

A Convenient Synthesis of Alkyl Substituted *p*-Benzoquinones from Phenols and H₂O₂ over TiAPO-5 Molecular Sieve Catalyst

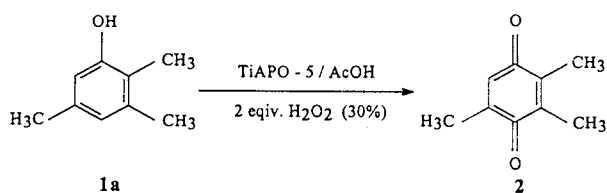
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Titanium substituted aluminophosphate (TiAPO-5) molecular sieves catalyze the oxidation reaction of alkyl substituted phenols with aqueous H₂O₂ in acidic medium to give the corresponding *p*-benzoquinones, in a single step, in high yield.

Selective oxidation of phenols with hydrogen peroxide is one of the attractive problems from the synthetic viewpoint as well as in biological oxygenation. Several oxidizing agents were used for the conversion of phenols to *p*-benzoquinones.¹ However, in most cases, they lead to complex problems, viz., evolution of toxic gases and disposal of solid wastes besides the process being highly expensive. On the other hand, molecular sieve based titanium silicalite catalysts such as TS-1 (ZSM-5 type) and TS-2 (ZSM-11 type) are proved to be excellent catalysts for such reactions under mild conditions.² The first commercial process (Enichem, Italy) utilizing TS-1 was the hydroxylation of phenol to hydroquinone and catechol.³ On the other hand, TS-1 catalyzed reactions are limited owing to its small pore size (< 6 Å). The catalyst described herein, TiAPO-5 having a larger pore size of (> 7 Å), however, facilitates oxidation of substituted phenols. One of the important phenolic oxidation reactions of considerable interest is the conversion of 2,3,5-trimethylphenol (TMP; **1a**) to the corresponding 2,3,5-trimethyl benzoquinone (TMQ; **2**), which is a key intermediate in the synthesis of tocopherol (Vitamin E).⁴ In this letter, we present a novel and convenient single step synthesis of alkyl substituted *p*-benzoquinones from the corresponding phenols using 30% H₂O₂ as an oxidizing reagent in the presence of acetic acid using TiAPO-5 catalyst (Scheme 1).



Scheme 1.

The catalyst (TiAPO-5) was prepared as per the following procedure given below. Dilute orthophosphoric acid (33.3 wt%; Glaxo) was taken in a teflon beaker and set under constant stirring. Then a required amount of pseudoboehmite (Catapal B, Vista) was added in portion wise to in the above solution under stirring and a gel (aluminophosphate) was formed. Calculated amount of titanium (IV) isopropoxide (Aldrich) was mixed with 10% aqueous HF (v/v) in a separate teflon beaker and then added to the aluminophosphate gel under continuous stirring. It was then filtered through 100 mesh nylon cloth to retain the unreacted and/or insoluble materials, if any. To this clear gel, triethylamine (template) was added drop wise under vigorous agitation followed by the addition of the remaining HF solution.

The pH was maintained at 6.2. The final homogenous gel with a (molar) composition of 0.6 Al₂O₃ : 1.0 P₂O₅ : 1.5 Et₃N : 0.2 TiO₂ : 0.4 F₂ : 60 H₂O was transferred into a teflon lined autoclave and kept in an air oven at 463 K for 24 h. After crystallization, the product was washed with 0.1M HCl followed by distilled water. It was then filtered and dried at 352 K for 12 h. The as-synthesized TiAPO-5 sample was calcined at 873 K for 6 h in a tubular furnace under a flow of air. The XRD pattern of the calcined TiAPO-5 show the typical APO-5 structure⁵ (Figure 1). ICP-AES analysis of the calcined catalyst indicates that it contains 1.5 wt% titanium.

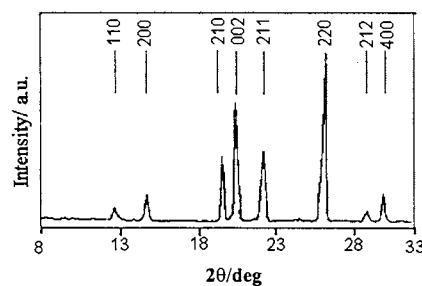


Figure 1. XRD pattern of calcined TiAPO-5.

All the reactions were carried out using the calcined TiAPO-5 catalyst as per the following procedure. To a mixture of alkyl substituted phenols and the catalyst in acetic acid, two equivalents of 30% aqueous H₂O₂ was added drop wise at room temperature for 5 h under nitrogen atmosphere. The products were analysed using gas chromatography and the results are summarised in Table 1. In the case of trialkyl phenols, both the isomers, viz., 2,3,5-TMP (**1a**) and 2,3,6-TMP (**1b**) gave 2,3,5-TMQ (**2**) in good yield. Among the by-products, traces of 2-hydroxy trimethyl benzoquinone and more of dimeric phenolic compounds were observed on prolonged reaction time.

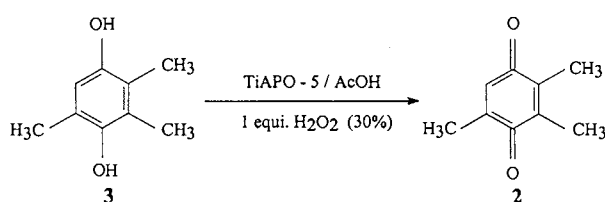
Table 1. Oxidation of TMP over TiAPO-5

| Substrate | Catalyst conc. g cat./g phenol / % | Product | Conversion / wt% | Yield / wt% | Selectivity / % |
|-----------|------------------------------------|---------|------------------|-------------|-----------------|
| 1a | 1.00 | 2 | 73.5 | 43.1 | 58.5 |
| 1a | 2.00 | 2 | 89.2 | 69.8 | 78.2 |
| 1a | 3.00 | 2 | 99.8 | 85.0 | 85.2 |
| 1b | 1.00 | 2 | 50.2 | 12.8 | 25.4 |
| 1b | 2.00 | 2 | 89.2 | 48.4 | 54.3 |
| 1b | 3.00 | 2 | 92.6 | 66.9 | 72.2 |
| 1a | None | 2 | 25.0 | 14.0 | 56.0 |

Use of other aliphatic acids, such as formic acid and propionic acid also gave quinone in good yield. However, solvents such as acetonitrile, *n*-hexane and ethyl acetate are not suitable for this reaction. In the case of methanol, TMP conversion is more

rapid but the selectivity of TMQ is very less.

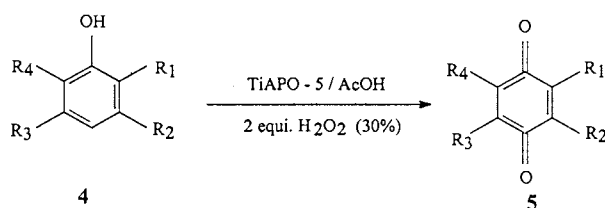
As far as the oxidation reaction of TMP is concerned, it requires two equivalents of H_2O_2 (cf. Scheme 1). Thus, the reaction seems to proceed through hydroxylation at the para position of TMP (**1a**) to give trimethyl hydroquinone (TMHQ; **3**) followed by the oxidative dehydrogenation to yield TMQ (**2**). In fact, TMHQ (**3**) can smoothly be converted to **2** by an equimolar amount of H_2O_2 under the same conditions (Scheme 2). However, we could not detect **3** in the reaction mixture thus suggesting the oxidation of **3** to **2** is far more rapid than the process **1a** to **3**. Table 2 gives the results of the oxidation of various alkyl substituted phenols to the respective *p*-benzoquinones (Scheme 3). Phenol gave only a trace amount of *p*-benzoquinone. Among the mono- and di-alkyl substituted phenols, the latter showed higher yields of quinone than the former.



Scheme 2.

Table 2. Oxidation of phenols over TiAPO-5

| Substrate | R ₁ | R ₂ | R ₃ | R ₄ | Product | Conversion / wt% | Yield / wt% | Selectivity / % |
|-----------|----------------|----------------|----------------|----------------|---------|------------------|-------------|-----------------|
| 4a | Me | H | H | Me | 5a | 49.2 | 19.4 | 39.4 |
| 4b | H | Me | Me | H | 5b | 99.0 | 71.3 | 72.0 |
| 4c | Me | H | H | H | 5c | 48.1 | 14.2 | 29.5 |
| 4d | H | Me | H | H | 5d | 51.4 | 25.3 | 49.3 |
| 4e | H | H | H | H | 5e | 7.0 | traces | ----- |



Scheme 3.

When the reactivity is compared between two phenol isomers **4a** and **4b**, the phenol (**4b**) in which the methyl groups at ortho position show higher reactivity and gave better yield of the benzoquinone (**5b**) than the phenol (**4a**) in which the methyl groups are at the meta position. It seems thus the oxidation of phenol proceeds under ortho and para inductive effect of substituents. A similar effect has been noted by Shimizu et al.⁶ in H_2O_2 /heteropolyacid system. The preference of *p*-oxygenation of phenol is predominantly shown in other substituted phenolic systems.⁷ We have also carried out the reaction of *o*-*t*-butylphenol which did not produce the corresponding quinone but yield dimeric coupling products. A similar observation was made in the oxidation of phenols using $RuCl_2$ catalyst.⁸

It is, therefore, concluded from this study that TiAPO-5 catalyze the oxidation of alkyl substituted phenols to the corresponding *p*-benzoquinones with aqueous H_2O_2 in presence of acetic acid. The reaction gives better yield and high selectivity of the products. The use of H_2O_2 as the oxidizing agent and the stable recyclable TiAPO-5 catalyst is expected to be less expensive and environmental compatible. Attempt to establish a more complete view of the reaction mechanism of the oxidation reactions is in progress.

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