Desalination and Water Treatment
www.deswater.com

doi:10.5004/dwt.2018.22939

125 (2018) 40–46
September

Simultaneous ammonium and colour removal from digested piggery wastewater for Arthrospira cultivation by coupling micro-electrolysis and cation exchange membrane

Qiangqiang Yu[a], Rui Liu[a,*], Lujun Chen[a,b,*], Dong Xia[c], Xiaobo Cai[a]

[a]*Zhejiang Provincial Key Laboratory of Water Science and Technology, Department of Environment in Yangtze Delta Region Institute of Tsinghua University, Zhejiang, Jiaxing 314006, China, Tel. +86 573 82582728, Fax +86 573 82582728, email: yuqq_top@163.com (Q. Yu), liuruitsinghuazj@gmail.com (R. Liu), chenlj@tsinghua.edu.cn (L. Chen), 664700919@qq.com (X. Cai)*

[b]*School of Environment, Tsinghua University, Beijing 100084, China,*

[c]*Faculty of Mathematics and physical science, School of Chemistry, University of Leeds, Leeds, LS2 9JT, United Kingdom, Tel. +44 32948, Fax +44 32948, email: cmdx@leeds.ac.uk (D. Xia)*

Received 15 November 2017; Accepted 10 August 2018

ABSTRACT

A coupling device integrated with the advantages of Fe-C micro-electrolysis and cation exchange membrane systems was successfully designed and operated for pretreatment of Arthrospira cultivation with digested piggery wastewater (DPW). In this coupling device, cation exchange process and Fe-C micro-electrolysis process are promoted mutually, and obtained better treatment efficiency than single system on ammonium, colour and total organic carbon (TOC). Specifically, it removed 77 % of NH_4^+, 83 % of NO_2^-, 92 % of colour and 62.5 % of TOC with the residual corresponding concentration of 51.9 mg/L, 50.6 mg/L, 79 mg-Pt/L and 47.4 mg/L, respectively. As these toxic contaminants were removed to a satisfied level, nitrate, the safest nitrogen source for Arthrospira, was retained approximately 72%. Thus, the cultivation of *Arthrospira platensis strain* (ZJWST-S1) in the effluent of coupling device, single CEM system, single Fe-C system and two controls (original wastewater and Zarrouk medium) showed that only the wastewater treated by the coupling device was suitable for cultivating Arthrospira and the related growth rate of ZJWST-S1 (0.172 g/L/d) was similar to that in Zarrouk medium (0.194 g/L/d). This work presented an alternative pretreatment method of wastewater with high ammonium content and dark colour for Arthrospira cultivation, which not only eliminated the inhibitions but also retained the useful nutrients (nitrate and nitrite) for Arthrospira growth.

Keywords: Iron-carbon micro-electrolysis; Cation exchange membrane; Colour; ammonium; Arthrospira

1. Introduction

With the rapid development of piggery industry and widespread application of anaerobic digestion in China, increasing quantities of digested piggery wastewater (DPW) are being discharged. DPW can contain up to several hundred mg ammonium and thousand mg COD/L, which are much higher than municipal sewage. On the other hand, the ratios of carbon/nitrogen (C/N) and BOD_5/COD (B/C) of DPW are much lower than municipal sewage [1,2]. Conventional biological treatment processes, such as anaerobic/oxic (A/O) process and anaerobic/anoxic/oxic (A2O) process, are increasingly adopted by many researchers and engineers, as aforementioned processes are economical and mature [3,4]. However, the nitrogen (ammonium and nitrite) and COD are hard to remove in meeting related discharge standards, especially without external carbon addi-

*Corresponding author.

tion [5]. Consequently, high concentrations of nitrogen and phosphorus remained in the biologically-treated effluent would result in severe eutrophication in rivers and lakes. Furthermore, the heavy metals (such as zinc and copper), colour, etc. will also cause environmental problems. Obviously, a single technology or process like biological treatment is difficult to solve the DPW problem in an effective and low-cost way.

Microalgae-based wastewater treatment method has been increasingly investigated since Oswald put forward it in 1957 due to its advantages in contaminant removal and high-value biomass harvest [6,7]. The residual contaminants (nitrogen, phosphorus, micro element, etc.) in the biologically-treated effluent are also abundant and essential nutrients for microalgae cultivation. However, the high ammonium concentration in the effluent can be toxic to many algae, including Arthrospira [8,9]. Therefore, dilution of the effluent before being used as Arthrospira cultivation medium is usually one of the most common choices for many researchers. Large volumes of pure water, as a result, are required which are unsustainable in large-scale systems [10]. On the other hand, the colour of DPW effluent usually not tends to decrease but increase after exposing excess aeration in biologically-treated process. This situation will cause light limitation for Arthrospira growth, therefore inhibiting its growth as well as the rate of nutrient recovery from the wastewater [10,11]. Thus, further treatment of biological system effluent aiming at removing ammonium, colour, etc. is crucial to Arthrospira cultivation.

Iron-carbon micro-electrolysis (Fe-C) is widely used as a low-cost treatment method for acid wastewater to improve biodegradability and remove colour [12–14]. Numerous microscopic galvanic cells are naturally formed between iron and carbon when Fe-C particles are in contact with wastewater. Fe^{2+}, hydroxyl and nascent hydrogen released from the galvanic corrosion reaction are highly active in the reduction of nitrite/colour and the decomposition of refractory organic pollutants, which might decrease the inhibitors to the growth of Arthrospira [15,16]. However, the outstanding performance of Fe-C micro-electrolysis almost only occurs under acidic conditions [17], while the biological system effluent is usually alkalescent. In other words, the effect of Fe-C micro-electrolysis cannot be durable in such alkalescent wastewater. On the other hand, a portion of nitrite and nitrate might be reduced into ammonium form after micro-electrolysis, which will build up toxicity for Arthrospira. Therefore, keeping the acidity of the system constant and removing ammonium continuously from it are of great importance to provide Fe-C an ideal reaction condition as well as a suitable culture medium for Arthrospira.

In this research, it could be interesting to combine Fe-C micro-electrolysis with cation exchange process, for it could simultaneously provide H^+ and remove NH_4^+ through cation exchange membrane. Therefore, colour, parts of refractory organic pollutants and ammonium in DPW could be enduringly removed in the iron-carbon micro-electrolysis and cation exchange membrane coupling device (Fe-C &CEM). Based on above mentioned viewpoints the enhancement of Arthrospira productivity in the wastewater treated by Fe-C&CEM was investigated.

2. Materials and methods

2.1. Piggery wastewater used in experiments

The wastewater used in this study was the DPW treated by intermittent aeration sequencing batch reactor (IASBR) which could achieve stable nitritation and thereby save 25% of the aeration energy and 40% of the external carbon source [18]. The IASBR effective volume of 10 L (Φ25 cm×H30 cm) were operated at a cycle duration of 8 h. In each cycle, wastewater was fed within 10 min, then four consecutive 40/60 min non-aeration/aeration phases, and then settled for 60 min before drainage. The liquor was stirring mixed with a paddle at a speed of 100–200 r/min during the non-aeration period. The dissolved oxygen (DO) concentration was controlled at 0.5–1.5 mg/L by adjusting air flow rate with an air flow meter during the first aeration phase. Water temperature was 25°C–30°C. The mixed liquor suspended solids (MLSS) and mixed liquor volatile suspended solids (MLVSS) concentration of the system were 5.5 g/L and 2.8 g/L, respectively. The wastewater had an initial content of NO_3^--N of 136.2 mg/L, NO_2^--N of 297.4 mg/L, PO_4^{3-}-P of 19.5 mg/L, ammonium of 221.3 mg/L and colour of 968 mg Pt/L. The more detailed physico-chemical characteristics of the wastewater are shown in Fig. 1. The parameters of the wastewater were analyzed according to the Standard Methods for the Examination of Water and Wastewater, 21st ed [19].

2.2. Iron-carbon micro-electrolysis and cation exchange membrane coupling device

The experimental equipment with an effective volume of 1.6 L was separated into two equal size chambers with a piece of polyethylene heterogeneous cation exchange membrane (GrION Environment) (Fig. 2). One chamber was filled with approximately 250 mL wastewater and 300 mL iron-carbon composite material (Fe-C, calcined at 1200°C under nitrogen with an iron/carbon ratio of 1.5 and particle size 3–5 mm) that had been pre-impregnated in wastewater for 48 h, and another chamber was filled with 450 mL sulfuric acid (10 w%). The cation exchange process

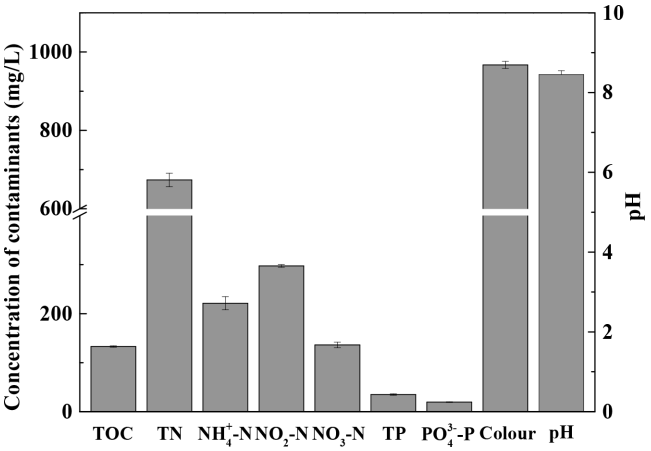

Fig. 1. Physico-chemical characteristics of the wastewater.

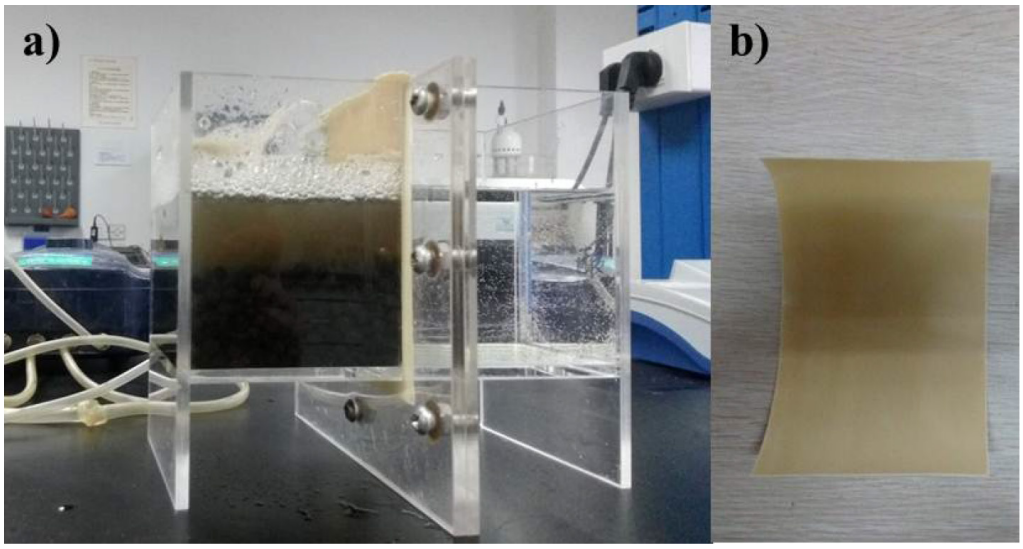

Fig. 2 (a) photograph of two-chamber Fe-C&CEM coupling device and (b) CEM.

and micro-electrolysis reaction were simultaneously operated for 2 h with aeration in our own lab with a constant temperature of 20°C. Then the pH of the wastewater was adjusted to 8.5 by adding 5 M NaOH which could precipitate the ferrous ion from the aqueous wastewater and provide a suitable alkalescent environment for Arthrospira growth.

2.3 Cultivation of Arthrospira

The *Arthrospira platensis* strain (ZJWST-S1) used in this study was isolated from a digested piggery wastewater (DPW) storage pool in Jiaxing City, China and possessed a high growth rate in DPW that had been demonstrated in our previous studies [9]. Cultivation experiments of ZJWST-S1 were carried out in 250 ml erlenmeyer flasks which had been pre-filled with 100 ml Zarrouk medium [20] or treated wastewater with 16.8 g/L $NaHCO_3$ added. It is noteworthy that nitrate is the single nitrogen source in 'Zarrouk medium' with the NO_3^--N concentration of 411.8 mg/L. Arthrospira strains in logarithmic growth phase were inoculated into the flasks, achieving a final algae density of 0.3 in terms of OD_{560}. OD_{560} is the optical density measurement at a wavelength of 560 nm using a spectrophotometer, which could indicate dry cell mass concentration of *A. platensis*. The flasks were then sealed with aluminum film and cultivated in an illuminating incubator (GZP-450, Jinghong Laboratory Instrument Co. Ltd, Shanghai, China) for 10 days. The culturing temperature was maintained at 30 ± 1°C. The light for Arthrospira cultivation in this study was provided by fluorescent lamps (white type) on the four insides of the illuminating incubator. The photo period was 12 h light (6000 ± 2000 lux) and 12 h dark. The biomass was calculated according to its relationship with $OD_{560,}$ as follows: $y = 0.7178x + 0.0025$ ($R^2 > 0.997$), where y (g/L) is the dry cell weight; x is the absorbance at 560 nm. OD_{560} of the mixed liquor in the flasks was measured after shaking by hand once per day. All of the above cultivation experiments were conducted in triplicates.

2.4. Analytical methods

FTIR spectra were obtained on a Nicolet Avatar 660 using the KBr pellet method. Fe-C and precipitation morphology and surface composition were investigated using a scanning electron microscope (SEM) with Energy Dispersion X-ray Spectrometry (EDX) capability (ZEISS SIGMA, Germany). Inorganic ions (Na^+, K^+, Mg^{2+}, Ca^{2+}) in wastewater were analyzed by cation chromatography (DIONEX ICS-90, USA). The data were analyzed using the Origin 9.0 program (OriginLab, Northampton, MA, USA) according to the methods provided by the manufacturer of the test kit.

3. Results and discussion

3.1. Simultaneous removal of ammonium, colour and TOC by coupling device

The wastewater treatment efficiency of the coupling device was compared with the single CEM system and the single Fe-C system, respectively, as shown in Fig. 3.

The nitrogen, colour and TOC were reduced to different degrees after being treated by the three devices. As for the single membrane system, although it removed ammonium from 231 mg/L to 78 mg/L with a removal rate of 66.2 % which was nearly as high as the coupling device (77.5 %) (Fig. 3a), it had slight effect on colour removal (Fig. 3b). Unexpectedly, the nitrite in the wastewater decreased significantly, which might be the combined effects of aeration, cation exchange membrane and the decreasing wastewater pH with the cation exchange process. In the single Fe-C system, due to the alkalinity of the wastewater and aeration of the operating condition, the half-cell reaction of carbon cathode can be represented as $O_2(g) + 2H_2O + 4e \rightarrow 4OH^-$ (aq), E^0 (O_2/OH^-) = +0.40 V [21]. The generated OH^- increased the effluent pH which would gradually passivate the iron-carbon composite material by forming an oxidation layer on its surface. As a result, only a small part of colour, nitrogen and TOC were removed by single Fe-C sys-

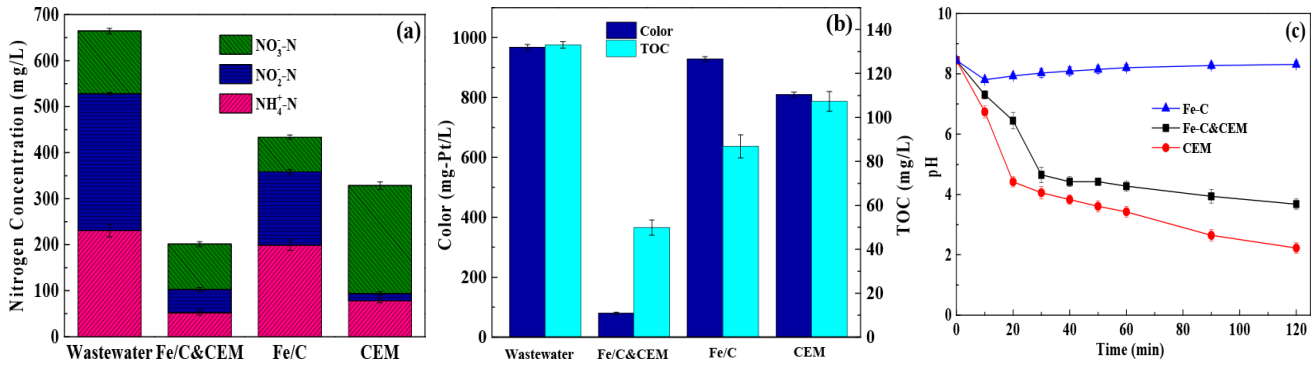

Fig. 3. Wastewater treatment efficiency of the coupling device (Fe-C&CEM), single CEM system (CEM) and single Fe-C system (Fe-C): **a** the concentration of inorganic nitrogen in wastewater after being treated by the three devices, **b** the concentration of colour and TOC in wastewater after being treated by the three devices, **c** the wastewater pH value in the three devices during the 2 h treatment. (Experiment condition: temperature = 20°C, operation time = 2 h, dosage = 1.2 g/mL).

tem with a slight pH increase of wastewater. In particular, among nitrogen, nitrite was removed the most followed by nitrate and ammonium. It was because the removal of contaminant by Fe-C was mainly through reduction effect, and nitrite was more easily reduced when compare with nitrate and ammonium [22,23]. In addition, it was notable that the nitrite and nitrate might not transform into ammonium but nitrogen. Because the concentration of ammonium, as shown in Fig. 3a, did not increase after the reduction of nitrate, but decreased from 221.3 mg/L to 190.9 mg/L. This was mainly attributed to ammonium adsorption by iron and/or activated carbon [24]. As expected, the coupling device combines the advantage of Fe-C and CEM and performs better than either of the single systems at colour, nitrite, TOC removal or ammonium decrease. In Fe-C&CEM, 83% of nitrite and 77% of ammonium were removed respectively, and the remained concentrations were below the corresponding toxic limits to Arthrospira [9]. Furthermore, the remained nitrite concentration in Fe-C&CEM was higher than that in single CEM system, which might do better in promoting the growth of Arthrospira [25]. Nitrate, the safest nitrogen source for Arthrospira, was retained approximately 72%. Meanwhile, the colour was dramatically decreased from 961 to 79 mg-Pt/L which would significantly reduce the light limitation.

On the one hand, the ammonium in wastewater was exchanged with H^+ through CEM which not only decreased the ammonium but also introduced H^+ and produced an acidic environment for Fe-C. The cation chromatography results showed that Na^+ (201.2 mg/L), K^+ (187.8 mg/L), Ca^{2+} (168.9 mg/L) and Mg^{2+} (21.1 mg/L) were the main cations in the wastewater except NH_4^+, and with the corresponded residual concentration of 69.1 mg/L, 54.2 mg/L, 73.8 mg/L and 8.5 mg/L after Fe-C&CEM treatment (without pH adjustment by NaOH solution), respectively. These cations were impossible removed by precipitation or other forms in such an acid environment, except for cation exchange as the NH_4^+ did. As a result, these cations in wastewater were also exchanged with H^+ in sulfuric acid (10 w%) through CEM which introduced H^+ and produced an acidic environment for Fe-C as well. Thus, the half-cell reaction of carbon cathode was changed to follow as $O_2(g)+ 4H^+(aq)+ 4e \rightarrow 2H_2O$, E^0 (O_2/H_2O) = +1.23 V [21]. Obviously, its potential difference was much higher than that in alkaline condition, which also indicated that the reaction of micro-electrolysis was accelerated. As a consequence, more nitrite, colour and TOC were removed by the coupling device when compared with the single Fe-C system under the same reaction time. Additionally, the consumption of H^+ in wastewater by Fe-C in the coupling device caused the rise of pH compared with single CEM system (Fig. 3c). It enlarged the chemical potential of the cation exchange and also promoted the process that resulted in a better ammonium removal performance of coupling device than that of single CEM system.

SEM images and EDX of Fe-C before/after reaction and the precipitation were obtained (Fig. 4). Obviously, the Fe and C were the main elements of Fe-C before/after reaction, even though the proportion of Fe element was decreased after reaction. Meanwhile, it was noteworthy that the P element was only detected in the precipitation, which also indicated the phosphorus in the wastewater might be removed by precipitation.

In addition, FT-IR analysis (Fig. 5) of the Fe-C before/after reaction and the precipitation were conducted. The peak at 1040 cm^{-1} that appeared on the precipitation showed characteristic stretching frequencies of P–O vibration [26]. Thus, it could be confirmed that the phosphate in the wastewater was removed by precipitation rather than adsorption on Fe-C.

The probable mechanism of high efficiency of contaminants removal in the coupling device is illustrated in Fig. 6. The high concentration of ammonium and other lower concentrations of cations in the wastewater were rapidly exchanged with H^+ through CEM, which not only decreased the ammonium concentration but also the pH of the wastewater. Then the reaction of micro-electrolysis was accelerated, and more nitrite, colour and TOC were removed by Fe-C micro-electrolysis process in an acidic environment. At last, the phosphate in the wastewater was removed by precipitation rather than adsorption on Fe-C.

3.2. *Cultivation of Arthrospira with the coupling device effluent*

In order to evaluate the influence of coupling device treatment on enhancing wastewater quality for Arthrospira cultivation, ZJWST-S1 was cultured with the coupling device effluent and four controls (raw wastewater, single

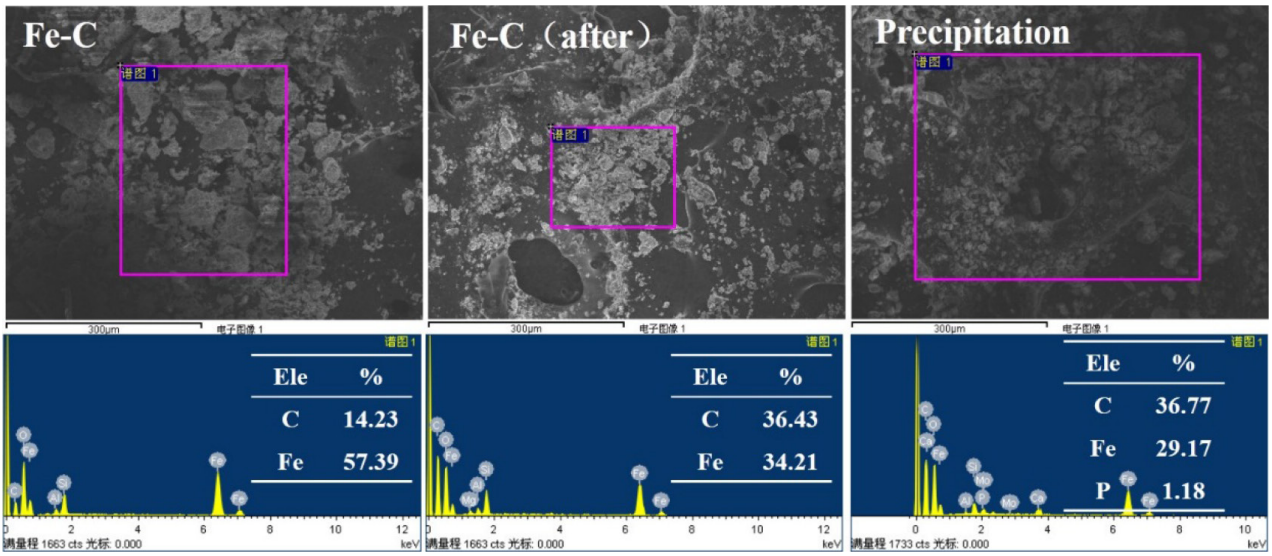

Fig. 4. SEM images and EDX spectra analyses of Fe-C before/after reaction and the precipitation.

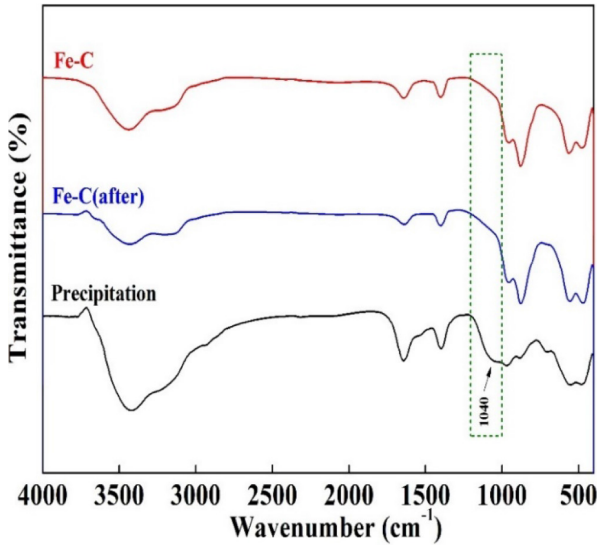

Fig. 5. FT-IR spectra of Fe-C before/after reaction and the precipitation.

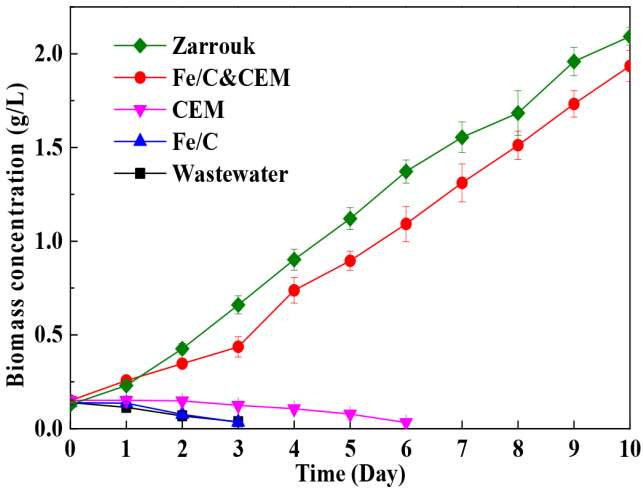

Fig. 7. Growth rate of *A. platensis* ZJWST-S1 in the three device effluent and the controls (raw wastewater and Zarrouk medium), (Experiment condition: Temperature = 30 ± 1°C, Light intensity = 6000 ± 2000 lux, Day–night cycle = 14–10 h).

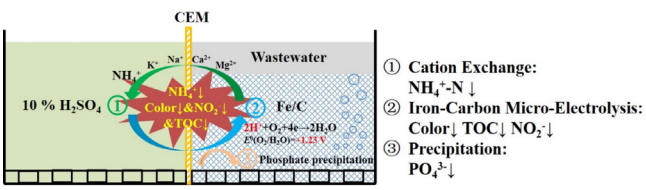

Fig. 6. Schematic diagram of the mutual promoted effects on cation exchange and Fe-C micro-electrolysis in the coupling device.

Fe-C treated wastewater, single CEM treated wastewater and Zarrouk medium), respectively, and the results of batch experiments are shown in Fig. 7.

The coupling device effluent and single Fe-C treated wastewater were both added approximate 20 mg/L PO_4^{3-}-P and in keeping with raw wastewater, because the original phosphate in wastewater was almost removed in the precipitation process. Meanwhile, there was nearly no phosphorus loss for the single CEM treated wastewater, therefore no extra phosphate was added.

The growth rate of ZJWST-S1 in coupling device effluent (0.172 g/L/d) was similar to that in Zarrouk medium (0.194 g/L/d). It was noteworthy that Zarrouk medium as a common medium for Arthrospira cultivation, whose cost was much more expensive than Pig Wastewater [27]. Thus, the wastewater treated by the iron-carbon micro-electrolysis and cation exchange membrane coupling device had advantage in cost efficiency for cultivating Arthrospira. On the other hand, although the nitrite and colour were able to be removed by single Fe-C micro-electrolysis, ZJWST-S1 cannot grow in the related effluents. This was because the

ammonium in Fe-C effluent still reached up to 200 mg/L that was too high and toxic for Arthrospira growth [28]. On the contrary, the single CEM process could remove only partial ammonium and little colour through cation exchange, thus the still high ammonium concentration and dark colour inhibited the growth rate of Arthrospira. Correspondingly, the Arthrospira also cannot survive in that medium and die in 6 days. As to the raw wastewater, its ammonium, nitrite and colour were all inadaptable for Arthrospira growth, obviously, ZJWST-S1 died in 3 d (Fig. 7).

4. Conclusion

A novel wastewater treatment coupling device which integrates the advantages of Fe-C micro-electrolysis and cation exchange membrane has been successfully designed and operated for Arthrospira cultivation. In the coupling device, 77% of ammonium and 92% of colour were removed respectively and below the corresponding toxic limitations, which are the two main inhibiting factors for Arthrospira cultivation. More importantly, the cation exchange process and Fe-C micro-electrolysis process are mutually promoted, and obtained better treatment efficiency than single system on ammonium, colour and TOC. Meanwhile, the nitrite and nitrate were retained to appropriate concentrations. Hence, the cultivation of *A. platensis* ZJWST-S1 in the three device effluents and controls showed that only the wastewater treated by the coupling device was more suitable for cultivating Arthrospira and the related growth rate of ZJWST-S1 (0.172 g/L/d) was similar to that in Zarrouk medium (0.194 g/L/d).

Acknowledgements

This research was supported by the Zhejiang Provincial Key Research Project (2014C03022) and the Science and Technology Program in Jiaxing (2016AY23102 and 2017AY33088). The authors sincerely thank Senior Engineer Wang Genrong in Nanhu Agricultural Economical Bureau, Jiaxing, China and Dong Qiaohong in Yangtze Delta Region Institute of Tsinghua University for providing wastewater and *Arthrospira*, respectively. The authors sincerely thank Pingxiang Top Environmental Protection Technology Co., Ltd. for providing iron-carbon composite material. The authors also give thanks to Dr. Xia Dong and Dr. Jamie Mannering for polishing English.

References

[1] S. Wang, L. Wang, L. Deng, D. Zheng, Y. Zhang, Y. Jiang, H. Yang, Y. Lei, Performance of auto trophic nitrogen removal from digested piggery wastewater, Bioresour. Technol., 241 (2017) 465–472.
[2] N. Kishida, J.H. Kim, M. Chen, Effectiveness of oxidation-reduction potential and pH as monitoring and control parameters for nitrogen removal in swine wastewater treatment by sequencing batch reactors, J. Biosci. Bioeng., 96 (2003) 285–290.
[3] L. Wang, J. Xu, S. Ma, B. Zhao, Z. Zhang, X. Zhou, H. Zhang, Biological nitrogen removal in a modified anoxic/oxic process for piggery wastewater treatment, Desal. Water Treat., 57 (2015) 11266–11274.
[4] R. Rajagopal, P. Rousseau, N. Bernet, F. Beline, Combined anaerobic and activated sludge anoxic/oxic treatment for piggery wastewater, Bioresour. Technol., 102 (2011) 2185–2192.
[5] S. Sun, i. Pellicer, B. Merkey, Q. Zhou, S. Xia, D. Yang, J. Sun, B. Smets, Effective biological nitrogen removal treatment processes for domestic waste waters with low C/N ratios: a review, Environ. Eng. Sci., 27 (2010) 111–126.
[6] M. Kim, J. Park, C. Park, S. Kim, K. Jeune, M. Chang, J. Acreman, Enhanced production of Scenedesmus spp. (green microalgae) using a new medium containing fermented swine wastewater, Bioresour. Technol., 98 (2007) 2220–2228.
[7] W. Oswald, H. Gotass, Photosynthesis in sewage treatment, Trans. Amer. Soc. Civil Engrs., (United States), 122 (1957).
[8] Y. Azov, J.C. Goldman, Free ammonia inhibition of algal photosynthesis in intensive cultures, Appl. Environ. Microb., 43 (1982) 735–739.
[9] R. Liu, Q. Guo, W. Zheng, L. Chen, J. Luo, Cultivation of an Arthrospira platensis with digested piggery wastewater, Water Sci. Technol., 72 (2015) 1774–1779.
[10] O. Depraetere, I. Foubert, K. Muylaert, Decolorisation of piggery wastewater to stimulate the production of Arthrospira platensis, Bioresour. Technol., 148 (2013) 366–372.
[11] X. Guo, X. He, H. Zhang, Y. Deng, L. Chen, J. Jiang, Characterization of dissolved organic matter extracted from fermentation effluent of swine manure slurry using spectroscopic techniques and parallel factor analysis (PARAFAC), Microchem. J., 102 (2012) 115–122.
[12] H. Cheng, W. Xu, J. Liu, H. Wang, Y. He, G. Chen, Pretreatment of wastewater from triazine manufacturing by coagulation, electrolysis, and internal micro electrolysis, J. Hazard. Mater., 146 (2007) 385–392.
[13] Y. Jin, Y. Zhang, W. Li, Micro-electrolysis technology for industrial wastewater treatment, J. Environ. Sci., 15 (2003) 334–338.
[14] B. Chen, X. Tian, L. Yu, Z. Wu, Removal of pigments from molasses wastewater by combining micro-electrolysis with biological treatment method, Bioproc. Biosyst. Eng., 39 (2016) 1867–1875.
[15] B. Lai, Y. Zhou, P. Yang, J. Yang, J. Wang, Degradation of 3,3′-iminobis-propanenitrile in aqueous solution by Fe(0)/GAC micro-electrolysis system, Chemosphere, 90 (2013) 1470–1477.
[16] C. Zhang, M. Zhou, G. Ren, X. Yu, L. Ma, J. Yang, F. Yu, Heterogeneous electro-Fenton using modified iron-carbon as catalyst for 2,4-dichlorophenol degradation: influence factors, mechanism and degradation pathway, Water Res., 70 (2015) 414–424.
[17] Y. Huang, T. Zhang, Effects of low pH on nitrate reduction by iron powder, Water Res., 38 (2004) 2631–2642.
[18] X. Song, R. Liu, L. Chen, B. Dong, T. Kawagishi, Advantages of intermittently aerated SBR over conventional SBR on nitrogen removal for the treatment of digested piggery wastewater, Frontiers of Environmental Science & Engineering, 11 (2017).
[19] A.P.H.A., A.W.W.A., W.E.F., Standard methods for the examination of water and wastewater, 21st Edition, American Public Health Association, Washington. DC, 2006.
[20] G. Markou, D. Vandamme, K. Muylaert, Using natural zeolite for ammonia sorption from wastewater and as nitrogen releaser for the cultivation of Arthrospira platensis, Bioresour Technol., 155 (2014) 373–378.
[21] X. Ruan, M. Liu, Q. Zeng, Y. Ding, Degradation and decolorization of reactive red X-3B aqueous solution by ozone integrated with internal micro-electrolysis, Sep. Purif. Technol., 74 (2010) 195–201.
[22] H.O. Tugaoen, S. Garcia-Segura, K. Hristovski, P. Westerhoff, Challenges in photocatalytic reduction of nitrate as a water treatment technology, Sci. Total Environ., 599–600 (2017) 1524–1551.
[23] P. Tandon, S. Singh, Redox processes in water remediation, Environ. Chem. Lett., 14 (2015) 15–25.
[24] J. Luo, G. Song, J. Liu, G. Qian, Z. Xu, Mechanism of enhanced nitrate reduction via micro-electrolysis at the powdered zero-valent iron/activated carbon interface, J. Colloid Interf. Sci., 435 (2014) 21–25.

[25] G. Markou, D. Georgakakis, Cultivation of filamentous cyanobacteria (blue-green algae) in agro-industrial wastes and waste waters: A review, Appl. Energ., 88 (2011) 3389–3401.
[26] X. Cheng, X. Huang, X. Wang, D. Sun, Influence of calcination on the adsorptive removal of phosphate by Zn-Al layered double hydroxides from excess sludge liquor, J. Hazard Mater., 177 (2010) 516.
[27] R. Chaiklahan, Cultivation of spirulina platensis using pig wastewater in a semi-continuous process, J. Microbiol. Biotechnol., 20(3) (2010) 609–614.
[28] M. Esen, R. Ozturk Urek, Ammonium nitrate and iron nutrition effects on some nitrogen assimilation enzymes and metabolites in Spirulina platensis, Biotechnol. Appl. Biochem., 62 (2015) 275–286.