

Silica Sulfuric Acid as an Efficient Solid Acid Catalyst for Friedel-Crafts Acylation Using Anhydrides

A. Alizadeh,* M. M. Khodaei,* and E. Nazari

Chemistry Department, Razi University, Kermanshah 67149, Iran. *E-mail: mmkhoda@razi.ac.ir; ahalizadeh2@hotmail.com
Razi University Center for Environmental Studies, Razi University, Kermanshah 67149, Iran

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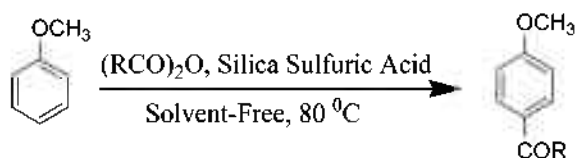
Key Words : F-C Acylation, Anhydrides, Heterogeneous catalyst, Solvent-free, Silica sulfuric acid

Friedel Crafts acylation reaction has been studied extensively and affords aromatic ketones.¹ The traditional method used acid chlorides or acid anhydrides as acylating agents and a stoichiometric or an excess amount of reaction promoter such as AlCl₃, BF₃, TiCl₄, FeCl₃, ZnCl₂, SnCl₄ or various Brønsted acids. These halogenated catalysts imposed several drawbacks including corrosion, environmental problems due to strongly acidic waste streams and necessity of more than stoichiometric amounts of catalysts. In addition, the acylating agents used in most of the traditional processes are the expensive and polluting acyl halides that require special cares in handling and working up. Therefore, the development of new methods using solid acid catalysts with the use of inexpensive and available non-polluting carboxylic acids and anhydrides as beneficial candidates is desirable.

Recently, considerable efforts have been made to use solid acid catalysts in Friedel-Crafts acylation reaction, since these heterogeneous catalysts can be easily separated from the reaction mixture. They are generally producing no problematic side products. Various classes of compounds which have been used as solid acid catalysts include zeolites,²⁻⁴ clays,^{5,6} heteropoly acids and their salts,^{7,8} Nafion-H,⁹ sulfate-doped metal oxides¹⁰ and silica sulfuric acid.¹¹⁻¹⁵ In continuing of our interest in Friedel-Crafts acylation reaction,¹⁶ we now report the acylation reaction in the presence of silica sulfuric acid (SSA) under solvent free conditions (Scheme 1).

Anisole and acetic anhydride were chosen as model compounds and their reaction in different solvents and solvent-free condition at 80 °C was treated using 25 mol% of silica sulfuric acid. The corresponding ketone was obtained in excellent yield (97%) after 20 min in solvent-less condition as shown in Table 1.

The effect of catalyst amount was tested and the results



R = CH₃, CH₃CH₂

Scheme 1

show that 5 mol% can also catalyze the reaction, but the yield was 85% after 20 min. However, when 20 mol% of the catalyst was used no significant changes in yield of the product and time of the reaction were observed.

In order to show the effectiveness of SSA with respect to the recently reported catalysts, SSA was compared with Hf[N(SO₂C₈F₁₇)₂]₄,¹⁷ AIPW₁₂O₄₀,¹⁸ Sc(OTf)₃,¹⁹ Yb(OTf)₃,^{20,21} In(OTf)₃,²² and Bi(OTf)₃.²³ The results indicated in Table 2 show that the catalyst SSA is better in respect to yield and the time of the reactions.

The acylation of benzene was not detected; however, toluene and *m*-xylene were acetylated to the methylacetophenone and dimethylacetophenone in high yields under very mild conditions. In the acylation of toluene, the most

Table 1. Effect of solvent upon Friedel-Crafts acylation of anisole catalyzed by SSA

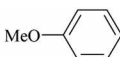
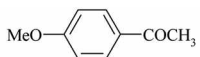
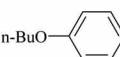
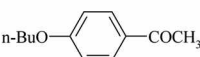
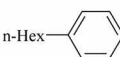
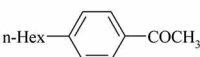
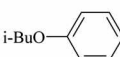
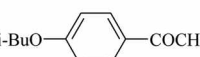
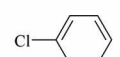
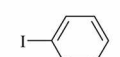
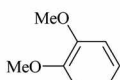
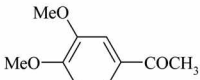
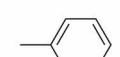
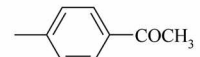
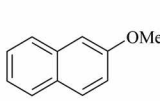
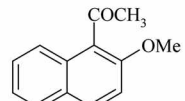
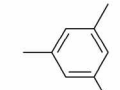
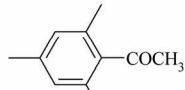
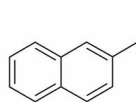
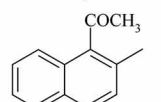
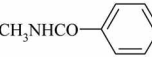
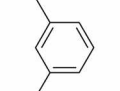

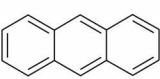
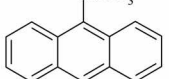
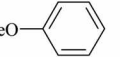

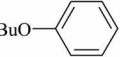
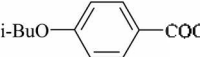
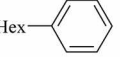
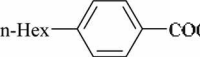

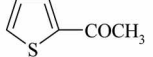
Run	Solvent	Time (h)	Temperature (°C)	Yield (%)
1	CHCl ₃	3	62	23
2	CH ₂ Cl ₂	3	40	71
3	Et ₂ O	3	36	25
4	CH ₃ CN	3	82	43
5	CH ₃ NO ₂	3	102	48
6	n-Hexane	3	69	89
7	None	0.3	80	97

Table 2. Comparison of the results for the acylation of anisole (1 mmol) that catalyzed by SSA and some other catalysts

Entry	Catalyst	Temp. (°C)	Time (h)	Yield (%)	Ref.
1	Hf[N(SO ₂ C ₈ F ₁₇) ₂] ₄	100	1 ^a	80	17
2	AIPW ₁₂ O ₄₀	60	0.8 ^b	94	18
3	Sc(OTf) ₃	50	18 ^c	99	19
4	Yb(OTf) ₃	50	4 ^d	70	20
5	Yb(OTf) ₃	50	18 ^e	99	21
6	In(OTf) ₃	50	1 ^f	96	22
7	Bi(OTf) ₃	50	2 ^g	80	23
8	SSA	80	0.33	97	—

^aCat. (1 mol%), chlorobenzene (1.5 mL) and SV 135 (1.5 mL). ^bNeat, cat. (3 mol%). ^cCat. (20 mol%), LiClO₄ (4 mmol) and MeNO₂ (1 mL). ^dCat. (20 mol%), Ac₂O (2 mmol), and MeNO₂ (1 mL). ^eCat. (20 mol%), LiClO₄ (1 mmol), Ac₂O (2 mmol) and MeNO₂ (1 mL). ^fCat. (1 mol%), LiClO₄ (1 mmol) and MeNO₂ (1 mL). ^gCat. (1 mol%), anisole/Ac₂O: 2/1.

Table 3. Reactions of aromatic compounds with anhydrides catalyzed by SSA under solvent-free conditions at 60–80 °C

Entry	Substrate	Time (min)	Product ^a	Yield ^b (%)
1		20		97
2		85		95
3		73		95
4		80		92
5		180	No Reaction	0
6		180	No Reaction	0
7		20		90
8		100		89
9		65		91
10		90		90
11		180		88
12		180	No Reaction	0
13		90		90
14		95		85
15		40		96
16		115		90
17		120		93
18		22		91

^aAll products were characterised by comparison of their physical and spectral data with those of authentic samples. ^bIsolated yields.

interesting feature is the excellent selectivity for *para*-acylated product.

The introduction of a methoxy group afforded higher yields of the acylation products. It was observed that electron-donating groups such as alkyl or methoxy groups afforded satisfactory yields and high regioselectivity (4-substituted acylated products). The other electron donating groups such as hydroxyl and amino groups gave no acetylated products. Phenol gave *O*-acylated and aniline afforded *N*-acylated products. *N,N*-Dimethylaniline, however, does not give the corresponding ketone, most likely because the catalytically relevant H⁺ species are inhibited by coordination with the nitrogen atom of this substrate.

The reaction did not proceed at all with arenes having electron-withdrawing substituents on aromatic ring. As expected, acylation of anisole is faster than those of alkylbenzenes and gave the acylated product in high yield. However, the *p*-selectivity for alkoxybenzenes is lower than alkylbenzenes. For example, 4%, 5%, 6% and 10% of *o*-alkoxy acetophenones were obtained respectively when *i*-butoxy-, *n*-hexoxy-, *n*-butoxy- and methoxybenzenes used. In the case of anthracene, 4 mmol of acetic anhydride was needed for the reaction to be completed and the reaction of thiophene was carried out at 60 °C.

In the case of the solid benzoic anhydride, the reaction was not completed and only 50% of the corresponding product was obtained.

No metal halide such as AlCl₃ as a catalyst and no acid halide such as acetyl chloride as an acylating agent were used. Therefore, this reaction is a halogen-free Friedel-Crafts acylation process.

Propionic acid anhydride can also be used with similar efficiency and excellent selectivity (Table 3, runs 15–17). It is also interesting to note that phenol is *O*-acylated rather than *C*-acylated under these conditions.

In conclusion, we have established a convenient heterogeneous catalytic method for acylation of alkylbenzene and alkoxybenzene derivatives using aliphatic anhydrides. The obvious advantages of heterogeneous catalysis in terms of easy separation, high yields and cheapness of the catalyst are noteworthy. The *p*-selectivity of alkoxybenzenes is lower than alkylbenzenes.

Experimental

General experimental procedure: A mixture of the aromatic compound (1 mmol), anhydride (2 mmol) and silica sulfuric acid¹⁴ (0.1 g, 0.25 mmol of H⁺) was heated at 80 °C, with stirring for 20–180 min. The progress of the reaction was followed by TLC. On completion of the reaction, saturated sodium carbonate (20 mL) was added to the reaction mixture and the product was extracted with Et₂O (3 × 10 mL). The organic layer was separated, dried over anhydrous MgSO₄. Evaporation of the solvent afforded the crude product which was purified by column chromatography. All of the compounds prepared are known.

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