

Synthesis of Methyl Phenyl Glyoxylate via Clean Oxidation of Methyl Mandelate over a Nanocatalyst Based on Heteropolyacid Supported on Clay

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Abstract:

Oxidation is an important class of reaction from both industrial and academic points of view. In recent years, a large number of oxidizing agents have been used for a variety of industrial reactions, but many of them are polluting, giving poor yields. Mandelates have played an important role in organic synthesis and are used in artificial flavoring and perfumes. Methyl phenyl glyoxylate, which contains two carbonyl groups, is an important intermediate used in fine chemical industry. Oxidation of methyl mandelate was carried out to prepare methyl phenyl glyoxylate, with 85% selectivity, by using hydrogen peroxide in the presence of a novel catalyst, namely, 20% w/w $\text{Cs}_{2.5}\text{H}_{0.5}\text{PW}_{12}\text{O}_{40}$ /K-10 catalyst, which is partly substituted dodecatungstophosphoric acid supported on clay. The catalyst is a nano material and reusable. The workup is easy.

Introduction

Carbonyl compounds are a prominent class in synthetic organic chemistry having several applications as solvents and precursors to several products such as alcohols, acids, and heterocyclic compounds.^{1–3} Methyl phenyl glyoxylate, which contains two carbonyl groups, is an important intermediate used in fine chemical industry. α -Dicarbonyl compounds are obtained by the oxidation of α -hydroxylcarbonyl precursors. Due to the sensitivity of the α -dicarbonyl compounds, special reagents and reaction conditions are required to prevent side reactions during the oxidation of α -hydroxycarbonyls.¹ Although a number of methods have been developed to achieve this transformation, most of them suffer from the use of corrosive acids or toxic metallic compounds that generate undesirable waste materials. There are several methods available in the literature on the oxidation of α -hydroxyl compounds by oxidizing agents such as *N*-bromosuccinimide,⁴ *N*-bromoacetamide,⁵ trichloroisocyanuric acid,⁶ *N*-bromobenzene sulphonamide,⁷ *N*-chlorobenzene

sulphonamide,⁸ 1-chlorobenzotriazole,⁹ *N*-bromosaccharin,¹⁰ bromate,¹¹ and *N*-bromophthalimide.¹² In the past few years, the oxidation of α -hydroxyl compounds has been reported by using catalytic amounts of chromium oxide in conjunction with *tert*-butylhydroperoxide^{13,14} or hydrogen peroxide.^{14,15} Oxidation is also reported with the catalytic amounts of VOCl_3 in acetonitrile under an oxygen atmosphere.¹³ Phenyl glyoxylic acid esters were prepared by treating a Grignard reagent phenylmagnesium bromide with diethyl oxalate.¹⁶ Oxidation of phenylacetylene derivatives can also be utilized for the synthesis of α -keto ester.¹⁷ Methyl phenylglyoxylate was synthesized via ozonolysis of 1-bromophenylacetylene followed by reaction with potassium iodide,¹⁸ whereas the oxidation was improved¹⁹ by treatment of trimethylsilyl phenylacetylenes with osmium tetroxide and *tert*-butyl hydroperoxide in methanol to get methyl phenyl glyoxylate. It is also reported that ammonium chlorochromate adsorbed on alumina was used for the preparation of phenyl glyoxylic esters.¹⁷ The use of heterogeneous catalysts with a clean oxidizing agent is necessary for the synthesis of methyl phenyl glyoxylate, and this work is concerned with that aspect.

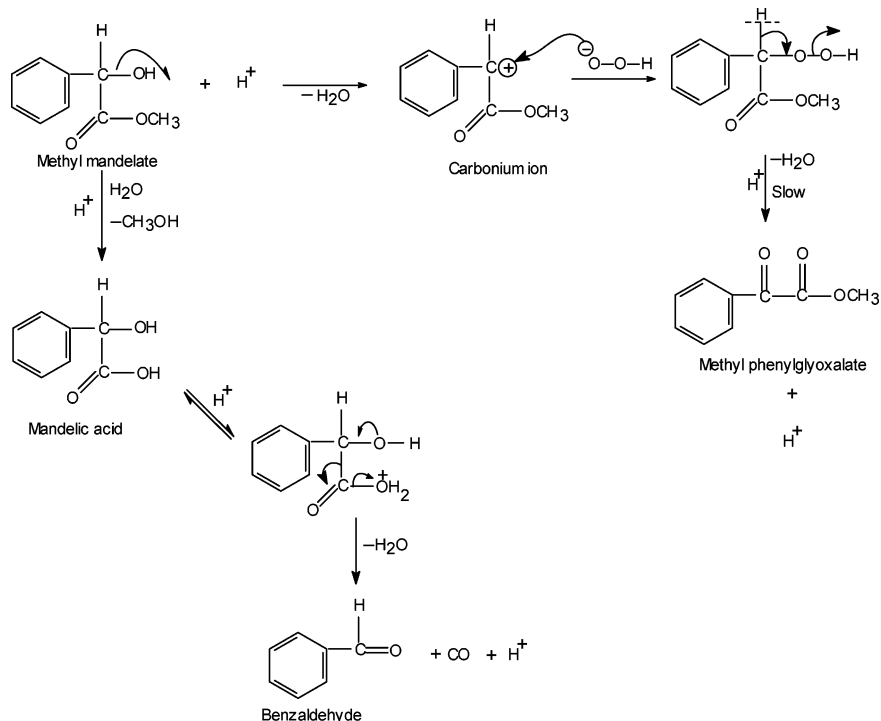
Heteropolyacids are a very important class of acid and redox catalysts. The novelty of clay-supported heteropolyacids as reusable benign catalysts was reported by us²⁰ for the first time, and a series of commercially important reactions were studied.^{21–27} We have also developed a novel nanocatalyst by using partially substituted dodecatungstophosphoric acid (DTP) with cesium and supporting it on acid-activated clay. Thus, nanoparticles of 20% w/w $\text{Cs}_{2.5}\text{H}_{0.5}\text{PW}_{12}\text{O}_{40}$ were created in the pore network of acid treated

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Scheme 1. Reaction mechanism involving H₂O₂ and Cs-DTP/K10



Effect of Catalyst Quantity. The effect of catalyst quantity was studied in the range 0.4–5.4 g keeping all other conditions the same (Figure 2). It was observed that as the catalyst quantity was increased, the conversion also increased but byproduct formation increased at higher catalyst quantity and the isolated yields suffered (Table 1). The best results were obtained with 1.4 g of catalyst quantity. Therefore, further reactions were carried out by using this quantity of the catalyst.

Effect of Mole Ratio. The effect of mole ratio of methyl mandelate to hydrogen peroxide was studied in the range 1:4.2, 1:8.3, 1:16.6, 1:24.5 (Figure 3, Table 2). It should be noted that the peroxide was added continuously, and hence the mole ratio relates to the total amount added. The

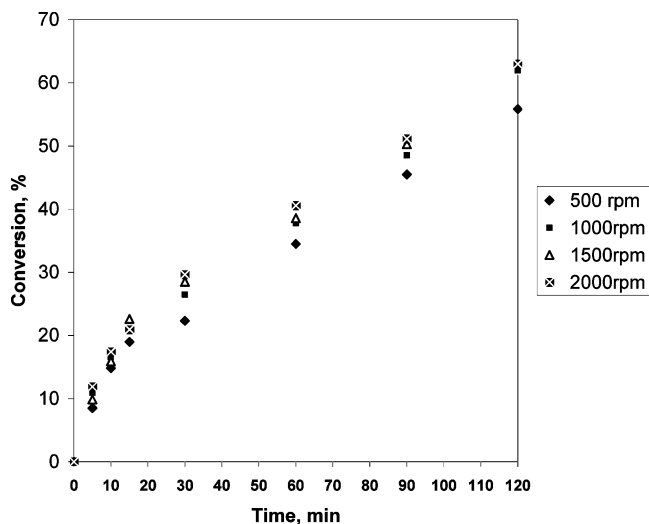


Figure 1. Effect of speed of agitation on conversion of methyl mandelate. Methyl mandelate, 0.0036 mol; acetonitrile, 50 mL; catalyst loading, 0.026 g/cm³; 50% hydrogen peroxide, 0.037 mol; temperature, 50 °C.

Table 1. Selectivity and yield of methyl phenyl glyoxalate at different catalyst quantities after 2 h^a

catalyst quantity (g)	selectivity (%)	isolated yield %
0.4	55.3	12.8
1.4	86.4	50.2
3.4	65.5	42.0
5.4	67.3	47.0

^a Methyl mandelate, 0.0036 mol; acetonitrile, 50 mL; 50% hydrogen peroxide, 0.037 mol; temperature, 50 °C; speed of agitation, 1000 rpm; time, 2 h.

selectivity observed towards the desired product methyl phenylglyoxalate was maximum at a mole ratio of 1:8.3. Therefore, further reactions were carried out with a mole ratio of 1:8.3.

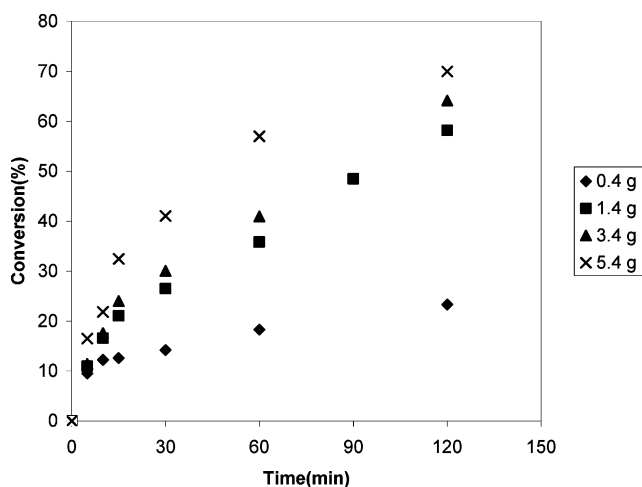


Figure 2. Effect of total catalyst quantity (g) on conversion of methyl mandelate. Methyl mandelate, 0.0036 mol; acetonitrile, 50 mL; 50% hydrogen peroxide, 0.037 mol; temperature, 50 °C; speed of agitation, 1000 rpm.

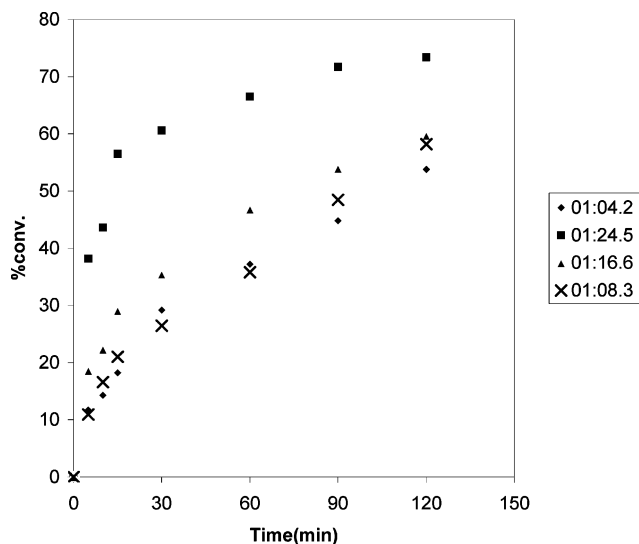


Figure 3. Effect of mole ratio of hydrogen peroxide to methyl mandelate on conversion of methyl mandelate. Acetonitrile, 50 mL; catalyst quantity (20% w/w Cs-DTP/K-10), 0.026 g/cm³; temperature, 50 °C; time, 2 h; speed of agitation, 1000 rpm.

Table 2. Selectivity and yield of methyl phenyl glyoxylate at different mole ratios after 2 h^a

mole ratio	selectivity (%)	isolated yield %
1:4.2	84.9	45.6
1:8.3	86.4	51.6
1:16.6	63.8	46.8
1:24.5	56.3	32.7

^a Acetonitrile, 50 mL; catalyst quantity (20% w/w Cs-DTP/K-10), 0.026 g/cm³; temperature, 50 °C; time, 2 h; speed of agitation, 1000 rpm.

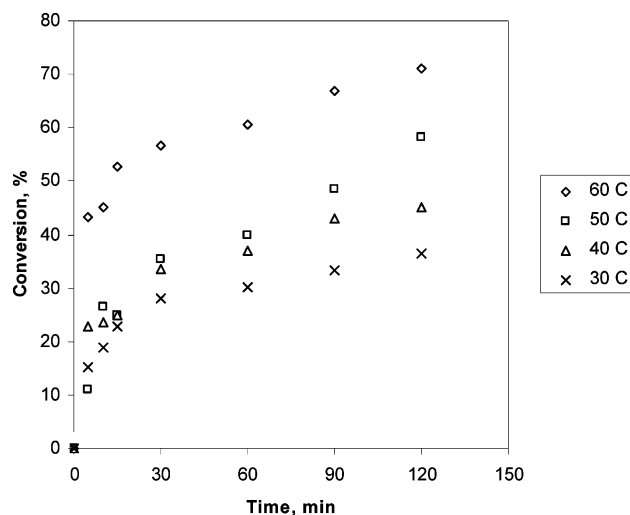


Figure 4. Effect of temperature on conversion of methyl mandelate. Methyl mandelate, 0.0036 mol; acetonitrile, 50 mL; catalyst quantity (20% w/w Cs-DTP/K-10), 0.026 g/cm³; 50% hydrogen peroxide, 0.037 mol; speed of agitation, 1000 rpm.

Effect of Temperature. The reaction was studied in the range 30–60 °C, under otherwise similar conditions (Figure 4). It was observed that, with an increase in temperature, the conversion increased. The selectivity decreased due to predominance of side reactions (Table 3).

Effect of Catalyst Reusability. The reusability of the catalyst was tested by employing it thrice. After each run

Table 3. Effect of temperature on selectivity and yield of methyl phenyl glyoxylate after 2 h^a

temperature, °C	selectivity (%)	isolated yield %
30	95.0	34.5
40	92.5	41.6
50	86.4	51.6
60	61.5	46.8

^a Methyl mandelate, 0.0036 mol; acetonitrile, 50 mL; catalyst quantity (20% w/w Cs-DTP/K-10), 0.026 g/cm³; 50% hydrogen peroxide, 0.037 mol; speed of agitation, 1000 rpm.

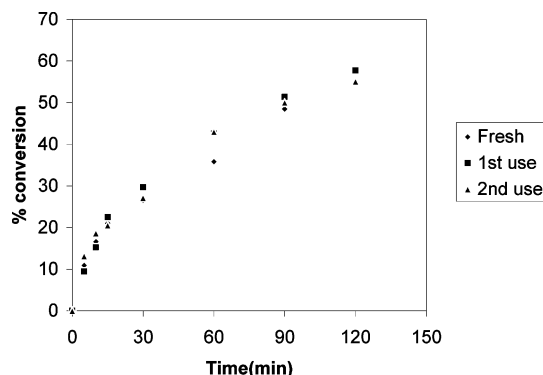


Figure 5. Effect of catalyst reusability on conversion of methyl mandelate. Methyl mandelate, 0.0036 mol; acetonitrile, 50 mL; catalyst loading (20% w/w Cs-DTP/K-10), 0.026 g/cm³; 50% hydrogen peroxide, 0.037 mol; temperature, 50 °C; speed of agitation, 1000 rpm.

the catalyst was filtered and washed with methanol in order to remove the adsorbed organic substances from the active sites. But washing was insufficient to remove all the adsorbed organic substance from the active sites, and therefore the catalyst was refluxed with methanol for 5 h. The marginal decrease in the conversion of methyl mandelate was observed. In the second and third reuse, makeup catalyst was added to match the losses during filtration to find if the catalyst is reusable, which is the case. The selectivity in all these cases practically remained the same (Figure 5).

Conclusions

Methyl phenyl glyoxylate is an important intermediate used in fine chemical industry. The normal routes of its synthesis are highly polluting. In the current work, a clean oxidation process was developed by which methyl phenyl glyoxylate was prepared with 85% selectivity, from methyl mandelate with hydrogen peroxide and 20% w/w Cs_{2.5}H_{0.5}-PW₁₂O₄₀/K-10 catalyst at 50 °C. This catalyst contains nanoparticles of the heteropolyacid trapped in cages of acid-treated clay and is reusable. The workup was simple, and the product can be easily separated. The procedure is better than others so far reported.

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