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Estimating design parameters for sustainable operation of a membrane bioreactor treating s-triazine herbicide

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ABSTRACT

An Ametryn (an s-triazine herbicide) fed laboratory-scale membrane bioreactor (MBR) was studied for 214 days under sub-tropical conditions (20–22 °C) for evaluating its treatment/operating performance and to consolidate the previous findings and establish the design parameters. Ten short-term critical flux tests were carried out at different stages of the study and the Critical Flux Values (CFV) varied from 6 to 33 L/m^{2}h for the experiments carried out under intermittent suction mode. Two numerical models were used to estimate the "*critical times*", which is useful to establish the chemical cleaning frequency of membrane modules and to assess the key kinetic parameters required to design a pilot/full scale MBR. The study also confirmed the overall fluctuation of the components of polymeric substances (proteins and carbohydrates of extra-cellular polymeric substances (EPS) and soluble microbial products (SMP)) in the MBR due to the addition of different concentrations of Ametryn (0–4 mg/L).

1. Introduction

Diuron, Atrazine, Ametryn Hexazinone,Tebuthiuron, and Metolachlor are the common types of herbicides used in farmlands in Queensland, Australia. Ametryn is a second-generation sulphur containing triazine herbicide which is used to control pre and post emergence of broadleaf and grass weeds in farmlands planted mainly with maize, pineapple, popcorn and sugarcane (Gao et al., 2009). As stated in Navaratna et al. (2010), Ametryn is commonly used in sugarcane farmlands located in Great Barrier Reef (GBR) catchment in Queensland, Australia. The environmental protection agency (EPA) classifies Ametryn as a Class III herbicide (slightly toxic as per the classification of World Health Organisation (WHO)) and it is moderately toxic to fish, large mammals and humans, but highly toxic to crustaceans and molluscs (Gao et al., 2009). Ametryn and its metabolites could be found in drinking water sources from run off to streams or leaching to ground water and they are persistent in the food chain/environment and toxic, which may cause chronic illnesses to humans and other life forms (Navaratna et al., 2010).

Herbicide and pesticide contaminated surface water is mainly discharged from the agricultural lands during wet season, and at the same time a significant amount of herbicide and pesticide residues are discharged unintentionally in to the environment through the existing wastewater treatment plants all over the world., In Switzerland, 75% of the herbicide/pesticide load that is entering the surface waters is through the existing wastewater treatment plants (Gerecke et al., 2002). Conventional treatment plants together with activated sludge process have shown poor and incomplete removal of micropollutants including pesticides and herbicides residues in wastewater (Luo et al., 2015). However, membrane bioreactor (MBR) technology, which is invented in early 90's, has been researched extensively for the past two decades for improving its performance in treating a wide spectrum of wastewater discharged from domestic and commercial/industrial waste generators. A recent study (Karray et al., 2016) found that MBR inoculated with four strains of microorganisms has demonstrated an excellent treatment performance of wastewater containing anionic surfactants. Although MBRs alone have shown superior treatment and operational performance than activated sludge processes (ASPs) for many effluents, MBR systems exhibited much higher efficiency and complete treatment when they combined with other advanced technologies such as moving bed biofilm reactor (MBBR) (Luo et al., 2015), ultraviolet (UV) treatment and granular activated carbon (GAC) filtration (Navaratna et al., 2012a), powdered activated carbon (PAC) and MBR (Zhang et al., 2015),

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Nomenclature

EPS	eEPS concentrations in the bioreactor (g/L)
EPS_e	effluent eEPS concentrations (g/L)
EPS_i	influent eEPS concentrations (g/L)
g	the constant of gravity (9.81 m/s^2)
J	flux through the membrane (m/d)
k_{dm}	detachment rate of eEPS (day^{-1})
k_{dp}	decay rate of eEPS (day^{-1})
k_{dx}	death (endogenous decay) rate of MLSS (day^{-1})
k_α	rate constant concerning the consolidation process (day^{-1})
m	eEPS density on the membrane surface (kg/m^2)
m_0	initial eEPS density on membrane (kg/m^2)
P	trans-membrane pressure -TMP (Pa)
p	eEPS concentration in MBR mixed liquor (g/L)
Q_e	effluent (permeate) flow rate (L/day)
Q_i	influent (organic feed) flow rate (L/day)
Q_w	sludge waste flow rate (L/day)
R	the total filtration resistance (m^{-1})
R_d	MLSS decay rate (g/L/day)
R_g	MLSS growth rate (g/L/day)
R_m	membrane resistance (/m)
S_e	effluent COD concentrations (g/L)
S_i	influent COD concentrations (g/L)
t	time (day)
V	hydraulic volume of the bioreactor (L)
x	MLSS concentration in the bioreactor (g/L)
x_e	effluent MLSS concentrations (g/L)
x_i	Influent MLSS concentration (g/L)
x_{stdy}	steady state MLSS concentration (g/L)
x_w	waste MLSS concentration (g/L)
Y	MLSS yield due to influent COD (g-MLSS/g-COD)
Y_0	observed biomass yield (g-MLSS/g-COD)

Greek letters

α	specific resistance of EPS (m/kg)
α_o	specific resistance of EPS at $P = 0$ (m/kg)
α_p	constant (m/kg/Pa)
$\alpha_\propto$	the ultimate value of α (m/kg)
β	the ratio of produced EPS to increased MLSS (g-EPS/g-MLSS)
γ	constant (day^{-1} Pa^{-1})
δ	thickness of EPS biofilm on the membrane (m)
λ_m	static friction coefficient (–)
μ	viscosity of permeate (Pa s)
μ_s	specific MLSS growth rate (day^{-1})
ρ_g	density of air (kg/m^3)
ρ_{ML}	density of MBR mixed liquor (kg/m^3)
ρ_w	density of water (kg/m^3)
τ_m	shear stress (Pa)

anoxic/anaerobic pre-treatment (Qiu et al., 2013) and advanced membrane systems; forward osmosis (FO) and reverse osmosis (RO) (Wang et al., 2014). Although a series of extensive studies carried out during the past two decades, the research interest in MBRs has not declined and further research work is continued to prevent operational and treatment issues under extreme conditions.

The MBR study was conducted in two episodes as follows: Episode #1–550 days of continuous operation under tropical conditions in Queensland and Episode #2 (*current study*) - 214 days of continuous operation under sub-tropical conditions in Geelong, Victoria. In addition to the temperature difference in two locations, there was a significant dissimilarity in MBR mixed liquor conditions. In Episode #2 operation, a significant amount of oligochaete worms (Navaratna et al., 2014) were present in MBR mixed liquor and this condition led to maintain a lower mixed liquor suspended solids (MLSS) concentrations and higher fouling rates. This article describes the findings and results obtained during the Episode #2 of the study. Practical applications of two mathematical models relating to the fouling of membrane are also described in this article.

2. Materials and methods

2.1. Experimental setup

A laboratory-scale MBR was installed and operated to study the performance of the system. MBR consists of a 40 L feed tank and a 13 L bioreactor. Activated sludge (approximately 6000 mg/L) was collected from the Anglesea Wastewater Treatment Plant in Geelong to acclimatise the bioreactor and a hollow fibre polyethylene (PE) membrane module (pore size 0.4 μm, effective area 0.2 m^2) was immersed in the MBR reactor. Feed recipe stated in Navaratna and Jegatheesan (2011) was used to prepare synthetic wastewater and fed to the MBR through the feed tank. Ametryn stock solution (160 mg/L) was made (Navaratna et al., 2012a) and mixed with synthetic wastewater to obtain the required concentrations (1–4 mg/L). COD concentration of synthetic feed wastewater was maintained around 800 ± 100 mg/L.

The upper limit of the trans-membrane pressure (TMP) in the MBR was restricted to 20 kPa and the membrane module was cleaned chemically using 3 g/L of NaOCl solution, when the TMP reached to its maximum level (60 kPa), as stated by the manufacturer. Compressed air was supplied through a perforated manifold at a rate of 10 L/min (for a hydraulic volume of 13 L) to maintain the dissolved oxygen (DO) concentration around 3.5 ± 1.0 mg/L in the MBR. MBR sludge was not wasted intentionally to provide a sound environment for slow growing bacterial communities which were important for the biodegradation of persistent micropollutants. However, small amounts of MBR sludge were collected weekly for experiments and by considering this sludge removal, the average sludge retention time (SRT) was estimated as 180 days.

It was found that the composition of microorganisms of MBR sludge was different in sub-tropical operating conditions probably due to the change of the environmental conditions in the new location. It was seen that the fouling of membrane of the MBR system behaved differently and filamentous bacteria and oligochaete worms appeared at different times during this operation. Hence, in most cases, the flow rate (membrane flux) could not be increased due to poor filterability of mixed liquor. In this case, HRT was maintained at 15.6 h and MBR was setup to operate at a uniform flow rate of 20 L/day with intermittent suction (12 min ON and 3 min OFF) of feed wastewater. In order to control frequent fouling of membrane, chemical cleaning and/or physical cleaning with a small brush and hands (with gloves) was carried out as required.

2.2. Experimental methods

This hybrid MBR system was operated continuously at different