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Oxidation of Phenols and Hydroquinones by Dioxygen Catalyzed by Mixed Addenda Heteropolyoxometalate on Active Carbon (NPV_6Mo_6/C)

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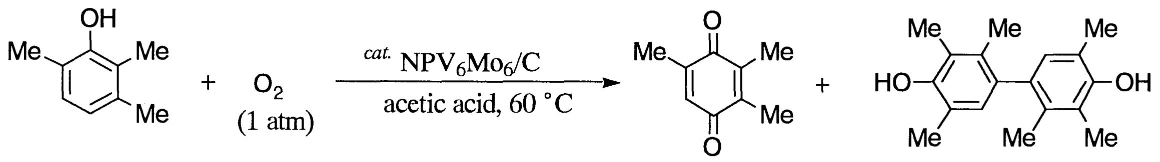
Vanadomolybdophosphate supported on active carbon, NPV_6Mo_6/C, catalyzed the oxidation and coupling reaction of 2,3,6-trimethylphenol by dioxygen to give trimethyl-*p*-benzoquinone and 4,4'-dihydroxy-2,2',3,3',5,5'-hexamethylbiphenyl, respectively, depending on the solvent used. Hydroquinones and benzyl alcohol were selectively dehydrogenated by the present system, giving the corresponding *p*-benzoquinones and benzaldehyde, respectively, in good yields.

The selective oxidation of phenol and hydroquinone derivatives to the corresponding quinones is a frequently used transformation in organic synthesis. In particular, the oxidation of phenols to quinones is an important reaction from industrial point of view. Therefore, a variety of oxidation methods have been developed for this purpose.1) Polyalkylphenols have been converted into the corresponding quinones with aqueous hydrogen peroxide by heteropolyacids such as 12-tungstphosphoric acid.1b) Recently, it has been reported that mixed addenda heteropolyacids such as $H_5PV_2Mo_{10}O_{40}$ catalyze the oxidation of various substrates by molecular oxygen (dioxygen) : *e. g.*, oxidation of alkane,2) HBr,3) and sulfides, 4) oxidative cleavage of ketones,5) and dehydrogenation of dienes,6) alcohols, amines,7) and phenols.8) In a previous paper, we reported that a highly selective oxidation of benzylic derivatives is promorted by NPV_6Mo_6 under oxygen atmosphere.9)

We now find that NPV_6Mo_6/C,10) obtained by supporting NPV_6Mo_6 on active carbon, catalyzes the oxidative dehydrogenation and oxidative coupling of phenols by dioxygen to afford quinones and dihydroxybiphenyl derivatives, respectively, in good yields.

The oxidation of 2,3,6-trimethylphenol (**1**) by dioxygen in the presence of NPV_6Mo_6 or NPV_6Mo_6/C giving trimethyl-*p*-benzoquinone (**2**), an important precursor of Vitamin E, was first examined. Table 1 shows the result for the oxidation of **1** under various reaction conditions. A typical reaction was carried out as follows.



1 **2** **3**

Into a three necked flask with a reflux condenser were placed **1** (1 mmol), NPV_6Mo_6/C (180 mg) and acetic acid (6 mL), and then oxygen was bubbled into the stirred solution at 60 °C for 5 h.

The selectivity of the reaction was markedly dependent on the solvent used. The oxidation of **1** with dioxygen in the presence of non-supported NPV_6Mo_6 in toluene did not occur (Run 1), but the same oxidation using NPV_6Mo_6/C as the catalyst afforded **2** (17%) and 4,4'-dihydroxy-2,2',3,3',5,5'-hexamethylbiphenyl (**3**) (53%) (Run 2). The reaction in benzonitrile resulted in a complex mixture of over oxidation products (Run 3). The oxidative coupling product **3** was obtained in higher selectivity in acetic acid (Run 4). It is interesting to note that the use of mixture of acetic acid and water as the solvent gave the benzoquinone **2** in preference to the coupling product **3**; the best result was obtained when the acetic acid / water ratio was 1 / 2 v/v% (Runs 6-8). In order to ascertain the formation of **2** from **3**, the oxidation of **3** was examined under the same conditions as the oxidation of **1**. By this oxidation, **2** was obtained in 7% yield, but most of **3** was degraded. Thus, it may be considered that the

Table 1. Oxidation of 2,3,6-Trimethylphenol (**1**) by NPV_6Mo_6/C-O_2 System in Various Solvents [a)]

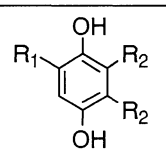
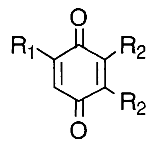
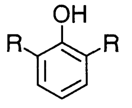
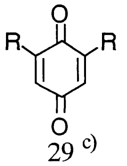
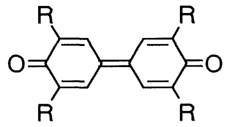
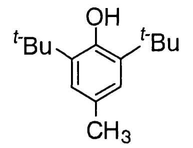
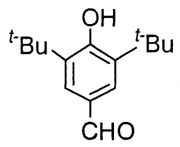
Run	Solvent / mL		Temp / °C	Time / h	Conv. / %	Yield / % [b)]	
						2	**3**
1 [c)]	toluene (10)		100	20	0	0	0
2	toluene (10)		100	20	95	17	53
3 [d)]	benzonitrile (6)		100	10	100	21	10
4	acetic acid (3)		100	0.25	78	7	64
5	acetic acid (6)		60	5	100	40	16
6	acetic acid / water (1 / 1 v/v%)	(6)	60	5	100	66	16
7	acetic acid / water (1 / 2 v/v%)	(6)	60	5	100	75	3
8 [e)]	acetic acid / water (1 / 2 v/v%)	(9)	60	5	100	68	7

a) Oxygen was bubbled into the suspended solution of **1** (1 mmol) and NPV_6Mo_6/C (180 mg). b) HPLC yields. c) NPV_6Mo_6 was employed instead of NPV_6Mo_6/C. d) A complex mixture of over oxidation products was formed. e) Recovered NPV_6Mo_6/C was used.

forming route of **2** through **3** is a minor one. Unfortunately, we can not determine at present time whether **2** is formed directly from **1** or indirectly from another intermediate.

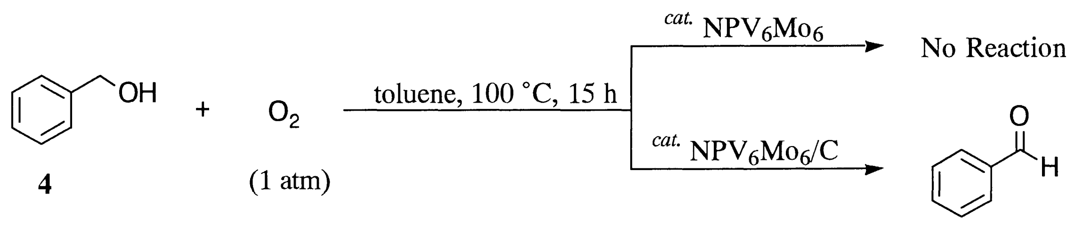
Table 2 shows the representative result for the dehydrogenation of various phenols and hydroquinones by this system. Methyl- and trimethylhydroquinones were dehydrogenated by NPV_6Mo_6/C under oxygen atmosphere in acetic acid, affording the corresponding quinones in good yields. Under the same conditions, however, non-substituted 1,4-hydroquinone was dehydrogenated in moderate yield (58%).

Table 2. Oxidative Dehydrogenation of Phenol and Hydroquinone Derivatives by $NPV_6Mo_6/C-O_2$ System [a)]

Run	Substrate	Time / h	Yield / % [b)]
			
1	R_1 = H R_2 = H	1	58
2	CH_3 H	1	84
3	CH_3 CH_3	1	87
			 
4	R = CH_3	5	29 [c)] 52 [c)]
5	${}^tBu$	5	81 [c)]
6		5	 59

a) Reaction conditions : substrate (2 mmol), NPV_6Mo_6/C (360 mg), acetic acid (6 mL), O_2 (1 atm), 60 °C, 1~5 h. b) GLC yield based on substrate used. c) Isolated yield.

Although the dehydrogenation of benzyl alcohol (**4**) to benzaldehyde (**5**) was difficult to be achieved by non-supported NPV_6Mo_6 catalyst, **4** was smoothly dehydrogenated by $NPV_6Mo_6/C-O_2$ system to give **5** in high yield (91%). This is probably due to the high concentration of substrate and/or oxygen adsorbed in the vicinity of active site of the NPV_6Mo_6/C. After the reaction, NPV_6Mo_6/C could be easily recovered by filtration, and the



4

5 91%

recovered NPV_6Mo_6/C retained the high catalytic activity. For instance, after five-times repetition of the oxidation of **4** by using the recovered NPV_6Mo_6/C, **5** was still formed in 93% yield.

From the industrial and synthetic points of view, the present oxidation method by NPV_6Mo_6/C using dioxygen as the primary oxidant has several advantages as follows : (i) the oxidation occurs selectively in the absence of any reducing agent, (ii) reaction conditions are relatively mild (60-100 °C, O_2 1 atm), (iii) the catalyst, NPV_6Mo_6/C, recovered by filtration, kept high catalytic activity after the repeated use.

In summary, we have developed a new efficient mixed addenda heteropolyoxometalate, NPV_6Mo_6/C, as the catalyst for the oxidation of phenols, hydroquinones, and benzyl alcohol by molecular oxygen.

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10) NPV_6Mo_6/C was prepared as follows. To a solution of $NaVO_3$ (7.32 g, 60 mmol) in water (38 mL) was added $Na_2MoO_4 \cdot 2H_2O$ (18.22 g, 34 mL) in water (12 mL). To the resulting solution was added 85% H_3PO_4 (7.6 g, 66 mmol) in water (10 mL) and the mixture was heated to 95 °C and stirred for 1 h. After cooling to 0 °C, a saturated aqueous ammonium chloride (150 mL) was added to the solution to give NPV_6Mo_6 as a brown precipitate. The NPV_6Mo_6 (1 g) thus obtained was dissolved in excess water and then added active charcoal (9 g). After stirring for 0.5 h at room temperature, NPV_6Mo_6/C was filtered off, washed with water, and dried *in vacuo* with heating at about 90 °C. The NPV_6Mo_6/C was obtained in almost quantitative yield.

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