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Integrating sludge microbial fuel cell with inclined plate settling and membrane filtration for electricity generation, efficient sludge reduction and high wastewater quality

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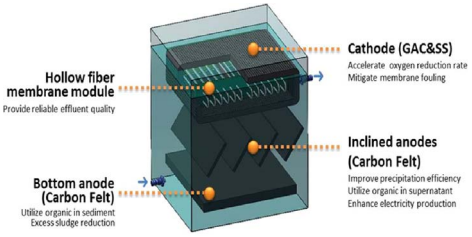
GRAPHICAL ABSTRACT



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ABSTRACT

Disposal of excess sludge generated in wastewater treatment plants is complicated, energy-consuming and potentially produce secondary pollution. In this study, sludge microbial fuel cell (SMFC) was innovatively introduced into secondary settling tank to complete sludge reduction *in situ*. Anode of SMFC was embedded in the sediment and cathode suspended in the supernatant, besides, inclined plate anodes were installed in the middle of tank to enlarge the area of anode significantly and facilitate the utilization of biomass in the middle of settler. What's more interesting is that, due to the inclined arrangement, anodes in the middle of reactors also stopped sludge from floating and accelerated the sludge sedimentation. The results showed that power density increased by 2.1 times, internal resistance decreased 50%, sludge reduction rate increased by 1.5 times with the installation of inclined anodes compared with normal SMFC (without inclined anodes). In addition, inclined anodes provide better conditions for the continuous operation of the reactor. Compared with static-stage, R_{int} of inclined plate SMFC and normal SMFC during continuous-stage were decreased by 29.77% and 35.67%, respectively. COD and SMP in supernatant decreased by 21.51% and 17.80%, respectively, and the membrane fouling of membrane module arranged in cathode was mitigated significantly.

1. Introduction

More than ninety percent of municipal wastewater treatment plants (WWTP) use activated sludge process, with excess sludge production as the main problem [1]. Excess sludge has been treated with complicated methods, such as thickening, dewatering and stabilizing, which were high in energy consumption [2]. Actually, excess sludge contains high amount of organic matters and could be treated as a biomass energy

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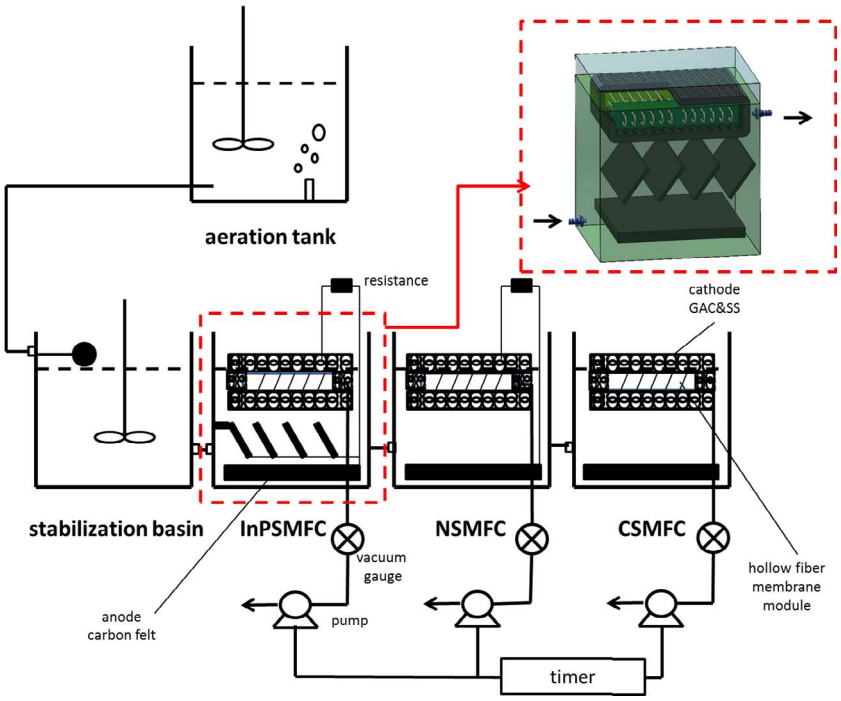

Fig. 1. Schematic diagram of the reactors.

resource. Anaerobic digestion has been used to convert excess sludge to biogas (methane) [3]. However, anaerobic digesters need to operate around 35 °C, and the energy loss is as high as 30% [4] during the transformation from biogas to electrical energy [5]. Therefore, it is critical to harvest the electrical energy contained in excess sludge *in situ* at ambient temperature.

One feasible solution is sludge microbial fuel cell (SMFC) capable of extracting biomass energy from excess sludge directly and reducing sludge yield. The anode of SMFC is embedded in the organic matter-rich sediment and the cathode suspended in the supernatant (e.g. settled water) on the top of the reactor. Microorganisms generate electrons from the oxidation of organic matters in sediment [6]. Electrons then transfer to the cathode through external circuit, and react with oxygen around cathode and hydrogen protons (H^+) from the anode to form water. To improve the biomass energy extraction performance of SMFCs, some existing techniques using multiple anodes connected in parallel, which would be a better choice for higher power output and more efficient sludge reduction [7–9].

As we all know the excess sludge is discharged from the secondary settling tank, and then transferred to the complex treatment processes [10], the cost of the subsequent sludge treatment would be reduced and the secondary pollution of landfill leachate or the sludge incineration would be alleviated if SMFC was integrated into secondary settling tank properly for sludge reduction. However, the problem is that the main function of secondary settling tank is to precipitate sludge and ensure the effluent water quality under continuous operation [11], and anodes of traditional multi-anode SMFCs cannot fulfill this purpose either, although they can shorten the distance between anodes and cathode, enlarge anode area and utilize biomass in the middle of reactors [12,13]. Considering these problems, in this study, anodes in the middle of the tank were arranged inclined from the horizontal to form inclined plate SMFC (termed as InPSMFC). The inclined plate anodes not only play the role of traditional anodes, but also improve the precipitation efficiency based on the theory that theoretically reduce the depth will double the precipitation efficiency under the condition of constant volume and length of a tank [14]. In addition, inclined anodes would stop sludge from floating, mitigate bio-fouling of cathode, ensure the contact between cathode and oxygen and make continuous operation of SMFC possible.

In previous studies, membrane filtration has been successfully used in MFCs for better effluent quality [15], but there still remains a gap in integrating membrane filtration with SMFCs. As the sludge floating in SMFCs will lead to serious membrane fouling, which cannot be mitigated by aeration method in single chamber SMFC [1]. This study innovatively installed a membrane module inside the cathode of the InPSMFC to enhance secondary effluent quality, and arranged inclined anodes in the middle of SMFC to accelerate sedimentation rate, stop sludge from floating and mitigate membrane fouling. Furthermore, some studies had proved that the weak electric field was effective to maintain the electrophoresis and electrostatic attraction/ repulsion against electronegative sludge particles or colloids, so that membrane fouling can also be mitigated by using the cathodic electric intensity to reject the negatively charged pollutants from membrane surface [16], thus prolonging the membrane filtration operational time and maintaining good effluent quality.

In this paper, the sludge reduction and power generation performance of InPSMFC combined with membrane separation, as well as the effluent quality and membrane fouling in continuous operation mode were studied in detail. Furthermore, the effect of inclined plate anodes on the performance of SMFC and mechanism were further discussed.

2. Materials and methods

2.1. Construction of membrane filtration inclined plate SMFC

Three acrylic reactors with same dimension (226 mm × 200 mm × 250 mm) and electrode spacing (between bottom anodes and cathodes, 190 mm) were used for parallel experiment (Fig. 1). Bottom anode made of carbon felt (205 mm × 185 mm, Dalian Xingke Carbon Fiber Co., Ltd., Dalian, China) was fixed 10 mm away from the bottom of reactor. The inclined plate anodes of InPSMFC consisted of four rectangle carbon felts (200 mm × 100 mm each) parallel to each other (horizontal distance was 50 mm, bottom aligned), slant fixed in the middle of the reactor (90 mm away from the bottom and inclined 60° from the horizontal that imitated the angle of inclined plate settlers to guarantee the high efficiency of precipitation). Titanium wire was used to connect bottom anode with four inclined anodes. For comparison, normal SMFC (NSMFC) was installed without inclined