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Functionalization of amines by ‘one pot–free solvent’ reductive alkylation with a recyclable catalyst

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Abstract

The ability to attach a preformed rhodium and iridium homogeneous catalyst to a support would have a distinct advantage over the ‘one pot–free solvent’ reductive alkylation of primary amines to form IPPD and DMPPD. © 2000 Elsevier Science Ltd. All rights reserved.

Environmentally benign processes which avoid the handling and generation of toxic materials are prompting the chemical industry to develop new chemical reactions. Heterogenized homogeneous catalysts obtained from organometallic complexes immobilized in solids such as polymers or metal oxides,^{1,2} have become important in various areas of organic synthesis because they are environmentally compatible, and they give good yields and selectivities. Recently, layered compounds such as clay minerals and in particular smectites (e.g. montmorillonite whose surface area, cation exchange capacity and swelling make it suitable to support catalysts) have attracted considerable attention.^{3–13}

Much effort has been devoted towards the development of strategies for synthesizing *N*-phenyl-*N'*-isopropyl-*p*-phenyldiamine (IPPD) and *N,N'*-di(1,4-dimethylpentyl)-*p*-phenyldiamine (DMPPD), which are used as antioxidant additives in rubber vulcanizers,^{14–22} additives in biomimetic sensors,²³ anticorrosive protectors of metals²⁴ and antiozonant agents.^{25,26} At present, a suitable ‘one pot–free solvent’ synthetic procedure for producing the diamines IPPD and DMPPD with heterogeneous catalysts based on Pt/C is being applied on an industrial scale.²⁷ However, from a synthetic standpoint one of the greatest challenges of this approach is to make the activity and selectivity of the heterogeneous Pt/C catalyst reproducible.

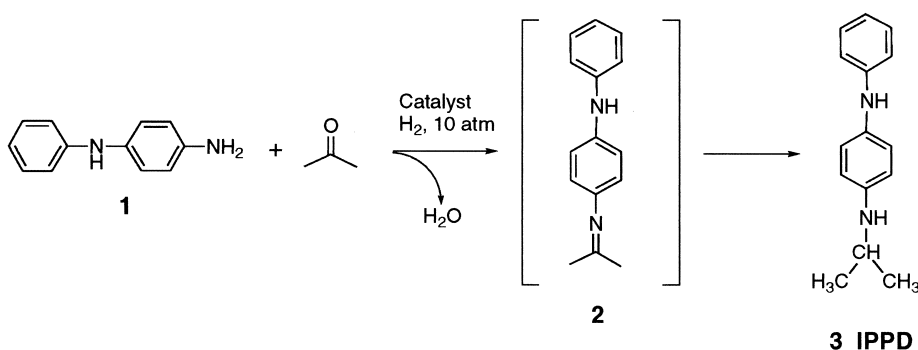
Our interest in this area is to develop an alternative approach to that synthetic pathway in which a primary amine is converted into a secondary amine by imine intermediate formation, but being catalyzed by preformed rhodium or iridium complexes immobilized on montmorillonite.

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This process is particularly attractive because the transformation takes place in a single step and under milder and solvent free conditions.

The economic and technological factors involved in any large-scale chemical manufacture are also taken into account in the proposed process because the immobilization of the transition metal catalyst can allow an easy recovery and reusability for further reactions.

The proposed 'one-pot' reaction takes place as follows: the condensation reaction of ketones with primary amines implies an addition in the first step in which the basic nitrogen of amine adds to the carbonyl carbon of ketone. The ensuing intermediate loses a water molecule to generate the imine in the second step. Finally, in the third step, the imine intermediate undergoes catalytic hydrogenation to yield the secondary amine.



Scheme 1.

Table 1
One-pot reductive alkylation of 4-aminodiphenylamine **1**^a

Catalyst	RUN	Conv. (%)	(%) Imine 2	(%) Diamine 3
Pt/C	1	74	14	86
[Ir(COD)(PPh ₃) ₂] ₂ PF ₆	1	32	49	51
[Rh(COD)(PPh ₃) ₂] ₂ BF ₄	1	89	10	90
[Rh(COD)(PPh ₃) ₂] ₂ BF ₄ / MM-K10	1	92	17	83
	2	70	29	71
	3	66	28	72

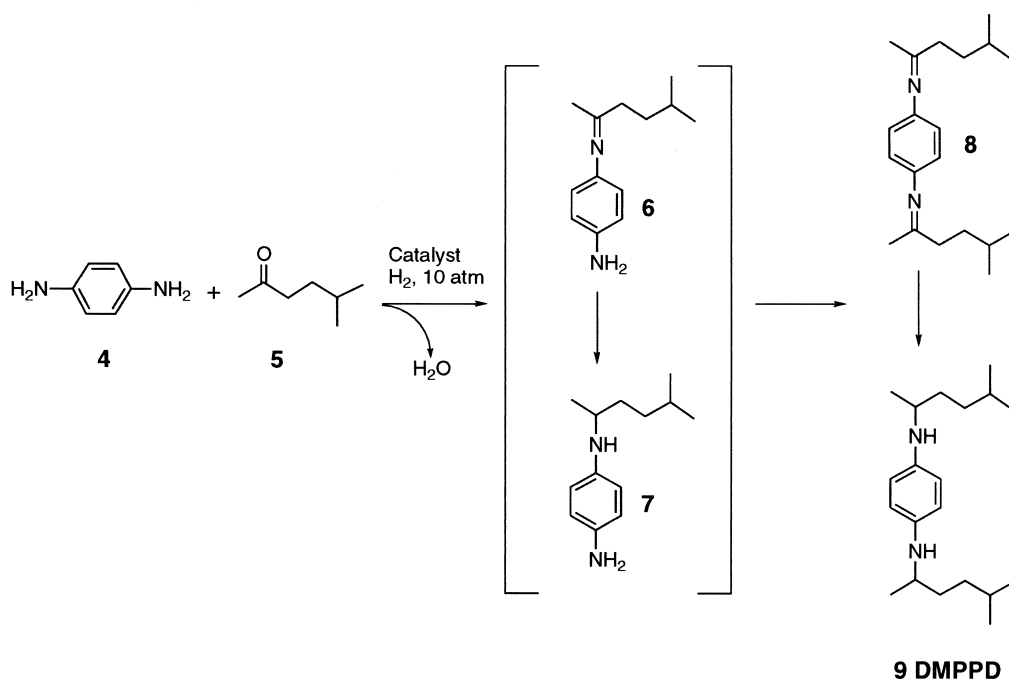
^aStandard conditions: 4-aminodiphenylamine, 19.9 mmol; catalyst precursor, 0.015 mmol; substrate / catalyst = 1325 / 1; solvent: acetone 10 mL (0.136 mol); P(H₂): 10 atm; temperature: 120°C; reaction time: 5h; conversion and selectivities determined by G.C. and ¹H NMR.

Each step in the process is well-documented in the literature: the synthesis of imines from primary amines and aldehydes in the presence of montmorillonite K10, (referred to below as MM-K10), gives high yields of the C=N product and water elimination.^{28,29} A more recent approach reduces the considerable excess of support and shortens reaction time using microwave irradiation.³⁰ Heterogenized homogeneous catalytic hydrogenation of aldimines by removable and reusable iridium complexes immobilized on montmorillonite clay has been reported by our group³¹ as a highly efficient system to obtain secondary amines, conducting solution-like reactions in the solid state and minimizing many of the barriers associated with the unremovable homogeneous solution catalysts.

To test this chemistry, we examined the reaction between 4-aminediphenylamine **1** and acetone, which have the double role of reagent and solvent of the reaction, therefore reducing the employment of ecologically suspected solvents (Scheme 1). The preliminary experiments were carried out in the presence of preformed cationic homogeneous catalysts so that we could determine whether the rhodium and/or iridium systems were suitable for our objectives.

Overall reaction was obtained for the diamine IPPD **3** formation when the [Rh(COD)(PPh₃)₂]BF₄ homogeneous catalytic system was used, and the conversions and selectivities were even better than its iridium analogue complex [Ir(COD)(PPh₃)₂]BF₄ and the heterogeneous catalytic system Pt/C, which was also checked under the same reaction conditions in our laboratories (Table 1). It is noteworthy that no ketone reduction or imine hydrolysis were observed during the reaction time.

The cationic rhodium complex was thus immobilized on the clay under N₂ at room temperature by stirring [Rh(COD)(PPh₃)₂]BF₄ and commercial MM-K10 in dichloromethane for 24 h. Powder X-ray diffraction of the resulting solid and conductimetric analysis of the solution suggested that



Scheme 2.

Table 2
One-pot reductive alkylation of *p*-phenyldiamine **4**^a

Catalyst	RUN	(%) Conv.	(%) Mono Imine 6	(%) Mono Alkyl Amine 7	(%) Di Imine 8	(%) Di Alkyl Amine 9
[Ir(COD)(PPh ₃) ₂]PF ₆	1	97	4	17	4	75
[Ir(COD)(PPh ₃) ₂]PF ₆ / MM-K10	1	100	0.5	2.5	1	96
	2	97	14	14	12	60
	3	88	19	10	23	48
[Rh(COD)(PPh ₃) ₂]BF ₄	1	99	1.5	9	1.5	88
[Rh(COD)(PPh ₃) ₂]PF ₆ / MM-K10	1	100	---	---	1	99
	2	99	3	6	4	87
	3	99	3	8	5	84
	4	96	3	20	2	75
	5	97	6	14	4	76

^aStandard conditions: *p*-phenyldiamine, 7 mmol; catalyst precursor, 0.035 mmol; substrate / catalyst = 200 / 1; solvent: methyl-isoamyl-ketone 10 mL (0.078 mol); P(H₂): 10 atm; temperature: 80°C; reaction time: 24h; conversion and selectivities determined by G.C. and ¹H NMR.

the rhodium complex was mainly adsorbed on the external surface³¹ rather than intercalated in the internal surface.^{9,32}

To compare the activity and stability of the supported catalyst [Rh(COD)(PPh₃)₂]BF₄/MM-K10 with its homogeneous counterpart, the 'one pot' reductive alkylation of 4-aminodiphenylamine **1** was carried out under the same standard conditions. The activity of the heterogenized catalyst was found to be slightly higher than that of the homogeneous system, which could be attributed to the fact that immobilization of the active catalyst on a rigid support prevents catalytically inactive species from forming as a result of oligomerization reactions.³³ The recovered support catalyst [Rh(COD)(PPh₃)₂]BF₄/MM-K10 can be reused in consecutive reductive alkylations showing a loss in activity and consequently in selectivity in **3** between runs 1 and 2, although the total conversion and diamine percentage were constant in the following runs. Leaching of rhodium complex is not responsible for the observed catalytic behaviour, as the filtrate from the active catalyst suspension is completely inactive.

To confirm the generality of this process, we faced the problem of the reductive alkylation of *p*-phenyldiamine **4** with methyl-isoamyl-ketone, in the presence of iridium and rhodium catalytic systems. Unlike the synthesis of IPPD, the production of *N,N'*-di(1,4-dimethylpentyl)-*p*-phenylenediamine (DMPPD) **9** may be accompanied by the formation of a considerable number of intermediates (Scheme 2).

Table 2 shows the results of the reductive alkylation of **4** with the homogeneous and heterogenized rhodium and iridium catalysts. Interestingly, both the rhodium and iridium homogeneous catalysts behave similarly although the selectivity on DMPPD **9** is higher in the case of $[\text{Rh}(\text{COD})(\text{PPh}_3)_2]\text{BF}_4$ (up to 88%). Significant differences in the activities and selectivities were observed when the reductive alkylation took place with the ‘one pot’ heterogenized catalytic systems $[\text{Rh}(\text{COD})(\text{PPh}_3)_2]\text{BF}_4/\text{MM-K10}$ and $[\text{Ir}(\text{COD})(\text{PPh}_3)_2]\text{BF}_4/\text{MM-K10}$, (the latter was immobilized using the same procedure as for the rhodium analogue). Total conversion and quantitative selectivities on **9** were achieved for these systems (96–98% on **9**). On reuse the catalytic activity of the rhodium-immobilized catalytic system maintained higher conversions and selectivities than the iridium system which can be explained by the basis of the more active metallic species being involved in the process for rhodium than iridium systems.

In summary, we reported herein the development of solid-supported transition metal complexes realizing high catalytic activity in a free solvent media which would provide a safe resource-saving and environmentally benign process.

Acknowledgements

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