

Oxidation of Benzylic Alcohols to Their Corresponding Carbonyl Compounds Using Ceric Ammonium Nitrate (CAN)/Brönsted Acidic Ionic Liquid

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A chemoselective and efficient procedure for the oxidation of alcohols to the corresponding carbonyl compounds is reported using ceric ammonium nitrate in the presence of 3-methylimidazolium hydrogensulfate as Brönsted acidic ionic liquid ([*Hmim*] HSO_4) as the solvent under mild conditions. The use of non-toxic and inexpensive materials, straightforward procedure, short reaction times and good yields of the products are the major advantages of this method.

Keywords: Oxidation, Alcohols, Ceric ammonium nitrate, Brönsted acidic ionic liquid

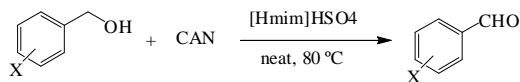
INTRODUCTION

Ionic liquids (IL) have frequently been used as a green solvent in place of classical organic solvents in modern synthetic chemistry [1-4]. Ionic liquids are superior to conventional organic solvents due to their extremely low vapor pressure, excellent thermal stability, reusability and ability to dissolve many organic and inorganic substrates [4]. The application of ionic liquids as solvent and catalyst has been reported for a variety of functional group transformations but their use as acid catalysts under solvent-free conditions requires more attention [1-4]. Ionic liquids with Brönsted acidic counter ions such as 1-hexyl-3-methylimidazolium bisulfate ([*hmim*] HSO_4) [5], 1-butyl-3-methylimidazolium dihydrogen phosphate ([*bmim*] H_2PO_4) [5], 1-[2-(2-hydroxyethoxy)ethyl]-3-methylimidazolium bisulfate ([*heemim*] HSO_4) [5], 1-butyl-3-methylimidazolium chloroaluminate

([*bmim*] ClAlCl_3) [6a], and 1-butyl-3-methylimidazolium bisulfate ([*bmim*] HSO_4) [6b], 3-methylimidazolium hydrogensulfate ([*Hmim*] HSO_4) [7] have been used as acid catalysts and provide a useful medium under solvent-free conditions because of their polar nature.

The oxidation of alcohols to the corresponding aldehyde or ketone is one of the most important functional group transformations in organic synthesis. Despite the using many reagents for this transformation [8] still there are many demands for mild and efficient methods. Tetravalent cerium salts are strong one-electron oxidizing agents that can be used as reagents for a wide variety of organic transformations [9]. The most extensively used cerium(IV) reagent in organic chemistry is cerium(IV) ammonium nitrate (CAN). The reasons for its general acceptance as a one-electron oxidant may be attributed to its large reduction potential value of +1.61 V vs. NHE (normal hydrogen electrode), also low toxicity, ease of handling, straightforward experiment, and solubility in a number of organic solvents. CAN is proved to

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Scheme 1

be very useful reagent for synthetic organic chemists over four decades.

The enormous growth for application of this reagent is evidenced by the publication of a large number of research papers and several reviews concerning CAN-mediated reactions [10]. The ability of cerium to display stable adjacent oxidation states +3 and +4 makes it so unique among the lanthanide elements. Unfortunately oxidation with this reagent suffers from various disadvantages such as using high amount of reagent (CAN) and long reaction times [11,12]. This reagent is not effective for oxidation of benzyl alcohol in refluxing acetonitrile and after 2.5 h, benzyl alcohol isolated without oxidation [13]. In continuation of our ongoing program to develop efficient reagents for oxidation of organic compounds [14-20], in this communication we report a synergy between ceric ammonium nitrate (CAN) and 3-methylimidazolium hydrogensulfate ($[Hmim]HSO_4$) as effective Brønsted acidic ionic liquid as solvent media which able to oxidize various benzylic alcohols (Scheme 1).

EXPERIMENTAL

General Procedure for the Oxidation of Benzylic Alcohol

Alcohol (1 mmol) and ceric ammonium nitrate (1 mmol) and 3-methylammonium disulfate $[Hmim]HSO_4$ (2 mmol) was added to a round-bottomed flask. The reaction mixture was placed in an oil bath at 80 °C and stirred for the specified time. The reaction was followed by TLC (EtOAc-cyclohexane, 20:80). After completion of the reaction, the product was extracted with ethylacetate (2×5 ml) and washed with water. The solvent was evaporated under reduced pressure to give the corresponding pure products. Purification of the residue using flash column chromatography (silica gel, EtOAc-cyclohexane, 20:80) provided the pure carbonyl compounds.

RESULTS AND DISCUSSION

For optimizing the reaction conditions, we tried conversion

Table 1. Conversion of 4-Nitrobenzyl alcohol to 4-Nitrobenzaldehyde in Different Organic Solvents and in the Presence of Different Ionic Liquids

Entry	Solvent	Yield (%)	Time (h)
1 ^a	Acetonitrile	30	4
2 ^a	Ethylacetate	45	4
3 ^a	Cyclohexane	5	4
4 ^a	n-Hexane	Trace	4
5 ^a	1,2-Dichloroethane	Trace	4
6 ^b	$[bmim]Br^-$	50	4
7 ^b	$[Hmim]HSO_4$	85	4

^aThe reaction was carried out in 5 ml of solvents under reflux conditions. ^bThe reaction was carried out in 2 mmol of ionic liquid at 80 °C.

of 4-nitrobenzyl alcohol (1 mmol) to 4-nitrobenzaldehyde in the presence of ceric ammonium nitrate (1 mmol) in various solvents and also in ionic liquids as a solvent. As shown in (Table 1), in comparison to conventional methods the yields of the reaction in the presence of Brønsted acidic ionic liquid ($[Hmim]HSO_4$) as the solvent are higher and no side products were obtained (Table 1).

We also studied the oxidation of 4-nitrobenzyl alcohol to 4-nitrobenzaldehyde with other metal nitrates and various non-nitrates oxidants using Brønsted acidic ionic liquid ($[Hmim]HSO_4$) at 80 °C (Table 2). The results show that most of these metal nitrates are not effective oxidants for this transformation under mentioned conditions, and ceric ammonium nitrate is the best oxidant under these conditions.

Our results for the oxidation of a variety of benzylic alcohols are summarized in (Table 3). The oxidation of various benzylic alcohols gave the carbonyl compounds in high yields and short to moderate reaction times. The competing reaction such as over-oxidation of aldehydes to the corresponding carboxylic acids, nitration of benzene ring or benzyl nitrite was not observed in any of the cases under above conditions. We observed that aliphatic alcohols did not oxidize with this system, even in long reaction time. Hydroxyl benzyl alcohol allylic and propargylic alcohols were converted to unidentified polymeric materials with explosion, therefore

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Table 2. Oxidation of 4-Nitrobenzylalcohol Using Various Metal Nitrates and Oxidants in the Presence of Brönsted Acidic Ionic Liquid ($[Hmim]HSO_4$) at 80 °C^a

Entry	Metal nitrate	4-Nitrobenzaldehyde (%)	4-Nitrobenzoic acid (%)	Time (h)
1	NaNO ₃	45	10	3.0
2	NH ₄ NO ₃	25	20	2.5
3	Zn(NO ₃) ₂ ·6H ₂ O	55	10	2.0
4	Ni(NO ₃) ₂ ·6H ₂ O	50	16	1.0
5	Cu(NO ₃) ₂ ·3H ₂ O	61	20	1.0
6	Cd(NO ₃) ₂ ·9H ₂ O	51	20	1.0
7	Ce(NH ₄) ₂ (NO ₃) ₆	85	-	4.0
8	Ca(OCl) ₂	Trace	Trace	2.0
9	KIO ₄	0	0	3.0
10	KBrO ₃	20	20	2.0
11	K ₂ S ₂ O ₈	10	10	2.0
12	CrO ₃	5	-	3.0

^aReaction conditions: metal nitrates or oxidants (1 mmol), $[Hmim]HSO_4$ (2 mmol) and 4-nitrobenzylalcohol (1mmol) were mixed and stirred at 80 °C.

Table 3. Oxidation of Various Alcohols Using Ceric Ammonium Nitrate in the Presence of Brönsted Acidic Ionic Liquid ($[Hmim]HSO_4$) at 80 °C^{a,b}

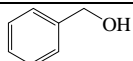
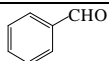
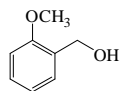
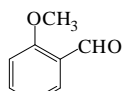
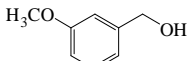
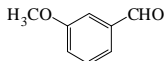
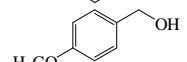
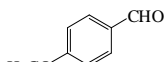
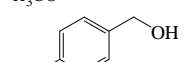
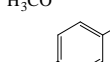
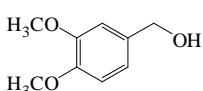
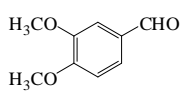
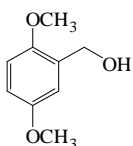
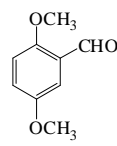
Entry	Substrate	Product	Time (min)	Yield (%)
1			25	90
2 ^c			7	91
3 ^c			7	94
4 ^c			45	90
5 ^c			20	91
6 ^c			20	90
7 ^c			20	92

Table 3. Continued

8			55	88
9			50	90
10			45	90
11			45	88
12			45	92
13			4h	86
14			4h	85
15			30	90
16			30	91
17			30	89
18			35	88
19			4h	90
20 ^d			3h	-
21 ^d			3h	-
22 ^d			3h	-

^aThe yields refer to the isolated pure products. ^bThe products were characterized from their spectral data (IR, ¹H NMR) and compared with authentic samples. ^cThe reaction was carried with catalytic amount of CAN (30 mol%). ^dThe yields refer to GC analysis.

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Table 4. Competitive Oxidation of Benzylic Alcohols by Using CAN/[*Hmim*] HSO_4^- ^a

1	
2	
3	
4	

^aBased on GC and TLC analysis.

we do not recommend using this system for oxidation of aliphatic, allylic, propargylic and hydroxyl benzyl alcohols derivatives.

To show the chemoselectivity of this method, the competitive reactions have been carried out as shown in Table 4. In comparison to benzylic-alcohols, oxidation of aliphatic ones with this method did occur with lower yields and longer reaction time. The donor substituted group in the benzene ring benzylic alcohols accelerates the reaction rate and the withdrawing groups reduced the reaction rate dramatically.

CONCLUSIONS

In conclusion, we have introduced a straightforward and efficient method for chemoselective oxidation of alcohols to their corresponding carbonyl compounds using ceric ammonium nitrate in the presence of Brønsted acidic ionic liquid ($[\text{Hmim}]\text{HSO}_4^-$) at 80 °C. The use of non-toxic and inexpensive materials, stability of the oxidation system, simple method, short reaction times, good yields of the products and mild reaction conditions are the advantages of this method.

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