

Carbonylation of Aryl Olefins and Alcohols using immobilized Pd Complex Catalysts

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Introduction

Carbonylation of aryl olefins and alcohols is one of the promising and environmentally benign routes [1] to aryl-propionic acids (e.g. *Ibuprofen*, *Naproxen*), important as non-steroidal anti-inflammatory agents. This reaction is considered as the best example of application of catalysis to develop “greener” routes for pharmaceuticals, replacing stoichiometric synthetic routes, as established commercially for *Ibuprofen* manufacture [2]. The key carbonylation step using a Pd-complex catalyst and aqueous HCl promoter requires high pressures (16 – 35 MPa) to achieve the desired high regioselectivity to the branched isomeric product [2]. In our previous work [3], it is shown that using a Pd(Pyca)(PPh₃)(OTs) catalyst with LiCl promoter, a significant enhancement in the catalytic activity (TOF = 800–2600 h⁻¹) as well as regioselectivity (>99%) can be achieved at low pressure conditions (5-6 MPa). However, the industrial applications of soluble Pd complex catalysts have limitations due to difficulties in their separation from non-volatile and thermally unstable products and regeneration. Several efforts to immobilize the Pd complex catalysts for carbonylation reactions have led to novel heterogeneous Pd catalysts retaining the high activity and regioselectivity [4,5]. Some leading examples of immobilized Pd(Pyca)(PPh₃)(OTs) catalysts are: (a) anchoring to mesoporous supports [4] like MCM-41 and MCM-48, (b) tethering to NaY zeolite using phosphotungstic acid as a tethering agent and (c) ossification [5] using water soluble derivative of the Pd(Pyca)(PPh₃)(OTs) catalyst followed by reaction with Ba or Ca salts. Though, the novel concepts of immobilization have been successfully demonstrated, a detailed understanding of the structural configuration of these catalysts, role of supports and variations in preparation methods etc is not yet complete. In this presentation, recent results on anchored Pd(Pyca)(PPh₃)(OTs) complex to MCM-41, MCM-48 and SBA-15 mesoporous supports and detailed characterization will be presented to demonstrate the factors influencing the catalytic activity, selectivity and stability.

Materials and Methods

The Pd(pyca)(PPh₃)(OTs) complex was prepared from Pd(OAc)₂, pyridine-2-carboxylic acid (pyca), *p*-toluenesulphonic acid and triphenylphosphine following the procedure described elsewhere [3]. The immobilized catalysts [M41-NH₂-Pd, M48-NH₂-Pd, S15-NH₂-(G)-Pd and S15-NH₂-(C)-Pd] were prepared by functionalization of the supports using APTS (amino propyl trimethoxy silane) followed by exchange with Pd(pyca)(PPh₃)(OTs) [4]. Carbonylation experiments were carried out using a 50 cm³ capacity high pressure stirred reactor made of Hastalloy C-276 material. The reactants/products were analyzed using HP GC 6890 fitted with a HP-FFAP capillary column.

Results and Discussion

Carbonylation of aryl olefins and alcohols were performed using the anchored Pd(pyca)(PPh₃)(OTs) complex inside the mesoporous channels of MCM-41, MCM-48 and SBA-15. The results on carbonylation of styrene using four different anchored Pd-complex catalysts M41-NH₂-Pd, M48-NH₂-Pd, S15-NH₂-(G)-Pd and S15-NH₂-(C)-Pd required long

durations of ~12 h to complete >98% conversion but the chemo- and regioselectivity > 99 % was observed for all the catalysts. Similar to the homogeneous Pd(pyca)(PPh₃)(OTs) complex catalyst, the carbonylation of styrene was found to proceed via intermediate chloro-derivative. A typical concentration-time profile for carbonylation of styrene using M41-NH₂-Pd is presented in Figure 1. The reaction showed an induction period of ~3 h unlike the homogeneous reaction using Pd(pyca)(PPh₃)(OTs) catalyst. A turnover number of 5568 was observed with a corresponding high turnover frequency of 464 h⁻¹. The regioselectivity of > 99.31% to the desired branched acid (2, phenyl propionic acid, 2-PPA) was obtained.

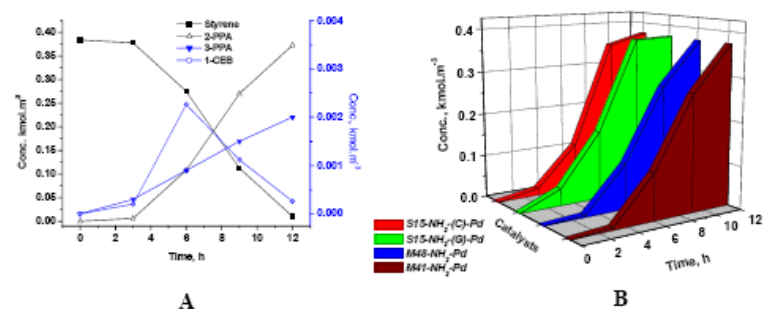


Figure 1: Typical concentration profiles for carbonylation of styrene using [A] M41-NH₂-Pd and [B] M48-NH₂-Pd, S15-NH₂-(G)-Pd and S15-NH₂-(C)-Pd catalysts.

The results on carbonylation of styrene (product profile) using different immobilized catalysts namely M48-NH₂-Pd, S15-NH₂-(G)-Pd and S15-NH₂-(C)-Pd, are presented in Figure 2. Among these, SBA-15 based catalyst [S15-NH₂-(G)-Pd] was found to be the most active anchored Pd-complex catalyst. Moreover, for both the SBA-15 based catalysts, the reactions moved to complete in lesser time than the MCM-based catalysts. Detailed characterization of these catalysts using XRD, SEM/TEM, XPS and CP Mass NMR techniques and stability tests using catalyst recycle will also be discussed.

Significance

The novel immobilized Pd catalysts reported have been shown to be highly active, selective and stable during carbonylation reactions. This is particularly significant from catalyst-product separation point of view for pharmaceutical products. The results also demonstrate the novel approach to prepare molecular heterogeneous catalysts and their surface characterization to understand the relationship between homogeneous and immobilized catalysts.

References

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