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Studies on Acylation Reactions withZnO supported on Alumina [ZnO/Al_2O_3]

B.R. Saikishorekumar, S.Sumathi* and P.S.Raghavan*
Department of Chemistry, Hindustan Institute of Technology & Science
Padur, Chennai-603103, India
sumathi@hindustanuniv.ac.in, raghavan@hindustanuniv.ac.in

Abstract- **Herein, the acylation reaction using benzoyl chloride catalyzed by ZnO supported on alumina (ZnO/Al_2O_3) is described. The catalyst was characterized by UV-DRS and SEM. ZnO/$Al_2O_3$is found to be efficient for the benzoylation of alcohols and phenols at room temperature under solvent free conditions. The catalyst can be effectively used up to four cycles.**

Keywords: **Friedel-crafts acylation; alumina; ZnO; aromatic compounds; solvent free conditions.**

I. Introduction

Synthesis of benzoate esters of phenols and alcohols has attracted considerable interest in recent times because of their important biological activities as antibacterial, anti-parasitic.(1). They are widely used in cosmetics and also in medicinal application such as, inflammation of skin and treatment of diabetes. Friedel-Crafts acylation, one of the most industrially important transformations in organic synthesis is employed for the preparation of esters and amides (2). In such reactions, conventional Lewis acid catalyst such as $AlCl_3$ leads to the formation of the product-Lewis acid complex and this demands the use of stoichiometric quantity of the catalyst (3, 4). In addition, isolation of the product by breaking the complex with mineral acid destroys the catalyst and leads to the generation of a large amount of toxic waste. Reactions involving other catalysts such as $Ln(OTf)_3$ –$LiClO_4$(5), $Rucl_3$(6),$InCl_3$(7), $ZrCl_4$(8),DMAP(9), $CoCl_2$(10),Bu_3P(11) and ionic liquids(12)also suffers from many disadvantages. Most of the reported methodologies work well on primary and secondary alcohols but sluggish with tertiary alcohols or less reactive phenols. Also, some of these methods suffer from the side reactions such as rearrangement and dehydration and may not be effective with substrates bearing acid-sensitive groups. A higher selectivity, easier work up and environmentally safe reactions can be achieved by the use of supported catalysts. Conventionally silica, sintered calcium phosphate, zeolites and clay etc. are used as catalyst supports. Recent years have witnessed more developments on heterogeneous reactions catalyzed by supported metal oxides (13, 14). Particularly, zinc oxide has been reported to catalyze the Friedel-Crafts acylation and alkylation reactions (15, 16). Catalysis by ZnO supported on Al_2O_3 for the acylation reactions has not been reported till now. In our efforts on developing solvent free procedures for these reactions, we investigated the benzoylation reactions catalyzed by ZnO prepared by chemical method and supported on alumina (Al_2O_3).

II. EXPERIMENTAL

A. Preparation of the catalyst

To the alumina powder (7.5 g) suspended in distilled water under continuous stirring, zinc nitrate (>99% purity, 9.16 g) was added followed by addition of ammonia solution (25%, 4.1 g) drop-wise under continuous stirring till the Ph reached 8. The precipitate formed was filtered, dried in hot air oven at 150°C for 2 hours and then calcined at 400°C for 30 minutes. The catalyst was labeled as ZnO/Al_2O_3 (400). The above catalyst prepared contains 25% of ZnO and rest support and were evaluated for their catalytic activity towards Friedel -Crafts acylation reactions (17, 18). In the catalyst preparation, the zinc salt is precipitated as zinc hydroxide using the ammonia solution. If excess ammonia is added, the precipitate dissolves in solution, forming a zinc complex. The volume of water used, the stirring speed and rate of addition of ammonia plays vital role in deciding the particle size of ZnO. Generally the zinc hydroxide gets converted to zinc oxide at temperatures above 125°C. Hence, the higher calcinations temperature of the catalyst was selected as 400°C. This catalyst was labeled as ZnO/Al_2O_3 (400**).**

B. Characterization of the catalyst

The catalyst ZnO/Al_2O_3 was characterized by SEM, EDX and UV-DRS. The SEM-EDX analysis of the catalyst was carried out using a SEM COXEM (TM 200). UV-visible spectra were recorded using PerkinElmer spectrometer (LAMBDA-850 UV-Visible Spectrophotometer), in reflectance mode. Based on the literature report, it is inferred that while the bulk ZnO absorbs around 300 nm, the nano ZnO absorbs between 380-400 nm (19). A similar observation was recorded for the catalyst ZnO/Al_2O_3, calcined at 400°C. The UV-DRS spectrum of ZnO/Al_2O_3 (400**)** (Figure 1) showed an absorption peak around 380-400 nm corresponding to nano ZnO. The morphology and elemental analysis of ZnO/Al_2O_3 (400**)** investigated using scanning electron microscopy (SEM/EDAX) (Figure 2) shows the formation of particles of ZnO deposited on the support.

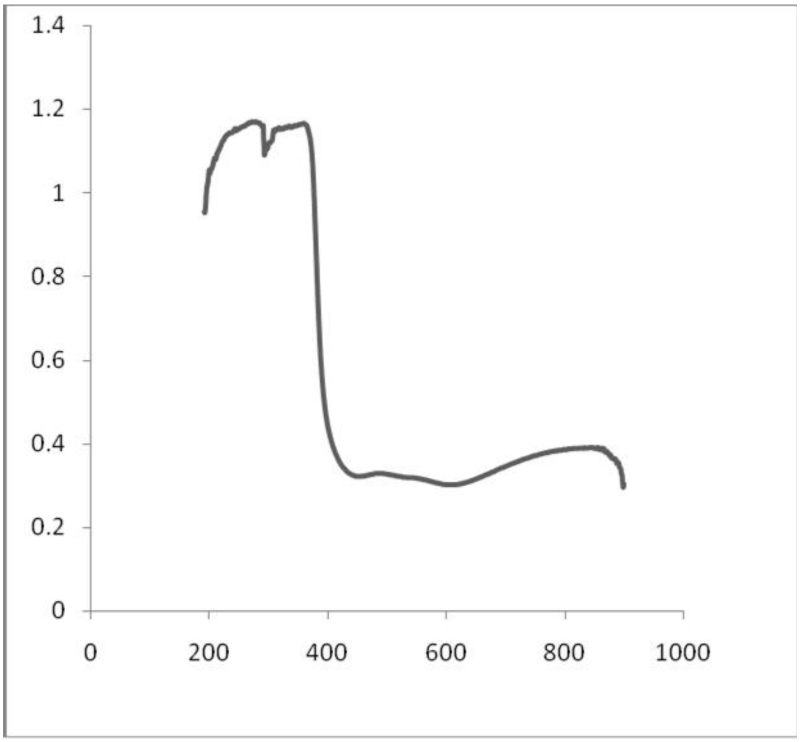


Figure 1: UV-DRS of ZnO/Al_2O_3 (400)

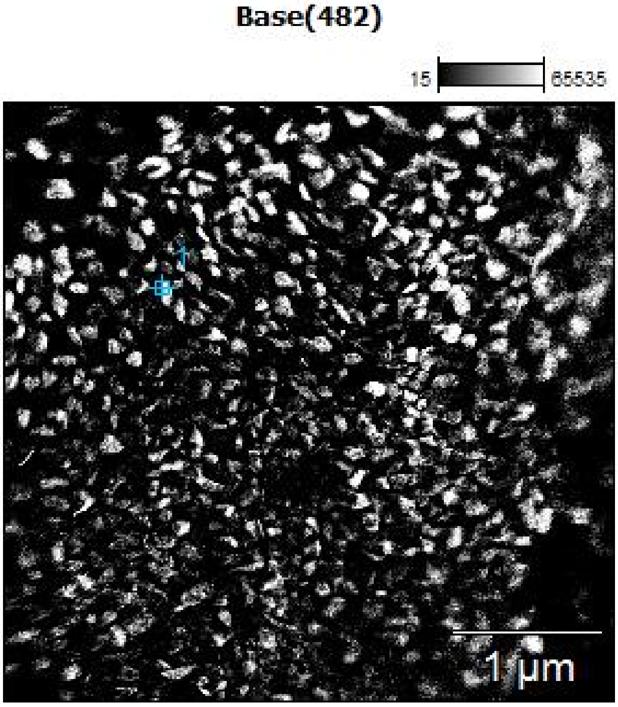


Figure 2-A: SEM of ZnO/Al_2O_3 (400)

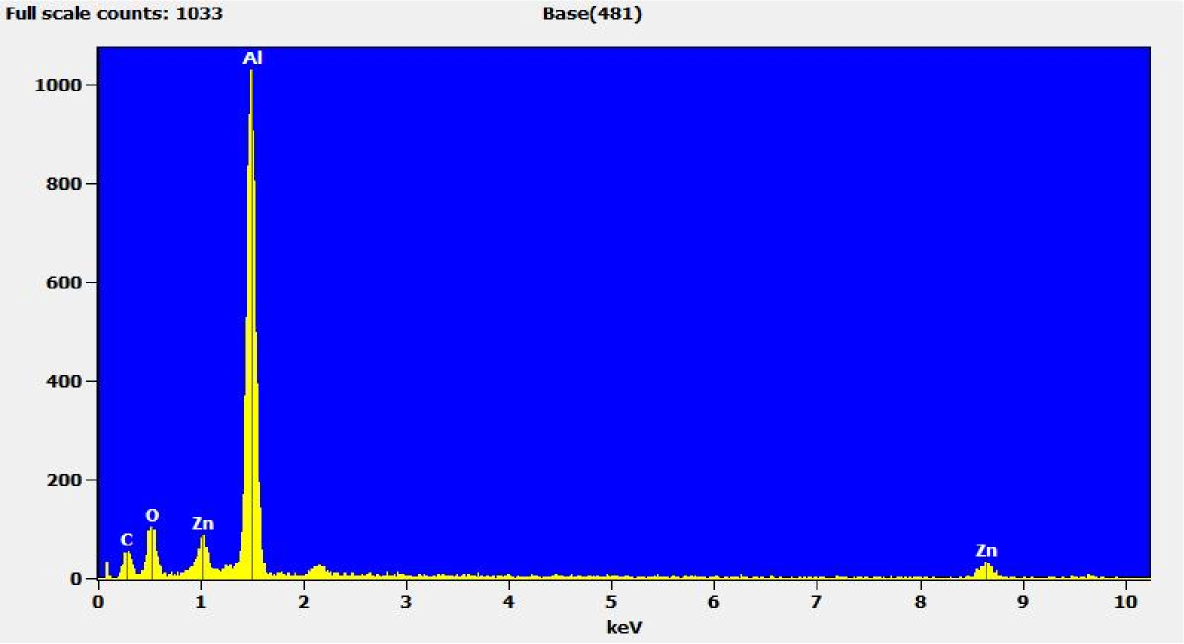


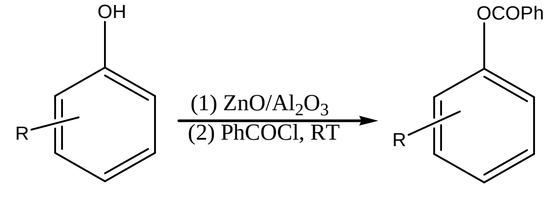
Figure 2-B: EDAX of ZnO/Al_2O_3 (400)

C. General experimental procedure for the synthesis of esters:

The mixture of phenol or alcohol (0.0255 mol) and acylchloride (0.0255 mol) and ZnO/Al_2O_3 (dry powder, 0.10 g, and 0.0003 mol) was added into a 50 ml round bottomed flask. This reaction mixture was stirred using a mechanical stirrer at room temperature. The progress of the reaction was monitored by TLC (2% ethyl acetate & hexane) (20). The reaction mass containing the catalyst (ZnO/Al_2O_3) was then diluted with CH_2Cl_2 (20 ml), filtered and the CH_2Cl_2 solution was then washed with an aqueous solution of sodium hydroxide (10%) and dried over anhydrous sodium sulfate. Evaporation of the solvent afforded the crude product. The product was recrystallized in ethanol.

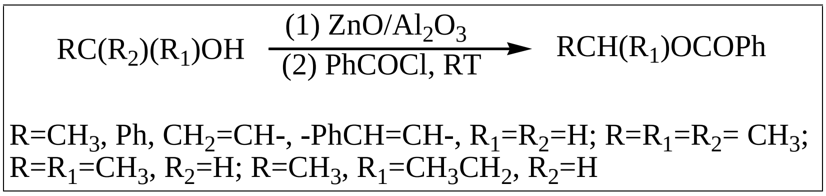
III. RESULTS AND DISCUSSIONS

Friedel-Crafts acylation of phenol with benzoyl chloride was selected for testing the activity of the catalyst ZnO/Al_2O_3 (400)**.**Thus, to one equivalent of phenol, 0.5 equivalent of the catalyst was added and stirred using a mechanical stirrer. To this reaction mixture, one equivalent of benzoyl chloride was added slowly in 5 minutes at room temperature and the contents were stirred at room temperature. The progress of the reaction, monitored by thin layer chromatography (TLC) revealed that the reaction was complete in 20 minutes. Work-up of the reaction mixture afforded the product, phenyl benzoate in 97% yield, as a colorless solid with a melting point of 69 ^{o}C (Table 3, entry 1). This reaction was extended to other phenols and alcohols as shown in the following schemes.



R=H, 4-CH_3, 4-Cl, 4-Br, 4-OCH_3, 2-NO_2, 2,4,6-trinitro, 2-COOH

Scheme 1 Benzoylation of phenols using ZnO/Al_2O_3



$$RC(R_2)(R_1)OH \xrightarrow[\text{(2) PhCOCl, RT}]{\text{(1) ZnO/Al}_2\text{O}_3} RCH(R_1)OCOPh$$

$R=CH_3$, Ph, $CH_2=CH-$, $-PhCH=CH-$, $R_1=R_2=H$; $R=R_1=R_2= CH_3$;
$R=R_1=CH_3$, $R_2=H$; $R=CH_3$, $R_1=CH_3CH_2$, $R_2=H$

Scheme 2 Benzoylation of alcohols using ZnO/Al_2O_3

A. Optimization and evaluation of catalytic activity

For optimizing the reaction conditions, benzoylation of phenol was chosen as standard. The benzoylationof phenol was repeated with different quantities of ZnO/Al_2O_3 (Table 1). From the data given in the table, it is evident that while a maximum yield of phenyl benzoate is achieved with 0.05 equivalents ZnO/Al_2O_3 (entry 2), the above reaction in ethanol required a longer reaction time and resulted in poor yield (entry 5). Thus, the optimum catalyst concentration in the benzoylation reaction was found to be the use of 0.05 equivalent of the catalyst for one equivalent of phenol and one equivalent of benzoyl chloride. It is important to note that while catalysis by unsupported nano ZnO reported earlier by Hosseini Sarvari et al., required 0.5 equivalent of the catalyst for the conversion of one equivalent of phenol to phenyl benzoate, in our case, we observed that one tenth of the Al_2O_3 supported ZnO is suffice for the effective reaction.

TABLE I OPTIMIZATION OF THE REACTION CONDITIONS

Entry	**Equiv. of ZnO/Al_2O_3**	**Solvent**	**Time (min)**	**Yield (%)**
1.	0.5	No solvent	20	97
2.	0.05	No solvent	30	96
3.	0.025	No solvent	60	46
4.	0.05	Water	60	56
5.	0.05	Ethanol	80	40
6.	No catalyst	No solvent	8 hr	trace

Next, we wanted to study the catalytic efficiency of the regenerated catalyst. For this, the catalyst separated by filtration from the first run was washed with methylene chloride and dried at room temperature for 3 hours. The catalyst regenerated by this method was employed for the conversion of phenol to phenyl benzoate and the details are shown in Table 2. The regenerated catalyst was found to be effective up to four runs and afforded the required product in 90-96% yield. Further use of the regenerated catalyst leads to a significant drop in the yield with longer reaction time.

TABLE II BENZOYLATION WITH REGENERATED CATALYST

No. of cycles	**Time (min)**	**Yield (%)**
1.	30	96
2.	30	92
3.	30	90
4.	40	88
5.	45	75

To check the general application of this catalyst, benzoylation of other substituted phenols (Scheme 1) and aliphatic alcohols (Scheme 2) were carried out using the optimized reaction conditions and the results are discussed in Table 3. From the table, it is clear that this catalyst is effective in the conversion of phenols and alcohols to the corresponding benzoates. As expected, the yield of aryl benzoates is found to be better than the yield of alkyl benzoates. Allyl alcohol and cinnamyl alcohol were also satisfactorily acylated under similar reaction conditions (entry 11 and entry 12). In general, phenols with electron withdrawing groups (entry 8, entry 9 and entry 10) and among the primary alcohols, olefinic alcohols (entry 13) require a longer reaction time.

TABLE III APPLICATION OF ZNO/AL$_2$O$_3$ (400) FOR THE BENZOYLATION OF PHENOLS AND ALCOHOLS

Entry	**Substrate**	**Product**	**Time (min)**	**Yield (%)**	**MP / BP (^{o}C) Observed (Reported)**
1.	Phenol	Phenyl benzoate	30	96	69 (69)
2.	p-Cresol	p-Cresyl benzoate	40	89	70 (71)
3.	4-Methoxyphenol	4-Methoxyphenyl benzoate	40	89	88 (90)

4.	p-Bromophenol	p-Bromophenyl benzoate	40	90	105 (103)
5.	p-Chlorophenol	p-Chlorophenyl benzoate	40	90	90 (90)
6.	β-Naphthol	β-Naphthyl benzoate	40	90	106 (107)
7.	Resorcinol	Resorcinol benzoate	45	85	115 (117)
8.	o-Nitrophenol	o-Nitrophenyl benzoate	40	86	60 (59)
9.	2-Hydroxybenzoic acid (Salicylic acid)	2-(Benzoyloxy)benzoic acid	50	80	131(133)
10.	Picric acid	Picryl benzoate	120	88	165 (163)
11.	Benzyl alcohol	Benzyl benzoate	20	86	323 (325)
12.	Allyl alcohol	Allyl benzoate	30	85	83 (85)
13.	Cinnamyl alcohol	Cinnamyl benzoate	60	80	33 (35)
14.	Ethanol	Ethyl benzoate	15	86	213(213)
15.	1-Propanol	Propyl benzoate	40	87	230 (229)
16.	2-Propanol	2-Propyl benzoate	40	87	218(220
17.	t-Butyl alcohol	t-Butyl benzoate	45	82	250 (251)
18.	Phenol + Benzyl alcohol	Benzyl benzoate	20	86	323 (325)

In order to study the reactivity of phenol in presence of an alcohol in the benzoylation with benzoyl chloride using the catalyst, ZnO/Al_2O_3 (400), we performed an experiment with a mixture of benzyl alcohol and phenol under the optimized conditions. It was observed that only benzyl alcohol formed the benzyl benzoate and the phenol remained unreacted (entry 18).

CONCLUSIONS

The reaction of phenols and alcohols with benzoyl chloride was found to be facile with zinc oxide supported on alumina. Less nucleophilic phenols are found to react slowly. Among phenol and alcohol, alcohol is preferentially acylated. In the case of secondary and tertiary alcohols, acylation occurs easily without the formation of any side products. The advantages associated with this reaction are simple reaction set-up, requirement of less quantity of the catalyst, shorter reaction times, high product yields and reusability of the catalyst under solvent free condition.

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REFERENCES

[1] Nanophase Materials: Synthesis, Properties, Applications; Hadjipanayis, G. C.,Siegel, R. W., Eds.; Kluwer: London, 1994.

[2] Mona HosseiniSarvari, HashemSharghi , TetrahedronVolume 61, Issue 46, 14 2005, Pages 10903–10907.

[3] Sharghi, H.; Hosseini Sarvari, M. Synthesis 2002, 8, 1057;

[4] Hosseini Sarvari, M.; Sharghi, H. J. Org. Chem. 2006, 71, 66523.

[5] Kawada, A.; Mitamura, S.; Kobayashi, S. *J. Chem. Soc.*,Chem. Commun. **1996**, 183.

[6] Kanta De, S. Tetrahedron Lett. 2004, 45, 2919.

[7] Chakraborti, A. K.;Gulhane, R. Tetrahedron Lett. 2003, 44, 3521.

[8] Chakraborti, A. K.; Gulhan, R. Synlett 2004, 627.

[9] Steglich, W.; Hofle, G. Angew. Chem., Int. Ed. Engl. 1969, 8,981.

[10] (a) Iqbal, J.; Srivastava, R. R. J. Org. Chem. 1992, 2001, 57. (b) Ahmad, S.; Iqbal, J. Tetrahedron Lett. 1986, 27, 3791.

[11] Vedejs, E.; Diver, S. T. J. Am. Chem. Soc. 1993, 115, 3358

[12] Lee, S. G.; Park, J. H. J. Mol. Catal. A: Chem. 2003, 194, 49.

[13] Sharghi, H.; Hosseini Sarvari, M. Synthesis 2002, 8, 1057;

[14] Hosseini Sarvari, M.; Sharghi, H. J. Org. Chem. 2004, 69, 6953;

[15] Hosseini Sarvari, M. Synthesis 2005, 5, 787;

[16] Hosseini Sarvari, M.; Sharghi, H. J. Org. Chem. 2006, 71, 66523.

[17] Schulz, H., Thiemann, K.H., *Solid State Commun.*, 32 ,783,1979.

[18] Sharghi, H.; Hosseini Sarvari, M. J. Chem. Res. (S) 2003, 3,176.

[19] Amarajothi Dhakshinamoorthy, Pitchai Visuvamithiran, Vairaperumal Tharmaraj, Kasi Pitchumani, *Catalysis Communications*, 16 15-19, 2011

[20] Sharghi, H.; Hosseini Sarvari, M. Tetrahedron 2002,58, 10323.