Adsorption removal of cyclopentanol generated from Fenton oxidation treatment industrial wastewater process with activated carbon fiber cloths

Lin Deng1,2*, Qing Wang2,3, Jianzhu Zhang2,3, Liyuan Ma2,3, Qian Pan2,3, Xuemei Hu2,3, Chen Chen2,3 and Huiyuan Zhang2,3

1 School of Environmental Science and Engineering, Tianjin University, Tianjin 300072, China
2 Tianjin TEDA New Water Resources Technology Development Co., Ltd., Tianjin 300457, China
3 Tianjin TEDA Water Industry Co. Ltd., Tianjin 300457, China
*Correspondence authors’ E-mail: barlinike322@cwnu.edu.cn (Lin Deng)

Abstract. Cyclopentanol (CPL) is an oxidation by-product in the industrial wastewater treatment process with Fenton advanced oxidation technology, which can not be further degraded into CO2 and H2O by adjusting the dosage of Fenton’s reagents. The enormous CPL generated in wastewater would have a serious effect on the chemical oxidation demand (COD) in the effluent quality. The adsorption removal of CPL onto activated carbon fiber cloth (ACFC) was investigated. Based on study of adsorption isothermal, kinetics, thermodynamics, pH, ACFC dosage experiments, the adsorption removal characteristics of ACFC were determined. The results showed that the Langmuir isotherm model describes well the equilibrium process. The removal capacities of CPL on ACFC are 36.1~63.0 mg g⁻¹ at 303~313 K. The adsorption behavior of CPL on ACFC is more fitted by the pseudo-second-order kinetic model. The thermodynamic analysis revealed that the adsorption reaction was an exothermic chemisorption process. The effect of pH and adsorbent dosage on CPL adsorption removal were also studied. The results presented in this work will be helpful to the removal of CPL for industrial wastewater treatment process especially that advanced oxidation technology was adopted.

1. Introduction
Fenton oxidation, is an encouraging technology for the oxidation of recalcitrant organic substances, in situ generating hydroxyl radicals (HO·) to indiscriminately oxidize complex organic compounds to smaller intermediates and further complete mineralization to CO2 and H2O[1-4]. With increasing attention to environmental protection, more stringent discharge standards of pollutants have been promulgated by environmental management agency in some cities, China, grimly stipulating chemical oxygen demand (COD) in sewage effluent below 30 mg/L. In order to meet high quality discharge standard for COD, AOPs are widely adopted during the sewage treatment processes renovations[5-7]. Although Fenton technology is effective for the degradation of refractory organic compounds[8-11], especially aromatic compounds[12-15], it should be noted that many chemicals are not sensitive to Fenton’s reagent, including acetic acid, acetone, carbon tetrachloride, maleic, malonic acid, oxalic acid,
etc[16-18]. Those substances can not be completely mineralized or their thorough mineralization needs a long oxidation degradation time. The organic compounds could become from original wastewater or oxidation by-product during degradation processes of complex organic pollutants by AOPs. For example, CPL and its substituted derivatives (e.g. chlorine, bromine) were generated in wastewater after Fenton advanced oxidation treatment, and accounted for more than 80% of all organic materials in an industrial wastewater treatment plant located in Tianjin, China. This was confirmed by the COD values in effluent which can not be further decreased by increasing Fenton’s reagent dosage. The analysis of organic composition in effluent by gas chromatography-mass spectrometry (GC-MS) was presented in Table S1 (Seen supplementary materials). Gerald Ruppert and Rupert Bauer[19] comparatively study mineralization of phenol, hydroquinone, cyclohexanol and cyclohexanone by the photo-Fenton reaction. The results showed that all aromatic substances (phenol, hydroquinone, cyclohexanol) were strongly degraded after five hours and up to 90% were mineralized into CO₂ and H₂O. But, cyclohexanol and cyclohexanone were seldom degraded. In alicyclic compounds, low mineralization can be attributed to the fact that conjugated C-C is not easily destroyed by HO• radicals and carbon ring opening not occurs. However, the studies on CPL removal from wastewater were not be found in the literature. This research conducted was also based on the fact that a large amount of CPL and its substituted derivatives were generated by Fenton oxidation process, which can not be further mineralized into CO₂ and H₂O by increasing Fenton’s reagents dosage. Thus, it is important to take some effective measures to remove the CPL to ensure COD meeting the high discharge standard.

Activated carbon fibers cloths (ACFC) is a novel and efficient adsorbent. Compared to traditional granular and powder activated carbon, ACFC generally has more advantages with larger surface areas, more microporous, higher capacities, and good formability, easy processing into felt, silk, cloth, paper and other forms[20], which has been widely used for water and wastewater treatment[21-24]. Many studies showed that ACFC has a good adsorption capacity for aqueous pollutants[25,26], including heavy metals on ACFC[27-30]. However, adsorption of CPL onto ACFC was rarely reported in the literature.

In this work, the removal of CPL by ACFC was evaluated. The adsorption isotherm, adsorption kinetics and adsorption thermodynamics of CPL onto ACFC were carried out. Moreover, the effect of pH and ACFC dosage on CPL removal efficiency was studied. The results presented in this study can bring new insight into the subsequent treatment of organic compounds that are difficult to be mineralized using Fenton advanced oxidation technology.

2. Materials and methods

2.1. Materials and analysis

The distilled water was used to prepare the required solutions. Cyclopentanol (CPL, C₅H₉OH, 99%) was obtained from Shanghai Aladdin Biochemical Technology Co., Ltd, China. ACFC (SY1000) was used in this study, which was acquired from Nantong Senyou Carbon Fiber Co., Ltd., Nantong, China. And its molecular structure as shown in Figure 1.

Batch experiments including adsorption isotherm, adsorption kinetics were carried out in an incubator shaker (HNY-100B, Tianjin Honour Instrument Co., Ltd., Tianjin, China). CPL concentration was indirectly determined by measuring its COD value (Heating digester PT593, Photometer 7500, Palintest).

![OH](Figure 1. Structure of cyclopentanol)
2.2. Test sample
Firstly, numerous 10cm×10cm sizes of ACFC were prepared. Then, these ACFC were washed with boiling water to remove impurity, and dried at 100 ± 5°C for 6h. Subsequently, it was cut into a suitable size according to the required ACFC dosage. A 1 g/L cyclopentanol mother liquor was prepared by weighing accurately 1.000 g cyclopentanol (99%) with an analytical balance to dissolve CPL into 1L distilled water. The CPL concentration required during the experiment processes was obtained by quantificationally diluting the CPL mother liquor.

2.3. Adsorption isotherm experiments
0.1 g of ACFC was added into 20-250 mg L⁻¹ cyclopentanol solution with concentration of 20-250 mg L⁻¹. Adsorption time with twenty-four hours was required to establish the adsorption equilibrium at 303-313K. A certain amount of solution was extracted to analyze to CPL equilibrium concentration after filtered through a syringe-driven filter with a 0.45 μm membrane. the solution was filtered, and the filtrate was analyzed to get the CPL. The equilibrium adsorption amount qₑ (mg g⁻¹) can be determined using Eq. (1).
\[ qₑ = \frac{(C₀ - Cₑ)V}{W} \]
Where, \(C₀\) (mg L⁻¹) is the initial CPL concentration, \(Cₑ\) (mg L⁻¹) is the CPL concentration at equilibrium, V (L) and W (g) are represented as solution volume and ACFC dosage.

2.4 Adsorption kinetics experiments
0.3g of ACFC was added into 400mL of CPL solution (20mg L⁻¹). Then, the experiments were conducted under a temperature of 298-308K. A certain of the solution was withdrawn and filtered with syringe-type filters with a pore size of 0.45μm to calculate the equilibrium adsorption amount, \(qₜ\) (mg g⁻¹).
\[ qₜ = \frac{(C₀ - Cₜ)V}{W} \]
Where, \(C₀\) (mg L⁻¹) is the initial CPL concentration, \(Cₜ\) (mg L⁻¹) is the CPL concentration at any time t, V (L) and W (g) are represented as solution volume and ACFC dosage.

3. Results and discussion

3.1. Morphology and surface structure characteristics
The morphology and structure characterization of ACFC was originated from the research by Zhumei SUN et[30]. It was because the ACFC used in their work and this study were both purchased from the same manufacturer. The SEM imagine of ACFC with 5000 times magnification and pristine morphology were presented in Figure 2. The ACFC is composed of bundles of thread with a diameter of about 10μm. Compared to granulated activated carbon and powdered activated carbon, ACFC presented adsorption kinetics with the thin-fiber shape. The pore size distribution of ACFC was generally dominated by the micropores (d<2 nm, over 90% of the total pore volume)]31][28]. Figure 2(b) shows the original SEM image of ACFC, which showed that it has a smooth surface with the thickness of about 2mm.
3.2. Adsorption isotherm
To study the degree of CPL accumulation onto the ACFC surface, adsorption isotherms of CPL were determined. Adsorption capacity of CPL on ACFC at 303, 308, and 313K can be modeled by the various adsorption equations, which was shown in Figure 3(a). The Langmuir equation, Freundlich equation and D-R equation were often adopted to model the CPL adsorption process. Langmuir equation assumes that there is a fixed number of active sites and all accessible sites have the same energy, and as adsorption site on adsorbent was occupied, further adsorption can not occur, at that adsorption site. Langmuir equation can be described as Eq. (3).

\[ q_e = \frac{q_{\text{max}}K_L C_e}{1 + K_L C_e} \]  

(3)

Four linearized forms of Eq.(3) can be expressed as Eq. (4-7)[32]. And, they have their own characteristics which have been elaborated by Bolster and Hornberger[33].Langmuir model (Type 1)

\[ \frac{C_e}{q_e} = \left(\frac{1}{Q_{\text{max}}}\right) C_e + \frac{1}{Q_{\text{max}} K_L} \]  

(4)

Langmuir model (Type 2)

\[ q_e = \left(\frac{-1}{K_L}\right) q_e + Q_{\text{max}} \]  

(5)

Langmuir model (Type 3)

\[ \frac{q_e}{C_e} = -K_L q_e + Q_{\text{max}} K_L \]  

(6)

Langmuir model (Type 4)

\[ \frac{1}{q_e} = \left(\frac{1}{Q_{\text{max}} K_L}\right) \frac{1}{C_e} + \frac{1}{Q_{\text{max}}} \]  

(7)

where \( q_e \) (mg g\(^{-1}\)) and \( C_e \) (mg g\(^{-1}\)) are the uptake amount of CPL from solution and CPL concentration at equilibrium. \( Q_{\text{max}}^0 \) (mg g\(^{-1}\)) is the max uptake amount of CPL at fixed temperature. \( K_L \) (L mg\(^{-1}\)) is the adsorption constant. The values of \( Q_{\text{max}}^0 \) and \( K_L \) can be calculated from the plots based on the four linear equations.

The heterogeneous adsorption process is usually fitted by the Freundlich equation. Freundlich equation has two forms:

\[ q_e = K_F C_e^\frac{1}{n} \]  

(8)
\[ \ln q_e = \frac{1}{n} \ln C_e + \ln K_F \]  \hspace{1cm} (9)

where \( K_F \) is the Freundlich constant, \((\text{mg/g})(\text{mg/L})^n\), and \( n \) is the Freundlich intensity parameter, which is dimensionless. The two parameters values can be obtained with a fitted line of \( \ln q_e \) versus \( \ln C_e \).

The D-R equation was developed to account for the effect of the porous structure of an absorbent. Its linear form can be expressed as Eq. (10)

In general, the effect of the adsorbent porous on the adsorption process can be described by D-R equation.

\[ \ln q_e = -K_{DR}R^2T^2\ln^2(1 + \frac{1}{C_e}) + \ln q_{DR} \]  \hspace{1cm} (10)

where \( q_{DR} \) is the maximum adsorption capacity at certain temperature, \( \text{mg/g} \); \( K_{DR} \) is the adsorption constant, \( \text{mol}^2/\text{kJ}^2 \); \( R \) is the gas constant, \( \text{J mol}^{-1}\text{K}^{-1} \). The parameters \( q_{DR} \) and \( K_{DR} \) can be obtained by a plot of \( \ln q_e \) against \( R^2T^2\ln^2(1 + 1/C_e) \).

Figure 3(a) shows the CPL adsorption isotherms at 303, 308 and 313K. Figure 3(a) showed that the \( q_e \) values of CPL adsorption on ACFC increased gradually while the CPL concentration was increased. For example, the \( q_e \) values increased from 14.2 to 62.3 mg g\(^{-1}\), while the CPL concentration was raised from 25 to 200 mg L\(^{-1}\) at 313K. The maximum adsorption amount of CPL adsorption on ACFC was found to increase from 36.84 to 62.3 mg L\(^{-1}\), while the temperature was increased from 303 to 313K.

Figure 3(b) shows the fitted results with Langmuir equation for CPL adsorption process. The obtained parameters values obtained from all equations were presented in Table 1. It can be seen that the fitting of CPL by the Type 4 equation was more suitable compared to the Freundlich and D-R model, evidenced by the higher \( R^2 \) value.

**Table 1. Adsorption parameters values of adsorption of cyclopentanol on ACFC at 303-313K.**

| Tem. (K) | Freundlich equation \( R^2 \) | D-R equation \( R^2 \) | Langmuir equation Type1 \( R^2 \) | Type2 \( R^2 \) | Type3 \( R^2 \) | Type 4 \( R^2 \) | \( Q_{max}^0 \) \( \text{mg g}^{-1} \) | \( K_L \) \( (\text{L mg}^{-1}) \) |
|---------|-------------------------------|------------------|-----------------|----------------|----------------|----------------|----------------|----------------|
| 303     | 0.972                         | 0.617            | 0.721           | 0.549          | 0.549          | 0.969          | 38.5           | 0.02121        |
| 308     | 0.967                         | 0.792            | 0.952           | 0.844          | 0.844          | 0.981          | 47.8           | 0.02478        |
| 313     | 0.961                         | 0.840            | 0.963           | 0.916          | 0.916          | 0.993          | 57.5           | 0.02834        |

![Figure 3. Adsorption isotherms (a), fitted plots (b) at 303-313K.](image-url)
3.3. Adsorption kinetics

Adsorption kinetics is of great significance to understand the adsorption mechanism and the equilibrium time. Figure 4(a) shows the adsorption amount of CPL on ACFC over adsorption time at different temperatures. Figure 4(a) showed that the adsorption uptakes of CPL increased gradually with time at any temperature. The final equilibrium can be achieved within about 120 min. The adsorption behavior implied that the adsorption process of CPL onto ACFC complies with the pore filling mechanism.

An increase of the adsorption capacities with raise in reaction temperature implied that the nature of CPL adsorption onto ACFC is an endothermic process. Both pseudo-first-order (Eq. 11) and pseudo-second-order model (Eq. 12) usually be used to simulate the adsorption kinetic data.

\[
\ln(q_e - q_t) = \ln q_e - k_1 t \\
\frac{1}{q_t} = \frac{1}{k_2 q_e^2} + \frac{t}{q_e}
\]

where \( k_1 \) is the rate constant for pseudo-first-order model, min\(^{-1}\); and \( k_2 \) indicates a rate constant for pseudo-second-order mg\(^{-1}\) min\(^{-1}\).

The calculated parameters based on the above kinetic models were presented in Table 2. It is obvious that the equilibrium adsorption capacity for both two models increases with elevating reaction temperature. The calculated adsorption capacity increased from 2.48 to 4.24 mg g\(^{-1}\) for pseudo-first-order model, and rise from 3.30 to 5.49 mg g\(^{-1}\) for (pseudo-second-order. The values of \( qe_2, \text{cal} \) were found to be close to the values of adsorption capacity in the experimental process. Compared to value of the adjustment coefficients (\( R^2 \)) for pseudo-first-order kinetics model, there is higher values of \( R^2 \) for pseudo-second-order kinetics model.

**Table 2.** Kinetics parameters of cyclopentanol adsorption onto ACFC

| Tem. (K) | \( qe,exp \) (mg g\(^{-1}\)) | Pseudo-first-order model | Pseudo-second-order model |
|----------|-------------------------------|--------------------------|----------------------------|
|          | \( qe_1,\text{cal} \) (mg g\(^{-1}\)) | \( k_1 \) (10\(^{-2}\) min\(^{-1}\)) | \( R^2_1 \) | \( qe_2,\text{cal} \) (mg g\(^{-1}\)) | \( k_2 \) (10\(^{-2}\) g mg\(^{-1}\) min\(^{-1}\)) | \( R^2_2 \) |
| 298      | 2.62                          | 2.48                     | 2.71                       | 0.984 | 3.30                     | 1.14 | 0.975 |
| 303      | 4.46                          | 3.00                     | 2.37                       | 0.825 | 4.74                     | 1.68 | 0.975 |
| 308      | 5.08                          | 4.24                     | 5.83                       | 0.974 | 5.49                     | 2.52 | 0.997 |

**Figure 4.** The variation of adsorption capacity with time for cyclopentanol at 298, 303 and 308K (a); Pseudo-second-order model for cyclopentanol adsorption onto ACFC at 298, 303 and 308K (b)
3.4. Adsorption thermodynamics

Adsorption mechanisms also can be elaborated by analyzing adsorption thermodynamic, including standard free energy ($\Delta G^\circ$), standard enthalpy ($\Delta H^\circ$), standard entropy ($\Delta S^\circ$), and activation energy ($E_a$). The $\Delta H^\circ$ and $\Delta S^\circ$ can be determined by Eq. (9):

$$\ln K_C = \frac{\Delta S^\circ}{R} - \frac{\Delta H^\circ}{RT}$$

where $R$ and $T$ are the gas constant (8.314 J mol$^{-1}$K$^{-1}$), reaction temperature (K), respectively. $K_C$ is the reaction equilibrium constant. The values of $\Delta H^\circ$ and $\Delta S^\circ$ can be determined by fitting $\ln K_C$ versus $1/T$. The values of $K_C$ in Eq. (13) can come from the Langmuir constant $K_L$ by Eq. (14).

$$K_C = M_W \times 55.5 \times 1000 \times K_L$$

where $M_W$ (86.13 g/mol) is the molar mass of CPL; $K_L$ is Langmuir constant from Table 1. Then $\Delta G^\circ$ can be obtained from Eq. (15) or Eq. (16):

$$\Delta G^\circ = \Delta H^\circ - T \Delta S^\circ$$

$$\Delta G^\circ = -RT \ln K_C$$

Based on Eq. (13), the values of $\Delta H^\circ$ and $\Delta S^\circ$ can be obtained by plot $\ln K_C$ against $1/T$ (Figure 5). The results showed that $\Delta H^\circ$ and $\Delta S^\circ$ were estimated as 22.9 kJ mol$^{-1}$ and 190.5 J mol$^{-1}$K$^{-1}$, respectively. According to the Eq. (15) and Eq. (16), Gibbs free energy was calculated to -34.86, -35.81 and -36.77 kJmol$^{-1}$ at 303, 308 and 313K, respectively. The reaction activation energy can be obtained by Eq. (17)

$$\ln k_2 = \ln A - \frac{E_a}{RT}$$

where $k_2$ is the rate constant, g mg$^{-1}$ min$^{-1}$, which is from Table 2. $E_a$ is the reaction activation energy, kJ mol$^{-1}$; $A$ is the Arrhenius factor. The values of $E_a$ can be determined by linear fitting with $\ln k_2$ against $1/T$. The results showed that the activation energy was estimated to 60.4 kJ mol$^{-1}$, implying the adsorption of CPL onto ACFC was chemisorption processes.

3.5. Effect of pH and ACFC dosage

The solution pH is an important factor in the study of adsorption process, which can affect the adsorption capacity. Analyses of the effect of pH on the CPL removal were performed as shown in Figure 7. It is well known that solution pH is not a negligible factor that would affect the adsorption of organic and inorganic contaminants. It can be observed that the uptake capacity of CPL on ACFC increases first when the pH was less than 4.16, and then decrease as solution pH varied from 4.16 to
11.57. The maximum uptake amount of CPL was obtained at about pH 4. The effect of ACFC dosage on CPL uptake was presented in Figure 8. The results showed that the CPL concentration in solution gradually decreased as the ACFC dosage varied from 0.050 g to 0.800 g, and no further decrease occurred with an increase in the dosage of ACFC.

**Figure 7.** Effect of pH on the adsorption of cyclopentanol  
**Figure 8.** Effect of ACFC dosage on the adsorption of cyclopentanol

### 4. Conclusion

The mineralization of cyclopentanol (CPL) by Fenton advanced oxidation in aqueous can not be realized, which would bring significantly important effects on the high discharge standard of chemical oxygen demand (COD) in effluent quality. In this study, the adsorption of cyclopentanol (CPL) onto activated carbon fiber cloth (ACFC) was studied, focusing on adsorption isotherm and kinetic, thermodynamics. The adsorption capacity of CPL onto ACFC was obtained at 36.84-62.33 mg g⁻¹ as the temperature was raised from 303 to 313 K, CPL concentration was varied from 20-250 mg L⁻¹. Adsorption isotherms of CPL at 303-313K were fitted by Langmuir, Freundlich and Dubinin-Radushkevich (D-R) equation, respectively. Compared with Freundlich and D-R equation, the Langmuir equation can better simulate the CPL adsorption onto ACFC. The thermodynamic results implied that the CPL adsorption onto ACFC is an endothermic process. Analysis of adsorption kinetics showed that the adsorption followed the pseudo-second-order kinetic equation. This work provides effective removal for CPL, which was usually generated as oxidation product during wastewater treatment as Fenton advanced oxidation technology was adopted.

### Acknowledgments

The present study was financially by the Major Science and Technology Program for Water Pollution Control and Treatment with Grant No. 2017ZX07107-003-02.

### Supplementary Materials:

The following are available online at https://zenodo.org/record/3905828#.XvLq9fkn0yg.

### References

[1] Oller I, Malato S and Sánchez-Pérez J A. (2011) Combination of Advanced Oxidation Processes and biological treatments for wastewater decontamination-A review Sci. Total Environ. 409: 4141-4166

[2] Wang N, Zheng T, Zhang G and Wang P. (2016) A review on Fenton-like processes for organic wastewater treatment J. Environ. Chem. Eng. 4: 762-787

[3] Babuponnusami A and Muthukumar K. (2014) A review on Fenton and improvements to the Fenton process for wastewater treatment J. Environ. Chem. Eng. 2: 557-572
[4] Vorontsov A V. (2019) Advancing Fenton and photo-Fenton water treatment through the catalyst design J. Hazard. Mater. 372: 103-112

[5] Bourgin M, Beck B, Boehler M, Borowska E, Fleiner J, Salhi E, Teichler R, von Gunten U, Siegrist H and Mcardell C S. (2018) Evaluation of a full-scale wastewater treatment plant upgraded with ozonation and biological post-treatments: Abatement of micropollutants, formation of transformation products and oxidation by-products Water Res. 129: 486-498

[6] Wu C, Li Y, Zhou Y, Li Z, Zhang S and Liu H. (2018) Upgrading the Chinese biggest petrochemical wastewater treatment plant: Technologies research and full scale application Sci. Total Environ. 633: 189-197

[7] Hollender J, Zimmermann S G, Koepke S, Krauss M, Mcardell C S, Ort C, Singer H, Von Gunten U and Siegrist H. (2009) Elimination of organic micropollutants in a municipal wastewater treatment plant upgraded with a full-scale post-ozonation followed by sand filtration Environ. Sci. Technol. 43: 7862-7869

[8] Li X, Chen W, Ma L, Wang H and Fan J. (2018) Industrial wastewater advanced treatment via catalytic ozonation with a Fe-based catalyst Chemosphere 195: 336-343

[9] Cetinkaya S G, Morcali M H, Akarsu S, Ziba C A and Dolaz M. (2018) Comparison of classic Fenton with ultrasound Fenton processes on industrial textile wastewater Sustain. Environ. Res. 28: 165-170

[10] Ebrahiem E E, Al-Maghrabi M N and Mobarki A R. (2017) Removal of organic pollutants from industrial wastewater by applying photo-Fenton oxidation technology Arab. J. Chem. 10: S1674-1679

[11] Dai X, Fang J, Li L, Dong Y and Zhang J. (2019) Enhancement of COD removal from oilfield produced wastewater by combination of advanced oxidation, adsorption and ultrafiltration Int. J. Environ. Res. Public Health 16: 1-10

[12] Bagal M V. and Gogate P R. (2013) Degradation of 2,4-dinitrophenol using a combination of hydrodynamic cavitation, chemical and advanced oxidation processes Ultrason. Sonochem. 20: 1226-1235

[13] Bartsch M, Meyerstein D and Neta P. (1966) Reactivity of aliphatic compounds towards hydroxyl radicals J.chem.soc 1966: 1348-1348

[14] CASADO J, FORNAGUERA J and GALAN M I. (2005) Mineralization of Aromatics in Water by Sunlight-Assisted Electro-Fenton Technology in a Pilot Reactor Environ. Sci. Technol. 39: 1843-1847

[15] Yavuz Y, Koparal A S and Ä-Gä½Tveren B. (2010) Phenol Removal through Chemical Oxidation using Fenton Reagent Chem. Eng. Technol. 30: 583-586

[16] Gogate P R and Pandit A B. (2004) A review of imperative technologies for wastewater treatment I: Oxidation technologies at ambient conditions Adv. Environ. Res. 8: 501-551

[17] De Laat J, Gallard H, Anselin S and Legube B. (1999) Comparative study of the oxidation of atrazine and acetone by H2O2/UV, Fe(III)/UV, Fe(III)/ H2O2/UV and Fe(II) or Fe(III)/ H2O2 Chemosphere 39: 2693-2706

[18] Lee Y, Bae S and Lee W. (2012) Degradation of carbon tetrachloride in modified Fenton reaction Korean J. Chem. Eng. 29: 769-774

[19] Analysis S. (1988) MINERALIZATION OF CYCLIC ORGANIC WATER CONTAMINANTS BY THE PHOTO-FENTON REACTION - INFLUENCE OF STRUCTURE AND SUBSTITUENTS Chemosphere 3016: 3779-3784

[20] Hassan M F, Sabri M A, Fazal H, Hafeez A, Shezad N and Hussain M. (2020) Recent trends in activated carbon fibers production from various precursors and applications—A comparative review J. Anal. Appl. Pyrolysis 145: 104715

[21] Yu F, Wang L, Ma H and Pan Y. (2020) Zeolitic imidazolate framework-8 modified active carbon fiber as an efficient cathode in electro-Fenton for tetracycline degradation Sep. Purif. Technol. 237: 116342
[22] Li Y, Liu F, Li M, Li W, Qi X, Xue M, Wang Y and Han F. (2020) Study on adsorption coupling photodegradation on hierarchical nanostructured g-C3N4/TiO2/activated carbon fiber composites for toluene removal J. Sol-Gel Sci. Technol. 93: 402-418

[23] Liu S, Hassan S U, Ding H, Li S, Jin F, Miao Z, Wang X, Li H and Zhao C. (2020) Removal of sulfamethoxazole in water by electro-enhanced Co2+/peroxydisulfate system with activated carbon fiber-cathode Chemosphere 245: 125644

[24] Attan D, Alghoul M A, Saha B B, Assadeq J and Sopian K. (2011) The role of activated carbon fiber in adsorption cooling cycles Renew. Sustain. Energy Rev. 15: 1708-1721

[25] Yang H, Yu X, Wang L, Guo M and Liu J. (2019) Adsorption of Sulfanilamide from Aquaculture Wastewater Using Modified Activated Carbon Fiber: Equilibrium, Kinetic and Thermodynamic. Specific and Informative: Surface Modification Surf. Eng. Appl. Electrochem. 55: 684-691

[26] Li G, Feng Y, Chai X, Yang Z and Zhang X. (2015) Adsorption of cyclic organics generated during electrochemical oxidation of Orange II by activated carbon fibers and toxicity test J. Water Process Eng. 7: 21-26

[27] Zhao Y, Cho C W, Wang D, Choi J W, Lin S and Yun Y S. (2020) Simultaneous scavenging of persistent pharmaceuticals with different charges by activated carbon fiber from aqueous environments Chemosphere 247: 125909

[28] Kim D W, Wee J H, Yang C M and Yang K S. (2020) Efficient removals of Hg and Cd in aqueous solution through NaOH-modified activated carbon fiber Chem. Eng. J. 392: 123768

[29] Yu J, Chi C, Zhu B, Qiao K, Cai X, Cheng Y and Yan S. (2020) High adsorptivity and recycling performance activated carbon fibers for Cu(II) adsorption Sci. Total Environ. 700: 134412

[30] Sun Z, Yu Y, Pang S and Du D. (2013) Manganese-modified activated carbon fiber (Mn-ACF): Novel efficient adsorbent for Arsenic Appl. Surf. Sci. 284: 100-106

[31] Chen C J, Wang R Z, Oliveira R G and Hu J Q. (2009) Adsorption models and structural characterization for activated carbon fibers J. Shanghai Jiaotong Univ. 14E: 35-39

[32] Tran H N, You S J, Hosseini-Bandegharaei A and Chao H P. (2017) Mistakes and inconsistencies regarding adsorption of contaminants from aqueous solutions: A critical review Water Res. 120: 88-116

[33] Bolster C H and Hornberger G M. (2007) On the Use of Linearized Langmuir Equations Soil Sci. Soc. Am. J. 71: 1796