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Application of sediment microbial fuel cell for *in situ* reclamation of aquaculture pond water quality

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ABSTRACT

Performance of sediment microbial fuel cell (SMFC) with external resistance (SMFC-1) as well as short-circuited mode (SMFC-2) was evaluated at different operating temperatures (28–30 °C and 21–25 °C) and in presence and absence of aeration at the cathode. The performance was evaluated in terms of chemical oxygen demand (COD) removal and total kjeldahl nitrogen (TKN) removal for offering *in situ* treatment of aquaculture pond water. SMFC-2 demonstrated maximum COD and TKN removal efficiencies both in the absence and presence of aeration near cathode as compared to SMFC-1. With aeration at cathode, the COD and TKN removal efficiencies were 79.4% and 92.6% in SMFC-1 and 84.4% and 95.3% in SMFC-2, respectively. Without aeration and at lower operating temperature, the COD and TKN removals were slightly lower, yet satisfying aquaculture quality norms. SMFCs demonstrated effective *in situ* remediation of aquaculture water and can drastically save the operating cost of aquaculture.

1. Introduction

Over the last two decades, aquaculture industry is growing due to the increase in per capita consumption of fish products. Therefore, to increase aquaculture production, the industry is moving towards more intensive practices and supplementing protein-rich feed. The uneaten protein rich feed, dead phytoplankton, fish excreta and other metabolic wastes can produce high concentration of ammonia in the water (Chen et al., 1994) which lead to sediment deterioration causing toxic effects in the fish. Further, at higher temperature and pH, concentration of ammonia and nitrite increases whereas that of dissolved oxygen (DO) decreases and this could also pose serious threat to the fish health.

In the aquaculture pond, total nitrogen (TN) exists in the inorganic forms of ammonium nitrogen (NH_4^+-N), nitrite nitrogen (NO_2^--N), nitrate nitrogen (NO_3^--N), and also in many other forms of organic nitrogen. Nitrogen removal is essential for aquaculture water remediation for the potential reuse of this water and to maintain the fish free of diseases. Maintaining water quality enhances the fish yield and the fish will have good taste. Nitrate contaminated water released into the environment can create serious problems, such as eutrophication of water bodies (Sumino et al., 2006), deterioration of water quality and potential hazard to human or animal health.

Constructed wetlands have been investigated as efficient solution for removal of nutrients from effluents (Lin et al., 2002). However, treatment by artificial wetlands outside the fish culture unit is not feasible for small farm holders because of high expenses on acquiring land and power required for pumping the water from pond to wetland. Similarly, other biological treatment or physicochemical treatment of this water is also not economical due to the cost involved in pumping of water from pond to the treatment system and operating cost of treatment system itself. Daily replacement of 5–10% volume of the system with new water may prevent accumulation of nitrate in aquaculture ponds (Masser et al., 1999), which will however lead to more water consumption. Increasing regulatory pressure focused on discharges of this used water to natural water bodies is forcing fish producers to adopt methods that are economical and environmentally friendlier.

Sediments are important components of aquatic environment. The condition of pond bottom and the exchange of substances between soil and water strongly influence water quality of aquaculture pond (Boyd, 1995). The surface layer of sediments contain significant amount of pollutants such as organic matter, nitrogen, and phosphorus, thus potentially threatening integrity of the ecosystem (Beg et al., 2001). The oxidized layer at the sediment surface prevents diffusion of most toxic metabolites into the pond water. Ammonia and nitrite will be oxidized to nitrate, ferrous iron will be converted to ferric iron, and hydrogen sulfide will be transformed to sulfate by chemical and biological activity while passing through the aerobic surface layer (Boyd et al., 2002). Thus it is extremely important to maintain the oxidized layer at the sediment surface in aquaculture ponds.

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Microbial fuel cell (MFC) is the most promising approach to treat domestic as well as industrial wastewater along with generation of electricity (Liu et al., 2004; Ghangrekar and Shinde, 2008). Sediment microbial fuel cells (SMFCs) or benthic microbial fuel cells (BMFCs) are a special application of MFC to generate electricity from the electro-potential difference between oxic water and anoxic sediments present in the water body. An anode of such SMFC is embedded in pond sediment and the cathode is placed in overlying water. Microorganisms degrade organic compounds present in sediment and wastewater, generating electrons and protons. Electrons are transferred from anode to cathode through an external circuit and protons flow from sediment to the cathode side and combine with oxygen on cathode to produce water. Reimers et al. (2001) employed platinum mesh electrodes to produce current from both salt-marsh and estuarine sediments. Microbial electrochemical snorkel (MES), which is a simplified design of a short-circuited MFC, was reported to be successful to optimize wastewater treatment without producing any current (Erable et al., 2011).

The intensive fish culture system often needs the introduction of artificial aeration systems (Boyd and Ahmad, 1987). However, for extensive aquaculture there is no need of aeration system. Hence, depending on the type of fish culture, oxygen may or may not be available through active aeration for cathodic reaction. However, even in the absence of active aeration, some amount of oxygen is always available near the cathode, due to passive aeration when cathodes are placed close to the water surface.

In the competitive world today, it has become absolutely essential for the aquaculture projects to reduce production cost by minimizing the cost involved in external treatment cum recirculation of water and increase fish yield by maintaining water quality in the prescribed optimum limit. A good solution for *in situ* remediation of aquaculture water is the use of SMFC, which offers simultaneous treatment to the water while generating some electricity. Hence, this study was aimed to investigate the performance of SMFC for *in situ* aquaculture water remediation in terms of chemical oxygen demand (COD) and nitrogenous compounds removal. The performance of SMFCs was investigated with an external load resistance and short-circuited connection, with and without aeration at the cathode. To take into account variation in the performance due to seasonal changes in temperature, the performance was evaluated in the operating temperature range of 28–30 °C and 21–25 °C, respectively.

2. Materials and methods

2.1. SMFC configuration and operation

Four SMFC experimental columns were constructed from a PVC cylinder, with three rectangular graphite plates working as anode and three plates making cathode. These electrodes had a total projected surface area of 1418 cm^2 for anode as well as cathode, and each graphite plate had dimension of 21 cm × 10.5 cm × 0.5 cm. The graphite plates were attached together with a stainless steel nut and bolt and the gap between each plate was kept at 1 cm. The cylinder had internal diameter of 11 cm and height of 1.5 m (Fig. 1). The anodes were installed vertically in the sediment zone. The sediment was collected from existing aquaculture pond and filled in the experimental column up to a height of 50 cm from bottom. The cathode was positioned vertically in the oxic water at a nearest distance of 77 cm from anode top edge. The remaining volume of the cylinder was filled with used water from the practicing aquaculture pond. Three ports were provided to the cylinder at a distance of 25 cm centre to centre between them from top of column for collection of water samples along the height. The anode and the cathode were connected with concealed copper wire through external load of 100 Ω in SMFC-1 and they were short-circuited in SMFC-2. Two experimental columns were operated as SMFC-1 and the remaining two were operated as SMFC-2. The results presented are average performance of the two SMFCs. For the experiments with aeration in cathode chamber, air was supplied through commercially available aquarium aerator (Zhongshan RISHENG Electrical Product Co. Ltd.) at a depth of 23 cm from top.

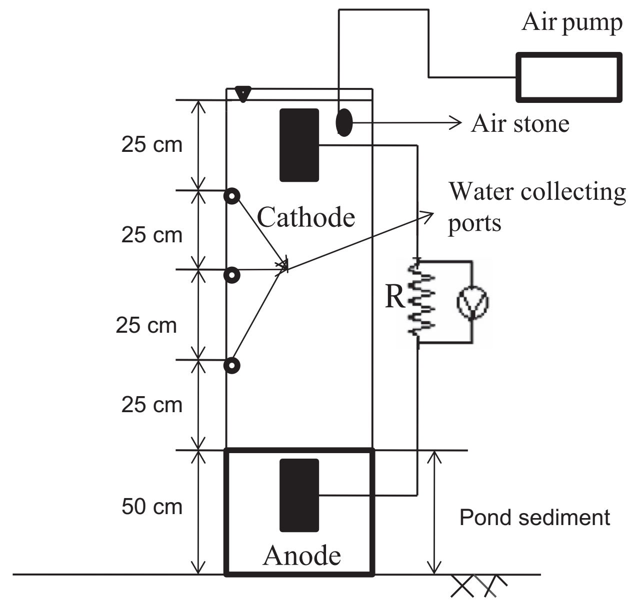

Fig. 1. Laboratory scale sediment microbial fuel cell used in the study.

Experiments were performed in a batch mode. Fresh feeding was given after achieving the water quality suitable for aquaculture. The performance of these SMFCs was evaluated under active aeration for the first 35 days. Later, they were operated under passive aeration at cathode. The aeration was stopped and the same anode and cathode were used after removing the biofilm developed on them during the earlier phase of cathodic aeration. Performance of these SMFCs was monitored for 22 days covering total four feed cycles under passive aeration at the cathode. Initially, the performance of these SMFCs was evaluated at ambient temperature in the range of 28–31 °C with aeration and without aeration in cathode. Later, performance of these SMFCs was evaluated at a lower operating temperature, due to winter season, in the range of 21–25 °C with aeration in cathode and without disturbing biofilm developed on the electrodes. A control experiment was also operated with and without aeration to evaluate performance without the presence of bio-electrode system. Control set up had no electrode system in it and was filled with the same quantity of sediments and aquaculture water as used in SMFCs.

2.2. SMFC inoculation

The sediment was collected from the fish pond bottom having oxidizable organic matter (OM) of 2.1% (w/w). The SMFCs were filled with this sediment up to a height of 50 cm from bottom. No other culture was added in these SMFCs as inoculum and entire experiments relied on the presence of naturally occurring bacteria in the aquaculture sediments and water. Water was collected from 15-year-old operating aquaculture pond in IIT Kharagpur. The pond had a dimension of 14 m × 10 m × 1.5 m. Stocking density of 3 fish/m^2 is being cultured in the pond. Fishes cultured were *Rohu*, *Catla* and *Mrigal* in the ratio of 1:1:1. Fish feeding rate of 5 kg per day is being adopted. The total kjeldahl nitrogen (TKN) concentration in the feed aquaculture used water collected from this pond was