



## Carbon foams as catalyst supports for phenol photodegradation

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### ABSTRACT

A carbon foam using coal tar pitch as precursor was prepared and investigated as support for titanium oxide for the photocatalytic degradation of phenol. The performance of the carbon foam/titania composite was compared to those of unsupported titania and other activated carbon composites from the literature. The photodegradation rate of phenol over the catalysts under UV illumination was fitted to the Langmuir–Hinshelwood model; data showed that the apparent rate constant of the carbon foam supported titania was almost three times larger than that of bare titania, and comparable to that of other carbon supported composites. Considering the low porous features of the carbon foam, this suggests that large surface area supports are not essential to achieve high degradation rates and efficiencies. Moreover, when titania is supported on the carbon foam large amounts of catechol are detected in solution after UV irradiation, indicating a better degradation efficiency.

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### 1. Introduction

One of the most important challenges for science is to develop efficient methods to control environmental pollution, particularly to remove hazardous organic compounds from water resources. Heterogeneous photocatalysis has proven to be a promising method for the degradation of these compounds, being titania ( $\text{TiO}_2$ ) the most commonly used photocatalyst, because it is non-toxic, photo-stable, cheap and very efficient under ultraviolet light irradiation (its band gap energy of 3.2 eV requires photoexcitation in the near-UV spectrum region) [1]. The reaction mechanisms and the electron/hole generation processes involved in photocatalytic reactions using titania have been widely studied and can be found in a number of reviews [2,3].

However  $\text{TiO}_2$  powders present some drawbacks as the powders are not easy to precipitate and recover from water, preventing their regeneration and reuse. Therefore, during the past few decades, many efforts have been devoted to develop strategies oriented to the large-scale implementation of this technology for water treatment, especially with regards to effective methods to separate the nanosized photocatalyst from water streams. Several engineering solutions are currently being investigated, from incorporating titania on the reactor walls and the use of slurry reactors, to immobilization techniques on different supports [4–8].

The use of carbon– $\text{TiO}_2$  catalysts has currently attracted much attention for the photocatalytic degradation of pollutants. Despite

carbon itself is a strong light absorbing material it has been successfully used as support of photoactive species [9–18]. The photoactivity of carbon–titania composites – provided by  $\text{TiO}_2$  particles – is strongly dependent on the features of the carbon material, and the immobilization of photoactive titanium oxide on carbon supports has been reported to show a synergistic effect for the photodegradation of organic pollutants [14–16]. It has also been reported that the presence of carbons actually changes the  $\text{TiO}_2$  catalytic behavior beyond this synergistic effect on the degradation kinetics [17,18]. On the other hand, high surface catalysts may also be advantageous since the basic photocatalytic effects are most likely to occur at the catalyst–water interface (or nearby) [18], and thus the immobilization of  $\text{TiO}_2$  on a porous substrate would yield a higher activity photocatalyst.

The aim of this work was to investigate the application of carbon foams obtained from coal tar pitch as a support for the immobilization of  $\text{TiO}_2$  for the photodegradation of phenol in aqueous solutions. The choice of carbon foams as support is made upon their structural characteristics; they can be synthesized as rigid materials with a moderate surface area comprised of an interconnected network. As probe molecule we have selected phenol, one of the most persistent aromatic compounds frequently found in wastewater.

### 2. Experimental

#### 2.1. Materials synthesis

The carbon foam was synthesized using coal tar pitch as precursor, which was first submitted to a chemical modification in concentrated  $\text{H}_2\text{SO}_4$  at 120 °C until solidification. This modification

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causes an increase in the viscosity and softening point of the coal tar pitch, allowing the foaming process to be conducted at atmospheric pressure. The solid was heated at atmospheric pressure up to 600 °C in a covered silica crucible under nitrogen atmosphere (10 °C min<sup>-1</sup>), yielding a rigid vitreous carbon foam; it was submitted to steam activation at 800 °C for 1 h for promoting the development of a more open porous structure. The sample after activation is denoted as CF. A commercial activated carbon AC (bituminous coal) was also used for comparison purposes (particle size 0.212–0.710 mm). This carbon is characterized by a low oxygen content (2.1 wt.%) and a basic nature (point of zero charge of 8.9 pH units).

The titania–carbon catalysts were prepared by infiltration of a suspension in ethanol of titanium oxide (P25 Degussa) on the carbon material (weight ratio 9 g carbon:1 g titania) in a rotary evaporator under vacuum for 2 h, followed by evaporation of the solvent. The samples were labeled as XT<sub>i</sub>, being X the reference to the carbon support (AC or CF). Bare-TiO<sub>2</sub> was also used as a standard for comparison purposes. Before usage, all the samples were washed in distilled water at 60 °C, dried at 110 °C overnight and kept in a desiccator.

## 2.2. Characterization

Nanotexture of both the carbon support and the titania/carbon composites was characterized by N<sub>2</sub> (ASAP 2010, Micromeritics) adsorption isotherms at –196 °C. Before the experiments, the samples were outgassed under vacuum (ca. 10<sup>-3</sup> Torr) at 120 °C overnight. The isotherms were used to calculate the specific surface area, S<sub>BET</sub>, and pore volumes using the t-plot method using a carbon-coated Sooty-silica as reference material [19]. The samples were further characterized by thermogravimetric analysis (Setaram Labsys). The instrument settings were as follows: heating rate 15 °C min<sup>-1</sup> and a N<sub>2</sub> atmosphere with 50 mL min<sup>-1</sup> flow rate. The morphology of the catalysts was characterized using a Ziess DSM 942 scanning electron microscope; particles were dispersed on a graphite adhesive tab placed on an aluminum stub. The images were generated in the backscattered electron signal mode, which yielded better quality pictures.

## 2.3. Adsorption and photodegradation of phenol

Photocatalytic reaction conditions were previously optimized concerning the initial phenol concentration, catalyst loading, and time of irradiation. Briefly, about 1 g L<sup>-1</sup> of catalyst was placed in a photoreactor of 400 mL capacity, containing an aqueous solution of phenol (distilled non buffered water) of initial concentration 100 mg L<sup>-1</sup> (solution pH ca. 6 units). The UV irradiation source was provided by a high pressure mercury lamp (125 W), vertically suspended in a cylindrical, double-walled quartz jacket cooled by flowing water, immersed in the center of the solution. The water cell was used to control the temperature during the experiments, preventing any overheating of the suspension due to the irradiation. The suspension of the photocatalyst in solution was stirred (500 rpm) during irradiation and small aliquots of the solution (~1 mL) were taken out at fixed time intervals and analyzed by reverse-phase HPLC (Spherisorb C18, 125 mm × 4 mm), using methanol–water mixtures as mobile phase, and a photodiode array detector. The samples were previously filtered using cellulose filters (mean pore size 0.45 μm).

Dark adsorption (in the absence of UV irradiation) was also carried out under the same experimental conditions, in order to counterbalance the fraction of photodecomposed phenol from that adsorbed on the pores of the carbon/titania catalysts. All the experiments were performed in duplicate and the average experimental error is below 5%.

## 3. Results and discussion

### 3.1. Characterization of the catalyst supports

The performance of carbon foam as catalyst support for phenol photodegradation was evaluated and discussed in terms of its textural and chemical features. For this purpose, carbon:titania composites were prepared by immobilization of titanium oxide (P25 Degussa) as detailed in the experimental section. The ratio support:titania (9:1) was chosen based on previous optimization studies concerning the activity of catalysts with various carbon loading (not published results).

The morphology of the catalysts was investigated by SEM (Fig. 1). The wall structure of the carbon foam obtained by pyrolysis of the modified coal tar pitch is characterized by a reticular vitreous structure, indicative of a closed cell structure frequently found in foams prepared by pyrolysis of polymers, and pitches of coal extracts [20]. Such close-cell foams typically show a smooth surface with a low porosity at a nanometric scale (surface area of 26 m<sup>2</sup> g<sup>-1</sup> before activation). After steam activation, a slight opening of the carbon matrix occurred and CF sample displayed a porous open structure of interconnected pores with a moderate surface area (ca. 375 m<sup>2</sup> g<sup>-1</sup>) and a micro/mesoporous structure. This sample was then selected for incorporating the photoactive catalyst. Additionally, the SEM micrographs of the composites (Fig. 1) show that titanium oxide is well dispersed over the carbon support, with particles of a few tens of nm in size comparable to those of bare P25.

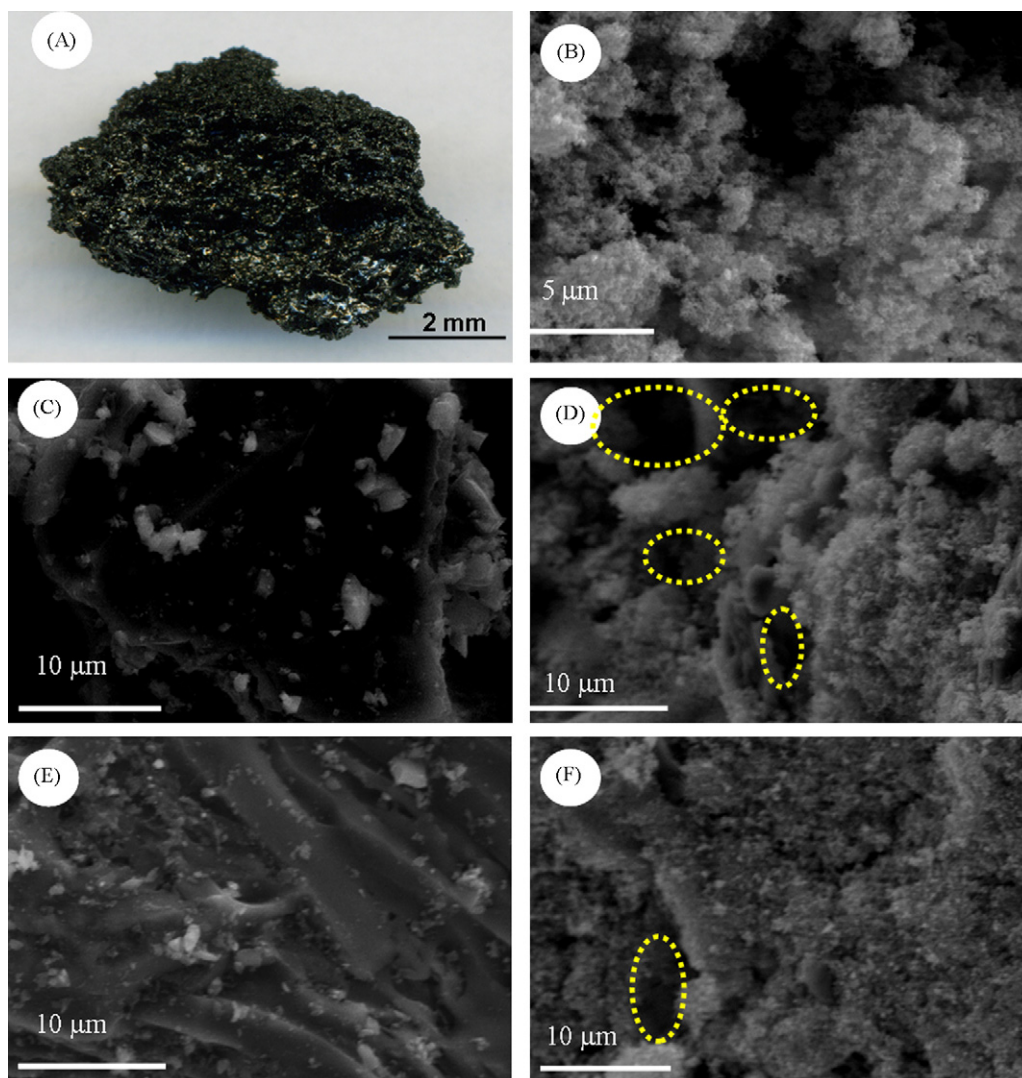
The immobilization of titania on the carbon foam partially blocked its initial porosity although the composite still displays a somewhat porous character (Table 1). A deeper insight into the porous features of the catalyst reveals that the modification affected mostly the microporosity, determined by N<sub>2</sub> adsorption data, indicating that titania is incorporated in the inner micropores of the carbon support during the impregnation, rather than remaining on the outer surface. In contrast, when titania is immobilized on a high surface area and microporous activated carbon support, the porous features of the composite are not substantially reduced. Similar observations have been reported in the literature [9,10,15,17] about the immobilization of TiO<sub>2</sub> on porous carbons.

Since the immobilization is based on a physical interaction/adsorption (no chemical bonding is expected), it is important to control any leaching out the photoactive particles during the photodegradation experiments from solution (which indeed was not observed). In this regard, weak interactions (like charge transfer) seem to be occurring between the carbon support and titania; this was confirmed by determined pH<sub>PZC</sub> of the carbon supports after the immobilization of titania. Their initial basic nature (pH<sub>PZC</sub> varies between 9 and 10 units in the non-doped carbon supports) was slightly modified after the incorporation of titania (pH<sub>PZC</sub> 6.8 and 7.3 units for ACTi and CFTi, respectively).

### 3.2. Phenol adsorption in dark conditions

It has to be considered that for a porous catalyst, the removal efficiency encompass both adsorption and degradation; so the performance of the catalysts under UV irradiation should also be compared to that in dark conditions (Fig. 2).

Upon adsorption in dark conditions on the carbon supports and the carbon/titania composites, the expected concentration decline curves due to phenol adsorption on the materials' surface were obtained. Analysis of the species in solution confirmed that no phenol degradation occurs in dark conditions, regardless the catalyst used. In the case of pure titania, the amount of phenol adsorbed was very low (removal efficiency below 3%), which is expected considering its non-porous nature. In contrast, phenol removal efficiency



**Fig. 1.** (A) Image of the carbon foam synthesized from coal tar pitch at atmospheric pressure and SEM micrographs of the materials used as catalysts and supports, (B) sample P25, (C) sample CF, (D) sample CFTi, (E) sample AC, (F) sample ACTi.

at dark conditions on both carbon:titania composites cannot be disregarded, as it reached almost 70% after 6 h for ACTi, as opposed to 28% for CFTi sample. This evidence is consistent with the porous features of both catalysts: the higher surface area and pore volume of sample ACTi results in a much higher adsorption capacity of phenol. However, the rate of adsorption under dark conditions appeared to be faster in the carbon foam composite – compared to ACTi catalyst – despite the poor porous development of CFTi. In

fact, 80% of phenol adsorption in sample CFTi takes place within the first 30 min, as opposed to ACTi (ca. 30%). This suggests that most of the adsorption sites in CFTi are readily accessible to the phenol molecules, and that external diffusion is favoured when the carbon foam is used as support.

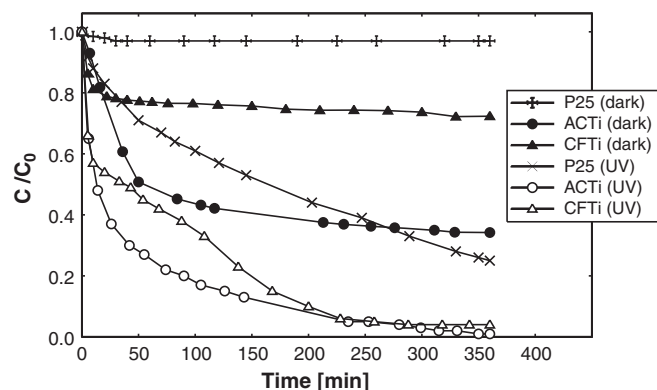
**Table 1**

Textural parameters obtained from N<sub>2</sub> adsorption isotherms at –196 °C of the as-received catalysts, and after phenol removal under dark conditions (dark series) and UV irradiation (UV series).

	$S_{\text{BET}}$ [m <sup>2</sup> g <sup>–1</sup> ]	$V_{\text{TOTAL}}^a$ [cm <sup>3</sup> g <sup>–1</sup> ]	$V_{\text{MICROPORES}}^b$ [cm <sup>3</sup> g <sup>–1</sup> ]	$V_{\text{MESOPORES}}^b$ [cm <sup>3</sup> g <sup>–1</sup> ]
P25	53	0.118	–	–
CFTi	165	0.109	0.074	0.019
ACTi	924	0.497	0.458	0.054
CFTi (dark)	146	0.096	0.069	0.016
ACTi (dark)	760	0.400	0.330	0.043
CFTi (UV)	103	0.068	0.049	0.012
ACTi (UV)	780	0.400	0.339	0.039

<sup>a</sup> Evaluated at relative pressures of 0.99.

<sup>b</sup> Evaluated by t-plot method.



**Fig. 2.** Phenol concentration decay curves on the investigated photocatalysts after dark adsorption and UV irradiation.



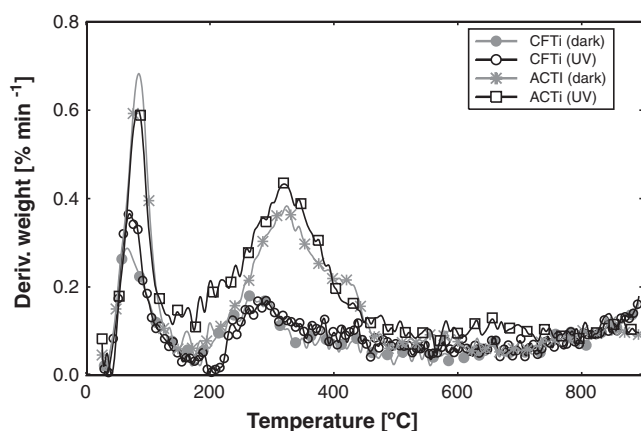


Fig. 3. DTG profiles of the studied carbon:titanium catalysts after phenol removal under dark conditions and UV irradiation.

Analysis of the porous features of the carbon/titanium composites after phenol exposure under dark conditions (Table 1) reveals that a significant fraction of the porosity of these materials still remains unoccupied after phenol loading (ca. less than 25% is occupied). Even though it seems that both catalysts have reached their maximal phenol uptake in the experimental conditions carried out (based on the shape of the kinetic curves), most of the pore volume of the catalysts remains unblocked.

The thermal analysis of the preadsorbed catalysts at dark conditions confirmed the presence of phenol inside the porous matrix in both cases (Fig. 3), with an overall mass loss of 4 and 1 wt.% for ACTi and CFTi, respectively. Besides the desorption peak corresponding to the evolution of moisture at 100 °C, the profiles show only one peak centred at about 300 °C corresponding to desorption of phenol retained in the catalysts. Similar DTG profiles have been obtained for the preadsorption of phenol at dark conditions on the carbon materials themselves (not shown), indicating that incorporation of titanium on the carbon support does not substantially change the phenol adsorption sites present on the carbon matrix.

### 3.3. Phenol degradation under UV light

When UV irradiation is applied, phenol removal efficiency is significantly improved in all the catalysts. While the rate of phenol photodegradation on P25 follows an almost linear trend, the supported catalysts exhibit faster and higher removal efficiencies (Fig. 2). This tendency was more remarkable in the early stages of the process, although the final overall yield after 6 h of irradiation was rather high in all the cases (i.e., 75% vs over 95% for both carbon supported photocatalysts). In all the catalysts, phenol removal efficiency under UV illumination is much larger than the corresponding adsorption at dark conditions. For instance, after 30 min the amount of removed phenol upon UV irradiation of sample CFTi accounts for 50%, as opposed to the 22% of phenol adsorbed at dark conditions. Thus, it appears that the immobilization of TiO<sub>2</sub> on the carbon support enhances the photoactivity of titanium particles. What is more significant is that – although some differences are observed below 200 min – phenol degradation efficiency in both carbon:titanium photocatalysts (ACTi and CFTi) is similar after 3 h of UV irradiation.

The enhancement in phenol removal upon irradiation can be regarded as a sequential two-steps process: a rapid concentration of phenol on the surface of the support – due to the preferential adsorption on the solid phase – followed by a spontaneous transfer of adsorbed phenol molecules from the support to titanium surface, where they are decomposed as a consequence of the UV irradiation. This enhanced photodegradation as a result of the combination of

the adsorption on a carbon support and the photoactivity of TiO<sub>2</sub> has been described in the literature when using activated carbons as additives to titania [14,17,21,22].

The photochemical degradation rate of phenol under UV illumination of the catalysts was fitted to the Langmuir–Hinshelwood (L–H) kinetics model given by the simplified apparent first-order equation [23]:

$$\ln \left( \frac{C_0}{C} \right) = k_{app} t$$

where  $k_{app}$  is the apparent rate constant, and  $t$  the illumination time (min).

The photodegradation rate (Table 2) of carbon supported titania was higher than that of P25, with an increase in the rate constant by a factor of three in both ACTi and CFTi, corroborating the higher photocatalytic activity of the carbon composites. Surprisingly, the rate constant does not seem to be correlated to the porosity of the carbon material used as support, since the increase in the degradation rate was also remarkable in the carbon foam composite (CFTi). Indeed, similar kinetic parameters (half time of photochemical reaction ( $t_{1/2}$ ) and initial degradation rate  $r_0$ ) are obtained for CFTi and ACTi, despite their different textural properties.

An increase in the phenol photodegradation rate on carbon supported titania – fitted to the L–H model – has been described in the literature for different operating conditions (radiated power, carbon:titanium ratio, solution concentration) [24]. Available data from the literature is also compiled in Table 2 for comparison purposes. Phenol photodegradation rates herein reported are larger than those from the literature, despite the investigated catalysts are characterized by a low titanium:carbon ratio [12,14,15,25,26].

It should not be forgotten that for porous catalysts, a fraction of the degradation compounds (even phenol itself) might be adsorbed inside the pores, as opposed to the case of TiO<sub>2</sub>, where all degradation intermediates are detected in the solution. For this reason, we have analyzed if any textural changes occurred in the catalysts after the adsorption and photodegradation process (dark and UV series in Table 1). Gas adsorption data revealed that the high phenol removal efficiencies detected after UV irradiation were not accompanied by a pore plugging effect. Although the amount of removed phenol in the photodegradation experiments increased up to 95–99% (from 66% and 28% in dark conditions), the decrease in the porosity of the catalysts is very similar in both experiments. This suggests that phenol is not relocated inside the porosity of the photocatalysts; it appears to be either fully mineralized or decomposed as small size intermediates that are not so readily retained in the pores of the carbon support.

The DTG profiles (Fig. 3) of the composites after phenol photodegradation also confirm this observation. The small mass loss values obtained in the catalysts (i.e., 1.9 and 1 wt.% for ACTi and CFTi, respectively) indicate that small amounts of gases evolve from the catalysts after phenol photodegradation (even lower than those at dark conditions). Neither phenol itself nor the aromatic intermediates created during the photodegradation were detected on the catalysts surface.

Analysis of the solution composition during irradiation of the catalysts allowed the extent of phenol degradation to be determined. When P25 is irradiated along with the decrease in phenol concentration in solution, rising amounts of p-benzoquinone (BZ), hydroquinone (HQ) and catechol (CAT) were detected (Fig. 4). The occurrence of these intermediates for phenol photodegradation using Degussa P25 is in good agreement with reported works in the literature [27]. Although all of them are detected at very low concentrations (below 0.5 mmol L<sup>-1</sup>), BZ and HQ are the dominant intermediates, particularly at the earlier stages of the reaction. Both compounds showed a concentration peak between 1 and 2 h, whereas upon longer irradiation times their concentration

**Table 2**

Apparent first-order rate constants ( $k_{app}$ ), half reaction time ( $t_{1/2}$ ), initial reaction rate ( $r_0$ ) and correlation coefficient ( $R^2$ ) obtained from fitting experimental data to the Langmuir–Hinshelwood model.

	$k_{app} \times 10^3$ [min <sup>-1</sup> ]	$t_{1/2}$ [min]	$r_0 \times 10^3$ [min <sup>-1</sup> ]	$R^2$ [min <sup>-1</sup> ]	Remarks	Reference
P25 (UV)	3.5	197	3.8	0.992	Solution: 100 ppm phenol UV lamp: 125 W Carbon:titania ratio 9:1 Catalyst 1 g L <sup>-1</sup>	This work
ACTi (UV)	10.6	65	10.9	0.982		
CFTi (UV)	9.3	74	10.0	0.972		
P25	5.6	–	–	–	Solution: 100 ppm phenol UV lamp: 125 W Carbon:titania ratio 1:5 Catalyst 3 g L <sup>-1</sup>	[14,15]
TiO <sub>2</sub> -AC <sub>M</sub>	13.9	–	–	–		
TiO <sub>2</sub> -AC <sub>PC</sub>	4.6	–	–	–		
Bare-TiO <sub>2</sub>	3.1	–	–	–	Solution: 100 ppm phenol UV lamp: 4 × 15 W Carbon:titania ratio 23:77 Catalyst 2 g L <sup>-1</sup>	[12,24]
23-AC-TiO <sub>2</sub>	2.5	–	–	–		
P25	1.7	–	–	–	Solution: 100 ppm phenol UV lamp: 20 W Carbon:titania ratio 1:2 Catalyst 1.5 g L <sup>-1</sup>	[25]
TiO <sub>2</sub> -CA	7.7	–	–	–		
TiO <sub>2</sub> -sol-gel	1.5	–	–	–		

decreased slightly, suggesting that they are also decomposed. In contrast, increasing concentrations of CAT are detected along the whole irradiation time at concentrations below 10  $\mu\text{mol L}^{-1}$ . Since P25 is a non-porous material, degradation intermediates remain in the solution where they should be necessarily detected. On the other hand, we cannot discard the presence of the formation of smaller degradation intermediates (such as short alkyl chain organic acids), that are not detected by reverse-phase HPLC in a standard C18 column, which was the analytical technique used to identify, separate and quantify the intermediates.

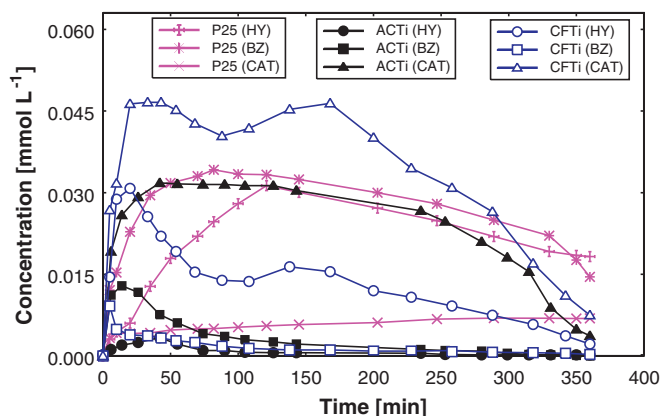
The nature of the degradation intermediates detected when the carbon supported photocatalysts are irradiated did not changed, although they were obtained in different proportions (Fig. 4). Increasing amounts of HQ, BZ and CAT were detected after UV irradiation of ACTi and CFTi, similarly to non-supported titania. With the exception of CAT, these intermediates are detected at lower concentrations than those in P25, confirming that supporting titania on porous carbon materials enhance the overall phenol photodegradation efficiency.

What is more interestingly inferred from this study is that, based on the identification and quantification of the intermediate products detected in solution (Fig. 4), the carbon supports appear to modify the phenol photodegradation pathway. For instance, BZ and HY being the predominant intermediates for P25 are now only detected during the first hour of irradiation of ACTi and CFTi, and at about 10 times lower concentration – whereas for P25 their concentration remained somewhat constant up to 3 h and then started

to fall at a slow rate. The third intermediate detected during the irradiation of P25 – CAT – was now found to be predominant in both carbon catalysts, with concentrations about 8 times higher during almost the whole time of irradiation. Comparing the two composites investigated, the carbon foam gives rise to a higher amount of intermediates during the degradation, which concentration dependence with time follows the sequence: CAT  $\gg$  HY  $\gg$  BZ. This effect is more remarkable in the case of CAT and could be due to a faster release of the generated intermediates in the solution, as a consequence of the less developed porous network of this support. However, the concentration of intermediates detected in solution was also higher in ACTi sample – compared to P25 – which possesses a higher porosity where a priori intermediates could be adsorbed. Moreover, the amount of organic compounds remaining in the solution after 6 h of irradiation of CFTi is almost negligible (Table 3), and comparable to that of the activated carbon composite with a higher surface area.

These results provide an interesting viewpoint on the photocatalytic degradation of phenol, indicating that the degradation reaction would mainly occur in the interface carbon/titania/solution. Thus the eventual beneficial effect of a highly porous supported catalyst does not seem to rule this system. On the contrary, accessible porosity for preventing mass transfer limitations of the pollutants from the bulk solution are required.

On the other hand, conversion of phenol to CAT has been reported to be more advantageous for the complete mineralization of phenol than conversion to BZ or HY [28,29]. Catechol is decomposed to oxalic acid, and then to CO<sub>2</sub> and water, whereas the pathways of mineralization of BQ and HQ proceed through the formation of a large number of intermediates (mainly non-aromatic acids such as maleic, oxalic and formic acid). Based on the higher amounts of CAT detected when CFTi is irradiated, it might be anticipated that the degradation of phenol is more efficient on the carbon



**Fig. 4.** Evolution of the concentration of phenol degradation intermediates (BZ, HY and CAT) upon UV irradiation of the different investigated photocatalysts.

**Table 3**

Quantification of phenol degradation intermediates ( $\mu\text{mol L}^{-1}$ ) remaining in the solution after 6 h of reaction under dark conditions (dark series) and UV irradiation (UV series). Phenol initial concentration was 1000  $\mu\text{mol L}^{-1}$  for all the samples.

	Total [ $\mu\text{mol L}^{-1}$ ]	Phenol [ $\mu\text{mol L}^{-1}$ ]	HY [ $\mu\text{mol L}^{-1}$ ]	BZ [ $\mu\text{mol L}^{-1}$ ]	CAT [ $\mu\text{mol L}^{-1}$ ]
P25 (dark)	970	970	n.d.	n.d.	n.d.
P25 (UV)	294	253	18	16	7
CFTi (dark)	723	723	n.d.	n.d.	n.d.
ACTi (dark)	340	340	n.d.	n.d.	n.d.
CFTi (UV)	46	36	2	0.3	8
ACTi (UV)	18	11	0	4	4

foam based photocatalyst – although short alkyl chain organic acids have not been quantified and will be further studied in ongoing works.

Although CAT is also formed in composites prepared from activated carbons (sample ACTi in this work, and previous studies in Ref. [17]), its concentration is higher for the carbon foam composite, suggesting the preferential photooxidation route of phenol. This is also confirmed by the smaller amount of BZ detected upon irradiation of CFTi compared to ACTi (Fig. 4).

These results confirm that supporting titania on porous carbon materials does not only enhance the overall phenol degradation efficiency (so-called synergistic effect), but also modifies the degradation pathway of this aromatic compound. Evidences, reporting that an activated carbon support may induce different interactions between titania and phenol molecules, had been reported in the literature [12,13].

On the other hand, the synergetic effect of carbon supports has been mostly correlated to the porosity of the support [14,15,22]. Our results show that high porous features on the supported catalysts are not decisive. In fact, high phenol photodegradation efficiency can be obtained using a low surface area carbon foam as support for the dispersion on titania nanoparticles. Even if the adsorption capacity of the carbon support towards the target pollutant under dark conditions is low (i.e. 275 vs 668  $\mu\text{mol}/\text{mg}$  for CFTi and ACTi, respectively), high photodegradation efficiencies are achieved. So this parameter would seem to be more related to the amount of titania incorporated in the photocatalyst.

#### 4. Conclusions

Carbon foams with a modest porous development are excellent supports for the immobilization of titania, since the obtained catalysts present an enhanced photoactivity towards phenol degradation. The performance of the carbon foam supported catalyst is comparable to that of catalysts supported on activated carbons, with a 3-fold increase in phenol degradation rate constant compared to P25. Moreover the degradation rate constant does not show a straightforward correlation with the porosity of the support, suggesting that large surface area supports are not essential to achieve high degradation rates and efficiencies.

Identification of the degradation intermediates in the solution demonstrated that supporting titania on the carbon foam also brings about a modification in the degradation route of phenol, compared to bare titania and other carbon supported catalysts. High amounts of catechol along with smaller concentrations of benzoquinone are detected when titania is supported on the carbon foam, suggesting a more efficient phenol degradation on this catalyst. This points out that the degradation would mainly occur in the interface carbon/titania/solution; consequently, it seems that high surface area supports are not necessary, but an accessible pore structure that avoids mass transfer limitations or kinetic diffusion restrictions for the accessibility of the pollutants from the bulk solution to the interface support/titania.

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