



## Removal of polychlorinated biphenyls and recycling of tween-80 in soil washing eluents

Binglu Deng<sup>a</sup>, Xingqiu Zhou<sup>a,b,\*</sup>, Xingjian Yang<sup>a</sup>, Zhi Dang<sup>a,b</sup>, Guining Lu<sup>a,b,c,\*</sup>

<sup>a</sup>School of Environment and Energy, South China University of Technology, Guangzhou 510006, PR China, Tel. +86-20-39380569; Fax: +86-20-39380508; email: xqzhou@scut.edu.cn (X. Zhou), GNLu@foxmail.com (G. Lu)

<sup>b</sup>The Key Lab of Pollution Control and Ecosystem Restoration in Industry Clusters, Ministry of Education, Guangzhou 510006, PR China

<sup>c</sup>Guangdong Provincial Engineering and Technology Research Center for Environmental Risk Prevention and Emergency Disposal, Guangzhou 510006, PR China

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### ABSTRACT

This study reports on the adsorption of polychlorinated biphenyls (PCBs) by powder activated carbon (PAC) in soil washing eluents containing tween-80 surfactant micelles. Factors influencing the adsorption were studied (i.e., time, adsorbent doses, molecular structure of different PCB congeners, dynamic and thermodynamic models). The adsorption of PCBs on nano bamboo charcoal (NBC) was compared with those on PAC. Finally, the prospect for recycling soil eluents was explored. We found that the PAC and NBC were both effective in removal of 12 mg/L PCBs in soil washing eluents. The results of the adsorption kinetics showed that both materials have different adsorption rate controlling step, the particles diffusion became adsorption rate controlling step of NBC while particle diffusion and adsorption reaction like chemical bonding reactions co-control the adsorption rate of PAC. The adsorption of PCBs on PAC was probably chemisorption through interaction between aromatic rings and oxygen-containing functional groups while the adsorption on NBC was mainly physisorption by micropore filling. After the PAC treatment, the residual tween-80 in the eluents was 27.78% (total mass ratio). The addition of acetone to break micelles before adsorption could increase the recovery of tween-80 to 73.30% while PCBs removal rate could still reach 78.06%. Therefore, the surfactant solutions can be reused after adsorption. The studies provide valuable information on the adsorption of PCBs by PAC in soil washing eluents, which may improve the utilization and selection of PAC in the recovery of soil washing eluents.

*Keywords:* Soil washing eluents; Polychlorinated biphenyls; Tween-80; Powdered activated carbon

### 1. Introduction

The increasingly serious contamination of electronic waste (e-waste) dismantling sites has become an important environmental issue in China [1]. Polychlorinated biphenyls (PCBs), a group of 209 homologous chlorinated aromatic hydrocarbons with the chemical formula  $C_{12}H_nCl_{(10-n)}$  ( $n = 0\sim 10$ ), are one of the major pollutant types found at e-waste dismantling sites [2]. PCBs which can pose a great threat to

human health and the environment through both direct and indirect exposure pathways are persistent, bioaccumulative and biologically toxic. The results of contamination surveys showed that PCBs concentrations ranged 3.34–4.58 mg/kg in electronic waste dismantling sites of Qingyuan and Guiyu, Guangdong Province, which is far above the normal background value (0.42 mg/kg) [1,3,4].

At present, the main methods for soil remediation include physical, chemical and biological techniques [5]. Many researchers have explored the use of various solutions to elute heavy metals and organic pollutants from soils [6]. PCBs are

\* Corresponding author.

one of the common organic eluates. At present, UV light with catalyst can degrade up to 95% trichlorobiphenyl and hexachlorobenzene without producing secondary gas or solid pollutants [7]. Specificity and chemical molecules properties of microorganisms can broke benzene ring structure [8]. However, both chemical and microbiological methods are complex, requiring large investments and difficult to reuse process solution. In contrast, sorption methods have certain advantages, such as effectiveness of treatment, low cost and simple operation [9]. These sorption methods are mainly physical in nature which may favour the reuse of chemical agents and the removal of hydrophobic organic contaminants (e.g., PCBs) [10]. There is a considerable amount of information in the literature concerning adsorption of chlorinated organics from wastewater. Fly ash, chitosan can be used as efficient adsorbents of PCBs in several aqueous solutions and adsorption mechanisms exploration have been conducted [11–13].

In our study, PCBs in eluting waste samples were dissolved by entrapping of surfactant tween-80 micelle, which are difficult to be adsorbed by common aperture adsorbents. Powder activated carbon (PAC), which has two-dimensional orderly microcrystalline structure and irregular cross-linked carbon hexagonal lattice space structure, is a type of non-polar fertile absorbent which can adsorb polar and non-polar organics through functional groups on its structure. Nano bamboo charcoal (NBC) obtained through high temperature carbonization and nano superfine grinding has small particle diameter, large specific microporous area. Such materials have been used to remove chlorinated pollutants from wastewater [11,13]. Hence, these adsorbent could be used as an effective remover of PCBs in theory and the adsorption mechanisms for PCBs need to be further explored.

A practical treatment method generally meets the requirements of the removal of organic pollutants as well as the reuse of chemical agents. However, there have been few reports on how to achieve both high removal efficiency of PCBs and high recovery rate of agents. In this study, PCBs dissolved in tween-80 solution was used as soil washing eluent, from which the PCBs (Aroclor 1254) were adsorbed on PAC and NBC. The effect of adsorption time, amount of PAC and PCBs concentrations were studied and the influence of molecular structure and dynamic and thermodynamic data on the adsorption were discussed. Moreover, in order to increase the recovery rate of tween-80, organic solvents (acetone, dimethylformamide and dimethylacetamide) were employed to destroy the tween-80 micelles prior to adsorption.

## 2. Materials and methods

### 2.1. Materials

The PAC (200 mesh particle size) was purchased from Aladdin Company. Industrial NBC powder (20 nm particle

size, purity  $\geq 97\%$ ) was purchased from Shanghai Hainuo Coal Industry Company. Aroclor 1254 was selected as the representative of PCBs and purchased from Chem Service, Inc. (West Chester, PA, USA), which physical and chemical properties were showed in Table 1. Tween-80 (AR) was purchased from ChengDu Kelong Chemical Reagent Company.

### 2.2. Methods

#### 2.2.1. Static adsorption experiments

A volume of 2.4 mL PCBs-hexane solution was placed in a 30 mL centrifuge tube, and was dried under a gentle stream of nitrogen. Tween-80 solution (20 g/L) was then added to the tube, so as to totally dissolve PCBs. Then adsorbents were added to the prepared samples and shake for 0.5–8 h at 25°C, 150 r/min.

#### 2.2.2. Extraction experiments

After being adsorbed, the samples were centrifuged and filtered. Then 20 mL extraction solvent were added to the sample (hexane:acetone = 9:1, V: V) and shaken for 6 h in a thermostatic shaker at 25°C, 150 r/min. After extraction, 1 mL supernatant was measured in chromatography bottle. PCBs concentration was measured by DSQ II gas chromatograph mass spectrometer. Each group with two parallels, blank control groups use the same volume distilled water instead of soil washing wastewater.

#### 2.2.3. PCBs detection

Aroclor 1254 was quantified by DSQ II gas chromatograph mass spectrometer. GC analysis conditions: CD-5MS capillary column (30 m  $\times$  0.25 mm  $\times$  0.25  $\mu$ m), the carrier gas is He, the carrier gas flow rate is 1.0 mL/min (constant), splitless, inlet temperature is 280°C. Temperature program: initial temperature is 120°C, keep in 1 min; rise to 280°C with the speed of 10°C/min, keep in 5 min. MS analysis conditions: Ion source temperature is 250°C, transfer line temperature is 280°C, the amount of electron impact is 70 eV, solvent delay in 4 min, scan mode is selected ion monitoring (SIM), scanning ion respectively select two features ion of tetrachloride, pentachlorophenol, six chlorine, seven chlorinated, characteristic ion mass nucleus cytoplasm ratio are 290, 292; 326, 328; 360, 362; 394, 396. Referencing standard curve and integrate all belongs to mixed PCBs peak area to measure PCBs.

#### 2.2.4. Surface area measurement

BET surface area was measured by Micromeritics ASAP 2020 adsorption measurement. Analysis bath temperature of adsorptive (liquid nitrogen) was 77 K. Samples were pre-treated at 400°C about 2 h.

Table 1  
Physical and chemical properties of Aroclor 1254

| Molecular weight | Colour | Existence form | Boiling point °C | Density (g/cm <sup>3</sup> ) | Solubility (mg/L) | Vapor pressure (mmHg) | Herry's constant     | log K <sub>ow</sub> |
|------------------|--------|----------------|------------------|------------------------------|-------------------|-----------------------|----------------------|---------------------|
| 328              | Buff   | Viscous liquid | 365–390          | 1.54                         | 0.012             | $7.71 \times 10^{-5}$ | $2.0 \times 10^{-3}$ | 6.5                 |

2.2.5. Adsorption kinetics

In general, the adsorption kinetic process was described by pseudo-first-order kinetic model, pseudo-second-order kinetic model, particles diffusion process and film diffusion model [9,14]. Pseudo-first-order kinetic model assumed adsorption was controlled by the diffusion step, and adsorption rate was proportional to the difference between the equilibrium adsorption capacity and adsorption time [15]. The specific expression was:

$$\lg(q_e - q_t) = \lg q_e - (k_1/2.303)t \tag{1}$$

where  $q_t$  is the adsorption capacity (mg/g),  $q_e$  is equilibrium adsorption capacity (mg/g),  $t$  is adsorption reaction time (h),  $k_1$  is pseudo first order adsorption rate constant ( $\text{min}^{-1}$ ).

Pseudo-second-order kinetic model assumed that the adsorption rate was under the control of chemical adsorption mechanism which involved the electronic share or transfer between adsorbents and adsorbates. The specific expression was:

$$\frac{t}{q_t} = (k_2 q_e^2)^{-1} + \frac{t}{q_e} \tag{2}$$

where  $k_2$  is pseudo second order adsorption rate constant ( $\text{g}/(\text{mg}\cdot\text{min})$ ).

For the particle diffusion model, the formula was:

$$\ln q_t = \ln k_p + 0.5 \ln t \tag{3}$$

where  $k_p$  is particle diffusion coefficient ( $\text{min}^{-1}$ ).

For the liquid film diffusion model, the formula was:

$$-\ln(1 - F) = k_t \tag{4}$$

where  $k$  is liquid film diffusion coefficient ( $\text{min}^{-1}$ ) and  $F = q_t/q_e$ .

2.2.6. Adsorption isothermal equilibrium

The most common adsorption isotherms are Langmuir model, Freundlich model and linear model. Langmuir model belongs to single molecular layer adsorption model [16]. When the adsorption sites on the adsorbent surface were saturated, the adsorb capacity of adsorbent reached to maximum value [17]. There were not adsorbed ions transfer movement at the adsorption sites on the adsorbent surface and adsorption and desorption rate was equal at equilibrium system. The specific expression was:

$$\frac{C_e}{q_e} = \frac{1}{(q_{\max} b)} + \frac{C_e}{q_{\max}} \tag{5}$$

Freundlich equation can be used to describe the irreversible adsorption of different systems and not limited to the adsorption of monolayer adsorption, assuming that the distribution of active adsorption sites at adsorbent surface was non uniform. The specific expression was:

$$\log q_e = \log K + \log \frac{C_e}{n} \tag{6}$$

The specific expression of Linear model was:

$$q_e = K_a C_e + a \tag{7}$$

where  $C_e$  is the equilibrium concentration (mg/L);  $q_e$  and  $q_{\max}$  are the equilibrium adsorption capacity and the maximum adsorption capacity (mg/g);  $a$  and  $b$  are Langmuir model constant and Linear model constant, respectively;  $K$  and  $n$  are Freundlich model constants.

2.2.7. Tween-80 measurement

0.1 mL treated samples were precisely measured in 10 mL volumetric flask and added up distilled water to 2.0 mL. Then, 3.0 mL of cobalt ammonium thiocyanate test solution was precisely added and shaken well, and 4.0 mL of three chloromethane was added and shaken well. Finally the samples were shaken for half an hour in 7 h and detected at 625 nm. Each sample sets three parallels.

3. Results and discussion

3.1. Comparison of PCBs adsorption between PAC and NBC

The effects of adsorbent concentration on PAC and NBC adsorption are shown in Fig. 1. When the concentration of PAC and NBC was 2 g/L, the removal rate of PCBs was 77.90% and 59.23%, respectively; when the adsorbents concentration increased to 10 g/L, PCBs removal rate reached to 96.53% and 93.44% respectively. However, the removal rate of PCBs almost kept unchanged when the adsorbents concentration increased to 10 g/L because the provided total capacity such as pore volume, specific surface area and active position exceeded the total pollutants demand. The treatment effect of NBC was slightly worse than that of PAC, as shown in Fig. 1.

Fig. 2 showed the PCBs content comparison between untreated water sample and after PAC and NBC adsorption samples from GC/MS in selective scanning mode. The experimental samples were mixed PCBs, the peak time of tetrachlorobiphenyl (PCB4), pentachlorobiphenyl (PCB5),

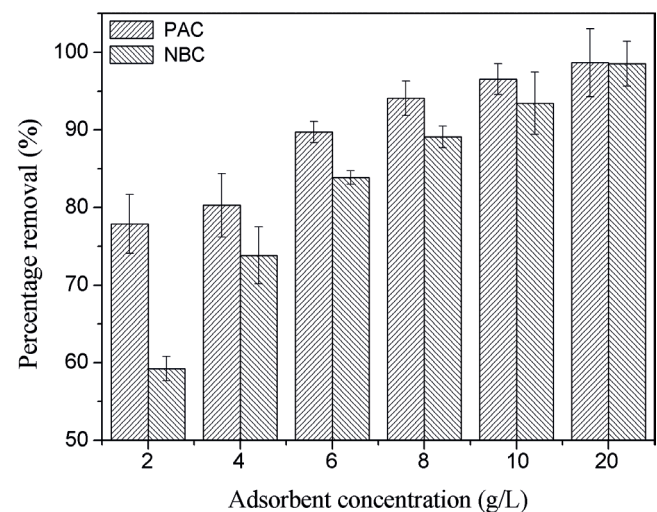


Fig. 1. The impact of adsorbent concentrations on PAC and NBC adsorption (25°C; pH = 7; adsorption time = 6h).

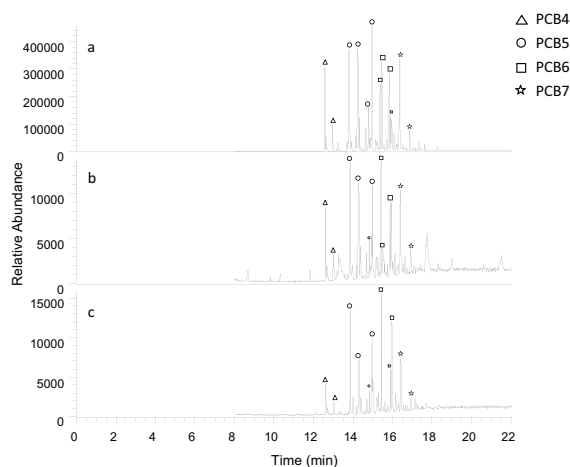


Fig. 2. GCMS of soils eluents: (a) without treatment; (b) adsorbed by PAC; (c) adsorbed by NBC.

hexachlorobiphenyl (PCB6) and heptachlorobiphenyl (PCB7) were mainly between 12.62–13.80 s, 13.85–15.40 s, 15.42–16.40 s, and 16.42–16.94 s, respectively. Under the same treated condition, selective adsorption was relatively stronger of NBC adsorption for the focused PCBs peak. While PAC had good adsorption effect about all kinds of PCBs, resulting in clutter peak of PCBs after adsorption.

The adsorption process was affected by the factors such as surface area, surface charge, functional group and effective adsorption sites [18]. Some studies have shown that the specific surface area and pore structure of adsorbent affected adsorption capacity, while surface chemistry affected interactions between adsorbent and polar or non-polar adsorbate (Moreno-Castilla et al., 1995; García et al., 2004). Table 2 shows the BET surface area test results of the two materials, PAC micropore area and surface area was 0.86 times, 4.98 times of NBC, respectively. The particle size of PAC was 75  $\mu\text{m}$ , while the particle size of NBC was less than 2  $\mu\text{m}$ .

The surface chemical properties of PAC and NBC are largely dependent on the characteristic and quantities of functional groups on the surface. The most common carbon surface functional groups are oxygen-containing functional groups [19]. The chemical structures of oxygen functional groups in PAC and NBC surface mainly include carboxyl, lactone, hydroxyl, carbonyl [14]. The Fourier transform infrared spectroscopy (FTIR) spectra of PAC and NBC were presented in Fig. 3. As shown in Fig. 3, PAC have stronger absorption peak than that of NBC. The two materials had wide and strong stretching bands in the range of 2500–3400  $\text{cm}^{-1}$  (carboxyl stretching vibration region), 1550–1850  $\text{cm}^{-1}$  (carbonyl stretching vibration region), 1,000–1,300  $\text{cm}^{-1}$

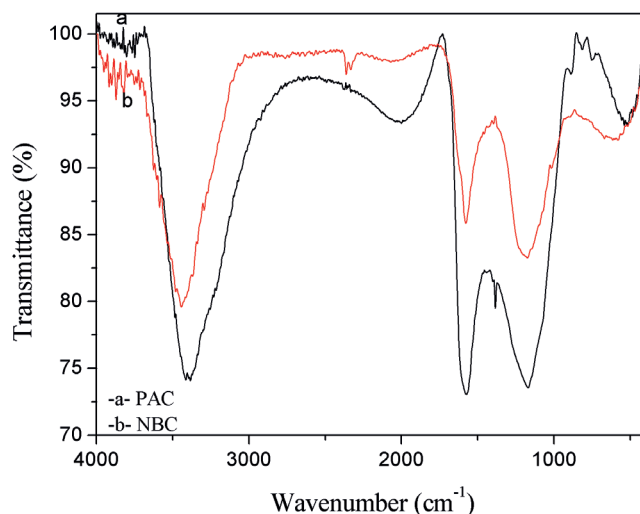


Fig. 3. FTIR spectra of PAC (curve a) and NBC (curve b).

(phenolic hydroxyl vibration area). Both materials almost have the same absorption band but without the same absorption intensity; the most intense contrast was carbonyl stretching vibration absorption peak area. According to the specific surface area analysis (Table 2), isothermal equilibrium diagram (Fig. 1), adsorbed component comparison diagram (Fig. 2) and FTIR spectra diagram (Fig. 3), the two materials have almost the same functional group and different kinds of surface area and pore structure, but the surface charge and effective adsorption sites required further studies.

### 3.2. Adsorption kinetics of PAC and NBC

Adsorption process mainly includes three steps: film diffusion, intraparticle diffusion, and adsorption reaction [20]. In order to study the adsorption mechanism and potential rate-controlling step of adsorption processes, the influence of film mass transfer resistance, internal particle diffusion and fast diffusion process were examined by kinetic models [17]. Kumar [21,22] concluded that if the plots of  $q_t$  vs.  $t^{0.5}$  were two lines, then there was the particles diffusion process after the film diffusion; if the plots of  $-\ln(1 - F)$  vs.  $t$  was a straight line, the film diffusion was the main rate control steps. As shown in Fig. 4(c),  $q_t$  for  $t^{0.5}$  had two linear relationships which indicated that the adsorption process of NBC was affected by both intraparticle diffusion and film diffusion. However, intraparticle diffusion model was not suitable to describe the adsorption process of PAC for the poor linear fitting, which indicated that after film diffusion the adsorption process exist chemical bonding reactions, not mainly affecting by particle diffusion

Table 2  
Physical property of PAC and NBC

| Material | Specific surface area ( $\text{m}^2/\text{g}$ ) | Microporous area ( $\text{m}^2/\text{g}$ ) | External surface area ( $\text{m}^2/\text{g}$ ) | Total pore volume ( $\text{cm}^3/\text{g}$ ) | Microporous volume ( $\text{cm}^3/\text{g}$ ) | Average pore size (nm) |
|----------|---|--|---|--|---|------------------------|
| PAC      | 1,314.569                                       | 461.758                                    | 852.811   | 0.952  | 0.205   | 28.979                 |
| NBC      | 709.495   | 538.140                                    | 171.355   | 0.403  | 0.249   | 22.724                 |



after film diffusion. Fig. 4(d) showed that  $-\ln(1 - F)$  for  $t$  had not a good linear relationship and the lines did not through the origin, which indicated that film diffusion was not the main initial adsorption rate controlling step. In conclusion, when organic molecules was sorbed onto adsorbent surface and increased to a certain extent, the particles diffusion became adsorption rate controlling step of NBC, while particle diffusion and adsorption reaction like chemical bonding reactions co-control the adsorption rate of PAC. According to the results, we can increase the

specific surface area of NBC and PAC to decrease particle diffusion obstruction to improve adsorption efficiency. What more, pseudo-first-order kinetic model could not be used to describe the adsorption process for negative coefficient, while pseudo-second-order kinetic model was suitable to describe the process (including all adsorption process: film diffusion, intra-particle diffusion and adsorption reaction) and truly reflected PAC and NBC adsorption mechanism in soil eluents treatment for the square of correlation coefficient was 0.9999 (Table 3).

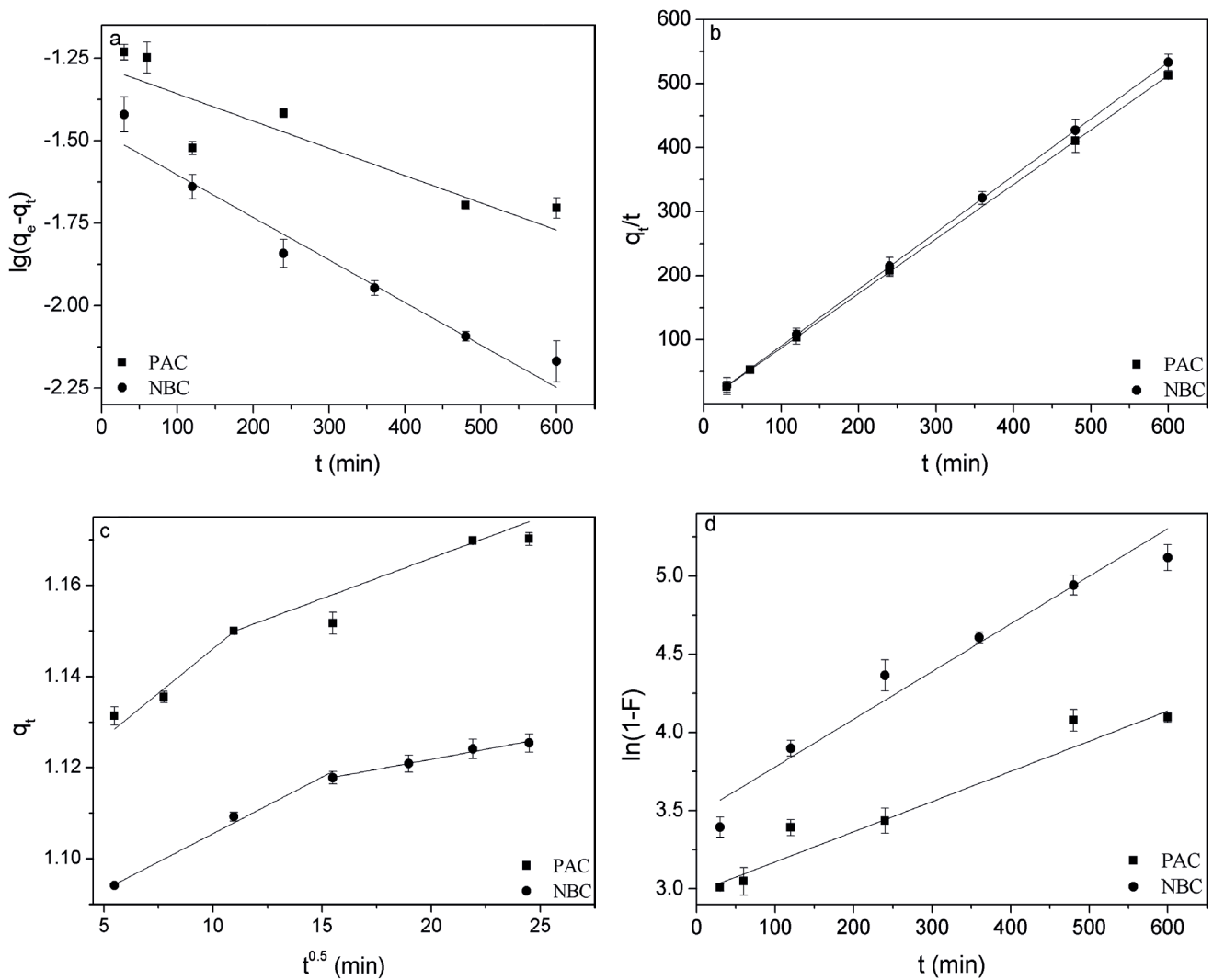


Fig. 4. Adsorption kinetics models of PCBs on PAC and NBC: (a) pseudo-first-order model; (b) pseudo-second-order model; (c) intraparticle diffusion model; (d) liquid film diffusion model.

Table 3  
Kinetic parameters for the adsorption of PCBs on PAC and NBC

| Material | Experimental value | Pseudo first order kinetic model |         |        | Pseudo second order kinetic model |        |        | Liquid film diffusion model |        |
|----------|--------------------|----------------------------------|---------|--------|-----------------------------------|--------|--------|-----------------------------|--------|
|          |                    | $q_e/(mg \cdot g^{-1})$          | $k_1$   | $R^2$  | $q_e/(mg \cdot g^{-1})$           | $k_2$  | $R^2$  | $k$                         | $R^2$  |
| PAC      | 1.1901             | -1.2649                          | -0.0008 | 0.7617 | 1.7599                            | 0.5822 | 0.9999 | 0.002                       | 0.9379 |
| NBC      | 1.1322             | -1.4622                          | -0.0013 | 0.9695 | 1.4899                            | 0.8867 | 0.9999 | 0.0029                      | 0.9598 |

### 3.3. Adsorption isothermal equilibrium of PAC and NBC

The relationship between the adsorption quantity of pollutants in the solid medium and the liquid concentration at the time of equilibrium was usually described by Freundlich, Langmuir, linear adsorption models. According to Table 4 and Fig. 5, Freundlich could not be used to describe the adsorption process of PAC and NBC for the negative coefficients. The adsorption isotherm of PAC was more congruous with the Langmuir equation, indicating that the process was mainly monolayer adsorption. NBC adsorption isotherm was more congruous with linear equations, which indicated

that adsorption process mainly allocated organic pollutants between NBC and water, basing on multilayer adsorption.

The adsorption of PCBs by PAC was mainly due to chemical bonding of PCBs and oxygen containing groups carried by activated carbon molecule. Chlorine atom was an electron withdrawing group, which could offset electrons on the phenyl ring by binding biphenyl [14,23]. Mattson thought that carbonyl had largest impact on activated carbon adsorption of organic matter, benzene ring in PCBs as an electron acceptor while carbonyl group as an electron donor, which formed the electron-electron acceptor complexes by interaction

Table 4  
Equilibrium parameters for the adsorption of PCBs on PAC and NBC

| Material | Linear |        |        | Langmuir                    |        |        | Freundlich |       |        |
|----------|--------|--------|--------|-----------------------------|--------|--------|------------|-------|--------|
|          | $K_d$  | a      | $R^2$  | $q_{max}/(mg \cdot g^{-1})$ | b      | $R^2$  | K          | 1/n   | $R^2$  |
| PAC      | 1.0462 | 1.038  | 0.9575 | 0.1446                      | 0.2191 | 0.998  | -0.369     | 0.644 | 0.9779 |
| NBC      | 0.7462 | 0.4989 | 0.9979 | 0.3059                      | 0.2559 | 0.8594 | -0.178     | 0.614 | 0.9675 |

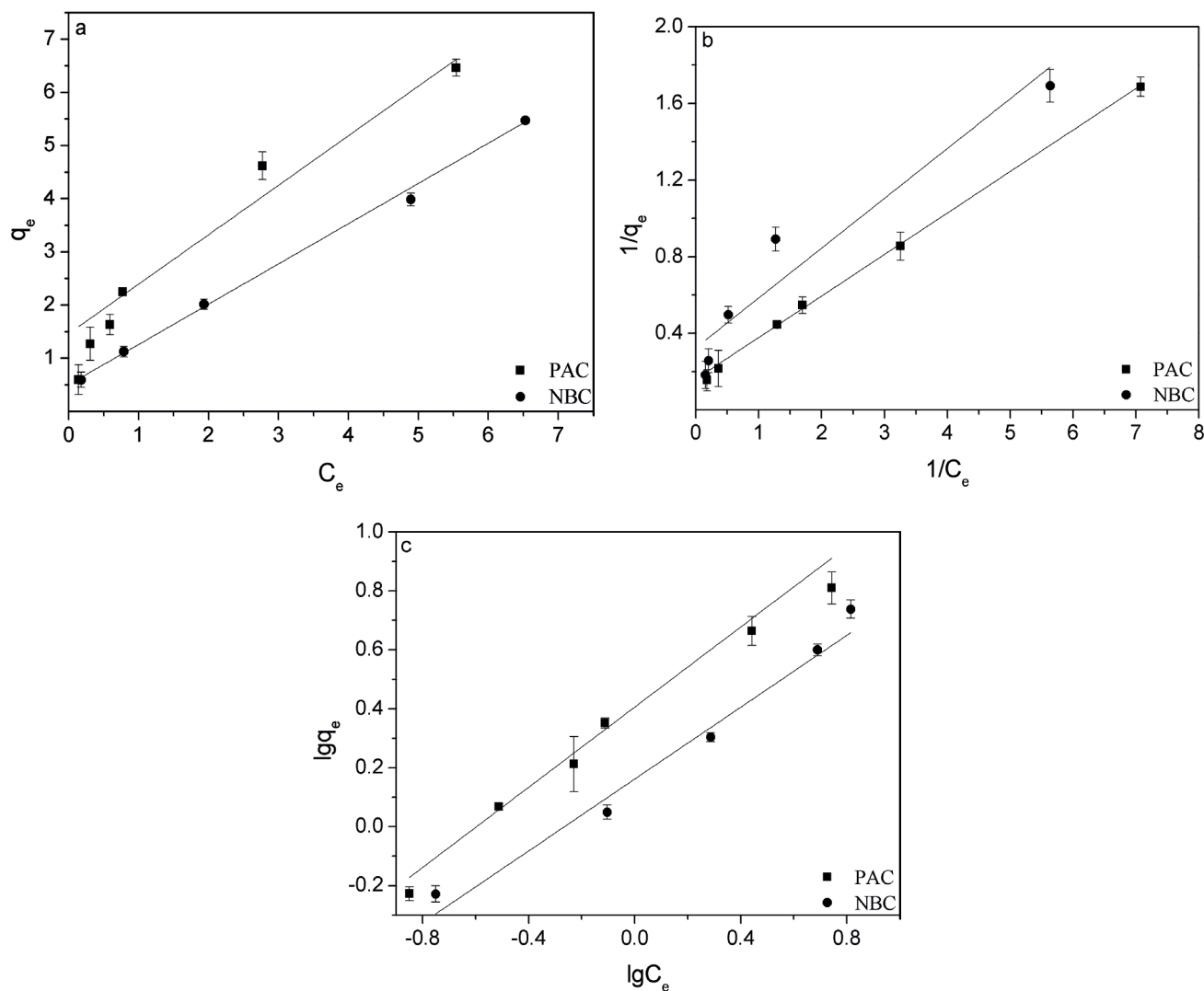


Fig. 5. The adsorption isotherms of PCBs on PAC and NBC: (a) linear model; (b) Langmuir model; (c) Freundlich model).

forces of  $\pi$  electrons in benzene ring and carbonyl [24]. This could also explain the different adsorption capacity of PAC and NBC partly. Thus, the more electron-withdrawing group in benzene ring, PAC gets more adsorption amount.

From Langmuir equation  $RL$  was defined as a dimensionless separation factor to predict whether the adsorption reaction was advantageously procedure, defined formula: , where  $C_0$  is the initial pollutant concentration (mg/L); when  $RL > 1$ , it could be a non-favourable adsorption; when  $RL = 1$ , it could be a linear adsorption; when  $RL = 0$ , it could be an irreversible adsorption; when  $0 < RL < 1$ , it could be a favourable adsorption and within this range, the large  $RL$ , the more conducive to the removal of pollutants [23,25, 26]. The  $RL$  of PAC was 0.2755 which could be a favourable adsorption.

### 3.4. Application of PAC adsorption in PCBs treatment in soil elution waste

In terms of cost and technical requirements, this experiment focused on the application of PAC in PCBs treatment, for more stringent conditions of NBC requiring. As can be seen from Fig. 6 adsorption equilibrium diagram, PCBs removal rate rose with the increase of PAC amount, which could achieve better absorption results in general. Under the condition of room temperature = 25°C, pH = 7, PAC adsorption finished in a short time; when adsorbent amount was 20 g/L, the amount of adsorption reached 1.184 mg/g in half an hour, and while increased to 8 h, the amount of adsorption was 1.189 mg/g. Therefore, the adsorption of PCBs on PAC complete in a short time.

In the process of practical application, PCBs concentrations changed from 1 ppm to 12 ppm, so the experiments were conducted in the adsorption process of PCBs with different concentrations by 2 g/LPAC. The results (Fig. 7) show the PCBs removal rate changed with concentrations under certain condition. When PCBs concentration was 1 ppm, the removal rate was 81.29%; while increasing concentration to 10 ppm, removal rate was 73.87%. Thus, the PAC had certain

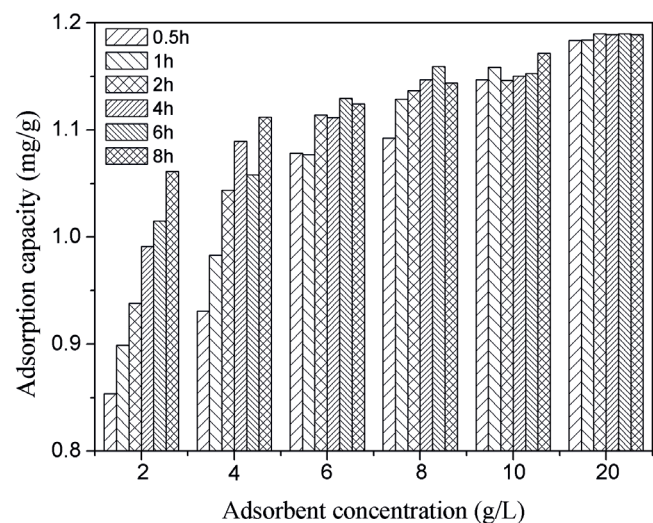


Fig. 6. The impact of time on PAC absorption (25°C; pH = 7; PCBs concentration = 12 ppm).

removal effect of different concentrations of PCBs, but hardly removes trace PCBs in wastewater.

### 3.5. Tween-80 recovery

Tween-80 recovery was affected by the good adsorption properties of PAC and the existence of PCBs. The experiments indicated that after adsorption by PAC soil washing waste water had lower content of tween-80 and the result of tween-80 recovery rate with different concentrations adsorbent after 6 h (increasing reaction time to examine recovery effect and ensure the reaction reaching adsorption equilibrium completely) was shown in Fig. 8. When the adsorbent concentrations was 2 g/L, tween-80 recovery rate was only 27.78%; with the increase of adsorbent, the adsorbent reached 10 g/L and recovery rate decreased to 17.68%.

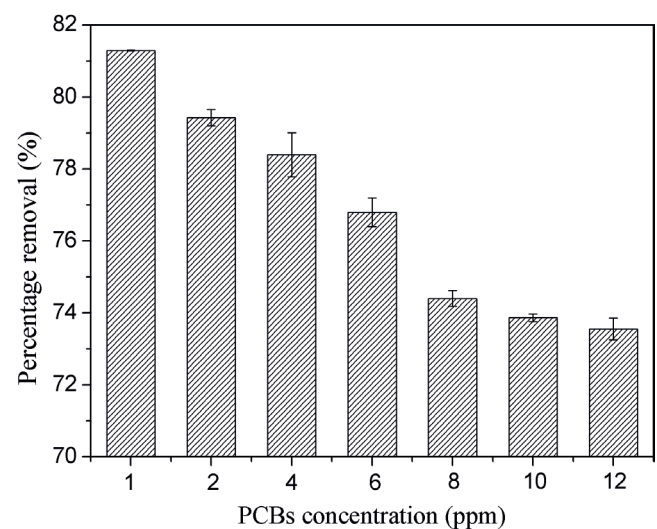


Fig. 7. The impact of PCBs concentrations on PAC absorption (25°C; pH = 7; adsorption time = 2h).

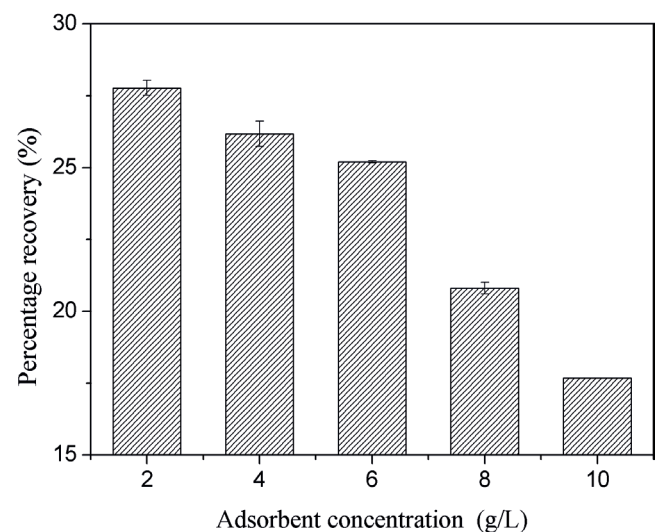


Fig. 8. The tween-80 recovery rate of 6h adsorption (25°C; pH = 7; tween-80 concentration = 20 g/L).

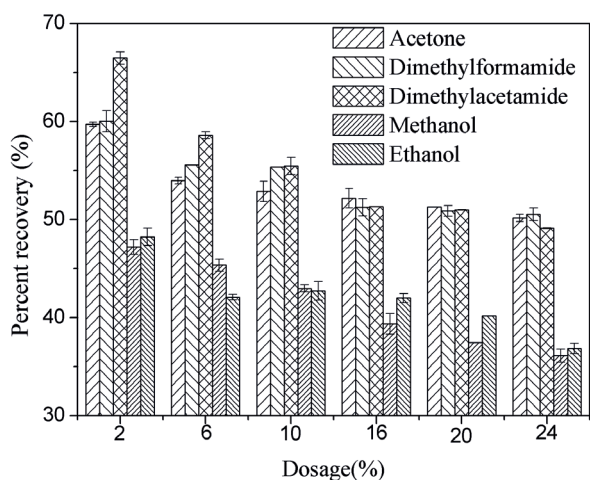


Fig. 9. The impact of solvents concentrations on tween-80 recovery rate (25°C; pH = 7; tween-80 concentration = 20 g/L; adsorbent amount = 2 g/L; adsorption time = 6h).

Tween-80 reduction was mainly due to two reasons; some was absorbed by PAC for its larger size of micelles which was easily absorbed in a large and porous carbon surface, and this partial loss of tween-80 was difficult to recycle. The PCBs adsorption of PAC was mainly bonding with interactions; another part of tween-80 was carried to PAC surface during the bonding process. When micelles were broken, tween-80 retransferred from the solid phase to liquid phase; therefore, this part was easily recycled.

Experiments applied high concentrations of methanol, ethanol, acetone, dimethylformamide, dimethylacetamide to destruct micelles, so the part of tween-80 lost by PCBs bonding interactions could transfer to the liquid. Fig. 9 was tween-80 recovery after different organic reagents treatment when adsorbent amount was 2 g/L, adsorption time was 6 h. The results showed that the recovery of tween-80 had been improved certainly, when added 2% methanol, the recovery rate was 47.22%; when added 2% of dimethylacetamide, the recovery rate was 66.47%. The overall recovery rate about tween-80 increased by 10% when dosed acetone, dimethylformamide, dimethylacetamide contrast to dose methanol, ethanol before adsorption. As the dosage increased, the recovery rate gradually decreased. Because that part of tween-80 lost by PCBs bonding interactions will transfer to the high concentration organic solvents that have strong solvent solubility instead of the liquid, a conclusion could be drawn from above that the part of tween-80 lost by PCBs bonding interactions can be recovered, adding a small amount high concentration tween-80 to reform micelles in treated eluent, the treated eluent can reuse for soil washing.

Moreover, the effect of different elution time on the tween-80 recoveries was studied when the adsorbent concentration was 2 g/L, acetone, dimethylformamide, dimethylacetamide concentration was 2%; the results are shown in Fig. 10(a). Within the adsorption time of 2 h, tween-80 recycling rate reached 85.12%, 88.56%, 87.77%, respectively; the recovery rate was gradually decreased with the time increased.

PCBs were insoluble in water; the destruction of micelles was conducive to further promote adsorption theoretically.

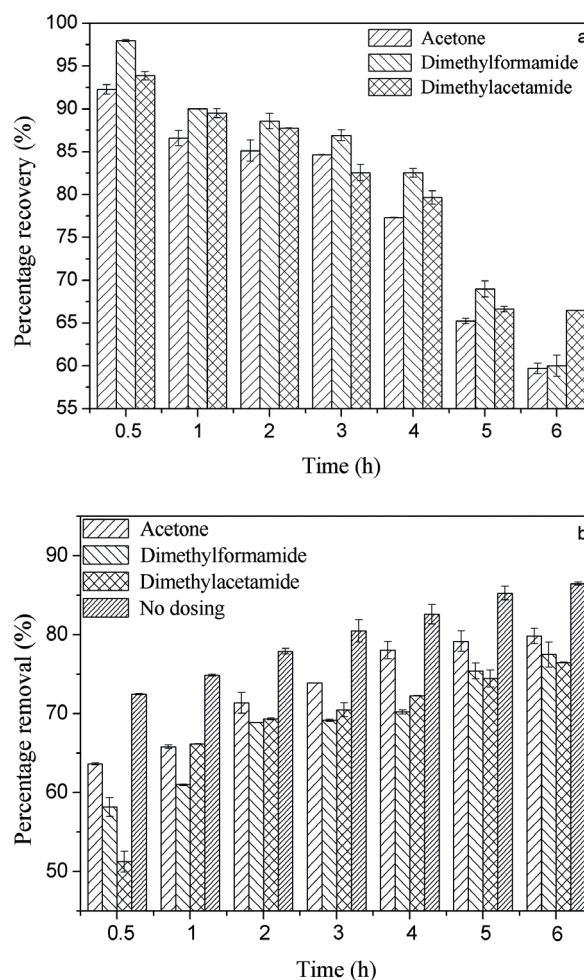


Fig. 10. The impact of time on tween-80 recovery rate (a) and PCBs removal rate (b) (25°C; pH = 7; tween-80 concentration = 20 g/L; PCBs concentration = 12 ppm; adsorbent amount = 2 g/L; organic solvents concentration = 2%).

However, organic solvent system had an impact for PCBs removal; therefore, it was necessary to further examine the removal of PCBs. Fig. 10(b) was the removal rate of PCBs at the conditions of 2 g/L adsorbent and 2% acetone, dimethylformamide, dimethylacetamide. The results showed that adding organic solvent before adsorption led PCBs removal to drop a certain extent. PCBs were difficult to dissolve in water but could be dissolved in some organic solvents. Part of PCBs released from the micelles was then transferred to organic solvents, and soluble PCBs were difficult to be adsorbed, thus causing decline of PCBs removal. In general, this study chooses the experimental conditions of 4 h as adsorption time, 2% as acetone volume capacity and 2 g/L as adsorbent concentration to treat soil washing eluents, which can remove 78.06% PCBs and recycle 73.30% tween-80.

#### 4. Conclusion

In summary, the approaches used in this study have the potential of practical application treatment of e-waste contaminated soils. PAC and NBC can effectively remove PCBs



in soil eluent and meet integrated wastewater discharge standard requirements. Kinetic analyses show that both materials have different adsorption rate controlling step. A pseudo-second-order kinetic model was fitted to both data. The adsorption on PAC was mainly chemisorption process resulting from the interaction of aromatic rings. In contrast, thermodynamic analysis revealed that the adsorption on NBC was mainly a physisorption process occurring over a large microporous surface. Moreover, the loss of the surfactant tween-80 can be reduced by the addition of organic solvents before adsorption. Dosing a small amount of high concentration of tween-80 can reform micelles and recycle eluents, and PCBs removal can still reach a high degree.

The studies provide valuable information on the adsorption of PCBs by PAC in soil washing eluents, which improve the utilization and selection of PAC in the recovery of soil washing eluents.

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