Oxidized activated carbon as support for titanium dioxide in UV-assisted degradation of 3-chlorophenol

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Abstract

Strong adsorption of pollutants on activated carbon may inhibit their diffusion to the catalyst on the surface of the adsorbent and hence reduce the whole photocatalytic process. Oxidation of the carbon surface will change the adsorption properties of the carbon; and increase the capability of carbon surface to carry more titanium dioxide. In this work, activated carbon was oxidized with different oxidizing agents (nitric acid, ammonium persulfate, and hydrogen peroxide) to produce carbons with different surface chemistries. Titanium dioxide was deposited on oxidized and non-oxidized carbons, in which titanium dioxide loading was higher in the oxidized carbons. The produced materials were tested in UV-assisted mineralization of 3-chlorophenol in aqueous medium. Results showed that 1 g of the product made by deposition of titanium dioxide on hydrogen peroxide-oxidized carbon (23.5% titanium dioxide) caused photo-mineralization of 40% of the 3-chlorophenol within 5h; while half gram of titanium dioxide (pure anatase) caused photo-mineralization of 58% of 3-chlorophenol within the same period. It seems that 3-chlorophenol decomposed entirely with titanium dioxide deposited on other oxidized and non-oxidized carbons, but complete mineralization into chloride, CO2 and H2O was not achieved. A mixture of titanium dioxide (anatase) and non-oxidized carbon showed that mineralization is taking place even when all 3-chlorophenol was adsorbed on carbon surface. This suggests that adsorbed 3-chlorophenol is involved in the mineralization process. © 2006 Elsevier B.V. All rights reserved.

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1. Introduction

Several published papers and review articles have cited the theory and environmental applications of heterogeneous photocatalysis by the use of semiconductors, such as titanium dioxide (TiO2), especially in the anatase crystal form [1–5]. One of its disadvantages is the power requirement due to the use of a UV lamp. However, improving the photocatalyst may increase reaction rate and thus decrease residence time, and reduce energy consumption per unit volume treated. It is generally accepted that this may be achieved by deposition of the photocatalyst on a high surface area material (support) that will selectively adsorb the pollutant molecules and concentrate them around the photocatalyst [6–9]. Unfortunately, strong adsorption of pollutants reduces the rate of diffusion into titanium dioxide particles, which will thus inhibit the efficiency of the photocatalyst. This limitation has directed many researchers to look for suitable supports for titanium dioxide for the treatment of specific pollutants, or to develop new deposition techniques [10–14]. In addition to pH of the solution, the type of pollutant and the support play an important role in the success of this process.

Several works have reported the use of activated carbon as a support for TiO2 [10–12,15–19], but warned that strong adsorption of pollutant to the adsorbent surface may inhibit diffusion to the catalyst and hence may cause severe problems to the whole process. The use of activated carbon as a support for TiO2 appears to give great advantages over other supports. These include its ability to rapidly adsorb pollutants, as well as its high adsorption capacity due to its high surface area and porosity. As suggested by Takeda et al. [10], activated carbon must be of medium surface area and porosity, to facilitate the diffusion of pollutants and release of products from the surface. Additionally, the high porosity of activated carbon may prevent penetration of UV light into small pores, and may cause trapping of pollutants within the pores without being able to diffuse onto the external surface.
surface for further reaction with hydroxyl radicals. Furthermore, some pollutants, such as phenols, may undergo polymerization on the carbon surface, which causes irreversible adsorption.

The surface properties of activated carbon play an important role in the adsorption of pollutant species. The role of surface chemistry and textural features of activated carbon have been reported by many authors [20–26]. They showed that basic activated carbon with low oxygen content is more capable of phenol adsorption [21,22]. Absence of acidic groups on the carbon surface increases the physisorption and surface polymerization of phenols [24]. Acidic surface groups hinder the ability of activated carbon to adsorb phenolic compounds [22]. The presence of oxygen-containing basic groups on the surface of activated carbon is the key factor in promoting oxidative coupling of phenolic compounds and thus causes irreversible adsorption [25]. Additionally, the graphite layers of an activated carbon increase the \( \pi \) electron density and thus enhance dispersive interactions between \( \pi-\pi \) electrons in activated carbon and phenols. Thus, regardless of the textural properties, adsorption capacity of phenol is expected to be higher in carbons of basic nature. Although there was no clear relationship between carbon basicity and 3-chlorophenol (3-CP) retention [27], retention of 3-CP is expected to be less in acidic carbons than in basic ones.

The purpose of the present work is to test the efficiency of titanium dioxide deposited on oxidized and non-oxidized activated carbon in photo-assisted degradation of 3-chlorophenol in aqueous medium. Various oxidized activated carbon samples were produced by using various oxidizing agents. Mixtures of titanium dioxide (anatase) and non-oxidized activated carbon were also used. Surface and adsorption properties of the carbons were also characterized. This study will explore, and probably improve, the performance of titanium dioxide photocatalyst deposited on activated carbon surface in photocatalytic degradation of pollutants in aqueous medium. This study is expected to find applications in environmental and industrial sectors, where purification of wastewater represents a serious problem.

2. Experimental

2.1. Materials

The activated carbon was prepared from Jordanian olive stones. Olive stones were first ground (<1 mm), dried overnight and then pyrolysed in a horizontal tube furnace under inert atmosphere of nitrogen (flow rate 3 L/min) at 850 °C (heating rate 200 °C/min) for 2 h, then immediately activated with steam/N\(_2\) for 1 h at the same temperature and left to cool to room temperature under inert atmosphere. This carbon was labelled AC-NO (which means non-oxidized activated carbon). This carbon (AC-NO) was used to prepare three oxidized activated carbon samples as described in Table 1. Samples were then washed in a Soxhlet apparatus to remove excess oxidizing agent and other water-soluble species. The produced samples were labelled AC-NA, -HP and -APS, which refers to activated carbon samples oxidized with nitric acid, hydrogen peroxide and ammonium persulfate, respectively (see Table 1). The produced activated carbon samples: AC-NO, -NA, -HP and -APS, were used as supports for titanium dioxide as describe in the next section.

Pure titanium (IV) oxide (99.9% anatase) was used in photocatalytic experiments for comparative purposes. All chemicals were supplied by Aldrich and used without further purification. Organic solvents were of HPLC-grade.

2.2. Deposition of titanium dioxide on carbon surface

The deposition procedure of titanium dioxide on activated carbons was a chemical vapour deposition procedure, based on the work of Ding et al. [11]. Three 50 ml round-bottomed flasks were used in this procedure, named in order as flasks (1), (2) and (3). They were connected with glass tubes and Dreschel heads. One gram sample of the carbon was placed in flask (2) and covered with distilled water. This was placed in an oven at 120 °C until it was just damp after which it was sonicated for 3 min and connected in the order above. Five milliliters of titanium tetraiso-propoxide TTIP (purity 99.999%) were placed in flask (1), while a third flask was kept empty and immersed in an ice bath. Flasks (1) and (2) were heated by using two adjacent boiling water baths, and kept under inert atmosphere of nitrogen gas flowing through the system at 1.5 L/min. This flow rate was sufficient to cause continuous movement of the particles inside the second flask to ensure homogeneity. When all the TTIP was consumed, water baths were switched off while nitrogen flow was kept on until the system reached room temperature. The sample was then washed several times with plenty of distilled water to remove any suspended undeposited titanium hydroxide. The sample was then dried at 150 °C overnight, and then calcined for 6 h at 500 °C to produce the anatase form of titanium dioxide. The produced photocatalysts were labelled according to the support as follows: TiO\(_2\)/AC-NO, TiO\(_2\)/AC-NA, TiO\(_2\)/AC-HP and TiO\(_2\)/AC-APS.

2.3. Instrumentation, characterization and analytical techniques

Titanium was analyzed by an X-ray fluorescence spectrometer (PW1410), fitted with a chromium tube operated at 50 kV.

<table>
<thead>
<tr>
<th>Sample name</th>
<th>Oxidizing agent</th>
<th>Temperature (°C)</th>
<th>Oxidation time (h)</th>
<th>Corresponding photocatalyst name</th>
</tr>
</thead>
<tbody>
<tr>
<td>AC-NO</td>
<td>Non-oxidized</td>
<td>–</td>
<td>–</td>
<td>TiO(_2)/AC-NO</td>
</tr>
<tr>
<td>AC-NA</td>
<td>100 ml of conc. HNO(_3)</td>
<td>25</td>
<td>18</td>
<td>TiO(_2)/AC-NA</td>
</tr>
<tr>
<td>AC-APS</td>
<td>100 ml of a saturated solution of (NH(_4))(_2)O(_3) in 1 M H(_2)SO(_4)</td>
<td>25</td>
<td>18</td>
<td>TiO(_2)/AC-APS</td>
</tr>
<tr>
<td>AC-HP</td>
<td>Mixture of 50 ml H(_2)O(_2) and 50 ml 1 M H(_2)SO(_4)</td>
<td>50</td>
<td>1</td>
<td>TiO(_2)/AC-HP</td>
</tr>
</tbody>
</table>

Table 1: Preparation conditions of oxidized activated carbons with appropriate labelling of the oxidized samples and the corresponding photocatalysts produced.

The activated carbon was prepared from Jordanian olive stones. Olive stones were first ground (<1 mm), dried overnight and then pyrolysed in a horizontal tube furnace under inert atmosphere. This carbon was labelled AC-NO for 1 h at the same temperature and left to cool to room temperature under inert atmosphere. This carbon was labelled AC-NO and AC-NA for 1 h at the same temperature and left to cool to room temperature under inert atmosphere. This carbon was labelled AC-NO and AC-NA for 1 h at the same temperature and left to cool to room temperature under inert atmosphere.
and 40 mA. Results from this part were referred to as total amount of titanium dioxide. Anatase was analyzed by an X-ray diffractometer (XRD), Philips PW1700 system fitted with copper tube, in which exactly same mass of each sample was loaded onto the holder each time. Thermal gravimetric analysis (TGA) was carried out using Setaram TGA 92-12 instrument, starting from the room temperature up to 850 °C at a heating rate of 20 °C/min, under nitrogen atmosphere. All spectrometric measurements were carried out using Shimadzu UV-2100 recording spectrometer.

Methylene blue relative surface area was estimated as follows: 25 mL of aqueous solutions of 10, 20, 30, 40, 50, 60, 70, 90, 110, 130, 150, 200 and 250 mg L⁻¹ methylene blue were separately added to 40 mL centrifuge tubes containing 25 mg of adsorbent. The tubes were stoppered tightly and left for 1 week in the dark, with shaking from time to time. The remaining concentrations were analyzed spectrometrically at 614 nm. Langmuir adsorption isotherm were plotted to find the monolayer capacity through which relative surface areas were estimated [28,29].

The determination of surface oxides was described by Boehm [30,31]. Iodine numbers were estimated according to procedure described by ASTM [32].

The analysis of 3-chlorophenol (3-CP) collected from the photocatalytic degradation experiments was conducted following a gas chromatographic/flame ionization detector procedure described in details elsewhere [27]. Analysis of 3-CP collected from the adsorption/desorption experiments was conducted spectrometrically at 270 nm.

Total organic carbon (TOC) was measured using a modified total carbon analyser SARTEC (DN-1900), in which output from the high temperature reaction furnace was directed to and analyzed by an infrared detector set-up for CO₂.

Chloride was analyzed colorimetrically after mercury thiocyanate solution was added to the tested solution to form mercury (II) chloride. Iron (III) nitrate was added to react with the released thiocyanate ions in acidic solution to give a red coloured iron (III) thiocyanate complex. Absorbance was recorded at 460 nm.

2.4. Adsorption/desorption of 3-chlorophenol

Twenty-five milliliters of (20, 40, 60, 80, 90 mg L⁻¹ solutions of 3-chlorophenol) were separately added to centrifuge tubes each containing 10 mg of the adsorbent. The pH was adjusted to 2 using 1:4 (v/v) aqueous H₂SO₄. Mixtures were agitated for 24 h at 25 °C to reach equilibrium. Samples were then centrifuged at 3000 rpm and the supernatant was analyzed spectrometrically at 270 nm. The adsorbent was then collected and washed with distilled water and 25 ml aqueous solution of pH 2 was then added. The amount of desorbed 3-chlorophenol from the carbon surface was determined spectrometrically at 270 nm.

2.5. The photocatalytic reactor design

A 500 mL glass vessel (height 6.0 cm; diameter 13.0 cm) was placed in a thermo-stated water tank. A 100 Watt mercury lamp, B-100AP Black-Ray lamp (UVP products) was used (wavelength 365 nm, 7 mW/cm² of 365 nm). The lamp outlet was circular and 13.0 cm in diameter. The vessel was raised by a lab jack until the distance between the UV lamp and the surface of the solution (250 mL) was 15 cm. The temperature of the water tank was adjusted to 25 °C. The lamp was firmly fixed in a constant position above the reaction vessel. High purity oxygen was bubbled (flow rate: 50 mL/min) into the reaction vessel through a glass tube. The reaction mixture was stirred using a submersible magnetic stirrer.

2.6. Photocatalysis experiments

Preliminary experiments showed that stirring for 24 h is sufficient to reach equilibrium between carbon and 3-chlorophenol. A 250 mL solution of 40 ppm 3-chlorophenol solution was placed in the reaction vessel. A 7.0 mL sample was withdrawn by pipette to determine the initial concentration of 3-CP. The catalyst (pure anatase, TiO₂/AC-NO, TiO₂/AC-NA, TiO₂/AC-APS, TiO₂/AC-HP) was added to the 3-CP solution and the pH was adjusted to 2.0. After 5 h of stirring, 7.0 mL sample was withdrawn. Oxygen bubbling started immediately (flow rate: 50 mL/min) and the UV lamp was switched on. Further 7.0 mL samples were withdrawn at intervals. These samples were centrifuged immediately for 3 min at 3000 rpm. After each, the supernatant was then separated. 5.0 mL was then placed in a volumetric flask and the volume was made up to 25.0 mL using distilled water. This solution was analyzed for 3-chlorophenol determination as described earlier. The remainder of each withdrawn sample was used for analysis of chloride ion and TOC (see Section 2.3).

2.6.1. Effect of evaporation and photolysis

A blank experiment was first carried out, in which no catalyst was added. The UV light was directed towards a 250 mL of 40 ppm 3-CP solution of pH 2 and 25 °C. The average rate of solution evaporation was 1.5 mL/h. Initial rate of 3-CP disappearance was 0.3 ppm 3-CP/h; concentration of 3-CP after 5 h was 38.5 ppm 3-CP.

2.6.2. Use of mixtures of anatase and AC-NO

In order to explore the effect of adsorption (of 3-CP on AC-NO) on photocatalytic degradation (of 3-CP by TiO₂), 0.150, 0.350, 0.750 and 2.000 g of AC-NO were added, in separate experiments, to a 250 mL of 40 ppm 3-CP solutions of pH 2. The mixture was stirred for 24 h to reach equilibrium. Next, 0.500 g of anatase was added, so that mass percent of TiO₂ relative to the mass of total solid (anatase and AC-NO) were as follows: 77%, 60%, 40% and 20%, respectively. The mixture was stirred for 1 h. Then oxygen bubbling was started and the UV lamp was switched on. Sampling and analyses were carried out as those described at the beginning of this section (Section 2.6).
3. Results and discussion

3.1. Properties of oxidized and non-oxidized activated carbons

Chemical and surface properties of the oxidized and non-oxidized activated carbon samples are given in Table 2. As expected, nitric acid oxidation produced significant number of oxygen-containing groups in each category as classified by Boehm [30,31], while ammonium persulfate treatment resulted in generation of the greatest number of strongly acidic carboxylic groups. Hydrogen peroxide treatment significantly reduced the number of basic groups but increased the number of carboxylic groups. It is generally noted, from Table 2, that oxidized carbons were capable of holding more titanium dioxide (as a total amount, i.e. “amorphous + anatase”) relative to the non-oxidized carbon, but the amount of anatase decreased in the oxidized carbons relative to the non-oxidized carbon. It was shown earlier [33] that anatase deposition is preferred inside the micropores, while deposition of amorphous titanium dioxide occurs mainly on the external surface. Thus smaller amount of anatase was formed inside the micropores while larger amount of amorphous titanium dioxide was deposited on the external surface. This is probably due to surface oxides mainly present on the external surface [34]. Methylene blue adsorption, which occurs mainly within large micropores and mesopores [35], was smaller in the oxidized carbon samples relative to the non-oxidized carbon. This is probably due to formation of water clusters by the acidic surface groups, which blocks micropore openings [22]. Thermal gravimetric analysis (Fig. 1) showed that the thermal stability of titanium dioxide deposited on oxidized carbons was less than that titanium dioxide deposited on the non-oxidized sample. This gives further evidence that titanium dioxide was mainly deposited on the external surface in the oxidized carbon, rather than in the micropores.

3.2. Adsorption/desorption of 3-chlorophenol

Adsorption isotherms of 3-chlorophenol on various samples are shown in Fig. 2. The monolayer capacity (\(X_m\)) derived from Langmuir adsorption isotherm [28] and fractions of reversible adsorption (FD = \(q_{o,rev}/q_o\)) are presented in Table 3. It is noted that adsorption of 3-chlorophenol was less favoured on the oxidized carbons and their corresponding photocatalysts. This is probably due to presence of acidic surface oxides in the oxidized carbons, which are responsible for blocking the micropores [22]. It is evident here that deposition of titanium dioxide caused a decrease in adsorption of 3-CP, due to presence of anatase in the micropores. For example, adsorption capacity for 3-CP has decreased from 9.97 \times 10^{-4} \text{ mol/g} for AC-NO to 6.86 \times 10^{-4} \text{ mol/g} for TiO_2/AC-NO (about 30% decrease in...
adsorption capacity). Samples AC-NO and TiO$_2$/AC-NO exhibited (favourable) irreversible adsorption (with zero desorption) of 3-CP, probably due to polymerization (oxidative coupling) of 3-CP induced by basic surface groups [24]. AC-HP and TiO$_2$/AC-HP exhibited small desorption, probably due to absence of basic oxides. Finally there was negligible amount of desorption from the other oxidized activated carbon samples AC-NA and AC-APS (and their corresponding photocatalysts).

3.3. Photocatalytic degradation of 3-chlorophenol (3-CP)

A pseudo first-order reaction was considered for 3-CP degradation, according to the equation:

$$\ln \left( \frac{C_{(3-CP)}}{C_{o(3-CP)}} \right) = -k_x t$$

where $C_{(3-CP)}$ is concentration of 3-CP at time $t$; $C_{o(3-CP)}$ the initial concentration of 3-CP; $k_x$ the rate constant of 3-CP; $t$ is time (h).

Chloride ion production was found to follow a first-order rate equation, which may be expressed by the formula [6]:

$$\ln \left( \frac{[Cl^-]_{max}}{[Cl^-]_{max} - [Cl^-]} \right) = k_{Cl} t$$

where $[Cl^-]$ is chloride ion concentration at time $t$; $[Cl^-]_{max}$ the maximum chloride ion concentration (at the end of the photocatalytic reaction); $k_{Cl}$ the rate constant of Cl$^-$ ion production; $t$ is time (h).

3.3.1. Oxidized carbons as supports

Concentration profile of Cl$^-$ production using pure anatase and TiO$_2$/AC-HP is presented in Fig. 3. Kinetic parameters for chloride production and 3-CP disappearance are presented in Table 4. It is usually proposed that complete mineralization of 3-CP is indicated by the release of chloride ion. Accordingly, only TiO$_2$/AC-HP succeeded in mineralization of 3-CP, where 39% of 3-CP initially present was mineralized. The other two samples (TiO$_2$/AC-NA and TiO$_2$/AC-APS) did not produce any chloride ion. This may be attributed to the absence of basic groups in TiO$_2$/AC-HP, which are responsible for polymerization (oxidative coupling) of 3-CP, and thus slightly reversible adsorption was observed (see Section 3.2). However, this sample is still not as effective as pure anatase for degradation of 3-CP (Fig. 3). Although it was proposed that activated carbon will work as a scavenger for 3-CP, but the problem here seems to be the difficulty for UV radiation to reach the 3-CP that present inside adsorbent, where it is usually adsorbed. However, it is quite promising that 1 g of TiO$_2$/AC-HP (containing 23.5% TiO$_2$) caused mineralization of 40% of the 3-CP solution in 5 h, while 0.50 gram of pure anatase (100% TiO$_2$) caused 58% mineralization of the 3-CP within the same period.

3.3.2. Non-oxidized carbon as support (TiO$_2$/AC-NO)

The concentration profiles for disappearance of 3-CP and TOC using TiO$_2$/AC-NO are presented in Fig. 4. The initial rate

Table 4

<table>
<thead>
<tr>
<th>Chloride ion production</th>
<th>3-CP disappearance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial rate of Cl$^-$ production (ppm Cl$^-$ h$^{-1}$)</td>
<td>Initial rate of 3-CP disappearance (ppm$^2$/CP h$^{-1}$)</td>
</tr>
<tr>
<td>-------------------------</td>
<td>--------------------</td>
</tr>
<tr>
<td>0.50 g anatase (pure)</td>
<td>1.47</td>
</tr>
<tr>
<td>1.00 g TiO$_2$/AC-HP</td>
<td>1.09</td>
</tr>
<tr>
<td>Mixture 0.500 g anatase + 0.150 g AC-NO</td>
<td>1.60</td>
</tr>
<tr>
<td>Mixture 0.500 g anatase + 0.350 g AC-NO</td>
<td>1.07</td>
</tr>
<tr>
<td>Mixture 0.500 g anatase + 0.750 g AC-NO</td>
<td>0.48</td>
</tr>
<tr>
<td>Mixture 0.500 g anatase + 2.000 g AC-NO</td>
<td>0.21</td>
</tr>
</tbody>
</table>

$q_{0,rev}$: amount of 3-CP that reversibly adsorbed. $q_o$: total amount of 3-CP adsorbed on adsorbent.
of 3-CP disappearance was 32.9 ppm 3-CP/h, with 1.59 h\(^{-1}\) rate constant (3-CP). No chloride ion was detected in this experiment. However, it is noted that all 3-CP was consumed within 2 h, but there was still some organic content in the solution even after 5 h. This may indicate that 3-CP was decomposed into other intermediate compounds on the surface of the catalyst (TiO\(_2\)/AC-NO) but the complete degradation to CO\(_2\), H\(_2\)O and Cl\(^-\) was not achieved. Partial degradation here may be attributed to two reasons: first, the presence of basic groups on the carbon surface, which induce polymerization of phenols (oxidative coupling), and thus produce heavier compounds that cannot diffuse into micropores of activated carbon where titanium dioxide present; second, part of the titanium dioxide deposition and 3-CP adsorption probably occur on the internal surface of TiO\(_2\)/AC-NO, a deep area where UV radiation cannot reach. That was not the case with TiO\(_2\)/AC-HP, in which micropores were probably blocked with water clusters due to the presence of acidic oxides; and basic groups were nearly absent.

3.3.3. Use of mixtures of anatase and AC-NO

The results of mineralization of 3-CP using mixtures of anatase with AC-NO are presented in Fig. 3 and Table 4. The behaviour of such mixtures was entirely different from that when AC-NO alone was used. When small amount of AC-NO (0.150 g) was mixed with 0.50 g of anatase, the process was slightly supported in the early stages of the mineralization process. That was reflected in the values of initial rate of chloride production and the rate constant of chloride production. This may probably indicate that adsorbed 3-CP is involved in the mineralization process when small amount of AC-NO is used. But increasing the amount of AC-NO generally inhibited chloride production relative to pure anatase (see Table 4) but did not prevent it, even when 2 g of AC-NO was mixed with 0.50 g anatase (X\(_m\) of AC-NO is 9.97 \times 10^{-4} \text{ mol/g}). There was an inverse proportionate between the amount of AC-NO added and the amount of chloride ion produced. This is probably due to shielding effect of carbon on titanium dioxide. Additionally adding too much AC-NO relative to TiO\(_2\) will probably cause an imbalance between the adsorption process of 3-CP and photo-degradation process. Thus 3-CP uptake by adsorption may be much faster than photo-degradation, and thus 3-CP may be polymerized on the surface of AC-NO, rather than photo-decomposed by TiO\(_2\).

4. Conclusion

Presence of basic groups in the non-oxidized carbon prevented the mineralization of 3-CP by titanium dioxide deposited on non-oxidized carbon, but did not prevent the formation of intermediate compounds. This is indicated by the presence of organic carbon after 3-CP concentration dropped to zero. In the hydrogen peroxide-oxidized carbon, the absence of basic groups induced reversible adsorption while the presence of acidic oxides on the external surface seems to block the micropores and thus directed deposition of titanium dioxide on the external surface of activated carbon. Those two factors, in addition to higher loading of titanium dioxide in the oxidized carbons, probably made photo-assisted mineralization of 3-CP possible by titanium dioxide deposited on hydrogen peroxide-oxidized carbon.

Physical mixtures of AC-NO with anatase generally inhibited the mineralization process, except when small amount of carbon was used. But the chloride ion production did not stop even when all 3-CP was adsorbed. This probably indicates that adsorbed 3-CP was involved in the mineralization process. Thus, the failure of the titanium dioxide deposited on non-oxidized carbon may indicate that titanium dioxide particles were either catalytically inactive due to its attachment to the carbon surface; or that the anatase was hiding inside the micropores and thus UV radiation could not activate it.

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