

Catalytic N-oxidation of picolinic acid in the presence of heteropolyacids including Mo and W

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Abstract

In the presence of hydrogen peroxide as an oxidizing agent, the heteropoly anions $H_6P_2W_{18}O_{62}$, $H_6P_2Mo_{18}O_{62}$, $\alpha-K_3PW_9Mo_3O_{40}$, $\alpha-K_7PW_9Mo_2O_{39}$, $H_4PMo_{11}VO_{40}$, $H_5PMo_{10}V_2O_{40}$ and $H_6PMo_9V_3O_{40}$ were studied as catalysts for the N-oxidation of picolinic acid, in various solvents such as toluene, benzene and carbon tetrachloride. The highly selective oxidation, gave good to excellent yields of the related N-oxide along with decarboxylation at 2-position of ring. Among the catalysts tested, $\alpha-K_3PW_9Mo_3O_{40}$ catalyzed the selective N-oxidation into related N-oxide product most efficiently. The effect of some operative variables, such as the mole numbers of hydrogen peroxide, amount of the catalyst, and the reaction time was studied. The reaction conditions were optimized.

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1. Introduction

In nanotechnology, industry and medicine, pyridine N-oxides are very important compounds [1,2]. Additionally, these compounds are useful synthetic intermediates and show biological activities [3]. Pyridine N-oxides are also useful as protecting groups, auxiliary agents, oxidants, ligands in metal complexes and catalysts [4]. Many researchers have studied the N-oxidation of pyridines using various oxidants and catalysts [5–9]. The shortcomings of these methods, are the requirement of high temperature or catalyst loading, longer reaction times or expensive and highly toxic catalysts, specific conditions and tedious work up procedures. Hence, a practical and more efficient method using inexpensive and environment friendly catalyst is still of interest. Recently, heteropolyacids are the most conventional homogeneous and heterogeneous used catalysts [10–15]. The application on these catalysts cause solving of some problems such as corrosion, loss of catalyst, tedious work up procedures, cost, long time reactions and environment problems. These com-

pounds have diverse structures and their constitutional elements can readily be varied and tuned for different catalytic applications in catalytic systems.

Our previous work was devoted to study the catalytic performance of Preyssler's anion as pure acid, $H_{14}[NaP_5W_{30}O_{110}]$, and mixed addenda, $H_{14}[NaP_5W_{29}MoO_{110}]$, in order to obtain pyridine N-oxides from pyridine carboxylic acids [16]. The study established that the Preyssler's anion catalyzes N-oxidation of pyridine carboxylic acids using hydrogen peroxide. With respect to the various applications of heteropolyacids in catalysis area [17–26], as a part of research project and in continuation of our researches on heteropolyacids [27,28], the present work screens the performance of the other heteropolyacids including Mo, W, and V in the preparation of pyridine N-oxides. To best of our knowledge there is not any report concerning the catalytic behavior of the studied heteropolyacids in this work in the oxidation of pyridines.

2. Experimental

2.1. Chemicals and apparatus

Toluene, benzene, carbon tetrachloride and pyridine carboxylic acids were obtained from commercial sources and used

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as received. Hydrogen peroxide was obtained from Merck company and was standardized by well-known methods (Hydrogen Peroxide product In formation Manual, Analytical procedure).

IR spectra were obtained with a Bruker 500 scientific spectrometer. GC-Mass analysis was performed on a GC-Mass model: 5973 network mass selective detector, GC 6890 Agilent Mass spectra were obtained with a Massens POEKTRO METER CH-7A VARIN MAT BREMEN spectrometer. H NMR spectra were recorded on a FT NMR Bruker 100 MHz Aspect 3000 spectrometer.

2.2. General procedure

In a typical reaction, in a vessel with a reflux condenser and thermometer were successively placed, solvent (10 ml), pyridine (5×10^{-3} mol), 15% aqueous hydrogen peroxide and catalyst as mentioned in Tables 2 and 3. The reaction mixture was stirred at reflux temperature for 6 h. Upon cooling the solid was filtered off, washed with water, diethyl ether and air dried to afford the products.

All pyridine N-oxides are known compounds and have been characterized by comparison of their GC-Mass, Mass, IR, H NMR and melting points with those of authentic samples.

3. Results and discussions

To optimize the reaction conditions picolinic acid (pyridine-2-carboxylic acid) was used as substrate and the catalytic oxidation reactions were carried out in the presence of $H_6P_2W_{18}O_{62}$, $H_6P_2Mo_{18}O_{62}$, $\alpha-K_3PW_9Mo_3O_{40}$, $\alpha-K_7PW_9Mo_2O_{39}$, $H_4PMo_{11}VO_{40}$, $H_5PMo_{10}V_2O_{40}$ and $H_6PMo_9V_3O_{40}$ as catalyst.

In the first stage the conversion of picolinic acid to the related pyridine N-oxide was carried out using various solvents like benzene, toluene and carbon tetrachloride. The results are shown in Table 1. According to our earlier studies [16], the GC-Mass results, mass and melting points of obtained pyridine N-oxides showed that picolinic acid can be oxidized along with decarboxylation at 2-position of heterocycle. This effect is related to the position of COOH group to the pyridine nitrogen. The carboxylate anion forming in the transition state is very close to the pyridine nitrogen, causing, to some extent, repulsion between the identical negative charges, resulting in the planar carboxylate anion being in a perpendicular position with respect to the

pyridine ring, which is therefore subjected to better carboxylate anion elimination. The results indicate that the highest yield of the product is different in various solvents in the presence of different heteropolyacids. In other words, when all conditions are similar, yields of product is variable in different solvents using different heteropolyacids as catalyst. This behavior attributed to the solvent effect.

Heteropoly anions are reducible chemical species, and thus the energy of the lowest unoccupied molecular orbitals must be sufficiently low to accept the incoming electron in catalytic reactions. The solvent molecules can stabilize these anions and place these molecular orbitals at the appropriate level. As shown in Table 1, the solvent effects change with the change of catalyst structure.

A significant interpretation for observed different activities of tested heteropoly anions is very difficult. Most of properties of the heteropoly anions in solution depends on the concentration, the pH value, the reaction temperature, and other factors. Additionally, their properties can be varied by their constitutive elements as heteroatom, polyatom, and counter-cation. At present, it is impossible to take all of these possible factors in a significant interpretation. However, because one of the important factors that affect the oxidation capacity and activity of poly anions is the energy gap between the highest occupied molecular orbital (HOMO) and the lowest unoccupied orbital (LUMO), it is suggested that the energy and composition of the LUMOs have significant effects on the redox properties and activity of the polyoxometalates. About the highest activity for $\alpha-K_3PW_9Mo_3O_{40}$ we can tell, the metal substitution may modify the energy and composition of the LUMO and thus also the redox properties of the heteropoly anions. Keeping in mind, that the hydrogen peroxide is degradable at high temperatures ($>60^\circ C$), thus radical products from the decomposition of hydrogen peroxide (HO^\bullet and HO_2^\bullet) act as oxidants in the heteropolyacid catalyzed oxidation at reflux temperature.

Our data indicate that among the used solvents with $H_6P_2W_{18}O_{62}$ and $H_6P_2Mo_{18}O_{62}$ as catalyst, the best solvent is toluene. Thus, the effects of mole numbers of hydrogen peroxide and catalyst and reaction time have been studied in toluene. The results are shown in Table 2. From the results, one can see that the yield of product has been affected by changing the mole numbers of catalyst and oxidant. This mole numbers for both Dawson catalysts, $H_6P_2W_{18}O_{62}$ and $H_6P_2Mo_{18}O_{62}$ are nearly similar.

Table 1
N-oxidation of picolinic acid using H_2O_2 and heteropolyacid catalysts with various solvents

Entry	Catalyst	Yield of N-oxide in toluene (%) ^a	Yield of N-oxide in benzene (%) ^a	Yield of N-oxide in carbon tetrachloride (%) ^a
1	$H_6P_2W_{18}O_{62}$	40.92	23.63	27.23
2	$H_6P_2Mo_{18}O_{62}$	65.99	45.38	37.03
3	$\alpha-K_3PW_9Mo_3O_{40}$	60.51	86.59	39.19
4	$\alpha-K_7PW_9Mo_2O_{39}$	77.80	92.79	93.51
5	$H_4PMo_{11}VO_{40}$	12.96	48.99	24.20
6	$H_5PMo_{10}V_2O_{40}$	17.00	Trace	22.33
7	$H_6PMo_9V_3O_{40}$	6.60	11.52	4.35

^a Determined by GC-Mass, based on decarboxylated product.

Table 2

Effect of mole numbers of oxidant and catalyst in the oxidation of picolinic acid in the presence of Dawson catalysts

Entry	Catalyst	Mole numbers of H ₂ O ₂ (%yield) ^a	Mole numbers of catalyst (%yield) ^b
1	H ₆ P ₂ W ₁₈ O ₆₂	0.022 (10.80)	1 × 10 ⁻⁵ (35.44)
2	H ₆ P ₂ W ₁₈ O ₆₂	0.026 (25.93)	2 × 10 ⁻⁵ (21.03)
3	H ₆ P ₂ W ₁₈ O ₆₂	0.031 (21.61)	3 × 10 ⁻⁵ (40.92)
4	H ₆ P ₂ W ₁₈ O ₆₂	0.036 (40.92)	4 × 10 ⁻⁵ (59.65)
5	H ₆ P ₂ W ₁₈ O ₆₂	0.036 (40.39)	5 × 10 ⁻⁵ (54.29)
6	H ₆ P ₂ W ₁₈ O ₆₂	0.046 (64.98)	6 × 10 ⁻⁵ (52.73)
7	H ₆ P ₂ W ₁₈ O ₆₂	0.051 (63.11)	7 × 10 ⁻⁵ (57.63)
8	H ₆ P ₂ Mo ₁₈ O ₆₂	0.022 (49.27)	1 × 10 ⁻⁵ (40.34)
9	H ₆ P ₂ Mo ₁₈ O ₆₂	0.026 (47.83)	2 × 10 ⁻⁵ (61.67)
10	H ₆ P ₂ Mo ₁₈ O ₆₂	0.031 (54.03)	3 × 10 ⁻⁵ (65.99)
11	H ₆ P ₂ Mo ₁₈ O ₆₂	0.036 (65.99)	4 × 10 ⁻⁵ (50.43)
12	H ₆ P ₂ Mo ₁₈ O ₆₂	0.041 (65.27)	5 × 10 ⁻⁵ (61.38)
13	H ₆ P ₂ Mo ₁₈ O ₆₂	0.046 (61.09)	6 × 10 ⁻⁵ (61.52)
14	H ₆ P ₂ Mo ₁₈ O ₆₂	0.051 (60.08)	7 × 10 ⁻⁵ (55.90)

^a Catalyst: 3 × 10⁻⁵ mol.^b H₂O₂: 0.036 mol.

As seen in Table 1, the product yield increases with the catalyst mole numbers up to 4 × 10⁻⁵ and 3 × 10⁻⁵ for H₆P₂W₁₈O₆₂ and H₆P₂Mo₁₈O₆₂, respectively. Any further increasing of the amount of the catalyst does not have any effect on the reaction yields.

Finally, at the best conditions for H₆P₂W₁₈O₆₂ (0.046 mol H₂O₂ and 4 × 10⁻⁵ mol catalyst) and H₆P₂Mo₁₈O₆₂ (0.041 mol H₂O₂ and 3 × 10⁻⁵ mol catalyst) the effects of reaction times on the product yield have been studied. The results are shown in Fig. 1. The best reaction times for H₆P₂W₁₈O₆₂ and H₆P₂Mo₁₈O₆₂ were obtained 2 and 6 h, respectively.

Similar reactions for α-K₃PW₉Mo₃O₄₀ and α-K₇PW₉Mo₂O₃₉ were carried out at the solvent of choice: benzene. The results are shown in Table 3. At the best conditions the effects of reaction times were studied (Fig. 2).

To establish, the generality of the method, under optimum conditions using the best catalysts with higher yields, α-K₃PW₉Mo₃O₄₀ and α-K₇PW₉Mo₂O₃₉, the oxidation reactions were extended to other pyridines. The catalytic oxidation of pyridine carboxylic acids such as 3-pyridine carboxylic acid, 3,5-pyridine dicarboxylic acid and 2,6-pyridine dicarboxylic acid. The results are shown in Table 4. These data indicate that these catalysts are also active for other pyridines.

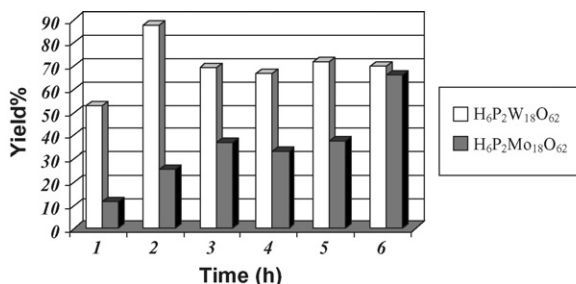
Fig. 1. Yield as a function of process time in the N-oxidation of picolinic acid in the presence of H₆P₂W₁₈O₆₂ and H₆P₂Mo₁₈O₆₂.

Table 3

Effect of mole numbers of oxidant and catalyst in oxidation of picolinic acid in the presence of mixed-addenda Keggin type catalysts

Entry	Catalyst	Mole numbers of H ₂ O ₂ (%yield) ^a	Mole numbers of catalyst (%yield) ^b
1	α-K ₃ PW ₉ Mo ₃ O ₄₀	0.022 (68.29)	1 × 10 ⁻⁵ (94.23)
2	α-K ₃ PW ₉ Mo ₃ O ₄₀	0.026 (62.68)	2 × 10 ⁻⁵ (92.79)
3	α-K ₃ PW ₉ Mo ₃ O ₄₀	0.031 (75.36)	3 × 10 ⁻⁵ (86.59)
4	α-K ₃ PW ₉ Mo ₃ O ₄₀	0.036 (86.59)	4 × 10 ⁻⁵ (87.75)
5	α-K ₃ PW ₉ Mo ₃ O ₄₀	0.041 (88.61)	5 × 10 ⁻⁵ (93.65)
6	α-K ₃ PW ₉ Mo ₃ O ₄₀	0.046 (72.19)	6 × 10 ⁻⁵ (81.84)
7	α-K ₃ PW ₉ Mo ₃ O ₄₀	0.051 (82.85)	7 × 10 ⁻⁵ (80.69)
8	α-K ₇ PW ₉ Mo ₂ O ₃₉	0.022 (78.96)	1 × 10 ⁻⁵ (52.44)
9	α-K ₇ PW ₉ Mo ₂ O ₃₉	0.026 (78.96)	2 × 10 ⁻⁵ (64.69)
10	α-K ₇ PW ₉ Mo ₂ O ₃₉	0.031 (76.08)	3 × 10 ⁻⁵ (93.51)
11	α-K ₇ PW ₉ Mo ₂ O ₃₉	0.036 (93.51)	4 × 10 ⁻⁵ (81.41)
12	α-K ₇ PW ₉ Mo ₂ O ₃₉	0.041 (70.60)	5 × 10 ⁻⁵ (82.99)
13	α-K ₇ PW ₉ Mo ₂ O ₃₉	0.046 (76.22)	6 × 10 ⁻⁵ (76.51)
14	α-K ₇ PW ₉ Mo ₂ O ₃₉	0.051 (64.40)	7 × 10 ⁻⁵ (73.05)

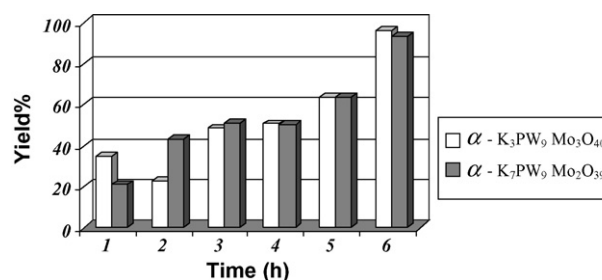
^a Catalyst: 3 × 10⁻⁵ mol.^b H₂O₂: 0.036 mol.Fig. 2. Yield as a function of process time in the N-oxidation of picolinic acid in the presence of α-K₃PW₉Mo₃O₄₀ and α-K₇PW₉Mo₂O₃₉.

Table 4

N-oxidation of pyridine carboxylic acids using H₂O₂ and mixed-addenda Keggin type catalysts

Entry	Substrate	%Yield with α-K ₃ PW ₉ Mo ₃ O ₄₀ ^a	%Yield with α-K ₇ PW ₉ Mo ₂ O ₃₉ ^a
1		53.60	80.40
2		70.13	67.28
3		70.13	71.00

^a Yield determined by GC-Mass.

4. Conclusions

In summary, the present study demonstrates the catalytic activity of Dawson and transition-metal substituted heteropoly anions as well as Preyssler catalyst (in our earlier studies) in N-oxidation of pyridine carboxylic acids.

The significance of this study with inexpensive and easily prepared catalysts fundamentally lies in the fact that their use would lead to an alternative technology for the other systems and amines, which are of interest for the pharmaceutical industry, and nanotechnology, with advantages from the point of view of the environmental care.

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