Pretreatment of evaporated condensate generated during metal cutting process by Fe-C micro-electrolysis
Weiteng Lin, Ji Li, Xiaolei Zhang and Wenyi Dong

ABSTRACT

Fe-C micro-electrolysis was employed to the pretreatment of evaporated condensate generated during metal cutting process. The effect of the reaction conditions on the contaminant removal and degradation mechanism were studied. Through single-factor experiments, the effects of solid–liquid ratio, gas–liquid ratio and reaction time on the treatment of wastewater were preliminarily determined. The optimal reaction condition obtained was: 500 g/L solid–liquid ratio, 30:1 gas–liquid ratio with 4 h reaction time. Under the optimal condition, the chemical oxygen demand (COD) removal efficiency of micro-electrolysis could reach around 25%, and the biodegradability of wastewater increased from 0.12 to 0.32. According to the analysis results of gas chromatography–mass spectrometry (GC-MS) qualitative analysis, it was observed that the most organic contaminants in the influent were degraded or converted into simple structures under Fe-C micro-electrolysis, indicates that Fe-C micro-electrolysis pretreatment could improve the biodegradability of the evaporated condensate generated during metal cutting process and achieve certain degree removal of COD.

Key words | biodegradability, evaporated condensate, Fe-C micro-electrolysis, pretreatment, qualitative analysis

INTRODUCTION

During the process of metal machining, metal cutting fluid is generally used to cool and lubricate cutting tools in order to prolong their service life and improve cutting efficiency (Rahman 2008). Water-based cutting fluid is the most popular one as it is non-flammable and easy to dilute (Feng 2011), and the main components of this fluid are emulsions and synthetic cutting fluid. However, high temperature is induced during the machining process, which leads to the cutting fluid losing its function and needing to be replaced. Thus, the waste liquid that generated during this process is called waste metal cutting fluid, and the evaporation condensate is obtained from this waste liquid by evaporation and degreasing. Contaminants in evaporated condensate are mainly derived from surfactants, oil and various types of additives, which contain various refractory organic pollutants (benzene series and halogenated hydrocarbons) as well as inorganic salts (Li 2013), such as benzene series and halogenated hydrocarbons, which seriously affect the biodegradability of wastewater and increase the difficulty of biological treatment.

The method for pretreatment of waste metal cutting fluid is first demulsification for separating the oil from the waste fluid. Currently the most widely used separation methods mainly include acidification-demulsification and evaporation-demulsification. Some researchers (Mao et al. 2016) have used demulsification-Fenton combination method to deal with waste metal cutting fluid. The study showed that the chemical oxygen demand (COD) of the waste metal cutting fluid was reduced by 80% and the biodegradability index increased to 0.32 at pH 2.0, 90 °C after 120 min reaction time, and it enhanced the biochemical treatment efficiency. However, the acidification method requires a large amount of acid to be added and the treatment facilities need to have strong resistance to acid, which leads to a large amount of alkali consumption in the later neutralization of acidity. In addition, when sulfuric acid is used for acidification-demulsification, a large amount of SO42− could have adversely impacted on the anaerobic phase of subsequent biochemical treatment (Pu et al. 2015). Therefore, from the perspective of economy and demulsification efficiency, the evaporation-demulsification method would be a better choice. Demulsification is achieved by changing the properties of the emulsion and increasing...
intermolecular thermal motion by heating, and also reducing the viscosity and interfacial tension of the emulsion, thus facilitating the separation of oil (Peng 2017). After removing the oil, the evaporated condensate still contains a high concentration of refractory organics, and it is necessary to conduct physicochemical treatment to increase the biodegradability of the waste liquid subsequently.

Micro-electrolysis is an effective physico-chemical pretreatment technology for high-concentration and hard-degradable wastewater. Micro-electrolysis is a process based on the principle of electrochemical redox reaction, supplemented by adsorption and coagulation, to break macromolecule organic contaminants and decompose it into easily biodegradable small-molecule organics without selectivity. It thus increases the biodegradability of wastewater and provides favorable conditions for following treatment (Cheng et al. 2007; Yang 2009; Liu et al. 2017). At present, micro-electrolysis technology is mostly used for wastewater pretreatment under acidic conditions. It was due to this that the following electrochemical reaction occurred when the reaction environment was acidic (Zhang et al. 2014).

Anode:

\[ 2\text{Fe}_0 - 4e^- \rightarrow 2\text{Fe}^{2+} \quad E_0(\text{Fe}^{2+/\text{Fe}}) = -0.44\text{V} \]

Cathode (under acidic aeration conditions):

\[ \text{O}_2 + 4\text{H}^+ + 4e^- \rightarrow 2\text{H}_2\text{O} \quad E_0(\text{O}_2/\text{H}^+) = 1.23\text{V} \]

\[ \text{O}_2 + 2\text{H}^+ + 2e^- \rightarrow \text{H}_2\text{O}_2 \quad E_0(\text{O}_2/\text{H}_2\text{O}_2) = 0.68\text{V} \]

Cathode (under neutral aeration conditions):

\[ \text{O}_2 + 2\text{H}_2\text{O} + 4e^- \rightarrow 4\text{OH}^- \quad E_0(\text{O}_2/\text{OH}^-) = 0.41\text{V} \]

The \( \text{Fe}^{2+} \) produced by the Equation (1) has a strong reducibility, which could trigger additional reaction and bond-breaking reaction with organic substances. Hence, macromolecule refractory organic matter is converted into small molecule organic matter. The \( \text{H}_2\text{O}_2 \) produced by Equation (3) could generate Fenton-like reaction system with \( \text{Fe}^{3+} \) in aerated micro-electrolysis system. The produced \( \text{OH}^- \) (hydroxyl radicals) with strong oxidizing property, allows the organic matter to be decomposed (Li et al. 2017). However, under the acidic reaction conditions, a large amount of \( \text{Fe}^{2+} \) is generated, and the pH of the effluent is generally below 7. If biological treatment is required after the micro-electrolysis pretreatment, the pH adjustment with alkali is required to ensure the biological reaction to proceed. It would hence increase the operating costs as well as generate large amounts of iron salt precipitate.

In Shenzhen, currently, many mechanical processing factories were using the following method to degrease the waste metal cutting fluid: the fluid is first allowed to pass through a film evaporator, and then the volatile hydrocarbons, organic acids and ammonia in the wastewater is evaporated at different temperatures. After the condensation process, evaporated condensates of wastewater are formed. The remaining concentrated solution obtained after evaporation mainly contains oil, heavy metals, inorganic and involatile organics. There are great demand on management of the evaporative concentrated wastewater. Biological method is considered to be a suitable option as it is cost-efficient and environmental friendly. However, the biodegradability of the concentrated solution is rather low. It is necessary to pretreat the solution for enhancing its biodegradability in order to improve the biological treatment efficiency.

In this study, a neutral aeration Fe-C micro-electrolysis pretreatment method was employed for COD removal and biodegradability improvement of evaporative condensate wastewater. The effect of the solid–liquid ratio, gas–liquid ratio and reaction time on COD removal and biodegradability improvement of the wastewater were investigated. In addition, the structural changes of organic contaminants were evaluated as well, so as provided a feasible approach for physicochemical pretreatment and subsequent biological treatment design.

**MATERIALS AND METHODS**

**Evaporated condensate wastewater**

The wastewater used in the experiment was collected from a mechanical processing factory located in Shenzhen. The wastewater is mainly the condensed water produced by evaporation of the waste metal cutting fluid but also includes a small amount of wastewater generated during mechanical production process. Considering the oil in the wastewater would impede the micro-electrolysis reaction, the wastewater was first treated by a small oil separation tank to remove the oil, and the remaining part was the target wastewater for treatment. The wastewater characteristics are shown in Table 1.

The wastewater contained high concentrations of COD and ammonia nitrogen. The biochemical oxygen demand (BOD) to COD ratio (represent the biodegradability of wastewater) was about 0.17, which indicated the poor biodegradability of the wastewater.
Materials

The filler of the Fe-C system was purchased from a water treatment agent company located in Henan province. The filler was ellipsoidal with 20–40 mm in diameter, and contained iron powder (≥82% w/w), activated carbon (≥12% w/w), non-ferrous metal catalyst (1%–3% w/w). The density of the mixture was 1.2 tons/m³. Before the experiment, the Fe-C filler was soaked in 5% sulfuric acid for 2 h to remove the oxidizing substance on the filler surface for activation.

Methods and analysis

Fe-C micro-electrolysis experiment

Studies have shown that the volume ratio of filler to wastewater, the amount of aeration and the reaction time were the three main factors that determined the performance of micro-electrolysis (Zhou et al. 2014; Hu et al. 2015). Therefore, in this study, the three factors of solid–liquid ratio, gas–liquid ratio and reaction time were investigated on the effect of the treatment. The single-factor experiment was performed in a beaker with a volume of 2 L and 6 levels were set for each factor (Figure 1). Parallel samples were taken after the completion of the reaction to determine the concentration of BOD, COD and total ferric ion in the effluent samples. The removal efficiency and the BOD/COD of the wastewater were also calculated.

The micro-electrolysis continuous experiment was carried out in a Plexiglas reaction column (Figure 2). The influent was charged from the bottom and the effluent was collected from the top. The aerator was set at the bottom of the column, and the aeration tube was connected with the air compressor. A gas flow meter was disposed in the middle of the aeration tube to control air volume. The continuous experiment lasted for 20 d and samples were withdrawn every 12 h. The COD, BOD, total ferric ion were analyzed with testing standard (State Environmental Protection Administration Editorial 2002).

Table 1 | The characteristics of the wastewater

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Range</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>COD (mg/L)</td>
<td>2,500–7,000</td>
<td>4,750</td>
</tr>
<tr>
<td>BOD (mg/L)</td>
<td>350–1,100</td>
<td>690.58</td>
</tr>
<tr>
<td>pH</td>
<td>6.4–7.3</td>
<td>6.86</td>
</tr>
<tr>
<td>SS (mg/L)</td>
<td>10–18</td>
<td>14</td>
</tr>
<tr>
<td>TP (mg/L)</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>NH₃-N (mg/L)</td>
<td>40–90.8</td>
<td>65.4</td>
</tr>
<tr>
<td>Cr (mg/L)</td>
<td>0.8–1.6</td>
<td>1.2</td>
</tr>
<tr>
<td>TDS (mg/L)</td>
<td>320–352</td>
<td>336</td>
</tr>
<tr>
<td>Salinity (psu)</td>
<td>0.28–0.38</td>
<td>0.33</td>
</tr>
</tbody>
</table>

COD, BOD and total ferric ion were all performed according to the relevant testing standards (State Environmental Protection Administration Editorial 2002). The reagents used in the experiments were of analytical grade.
In order to control the concentration of iron ions in the micro-electrolysis effluent and facilitate subsequent processing, the influent pH was controlled to be neutral in this study. Under neutral conditions, the system has no obvious degradation effect on ammonia nitrogen, so the changes of system pH and ammonia nitrogen will not be investigated in the later study.

Gas chromatography–mass spectrometry (GC-MS) analyze method

Certain amount of sample was taken and mixed with dichloromethane at a volume ratio of 1:1 under neutral conditions, and mixing was performed for 10 min in a shaker. After the aqueous phase was separated, secondary extraction was continued using dichloromethane, and finally the organic phases obtained by the two extractions were united. An appropriate amount of anhydrous sodium sulfate was added to absorb the residual moisture in the organic phase. 1.5 mL of the extract was withdrawn and analyzed with Agilent GC-MS (model 7890A-5975C). Detection parameters employed were as follows: split injection, split ratio was 20:1, inlet temperature was 250 °C, He flow rate was 1 mL·min⁻¹ with 9.5825 psi pressure, temperature increase at 10 °C·min⁻¹. Mass spectrometry operating conditions: ionization method was EI, electron bombardment energy was 60 eV, and the scan range m/z was from 50 to 500 amu (Ye et al. 2011).

RESULTS AND DISCUSSION

Optimization of micro-electrolysis operation parameter

Effect of solid–liquid ratio on COD removal and improvement of biodegradability of the wastewater

The experiment was carried out in a beaker under the conditions of a gas–liquid ratio of 30:1 and a reaction time of 3 h. The solid–liquid ratio was designed to be 100, 200, 300, 400, 500 and 600 g/L, respectively. The COD, BOD and total ferric ion were measured in triplicate. The experimental results are shown in Figure 3(a) and 3(b).

As shown in Figure 3(a) and 3(b), the COD removal efficiency, total ferric ions precipitation, BOD concentration and biodegradability of the effluent were positively correlated with the solid–liquid ratio. It was due to that the solid–liquid ratio determines the number of galvanic batteries for treating per unit volume wastewater. The higher the solid–liquid ratio was, the greater the number of galvanic cells could be provided in the micro-electrolysis system. Hence, it increased the removal of COD. When the solid-liquid ratio was 600 g/L, the COD removal efficiency reached a maximum of 31.5%, the total ferric ions precipitation amount was 12.762 mg/L, and the BOD concentration reached to 443.96 mg/L with the corresponding BOD/COD value was 0.426. It showed that the effluent biodegradability could be improved. However, in increasing the rate of the removal efficiency of COD was not obvious when the solid–liquid ratio was relatively high. When the amount of Fe-C filler is sufficient, the solid–liquid ratio will not be the critical parameter on determining the micro-electrolysis treatment effect. In addition, if the ratio of solid to liquid is too high, the dissolution amount of iron ions will accordingly increase. It would lead to the effluent with a certain degree of chroma, and hence increase the difficulty of the following treatment. Therefore, in order to ensure the efficient performance of micro-electrolysis, and consider the control of ferric ion concentration and facilitate the subsequent activation of filler, the solid–liquid ratio of 500 g/L.
was more suitable than other ratios for COD removal and biodegradability improvement of the wastewater.

Effect of gas–liquid ratio on COD removal and improvement of biodegradability of the wastewater

The experiment was carried out in a beaker under the conditions of a solid–liquid ratio of 500 g/L and a reaction time of 3 h. The gas–liquid ratio was designed to be 5:1, 10:1, 20:1, 30:1, 40:1 and 50:1, respectively. The COD, BOD and total ferric ion were measured in triplicate. The experimental results are shown in Figure 4(a) and 4(b).

As shown in Figure 4(a), with the increase of gas–liquid ratio, the COD removal efficiency showed a trend of increasing first and then decreasing. When the ratio of gas to water was 30:1, the COD removal efficiency reached a maximum of 23.2%, and the total iron dissolution was 8.58 mg/L. Low gas–liquid ratio caused insufficient oxygen supply, which led to the failure of the reaction in the cathode. Moreover, the micro-bubbles generated at the low gas–liquid ratio would adhere to the surface of the Fe-C filler, and hence hinder the contact between wastewater and filler. When increasing the ratio of gas to liquid, the disturbance of the water flow could promote the renewal of the surface of the filler. Hence the wastewater could make full contact with the filler. Under neutral conditions, the increase of the gas–liquid ratio could promote the reaction of Equation (4), thus increase the potential difference between cathode and anode, as well as the number of electron acceptors. More OH⁻ would be generated in the system. These OH⁻ could combine with Feⁿ⁺ produced from the anode to generate Fe(OH)ₙ. Fe(OH)ₙ could adsorb organic contaminants in the water and promote the removal of COD.

However, when the gas–liquid ratio continued to increase, the COD removal efficiency decreased. The pollutants degradation by micro-electrolysis mainly depended on the reduction of H⁺ (reductive hydrogen). However, excessive gas–water ratio would cause extremely high concentration of O₂ in the system and consume the generated H₂, thereby limiting the micro-electrolysis reaction. Moreover, excessively high concentration of O₂ will accelerate the anodic reaction of micro-electrolysis, accelerate the oxidation of Fe and increase the concentration of ferric ions in the wastewater.

As shown in Figure 4(b), with the increase of the gas–liquid ratio, the BOD/COD of the wastewater increased first and then tended to be flat. It indicates that excessive high gas–liquid ratio had no obvious improvement on the degradation of organic pollutants, the reason was similar to the decrease in the removal efficiency of COD. Therefore, the gas–liquid ratio of 30:1 was considered to be the optimal one for COD removal and biodegradability improvement.

Effect of reaction time on COD removal and improvement of biodegradability of the wastewater

The experiment was carried out in a beaker under the conditions of a solid–liquid ratio of 500 g/L and a gas–liquid ratio of 30:1. The reaction time was set to be 1, 2, 3, 4, 5 and 6 h, respectively. The COD, BOD and total ferric ion were measured in triplicates. The experimental results are shown in Figure 5(a) and 5(b).

As shown in Figure 5(a) and 5(b), the COD concentration in the wastewater gradually decreased with the increase of reaction time, but the amount of COD removal efficiency increased first and then gradually decreased. Moreover, the concentration of BOD initially increased from 0 h to 4 h, thereafter it remained stable. The BOD to COD ratio of the wastewater reached more than 0.3 after 4 hours of reaction. At the beginning of the reaction, the filler activity was high, and the wastewater and the filler...
could effectively make contact. The COD removal efficiency was reached 13% within the first two hours. With the increase of reaction time, the increment of COD removal efficiency was slowed down. It was due to that the reaction shown in Equation (4) was continuously carried out in the neutral aeration micro-electrolysis system, and the amount of \( \text{OH}^- \) generated by the reaction also increased. It promoted the production of colloidal floculant \( \text{Fe(OH)}_n \). Some of the contaminants were partially removed according to the mechanism of electro-neutralization, adsorption bridges and roll sweeps. However, in the later stage of the reaction, the flocculation of organic contaminants was accumulated on the surface of the filler due to the effect of electro-adhesion. It caused the decrease in the electrode reaction rate and thus hindered further degradation of the organic contaminants, which lead to the COD removal efficiency and BOD concentration were almost stable after 4 h.

With the increase of reaction time, the reaction shown in Equation (1) continuously carried out, and the concentration of iron ions dissolved in wastewater also increased. The effluent at 5 h has appeared yellow color due to the formation of \( \text{Fe}^{3+} \). It was detected that the ferric ion concentration was 15 mg/L. Considering the filler activity and the amount of ferric ions dissolved, the reaction time of 4 h was suitable for COD removal and biodegradability improvement.

**Continuous Fe-C micro-electrolysis system for COD removal**

Based on the results of single-factor experiments, the optimal experimental conditions for pretreatment of evaporative condensate with micro-electrolysis were determined: the solid–liquid ratio was 500 g/L, the gas–water ratio was 30:1 and the reaction time was 4 h. For a single experiment, Fe-C micro-electrolysis could achieve the theoretical COD removal efficiency, but for continuous operation conditions, the anastomosis of the treatment effect cannot be fully guaranteed. Therefore, the conclusions obtained from single-factor experiments could be used as a reference for continuous operation experiments.

To examine the effective operation period of Fe-C micro-electrolysis and maintain the processing efficiency of the filler, the activated fresh filler was used in the continuous experiment. The continuous experiment lasted for 20 d, and the results are shown in Figure 6.

The operating state of the Fe-C micro-electrolysis system could be roughly divided into three periods: active period, stable period and decay period (Figure 6). In the first 5 days, COD removal efficiency was up to 35.5%. According to the analysis, in the early stage of micro-electrolysis, the activated carbon in the filler had its adsorption function. Organic pollutants were removed due to the adsorption. In addition, there was the redox effect of the micro-electrolytic galvanic cells, which could synergistically degrade the organic substances.

![Figure 5](https://iwaponline.com/wst/article-pdf/79/3/580/589677/wst079030580.pdf)

**Figure 5** | (a) Effect of reaction time on COD degradation and total iron precipitation. (b) Effect of reaction time on BOD concentration and biodegradability.

![Figure 6](https://iwaponline.com/wst/article-pdf/79/3/580/589677/wst079030580.pdf)

**Figure 6** | Continuous operation experimental results of micro-electrolysis column.
The COD removal efficiency tended to be flat and fluctuated around 27%. The COD removal efficiency entered a stable period. It could be due to the fact that the adsorption of activated carbon was nearly saturated. Moreover, the aeration and wastewater flowing caused a portion of activated carbon on the surface of the filler is taken out along with the effluent, resulting in a reduction in the number of cathodes in the micro-electrolytic galvanic cells system, which leads to a decrease in treatment efficiency.

On the 10th day, the surface of the filler was covered with white flocculant substance. The color gradually changed from the original black to rust yellow, the effluent water also became turbid. The micro-electrolysis column entered the decay period, and the COD removal efficiency dropped to only 8.3% on 20th day. According to the analysis, the Fe-C filler was porous and had a high adsorption effect. After the filler was used for a period of time, the particles in the wastewater would tightly adhere on the surface of the filler and block the effective contact between the wastewater and the filler. It then hindered the micro-electrolysis reaction. Moreover, a dense oxide film was formed on the surface of filler due to aeration, which also had negative impact on the treatment effect (Hu 2008).

Table 2 | GC-MS testing results of micro-electrolysis influent

<table>
<thead>
<tr>
<th>Retention time (min)</th>
<th>Substance</th>
<th>Structural formula</th>
<th>CAS number</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.503</td>
<td>Benzyl alcohol</td>
<td><img src="image" alt="Benzyl alcohol" /></td>
<td>100-51-6</td>
</tr>
<tr>
<td>6.719</td>
<td>Butyldiglycol</td>
<td><img src="image" alt="Butyldiglycol" /></td>
<td>112-34-5</td>
</tr>
<tr>
<td>6.745</td>
<td>2-Amino-3-propylhexanoic acid</td>
<td><img src="image" alt="2-Amino-3-propylhexanoic acid" /></td>
<td>2801-58-3</td>
</tr>
<tr>
<td>7.767</td>
<td>3-Methyl-2-butanone</td>
<td><img src="image" alt="3-Methyl-2-butanone" /></td>
<td>563-80-4</td>
</tr>
<tr>
<td>8.006</td>
<td>Enol derivatives</td>
<td><img src="image" alt="Enol derivatives" /></td>
<td>56335-74-1</td>
</tr>
<tr>
<td>8.845</td>
<td>Ester derivatives</td>
<td><img src="image" alt="Ester derivatives" /></td>
<td>-</td>
</tr>
<tr>
<td>13.999</td>
<td>Ester derivatives</td>
<td><img src="image" alt="Ester derivatives" /></td>
<td>-</td>
</tr>
<tr>
<td>15.384</td>
<td>Diisobutyl phthalate</td>
<td><img src="image" alt="Diisobutyl phthalate" /></td>
<td>84-69-5</td>
</tr>
<tr>
<td>18.715</td>
<td>2,2′-Methylenebis(6-tert-butyl-4-methylphenol)</td>
<td><img src="image" alt="2,2′-Methylenebis(6-tert-butyl-4-methylphenol)" /></td>
<td>119-47-1</td>
</tr>
</tbody>
</table>
Therefore, it is necessary to periodically reactivate the micro-electrolysis filler under continuous operating conditions. According to the continuous operation result, it was advisable to select the end of the stable period as the time of reactivation of the filler, which was around the 10th day of continuous operation for the wastewater used in this study. The filler was cleaned with 5% dilute sulfuric acid to remove the adsorbate and the passivation film on the surface, and the activation time was suggested to be 2 h (Essadki et al. 2008). After the filler activation was completed, an appropriate amount of iron scrap was added to the reaction column to supplement the anode consumed by the micro-electrolysis reaction. It was determined that the reactivated Fe-C filler could achieve the effect during the active period, and 30% of the COD removal efficiency was achieved again.

Organic substances transformation of the evaporated condensed wastewater

Under continuous operating system, the influent and effluent of the 3rd day were sampled and GC-MS qualitative analysis was performed to examine the changes of organic pollutants in the wastewater before and after the micro-electrolysis reaction. Then qualitative analysis was performed based on mass spectrometry characteristic ions and their retention index. By comparing the standard spectra with the NIST MS Search 2.0 mass spectrometry library, the type of organic pollutants were determined according to the principle of higher matching degree (>60%), and listed in order according to their retention time, as shown in Tables 2 and 3.

As shown in Table 2, nine major organic pollutants were detected in the evaporated condensate. The types of pollutants were mainly benzene series, ethers and esters, which basically contained unsaturated bonds and the structure was relatively stable. The retention times of the two main organic pollutants were 4.503 min and 6.719 min respectively, and the corresponding substances were benzyl alcohol and butyldiglycol, which were the main contributor of COD.

According to the results of GC-MS, the abundance of organic matter in the effluent was greatly reduced and the peak amount of organic matter was smaller than that of the micro-electrolysis influent. Benzyl alcohol was not detected in micro-electrolyte effluent, but ketones, alcohols and alkanes with relatively simple structure were presented instead. Some structurally stable refractory organics could have been broken during the micro-electrolysis reaction, then oxidized into easily degradable substances. It can be seen that after micro-electrolysis pretreatment, some organic substances in the wastewater were effectively degraded, and the biodegradability of the effluent was greatly increased.

<table>
<thead>
<tr>
<th>Retention time (min)</th>
<th>Substance</th>
<th>Structural formula</th>
<th>CAS number</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.188</td>
<td>Trimethylacetaldehyde</td>
<td></td>
<td>630-19-3</td>
</tr>
<tr>
<td>6.719</td>
<td>Butyldiglycol</td>
<td></td>
<td>112-34-5</td>
</tr>
<tr>
<td>8.634</td>
<td>2,3-Dimethylheptane</td>
<td></td>
<td>3074-71-3</td>
</tr>
<tr>
<td>16.012</td>
<td>3,6-Dimethyl-2,6-octadiene-4,5-diol</td>
<td></td>
<td>10317-05-2</td>
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</table>

CONCLUSIONS

The study revealed that Fe-C micro-electrolysis treatment on the evaporated condensate wastewater significantly enhanced the biodegradability. It indicates that Fe-C micro-electrolysis could be employed as pre-treatment on the evaporated condensate wastewater when biological treatment was the method to be utilized to treat the wastewater. It was seen that the complexed organic compounds were broken into more easily degraded substances.
suggests that the Fe-C micro-electrolysis could be a suitable approach to treat wastewater containing complexed organic compounds and improve the biodegradability of wastewater.

ACKNOWLEDGEMENT

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