Fabrication of Activated Charcoal Adsorption Bi$_2$O$_3$/TiO$_2$ Composite Powders and the Study of Their Photocatalytic Activity

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Abstract. A visible light-driven activated charcoal adsorption Bi$_2$O$_3$/TiO$_2$ composite photocatalyst was prepared by a sol–gel method in which activated charcoal acted as an adsorption to capture metal ions by reacting with bismuth and titanium sources via a complex polycondensation pathway. The phase and particle size of the photocatalyst were characterized by X-ray diffraction (XRD), scanning electron microscopy (SEM). The results revealed that adsorption of Bi$_2$O$_3$/TiO$_2$ composite powder with activated carbon is not easy to agglomerate and sinter during the preparation and calcination process, and it has the advantages of good dispersibility, less agglomeration and uniform particles. The photocatalytic activity of the as-prepared catalyst was evaluated by degradation of methylene blue under visible light irradiation. The results showed that the decomposition rate of methylene blue was 93% at 50 min catalyzed by composite powder.

1. Introduction

Sewage treatment, indoor air quality and other environmental problems has an important link with human health and has a very important impact on peoples living environment. The semiconductor titanium dioxide has a broad application prospects based on dioxide visible light photocatalytic degradation of organic pollutants and the provision of many potential environmental solutions. TiO$_2$ has many advantages such as: high stability, high sensitivity, non-toxic and so on. However its light quantum efficiency is only 4%, in the practical application of a greater limitation. So the modification of TiO$_2$ has aroused widespread concerning the chemical industry. The modification methods of TiO$_2$ are as follows: precious metal deposition [1], metal ionization [2], non-metallic element doping [3], composite semiconductor doping [4] and other methods, which the most effective improve the photocatalytic performance of TiO$_2$ is the way to be combined with other semiconductors. And the composite oxide photocatalyst will generally have better catalytic performance than pure TiO$_2$. The difference in energy levels between two kinds of semiconductor can make effective separation of charge, so that its excitation wavelength extends to the visible light region [5-6]. The band gap of Bi$_2$O$_3$ is 2.8 eV, there are many reports on the modification of TiO$_2$ with Bi$_2$O$_3$[7-10]. Known methods are sol-gel method [11], hydrolysis method [12], etc. But the methods have many the shortcomings, such as: poor dispersion, particle radius is not easy to control, preparation, drying, and roasting particles easy to agglomerate and sintering and so on [13]. In the reaction solution to prepare activated charcoal adsorption Bi$_2$O$_3$/TiO$_2$ composite powders, the nanoparticles are adsorbed to the surface of the activated carbon in the reaction solution. Thereby the agglomeration of the granules reduced during the preparation. The photocatalytic activity of
activated charcoal adsorption Bi$_2$O$_3$/TiO$_2$ composite powders was investigated by using the composite powders as the photocatalyst and methylene blue solution as the target degradation product under the UV irradiation of xenon lamp.

2. Results and Discussion

2.1 Activated carbon adsorption and sol–gel method

It is not uncommon to study the preparation of Bi$_2$O$_3$/TiO$_2$ nanoparticles by ordinary methods. However, this method has many disadvantages, such as particle size is difficult to control and it's easy to easy agglomeration and sintering during sample drying and roasting. The sol-gel method in which activated charcoal is used as adsorbent can effectively avoid the shortcomings of the traditional method. Adding the right amount of activated carbon with strong adsorption capacity in the reaction solution, precursor once formed in the solution will be adsorbed on activated carbon surface. And the activated carbon has a good dispersion, so the product obtained in the drying and roasting process is not easy to reunite and sintering of the situation. Bi(NO$_3$)$_3$ will produce bismuth nitrate when it soluble in water, bismuth nitrate will generates Bi(OH)$_3$ with low-solubility in aqueous solution. The calcination process was heated by a high-temperature furnace (temperature ramp rate of 20℃ / min). when the temperature increased from 200 ℃ to 400 ℃, Ti(OH)$_4$ begins to lose crystal water generating TiO$_2$ and partials of Bi(OH)$_3$ is decomposed into Bi$_2$O$_3$. When the temperature reaches 500 ℃, the activated carbon begins to be oxidized. As the temperature increases, the activated carbon will gradually decrease. When the temperature reaches 700 ~ 800 ℃, the activated carbon tends to be completely oxidized, the composite powder will appears sintering situation after a long time. Therefore, the addition of activated carbon can effectively control the particle size of Bi$_2$O$_3$/TiO$_2$ composite powder adsorbed by activated carbon at the nano scale level. And the composite powder has a larger specific surface area and higher photocatalytic performance.

2.2. Phase analysis

The XRD pattern of activated charcoal adsorption Bi$_2$O$_3$/TiO$_2$ composite photocatalyst was prepared by an sol–gel method under different calcination temperature are shown in figure 1. Where in the calcination temperatures of the figure 1a, figure 1b, figure 1c and figure 1d are 400 ℃, 600 ℃, 700 ℃ and 800 ℃, respectively. Due to the low content of Bi$_2$O$_3$ with high dispensability, The peaks in figure 1 is essentially diffraction peaks of TiO$_2$. According to the diffraction peak, it can be seen that the crystallization rate is not high and the diffraction peak is weak with calcination temperature 400 ℃ composite photocatalysts are crystalline under the 600 ℃, 700 ℃ and 800 ℃.

![XRD pattern of and Bi$_2$O$_3$/TiO$_2$ composite synthesized at different calcination temperature (a:400 ℃, b:600 ℃, c:700 ℃, d:800 ℃).](image)

The pattern of activated charcoal adsorption B$_2$O$_3$/ TiO$_2$ composite powders was prepared by a sol–gel method shows that the peaks both are anatase diffraction peaks when the calcination temperature is 600 ℃ and 700 ℃. The composite powder is still anatase phase, and no rutile phase conversion under 800 ℃ of the calcination temperature. It is known that the powder prepared by ordinary sol-gel
method is converted from anatase phase to rutile phase when the calcination temperature reaches 800 °C.

2.3 SEM analysis

![Figure 2. SEM images of composite powders at 400 °C.](image1)

![Figure 3. SEM images of composite powders at 600 °C.](image2)

![Figure 4. SEM images of composite powders at 700 °C.](image3)

![Figure 5. SEM images of composite powders at 800 °C.](image4)

In figure 2, the length of figure 2a unit is 1 μm, and the length of figure 2b and figure 2c is 10 μm. It can be seen from the three figures that the composite powder is well dispersed and the particles are uniform with no obvious agglomeration. The three graphs unit length is 1μm in figure 3. The crystal is very regular, while uniform dispersion, no agglomeration phenomenon at calcination temperature 600 °C. The three graphs unit length is 1μm in figure 4. From the three figures to see when the calcination temperature is 700 °C, there is a slight reunion phenomenon, but the overall dispersion is more uniform. When the calcination temperature reaches 800 °C, there is a clear phenomenon of
agglomeration are shown in figure 5. This result is similar to the previous XRD analysis results. Those show that activated carbon adsorption Bi$_2$O$_3$ / TiO$_2$ composite powder at calcination temperature of 600 °C light catalytic effect is best.

2.4. Photocatalytic performance

Figure 6 shows the different degradation rates of methylene blue under different catalysts. The degradation rate of methylene blue is only 1.5% without catalyst, which shows that the stability of methylene blue is very good in the absence of catalyst. The degradation rate of methylene blue increased obviously with the increase of time after adding different photo catalysts. Degradation rate is maximum when the calcination temperature was 600 °C. And the degradation rate is the smallest at calcination temperature of 800 °C. The decomposition rate of methylene blue was 86% at 40 minutes. With activated carbon adsorption of composite powder as catalyst prepared by activated carbon adsorption sol-gel method and was calcined at 600 °C, and the decomposition rate of methylene blue was 93% at 50 minutes. The decomposition rate of methylene blue was only 24% at 40 min. With Bi$_2$O$_3$/TiO$_2$ as catalyst prepared by ordinary sol-gel method and was calcined at 600 °C. When adding activated carbon to the reaction solution, the formation of nanoparticles in the initial reaction solution will immediately activated by carbon adsorption. This effectively prevents the superfine particles agglomerating and sintering in the subsequent preparation and drying process and roasting stage. The nano-composite Bi$_2$O$_3$/TiO$_2$ powder with small particle size and large specific surface area can be obtained when the temperature is raised to 600 °C. The temperature continues to rise, the composite powder will have sintering phenomenon, so the catalytic effect will be worse.

![Figure 6](image)

**Figure 6.** The chart of photo-degradation rate changing with the illumination time(calcination temperature: a: control experiment without catalyst b: 400 °C, c: 600 °C, d: 700 °C, e: 800 °C.).

3. Conclusion

Activated carbon adsorption Bi$_2$O$_3$/TiO$_2$ composite powders average particle diameter is of about 19.9 nm at calcination temperature of 600 °C. The adsorption of activated carbon can effectively reduce the agglomeration and sintering of Bi$_2$O$_3$/TiO$_2$ composite powder during the preparation, drying and high temperature calcination, thus inhibiting the growth of the particles and suppressing the composite powder from Anastasia phase to lutite phase. The photocatalytic activity of the as-prepared catalyst was evaluated by degradation of methylene blue under visible light irradiation. The results showed that the decomposition rate of methylene blue was 93% at 50 min catalyzed by composite powder.

4. References

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