Available online at www.sciencedirect.com

SCIENCE DIRECT®

Tetrahedron Letters 45 (2004) 2003–2007

Tetrahedron Letters

# Chemo- and regioselective reduction of nitroarenes, carbonyls and azo dyes over nickel-incorporated hexagonal mesoporous aluminophosphate molecular sieves

Parasuraman Selvam,[a,*] Susanta K. Mohapatra,[a] Sachin U. Sonavane[b] and Radha V. Jayaram[b]

[a] *Department of Chemistry, Indian Institute of Technology—Bombay, Powai, Mumbai 400076, India*
[b] *Applied Chemistry Division, University of Mumbai, Institute of Chemical Technology, Matunga, Mumbai 400019, India*

Received 21 September 2003; revised 6 December 2003; accepted 15 December 2003

**Abstract**—Nickel-incorporated hexagonal mesoporous aluminophosphate (NiHMA) molecular sieves were found to be highly efficient heterogeneous catalysts for the chemo- and regioselective reduction of nitroarenes and carbonyl compounds as well as the reductive cleavage of azo functions, including bulkier substrates, by the hydrogen transfer method.

© 2004 Elsevier Ltd. All rights reserved.

The reduction of nitroarenes and carbonyl compounds to the corresponding amines and alcohols, respectively, is an important step in the industrial synthesis of dyes and of biologically active compounds.[1] In comparison to the commonly used reduction processes, which involve hazardous molecular hydrogen,[2] catalytic transfer hydrogenation (CTH) employing hydrogen donors, for example, propan-2-ol (Meerwein–Pondorff–Verley (MVP) reduction), is safer, highly selective and eco-friendly.[3] A wide variety of homogeneous metal complexes have been reported for the CTH process and most of them involve metal-catalyzed hydrogenations, complex hydrides or metal ions in solution.[4] However, these catalysts are not reusable due to various problems such as deactivation by metal precipitation or ligand degradation, separation difficulties, etc. On the other hand, the use of heterogeneous catalysts offers several advantages over homogeneous systems with respect to easy recovery and recycling of the catalysts as well as minimization of undesired toxic wastes. In this regard, Raney-Ni has been extensively used for heterogeneous CTH reactions.[5,6] Although, CTH reactions are very facile using this catalyst, they are not selective towards functional groups such as –X (X = a halogen) and $-NO_2$, and almost all labile functional groups undergo reduction under these reaction conditions. Furthermore, the Raney-Ni catalyst is flammable and presents hazards during handling. Hence, attention has been focused on the design of nickel-based oxide and nickel oxide supported catalysts.[7] However, these catalyst systems also have several drawbacks such as long reaction times, competing nucleophilic attack, the formation of by-products, low yields and the lack of true heterogeneity, etc. In this communication, we report a very efficient, highly selective and rapid method for the reduction of nitroarenes and carbonyl compounds and the reductive cleavage of azo compounds using a nickel-containing hexagonal mesoporous aluminophosphate (NiHMA) molecular sieve catalyst.

Hexagonal mesoporous aluminophosphates (HMA)[8] are novel molecular sieves, analogous to mesoporous silicates,[9] having a high surface area, and large pore size and volume. Various transition metal ion incorporated HMA catalysts have been reported.[10] They can be used to carry out organic transformations more efficiently than the corresponding microporous analogues or supported metal oxide systems. Since the CTH process requires Lewis acidic sites, mesoporous NiHMA, which possesses such characteristics,[11] may be suited for this purpose. Hence, in this investigation, we used NiHMA for CTH reactions. The catalyst was prepared by a very simple and highly reproducible procedure[12] and

---

*Keywords*: Catalytic transfer hydrogenation; Nitro compounds; Carbonyl compounds; Mesoporous molecular sieves; Nickel.

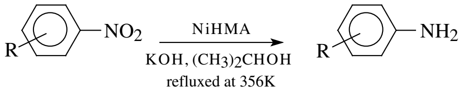
* Corresponding author. Tel.: +91-22-2576-7155; fax: +91-22-2572-3480/2576-7152; e-mail: selvam@iitb.ac.in

0040-4039/$ - see front matter © 2004 Elsevier Ltd. All rights reserved.
doi:10.1016/j.tetlet.2003.12.091

characterized using several easily available analytical and spectroscopic techniques.[13] The CTH reactions were carried out as per the standard procedure.[14,15]

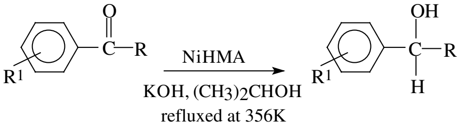
Tables 1 and 2 summarize the results of CTH of several aromatic nitro and carbonyl functions attached to an aromatic ring using the NiHMA catalyst, wherein the compounds were reduced with excellent yields to the corresponding alcohols and amines, respectively. It can be seen from Tables 1 and 2 that the activity is significantly influenced by the nature/position of the substituents on the aromatic ring. The presence of a methyl group, *ortho* to the nitro group, decreased the yield to a larger extent than at the *para*-position due to steric effects. On the other hand, electron withdrawing/donating groups such as chloride, amine and methoxy, did not have a significant influence on the reaction (see also Scheme 1).

**Table 1.** Reduction of nitroarenes over NiHMA

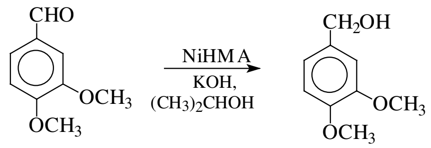


| Entry | R | Time (h) | Yield (%) | |
|---|---|---|---|---|
| | | | First run | Sixth run |
| 1 | H | 1.5 | 97 | 95 |
| 2 | 2-Cl | 2.0 | 86 | 84 |
| 3 | 3-Cl | 2.5 | 90 | 89 |
| 4 | 4-Cl | 2.0 | 93 | 93 |
| 5 | 4-F | 2.0 | 91 | 92 |
| 6 | 4-Br | 2.5 | 93 | 91 |
| 7 | 2-$CH_3$ | 1.5 | 82 | 79 |
| 8 | 3-$CH_3$ | 2.0 | 90 | 90 |
| 9 | 4-$CH_3$ | 1.5 | 89 | 88 |
| 10 | 4-$OCH_3$ | 2.0 | 93 | 91 |
| 11 | 2-$NH_2$ | 2.0 | 89 | 90 |
| 12 | 3-$NH_2$ | 1.5 | 92 | 90 |

**Table 2.** Reduction of aromatic carbonyls over NiHMA



| Entry | R | $R^1$ | Time (h) | Yield (%) | |
|---|---|---|---|---|---|
| | | | | First run | Sixth run |
| 1 | H | H | 2.0 | 90 | 92 |
| 2 | H | 2-Cl | 1.5 | 81 | 79 |
| 3 | H | 4-Cl | 1.5 | 89 | 89 |
| 4 | H | 4-$OCH_3$ | 2.0 | 90 | 91 |
| 5 | H | 4-$N(CH_3)_2$ | 4.0 | 67 | 65 |
| 6 | H | 4-CN | 3.5 | 82 | 82 |
| 7 | $CH_3$ | H | 3.5 | 85 | 84 |
| 8 | $CH_3$ | 3-$NH_2$ | 3.0 | 72 | 70 |
| 9 | $CH_3$ | 4-Cl | 3.0 | 84 | 82 |



**Scheme 1.**

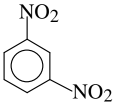
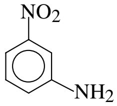
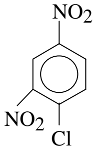
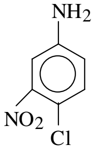
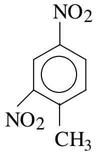
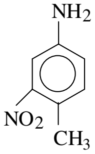
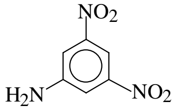
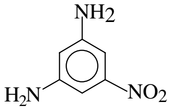
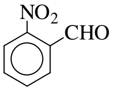
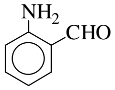
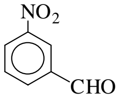
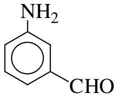
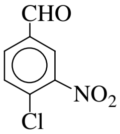
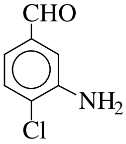
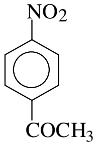
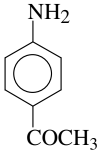
The catalyst was highly chemoselective for the reduction of nitro and carbonyl compounds, and other functional groups, viz., –F, –Cl, –Br, –OH, –CN, –$NH_2$ and –$OCH_3$, etc. were not affected.

The catalyst also showed promise for regioselective (Table 3, entries 2 and 3) and chemoselective (Table 3; entries 5–8) reductions. Since nitro groups attached to aromatic rings can withdraw electrons more strongly in comparison to carbonyl groups, they can be adsorbed more easily onto the catalyst surface. This may explain the chemoselective reduction of a nitro group ahead of a carbonyl group. All these compounds were reduced in excellent yields affording a single product, which reduced the difficulties of separation of the products from unreacted substrates. The yields and the reaction times (1.5–4 h) for these transformations over NiHMA were encouraging from the organic synthesis point of view in terms of the practical utility of the catalyst compared to other reported catalysts (reaction time 30–50 h).[16] NiHMA also required less time for these conversions to achieve optimum yields, compared to mesoporous CoHMA molecular sieves. This may be due to the fact that the Lewis acid characteristics of nickel are higher than those of cobalt.

Furthermore, this reduction was also successfully carried out using heterocyclic compounds (Table 4, entries 1–3) as well as bulkier compounds (Table 4, entries 4–6) with high yields being obtained. Table 5 presents the results of the rapid (1–2 h) reductive cleavage of azo functions over the NiHMA catalyst in good yields (~90%). It is interesting to note that the cleavage of azo compounds over NiHMA is rapid (1–2 h) compared to other catalysts used for this purpose.[17] Unlike palladium-based catalysts, many functional groups such as –Cl, –Br and –$OCH_3$ were tolerated over NiHMA.[18] The Pd-based catalysts also gave poor yields due to the formation of intermediate hydrazo compounds, which were not observed when using NiHMA. Furthermore, the catalyst showed true heterogeneity for all the above substrates over six cycles. In contrast, the use of the $NiO/ZrO_2$ supported system[18] exhibited very good activity for the reduction of nitrobenzene, however, it showed a loss in activity upon recycling and the yield decreased drastically. Isopropanol was found to be the best hydrogen donor compared to the others.[19]

The reaction mechanism for the reactions under study may relate to the MPV reduction of ketones that were reported using aluminium isopropoxide.[20] Accordingly, adsorption of propan-2-ol onto the catalyst is followed by the formation of an alkoxide, which is also known to

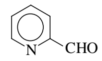
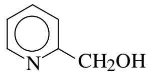
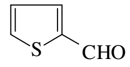
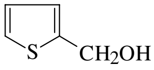
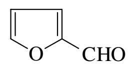
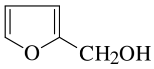
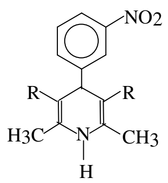
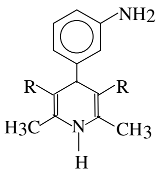
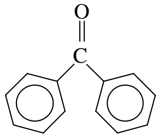
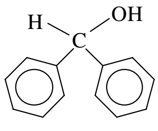
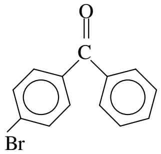
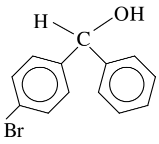
**Table 3.** Regio- and chemoselective reduction of aromatic compounds over NiHMA

| Entry | Substrate | Time (h) | Product | Yield (%) | |
|---|---|---|---|---|---|
| | | | | First run | Sixth run |
| 1 |  | 2.5 |  | 85 | 84 |
| 2 |  | 3.0 |  | 88 | 87 |
| 3 |  | 3.0 |  | 87 | 87 |
| 4 |  | 4.0 |  | 89 | 89 |
| 5 |  | 3.5 |  | 84 | 82 |
| 6 |  | 3.0 |  | 88 | 88 |
| 7 |  | 2.5 |  | 89 | 87 |
| 8 |  | 2.0 |  | 92 | 91 |

be the activated H-donor in MPV reductions.[21] Furthermore, the coordinative interaction of the substrates with the Lewis acidic centre allows the formation of a six-membered transition state in which hydride transfer takes place.[22–24] Thus the role of NiHMA is to hold both the H-donor and the H-acceptor through the Lewis acid sites in close proximity so that direct hydrogen transfer can take place smoothly.[25] The surface alkoxide species thus formed may lead to hydride ion transfer to the substrate promoted by the presence of KOH.[20,26] The formation of aniline from nitrobenzene goes through three steps via the formation of nitrosobenzene and *N*-phenylhydroxylamine as the intermediates.[27] In a similar way, the reductive cleavage of azobenzene also proceeds by hydride transfer from the H-donor to the –N=N– of the adsorbed azobenzene at the Lewis acid site, followed by a proton transfer, which in turn proceeds through the intermediate hydrazobenzene to form aniline.

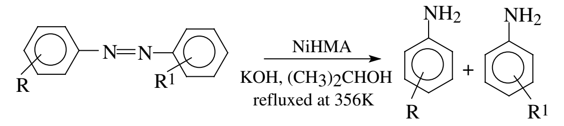
In conclusion, we have shown that NiHMA is a versatile heterogeneous catalyst for the reduction of nitroarenes and carbonyl compounds as well as for the reductive cleavage of azo functions. The CTH process can be accomplished using this novel catalyst without affecting the reduction of any other reducible functional group.

**Table 4.** Reduction of heterocyclic and bulky aromatic compounds over NiHMA

| Entry | Substrate | Time (h) | Product | Yield (%) | |
|---|---|---|---|---|---|
| | | | | First run | Sixth run |
| 1 |  | 3.0 |  | 76 | 78 |
| 2 |  | 3.5 |  | 82 | 80 |
| 3 |  | 3.5 |  | 80 | 79 |
| 4[a] |  | 4.0 |  | 73 | 72 |
| 5 |  | 2.5 |  | 87 | 87 |
| 6 |  | 2.5 |  | 85 | 83 |

[a] R = $COOCH_3$.

**Table 5.** Reductive cleavage of azo compounds over NiHMA



| Entry | R | $R^1$ | Time (h) | Yield (%) | |
|---|---|---|---|---|---|
| | | | | First run | Sixth run |
| 1 | H | H | 1.0 | 94 | 94 |
| 2 | 4-Cl | $4^1$-Cl | 1.5 | 90 | 91 |
| 3 | 3-Br | $3^1$-Br | 1.5 | 88 | 90 |
| 4 | 3-$CH_3$ | $3^1$-$CH_3$ | 2.0 | 89 | 88 |
| 5 | 4-$CH_3$ | $4^1$-$CH_3$ | 1.5 | 93 | 89 |
| 6 | 4-$OCH_3$ | $4^1$-$OCH_3$ | 1.5 | 91 | 90 |
| 7 | H | 4-$NH_2$ | 2.0 | 45[a]<br>37[b] | 43<br>36 |
| 8 | H | 3-$CH_3$ | 2.0 | 54[c]<br>37[d] | 53<br>35 |

[a,c] Aniline; [b,d] Substituted aniline.

## Acknowledgements

The authors thank Sophisticated Analytical Instrumentation Facility, IIT-Bombay for ICP-AES data.

## References and notes

1. Kabalka, G. W.; Verma, R. S. In *Comprehensive Organic Synthesis*; Trost, B. M., Fleming, I., Eds.; Pergamon: Oxford, 1991; Vol. 8, p 363.
2. Merlic, C. A.; Motamed, S.; Quinn, B. *J. Org. Chem.* **1995**, *60*, 3365.
3. Johnstone, R. A. W.; Wilby, A. H.; Entwistle, I. D. *Chem. Rev.* **1985**, *85*, 129.
4. (a) Zassinovich, G.; Mestroni, G.; Gladiali, S. *Chem. Rev.* **1992**, *92*, 1051; (b) For a monograph, see: Hudlicky, M. *Reduction in Organic Chemistry*; 2nd ed.; ACS: Washington, DC, 1996.
5. (a) Andrews, M. J.; Pillai, C. N. *Indian J. Chem. B* **1978**, *16*, 465; (b) Ayyanger, N. R.; Lugade, A. G.; Nikrad, P. V.; Sharma, V. K. *Synthesis* **1981**, 640.
6. Gilchrist, T. L. In *Comprehensive Organic Synthesis*; Trost, B. M., Fleming, I., Eds.; Pergamon: Oxford, 1991; Vol. 8, p 388.
7. (a) Upadhya, T. T.; Ramaswamy, V.; Sabade, D. P.; Katdure, D. P.; Sudalai, A. *Chem. Commun.* **1997**, 1119; (b) Sonavane, S. U.; Jayaram, R. V. *Synth. Commun.* **2003**, *33*, 843.
8. Kimura, T.; Sugahara, Y.; Kuroda, K. *Chem. Mater.* **1999**, *11*, 508.
9. (a) Kresge, C. T.; Leonowicz, M. E.; Roth, W. T.; Vartuli, J. C.; Beck, J. S. *Nature* **1992**, *359*, 710; (b) Selvam, P.; Bhatia, S. K.; Sonwane, C. G. *Ind. Eng. Chem. Res.* **2001**, *40*, 3237.

10. (a) Mohapatra, S. K.; Sahoo, B.; Keune, W.; Selvam, P. *Chem. Commun.* **2002**, 1466; (b) Mohapatra, S. K.; Selvam, P. *Top. Catal.* **2003**, *22*, 17; (c) Mohapatra, S. K.; Hussain, F.; Selvam, P. *Catal. Commun.* **2003**, *4*, 57.
11. Temperature programmed desorption of ammonia ($NH_3$-TPD) confirmed the presence of Lewis acid sites in the catalyst (desorption band around 873 K).
12. The hydrothermal synthesis of NiHMA was carried out with a final (molar) gel composition of $Al_2O_3$:$P_2O_5$:0.08 NiO:cetyltrimethylammonim chloride (CTAC):2.5 tetramethylammonium hydroxide (TMAOH):70$H_2O$ at 373 K for 72 h. Nickel nitrate hexahydrate (>99%, Sarabhai) was used as the metal source. Removal of the template molecules was carried out by calcination of the sample at 823 K for 1 h in a flow of $N_2$, followed by 2 h in air.
13. X-ray diffraction patterns (Rigaku-miniflex, Cu-K$\alpha$) of both synthesized and calcined NiHMA samples showed a typical hexagonal mesoporous structure.[9,10] Further, $N_2$ adsorption measurements (BET surface area, 720 $m^2 g^{-1}$; pore volume, 0.32 $cm^3 g^{-1}$; and pore size, 26 Å) support the mesoporous nature of the sample. ICP-AES analysis shows 3.5 wt% Ni loading in the catalyst.
14. In a typical CTH reaction, KOH pellets (20 mmol) were dissolved in propan-2-ol (20 mL) to which the substrate (20 mmol) was added along with 100 mg of catalyst. It was then refluxed at 356 K for a few hours depending upon the nature of the substrate. The products were analyzed using a gas chromatograph (Eshika) fitted with an OV-101 column. For recycling purposes, the catalyst after filtration was washed several times with acetone followed by thorough washing with water to remove any alkali; it was then activated at 373 K and reused.
15. (a) Mohapatra, S. K.; Sonavane, S. U.; Jayaram, R. V.; Selvam, P. *Tetrahedron Lett.* **2002**, *43*, 8527, **2003**, *44*, 1107; (b) Mohapatra, S. K.; Sonavane, S. U.; Jayaram, R. V.; Selvam, P. *Org. Lett.* **2002**, *4*, 4297, **2003**, *5*, 233.
16. (a) Iyer, S.; Varghese, J. P. *J. Chem. Soc., Chem. Commun.* **1995**, 465; (b) Le Page, M. D.; James, B. R. *Chem. Commun.* **2000**, 1647.
17. (a) Gilchrist, T. L. In *Comprehensive Organic Synthesis*; Trost, B. M., Fleming, I., Eds.; Pergamon: Oxford, 1991; Vol. 8, p. 381; (b) Gowda, S.; Abiraj, K.; Gowda, D. C. *Tetrahedron Lett.* **2002**, *43*, 1329.
18. The reduction of nitrobenzene was carried out over NiO/$ZrO_2$ (7.85% Ni) under identical reaction conditions, which gave a >95% yield in the first run, and 83% yield for the sixth run.
19. The effect of various hydrogen donors such as primary and secondary alcohols on the CTH of nitrobenzene was performed over NiHMA. The former gave lower yields (methanol/11%; ethanol/23%; propan-1-ol/72%; butan-1-ol/55%; pentan-1-ol/46%; octan-1-ol/30%) while the latter (propan-2-ol/97%; butan-2-ol/87%) gave higher yields of aniline. In addition, the dehydrogenation product is a ketone, which can easily be removed from the reaction system. In the case of tertiary alcohols, for example, 2-methylpropan-1-ol, the reaction did not proceed as there is no $\alpha$-hydrogen and hence they cannot act as hydrogen donors. Therefore, in this study, we used propan-2-ol as the hydrogen donor.
20. de Graauw, C. F.; Peters, J. A.; van Bekkum, H.; Huskens, J. *Synthesis* **1994**, 1007.
21. Quignard, F.; Graziani, O.; Choplin, A. *Appl. Catal. A* **1999**, *182*, 29.
22. Ho, T. L.; Olah, G. A. *Synthesis* **1977**, 169.
23. Creyghton, E. J.; Ganeshie, S. D.; Downing, R. S.; van Bekkum, H. *J. Mol. Catal. A.* **1997**, *115*, 457.
24. van der Waal, J. C.; Kunkeler, P. J.; Tan, K.; van Bekkum, H. *J. Catal.* **1998**, *173*, 74.
25. Creyghton, E. J.; Downing, R. S. *J. Mol. Catal. A* **1998**, *134*, 47.
26. Zassinovich, G.; Mestroni, G. *Chem. Rev.* **1992**, *92*, 1051.
27. Aramendia, M. A.; Borau, V.; Gomez, J.; Jimenez, C.; Maranas, J. M. *Appl. Catal.* **1984**, *10*, 347.