A novel microbial electrolysis cell-A/O system treating cotton dyeing pretreatment wastewater: performance and microbial diversity analysis

Donglei Wu, Mingjie Zhang, Meiqing Yang, Shuwen Du, Weiwang Chen and Ran Cheng

ABSTRACT

The textile industry is developing rapidly in China. It generates large volumes of cotton dyeing pretreatment wastewater (CDPW). CDPW contains high concentrations of pollutants characterized by their strongly alkaline and recalcitrant nature for microbial degradation. This project aimed to evaluate the performance of a microbial electrolysis cell (MEC) coupled with anoxic/oxic (A/O) system (MEC-A/O) in treating CDPW, as well as analyze changes in microbial diversity. The results indicated that the effect of biological treatment in an electrolytic cell to treat CDPW was optimal at the voltage of 0.6 V. The chemical oxygen demand (COD) removal efficiency under optimum conditions was 69.13%, higher than that of the A/O system alone (48.93%). Within a certain range, applied voltage was able to enhance microbial activity, increase the sludge concentration and enlarge the sludge particle size. At the same time, the applied voltage could effectively increase the abundance and the diversity of Bacteria and Archaea, as well as accelerate the degradation of pollutants.

Key words | applied voltage, cotton dyeing pretreatment wastewater, MEC-A/O, microbial diversity

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INTRODUCTION

With economic development, improving standards, and an expanding export market, China's textile dyeing and printing industry has been rapidly developing. In 2014, the amount of wastewater from the textile industry was estimated to be 2,150 million tons in China, which accounted for 11.2% of industrial wastewaters (China Environment Statistical Yearbook in 2014). Besides, the negative effects of wastewaters are also increasing. Dyeing and printing pretreatment processes for desizing, boiling and bleaching produce a small amount of wastewater known as cotton dyeing pretreatment wastewater (CDPW). CDPW contains high concentrations of pollutants such as polyvinyl alcohol (PVA) size, and auxiliaries (Lin *et al.* 2017) which are strongly alkaline and recalcitrant to microbial degradation. After a pretreatment processes, the cotton fabric undergoes a process of dyeing and printing and a large amount of low strength wastewater is produced. It is a common approach to pre-treat CDPW separately before mixing it with low strength printing and dyeing effluents for further treatment. There are diverse kinds of methods employed to pretreat CDPW, such as membrane separation (Xu *et al.* 2002; Yadav *et al.* 2017; Ying *et al.* 2017), anaerobic sequencing batch reactor activated sludge process (AnSBR) (Yu *et al.* 1996; Srisuwun *et al.* 2018), anaerobic baffled reactor (ABR) process (Ibrahim *et al.* 2009), advanced oxidation processes (AOPs) (Samuel *et al.* 2011; Negueroles *et al.* 2017), chemical flocculation (Freitas *et al.* 2015; Sultan 2017) and liquid-liquid extraction (Bukman *et al.* 2017). Membrane separation could efficiently recycle PVA substances, but the high investment cost and membrane fouling were significant drawbacks. The process of adjusting the pH of wastewater to neutrality is costly for the iron-carbon microelectrolysis procedure. Although chemical flocculation could effectively treat CDPW, it could produce a considerable amount of sludge and therefore increase the sludge disposal cost. The cost of AOPs is generally high, and some AOPs require strict operating conditions. The AnSBR faces a common deficiency, as anaerobic systems have long start-up times typically associated with high-rate anaerobic treatment systems (Ng *et al.* 2002) The ABR faces several disadvantages, including accumulation of volatile fatty acids, sensitivity to toxic compounds, low methane content in

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biogas production (Arvin *et al.* 2019). Despite all these existing methods, economically and environmentally acceptable technological solutions have not yet been developed.

New emerging standards are more stringent and existing technologies cannot balance the economic and environmental benefits. The microbial electrolysis cell-A/O system (MEC-A/O) can degrade organic pollutants, transmute hazardous substances and results in energy production (Logan & Rabaey 2012). So far, MEC has reportedly been applied to treat domestic wastewaters (Ditzig *et al.* 2007), simulated wastewaters (Ullery & Logan 2014), chloramphenicol (Kong *et al.* 2014), fermentation wastewater (Nam *et al.* 2014) and so on. These studies showed that MEC could obtain good wastewater treatment under low energy consumption conditions.

In this study, a novel microbial electrolysis cell-A/O system was originally applied and a two-chambered MEC system coupled with A/O processes was used to treat CDPW at bench scale for the first time. After more than 160 days of stable operation, different operating modes were compared to explore suitable operating parameters. Meanwhile, the coupling mechanism was studied.

MATERIALS AND METHODS

Reactor construction

A novel microbial electrolysis cell-A/O system was used for the experiment (Figure 1). The treatment process consisted of two Plexiglas reactors. The first reactor (reactor1, R1) had an inner diameter of 9 cm, a height of 18 cm and an effective volume of 960 mL. In its interior, a carbon brush electrode was connected to the anode of an external power source through a titanium wire ($Ø = 1$ mm). A three-phase separator and exhaust vent were located at the upper end and the gas was collected via an air collecting bag. R1 was sealed with a silicone loop to maintain the anaerobic condition. The second reactor (reactor2, R2) had an inner diameter of 7 cm, a height of 16 cm and an effective volume of 480 mL. In its interior, a carbon brush electrode was connected to the cathode of the external circuit through titanium wire ($Ø = 1$ mm) with a resistance of 10 Ω series. To maintain the aerobic condition, there was an aeration device in the bottom of R2. R1 and R2 were both placed in a water tank at a constant mesophilic temperature maintained at about 32 °C. The wastewater was pumped into R1 in upflow mode at the lower end; it went out through the upper end and then flowed to R2. R2 was flooded from the lower end and drained the effluent through the upper end.

The carbon brush electrodes were made of TA2 size titanium wire and 6 K size carbon fiber (Toho Tenax Company, Japan). The packing ratio of the electrodes in the reactors is shown in Table 1.

Experimental wastewater and sludge

The cotton dyeing pretreatment wastewater used in this research was collected from a textile printing and dyeing

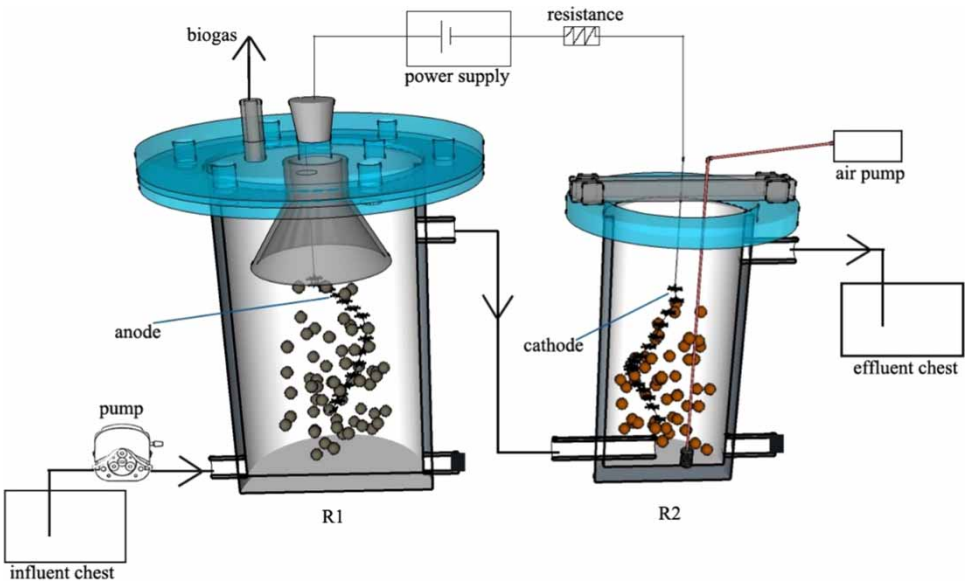

Figure 1 | Schematic diagram of the experimental device (R1:reactor1; R2: reactor2).

Table 1 | The packing ratio of the electrodes

Electrode size (mm)	Volume (cm^3)	Filling ratio of R1 (%)	Filling ratio of R2 (%)
$D \times L = 110 \times 30$	78	8.15	16.16

factory in Zhejiang province, China. The pH of the pretreatment wastewater varied greatly. After hydrolytic acidification pre-treatment in the laboratory, the pH of the wastewater was adjusted to about 7.0 by adding sulfuric acid solution. Then, the wastewater was pumped into R1. The water quality parameters in the different operating modes are shown in Table 2.

The sludge for inoculation in this experiment was obtained from the aerobic pool of the wastewater biochemical treatment in the printing and dyeing factory. 500 mL and 200 mL sludge were added into R1 and R2, respectively, for inoculation. And the mixed liquid suspended solids (MLSS) in R1 and R2 were about 10 g/L (the total liquid volumes in R1 and R2 were about 960 mL and 385 mL respectively).

Experiment procedure

In a previous study (Ding *et al.* 2018), 0.6 V was proved to be the best value of applied voltage for chemical oxygen demand (COD) removal in the treatment of synthetic wastewater by MEC-AnMBR. Here are the wastewater treatments in different operating modes:

Mode 1 (ES), electrochemical system: there was no sludge in R1 and R2. The anode of the circuit was connected to the electrode in R1 and the cathode was connected to the electrode in R2 and there was a resistance of 10 Ω in series through the titanium wire. The circuit had an applied voltage of 0.6 V. The dissolved oxygen (DO) in R2 was maintained at 3–6 mg/L, the hydraulic retention time (HRT) of R1 was 28 h, and the HRT of R2 was 14 h.

Table 2 | Quality of the wastewater for the experiment

		Influent of R1 (mg/L, except BOD_5/COD)			
Operating mode	Time (d)	COD	BOD_5/COD	NH_4^+-N	TP
ES	5	5,867±182	0.42±0.07	50±6	51±6
A/O system	20	5,209±284	0.41±0.07	38±2	46±8
MEC-A/O at 0.3 V	20	5,263±514	0.44±0.03	68±5	55±3
MEC-A/O at 0.6 V	30	5,820±527	0.43±0.81	55±3	68±7
MEC-A/O at 0.9 V	20	5,973±535	0.42±0.06	47±8	48±6
MEC-A/O at 1.2 V	20	5,426±511	0.46±0.13	51±9	42±5

Mode 2 (A/O), A/O system and the start-up stage: in R1 and R2, 10 g/L of sludge was inoculated, and the external circuit was in a discontinuous state. The other parameters such as DO and HRT were the same as for mode 1 (ES). The influent concentration of R1 was maintained constant, the HRT was gradually shortened until the HRT of R1 was 28 h and the HRT of R2 was 14 h. Meanwhile, the organic load was gradually increased to enrich the bacterial communities. After stable operation of 1 week, COD removal efficiency tended to be stable and the system start-up had succeeded.

Mode 3 (MEC-A/O), a MEC coupled with A/O system: After the start-up stage, the HRTs of R1 and R2 were controlled as 28 h and 14 h, respectively. Then, R1 and R2 were connected to an external circuit, and the applied voltage was set to 0.6 V. The rest of the parameters were the same as mode 1 (ES).

Pollutant removal efficiency of MEC-A/O was compared at different applied voltages.

The operational mode was the same as mode 3 (MEC-A/O) except for the applied voltage value. The applied voltage of the external circuit was set to 0.3 V, 0.6 V, 0.9 V, and 1.2 V in turn.

Analysis methods

COD, NH_4^+-N, total phosphorus (TP), MLSS and mixed liquor volatile suspended solids (MLVSS) were determined according to the standard methods (APHA 2005). COD was determined by closed reflux, titrimetric method. NH_4^+-N was determined by Ammonia-Nessler's Reagent Colorimetric Method. TP was determined by persulfate digestion method. MLSS was dried at 103–105 °C and MLVSS was dried at 550 °C. The semi-volatile organic compounds in the wastewater were determined by gas chromatography–mass spectrometry (GC-MS) system (7890A/5975C, Agilent Technologies), and the instrument testing conditions and methods were directed by the EPA 625 method. The pollutant removal efficiency was calculated using Equation (1).

$$\text{The removal efficiency } \% = \frac{I - E}{I} \times 100 \quad (1)$$

where I and E represent the pollutant concentration of the influent and effluent, respectively.

The sludge particle size and distribution were measured by a dynamic particle image analyzer (Qicpic-Lixell, PT201001A). The samples were sent to the Majorbio Company (Shanghai) for analysis of the microbial sequence (Illumina Inc.).

RESULTS AND DISCUSSION

Reactor start-up

Figure 2 shows the COD removal efficiency in the influent and effluent of the reactors during the start-up stage. The influent COD of R1 was maintained at 4.8–5.8 g/L. The effluent COD values were stable in the range of 3.5–4.0 g/L and 2.3–2.8 g/L in R1 and R2, respectively. The HRT was gradually shortened while the organic load gradually increased to enrich the bacteria. Finally, when the HRTs of R1 and R2 were 28 h and 14 h, respectively, the overall COD removal efficiency of the A/O system was stable at 48.90%. The removal efficiency in R1 and R2 was stable at 27.45% and 29.65% respectively. The start-up stage was considered to be successful after a week of operation.

The performance of the MEC-A/O system

The reactor initially ran in mode 1 (ES) for 5 days, and then the sludge was inoculated in R1 and R2 for the start-up stage. After this stage, the reactor was run in mode 2 (A/O) and mode 3 (MEC-A/O) in turn. The pollutant concentration was monitored in both the influent and the effluent throughout the whole experiment. Table 2 shows the quality of the wastewater in the experiment.

COD removal performance

As shown in Figure 3(a), the COD was only removed by adsorption onto the carbon fiber electrode and the overall COD removal efficiency was only 5.20% when the reactors were operated in mode 1 (ES). The textile dye removal efficiency was related to particle size, adsorbent dose, pH, contact time and adsorbate concentration according to the study by Igwegbe *et al.* (2016). COD removal mainly occurred in the first few days in mode 1 (ES). After the adsorption onto carbon fiber reached the point of saturation, the COD was barely removed. During mode 2 (A/O), the COD removal efficiencies of R1 and R2 were 27.45% and 29.65%, with an overall COD removal efficiency of 48.90%. After applying 0.6 V voltage in mode 3 (MEC-A/O), the applied voltage strengthened the treatment effect of the microorganisms and the COD removal efficiency was increased. The COD removal efficiencies of R1 and R2 were 50.57% and 37.50%, respectively. Additionally, the overall COD removal efficiency was 69.13%, which was 20.23% higher than that of the A/O system. In CDPW treatment in the MEC-A/O system, the removal process did not merely involve microorganisms, as the treatment was aided by electrochemical superposition. The applied voltage within the reactors formed a local electric field to speed up the reactor electron transfer and accelerate the COD degradation rate. Wang *et al.* (2016) also reached a similar conclusion while using a continuous stirred microbial electrochemical reactor to treat brewery wastewater.

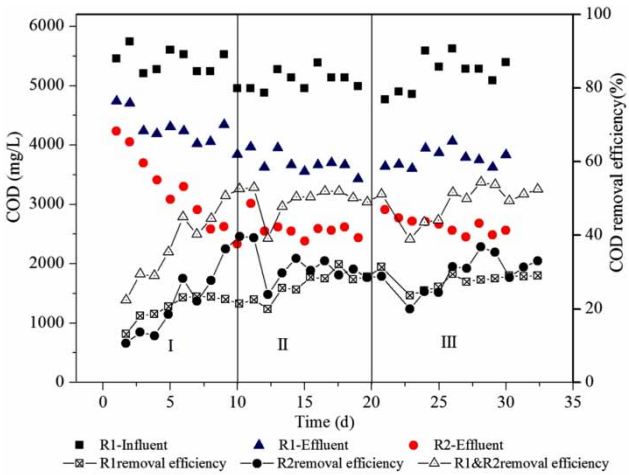

Figure 2 | The change in the COD removal efficiency in the start-up stage. (In stages I, II, and III, the HRTs of R1 were 90, 46, and 28 h and the HRTs of R2 were 45, 23, and 14 h.)

NH_4^+-N removal performance

As shown in Figure 3(b), adsorbed onto carbon fiber, the effluent NH_4^+-N concentration of R1 and R2 gradually decreased during mode 1 (ES), with the overall NH_4^+-N removal efficiency being only 20.64%. In the presence of microorganisms in the reactor, the degradation of organic nitrogen in CDPW resulted in production of NH_4^+-N. Therefore, the NH_4^+-N concentration in the effluent of R1 increased when the reactors were operated in the A/O system or MEC-A/O system. Meanwhile, NH_4^+-N was transformed into its nitrate form with the presence of nitrifying bacteria. Therefore the NH_4^+-N concentration of the effluent of R2 decreased again. Due to the increased microbial activity after applying 0.6 V voltage, the degradation of organics accelerated. The effluent NH_4^+-N concentration of R1 in the MEC-A/O system was higher than that of the A/O system. Montpart *et al.* (2015) treated a substrate of milk with a MEC system and found that the applied voltage could promote microbial degradation of organic nitrogen. In this study, the overall NH_4^+-N removal efficiency in the MEC-A/O system was 68.7%, higher than that in the A/O

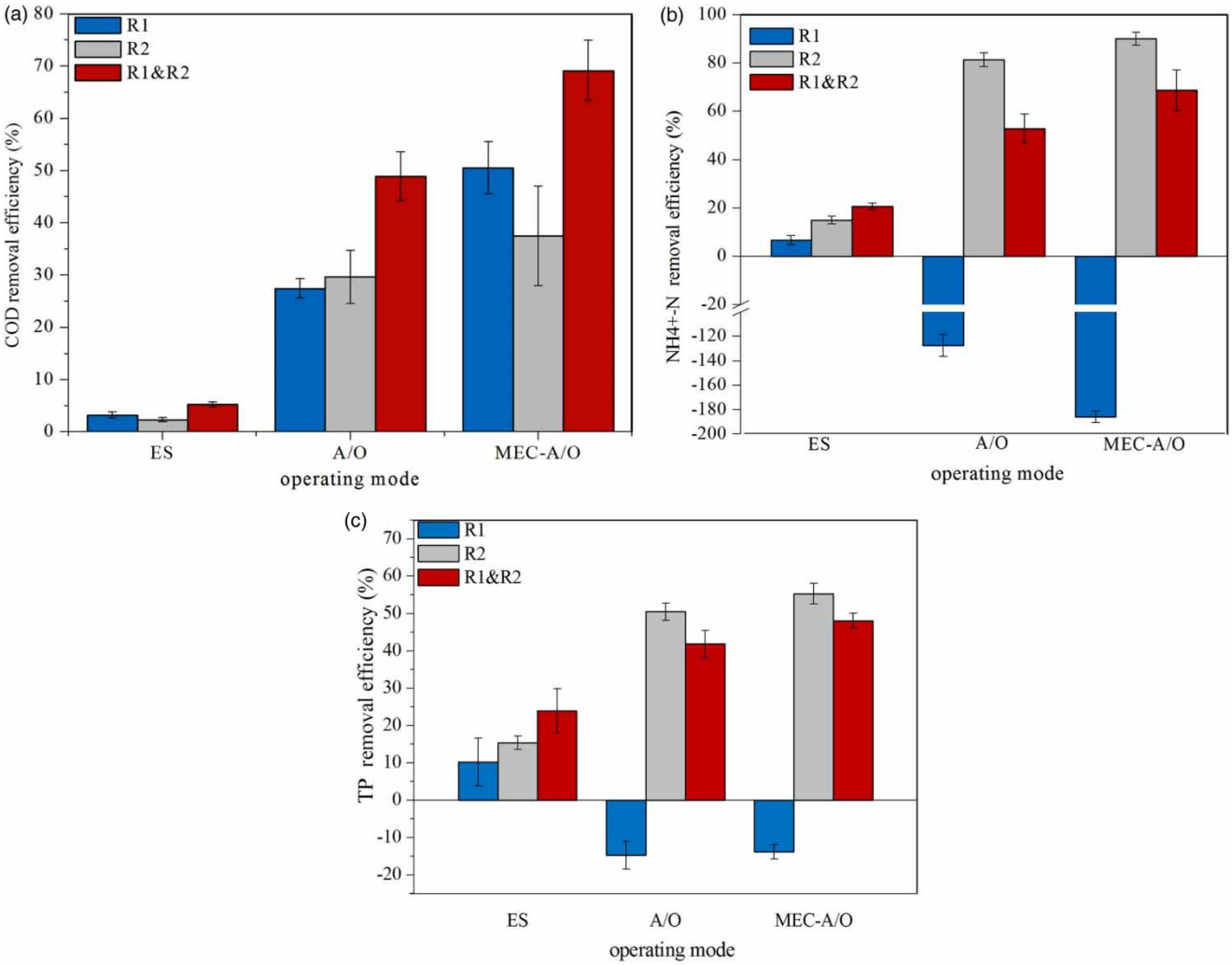

Figure 3 | (a) The COD removal efficiency in different operating modes. (The applied voltages for ES and MEC-A/O were 0.6 V.) (b) The NH_4^+-N removal efficiency in different operating modes. (The applied voltages for ES and MEC-A/O were 0.6 V.) (c) The TP removal efficiency in different operating modes. (The applied voltages of ES and MEC-A/O were 0.6 V.)

system (52.9%). In summary, coupling A/O with MEC could promote organic nitrogen removal by microorganisms.

TP removal performance

As shown in Figure 3(c), the TP concentration of effluent of R1 and R2 gradually decreased in mode 1 (ES), with an overall TP removal efficiency of 24.0%. Phosphorus accumulating organisms release phosphorus under anaerobic conditions and absorb phosphorus under aerobic conditions. Thus, the TP concentration first increased in R1 under anaerobic and then decreased in R2 under aerobic condition in the presence of microorganisms in the reactors. The applied voltage influenced microorganisms to release or absorb phosphorus both in R1 and R2. The overall TP removal efficiencies of the A/O system and MEC-A/O system were 41.8% and 48.1%, respectively. So, with or without applied voltage, the change of TP removal efficiency was not obvious.

The conversion of pollutants in different operating modes

To compare the effects of the reactor operating modes on the removal of organisms in wastewater, a GC-MS system was used to detect the influent and effluent of the reactors in the A/O system and MEC-A/O system. The detected substances were screened under the condition of an abundance >20,000 and marching degree >75%. And the detected organic pollutants are listed in Table 3(a) and (b).

Table 3 | Analyzed organic substances of wastewater samples in (a) mode 2 (A/O) and (b) mode 3 (MEC-A/O) at 0.6 V

Samples categories	Influent of R1		Effluent of R1		Effluent of R2	
	Kinds	Peak area $\times 10^6$	Kinds	Peak area $\times 10^6$	Kinds	Peak area $\times 10^6$
(a) mode 2 (A/O system)						
Alkanes, alkenes	1	0.0282	2	0.4997	2	0.1813
Ketones	4	2.7399	2	1.2594	1	0.0223
Fatty acids	5	5.3012	2	0.5753	1	0.4238
Ethers	–	–	–	–	–	–
Benzene, phenols	2	6.3066	2	1.7736	3	3.1379
Alcohols	1	0.5025	1	0.4937	–	–
Lipids	2	0.3035	4	0.7626	3	1.1815
Indoles	1	0.1545	1	0.0750	1	0.0262
Amine	–	–	1	0.1220	–	–
Siloxanes	1	0.0567	1	0.0429	1	0.0380
Other	1	0.2040	–	–	–	–
Total	18	15.5971	16	5.6040	12	5.0110
(b) mode 3 (MEC-A/O) at 0.6 V						
Alkanes, alkenes	1	0.1260	1	0.1647	2	0.2205
Ketones	3	3.8377	–	–	–	–
Fatty acids	13	108.4701	1	2.1658	–	–
Ethers	–	–	1	0.0821	–	–
Benzene, phenols	3	29.8986	1	3.8457	2	0.9843
Alcohols	1	0.1556	1	0.6906	–	–
Lipids	3	1.1165	2	0.6164	2	0.2205
Indoles	–	–	–	–	–	–
Amine	1	0.1047	–	–	–	–
Siloxanes	2	0.3504	1	0.3287	–	–
Other	–	–	1	0.0993	1	0.3398
Total	27	144.0598	9	7.9934	7	1.7651

Table 3 shows that R1 only removed parts of the organic acids and a small amount of the ketones in mode 2 (A/O). Meanwhile, R2 only removed some alcohols and amines. The removal effect of microorganisms was poor, and 12 organic pollutants could still be detected after the treatment. After applying voltage of 0.6 V (mode 3, MEC-A/O), microbial degradation of organic pollutants had been strengthened. The removal effect of R1 was most obvious the long chain fatty acids, indoles, ketones, benzene and phenols. In addition, pollutants were also removed further in R2. In a previous study (Dongsheng Shena *et al.* 2014) stimulated the mineralization of p-fluoronitrobenzene in a biocathode MEC with an oxygen-limited environment and found that the mineralization in MEC was better than that in the ES and A/O system. In different studies by Cui *et al.* (2014) and González-Gutiérrez *et al.* (2015), there were similar conclusions in which the degradation of pollutants was enhanced by coupling MECs in reactors to treat azo dye. In conclusion, the treatment efficiency can be improved by coupling MEC to degrade refractory organics.

The impact of different applied voltages on MEC-A/O system

As shown in Figure 4, COD removal efficiency initially increased and then decreased with increasing applied voltage. When the applied voltage was 0.6 V, the overall COD removal efficiency reached 69.13%, which was 20.23% higher than that was 0 V. When the applied voltage was 0.6 V, the COD removal efficiency of R1 reached

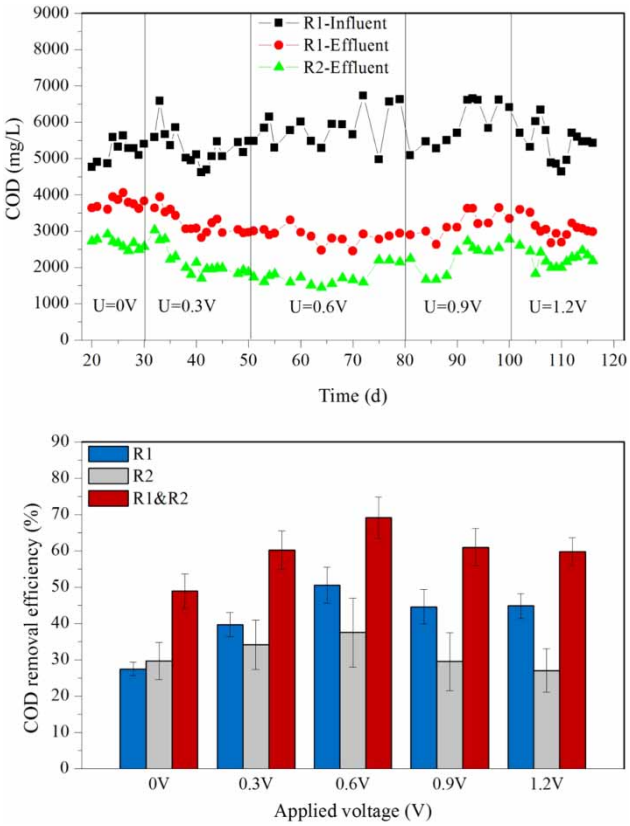

Figure 4 | COD removal efficiency of the reactors at different applied voltages.

50.57%, which was 23.12% higher than that at 0 V. Meanwhile, the COD removal efficiency of R2 reached 37.50%, which was 7.85% higher than that at 0 V.

The applied voltage could improve the COD removal efficiency and the influence on the anode chamber (R1) was greater than that on the cathode chamber (R2). The most suitable applied voltage was related to the reactor configuration. In a previous study (Ding *et al.* 2016), application of low voltage could promote the pollutant degradation, but there was an inhibition of microbial activity and reduction of the water treatment effect when the applied voltage was higher than 0.8 V. Katuri *et al.* (2014) used a single-chambered anaerobic MBR (AnEMBR) to treat a low strength simulated wastewater with an initial COD of 320 mg/L. The effluent COD was 20 mg/L with a 0.5 V applied voltage, 0.3 mg /L at 0.7 V, and 10 mg/L at 0.9 V. The current experiment showed a similar result: as the applied voltage increased, the COD removal efficiency initially increased and then decreased. Cui *et al.* (2014) studied the effect of azo dye (alizarin yellow R) wastewater treatment with a four-chambered ABR incorporated with an MEC at 0.3, 0.5 and 0.7 V. The results showed that the decolorization efficiency with 0.5 V and 0.7 V were similar

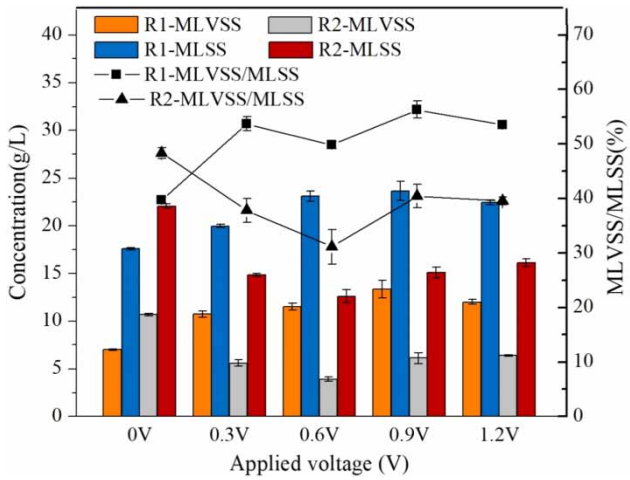

Figure 5 | The effect of different voltages on the sludge concentration in reactors.

and the removal efficiencies of both were more than 95%. Considering the wastewater treatment effect of the MEC-A/O system, 0.6 V was the optimum applied voltage in this study.

Microbial community analysis

Biomass at different voltages

From Figure 5 and Table 4, it was evident that, with increasing applied voltage, the sludge particle size in R1 and R2 increased constantly and reached the maximum value when the applied voltage was 0.6 V. Under anaerobic conditions, the applied voltage promoted the microbial growth of microorganisms. Therefore, the sludge concentration in R1 increased with the increasing applied voltage. The MLVSS/MLSS value was higher after applying the voltage. However, under aerobic conditions, the sludge concentration decreased to varying degrees, and the MLVSS/MLSS value first decreased and then increased with the increase in applied voltage.

Table 4 | Sludge particle size distribution in MEC-A/O at different applied voltages

Applied voltage (V)	days	Sludge particle size in R1 (μm)	Sludge particle size in R2 (μm)
0	20	236.26–299.96	244.17–331.29
0.3	20	240.04–317.16	256.38–360.36
0.6	30	249.89–353.01	262.47–383.69
0.9	20	243.42–330.75	257.82–372.55
1.2	20	241.03–328.23	244.16–327.99

Table 5 | (a) Bacteria alpha-, (b) Archaea alpha-diversity of samples

		0.97					
Sample	**Reads**	**OTU**	**Coverage**	**Ace**	**Chao**	**Shannon**	**Simpson**
(a) Bacteria alpha-diversity							
Anode-0 V	35,904	552	0.988858	570	572	4.55	0.0286
Anode-0.6 V	38,717	578	0.998450	606	618	4.27	0.0492
Cathode-0 V	31,610	498	0.997343	557	587	4.54	0.0229
(b) Archaea alpha-diversity							
Cathode-0.6 V	32,881	563	0.997506	617	616	4.74	0.0167
Anode-0 V	32,410	19	0.999907	21	21	1	0.4234
Anode-0.6 V	32,993	23	1.00000	23	23	1.04	0.4227

Microbial community structure at different applied voltages

The Shannon index and Simpson index reflected the microbial diversity and evenness, respectively. As shown in Table 5(a), after applying a voltage of 0.6 V, the bacterial diversity decreased in the anode and increased in the cathode.

As shown in Figure 6, the applied voltage could promote the bacterial abundance and diversity and had a selective effect on different bacteria. After applying 0.6 V voltage, *Thermovirga*, *Synergistaceae_uncultured* and *Mesotoga* increased in abundance while *Syntrophomonas* and *Desulfovibrio* decreased in abundance in the anodic chamber. In addition, a new strain called *Smithella* was found in the anode, which could degrade long-chain alkanes and had a syntrophic relation with hydrogenotrophic methanogens. In the cathodic chamber, microbial abundance of *WCHB1-69norank* and *Azoarcus* increased from 8.96% and 6.59% to 10.88% and 9%, respectively. The abundance of *Thauera* decreased from 6.66% to 1.23% after applying 0.6 V voltage. Meanwhile, *Fluviicola* was no longer detected in the cathode.

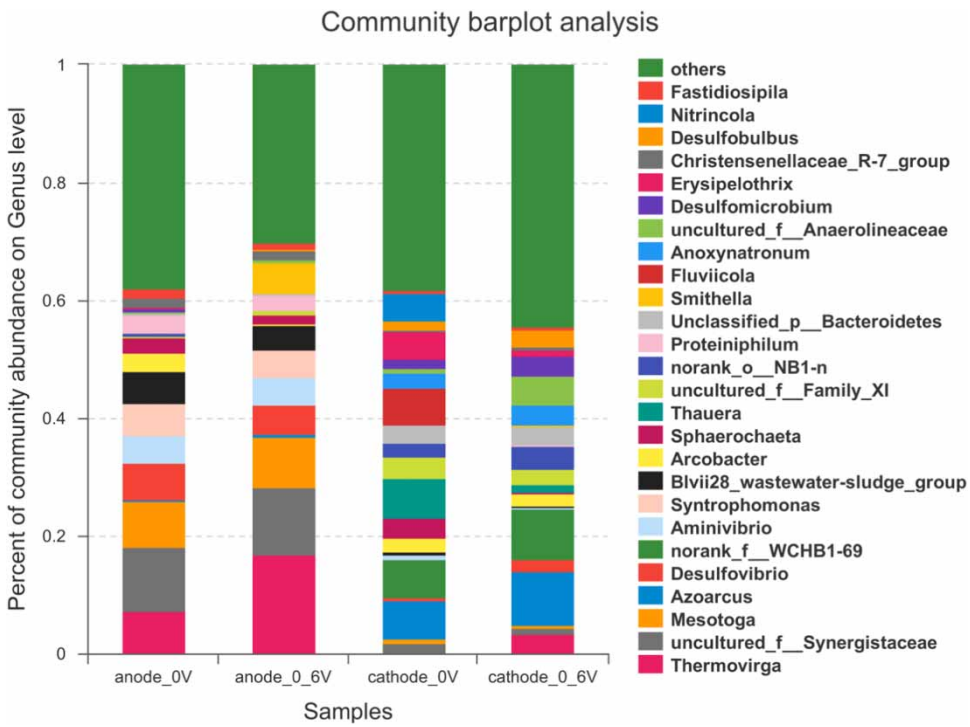

Figure 6 | The relative abundance of Bacteria at the genus level in the reactors.

Table 6 | The relative abundance of Archaea at the genus level

Genus	Anode – 0 V (%)	Anode – 0.6 V (%)
Methanocorpusculum	49.11	1.93
Methanosarcina	42.16	53.23
Methanospirillum	6.59	36.61
Methanocalculus	1.13	6.96
TerrestrialMiscellaneousGpTMEGnorank	0.51	0.66
SoilCrenarchaeoticGroupSCGnorank	0.3	0.07
Unclassified Archaea	0.08	0.28
CandidatusMethanoplasma	0.03	0.14
MarineGroupInorank	0.03	0
Unclassified Methanobacteriaceae	0.03	0.08
ThermoplasmatalesIncertaeSedisnorank	0.02	0.03
Unclassified Thermoprotei	0.01	0

As shown in Table 5(b), the change of archaeal diversity was not obvious after applying voltage. The relative abundance of Archaea at the genus level is shown in Table 6. With or without the applied voltage, *Euryarchaeota* was the main archaeal group at the phylum level. The applied voltage could promote the archaeal abundance and diversity due to suspected mutations and genetic changes under applied voltage. At the genus level, the proportion of *Methanosorpusculum* decreased from 49.11% to 1.93% when 0.6 V was applied. Meanwhile, the proportion of *Methanosarcina* increased from 42.16% to 53.23% and *Methanospirillum* increased from 6.59% to 36.61%. The abundance of these two archaeal species increased the methanogenesis through promoted pollutant.

CONCLUSION

Applied voltage could promote treatment of CDPW using the technology of MEC-A/O system (MEC coupled with A/O system). The CDPW treatment in the MEC-A/O system was optimal when the applied voltage was 0.6 V (the COD removal efficiency was 69.13%, which was 20.23% higher than that of the A/O system). Within a certain range, the applied voltage was able to enhance microbial activity, increase the sludge concentration and enlarge the sludge particle size. At the same time, it can effectively increase both the abundance and the diversity of Bacteria and Archaea, accelerating the degradation of pollutants.

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