Assessment of the Effect of Dielectrophoresis (DEP) on the Viability of Activated Sludge Biomass

B. Larbi, A. Ltaief, A. Hawari, F. Du, M. Baune, and J. Thöming

***Abstract*—Effective application of dielectrophoretic forces in membrane bioreactor (MBR) systems has the potential to suppress membrane fouling. Nevertheless, minimizing the impact of the electric field on biomass suspension is essential to maintain the efficiency of the wastewater treatment process. In this study, interdigitated cylindrical electrodes (IDE), placed inside the membrane module, were used to generate dielectrophoresis (DEP) in an MBR system. The viability of the biomass was determined at different voltages (5-150 V) after 1-hour exposure to a pulsed alternating current (AC) electric field. The results of the behavioral response of the microorganisms revealed that at low voltage applications, the bacteria exhibited good performance and no major impact was found on their viability/metabolism. Whereas at high voltage applications (beyond 100 V), the current intensity and medium temperature increased due to the joule heating effect and caused a significant decline in the bacterial activity and pollutant removal efficiency as a result of bacterial lysis.**

***Index Terms*—Bacterial lysis, dielectrophoresis, interdigitated cylindrical electrodes, microorganisms, membrane bioreactor.**

I. Introduction

Membrane Bioreactors (MBRs) have recently gained wide utilization in the treatment of wastewater. They are well known for their ease of operation and enhanced effluent quality. Membrane fouling remains a significant issue in MBRs that reduces the filtration performance and increases the operational costs, as it becomes more necessary to clean or replace the fouled membranes. Many methods have been proposed to alleviate this issue among which the application of an electric field using electrophoresis (EP). It was demonstrated that the applied electric field of high voltages inside the bioreactor has the potential to repel particles away from the membrane [1]–[3]. Yet, it has been reported that different voltage strengths will have different effects on the microorganisms [4]–[7].

Many studies have focused on the use of electrophoresis, this is usually associated with the assumption that the bioparticles are negatively charged, however the feed suspension complexity inhibits the use of such an assumption [8], [9]. In addition, direct current (DC) electric field is often used to generate EP which induces higher energy consumption. Recently, Dielectrophoresis (DEP) has been applied successfully in a MBR to control fouling. This technique involves inducing a non-uniform electric field that creates a dielectric polarization on the particles and causes their translational motion [10]. DEP has gained wide utilization in many nanoscale biological applications. In the wastewater industry, it was used by Du *et al*. and Hawari *et al*., [9], [11] to suppress fouling in membrane treatment processes. Upon the application of dielectrophoretic forces to wastewater, a net repulsive force is created that causes the migration of particles away from the membrane as a result of the differences in permittivity between the medium and bioparticles. In their study, Du *et al*., successfully increased the permeate flux by 50%. Then, they further enhanced the permeate flux by 68% [12]. The same research group [11] demonstrated later that a stronger electric field induces stronger DEP forces on the particles that alleviate fouling more effectively and result in a better permeate flux. On the other hand, they found that stronger electric fields are associated with joule heating. This effect creates temperature gradients that introduce buoyancy forces and affect the particle's motion which may reduce the fouling suppression effectiveness in specific conditions.

Yet the influence of such a process on the biomass viability has not been studied. Therefore, the aim of this research is to study the effect of pulsed DEP electric field and joule heating on microorganisms of the activated sludge. The dielectrophoretic forces will be generated by interdigitated electrodes placed below the membrane, through which a low frequency (50 Hz) alternating current (AC) will be applied intermittently at different voltages ranging from (5, 25, 50, 100, and 150 V). Bacteria viability will be determined through quantitative analysis on its physiological changes.

II. Materials and Method

A. MBR System

A 4 L bioreactor was used for this study, into which a Chlorinated Polyethylene (CPE) membrane module was submerged (Fig. 1a). An array of interdigitated electrodes was integrated inside the membrane module as shown in Fig. 1b. The electrodes were coated with a thin titanium dioxide layer to insulate them from electrochemical corrosion on their surface and to protect from the risk of human electric shock. The membrane module was kept submerged throughout the experiment by controlling the water level. And a magnetic stirrer was used to ensure complete

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homogeneity in the bioreactor. Activated sludge from a local wastewater treatment plant was used within 48 hrs. of its extraction and was supplied continuously with appropriate aeration. The medium temperature, pH, and conductivity were monitored throughout the experiment using WTW Multi3430 multiparameter meter.

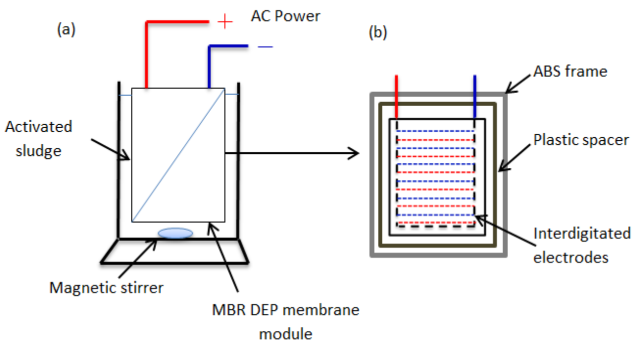

Fig. 1. Schematic diagram for the MBR system (a), cross sectional diagram for the membrane module (b).

B. *Methodology*

The membrane module was connected to an AC power supply. The applied voltages were set to 5, 25, 50, 100, and 150V at 50 Hz, and applied intermittently for 1 hour; with 10 s of electric field on and 15 s of the electric field off.

The physiological changes of the sludge upon DEP application at different voltages was determined through analyzing for the total organic carbon (TOC), Ammonium concentration [NH_4^+] and oxygen uptake rate (OUR).

The TOC was obtained by filtering the withdrawn sample through a 1.5 µm glass microfiber filter, and the filtrate was used to determine the TOC using the Aurora 1030W TOC Analyser.

The Ammonium concentration was obtained in duplicates using the Nesslerization method: Anhydrous Ammonium Chloride solution was initially used to calibrate the Orion AquaMate UV-VIS Spectrophotometer at a wavelength of 425 nm, then [NH_4^+] of the samples was obtained after Nesslerization of the filtrate.

To obtain the oxygen uptake rate, the following standard method was applied [13] a 200 ml of the biological suspension was withdrawn from the MBR at the end of each voltage application in which a Dissolved oxygen (DO) probe is inserted. The sample was stirred continuously to avoid sludge settling and tightly sealed to isolate the contents from the external oxygen. DO concentrations were recorded over a 10 minute period. The slope of DO-time represents the oxygen uptake rate in mg O_2 /L.min.

III. Results and Discussion

A. *Effect of DEP on the Medium Parameters*

The temperature change and the electric current inside the bioreactor were monitored during the course of the experiments and are displayed in Fig. 2a and b, respectively. At low voltage applications of 5 V, 25 V and 50 V, the temperature change was almost negligible (±2 ℃). However, the temperature was found to increase significantly at high voltage applications to values beyond the optimum temperature (31 ℃) for the biological reactions of the studied mesophilic microorganisms [14]. At 100 V the temperature rose by 47% reaching 41.3 ℃ at the end of the test. At 150 V the temperature rose by 123% reaching 67.4 ℃ after 50 minutes of pulsed DEP application after which the test had to be stopped for safety.

Similarly, the electric current was affected by the same degree; at low voltage applications, the current increase was insignificant whereas at 100 V and 150 V the electric current reached 2.33 A and 6 A respectively at the end of the test. This sudden change in temperature and current intensity at high voltage applications are speculated to be caused by the electrothermal effect as a result of joule heating. The highly conductive medium, wastewater in this case, along with the high electric field mutually caused the increase in the electric current. Consequently, producing heat that spread through the medium. On the other hand, the measured conductivity and the pH of the medium were invariant throughout the tests.

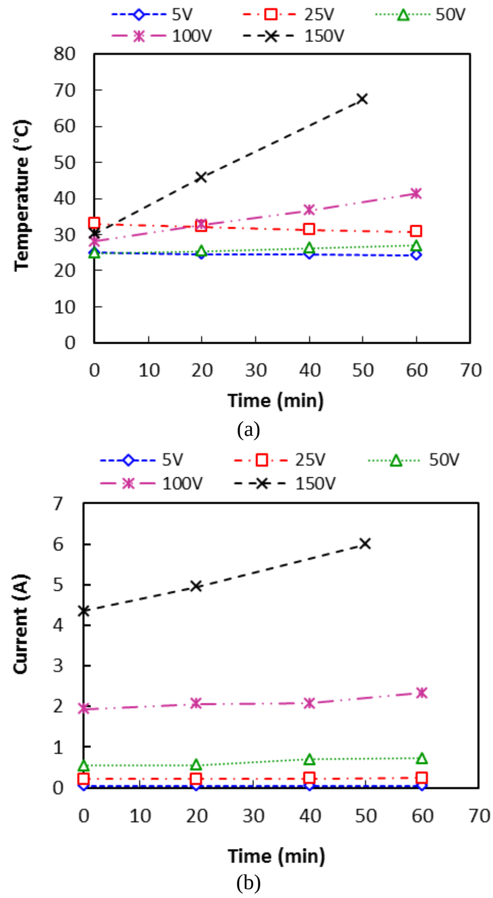

Fig. 2. Temperature (a) and electric current (b) change inside the MBR.

B. *Effect of DEP on the Medium Parameters*

According to the experimental results in Fig. 3a, one can conclude that successful TOC removal after 1 hour of pulsed DEP induction was obtained at low voltages. For instance, the TOC was removed by 39.1% when 25 V of pulsed DEP was applied. Similarly, Ammonium removal by the nitrifying bacteria has also been successful at these low voltages with high efficiency. Fig. 3b shows the decline in ammonium concentration at the end of the test for the 25 V and 50 V. These results explain that at low voltage applications the bacterial activity is enhanced through an increase in substrate metabolism. Indeed, these results agree with many studies conducted at low voltages using electrophoretic forces [6], [7].

Yet, at high voltage applications of 100 V the TOC removal decreased to 20.2%. More importantly, after 50 minutes of 150 V application TOC concentration increased by 121.9%. This increase in TOC at high voltage applications suggests an increase in the soluble microbial products (SMP). These are intracellular organic components that get released out from the microorganisms as a result of cell wall perforations. In addition, the increase in TOC can also be explained by an increase in the extracellular polymeric substances (EPS) namely polysaccharides and proteins; the EPS are believed to act as the glue that binds cells together and result in their bio-flocculation [2], [3].

Likewise, the ammonium concentration in the bulk solution has obviously increased rapidly at high voltage applications which can be due to the denaturation of the proteins releasing more ammonium ions into the bulk.

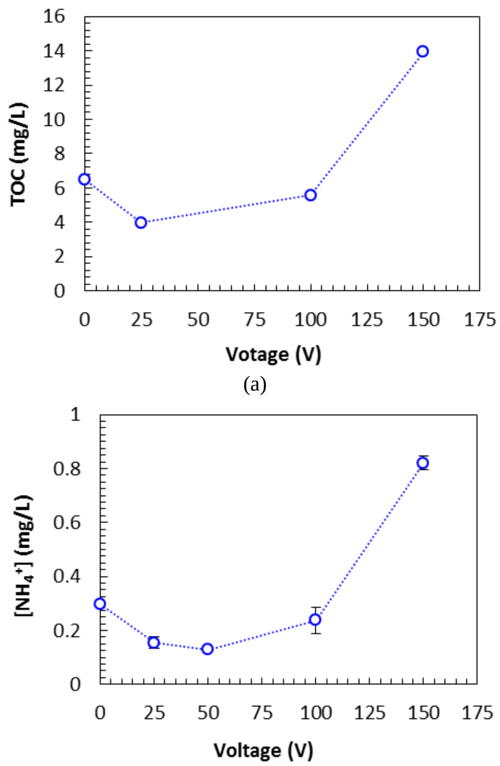

Fig. 3. TOC (a) and Ammonium concentration (b) after 60 minutes of different voltage strength applications.

With the application of high electric fields in a highly conductive medium, the joule heating effect is inevitable and caused the electric currents to increase above 2 A. The high current intensity could have potentially caused bacterial lysis and stimulated the production of SMP, EPS, and ammonium in the bulk. Previous study on the effect of DC-electrophoretic forces [4] also found that above a current intensity of 2 A the bacteria destruction rate increases, due to the formation of nanoscale defects at the membrane wall causing the cytoplasmic contents to escape. The joule heating effect has also inhibited the metabolism of the mesophilic microorganisms including the nitrifying bacteria by the rise in fluid temperature to values beyond 39 ℃ [14] that caused protein denaturation.

The microbial community inside the bioreactor was assessed by determining the oxygen uptake rate at the end of the experiment for each voltage application as shown in Fig. 4. Remarkably, the OUR trend decreases with the voltage strength. For instance, at the end of the test, the OUR dropped by 28% for the 25 V application whereas it dropped by 79.7% when 150 V is supplied. The significant reduction in OUR at high voltage applications further explain the reduction in microbial activity of the cells in the medium as a result of bacterial lysis.

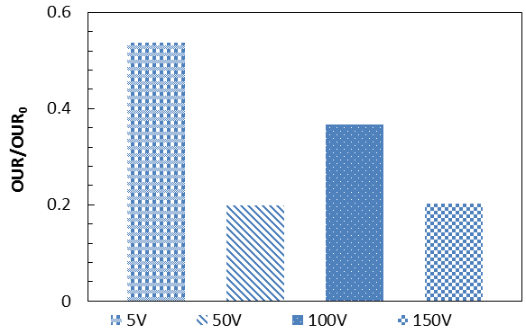

Fig. 4. Measured oxygen uptake rate after 60 min of different voltage strength applications.

IV. Conclusion

Despite the effectiveness of strong electric fields at generating high DEP forces to suppress membrane fouling and enhance the permeate flux, it was demonstrated from this study that high voltage applications are associated with the joule heating effect. This caused the generation of high current intensities that in return increased the medium temperature to values beyond the optimal temperature for the studied bacterial viability, eventually resulting in cell wall destruction and bacterial lysis. More research work on bacteria viability will be performed in future studies through extending the DEP force duration and measuring additional parameters for verification. This will, in expectation, enable us to determine the optimum working conditions for the DEP MBR system to control fouling while preserving the microbial community.

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