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Recyclable polyisobutylene-supported pyridyl *N*-oxide allylation catalysts

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ABSTRACT

Polyisobutylene (PIB) is a useful soluble polymer support that facilitates catalyst recovery and recycling in liquid–liquid biphasic systems because the long polyisobutylene chain confers high phase selective solubility in the nonpolar phase of polar–nonpolar liquid–liquid biphasic systems on groups attached to the polymer's terminus. This work shows that PIB-supports that are effective with metal catalysts can also facilitate synthesis and use of organocatalysts. This is demonstrated by the use of a PIB-supported pyridyl *N*-oxide to promote the allylation of several aromatic aldehydes with allyltrichlorosilane. These studies show that a PIB-supported pyridyl *N*-oxide is a very active recyclable catalyst that promotes the allylation of aromatic aldehydes in yields of up to 99% yield. These PIB-supported pyridyl *N*-oxide catalysts were recovered in the hexane phase of a hexane/90% EtOH–H_2O solvent system and were successfully recycled through 5 cycles with little effect on catalyst efficiency.

1. Introduction

Organocatalysts are currently of intense interest as metal-free alternatives to commonly used organometallic catalysts.[1] While organocatalysts avoid the use of transition metals, recycling of these potentially environmentally friendly catalysts remains an important objective in green chemistry as recycling can reduce costs involved in these catalysts' synthesis and use. Recycling of organocatalysts on soluble and insoluble polymer supports has been described by various authors using liquid/solid separations.[2–6] However, few examples use liquid/liquid separation to recover and reuse organocatalysts on nonpolar soluble polymers.[7,8] This Letter describes the use of hydrocarbon-soluble, terminally functionalized, polyisobutylene (PIB) to support an amine *N*-oxide catalyst. The studies described below show that this support facilitates the synthesis, separation, and reuse of this organocatalyst. This catalyst is efficiently recovered and separated from products using a gravity separation of a biphasic liquid/liquid mixture after a homogeneous catalytic allylation of a variety of aromatic aldehydes by allyltrichlorosilane.

Allylation of aldehydes is a useful carbon–carbon bond forming reaction. The product homoallylic alcohols prepared in such reactions can be easily converted into a variety of other products. Allylation reactions with chiral catalysts can introduce chirality into products with high ee. Historically, these reactions have been catalyzed by electrophilic Lewis acidic metal catalysts. Common examples of such catalysts include transition metals that coordinate to the carbonyl group activating the carbonyl toward nucleophilic attack.[9] More recently Denmark described schemes that use a Lewis basic catalyst that acts as an electron-pair donor and strong nucleophile toward silicon forming a reactive hypervalent silicate intermediate.[10] His group described phosphoramides,[7] but others have noted that other bases including formamides, imines, and amine *N*-oxides are also useful Lewis base catalysts for allylation reactions.[12–18] Kobayashi has also described insoluble-supported catalysts for similar reactions.[19] Here we show that a hydrocarbon polymer, polyisobutylene, can effectively be used as a phase anchor for these Lewis basic catalysts, and that this polymer facilitates separation, recovery, and reuse of pyridine *N*-oxide catalysts in allyltrichlorosilane allylations of aromatic aldehydes.

2. Results and discussion

As we noted above, others have previously shown amine *N*-oxides are effective catalysts for allylation reactions.[11–14] Based on that work, we sought to design a PIB-supported amine *N*-oxide and to use it to show that nonpolar soluble supports could be useful for organocatalysis. To do this, low molecular weight analogs of possible PIB-supported pyridyl *N*-oxides were first synthesized and tested to determine which mode of attachment to the polymer would provide the most active basic pyridine *N*-oxide catalyst for catalytic formation of homoallylic alcohols from aryl aldehydes. To this end, pyridyl *N*-oxides **3** and **6** were synthesized (Eqs. 1 and 2). Then allylation reactions were carried out in 5 mL of CH_2Cl_2 at 40 °C for 24 h or 48 h using 10 mol % of **3** or **6** as catalyst (Eq. 3). Catalyst **3** did not show much activity in allylation of either

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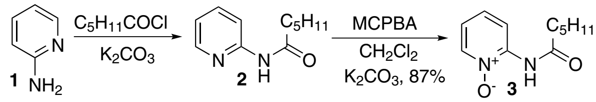
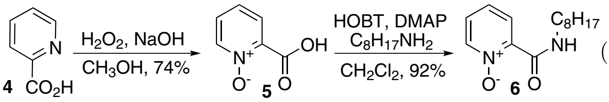
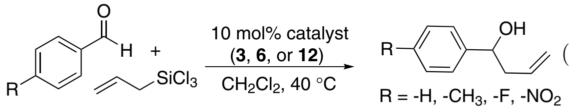
benzaldehyde or tolualdehyde (⩽3% conversion after 48 h). In contrast, catalyst **6** was effective under these same conditions (⩾99% conversion of benzaldehyde, *p*-tolualdehyde, *p*-fluoro-benzaldehyde, or *p*-nitrobenzaldehyde).



(1)



(2)



(3)

The results obtained from the studies of catalysts **3** and **6** suggest that the six-membered cyclic transition state between the allylsilane and the oxygen atoms of the pyridine *N*-oxide catalyst is important in these allylations. Only catalyst **6** can form this six-membered ring between the allylsilane and the catalyst (Fig. 1).[14,15,20] On the basis of these results, a PIB–pyridyl *N*-oxide similar to picolinic acid amide *N*-oxide **6** was synthesized following the procedure shown in Scheme 1.

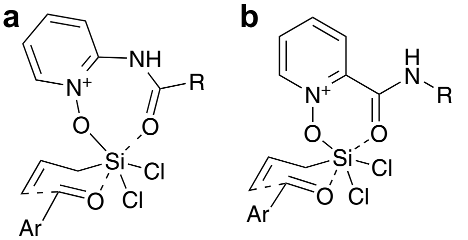
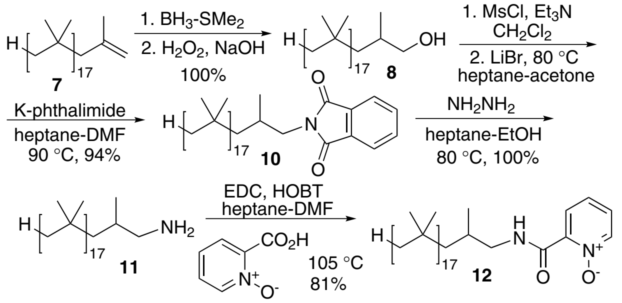


Figure 1. Possible seven- and six-membered transition states (a and b, respectively) for the allylation reaction of benzaldehyde with allyltrichlorosilane using catalysts **3** and **6**.

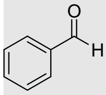
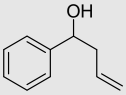
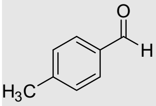
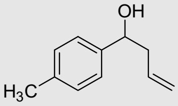
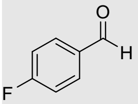
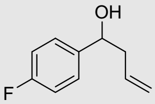
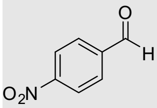
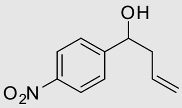


Scheme 1. Synthesis of PIB-supported pyridyl *N*-oxide **12**.

The synthesis of the PIB-supported pyridyl *N*-oxide **12** started with hydroboration–oxidation of a vinyl-terminated PIB **7**[21] to form the alcohol **8**. A primary bromide **9** was then prepared in a two-step, one-pot reaction and **9** was in turn converted into a PIB–phthalimide **10** by reaction with potassium–phthalimide in a 1:1 v/v mixture of heptane/DMF at 90 °C. Hydrazinolysis in a heptane–ethanol mixture at 80 °C converted **10** into the primary amine **11**. Finally, the PIB–amine **11** was coupled with picolinic acid *N*-oxide to form **12** using EDC and HOBT in a mixture of heptane–DMF (1:1 v/v). These syntheses were facilitated by the preferential solubility of the PIB products in an alkane phase and the polar by-products in a polar phase. All the intermediates could be fully characterized by solution-state NMR spectroscopy.

Catalytic allylation reactions of benzaldehyde, *p*-tolualdehyde, *p*-fluorobenzaldehyde, or *p*-nitrobenzaldehyde using **12** were carried out on a 1 mmol scale. These reactions used 10 mol % **12** and the corresponding aldehyde in 5 mL of CH_2Cl_2. Then, 2 equiv of allyltrichlorosilane was added, and the reaction mixture was stirred for 48 h at 40 °C. The reactions were quenched with 7 mL of saturated aqueous $NaHCO_3$. The organic phase was isolated and the CH_2Cl_2 was removed under reduced pressure. Catalyst/product

Table 1
Allylation reactions catalyzed by PIB-supported pyridyl *N*-oxide **12**[a]

Substrate	Product	Cycle 1[b,c] (%)	Cycle 2[b,c] (%)	Cycle 3[b,c] (%)	Cycle 4[b,c] (%)	Cycle 5[b,c] (%)
		74 (100)	84 (100)	99 (100)	95 (100)	47 (77)
		86 (98)	⩾99 (97)	99 (98)	99 (95)	99 (90)
		67 (91)	84 (90)	84 (90)	84 (90)	66 (80)
		89 (100)	92 (100)	99 (100)	99 (100)	95 (100)

[a] In a typical reaction, 10 mol % of the PIB-supported pyridyl *N*-oxide was used. The reactions were carried out in 5 mL of CH_2Cl_2 with 1 mmol of the aldehyde and a 2-fold excess of allyltrichlorosilane at 40 °C. After each cycle, the reaction was quenched with 7 mL of saturated aqueous $NaHCO_3$. After workup, the product and catalyst were partitioned between hexane and 90% aqueous EtOH. The PIB-supported catalyst was recycled from the hexane phase.

[b] Isolated yield of ^1H NMR-characterized product.

[c] Conversion (%) based on starting aldehydes using GC analysis of the ethanolic phase using decanol as an internal standard.

separation was then effected by dissolving the residues in 10 mL of hexane and 10 mL of 90% EtOH–H_2O. The phases were separated by a liquid–liquid extraction. The catalyst-containing hexane phase was concentrated under reduced pressure, and the residue catalyst was reused with fresh substrate and solvent. Catalysts could be used in this way for 5 cycles. Conversions were analyzed by gas chromatography. Isolated yields of products characterized by ^1H NMR spectroscopy were based on the product obtained after removing solvent from the ethanol phase. Solvent removal presumably led to some loss in product so conversions and isolated yields are not usually equal. A control reaction using benzaldehyde under the same reaction conditions but without **12** showed that allylation of benzaldehyde did not occur in the absence of the catalyst.

As shown in Table 1, PIB–pyridyl *N*-oxide **12** is an efficient catalyst for the allylation of aromatic aldehydes. As shown in the Table, essentially complete conversion was possible for multiple cycles with high isolated yields of product.

3. Conclusion

A PIB-supported pyridyl *N*-oxide **12** was synthesized and was successfully utilized as a recoverable organocatalyst in allylation of aromatic aldehydes with allyltrichlorosilane. PIB-supported pyridyl *N*-oxide **12** was effective in promoting the allylation of benzaldehyde, *p*-tolualdehyde, *p*-fluorobenzaldehyde, and *p*-nitrobenzaldehyde with isolated yields of pure products based on ^1H NMR spectroscopy from the ethanol phase that generally ranged from 66% to 99%. Catalyst **12** was active through 5 cycles with no significant loss in activity. The success of this simple PIB-supported amine *N*-oxide as an organocatalyst suggests that these hydrocarbon polymers could be generally useful as supports for recoverable organocatalysts.

Acknowledgments

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21. The PIB was a gift of BASF and is sold under the tradename Glissopal.