Supplementary Information

Selective Synthesis of N-Aryl Hydroxylamines by the Hydrogenation of Nitroaromatics Using Supported Platinum Catalysts

Yasumasa Takenaka,*a Takahiro Kiyosu,b Jun-Chul Choi,a Toshiyasu Sakakuraa and Hiroyuki Yasuda*a

a National Institute of Advanced Industrial Science and Technology (AIST), Tsukuba Central 5, 1-1-1 Higashi, Tsukuba, Ibaraki 305-8565, Japan
b Wako Pure Chemical Industries, Ltd., 1633 Matoba, Kawagoe, Saitama 350-1101, Japan

* Corresponding author. Tel: +81-29-861-4579 & Fax: +81-29-861-4580 (Y. Takenaka)
Tel: +81-29-861-9399 & Fax: +81-29-861-4580 (Y. Yasuda)
E-mail address: takenaka-yasumasa@aist.go.jp (Y. Takenaka), h.yasuda@aist.go.jp (H. Yasuda)
**Reaction Condition of Selective Hydrogenation and Analytical Data of Products**

**Hydrogenation of Nitrobenzene Catalyzed by Pt/SiO₂ under 10 bar of H₂ (Table 1, entry 2).**

Conditions: 10 mL autoclave, 5 wt% Pt/SiO₂ (Escat™ 2351: 20 mg), isopropanol (2 mL), dimethyl sulfoxide (0.42 mmol), nitrobenzene (2 mmol), H₂ (10 bar), room temperature, 5 h, giving N-phenyl hydroxylamine (PHA) (73.2% HPLC yield, 75.4% selectivity).

**Selective Hydrogenation of Nitrobenzene Catalyzed by Pt/SiO₂ under 1 bar of H₂ (Table 1, entry 3).**

Conditions: 25 mL glass vessel, 5 wt% Pt/SiO₂ (Escat™ 2351: 20 mg), isopropanol (2 mL), dimethyl sulfoxide (0.42 mmol), nitrobenzene (2 mmol), H₂ (1 bar), room temperature, 2 h, giving N-phenyl hydroxylamine (PHA) (7.2% HPLC yield, 98.6% selectivity).

**Selective Hydrogenation of Nitrobenzene Catalyzed by Pt/SiO₂ with NEt₃ (Table 1, entry 5).**

Conditions: 25 mL glass vessel, 5 wt% Pt/SiO₂ (Escat™ 2351: 20 mg), isopropanol (2 mL), dimethyl sulfoxide (0.42 mmol), NEt₃ (0.36 mmol), nitrobenzene (2 mmol), H₂ (1 bar), room temperature, 2 h, giving N-phenyl hydroxylamine (PHA) (98.8% HPLC yield, 98.8% selectivity).

**Selective Hydrogenation of Nitrobenzene Catalyzed by Pt/C (Table 1, entry 7).**

Conditions: 25 mL glass vessel, 5 wt% Pt/C (20 mg), isopropanol (2 mL), dimethyl sulfoxide (1.26 mmol), NEt₃ (0.072 mmol), nitrobenzene (2 mmol), H₂ (1 bar), room temperature, 2 h, giving PHA (97.2% HPLC yield, 97.2% selectivity).

**Selective Hydrogenation of Nitrobenzene Catalyzed by Pt/Al₂O₃ (Table 1, entry 8).**

Conditions: 25 mL glass vessel, 5 wt% Pt/Al₂O₃ (20 mg), isopropanol (2 mL), dimethyl sulfoxide (1.26 mmol), NEt₃ (0.072 mmol), nitrobenzene (2 mmol), H₂ (1 bar), room temperature, 1.5 h, giving PHA (96.7% HPLC yield, 96.7% selectivity).

**Selective Hydrogenation of Nitrobenzene Catalyzed by Pt/SiO₂ (P) (Table 1, entry 9).**

Conditions: 25 mL glass vessel, 5 wt% Pt/SiO₂ (P) (20 mg), isopropanol (2 mL), dimethyl sulfoxide (0.84 mmol), NEt₃ (0.072 mmol), nitrobenzene (2 mmol), H₂ (1 bar), room temperature, 1.5 h, giving PHA (95.0% HPLC yield, 96.6% selectivity).

**Selective Hydrogenation of Nitrobenzene Catalyzed by Pd/SiO₂ (Table 1, entry 10).**

Conditions: 25 mL glass vessel, 5 wt% Pd/SiO₂ (Escat™ 1351: 20 mg), isopropanol (2 mL), dimethyl sulfoxide (0.42 mmol), NEt₃ (0.36 mmol), nitrobenzene (2 mmol), H₂ (1 bar), room temperature, 6 h, giving PHA (15.0% HPLC yield, 15.3% selectivity).

**Selective Hydrogenation of Nitrobenzene Catalyzed by Ru/SiO₂ (P) (Table 1, entry 11).**
Conditions: 25 mL glass vessel, 5 wt% Ru/SiO₂ (P) (20 mg), isopropanol (2 mL), dimethyl sulfoxide (0.42 mmol), NEt₃ (0.36 mmol), nitrobenzene (2 mmol), H₂ (1 bar), room temperature, 12 h, giving PHA (9.0% HPLC yield, 90.0% selectivity).

**Promote Effect of the Addition of Amines ("BuNH₂) (Table 2, entry 7).**

Conditions: 25 mL glass vessel, 5 wt% Pt/SiO₂ (Escat™ 2351: 20 mg), isopropanol (2 mL), dimethyl sulfoxide (0.42 mmol), nBuNH₂ (0.072 mmol), nitrobenzene (2 mmol), H₂ (1 bar), room temperature, 1 h, giving PHA (77.5% HPLC yield, 99.0% selectivity).

**Selective Hydrogenation of Nitrobenzene in Organic Solvents (THF) (Table 3, entry 5).**

Conditions: 25 mL glass vessel, 5 wt% Pt/SiO₂ (Escat™ 2351: 20 mg), THF (2 mL), dimethyl sulfoxide (0.42 mmol), nBuNH₂ (0.072 mmol), nitrobenzene (2 mmol), H₂ (1 bar), room temperature, 4.5 h, giving PHA (99.8% HPLC yield, 99.8% selectivity).

**Selective Hydrogenation of Nitrobenzene in NEt₃ (Table 3, entry 11).**

Conditions: 25 mL glass vessel, 5 wt% Pt/SiO₂ (Escat™ 2351: 20 mg), NEt₃ (2 mL), dimethyl sulfoxide (0.42 mmol), nitrobenzene (2 mmol), H₂ (1 bar), room temperature, 8 h, giving PHA (94.4% HPLC yield, 99.9% selectivity).

**Hydrogenation of Nitrosobenzene (Figure 2 (a)).**

Conditions: 25 mL glass vessel, 5 wt% Pt/SiO₂ (Escat™ 2351: 20 mg), isopropanol (2 mL), dimethyl sulfoxide (0.42 mmol), nitrosobenzene (2 mmol), H₂ (1 bar), room temperature, 30 min, giving PHA (4.2% HPLC yield) and azoxybenzene (47.0% HPLC yield).

**Hydrogenation of Nitrosobenzene with NEt₃ (Figure 2 (b)).**

Conditions: 25 mL glass vessel, 5 wt% Pt/SiO₂ (Escat™ 2351: 20 mg), isopropanol (2 mL), dimethyl sulfoxide (0.42 mmol), NEt₃ (0.072 mmol), nitrosobenzene (2 mmol), H₂ (1 bar), room temperature, 30 min, giving PHA (5.8% HPLC yield) and azoxybenzene (47.0% HPLC yield).

**Hydrogenation of Azoxybenzene.**

Conditions: 25 mL glass vessel, 5 wt% Pt/SiO₂ (Escat™ 2351: 20 mg), isopropanol (2 mL), dimethyl sulfoxide (0.42 mmol), NEt₃ (0.072 mmol), azoxybenzene (1 mmol), H₂ (1 bar), room temperature, 2 h. Azoxybenzene was not hydrogenated in this reaction conditions.

**Selective Hydrogenation of 4-Cyano Nitrobenzene (Table 4, entry 1).**

Conditions: 25 mL glass vessel, 5 wt% Pt/SiO₂ (Escat™ 2351: 20 mg), isopropanol (2 mL), dimethyl sulfoxide (0.42 mmol), nBuNH₂ (0.072 mmol), 4-cyano nitrobenzene (2 mmol), H₂ (1 bar), room temperature, 95 min, giving 4-cyano-N-phenyl hydroxylamine (98% NMR yield, >99% selectivity).
NMR (400MHz, CDCl₃) in crude product: δ 5.22-6.18 and 6.93-7.00 (br, 2H, NH₂OH), 7.01 (d, J_H-H = 8.9 Hz, 2H, C₆H₄), 7.75 (d, J_H-H = 8.9 Hz, 2H, C₆H₄).

Selective Hydrogenation of 4-Methoxycarbonyl Nitrobenzene (Table 4, entry 2).

Conditions: 25 mL glass vessel, 5 wt% Pt/SiO₂ (Escat™ 2351: 20 mg), isopropanol (2 mL), dimethyl sulfoxide (0.42 mmol), nBuNH₂ (0.072 mmol), 4-methoxycarbonyl nitrobenzene (2 mmol), H₂ (1 bar), room temperature, 95 min, giving 4-methoxycarbonyl-N-phenyl hydroxylamine (>99% NMR yield, >99% selectivity). ¹H NMR (400MHz, CDCl₃) in crude product: δ 3.85 (s, 3H, CO₂C₆H₃), 6.98 (d, J_H-H = 8.8 Hz, 2H, C₆H₄), 7.75-7.84 (br, 2H, NH₂OH), 7.89 (d, J_H-H = 8.8 Hz, 2H, C₆H₄). Purification by column chromatography on silica gel (Kanto Chemicals, silica gel 60 (spherical), 63-210 μm) using hexane/ethyl acetate (5/1 and 2/1 v/v) yielded 293 mg (88%) of 4-methoxycarbonyl-N-phenyl hydroxylamine (Rf = 0.30; hexane/ethyl acetate = 2/1 v/v) as a white solid. ¹H NMR (400MHz, CDCl₃): δ 3.89 (s, 3H, CO₂C₆H₃), 5.05-5.45 (br, 1H, NH₂OH), 6.99 (d, J_H-H = 8.8 Hz, 2H, C₆H₄-N-ortho), 6.70-7.25 (br, 1H, NH₂OH), 7.97 (d, J_H-H = 8.8 Hz, 2H, C₆H₄-N-meta). ¹³C NMR (400MHz, CDCl₃): δ 51.85 (CO₂C₆H₃), 112.96 (C₆H₄-N-ortho), 123.34 (C₆H₄-C-ipsos), 130.98 (C₆H₄-N-ortho), 153.88 (C₆H₄-N-ipso), 167.00 (CO₂CH₃). IR (KBr): 3341.8, 3248.7, 2956.5, 2360.0, 1929.8, 1684.4, 1603.9, 1582.2, 1514.2, 1489.1, 1436.1, 1406.6, 1374.8, 1323.2, 1293.3, 1261.5, 1198.8, 1172.8, 1125.5, 1026.2, 968.3, 897.9, 846.8, 773.5, 749.9, 702.1, 667.9, 625.0, 517.4, 501.5, 470.7 cm⁻¹.

Selective Hydrogenation of 4-Chloro Nitrobenzene (Table 4, entry 3).

Conditions: 25 mL glass vessel, 5 wt% Pt/SiO₂ (Escat™ 2351: 20 mg), isopropanol (2 mL), dimethyl sulfoxide (0.42 mmol), nBuNH₂ (0.072 mmol), 4-chloro nitrobenzene (2 mmol), H₂ (1 bar), room temperature, 100 min, giving 4-chloro-N-phenyl hydroxylamine (98% NMR yield, 98% selectivity). ¹H NMR (400MHz, CDCl₃) in crude product: δ 5.42-5.76 and 6.68-6.82 (br, 2H, NH₂OH), 6.93 (d, J_H-H = 8.9 Hz, 2H, C₆H₄-N-ortho). ¹³C NMR (400MHz, CDCl₃): δ 3.89 (s, 3H, CO₂C₆H₃), 112.96 (C₆H₄-N-ortho), 123.34 (C₆H₄-C-ipsos), 130.98 (C₆H₄-N-ortho), 153.88 (C₆H₄-N-ipso), 167.00 (CO₂CH₃). IR (KBr): 3341.8, 3248.7, 2956.5, 2360.0, 1929.8, 1684.4, 1603.9, 1582.2, 1514.2, 1489.1, 1436.1, 1406.6, 1374.8, 1323.2, 1293.3, 1261.5, 1198.8, 1172.8, 1125.5, 1026.2, 968.3, 897.9, 846.8, 773.5, 749.9, 702.1, 667.9, 625.0, 517.4, 501.5, 470.7 cm⁻¹.

Selective Hydrogenation of 4-Fluoro Nitrobenzene (Table 4, entry 4).

Conditions: 25 mL glass vessel, 5 wt% Pt/SiO₂ (Escat™ 2351: 20 mg), isopropanol (2 mL), dimethyl sulfoxide (0.42 mmol), nBuNH₂ (0.072 mmol), 4-fluoro nitrobenzene (2 mmol), H₂ (1 bar), room temperature, 100 min, giving 4-fluoro-N-phenyl hydroxylamine (96% NMR yield, 99% selectivity). ¹H NMR (400MHz, CDCl₃) in crude product: δ 5.44-5.65 and 6.67-6.79 (m, 4H, C₆H₄). ¹³C NMR (400MHz, CDCl₃): δ 3.89 (s, 3H, CO₂C₆H₃), 112.96 (C₆H₄-N-ortho), 123.34 (C₆H₄-C-ipsos), 130.98 (C₆H₄-N-ortho), 153.88 (C₆H₄-N-ipso), 167.00 (CO₂CH₃). IR (KBr): 3341.8, 3248.7, 2956.5, 2360.0, 1929.8, 1684.4, 1603.9, 1582.2, 1514.2, 1489.1, 1436.1, 1406.6, 1374.8, 1323.2, 1293.3, 1261.5, 1198.8, 1172.8, 1125.5, 1026.2, 968.3, 897.9, 846.8, 773.5, 749.9, 702.1, 667.9, 625.0, 517.4, 501.5, 470.7 cm⁻¹.

Selective Hydrogenation of Nitrobenzene (Table 4, entry 5).

Conditions: 25 mL glass vessel, 5 wt% Pt/SiO₂ (Escat™ 2351: 20 mg), isopropanol (2 mL), dimethyl sulfoxide (0.42 mmol), nBuNH₂ (0.072 mmol), nitrobenzene (2 mmol), H₂ (1 bar), room temperature, 105 min, giving N-phenyl hydroxylamine (97.3% HPLC yield, 98.7% selectivity; 98% NMR yield, 99%
selectivity). $^1$H NMR (400MHz, CDCl$_3$) in crude product: $\delta$ 5.82-6.25 and 6.60-6.90 (br, 2H, NHOH), 6.96-7.01 (m, 3H, C$_6$H$_5$), 7.26-7.28 (m, 2H, C$_6$H$_5$).

**Selective Hydrogenation of Nitrobenzene by recovered Pt/SiO$_2$ (Table 4, entry 6).**

After the run of Table 4, entry 5, Pt/SiO$_2$ catalyst was separated from the product solution by filtration using a PTFE membrane filter (0.5 $\mu$m), washed with IPA (three times of 5 mL), and dried under reduced pressure at room temperature. The recovered Pt/SiO$_2$ catalyst (20 mg) was then placed in a glass vessel (25 mL) and air was replaced by an argon stream. A Teflon-coated magnetic stir bar, solvent (2 mL), DMSO (0.42 mmol), $n$BuNH$_2$ (0.072 mmol), and nitroaromatics (2 mmol) were successively placed in the vessel, and the suspension was purged with hydrogen. Then, the reaction mixture was stirred (1500 rpm) under 1 bar of hydrogen at room temperature for 115 min, giving PHA (97.0% HPLC yield, 98.8% selectivity).

**Selective Hydrogenation of 4-Vinyl Nitrobenzene (Table 4, entry 7).**

Conditions: 25 mL glass vessel, 5 wt% Pt/SiO$_2$ (Eschat$^\text{TM}$ 2351: 20 mg), isopropanol (2 mL), dimethyl sulfoxide (0.42 mmol), $n$BuNH$_2$ (0.072 mmol), 4-vinyl nitrobenzene (2 mmol), H$_2$ (1 bar), room temperature, 180 min, giving 4-vinyl-N-phenyl hydroxylamine (97% NMR yield, 97% selectivity). $^1$H NMR (400MHz, CDCl$_3$) in crude product: $\delta$ 5.02 (dd, $J_{H-H} = 11.0, 1.1$ Hz, 1H, CH=C$_2$H), 5.60 (dd, $J_{H-H} = 17.6, 1.1$ Hz, 1H, CH=C$_2$H), 5.02 (dd, $J_{H-H} = 17.6, 11.0$ Hz, 1H, C$_2$H$_2$), 6.94 (d, $J_{H-H} = 8.6$ Hz, 2H, C$_6$H$_4$), 7.31 (d, $J_{H-H} = 8.6$ Hz, 2H, C$_6$H$_4$), 7.74-7.86 (br, 2H, NHOH).

**Selective Hydrogenation of 4-Methyl Nitrobenzene (Table 4, entry 8).**

Conditions: 25 mL glass vessel, 5 wt% Pt/SiO$_2$ (Eschat$^\text{TM}$ 2351: 20 mg), isopropanol (2 mL), dimethyl sulfoxide (0.42 mmol), $n$BuNH$_2$ (0.072 mmol), 4-methyl nitrobenzene (2 mmol), H$_2$ (1 bar), room temperature, 180 min, giving 4-methyl-N-phenyl hydroxylamine (97% NMR yield, 98% selectivity). $^1$H NMR (400MHz, CDCl$_3$) in crude product: $\delta$ 2.30 (s, 3H, CH$_3$), 6.52-6.77 and 6.63-6.82 (br, 2H, NHOH), 6.91 (d, $J_{H-H} = 8.5$ Hz, 2H, C$_6$H$_4$), 7.09 (d, $J_{H-H} = 8.5$ Hz, 2H, C$_6$H$_4$).

**Selective Hydrogenation of 3-Methyl Nitrobenzene (Table 4, entry 9).**

Conditions: 25 mL glass vessel, 5 wt% Pt/SiO$_2$ (Eschat$^\text{TM}$ 2351: 20 mg), isopropanol (2 mL), dimethyl sulfoxide (0.42 mmol), $n$BuNH$_2$ (0.072 mmol), 3-methyl nitrobenzene (2 mmol), H$_2$ (1 bar), room temperature, 150 min, giving 3-methyl-N-phenyl hydroxylamine (98% NMR yield, 98% selectivity). $^1$H NMR (400MHz, CDCl$_3$) in crude product: $\delta$ 2.29 (s, 3H, CH$_3$), 6.70-7.11 (br, 2H, NHOH), 6.76, 6.77 and 6.78 (m, 3H, C$_6$H$_4$), 7.13 (t, $J_{H-H} = 7.6$ Hz, 1H, C$_6$H$_4$).

**Selective Hydrogenation of 2-Methyl Nitrobenzene (Table 4, entry 10).**

Conditions: 25 mL glass vessel, 5 wt% Pt/SiO$_2$ (Eschat$^\text{TM}$ 2351: 20 mg), isopropanol (2 mL), dimethyl sulfoxide (0.42 mmol), $n$BuNH$_2$ (0.072 mmol), 2-methyl nitrobenzene (2 mmol), H$_2$ (1 bar), room temperature, 300 min, giving 2-methyl-N-phenyl hydroxylamine (97% NMR yield, 97% selectivity). $^1$H
Selective Hydrogenation of 4-Methoxy Nitrobenzene (Table 4, entry 11).

Conditions: 25 mL glass vessel, 5 wt% Pt/SiO$_2$ (Escat$^{\text{TM}}$ 2351: 20 mg), isopropanol (2 mL), dimethyl sulfoxide (0.42 mmol), $n$BuNH$_2$ (0.072 mmol), 4-methoxy nitrobenzene (2 mmol), H$_2$ (1 bar), room temperature, 300 min, giving 4-methoxy-N-phenyl hydroxylamine (96% NMR yield, 97% selectivity).

$^1$H NMR (400MHz, CDCl$_3$) in crude product: $\delta$ 3.79 (s, 3H, OCH$_3$), 5.58-5.85 and 6.54-6.80 (br, 2H, NHOH), 6.85 (d, $J_{\text{H-H}} = 8.9$ Hz, 2H, C$_6$H$_4$), 7.00 (d, $J_{\text{H-H}} = 8.9$ Hz, 2H, C$_6$H$_4$), 7.00 (d, $J_{\text{H-H}} = 8.9$ Hz, 2H, C$_6$H$_4$).