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Efficient acylation of toluene and anisole with aliphatic carboxylic acids catalysed by heteropoly salt $Cs_{2.5}H_{0.5}PW_{12}O_{40}$

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Heteropoly salt $Cs_{2.5}H_{0.5}PW_{12}O_{40}$ is a highly efficient and reusable solid acid catalyst for the liquid-phase acylation of toluene or anisole with $C_2 – C_{12}$ aliphatic carboxylic acids.

Friedel–Crafts aromatic acylation catalysed by strong acids is the most important route for the synthesis of aromatic ketones that are intermediates in manufacturing fine and speciality chemicals as well as pharmaceuticals.[1] Present practice uses acyl chlorides or acid anhydrides as acylating agents and requires a stoichiometric amount of soluble Lewis acids (*e.g.* AlCl₃) or mineral acids (*e.g.* HF) as the catalysts, which results in substantial amounts of waste and corrosion problems.[2] Recently, in view of the increasingly strict environmental legislation, considerable effort has been put into developing cleaner Friedel–Crafts chemistry using solid acid catalysts such as zeolites, clays, Nafion-H, heteropoly acids, *etc.*, zeolites being the most studied catalysts.[2] Likewise, the environmentally benign aromatic acylation with carboxylic acids [eqn. (1)] instead of the anhydrides and acyl chlorides, resulting in the formation of water as the only by-product, has been attempted in a few studies, mostly with zeolites as catalysts.[3–5] The acylation of anisole with acetic anhydride using a zeolite catalyst has been commercialised by Rhodia.[2]

$$\text{(R' aryl)} + RCOOH \longrightarrow \text{(R'-COR aryl)} + H_2O \quad (1)$$
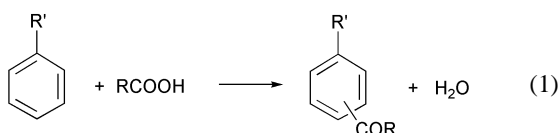
Keggin type heteropoly acids (HPAs) that are very strong Brønsted acids of formula $H_{8-x}[XW_{12}O_{40}]$, where X is the heteroatom (*e.g.* P^{5+} or Si^{4+}) and x is its oxidation state,[6–8] are promising solid acid catalysts for aromatic acylation.[6–9] HPAs have been widely used as catalysts for organic synthesis and have found several industrial applications.[6–8] The insoluble acidic caesium salt $Cs_{2.5}H_{0.5}PW_{12}O_{40}$ (CsPW) introduced by Misono *et al.*[7] has attracted considerable interest as a solid acid catalyst for various reactions, including Friedel–Crafts reactions, because of its strong acidity, high surface area and hydrophobicity.[7,8]

Here we report on a very efficient heterogeneous catalysis by CsPW for the acylation of toluene and anisole with $C_2–C_{12}$ aliphatic carboxylic acids in the liquid phase [eqn. (1), R' = Me or OMe]. CsPW is compared with bulk and silica-supported $H_3PW_{12}O_{40}$ (PW) which is the strongest acid in the HPA series.†

The acylation of toluene was carried out at a molar ratio PhMe/RCOOH = 50 and 110 °C (reflux) in the presence of *ca.* 10 wt% CsPW in the reaction mixture. The reaction was clearly heterogeneous, as CsPW is insoluble; it stopped when the catalyst was filtered off the reacting mixture. With acetic, propionic and butyric acids, the yield of acylated products was very low, though increasing in this series, similar to that observed for zeolites.[3] This may be due to the preferential adsorption of the lower acids on CsPW, blocking access for toluene to the catalyst surface. The higher acids $C_6–C_{12}$ were more reactive in acylation, yielding 31–51% aromatic ketones (Table 1). All three possible isomers, *ortho, meta* and *para*, were formed, the *para* isomers being the major products (55–73%), as expected. The reaction selectivity is virtually 100%, no other products were found. The yield increases in the series of acids from hexanoic to dodecanoic acid like in the reaction with CeY zeolite[3] and cation-exchanged montmorillonite.[4] CsPW (S_{BET} 112 m² g⁻¹) is a much more efficient catalyst than bulk PW (S_{BET} 7 m² g⁻¹) (*cf.* entries 3 and 5), which may be explained by a greater number of H⁺ surface sites in CsPW.[7] The Cs salt is also more active than silica-supported HPA, 40% PW/SiO₂ (entry 6), which may be the result of the higher hydrophobicity of CsPW,[7] favouring the adsorption of nonpolar reactants on the catalyst surface and making CsPW more resistant towards deactivation by co-produced water compared to the more hydrophilic PW. After the reaction, CsPW can be easily separated by filtration and reused (entry 4). Some catalyst deactivation was observed, though, which was probably caused by coking. Similar behaviour has been observed for the acylation of anisole and toluene over HPA[9d] and zeolite.[2]

The most important advantage of the CsPW catalyst is that it gives much higher productivity in aromatic ketones than the zeolite and clay catalysts reported so far, which may be attributed to the stronger acidity of CsPW.[7] Thus, for the acylation of toluene with dodecanoic acid, CsPW gives a 1.0% yield of ketone based on toluene (Table 1, run 3) which is three times that reported for CeY (0.31%) and for Al³⁺-montmorillonite (0.32%). For CeY, a 96% yield based on dodecanoic acid at PhMe/acid = 313 has been obtained (150 °C, 48 h).[3a]

Table 1 Acylation of toluene (100 mmol) with carboxylic acids (2.0 mmol) at 110 °C (reflux), 48 h

	Catalyst/g	Acid	Yield (%)[a]	Product distribution (%)		
				para	*ortho*	*meta*
1	CsPW (1.0)	Hexanoic	31	55	37	8
2	CsPW (1.0)	Octanoic	47	72	22	6
3	CsPW (1.0)	Dodecanoic	51	71	22	7
4	CsPW (1.0)[b]	Dodecanoic	44	73	21	6
5	PW (1.0)	Dodecanoic	14	60	23	17
6	40% PW/SiO₂ (2.5)	Dodecanoic	35	83	11	6

[a] The yield of aromatic ketones based on carboxylic acid; the yield based on toluene is 50 times lower. *[b]* A reuse of run 3. The catalyst was filtered off, washed with CH₂Cl₂, dried at 150 °C/0.1–0.5 Torr/1.5 h and rerun.

For Al^{3+}-montmorillonite, a 60% yield at PhMe/acid = 187 (110 °C, 24 h) has been reported.[4] It should be noted, however, that CeY gives a higher selectivity towards *para*-acylation (94%)[3a] than CsPW, which may be the result of shape selectivity of the zeolite.

The acylation of more reactive anisole with C_2–C_{12} acids was carried out under the same conditions as that of toluene, except a shorter reaction time (5 h). The acylated anisole formed as the major product (*para*/*ortho* = 59:1–96:1 and no *meta* isomers) together with esterification products—methyl esters of carboxylic acids and phenol (Table 2). No phenyl esters were found. The selectivity to esters increases from acetic to dodecanoic acid, reaching 40% for the latter. The acylation of anisole, in contrast to that of toluene, is most efficient with C_2–C_6 acids, giving a 62–65% yield of acylated products and only 2–6% of methyl esters. When the acylation of anisole by acetic, propanoic or butyric acid was carried out in air instead of nitrogen, 4-methoxy-4′-acyl derivatives of diphenyl ether, in a molar ratio to acylated anisole of 1:3–1:5, were found (identified by GC-MS). Only traces of such products formed in the case of C_6–C_{12} acids. Apparently, these products are formed by the C–O oxidative coupling of phenol and anisole, followed by acylation.

The acylation of anisole with HZSM-5 zeolite (Si/Al = 30) as a catalyst has been reported[5] to proceed differently. With C_2–C_3 acids, at 120 °C, PhOMe/acid = 4 and 20% HZSM-5, the phenyl esters are the main products; no methyl esters have been found. At 150 °C and otherwise the same conditions, a 2:1–5:1 mixture of acylated anisole and phenyl ester forms at an 87–100% acid conversion. The conversion drops sharply for acids higher than C_3, down to 0.6% for C_{12}, probably because of restricted access into zeolite pores. Thus CsPW is a more active as well as a more selective catalyst than HZSM-5 for anisole acylation.

Table 2 Acylation of anisole (100 mmol) with carboxylic acids (2.0 mmol) catalysed by CsPW (1.0 g) at 110 °C, 5 h

Acid	Conversion (%)	Product distribution (%)[a]		
		para	*ortho*	methyl ester
Acetic	65	96	1	3
Propionic	53	93	3	4
Butyric	66	89	2	9
Hexanoic	71	89	2	9
Octanoic	45	73	1	26
Dodecanoic	42	59	1	40

[a] Based on carboxylic acid converted; *para* and *ortho* are the corresponding acylated anisoles. Phenol in a molar ratio of 1:4–1:5 to acylated anisole is also formed.

In conclusion, the heteropoly salt CsPW is a very efficient catalyst for the environmentally friendly aromatic acylation with aliphatic acids in heterogeneous liquid-phase systems.

Notes and references

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