 60% of the Uruguayan population. The local environmental authorities have been strengthening the discharge standards for that particular river basin. There are several industries currently discharging their wastewater directly into the SLRB; some of these industries are required to upgrade their current wastewater treatment systems to comply with the new regulations. This study evaluated the performance of a membrane bioreactor (MBR) on dairy wastewater as a potential treatment technology for fulfilling the new discharge standards. A pilot MBR was placed at the dairy industry wastewater treatment system at two different locations: (i) receiving the wastewater from the industrial process after passing through a grease removal pond (high load stream); and (ii) receiving the wastewater after passing through the grease removal pond and an anaerobic pond (low load stream). The pilot MBR was operated at the following conditions for approximately four months: total sludge retention, hydraulic retention time (HRT) of 25 h, an average influent flow rate of 1.3 m^3 day^{-1}, and at two different average chemical oxygen demand (COD) influent concentrations: 1300 mg L^{-1} (high load stream) and 385 mg L^{-1} (low load stream). The average reported removal efficiencies on COD, biological oxygen demand (BOD), and ammonium (NH_4-N) were 94.1, 98.1, and 99.6%, respectively. In addition, it was observed that for a COD/N ratio above 10, total nitrogen (TN) and total phosphorous (TP) were well removed with average removal efficiencies of 93.1 and 91.0%, respectively. The MBR effluent met the new Uruguayan standards for discharging into the SLRB, and it can be further considered for water reuse at the industrial process. Moreover, a financial feasibility study was carried out for the implementation of a full scale MBR at the existing dairy facility. The results of the feasibility study suggested to accept the investment for the implementation of the MBR technology at the dairy industry. The results of the feasibility analysis considered the high impact of penalties and fines imposed by the local government to the industry when not complying with the effluent discharge standards, as well as the critical situation regarding eutrophication of the SLRB while being the most important source for drinking water in Uruguay.

1. Introduction

The SLRB is one of the most important sources of fresh water for human consumption in Uruguay providing drinking water to approximately 60% of the Uruguayan population. Approximately 400,000 m^3 day^{-1} of water are extracted from the SLRB to supply drinking water to the metropolitan area of Montevideo, the capital of Uruguay. The water quality of the SLRB has deteriorated by the uncontrolled discharge of nutrients to the basin; trophic conditions have been frequently observed (El País, 2015a). Several industries are located at the proximities of the SLRB including slaughterhouses, dairy processing plants, tanneries, fertilizer production industries, among others. A study conducted at several industrial wastewater treatment plants located at the SLRB concluded that most of the industries were not complying with the local standard

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http://dx.doi.org/10.1016/j.ibiod.2016.11.025
0964-8305/

(Decree 253/79 regulating the water code Law No: 14859) as follows: 86% of the industries were not complying with the NH_4-N effluent standard set at 5 mg L^{-1}, 71% were not to complying with the TP standard set at 5 mg L^{-1}, and 43% exceeded the BOD standard set at 60 mg L^{-1} (DINAMA, 2010).

The dairy sector is one of the main industrial activities in Uruguay. This sector has been continuously growing in terms of production capacity and exports during the last four decades. Approximately more than half of the total dairy industries in Uruguay are located in the proximity of the SLRB, and are currently discharging their wastewater into the SLRB. The dairy industry is considered among the food industries as one of the most polluting sectors (Andrade et al., 2013; Mendes et al., 2014). Dairy wastewater is characterized by a high content of BOD, COD, dissolved and suspended solids, fats and oils, and nutrients (Praneeth et al., 2014; Farizoglu and Uzuner, 2011). The dairy sector in Uruguay continuously discharges to the SLRB approximately 275 kg of BOD day^{-1}, 46 kg of TN day^{-1}, and 21 kg of TP day^{-1} (DINAMA, 2010).

Most of the dairy industries in Uruguay are provided with their own wastewater treatment system; commonly, natural wastewater treatment systems such as ponds and wetlands. Disadvantages of natural systems include the requirement of large surface area and low wastewater treatment removal efficiencies on organic matter and nutrients. Therefore, intensive and modern wastewater treatment systems must be considered for assuring that the effluent quality from these industries comply with the current legislation for discharging into water courses (Decree 253/79 - regulating the water code Law No: 14859).

The compliance with new standards introduces extra costs and challenges for the industrial sector (Sarkar et al., 2006); therefore, alternatives for recovering the investment are being explored such as promoting water reclamation (Bixio et al., 2006; Buntner et al., 2013). Water reclamation in the food processing sector, such as in the dairy sector, needs to be carefully analysed since there is a high risk of potential contamination of the dairy products with the treated wastewater. However, water reclamation may be feasible for supplying service water for cooling, heating, and/or cleaning of floors and external areas (Mendes et al., 2014). Several studies have been conducted evaluating the possibilities of water reclamation in the dairy sector by using membrane filtration processes (Balannec et al., 2002; Hoinkis et al., 2012; Melin et al., 2006). The production of high water quality by reverse osmosis systems has gained interest in the sector (Lawrence et al., 2003). However, the most commonly applied wastewater post-treatment or tertiary treatment processes nowadays for water reuse at the dairy industries consist of chlorination and UV disinfection and not membrane filtration processes (Chowdhury, 2014; Hai et al., 2014).

MBRs may be considered a feasible wastewater treatment technology for promoting water reclamation at the dairy industry. MBRs combine a biological wastewater treatment process (based on the activated sludge process) with a membrane filtration process (either micro or ultrafiltration). The conventional biological process aims at removing most of the biodegradable compounds in the wastewater, while the membrane filtration process performs a very effective solid/liquid separation of the treated water from the mixed liquor. Advantages of MBRs include: (i) the production of a clarified and largely disinfected treated effluent; (ii) the reduced footprint when compared with conventional wastewater treatment systems; and (iii) the possibility for reusing the treated wastewater. Major disadvantages of membrane processes include membrane fouling, and high capital and operational costs (Judd, 2011). As shown in the recent literature, MBR processes are versatile, promising, and they have been applied in different configurations for the treatment of wastewater containing a wide range of pollutants from different process industries (Cappello et al., 2016; Friha et al., 2016; Sun et al., 2016; Waheed et al., 2016).

The widespread application of large-scale MBRs is still limited compared to other conventional wastewater treatment systems (Frederickson, 2005). Moreover, despite the high potential for the application of MBRs for the treatment of dairy effluents, only a few technical studies have been reported on that subject (Andrade et al., 2013). Some of the main reasons limiting the broader implementation of advanced wastewater treatment technologies such as MBRs were described by Frederickson (2005) as follows: (i) the high required capital expenditures (CAPEX); (ii) the high operational costs (OPEX); and (iii) the minimization of risks adopted by conservative local governments. However, financial considerations are the main limitation for implementing modern technologies such as MBRs.

The main objective of this research was to evaluate the performance of a pilot scale MBR treating dairy wastewater at a dairy industry located at the proximities of the SLRB and to investigate the potential for water reuse. The specific objectives of the present study included: (i) the characterization of the influent dairy wastewater; (ii) the evaluation of the pilot MBR considering operational conditions as well as compliance of the treated effluent with the Uruguayan standards; and (iii) the evaluation of the water quality of the treated effluent for promoting water reclamation reducing the water consumption at the dairy industry. Moreover, a preliminary financial analysis was carried out discussing the financial viability for implementing a large-scale MBR system at the dairy industry.

2. Materials and methods

2.1. Experimental procedures

2.1.1. Location of the MBR pilot plant

The pilot MBR was placed at the industrial facilities of one of the largest dairy company in Uruguay. The dairy plant produces powdered milk (whole and skimmed), cheese whey powder (demineralised), butter whey, butter, caramel cream, and butter oil. The production process generates two different raw wastewater streams which are combined and treated together at the wastewater treatment system at the dairy industry: the powder effluent stream (1620 m^3 d^{-1}) and the butter effluent stream (350 m^3 d^{-1}).

The wastewater treatment system consists of the following treatment units: (i) grease removal ponds; (ii) anaerobic ponds; (iii) an intermittent aeration complete mixed reactor; (iv) a sedimentation pond; (v) polishing ponds; and (vi) wetlands. The MBR was evaluated at two different locations at the wastewater treatment system: (i) receiving the wastewater coming from the industrial process after passing through the grease removal pond (high load stream); and (ii) receiving the wastewater after passing through the grease removal and anaerobic ponds (low load stream). The MBR was evaluated at these two different locations to compare the performance of the MBR when treating a high load stream and a low load stream. When treating the high load stream the MBR can replace the entire existent wastewater treatment system; however, when treating the low load stream, the MBR can be used as a polishing treatment system for achieving the new challenging standards or for water reclamation.

2.1.2. Description of the MBR pilot plant

A submerged MBR pilot plant was built by the company Almeseko (Rijeka, Croatia). The MBR was provided with two ultrafiltration tubular membrane modules (MEMOS, Germany) vertically arranged with an average pore size of 0.04 μm and a total filtration area of 6.6 m^2. The direction of the flow was from the outer to the inner surface of the tubular elements. The tubular individual