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Effect of operating parameters on the performance of sediment microbial fuel cell treating aquaculture water

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ABSTRACT

While performing *in situ* water quality remediation of aquaculture water using sediment microbial fuel cell, the present study provides effect of operating pH, distance between electrodes, and external resistance on organic matter and nitrogen removal as well as on power generation. Chemical oxygen demand (COD) removal was observed to be directly proportional to the distance between electrodes and inversely proportional to the influent pH as well as external resistance. However, total nitrogen (TN) removal increased with increase in pH and distance between electrodes; whereas it decreased with increase in external resistance. Power production reduced with decrease in pH, but increased with decrease in external resistance and distance between electrodes. Two factor and three factor interactions were observed to be less significant for COD, TN removal and power density. From the statistical correlation among these parameters, feed pH of 7.6–8.5, distance between electrode of 90–100 cm and external resistance of 0–52 Ω were found to be optimum for achieving optimal COD removal, TN removal and power density. Validation of model predictions for treatment of aquaculture water conceded that the SMFC exhibited acceptable COD and TN removal efficiencies which in turn facilitate its use for *in situ* aquaculture water remediation effectively.

1. Introduction

Due to the increase in per capita consumption of fish products, the aquaculture industry is moving toward more intensive practices. Except for cold water fish production and mollusks culture, probably more than 90% of aquaculture production comes from aquaculture ponds (Boyd and Tucker, 1998). Intensive practice leads to the deterioration of water quality as well as sediment in ponds. Removal of nitrogenous compounds is crucial for aquaculture water remediation for potential reuse of the water and to enhance fish yield. The current practices for pond aquaculture water treatment are artificial wetland treatment, earthen treatment ponds, and water exchange. Construction of artificial wetlands and earthen treatment ponds outside intensive fish production ponds are not reasonable for small farm holders due to high expenses on land. Also, earthen treatment ponds have the drawbacks such as requirement of periodic aeration at the pond sediment and the unpredictable phytoplankton biomass growth and deposition of dead cells at pond bottom, which undergoes subsequent decomposition (Crab et al., 2007). In water exchange method (Masser et al., 1999), the accumulation of nitrate in aquaculture pond is prevented by replacing 5–10% volume of system water with freshwater. All three treatments mentioned above need power for pumping which makes them uneconomical. This is pointing toward the need for a method which is economical as well as environment friendly.

Employment of sediment microbial fuel cell (SMFC) offers simultaneous *in situ* treatment of aquaculture water and organic matter present in the sediment while generating electricity (Sajana et al., 2013b). Benthic microbial fuel cells (BMFCs) or SMFCs generate electricity from the electro-potential difference between oxic water and anoxic sediments. The performance of SMFC is affected by many factors, such as electrode materials (Scott et al., 2008a, 2008b), distance between the electrodes (Liu et al., 2005; Hong et al., 2009a), pH (Behera and Ghangrekar, 2009; Jadhav and Ghangrekar, 2009), external resistance (Jang et al., 2004; Hong et al., 2009a; Jadhav and Ghangrekar, 2009), temperature (Hong et al., 2009a; Renslow et al., 2011), conductivity (Reimers et al., 2001; Hong et al., 2009b) and organic matter of the sediment (Song et al., 2010; Wang et al., 2012).

The operating pH in the anodic chamber affects the efficiency of wastewater treatment and power generation in microbial fuel cell (MFC). Highest current was reported between pH of 7 and 8.

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The current values were lower at pH of 9 and pH below 7 (He et al., 2008). Ren et al. (2007) reported that significant decrease in power production occurred when the pH in anode compartment dropped to 5.2 due to the acidic products of fermentation, and power production was quickly resumed when the pH of anolyte was increased to 7.0. Most MFCs are operated at neutral pH in order to optimize bacterial growth conditions. Pertaining to aquaculture, the pH of water between 6.7 and 9.0 is suitable for fish survival and growth (Santhosh and Singh, 2007).

Hong et al. (2009a) found that current density can be expressed as a function of electrode spacing in SMFCs. They obtained current densities of 11.5, 7.64, 2.51 and 2.11 mA m^{-2} for spacing between the electrodes of 12, 20, 80 and 100 cm, respectively. Increase in power density, from 0.37 to 1.01 mW m^{-2}, was reported when the electrode spacing was decreased from 100 to 12 cm. Electrode spacing in SMFCs used for *in situ* remediation of aquaculture water depends on the overall depth of water in the aquaculture pond. Water depth used in aquaculture pond ranges from 0.5 to 2.5 m and it depends on the organism under culture (Santhosh and Singh, 2007).

Jang et al. (2004) demonstrated that current production and chemical oxygen demand (COD) removal efficiency were lower at higher external resistance in MFCs fed with artificial wastewater. External resistance affects the performance of SMFCs by controlling the flow of electrons from anode to cathode (Song et al., 2010; Rismani-Yazdi et al., 2011).

The statistical problem solving approach involves steps such as determination of response variables, factors and factor levels, choice of the experimental design, and statistical analysis of the data with final aim to obtain a statistically sound regression model. Studies have been carried out to evaluate the individual effect of the operating parameters such as pH of influent aquaculture water, distance between electrodes and external resistances on the performance of SMFC. However, the combined effects of these parameters have not yet been explored. Therefore, in the present study, it was aimed to evaluate the individual as well as combined effect of operating parameters such as influent pH, distance between electrodes (D) and external resistance (ER) on the performance of SMFC using statistical model to optimize the COD removal, total nitrogen (TN) removal and polarization maximum power density, the later representing better electrochemical behavior of the SMFC in terms of power production at optimum resistance.

2. Materials and methods

2.1. Statistical experiment design

The statistical design of experiments is an efficient procedure for planning experiments. Factorial designs are efficient at evaluating the effects and possible interactions of independent variables on the response. In the present study, two levels, 2^3 full factorial design was selected for the three selected variables, *i.e.*, influent pH, distance between electrodes and external resistance. The two level full factorial design for three experimental factors would require 2^3 number of experiments to be conducted involving combinations of high (+1) and low (−1) setting of three factors. Apart from these experiments, three central point (0) experiments were also conducted in which all the experimental factors have an intermediate value in between the high and low values. The full factorial design will facilitate independent estimation of effect of individual parameter and two and three factor interactions on the response COD removal, TN removal and maximum power generation (polarization power density). The polarization power density is one of the electrochemically important parameters representing the performance of SMFC. This is due to the fact that substrate degradation rate varies with the substrate demand at anode, which in turn controlled by the external resistance because of the resistance to the passage of electron flow. Design values adopted in this study for total eleven experimental runs are summarized in Table 1.

2.2. Experimental set up of SMFCs

SMFCs were constructed from a PVC cylinder having internal diameter of 13 cm. Three rectangular graphite plates were used as anode and cathode with each plate having dimension of 21 cm × 10.5 cm × 0.5 cm. These electrode plates had surface area of 1418 cm^2 each. The plates were attached together with a stainless steel nut and bolt and the gap between them was kept at 1 cm. Anode was placed in the sediment zone. Aquaculture pond sediment was filled up to a height of 50 cm from bottom and the cathode was installed at 6 cm below the top water level in these experimental columns. The distance between anode top edge to the cathode bottom edge varied from 50 cm to 100 cm in these SMFCs (Table 1). After addition of the sediments, remaining volume was filled with practicing aquaculture pond water up to a total height (including sediment zone) of 1.77 m, 1.52 m, and 1.27 m for these SMFCs. The anode and cathode were connected with concealed copper wire through external load of 350 Ω, 700 Ω and short-circuited (0 Ω) as per details provided in Table 1. Aeration was provided near the cathode through commercially available aquarium aerator (Zhongshan RISHENG Electrical Product Co. Ltd.) at a depth of 25 cm from the top liquid level in all these SMFCs.

For the validation experiments, two independent experiments in duplicates were carried out to validate the model predictions. Each validation experiment was carried out in the two identical SMFCs with same operating conditions. SMFC-1 and SMFC-2 were operated at a pH of 8.5, distance between electrodes at 90 cm and external resistance of 0 Ω. Similarly, SMFC-3 and SMFC-4 were operated at a pH of 7.6, distance between electrodes at 100 cm and external resistance of 52 Ω.

Experiments were performed in a batch mode. SMFCs were allowed to acclimatize for first three feed cycles of operation, and afterwards the performance was monitored for 25 days covering five feed cycles. Feeding was done at an interval of 5 days. The COD (170–185 mg L^{-1}) and ammonium nitrogen concentration (4–6 mg L^{-1}) were maintained by adding sucrose and ammonium chloride for each feed cycle. The pH of feed water was maintained by using 10 mM phosphate buffer. Performance of these SMFCs was evaluated at ambient temperature in the range from 29 to 30 °C. Later, minimum day temperature decreased to 10 °C due to winter season and one of the validation experiment (SMFC-1) was continued to operate at this lower temperature condition to evaluate effect of temperature on performance of SMFC.

Sediments and used aquaculture water were collected from the existing 15 year old freshwater aquaculture pond of IIT Kharagpur, having a dimension of 14 m × 10 m × 1.5 m exposed to natural climatic conditions. Stocking density of 7 fish/m^2 was adopted in this pond. Fishes reared in this pond were Silver Carp, *Rohu*, *Catla* and *Mrigal* in the ratio of 1:2:2:2. Total kjeldahl nitrogen (TKN) concentration in the aquaculture used water was in the range of 8.48–10.64 mg L^{-1}. Also, dissolved oxygen (DO) concentration in this water was found to be in the range of 5–6 mg L^{-1}; whereas COD ranged from 145 to 192 mg L^{-1}. Conductivity of the aquaculture water used in the experiment varied from 1.28 to 1.93 mS cm^{-1} after correcting the pH.

2.3. Analyses and calculation

Analysis of the parameters such as DO, COD, TKN, ammonium nitrogen (NH_4^+-N), nitrite nitrogen (NO_2^--N) and nitrate nitrogen (NO_3^--N) was done regularly according to APHA standard methods