Isothermal Adsorption Characteristics of Phenol from Straw Biochar

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Abstract. Peanut straw, sugarcane residue, cotton straw, was used as raw material to prepare the biochar adsorbent at 500°C, which were named PBC, SBC, and CBC. Phenol was subject to batch adsorption in aqueous medium by the prepared biochar. The results of adsorption experiments show that the kind of raw materials significantly affects its adsorption effect on phenol. The adsorption capacity of phenol from three kinds of biochar was PBC > SBC > CBC. In addition, the initial concentration of phenol in waste water, the temperature and time of adsorption can also affect the adsorption effect. The removal rates of phenol by three biochar decreased with increasing initial concentration of phenol. High temperature is beneficial to adsorption. When the initial concentration of phenol was 20 mg/L and the adsorption temperature was 45°C, the removal rate of phenol was up to 99.7% after PBC adsorption. The reaction increased rapidly at the beginning of 60 min and reached the adsorption equilibrium after 180 min. The isothermal adsorption line for phenol conforms to the Langmuir mode and the Freundlich mode. The results provided a theoretical basis for the removal of organic pollutants such as phenol.

1. Introduction
As an important renewable biomass resource, the rational development and utilization of straw has attracted more and more attention \cite{1-2}. As a good adsorbent, biochar has attracted more and more attention in adsorbing organic pollutants and improving soil environment. Therefore, biochar has great potential in the treatment of environmental pollution, and biochar has a wide range of raw materials, so it is expected to be widely used as a cheap adsorbent.

At present, the application of biochar in water mainly focuses on the removal of heavy metal ions and other charged pollutants, but the removal of phenol and other hydrophobic pollutants is less \cite{3-4}. In this study, biochar was prepared from peanut straw, sugarcane residue, cotton straw at 500°C pyrolysis temperature to adsorb phenol in water. The effects of pyrolysis temperature, initial concentration of phenol and adsorption time on the adsorption efficiency of phenol were studied, and the adsorption characteristics of biochar on phenol were revealed.
2. Materials and Methods

2.1. Biochar preparation
The sugarcane residue was from a market in Xianyang, Shaanxi. The cotton straw and peanut straw was from a rural area in Xianyang, Shaanxi. Take a certain amount of dry residue in the small porcelain crucible covered with lid, placed in a muffle furnace to the target temperature 500℃, then keep the temperature for 2 h. After cooling, grinding over 60 mesh sieve, sealing in reagent bottles and stored in a desiccator standby. The markings are SBC, CBC, and PBC.

2.2. Removal rate of phenol
The concentration of phenol after adsorption was measured by UV spectrophotometry (λ =270 nm). Phenol adsorption capacity of $q_e$ reached the adsorption equilibrium and the removal rate is calculated by the following formula:

$$q_e = \frac{(C_0 - C_e)}{W} \cdot V$$

$$\eta = \frac{C_0 - C_e}{C_0} \times 100\%$$

Formula: $q_e$ is the adsorption capacity of equilibrium, mg/g, $C_0$ and $C_e$ are content of phenol before adsorption and after adsorption, mg/L, $V$ is volume of solution, L, $W$ is adsorbent dosage, g, respectively.

2.3. Effect of reaction time on adsorption
Under the room temperature, samples of phenol concentration of 50 mg/L were placed in 50 mL Erlenmeyer flask, adding 0.1 g SBC, CBC, PBC, respectively. Determine the residual phenol concentration at different adsorption time.

2.4. The mechanism of adsorption
The adsorption isotherms of SBC, CBC, and PBC on phenol were fitted by Langmuir and Freundlish models. The Langmuir model formula is:

$$q_e = \frac{abC_e}{1 + aC_e}$$

In the formula, $q_e$ is the adsorption capacity, $C_e$ is the adsorption equilibrium concentration, and $a$ and $b$ are constant, and the reciprocal formula is:

$$q_e^{-1} = \frac{1}{ab} C_e^{-1} + \frac{1}{b}$$

In form (4), we can see that $q_e^{-1}$ has a linear relationship with $C_e^{-1}$. According to the Freundlish experiential formula:

$$q_e = KC_e^{1/n}$$

In the formula, $K$ is a constant, the linear form of its equation:

$$\log q_e = \log K + \frac{1}{n} \log C_e$$

3. Results and Discuss

3.1. Removal rate of phenol with different initial concentrations
The phenol removal rate of three biochar decreased as the initial concentration of phenol increased.
When the initial concentration of phenol was 30 mg/L, SBC had the highest removal rate of 98.8%; when the initial concentration of phenol was 20 mg/L, CBC had the highest removal rate of 98.7%; when the initial concentration of phenol was 20 mg/L, and PBC had the highest removal rate of 99.3%.

3.2. Effect of reaction time on adsorption
At the beginning of the reaction, the removal rate of phenol by straw biochar increased rapidly, and increased rapidly in the first 60 minutes. With the reaction proceeding, the removal rate increased gradually. The adsorption rate increased slowly within 60 minutes to 120 minutes, and then the adsorption process gradually stabilized. After 120 minutes, the reaction time was prolonged and the removal rate was removed. The rate remained basically unchanged, and the adsorption reaction reached equilibrium after fully oscillating for 180 min.

3.3. Discussion on the mechanism of adsorption
Langmuir isothermal model and Freundlich isothermal model were used to fit the experimental data, and the two fitting models showed good linear relationship. Table 1 shows that the adsorption of phenol by straw biochar at different adsorption temperatures conforms to Langmuir and Freundlich adsorption isotherms. In Langmuir equation, \( b \) represents adsorption equilibrium constant, which is the ratio of adsorption to analytical rate constant. The larger the \( b \) value, the greater the adsorption capacity. It can be seen from Table 1 that the value of \( b \) increases with the increase of adsorption temperature, indicating that high temperature is beneficial to the adsorption of phenol by biochar. The adsorption constant \( K \) in Freundlich equation reflects the adsorption capacity. The larger the \( K \) value is, the stronger the adsorption capacity is. It can be seen from Table 1 that \( K \) value decreases with the decrease of adsorption temperature, indicating that the lower temperature is not conducive to the adsorption of phenol by biochar.

| Adsorption mode | Linear regression equation | \( R^2 \) | Adsorption isotherm constant | \( p \) |
|-----------------|----------------------------|-----------|-----------------------------|-------|
| Langmuir        |                            |           |                             |       |
| SB500 25°C      | \( y = 0.0202x + 0.054 \)  | 0.9906    | \( a=2.67, b=18.52 \)       | <0.05 |
|                 | 35°C \( y = 0.0357x + 0.0401 \) | 0.8867    | \( a=1.12, b=24.94 \)       | <0.05 |
|                 | 45°C \( y = 0.0543x + 0.0246 \) | 0.9893    | \( a=0.45, b=40.65 \)       | <0.05 |
| PB500 25°C      | \( y = 0.0158x + 0.0443 \)  | 0.9774    | \( a=2.80, b=22.57 \)       | <0.05 |
|                 | 35°C \( y = 0.0264x + 0.0407 \) | 0.8681    | \( a=1.54, b=24.57 \)       | <0.05 |
|                 | 45°C \( y = 0.0428x + 0.0176 \) | 0.9693    | \( a=0.41, b=56.82 \)       | <0.05 |
| CB500 25°C      | \( y = 0.0076x + 0.0595 \)  | 0.9483    | \( a=7.83, b=16.81 \)       | <0.05 |
|                 | 35°C \( y = 0.0172x + 0.0446 \) | 0.9881    | \( a=2.59, b=22.42 \)       | <0.05 |
|                 | 45°C \( y = 0.0241x + 0.0355 \) | 0.9930    | \( a=1.47, b=28.17 \)       | <0.05 |
| Freundlish      |                            |           |                             |       |
| SB500 25°C      | \( y = 0.704x + 1.0845 \)   | 0.9872    | \( K=12.15, 1/n=0.704 \)    | <0.05 |
|                 | 35°C \( y = 0.542x + 1.0894 \) | 0.9468    | \( K=12.29, 1/n=0.542 \)    | <0.05 |
|                 | 45°C \( y = 0.4322x + 1.103 \) | 0.9834    | \( K=12.68, 1/n=0.4322 \)   | <0.05 |
| PB500 25°C      | \( y = 0.7046x + 1.1903 \)  | 0.9781    | \( K=15.50, 1/n=0.7046 \)   | <0.05 |
|                 | 35°C \( y = 0.6244x + 1.1988 \) | 0.8799    | \( K=15.81, 1/n=0.6244 \)   | <0.05 |
|                 | 45°C \( y = 0.4918x + 1.2302 \) | 0.9548    | \( K=16.99, 1/n=0.4918 \)   | <0.05 |
| CB500 25°C      | \( y = 0.5658x + 1.2142 \)  | 0.9969    | \( K=16.38, 1/n=0.5658 \)   | <0.05 |
|                 | 35°C \( y = 0.5353x + 1.2351 \) | 0.9929    | \( K=17.18, 1/n=0.5353 \)   | <0.05 |
|                 | 45°C \( y = 0.4217x + 1.2415 \) | 0.9757    | \( K=17.44, 1/n=0.4217 \)   | <0.05 |
4. Conclusion
In this study, straw biochar was prepared at 500°C to adsorb phenol in water, so as to realize resource utilization of agricultural straw waste. It was found that these three kinds of biochars had strong adsorption capacity for phenol at low concentration, and the adsorption capacity was PBC > SBC > CBC. Straw biochar is a kind of good adsorbent, the raw material is easy to obtain and the production method is simple, has a high value of development and application, and has a broad application prospect in the field of sewage treatment.

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