Study on adsorption of phenol by modified montmorillonite

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Abstract: Organic montmorillonite was prepared from montmorillonite and cetyltrimethylammonium bromide. The absorption of phenol under different condition of time, temperature and initial concentration of phenol was measured with montmorillonite, organic montmorillonite and bentonite as raw materials. Experimental results indicated that organic montmorillonite was the best adsorbent for phenol among the three raw materials, followed by montmorillonite. And the adsorption effect of bentonite was the worst. The results also showed that the optimal conditions for adsorption were 25°C and two hours. And montmorillonite was suitable for the absorption of high concentrations of phenol. Compared with the infrared spectra of organic montmorillonite before and after adsorption, no new chemical bonds were formed in organic montmorillonite. The organic montmorillonite only absorbed phenol in the form of physical adsorption.

1. Introduction
Phenol is often used to prepare chemical products and intermediates as an important chemical raw material, such as phenolic resin and adipic acid [1]. Chemical plants, pharmaceutical plants, refineries and other plants produce a large amount of phenol-containing wastewater every year. It will pollute the environment and endanger the health of people if the wastewater is discharged without treatment [2]. Therefore, the treatment of phenol-containing wastewater has drawn attention.

The current treatment methods of wastewater containing phenol industrially are divided into three categories, namely, chemical, biochemical, physical and chemical methods [3]. The adsorption method in the physicochemical method is most commonly used of these three methods [4]. In order to ensure the separation effect, adsorbents with good adsorption effect, large adsorption capacity, easy regeneration and durability are often used.

Montmorillonite is a white, natural mineral with adsorption capacity [5]. Modified montmorillonite can be used as an adsorbent and coating agent [6]. Phenol can be adsorbed at room temperature by montmorillonite since it adsorbs phenol by physical adsorption without chemical reaction [7]. Moreover, the use of montmorillonite to adsorb phenol is pollution-free and environmentally friendly. Therefore, montmorillonite can be used to adsorb phenol, which can purify the environment and clean water.

2. Experiment

2.1 Preparation of organic montmorillonite
Put an appropriate amount of montmorillonite into hot water at 80 °C. Stir well and add cetyltrimethylammonium bromide. Mechanical stirring until a large amount of precipitate is generated, then suction filtration and drying at 60°C for 24 h [8].

2.2 Phenol adsorption experiment
Put an appropriate amount of the sorbent into phenol solutions of different concentrations. Take part of the solution for centrifugation after stirring at a certain temperature for a certain time. Measure the absorbance of the supernatant, and evaluate the temperature, adsorption time, and phenol based on the concentration of phenol after adsorption.

2.3 Infrared spectrum analysis
Infrared spectrometer (Nicoletis5, Thermo Scientific) was used to determine the infrared spectrum of phenol adsorbed by organic montmorillonite.

3. Results and discussion

3.1 Drawing of Phenol Standard Curve
Phenol standard solutions were prepared with a concentration of 5 mg/L, 10 mg/L, 20 mg/L, 30 mg/L, 40 mg/L, 50 mg/L. The standard curve of absorbance at wavelengths up to 270 nm is shown in Figure 1.

As can be seen from the figure, the phenol concentration has a linear relationship with the absorbance. The equation is $y = 0.022x$, and $R^2$ is 0.9992.

3.2 Effect of temperature on phenol adsorption
The absorbance of the montmorillonite, organic montmorillonite and bentonite at different temperatures for one hour was plotted.

The concentration of phenol decreases first and then increases with the change of temperature under the adsorption of different adsorbents, as the lines demonstrate in Figure 2. This may be because the three adsorbents adsorb phenol by physical adsorption. When the carrier adsorbs phenol on the surface, some of the phenol molecules form a chemical bond with the carrier under the action of electrostatic attraction. However, the pores of the adsorbent will become smaller, resulting in a decrease in the amount of adsorption when the temperature is too high because the pores of the adsorbent will change with temperature [9]. It can be seen that the optimal temperature for montmorillonite, organic montmorillonite and bentonite to adsorb phenol is 25°C.
Comparing the three lines in Figure 2, we can see that organic montmorillonite has the best adsorption effect on phenol while montmorillonite and bentonite have similar adsorption capacity for phenol.

![Figure 2 Effect of temperature on phenol adsorption](image)

### 3.3 Effect of time on phenol adsorption

It can be seen from Figure 3 that the concentration of residual phenol gradually decreases with time and the concentration is almost invariant after 2 hours. The reason may be that the pore volume of the adsorbent is constant. More and more phenol molecules are filled into the pores of the adsorbent with the increase of time. The amount of phenol adsorbed does not change when the pores are completely filled while time is continuously extended. And the rate of adsorption for phenol becomes smaller two hours later. The optimum time to adsorb phenol is two hours with comprehensive consideration of various factors.

Comparing the three lines in Figure 3, we can come to the conclusion that the amount of phenol adsorbed by organic montmorillonite is the largest while bentonite the smallest.
3.4 Effect of initial phenol concentration on phenol adsorption

Figure 4 Effect of initial phenol concentration on phenol adsorption

It can be concluded from the figure 4 that the concentration of the phenol changed is increasing with the initial concentration of phenol increasing. It indicates that the amount of phenol adsorbed is increasing. The reason may be that there are two different mechanisms for the adsorption of organic pollutants by montmorillonite which are the mechanism of adsorption on the surface and the mechanism of distribution of organic matter in montmorillonite organic matter. The adsorption effect is affected by the content of organic matter in montmorillonite. Phenol in the water phase will be transferred to montmorillonite with higher concentration, resulting in a further increase in the concentration of organic matter in montmorillonite. As a result, the rate of adsorption for phenol of montmorillonite is higher with the increase of the initial concentration of phenol [10]. It can be seen from Figure 4 that the three adsorbents are suitable for adsorbing high concentration of phenol. And organic montmorillonite has the best adsorption effect on phenol.

3.5 Infrared Spectral Characterization

Figure 5 FT-IR spectrum of organic montmorillonite
Infrared spectra of organic montmorillonite before and after adsorption of phenol is shown in Figure 5 and Figure 6. The absorption peaks of typical montmorillonite at 1360 cm\(^{-1}\) [\(\nu\) (Si-O)], 1030 cm\(^{-1}\) [\(\nu\) (Si-O-Si)], and 518 cm\(^{-1}\) [\(\delta\) (Si-O-Al)] can be seen clearly in the two spectra. Furthermore, the peaks of organic montmorillonite after adsorption of phenol at 804 cm\(^{-1}\) [\(\nu\) (C-H)] indicated that phenol is adsorbed into the organic montmorillonite in Figure 6. Compared Figure 6 with Figure 6, we can come to the conclusion that no new chemical bond is formed. Therefore, it can be known that montmorillonite adsorbs phenol as physical adsorption.

4. Conclusion
In summary, the best conditions for montmorillonite, organic montmorillonite, and bentonite to adsorb phenol are 25 °C and 2 hours, which are all suitable for adsorbing high concentration of phenol. Organic montmorillonite has the best adsorption effect on phenol while bentonite has the worst adsorption effect among the three adsorbents. Organic montmorillonite adsorption of phenol is a physical adsorption process.

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