Separation and Purification Technology 187 (2017) 102–109

Contents lists available at ScienceDirect

Separation and Purification Technology

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

Impact of the pulsed voltage input and the electrode spacing on the enhancement of the permeate flux in a dielectrophoresis based anti-fouling system for a submerged membrane bioreactor

B. Larbi [a], A.H. Hawari [a,*], F.Du [b], M. Baune [b], J. Thöming [b]

[a] Department of Civil and Architectural Engineering, College of Engineering, Qatar University, 2713 Doha, Qatar
[b] Center for Environmental Research and Sustainable Technology, University of Bremen, Leobener Str., D 28359 Bremen, Germany

ARTICLE INFO

Article history:
Received 30 December 2016
Received in revised form 13 May 2017
Accepted 16 June 2017
Available online 19 June 2017

Keywords:
MBRs
Fouling suppression
Dielectrophoresis
Interdigitated electrode configuration

ABSTRACT

A new electrode configuration based on dielectrophoresis (DEP) for a Submerged Membrane Bioreactors was suggested. The intensification of the permeate flux with the new system was examined experimentally using a pulsed DEP of 10 s on and 15 s off.

In comparison with the test without DEP effect, the normalized permeate is 3.5; 3.9 and 4.5 times higher when applying 105 V_{eff}, 144 V_{eff}, and 220 V_{eff} respectively. The membrane working time is found to be 10 times higher when using DEP. The impact of electrodes spacing was also examined experimentally and numerically. It was demonstrated that a large electrodes spacing is not able to intensify the permeate flux, but it could increase the membrane lifespan by stabilising the permeate flux.

1. Introduction

The application of Membrane Bioreactors (MBR) in wastewater treatment has expanded promptly over the past years. In fact, this technique offers many advantages in comparison to the conventional activated sludge process such as higher effluent quality, small space requirement, lower energy consumption and less sludge production [1–3]. Nevertheless, it presents some shortcomings such as membrane fouling. Solving such a problem would undoubtedly result in a widespread use of MBRs and a reduction of its operational cost.

In MBRs, membrane fouling is mainly caused by membrane pore obstruction and sludge cake deposition on the membrane surface [4–6]. It results in an unstable permeate flux or an increase in the transmembrane pressure depending on the operation mode. This fouling problem has been the focus of many researchers. Recent advances have proved that the use of electrokinetic techniques is effective in fouling reduction and permeate flux enhancement. The filtration operation would not be interrupted for membrane cleaning, which is the case in conventional methods such as back-pulsing and flushing techniques. However, more interest has been focused on the electrophoresis (EP) to reduce fouling [7–11]. This method is well adapted to reduce fouling problems associated with charged particles and colloids [12], but, the ion-complexity of feed suspensions inhibits the use of the electrophoresis in many cases [13]. Moreover, the application of direct current and bare electrodes required by EP result in electrochemical reactions, causing pH modifications or even the production of toxic by-products, and increases the risk of short circuit and human electric shock [14]. Electrophoresis-based methods were usually associated with the application of a direct current (DC) field which induces high energy consumption.

Du et al. [15] were one of the first to experimentally examine a lab scaled dielectrophoretic (DEP) cross-flow membrane filtration process. The inhomogeneity of the electric field was achieved using a bare grid electrode as a membrane supporter and an insulated plate electrode on the opposite side. An optimized pulsed DEP with an applied electric field of 160 V_{eff} (AC), and 200 kHz showed a membrane working time 3.3 longer to have a 50% permeate flux of the initial one (470 mL/(min m^2)) and an energy consumption of 31.3 kJ. With this DEP based method, nearly all the particles in suspension can be prevented from depositing on the membrane surface no matter whether they are charged or uncharged. Moreover, the DEP force is found to be more dependent upon the electric field gradient than the voltage applied. When the applied voltages in DEP and EP systems are identical, the dielectrophoretic motion of particle presents much higher speed than electrophoretic movement [16].

Other systems using dielectrophoresis were developed and tested [17,18]. Details of electrode configuration and operational conditions are summarized in Table 1. It has been demonstrated

* Corresponding author.
E-mail address: a.hawari@qu.edu.qa (A.H. Hawari).

http://dx.doi.org/10.1016/j.seppur.2017.06.045
1383-5866/

that high voltage electric field is effective in fouling reduction, but the Joule heating effects and the energy consumption involved are also high. In fact, the joule heating generated by the high electric field strength, always applied in DEP systems, forms temperature gradients due to the energy friction on the medium and drives the fluid to flow. This fluid flow caused by Joule heating and termed to be electrothermal effect does influence particles motion when it is dominant compared to the DEP.

One possible way of reducing these side effects is to apply the electric field more efficiently using better configuration of electrodes and membrane module in MBR, or maintaining an effective electrostatic repulsion force against sludge foulants on the membrane surface.

In the present study, we propose an anti-fouling fouling solution for the case of submerged membrane bioreactor (MBRs). This system is based on the application of alternating current (AC) dielectrophoretic (DEP) force in an inhomogeneous electrical field. An electrode configuration is developed to generate the AC DEP forces.

Compared to the preceding studies [15,17,18], the proposed system is based on a cartridge model of a real MBRs plant. This cartridge permits a higher permeate flux with its two membrane sides and reduces the Joule heating effect within the MBR tank unlike the module proposed previously [18] where only one membrane side is considered. Moreover, the filtration area is almost four times bigger in this study. The cartridge is slightly modified to integer the electrode configuration. The electrodes insulation layer is reduced to the nanometer scale comparing to the micrometer scale in the previous studies so to decrease the high pass filter effect and increase the DEP force for the same voltage input. Shorter pulsation duration is also tested.

The main intention of this paper is to demonstrate the efficiency of the suggested solution on the enhancement of the permeate flux and to study the impact of the voltage input and the spacing between the cylindrical electrodes on the electric field gradient and so DEP force. The findings of this work would help optimizing the electrodes configuration for more energy savings.

2. Materials and methods

2.1. Numerical simulation

2.1.1. Dielectrophoresis model

Dielectrophoresis was first defined by Pohl [19] as the motion of neutral particle caused by dielectric polarization in an inhomogeneous electric field. With the polarization of particle in an electric field, a dipole moment is induced in the particle and is expressed as two equal but opposite charges at the particle boundary [20]. However, when the charges are not uniformly distributed on the particle surface, a macroscopic dipole will be created. If the electric field is inhomogeneous, the local electric field and resulting force on both sides of the particle are different; hence a net force arises termed as dielectrophoretic force F_{DEP}.

For a homogeneous sphere of a radius 'a' in a medium with a permittivity ε_m, the DEP force can be calculated as shown in Eq. (1):

$$F_{DEP} = 2\pi a^3 \varepsilon_0 \varepsilon_m Re(\tilde{K}) \nabla |E|^2 \quad (1)$$

where $\nabla|E|^2$ is the electric field gradient squared (EFG), Re $(\tilde{K})$ is the real part of the Clausius-Mossotti $(\tilde{K})$ factor, ε_0 is the permittivity of free space with the value of 8.854×10^{-12} F/m and ε_m is the permittivity of the medium. The Clausius-Mossotti factor describes the frequency dependence of the effective dielectric polarizability of the particle in suspension. It is expressed as in the following Eq. (2).

$$\tilde{K} = \frac{\tilde{\varepsilon}_p - \tilde{\varepsilon}_m}{\tilde{\varepsilon}_p + 2\tilde{\varepsilon}_m} \quad (2)$$

where, $(\tilde{\varepsilon}_p)$ and $(\tilde{\varepsilon}_m)$, are complex permittivity of the particle and the suspension medium respectively. The calculation of the complex permittivity $(\tilde{\varepsilon})$ is given as:

$$\tilde{\varepsilon} = \varepsilon - \frac{j\sigma}{\omega} \quad (3)$$

ε is the dielectric constant and σ (S/m) is the conductivity, ω (rad/s) is the angular frequency of the applied electric field E, $\omega = 2\pi f$ in which f (Hz) is the frequency, and $j = \sqrt{-1}$.

The direction of particle movement depends on the sign of the Clausius-Mossotti factor $\tilde{K}$, which in turn depends on the frequency. In a certain electric field, with a certain frequency, when the permittivity of particle is higher than that of suspending medium, the direction of dielectrophortic force of the particle will be along the direction of the electric field gradient, which directs from lower electric field to higher electric field. In this case, the particle is trended to be moved towards higher electric field region, presenting positive DEP effect (pDEP). Inversely, when the real part of Clausius-Mossotti factor is negative, i.e. the permittivity of particle is lower than that of suspending medium, the dielectrophortic force directs oppositely to the direction of electric field gradient, which is from higher electric field to lower electric field. Therefore, the dielectrophoretic force can move the particle towards the lower electric field region, presenting negative DEP effect (nDEP).

Table 1
Summary of developed systems that applied dielectrophoresis.

Reference		[15]	[17]	[18]
Electrodes configuration	Type	Bare grid electrode and a stainless steel plate insulated with plastic film of 0.25 mm thick	Interdigitated cylindrical electrodes (IDE)	IDE: electrodes of 2 mm diameter coated with 2 μm insulation (TiO_2)
	Electrodes spacing	1 mm	1 mm	2 mm
	Length	Filtration area 28 cm^2	Filtration area 30.16 cm^2	5 cm
Voltage input		200 V_{rms}	200 V_{eff}	60–160 V
Generated electric field		160 V/mm AC	–	–
Frequency		200 kHz	200 kHz	50–1000 Hz
The medium		Clay in a demineralized water, particle suspension of 5 g/L	Clay + demineralized water particle suspension of 5 g/L. Particle size between 100 et 3000 nm	Real sample of biomass. Biomass concentration is 10 g/L
Pulse duration		Continuous and pulsed DEP 10–10 min 5–15 min	Continuous and pulsed DEP 5–15 min	–
Feed velocity		40 L/min m^2	12 mL/min	–
Transmembrane pressure		–	–	0.8 bar
Electrothermal effect		Temperature rised by 11 °C	3 K/h	Above 130 V and 1 kHz high electrothermal effect
Energy consumption		31.3 kJ	2.5 W	53 W at 1000 Hz