

Preparation of a Resin-Bound Cobalt Phosphine Complex and Assessment of Its Use in Catalytic Oxidation and Acid Anhydride Synthesis

Nicholas E. Leadbeater^{*,†} and Kathryn A. Scott[‡]

Department of Chemistry, King's College London, Strand, London, WC2R 2LS United Kingdom, and Department of Chemistry, University of Cambridge, Lensfield Road, Cambridge, CB2 1EW United Kingdom

nicholas.leadbeater@kcl.ac.uk

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Introduction

Supporting homogeneous transition metal catalysts on organic polymers has rapidly become an area of intense research activity because of their use in metal-mediated synthetic organic chemistry.^{1–4} One of the key advantages of using polymer-supported catalysts is the ease of separation from the product mixture at the end of a reaction. As well as allowing for more rapid purification of the product mixture, this means that the supported complex can be reused in subsequent reactions. In this note we report the preparation and synthetic versatility of the polymer-supported cobalt phosphine complex **1**. We have used this complex as a catalyst for the oxidation of alcohols and for the synthesis of acid anhydrides from acid chlorides and carboxylic acids. Our attention has also been focused on leaching, if any, of the metal complex from the polymer support and on the effect of catalyst recycling.

Results and Discussion

Preparation of Polymer-Supported Catalyst, **1**.

The polymer support chosen for immobilization of the cobalt phosphine complex was commercially available "polymer-supported triphenylphosphine" (polystyrene cross-linked with 2% divinylbenzene; 3 mmol P/g resin). The immobilized complex **1** was prepared by agitating a dichloromethane solution of $\text{CoCl}_2(\text{PPh}_3)_2$ (**2**) with the functionalized resin overnight using a mechanical shaker (Figure 1). Filtration, washing, and drying of the polymer gave a blue powder which was characterized as **1** by elemental analysis and by comparison of IR spectroscopic data with that of **2** which is also blue in color. The catalyst loading was estimated as ~2.4 mmol/g of resin. The polymer-bound complex formed is stable in air, no decomposition being noted over the period of four months at room temperature.

Use of **1 as a Catalyst for the Oxidation of Alcohols.** In the presence of a catalytic amount of **1**, the efficient oxidation of benzylic alcohols using *tert*-butyl hydroperoxide as oxidant can be effected as shown in

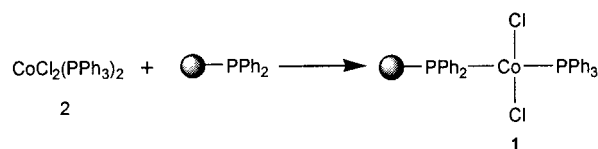


Figure 1. Preparation of resin-bound catalyst **1**.

Alcohol	Product	Yield using 1	Yield using 2
		86	40
		91	93
		92	95
		75	80
		70	41
		68	60

Figure 2. Use of **1** in alcohol oxidation.

Figure 2. For comparative purposes, reported yields for the analogous reactions using **2** are also shown where available.⁵ Product purity was monitored using IR, ¹H NMR, and ¹³C NMR spectroscopy, comparing data with that reported in the literature for the carbonyl compounds.

From these results, it is clear that the attachment of the metal complex to the polymeric support has little effect on the yields of reaction compared to the homogeneous analogue. Using both **1** and **2** the oxidation is selective for benzylic and allylic alcohols, simple aliphatic alcohols being unaffected. When using **2** as a catalyst for the oxidation, 7.5 mol % of the cobalt complex is reported to be required to obtain optimum yields.⁵ In our experiments we find that yields level off to a maximum at 1–2 mol % of cobalt complex supported on the resin, and the use of more catalyst has no advantage. As a consequence, only a small amount of **1** is required for each reaction. One further difference between the homogeneous and supported cobalt catalysts is the amount of acid formed in the case of primary alcohol oxidation. Using **2**, equal yields of benzaldehyde and benzoic acid are reported on oxidation of benzyl alcohol after 1.5 h.⁵ Using the supported catalyst, formation of the acid is greatly reduced although not fully inhibited (86% aldehyde and 9% acid after 1.5 h). Pure aldehyde can be obtained if the reaction

[†] King's College London.

[‡] University of Cambridge.

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Table 1. Reusability of 1^a

experiment	yield using 1 (%)
1	89
2	91
3	90
4	88
5	89

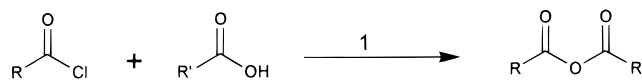
^a Oxidation of 1-phenylethanol to acetophenone.

is performed for a shorter time but this is at the expense of yield, 80% of aldehyde being formed after 1 h, the remaining 20% being unreacted alcohol. Similar results are obtained in the case of primary allylic alcohols, the yield of aldehyde being much greater using the polymer-supported complex compared to that achieved using 2.

To show that 1 can be recycled a number of times, the oxidation of 1-phenylethanol to acetaldehyde was repeated five times using the same batch of supported catalyst. As seen in Table 1, the yields remain around 90% clearly illustrating the reusability of the catalyst. The entire crude reaction mixture in each case was dissolved in CDCl₃ (200 mg in 1 mL) and analyzed by ³¹P{¹H} NMR. There were no peaks observed in any of the spectra in the range from δ +300 → -300 ppm. Also, the UV-vis spectrum of the product mixture showed no absorptions due to Co(II) complexes. This was taken as a preliminary indication that there was no significant leaching of the catalyst from the polymer support to at least this level of detection. Elemental analysis of the product mixture for chlorine showed only traces to be present but varied from one reaction to another, and hence the results were slightly inconclusive. Work is under way to look more closely at the leaching process in polymer-supported catalyst systems, as this is of key importance when considering the viability of such systems in large-scale synthesis of fine chemicals where contamination of the product with heavy metals is highly undesirable.

The polymer-supported catalyst 1 complements other polymer-supported oxidation catalysts such as ion-exchange resin-bound perruthenate, ([RuO₄)⁻] 3.^{6,7} Indeed in some regards 1 has distinct advantages over 3, the loading in 1 of 2.4 mmol/g of resin representing a significantly higher loading than that reported for 3 (0.1 mmol/g⁷). Consequently much less of the polymer-supported catalyst is required in the case of 1.⁸ Comparing the activity of 1 and 3, the two systems are complementary in their activity, primary aliphatic alcohols being unaffected when using 1 whereas 3 catalyses the oxidation of all primary alcohols but not secondary alcohols. An advantage of 3 is that molecular oxygen can be used as co-oxidant, and hence no peroxide is required but this is somewhat offset by the low loading and the high catalyst-to-substrate ratio required (10 mol % catalyst reported⁷).

Use of 1 in Acid Anhydride Synthesis. To broaden the study of the use of 1 in synthesis, we assessed its use as a catalyst in the coupling of acid chlorides and carboxylic acids to yield acid anhydrides. The synthesis



R	R'	Yield using 1 (%)	Yield using 2 (%)
Ph	Ph	87	91
Ph	Et	78	-
ⁱ Pr	ⁱ Pr	86	87
Ph	ⁱ Pr	77	-
<i>p</i> -tol	<i>p</i> -tol	70	79

Figure 3. Use of 1 in acid anhydride synthesis.

of asymmetrically substituted anhydrides often involves reagents that are unstable or not easy to handle or else requires lengthy workup. Recently, however, the use of CoCl₂ as a catalyst for anhydride formation has been reported.⁹ This removes the need for difficult reagents but the sequestration of the cobalt salt at the end of a reaction often proves a problem. Using 1, we have found that both symmetrically and asymmetrically substituted anhydrides can be prepared rapidly and in high yield with the catalyst being easily removed at the end of the reaction by filtration (Figure 3). Again the catalyst can be reused a number of times without loss of activity.

In conclusion, we have shown that attachment of CoCl₂-(PPh₃)₂ to polymer-supported triphenylphosphine leads to an air stable, versatile immobilized catalyst that is as active as its homogeneous analogue and has the advantage that it can be reused numerous times. The only reaction workup required is a filtration to remove the polymer-supported catalyst and then isolation of the pure product by recrystallization or passing through a short column of silica gel. Work is currently underway to exploit the activity of other polymer-supported organometallic complexes in metal-mediated organic synthesis.

Experimental Section

General. All chemicals were reagent grade and used as purchased including polymer-supported triphenylphosphine (Fluka, 3 mmol P/g resin). All reactions were performed under an inert atmosphere of dry nitrogen using distilled dried solvents. The ¹H and ¹³C NMR spectra were recorded at 400 MHz and 293 K, the ³¹P{¹H} NMR spectra at 250 MHz and 293 K. IR spectra of polymer-bound complexes were recorded using diffuse reflectance spectroscopy. IR spectra of nonsupported complexes were recorded in KBr pellets.

Preparation of Polymer-Supported Cobalt Phosphine Complex 1. Commercially available polymer-supported triphenylphosphine (Fluka) was first washed several times with THF and then dichloromethane before being dried in vacuo and 100 mg added to a dichloromethane solution of CoCl₂(PPh₃)₂ (114 mg, 0.175 mmol). The resultant mixture was shaken overnight using a mechanical stirrer during which time the originally light brown polystyrene beads turned blue in color. The beads were filtered off using a sintered funnel and washed five times with dichloromethane and then twice with hexane before drying in vacuo. Loading of the cobalt complex on the resin was found to be 2.4 mmol/g resin by elemental analysis (comparison of P, Cl, and Co content).

General Method for Cobalt-Catalyzed Oxidation Reactions. The appropriate alcohol (3 mmol), ^tBuOOH (70% solution in water, 6 mmol), and 1 (25.6 mg, 1 mol % Co complex) in dichloromethane (20 mL) were refluxed for 4 h, the reaction mixture being agitated using a slow nitrogen bubble flow. After

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(8) Ley et al. have recently reported a new oxidation catalyst containing perruthenate immobilized within MCM-41 has been prepared and used in the clean oxidation of alcohols to carbonyl compounds with molecular oxygen. This has a much increased loading of catalyst. See: Bleloch, A.; Johnson, B. F. G.; Ley, S. V.; Price, A. J.; Shephard, D. S.; Thomas, A. W. *Chem. Commun.* **1999**, 1907.

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cooling, the polymer-bound catalyst was removed by filtration and the product mixture quenched with sodium sulfite. The purity of the crude product mixtures was found by spot TLC to be high, and final purification was by recrystallization in the case of solids and by flash chromatography in the case of liquids. IR, ^1H NMR, and ^{13}C NMR spectroscopic data for the products were compared with those in the literature, showing formation of the appropriate carbonyl compound.

Assessment of the Reusability of 1 in Oxidation Reactions. As a representative reaction, the oxidation of 1-phenylethanol to acetophenone was repeated five times using the same batch of **1** in each case. Between experiments the supported catalyst was washed twice with dichloromethane (25 mL) and twice with hexane (25 mL) and dried in vacuo before placing it back in the recharged reaction vessel for the next reaction.

General Method for Acid Anhydride Synthesis Catalyzed by 1. The appropriate acid chloride (3 mmol), carboxylic

acid (3 mmol), and **1** (25.6 mg, 1 mol % Co complex) in dichloromethane (20 mL) was held at 40 °C for 4 h using a water bath and the solution agitated using a slow nitrogen bubble flow. After cooling, the polymer-bound catalyst was removed by filtration and the product purified by recrystallization in the case of solids and by flash chromatography in the case of liquids. IR, ^1H NMR, and ^{13}C NMR spectroscopic data for the products were compared with those in the literature, showing formation of the appropriate anhydride.

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