Supporting information

The reactor construction

The electrocoagulation reactors were built on cuboid plexiglas cells (length (x) × width (y) × height (z), 100 mm×100 mm× 120 mm). The driving electrodes consist of one graphite plate (100 mm×120 mm×5 mm) as cathode electrode and one Fe or Al plate (100 mm×120 mm×0.2 mm) as anode electrode. This pair of driving electrodes are fixed on the two side inner wall oppositely of the reactor and connected to a direct current (DC) power supply (HSPY-36-03, China) via copper wire as shown in Fig. 1(b). Fe plates (50 mm × 50 mm × 0.2 mm) and Al plates (50 mm × 50 mm × 0.2 mm) were used as BPEs which were placed and fixed at the center of the cell using white nylon 66 sewing thread. Before installed in the reactor, all electrode materials were cleaned by ultrasonic wave, and then washed with ethanol and DI-water. The municipal wastewater source used in this study had turbidity of 46.9 ± 2 NTU, a pH of 6.7-6.8, a TOC of 286 ± 5 mg/L, a total nitrogen concentration of 83.6 ± 3 mg/L, and a phosphate concentration of 2.8 ± 0.2 mg/L.

Analytical methods

The concentration of Fe and Al were detected by inductively coupled plasma optical emission spectrometer (ICP-OES, Perkin-Elmer Optima 5300DV, U.S.). The total organic carbon (TOC) was analyzed by using total organic carbon analyzer (Shimadzu, VSCN8, Japan). Total phosphorus (TP) by using Method 10031 (HACH Company, Loveland, CO) and total nitrogen (TN) was analyzed by using Method 10071 (HACH Company, Loveland, CO). The turbidity of water samples was measured using a portable turbidimeter (VELP Scientifica, Italy), the conductivity and pH of solution were measured by using conductometer (Type CON2700, Eutech, U.S.) and pH meter (Type MT-5000, China), respectively.

Mechanisms

Fig.1(a) shows the basic content and running mechanism of conventional two-dimension EC process. The sacrificial metal M (Fe or Al) is dissolved at the anode to produce the corresponding Fe or Al hydroxides and/or polyhydroxides that absorb or co-precipitate with the dissolved pollutants and suspended particles. Simultaneously, the generated gas at the cathode also helps to stir and float the flocculated particles at the water surface (Moreno-Casillas et al., 2007; Song et al., 2014). Fig. 1(b) is a side view of the experimental configuration used to control a single BPE within an EC reactor, we have described this type of device in detail previously (Qi et al., 2017). As demonstrated Fig. 1(b), a voltage difference (E_{tot}) between two driving electrodes dropped linearly along the BPE length in solution. In the present of electric field, the interfacial potential difference between the solution and the poles of the BPE (ΔE_{bpe}) drives a pair of redox reactions on BPE surface, dissolution reactions of metal (M) on anode pole and gas (H_2) generation reactions on cathode pole. The magnitude of ΔE_{bpe} depends on the length of the BPE (l_{bpe}) and the solution (l_{sol}) (Duval et al., 2001), which can be approximated by the below equation (Eq. (1)):

$$\Delta E_{bpe} = \frac{E_{tot}}{l_{sol}} l_{bpe} \quad (1)$$

With the integration of EC and BPE, flocculant ions generates from both on the driving anode and BPE anodic pole, which will effectively improve the EC performance as illustrated in Fig. 1(b).

Figures

Fig. S1 shows the most common electrodes arrangement for EC process, for monopolar electrodes in parallel connections (Fig. S1(a)), all the anodes are connected in series and to the driving anode, and the cathode electrodes are connected in the same way. For monopolar electrodes in parallel connections (Fig. S1(a)), each pair of cathode/anode is applied by a same voltage, whereas the current is divided between the electrodes resulting in a higher current on each electrode. Consequently, monopolar electrodes require a low voltage but a higher current contrary to two-dimension EC (Emamjomeh and Sivakumar, 2009). For bipolar electrodes in parallel and series connections (Fig. S1(b) and (c)), outermost electrodes are directly connected to the external power supply, while the inner electrodes connected (Fig. S1(b)) or not (Fig. S1(b)) are placed in electrolyte without any wire connection to the outermost electrodes. In such case, the bipolar electrodes can act simultaneously as an anode and a cathode, which means that bipolar electrodes will operate under a lower current but require a higher voltage (Mahvi et al., 2011; Sahu et al., 2014).

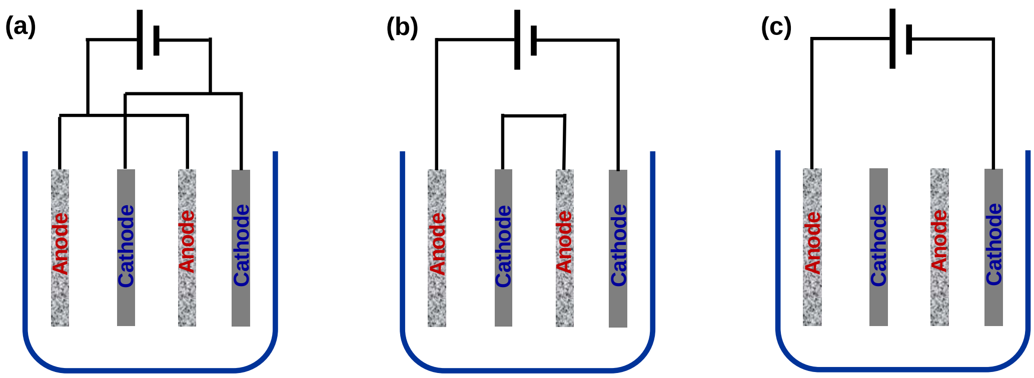

Fig. S1 Monopolar electrode (a) in parallel in series connections; bipolar electrode (b) in series connections; (c) in parallel connections.

Fig. S2 presents the pH value at the end of each EC reactor with the initial pH of municiple wastewater of 6.77. The pH value is an important parameter in electrocoagulation process as it directly affects the hydrolysis polymerization reaction in EC process (Ben Sasson et al., 2009; Dubrawski and Mohseni, 2013). With either Fe or Al as driving electrode, the pH value increased negligibly and the solution remained neutral or weakly alkaline with a maximum pH value of 7.45 obtained in Fe-WEC-2Fe/BPE. As a result, the addition of BPEs has slightly effect on pH in solution.

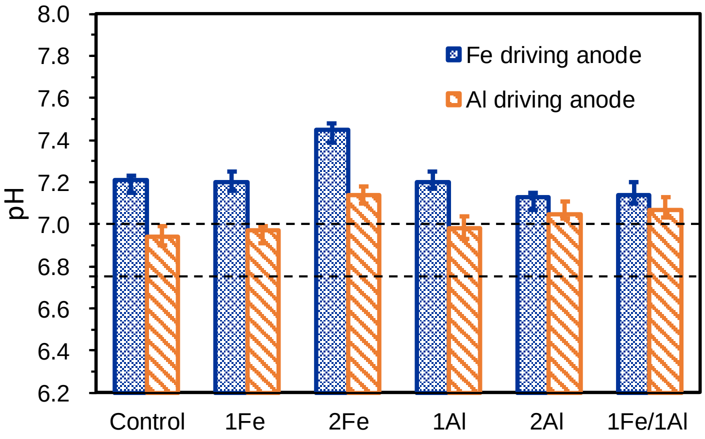

Fig. S2 Effect of different integrations of EC and BPEs on pH value of municiple wastewater (initial pH 6.77).

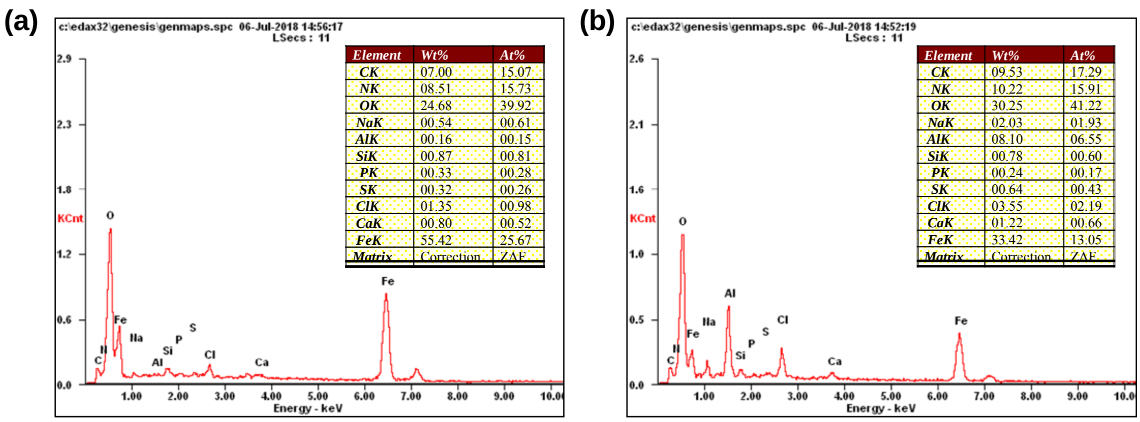

Fig. S3 EDS of sediments in (a) Fe-WEC-2Fe, (b) Fe-WEC-2Al.

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