Electronic Supplementary Information

Cupreine grafted onto silica as enantioselective and recyclable catalyst for the 1,4-addition of malonate to trans-β-nitrostyrene.

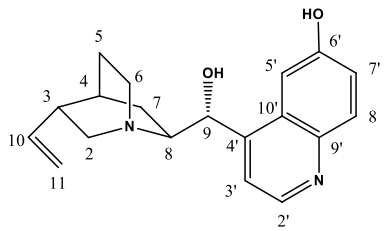
I. Billault, R. Launez and M.-C. Scherrmann

General information

All reagents were used without further purification. Quinine (99%), 2-methyltetrahydrofuran (2-MeTHF, 99%), and *trans*-β-nitrostyrene (98%) were purchased from Alfa Aesar. Sodium ethanethiolate (NaSEt, 90%) and *N*,*N*-dimethyltrimethylamine (TMS-DMA, 97%) were purchased from Sigma-Aldrich. The 2,2'-Azobis(2-methyl-propionitrile) (AIBN, 98%) and dry *N*,*N*-dimethylformamide (DMF, 99.8%) were purchased from Acros. Dimethyl malonnate (97%) was purchased from Janssen Chemica and (3-mercaptopropyl)-triethoxysilane (MPTES, 95%) was purchased from TCI Europe N.V.. The Silica 60 Å C.C. Chromagel SDS (70-200 μm) was purchased from Carlo-Erba and was dried under vacuum at 110°C for 24 h before use. ^{1}H and ^{13}C-NMR spectra were recorded on Bruker spectrometers (250, 360 or 400 MHz). Chemical shifts (δ) in ppm, are given relative to tetramethylsilane (TMS) for ^{1}H NMR and relative to CD_3OD and $CDCl_3$ resonances at 49.00 and 77.00 ppm respectively for ^{13}C NMR. Signals were assigned on the basis of ^{1}H-^{1}H COSY and HSQC experiments. Melting point were determined on a Büchi M560 apparatus. Optical rotations were measured on Jasco P1010 Polarimeter at the specified temperature and concentration (g/100 mL). HR-MS spectra were recorded in positive or negative mode with a microtof-QII spectrometer (Bruker) using electrospray ionization. Elemental analyses were performed at CNRS, "Institut des sciences analytiques", Villeurbane, France. FTIR spectra were recorded on FTIR spectrometer "Spectrum One" from Perkin Elmer with a resolution of 4 cm^{-1} and 100 scans. Si-CPN samples (15-20 mg) were mixed with dry KBr (~100 mg) then pressed in pellet form. TGA measurements were carried out under air on a SDT Q600 from Thermal Advantage. Si-CPN samples (15 mg) were placed in alumina crucible in the sample compartment then heated from 25 to 800°C at 5°C/min.

The adsorption-desorption isotherms were recorded at 77 K using a BelSorpII mini from BelJapan Inc. Average pore diameter have been evaluated from nitrogen desorption branch according to the Barret-Joyner-Halenda (BJH) plot. High performance liquid chromatography (HPLC) analysis was performed on an Agilent 1260 infinity chromatograph equipped with diode array detector and using a Kromasil 3-CelluCoat RP column (150 x 4.6 mm). Chromatograms were recorded and integrated at 215 nm.

Preparation of cupreine (CPN)[1]:

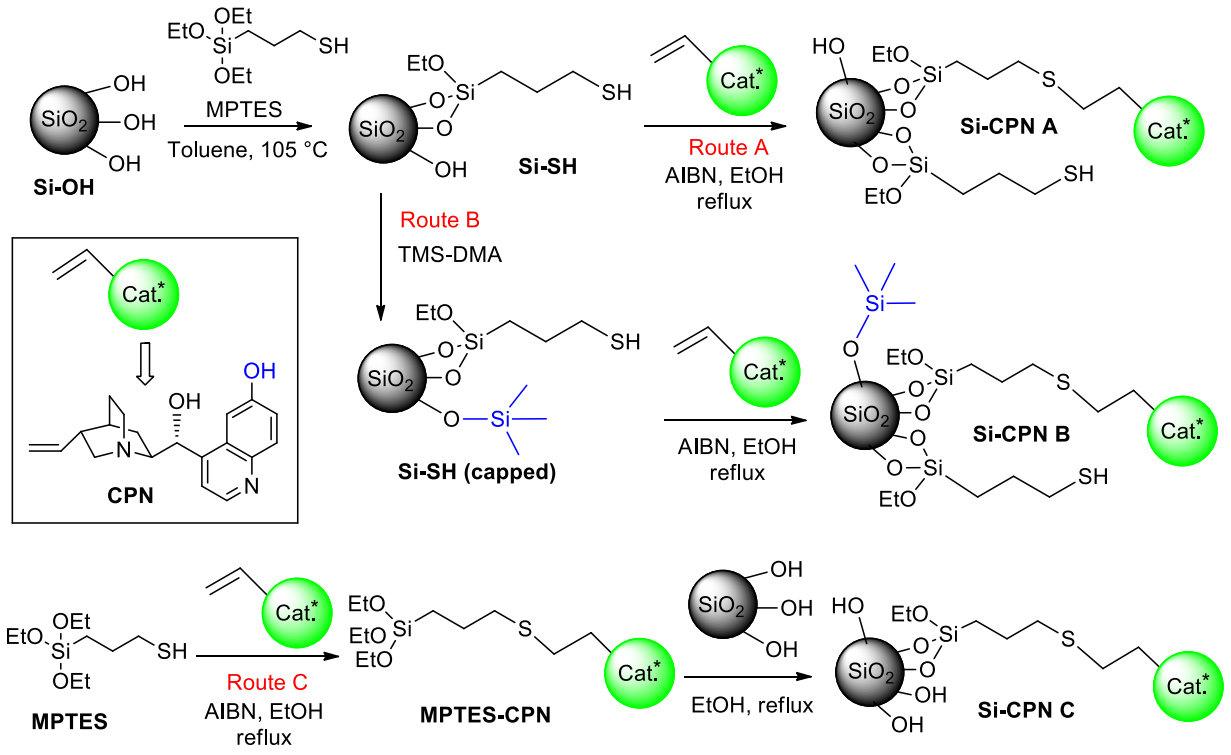


[1] H. Li, Y. Wang, L. Tang, and L. Deng, *J. Am. Chem. Soc.*, 2004, **126**, 9906-9907.

A mixture of quinine (5 g; 15.4 mmol) and NaSEt (5.18 g; 61.6 mmol) in dry DMF (60 mL) was stirred at 110 °C under argon for 16 h. After cooling to room temperature, aq. soln of HCl (0.1 M; 50 mL) was added to adjust the pH at 1, and the aq. phase was washed with EtOAc (3 x 100 mL). The pH of aq. phase was then adjusted to 7 by adding an aq. soln of NaOH (6 M, 25 mL) then the cupreine (CPN) was extracted with EtOAc (7 x 150 mL). The combined organic phases were washed with a sat. soln of NaCl (2 x 100 mL), dried over Na_2SO_4, filtered and concentrated. The same treatment was repeated once again to give the CPN as a white powder (m = 4.06 g; 85%).

^{1}H NMR (360 MHz, CD_3OD): δ 8.60 (d, *J* = 4.7 Hz, 1 H), 7.91 (d, *J* = 9.0 Hz , 1 H), 7.63 (d, *J* = 4.3 Hz , 1H), 7.34 (dd, *J* = 2.9 Hz, 9.0 Hz, 1H), 7.31 (d, *J* = 2.9 Hz, 1H), 5.60-5.80 (m, 1H), 5.52 (d, *J* = 3.2 Hz, 1H), 4.98 (d, *J* = 17.3 Hz, 1H), 4.92 (d, *J* = 10.4 Hz, 1H), 3.63 (m, 1H), 3.08-3.15 (m, 2H), 2.65-2.77 (m, 2H), 2.36 (m, 1H), 1.80-1.91 (m, 3H), 1.53-1.67 (m, 1H), 1.41-1.50 (m, 1H); ^{13}C NMR (62.9 MHz, CD_3OD): δ 158.0 (C6'), 149.8 (C9'), 147.6 (C2'), 144.1 (C10'), 142.7 (C10), 131.6 (C8'), 128.5 (C4'), 123.4 (C7'), 119.9 (C3'), 115.1 (C11), 105.3 (C5'), 72.3 (C9), 61.1 (C8), 57.6 (C2), 44.4 (C6), 40.9 (C3), 29.3 (C4), 28.2 (C5), 21.9 (C7); FTIR (KBr): ν (cm^{-1}) 3625, 3220 (br), 3074, 2970, 2948, 2862, 1622, 1596, 1579, 1533, 1467, 1338, 1291, 1260, 1239, 1224, 1131; $[\alpha]_D^{25}$ = -164.3 (c 0.93, EtOH). Lit[1]: $[\alpha]_D^{25}$ = -162.8 (c 0.93, EtOH); Mp = 196 °C (Lit[2] mp 202°C, recrist. From alcohol); HR-MS (ESI^+): *m/z* = 311.1757, calcd. for $C_{19}H_{24}N_2O_2^+$ $[M+H]^+$: 311.1754; HRMS (ESI^-): *m/z* = 309.1608 calcd. for $C_{19}H_{22}N_2O_2^-$ $[M-H]^-$: 309.1609.

General scheme for the preparation of Si-CPN

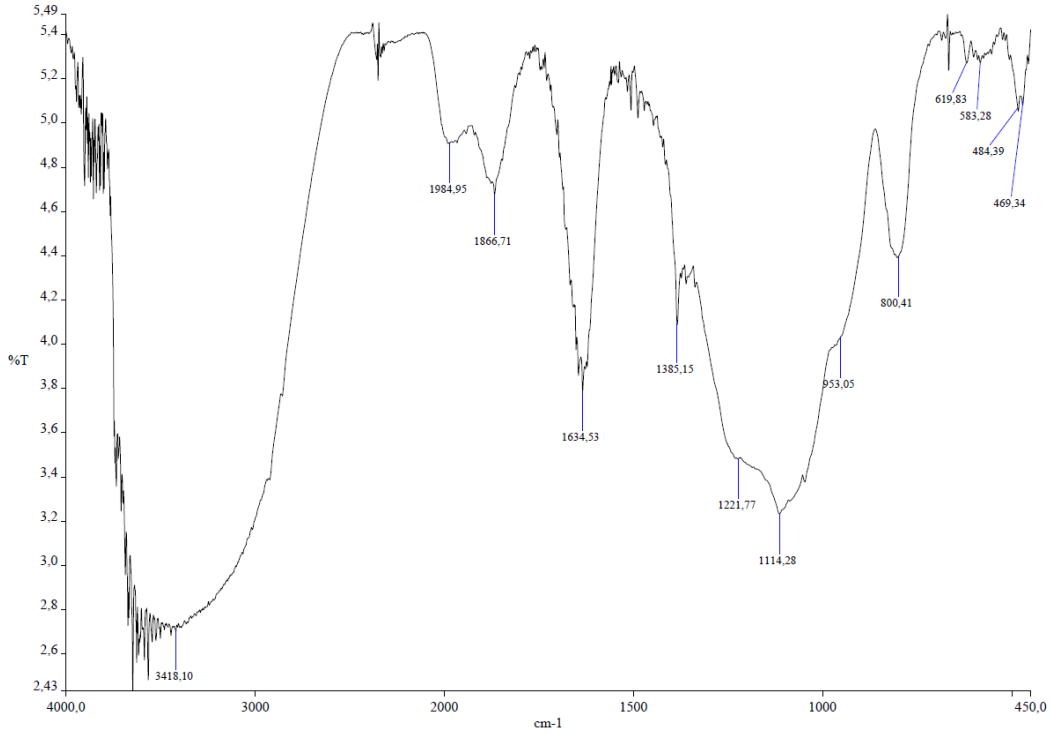


[2] The Merk index, 11th edition, Merc & Co., Inc, 1989.

Commercial silica gel 60 Å

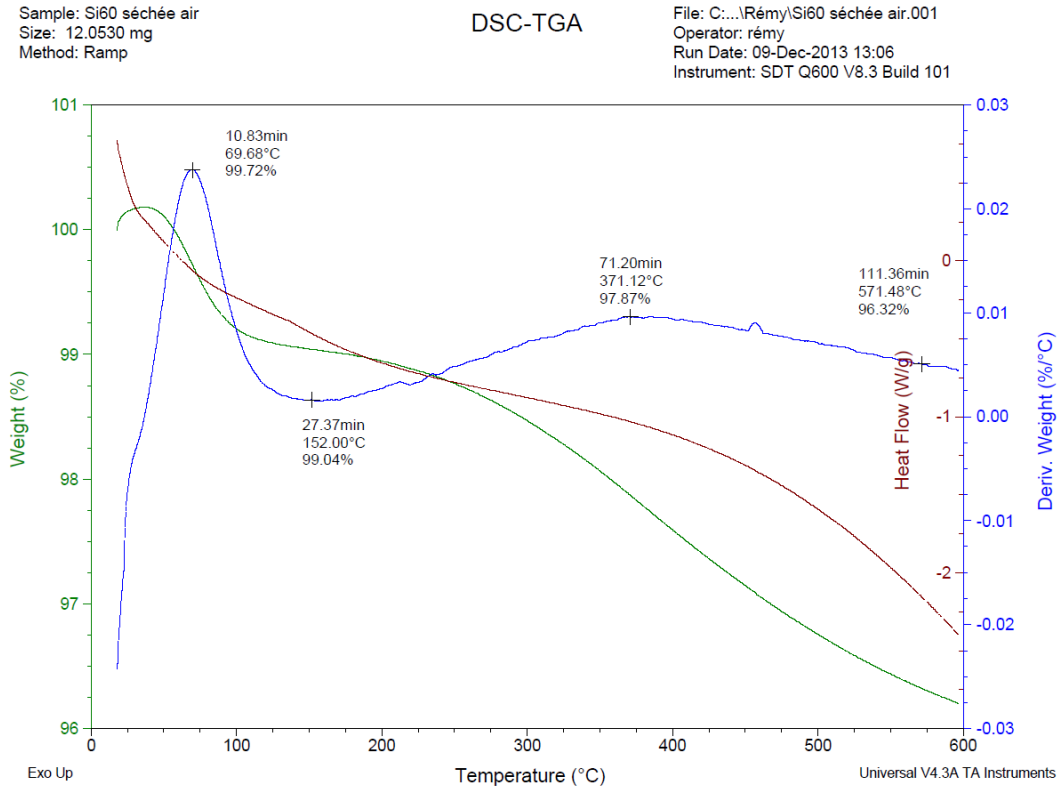
All characteristic vibration frequencies (cm^{-1}) in FTIR spectra of commercial silica and supported catalyst Si-CPN have been assigned on the base of ref 3.

FTIR Si 60 Å (NS = 20): ν (cm^{-1}) 3418 (ν Si-O-H, H-O-H), 1985, 1866 (overtone), 1634 (δ H-O-H), 1385 (δ_s CH_2 residual), 1221, 1114 (ν_{as} Si-O-Si), 953 (ν Si-OH), 800 (ν Si-O).



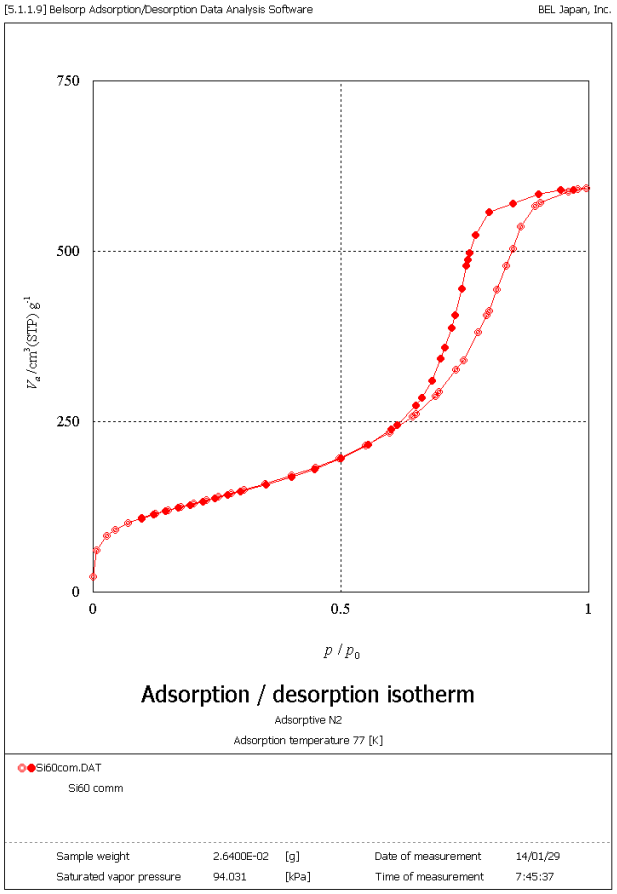
Thermogravimetry analysis

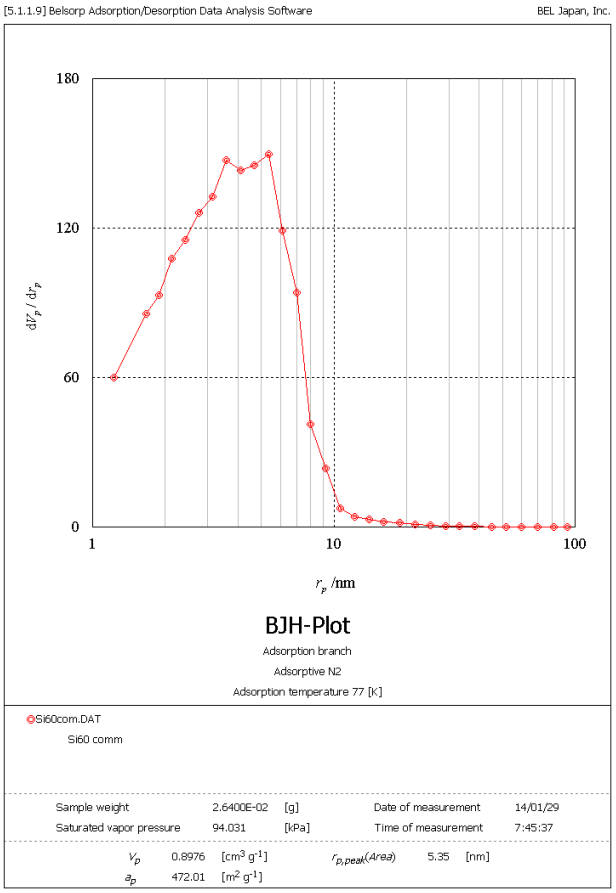
Weight loss at 79 °C for residual H_2O.



[3] (a) R. Al-Oweini and H. El-Rassy, *J. mol. Struct.*, 2009, **919**, 140-145. (b) J. Hong, I. Lee, F. Zaera, *Top. Catal.*, 2011, **54**, 1340-1347.

BET Analysis: N_2 adsorption /desorption isotherm and BJH plot treatment

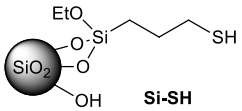




BJH-Plot treatment: specific area = 472 m².g^{-1}; pore volume = 0.90 cm^3.g^{-1}; pore diameter = 10.7 nm

ROUTE A for the preparation of the supported catalyst Si-CPN A

Preparation of silica Si-SH:



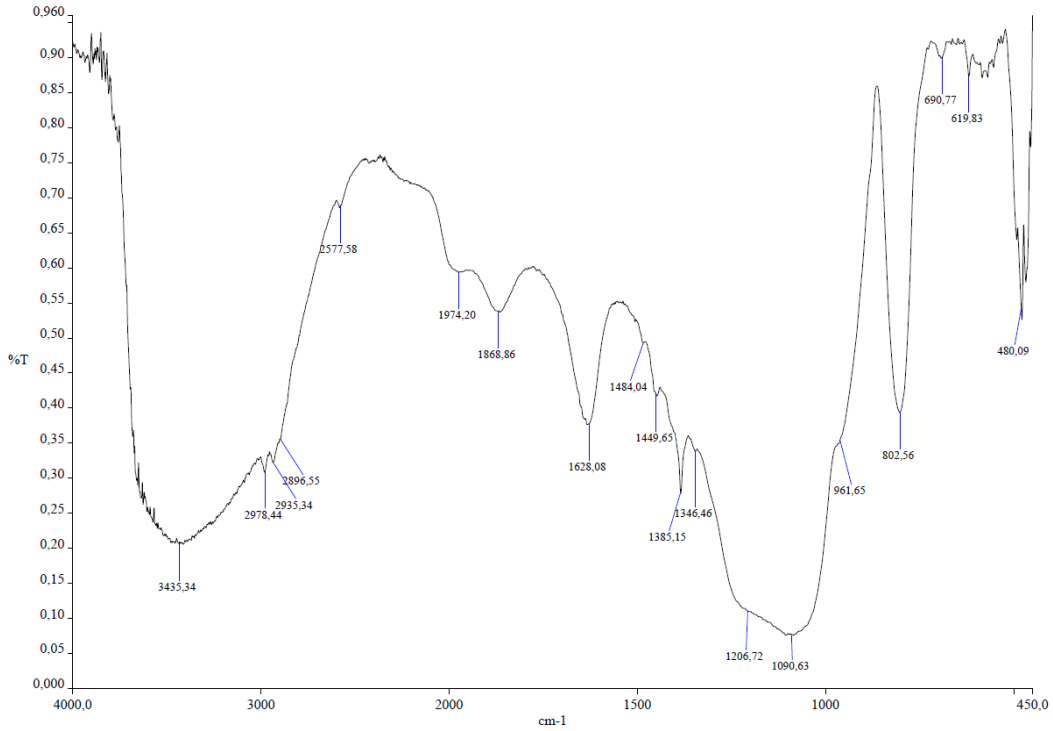
Si-SH

To dry silica 60 Å (10 g) were added toluene (15 mL) and MPTES (2.4 mL; 10 mmol) then the reaction mixture was heated under argon at 105°C for 48 h. After cooling to room temperature, the silica (Si-SH) was recovered through filtration, then washed with toluene (200 mL), EtOH (200 mL) and CH_2Cl_2 (100 mL). The silica Si-SH was dried under *vacuum* at room temperature for 12 h to give white powder (12.1 g).

Elemental analysis: % C 4.55; % H 1.51; % S 2.87 (0.9 mmol of SH group.g^{-1} of silica)

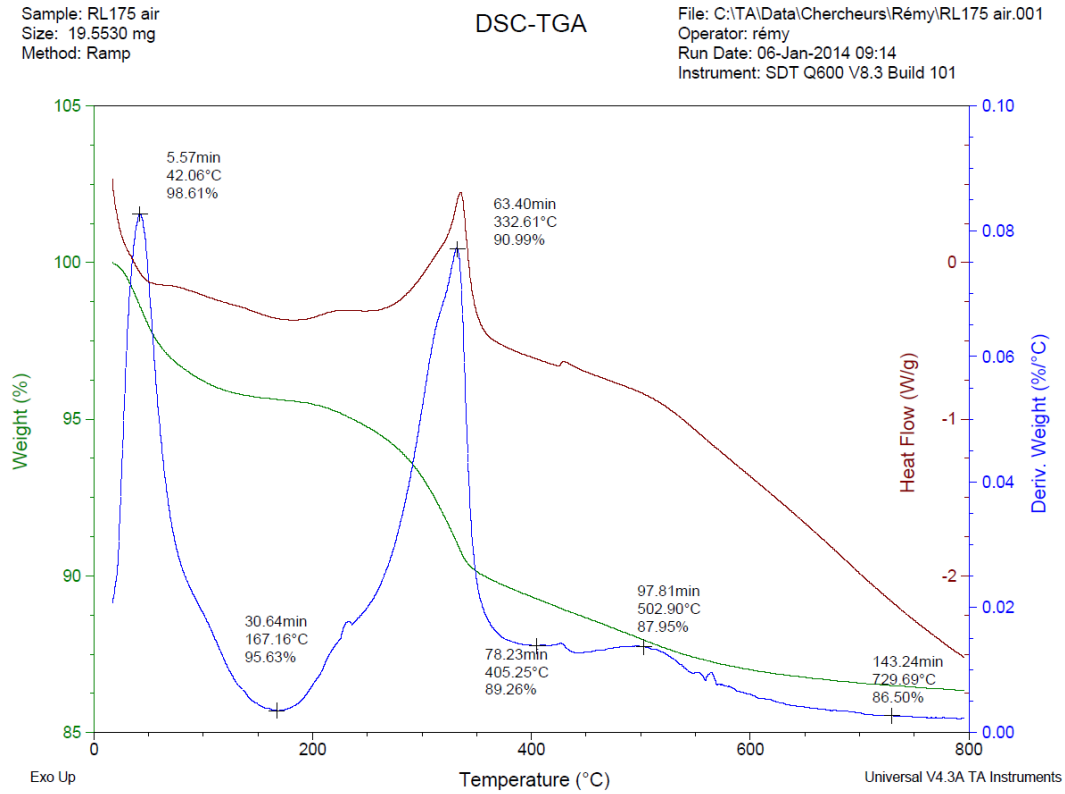
Grafting yield of MPTES: 90%

FTIR of silica Si-SH: ν (cm^{-1}) 3435 (ν Si-O-H, H-O-H), 2978, 2935, 2896 (ν C-H, CH_3, CH_2), 2577 (ν S-H), 1974, 1868 (overtone), 1628 (δ H-O-H), 1484, 1449, 1385, 1346 (δ_{as}, δ_s, CH_3, CH_2), 1206, 1090 (ν_{as} Si-O-Si), 961 (ν Si-OH), 802 (ν Si-O).

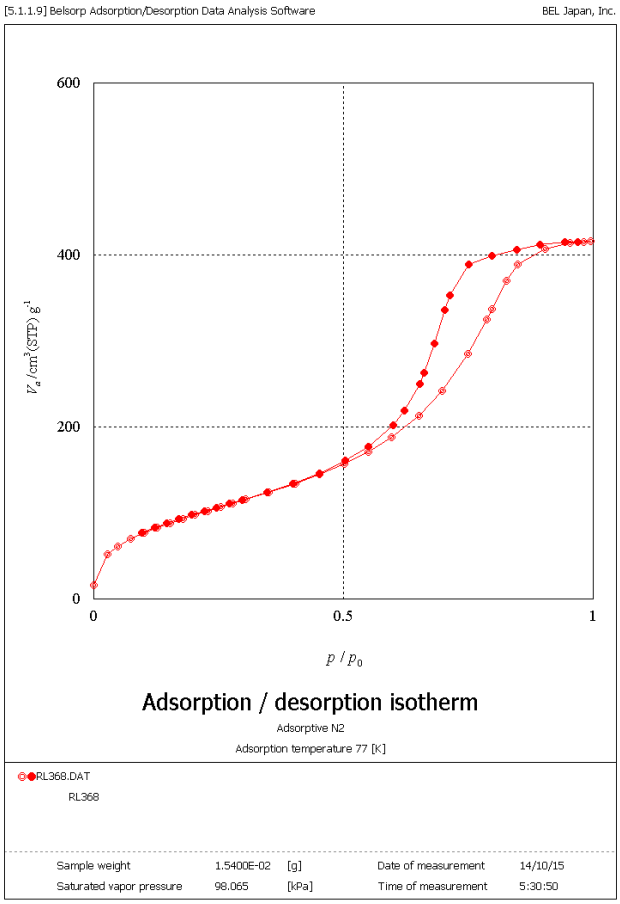


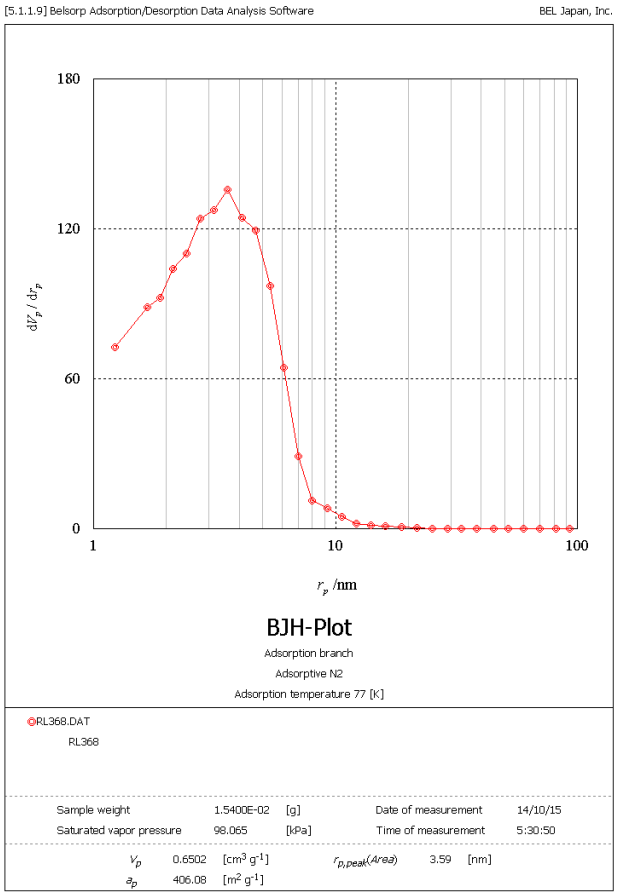
Thermogravimetry analysis of Si-SH

Weight loss at 42 °C for residual solvent. The linker with SH group induced a weight loss at 332°C.



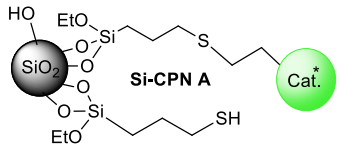
BET analysis: N_2 adsorption /desorption isotherm and BJH plot treatment





BJH-Plot treatment: specific area = 406 $m^2.g^{-1}$; pore volume = 0.65 $cm^3.g^{-1}$; pore diameter = 7.2 nm

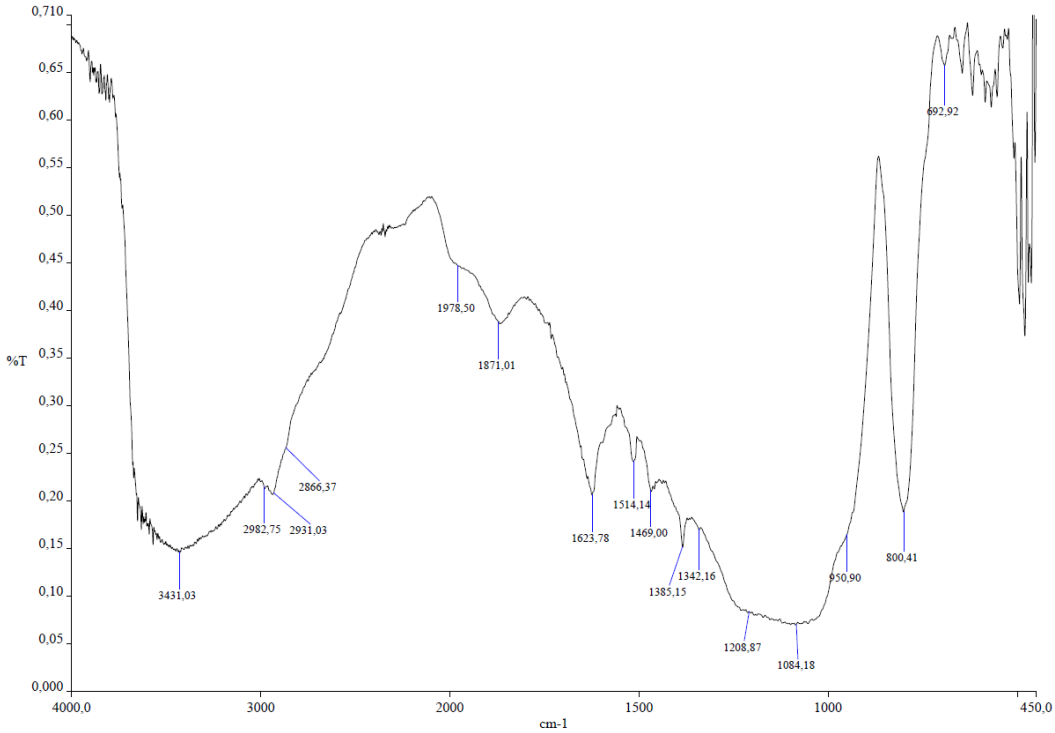
Preparation of supported catalyst Si-CPN A from silica Si-SH:



To a solution of CPN (1.55 g; 5 mmol) in dry EtOH (25 mL) under argon were added silica Si-SH (5 g; 0.9 mmol of SH/g of silica) and AIBN (0.250 g; 1.52 mmol). The mixture was heated at 90°C for 24 h. After cooling at room temperature, the silica Si-CPN A was recovered by filtration, then washed with EtOH (150 mL) and CH_2Cl_2 (75 mL). The silica Si-CPN A was washed by solid-liquid extraction in a Soxhlet apparatus with dry EtOH (150 mL) for 6 hours under argon, then washed with CH_2Cl_2 (100 mL) and dried under *vacuum* for 12 h to give yellowish powder (5.49 g).

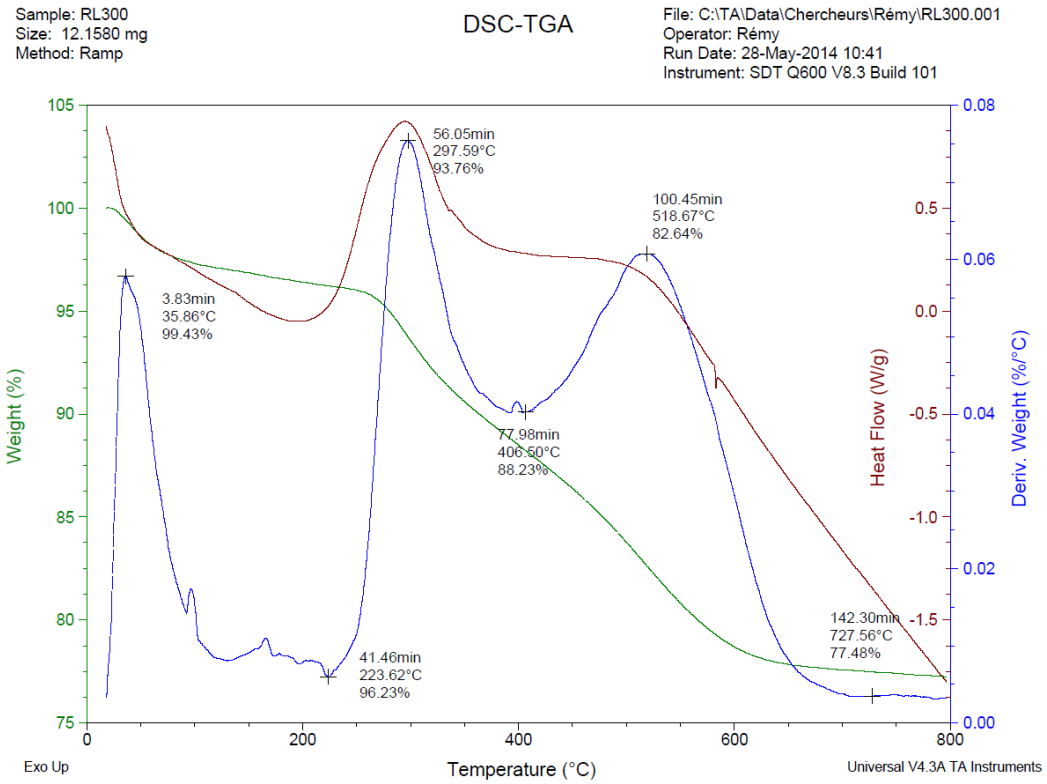
Elemental analysis: % C 11.3; % S 2.68; % N 1.02
Catalyst loading: 0.364 mmol of CPN.g^{-1} of silica
Residual SH groups: 60%

FTIR of Si-CPN A: ν (cm^{-1}) 3431 (ν Si-O-H, H-O-H), 2982, 2931, 2866 (ν C-H, CH_3, CH_2), 1978, 1871 (overtone), 1623 (δ H-O-H), 1514 ($\delta_{quinoline\ ring}$, $\delta_{CH\ quinoline}$), 1469, 1385, 1342 (δ_{as}, δ_s, CH_3, CH_2), 1208, 1084 (ν_{as} Si-O-Si), 950 (ν Si-OH), 800 (ν Si-O).

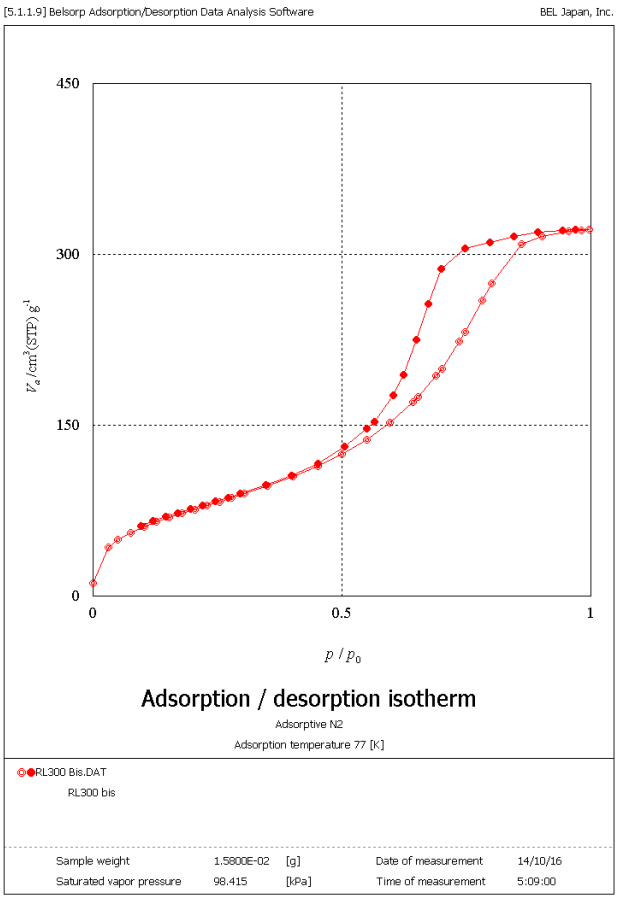


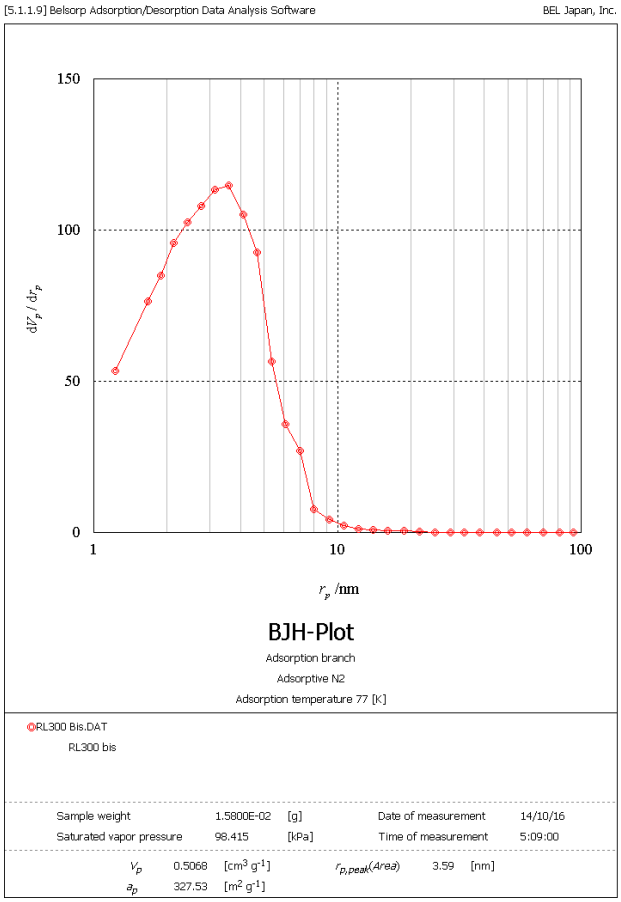
Thermogravimetry analysis

Weight loss at 37 °C for residual solvent. The residual linker with SH group and grafted catalyst Si-CPN induced a weight loss at 298°C and 518 °C, respectively.



BET Analysis: N_2 adsorption /desorption isotherm and BJH plot treatment

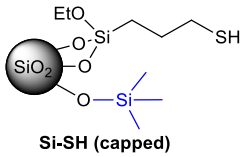




BJH-Plot treatment: specific area = 327 $m^2.g^{-1}$; pore volume = 0.5 $cm^3.g^{-1}$; pore diameter = 7.2 nm

ROUTE B for the preparation of supported catalyst Si-CPN B

Preparation of TMS capped silica Si-SH from silica Si-SH:

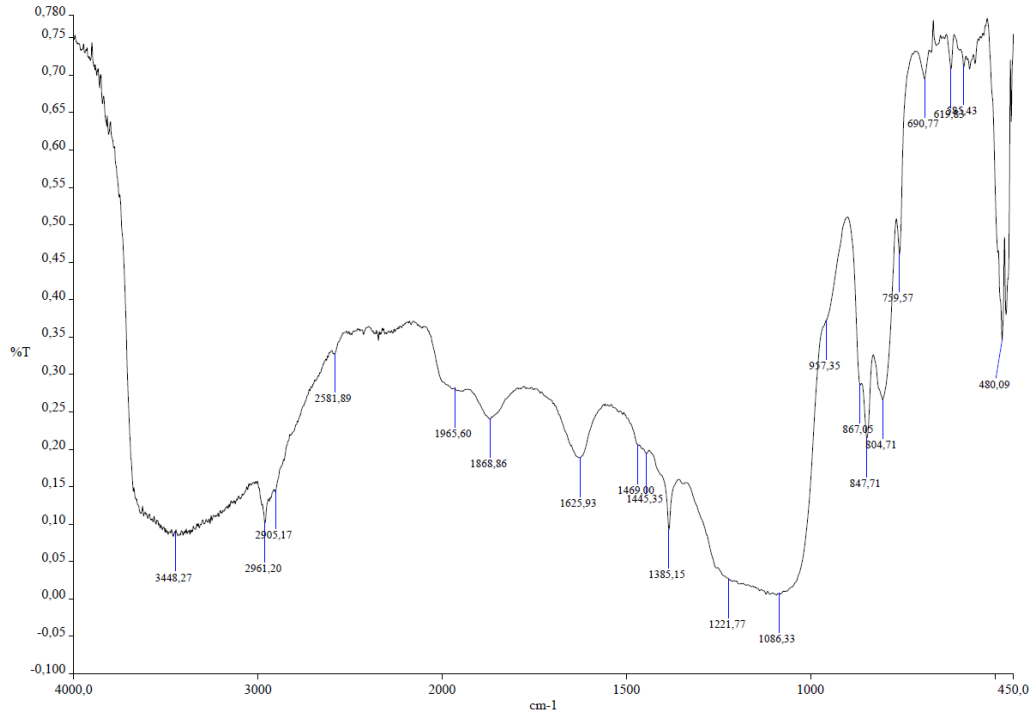


Si-SH (capped)

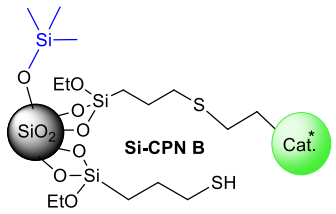
To the silica Si-SH (4 g; 0.9 mmol of SH group.g^{-1} of silica; % C 4.55) in dry toluene (25 mL) was added TMS-DMA (2.64 g; 22.5 mmol). The mixture was heated to 105°C for 24 h under argon. The reaction mixture was cooled down to room temperature and the TMS capped silica Si-SH was recovered by filtration, washed with toluene (2 x 75 mL) and CH_2Cl_2 (2 x 75 mL) then dried under *vacuum* for 12 h to give 4.2 g of a white powder.

Elemental analysis: % C 6.6; % S 2.76 => 0.862 mmol of SH.g^{-1} of silica and 0.55 mmol $Si(Me)_3$ group.g-1 of silica calculated from the initial % C of silica Si-SH (4.55 C%).

FTIR of Si-SH (TMS capped): ν (cm^{-1}) 3448 (ν Si-O-H, H-O-H), 2961, 2905 (ν C-H, CH_3, CH_2), 2581 (ν S-H), 1965, 1868 (overtone), 1625 (δ H-O-H), 1469, 1445, 1385 (δ_{as}, δ_s, CH_3, CH_2), 1221, 1086 (ν_{as} Si-O-Si), 957 (ν Si-OH), 847 (ν Si-C), 804 (ν Si-O).



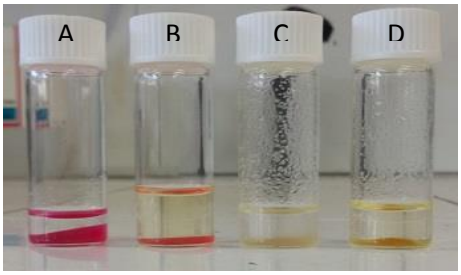
Preparation of supported catalyst Si-CPN B from TMS capped silica Si-SH:



To the TMS capped silica Si-SH (3 g; 0.86 mmol of $SH.g^{-1}$ of silica) in dry EtOH (20 mL) were added CPN (310 mg; 1 mmol) and AIBN (0.120 g; 0.73 mmol) under argon. The reaction mixture was heated to 90 °C for 48 h. After cooling to room temperature, the silica Si-CPN B was recovered by filtration, washed with EtOH (150 mL), CH_2Cl_2 (75 mL). The silica Si-CPN B was washed by solid-liquid extraction in a Soxhlet apparatus with dry EtOH (150 mL) for 6 hours under argon, then washed with CH_2Cl_2 (100 mL) and dried under *vacuum* for 12 h to give yellowish powder (3.21 g).

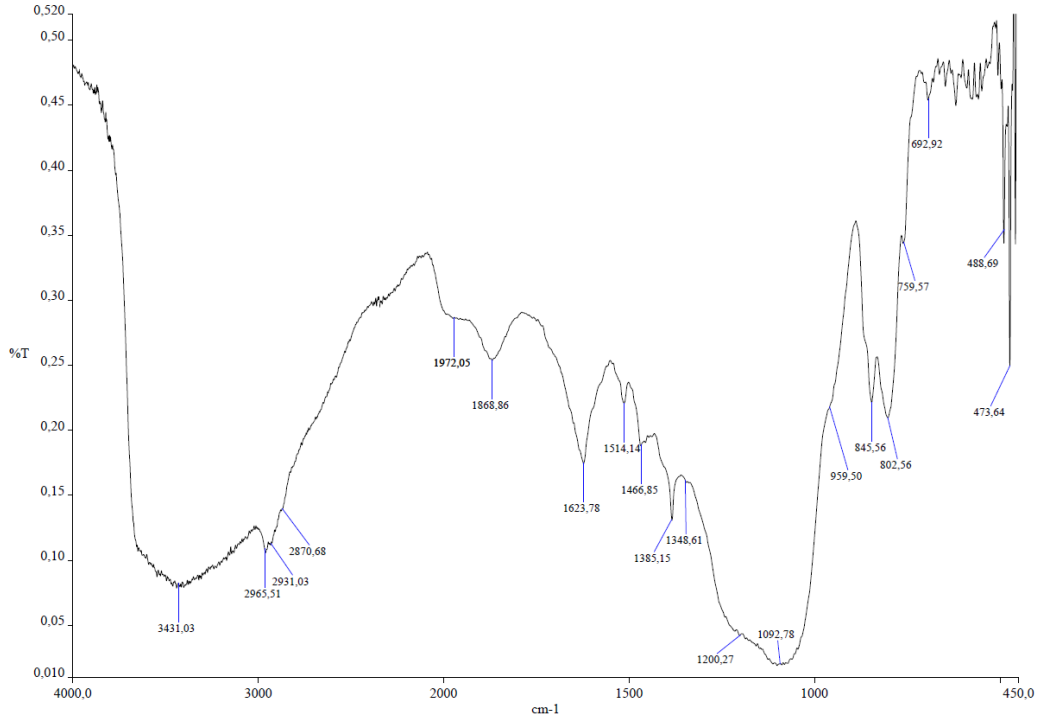
Elemental analysis: % C 9.63; % S 2.75; % N 0.75
Catalyst loading: 0.268 mmol of $CPN.g^{-1}$ of silica.
Residual SH groups: 69%

Methyl Red Test[4]: Silica sample (50 mg) was added to a solution of dimethylamino-4 phenylazo-2 benzoïc acid (1 mL, 1.5 mmol.L^{-1}). Commercial silica sample (A) or silica Si-SH sample (B) turned pink by adsorption of methyl red onto acidic silica surface in the presence of free silanol while samples of silica TMS-capped silica such as Si-SH capped (C) or Si-CPN B (D) remain colorless.



Methyl Red test :
(A) Commercial silica 60 Å; (B) silica Si-SH, (C) TMS-capped silica Si-SH and (D) Si-CPN B.

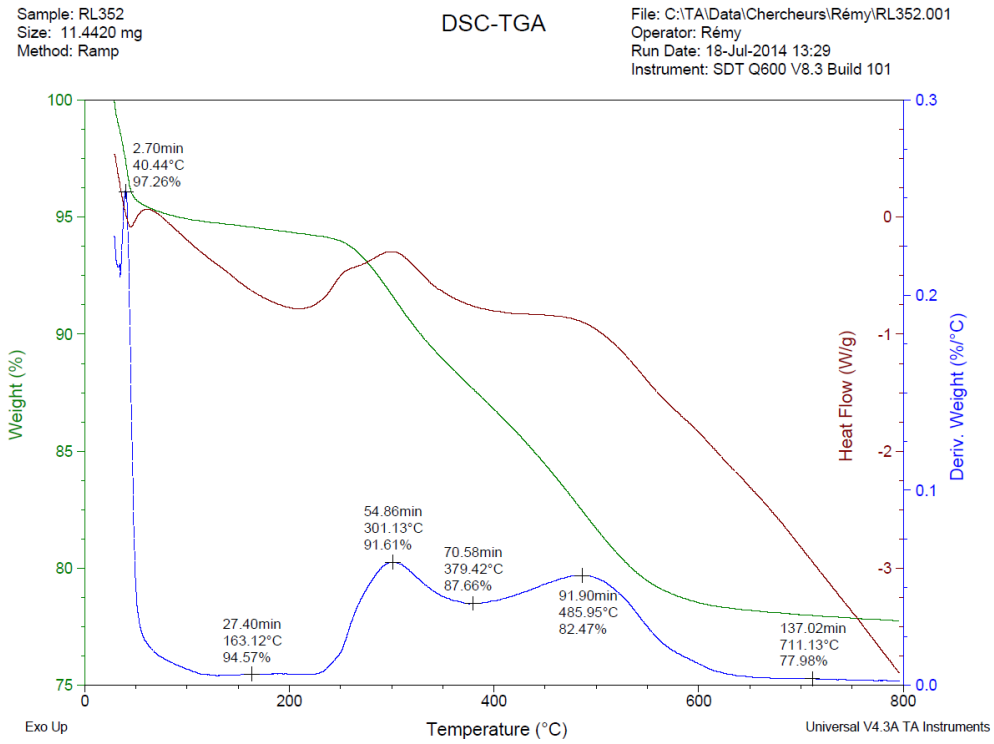
FTIR of Si-CPN B: ν (cm^{-1}) 3431 (ν Si-O-H, H-O-H), 2965, 2931, 2870 (ν C-H, CH_3, CH_2), 1972, 1868 (overtone), 1623 (δ H-O-H), 1514 ($\delta_{quinoline\ ring}$, $\delta_{CH\ quinoline}$), 1466, 1385, 1348 (δ_{as}, δ_s, CH_3, CH_2), 1200, 1092 (ν_{as} Si-O-Si), 959 (ν Si-OH), 845 (ν Si-C), 802 (ν Si-O).



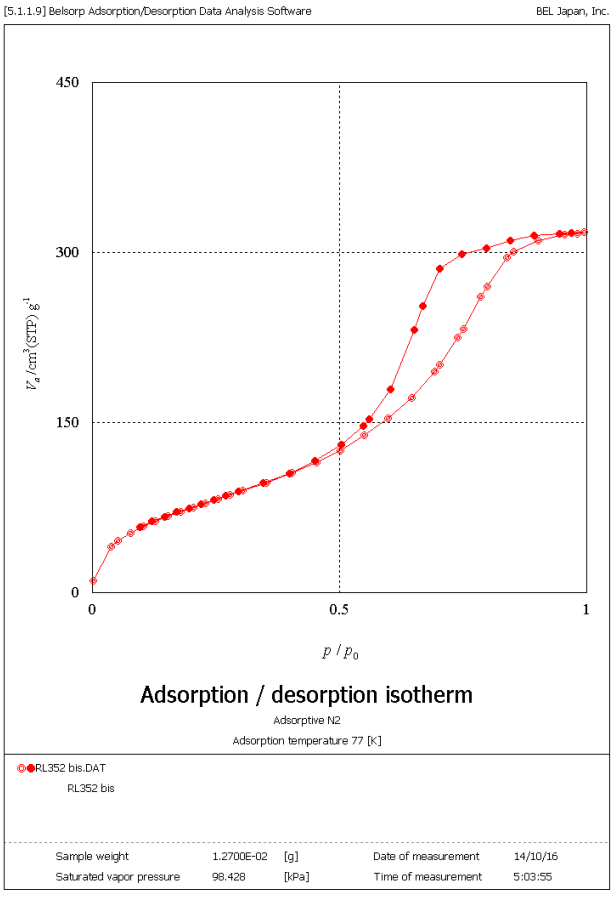
[4] A. Heckel and D.Seebach, *Chem. Eur. J.* 2002, **8**, 559-572

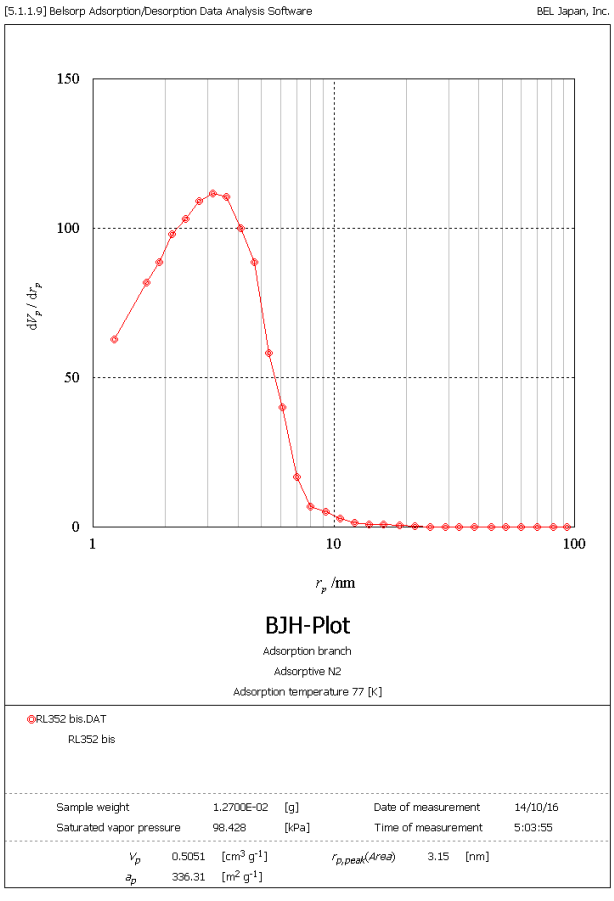
Thermogravimetry analysis

Weight loss at 40 °C for residual solvent. The residual linker with SH group and grafted catalyst Si-CPN induced a weight loss at 301°C and 485 °C, respectively.



BET Analysis: N_2 adsorption /desorption isotherm and BJH plot treatment

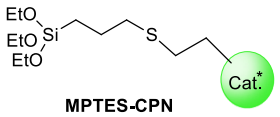




BJH-Plot treatment: specific area = 336 $m^2.g^{-1}$; pore volume = 0.50 $cm^3.g^{-1}$; pore diameter = 6.3 nm

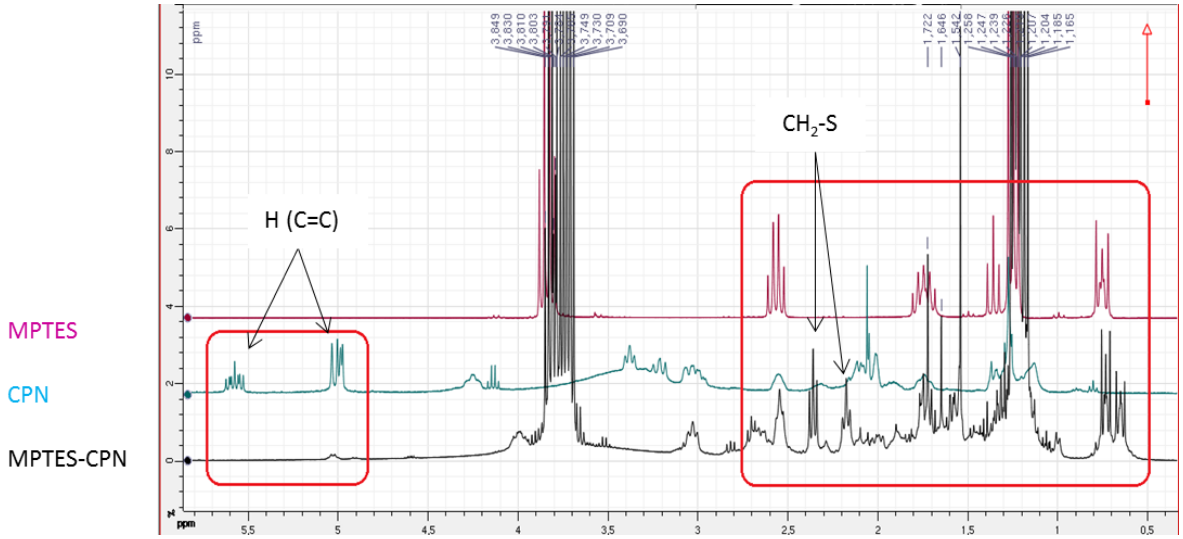
ROUTE C for the preparation of supported catalyst Si-CPN C

To a solution of CPN (500 mg, 1.61 mmol) in dry EtOH (5 mL) under argon were added MPTES (582 µL; 2.42 mmol) and AIBN (53mg; 0.32 mmol). After 8 h at 90 °C, CPN was completely consumed (^{1}H-NMR analysis) to give the adduct MPTES-CPN.

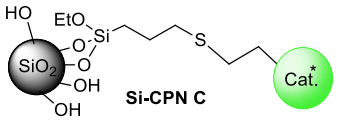


MPTES-CPN

^{1}H-NMR (CDCl$_3$; 360 MHz)



MPTES-CPN: HR-MS (ESI$^+$): *m/z* = 549.2803, calcd. for $C_{28}H_{46}N_2O_5SSi^+$ [M+H$^+$]: 549.2813.

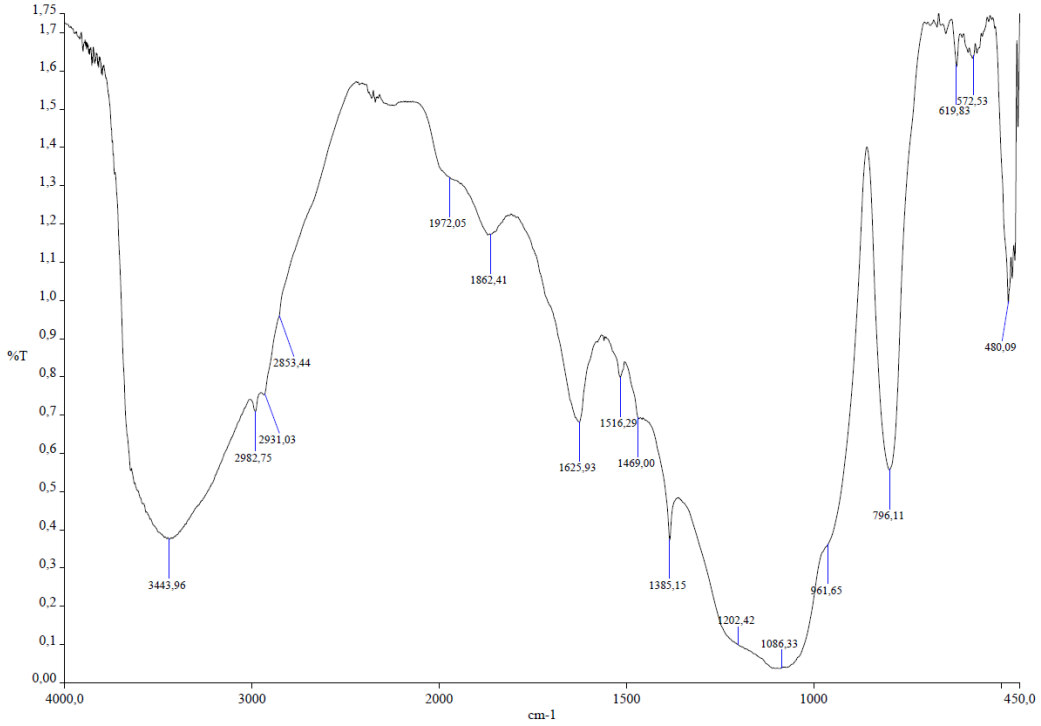


Si-CPN C

The reaction mixture was cooled down to room temperature then dry commercial silica Si 60 Å (5 g) and EtOH (10 mL) were added. After removing of EtOH under vacuum, the silica sample was washed with CH_2Cl_2 (2 x 150 mL) to eliminate the excess MPTES. Dry EtOH (25 mL) was added to the silica and the mixture was heated at 90 °C for 24 h under argon. After cooling at room temperature, the Si-CPN C was recovered through filtration and washed with EtOH (250 mL) then CH_2Cl_2 (100 mL). The Si-CPN C was washed by solid-liquid extraction in a Soxhlet apparatus with dry EtOH (150 mL) for 6 h under argon, recovered, washed with CH_2Cl_2 (100 mL) and dried under *vacuum* for 12 h to give yellowish powder (5.37) g

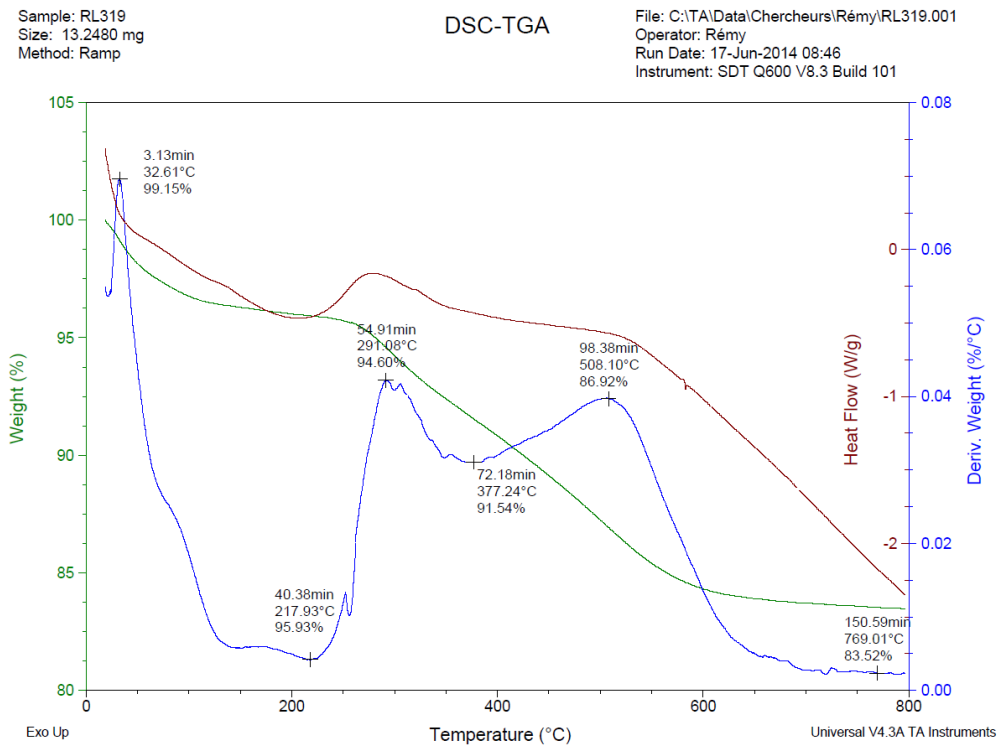
Elemental analysis: % C 7.09; % S 0.88; % N 0.63
Catalyst loading: 0.225 mmol of CPN.g^{-1} of silica
Residual SH group: 18 %

FTIR of Si-CPN C: ν (cm^{-1}) 3443 (ν Si-O-H, H-O-H), 2982, 2931, 2853 (ν C-H, CH_3, CH_2), 1972, 1862 (overtone), 1625 (δ H-O-H), 1516 ($\delta_{quinoline\ ring}$, $\delta_{CH\ quinoline}$), 1469, 1385 (δ_{as}, δ_s, CH_3, CH_2), 1202, 1086 (ν_{as} Si-O-Si), 961 (ν Si-OH), 796 (ν Si-O).

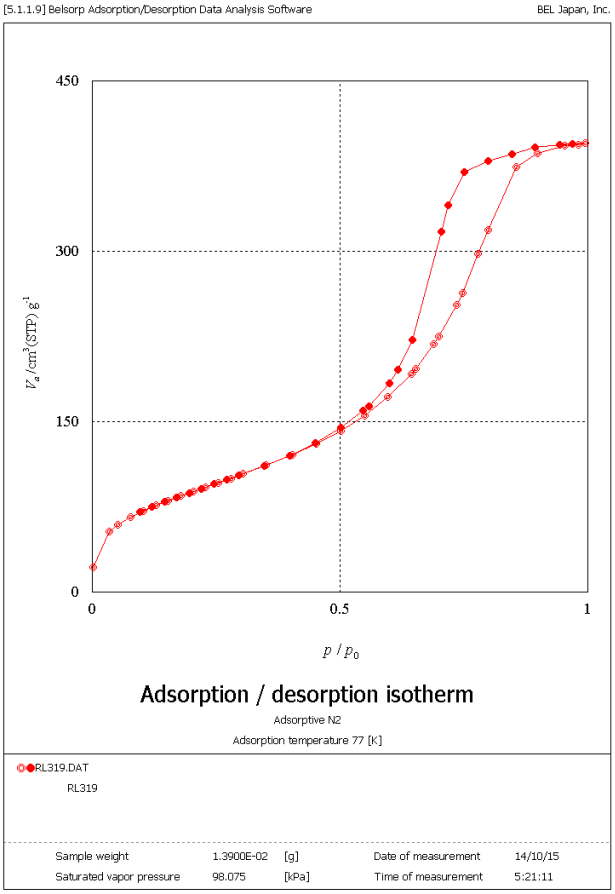


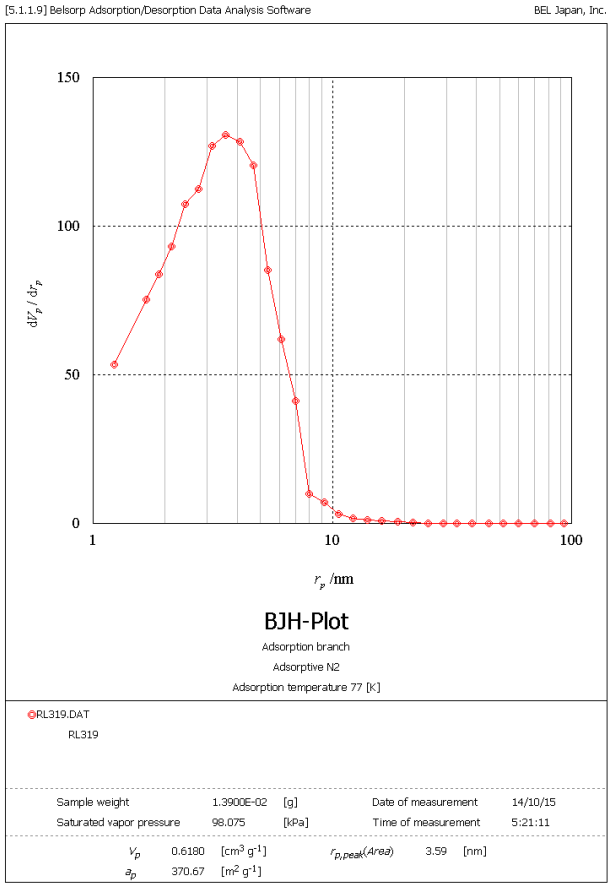
Thermogravimetry analysis

Weight loss at 32 °C for residual solvent. The residual linker with SH group and grafted catalyst Si-CPN induced a weight loss at 291°C and 508 °C, respectively.



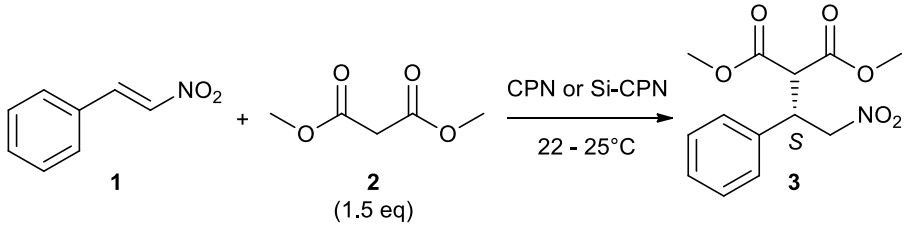
BET Analysis: N_2 adsorption /desorption isotherm and BJH plot treatment





BJH-Plot treatment: specific area = 371 m².g^{-1}; pore volume = 0.62 cm^3.g^{-1}; pore diameter = 7.2 nm

General procedure for enantioselective Michael addition of dimethyl malonate (2) to trans-β-nitrostyrene (1) for the preparation of (S)-(+)-methyl 2-carboxymethoxy-4-nitro-3-phenyl-butyrate (3).



Homogeneous conditions

To a solution of *trans*-β-nitrostyrene **1** (37.5 mg; 0.25 mmol) in solvent (0.5 mL) were added dimethyl malonate **2** (43 µL, 0.375 mmol) and CPN (7.8 mg, 0.025 mmol). The resulting mixture was kept at room temperature on an orbital stirrer at 400 rpm. When **1** was consumed (TLC analysis and ^{1}H-NMR), the reaction mixture was concentrated under *vacuum* and the residue was purified by flash chromatography (Petroleum ether / diethyl ether 90/10 then 70/30) to give **3** as white solid (84-97%). Enantiomeric excess (ee%) was determined by HPLC analysis.

Heterogeneous conditions

To a solution of *trans*-β-nitrostyrene **1** (37.5 mg, 0.25 mmol) in solvent (0.5 mL) were added dimethyl malonate **2** (43 µL, 0.375 mmol) and the supported chiral catalyst Si-CPN (12-27 mol%).

The resulting mixture was kept at room temperature on an orbital stirrer at 400 rpm for the appropriate time (see table), then filtered and the supported catalyst was washed with CH_2Cl_2 (10 mL) and drying under *vacuum*. The filtrate was concentrated, enantiomeric excess ee% and conversion were determined by HPLC analysis on crude product, then the residue was purified by flash chromatography (Petroleum ether/ diethyl ether 90/10 then 70/30) to give **3** as a white solid (89-97%).

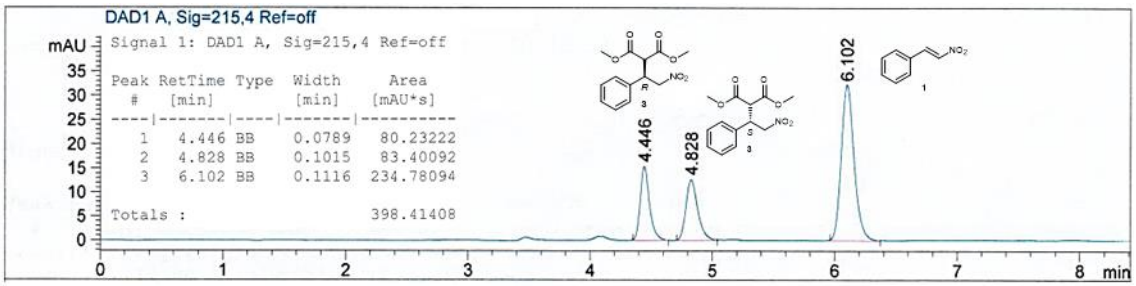
(*S*)-(+)-Methyl 2-carbomethoxy-4-nitro-3-phenyl-butyrate **3**:[1]
^{1}H NMR (400 MHz, $CDCl_3$) δ 7.30-7.37 (m, 3H), 7.24-7.26 (m, 2H), 4.95 (dd, J_1 = 5.2 Hz et J_2 = 13.6 Hz, 1H), 4.90 (dd, J_1 = 8.8 Hz et J_2 = 13.6 Hz, 1H), 4.27 (td, J = 5.2 Hz, J = 8.8 Hz, 1H), 3.88 (d, J = 8.8 Hz, 1H), 3.78 (s, 3H), 3.59 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 167.7 (Cq), 167.1 (Cq), 136.0 (Cq), 128.9 (CH), 128.3 (CH), 127.7 (CH), 77.3 (CH_2), 54.7 (CH), 52.9 (CH_3), 52.7 (CH_3), 42.8 (CH). FTIR: ν (cm^{-1}) 3056, 3034, 3012, 2952, 2926, 2849, 1733, 1602, 1561, 1544, 1428, 1383, 768, 706.
The absolute configuration of (+)-**3** enantiomer was determined to be *S* isomer by comparing with data of literature:
$[\alpha]_D^{25}$ = + 5.55 (c 1.02, $CHCl_3$); ee% = 90%, HPLC analysis; literature[1]: $[\alpha]_D^{25}$ = + 5.90 (c 1.02, $CHCl_3$); ee % = 96%, HPLC analysis; Mp = 61-62°C (Lit.[5] 63°C recrist. From methyl alcohol)
HR-MS (ESI^+): *m/z* = 304.0788 calcd. for $C_{13}H_{15}NO_6Na^+$ [M+Na^+]: 304.0792.

Preparation of racemic mixture of 3

To a solution of *trans*-β-nitrostyrene **1** (75 mg, 0.5 mmol) in 2-MeTHF/MeOH 50:50 (1 mL) were added dimethyl malonate **2** (171 µL, 1.5 mmol) and K_2CO_3 (14 mg, 0.1 mmol). The reaction mixture was kept at room temperature on an orbital stirrer at 400 rpm for 24 h. Water (5 mL) was added and the adduct **3** was extracted with EtOAc (3x 5 mL). The combined organic phases were dried over Na_2SO_4, filtered and concentrated. The residue was purified by flash chromatography (petroleum ether / diethyl ether 90/10 then 70/30) to give racemic **3** as white solid (115 mg, 88 %).

High Performance Liquid Chromatography (HPLC) analysis conditions: Kromasil 3-CelluCoat RP (150 x 4.6 mm), Acetonitrile: H_2O, 70:30, 0.5 mL/min, λ = 215 nm.

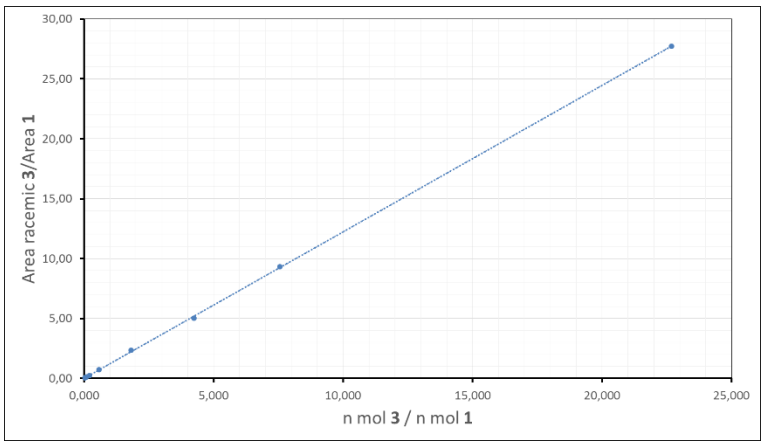
- Typical chromatogram for a mixture1:1 of **3 (**racemic) and **1.**



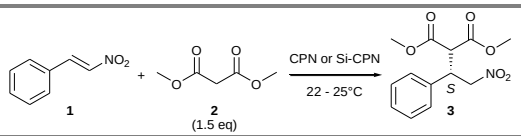
[5] E. P. Kohler and H. Engelbrecht, *J. Am. Chem. Soc.*, 1919, **41**, 764-770.

- Calibration curve for the determination of conversion %

n mol **3** /n mol **1**	0.025	0.06	0.09	0.20	0.57	1.81	4.23	7.56	22.67
racemic **3** Area / **1** Area	0.03	0.07	0.11	0.25	0.71	2.33	5.04	9.34	27.73
conversion %	3%	5%	8%	17%	34%	64%	81%	88%	96%



- Determination of enantiomeric excess ee %



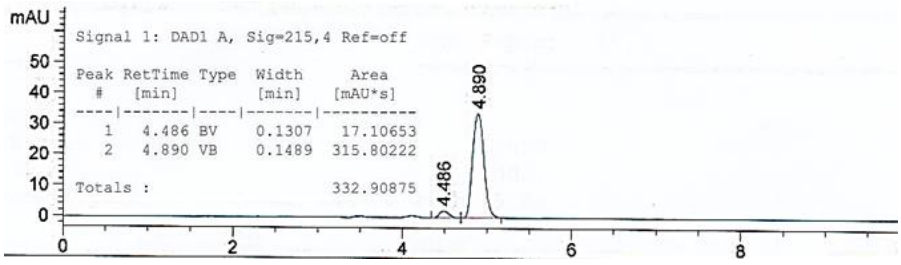
Entry	Catalyst (mol %)	Solvent	Time (h)	Yield[a] (%) (conv[b] (%))	ee[c] (%) **3**
1	CPN (10)	THF	24	88 (100)	90
2	Si-CPN A(12)	THF	62	90 (95)	87
3	Si-CPN B (27)	THF	28	97 (99)	73
4	Si-CPN C (22)	THF	72	95 (99)	80
5	CPN (10)	2-MeTHF	16	89 (100)	92
6	Si-CPN A(12)	2-MeTHF	41	89 (97)	87
7	Si-CPN B (27)	2-MeTHF	20	90 (94)	77
8	Si-CPN C (22)	2-MeTHF	20	95 (99)	88
9	CPN (10)	EtOAc	48	84 (100)	89
10	Si-CPN A(12)	EtOAc	62	90 (95)	82
11	Si-CPN B (27)	EtOAc	48	93 (97)	76
12	Si-CPN C (22)	EtOAc	72	93 (97)	83
13	CPN (10)	EtOH	24	97 (100)	57
14	Si-CPN A(12)	EtOH	30	93 (96)	60
15	Si-CPN B (27)	EtOH	21	93 (96)	42
16	Si-CPN C (22)	EtOH	48	92 (98)	54

[a] Isolated yield. [b] Conv (%) determined on crude reaction mixture by HPLC with Si-CPN or RMN-^{1}H with CPN. [c] Determined by HPLC analysis on a Kromasil 3-CelluCoat RP column.

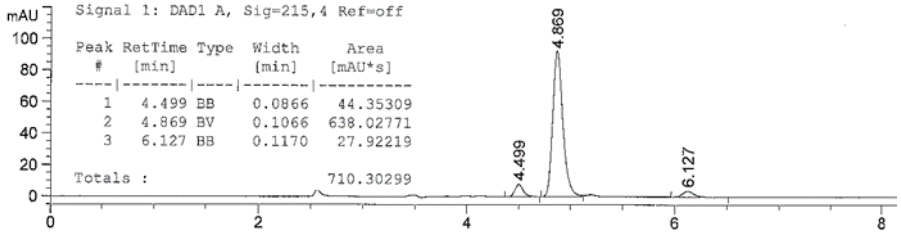
Entry

HPLC conditions: Kromasil 3-CelluCoat RP (150 x 4.6 mm), Acetonitrile: H_2O, 70:30, 0.5 mL/min, λ = 215 nm.

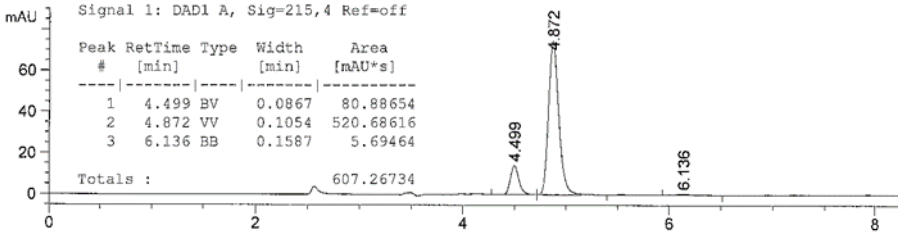
1
CPN
THF, ee% = 90



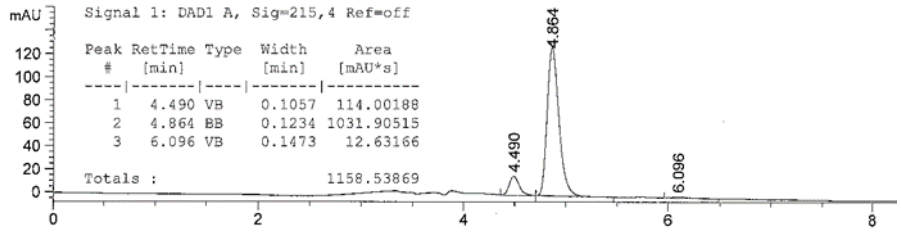
2
Si-CPN A
THF, ee% = 87



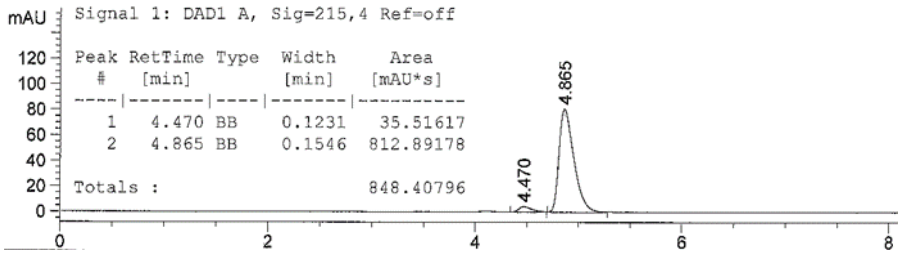
3
Si-CPN B
THF, ee% = 73



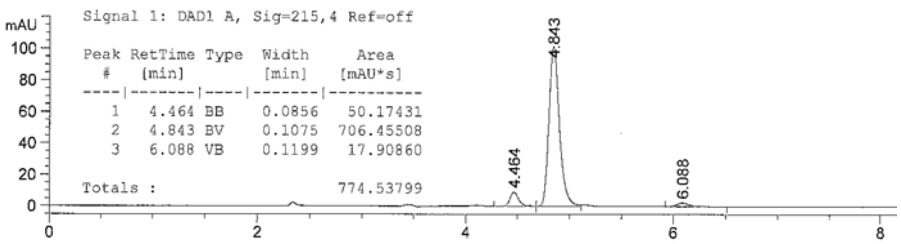
4
Si-CPN C
THF, ee% = 80



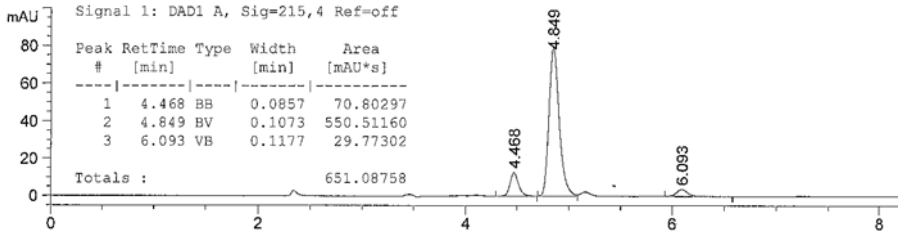
5
CPN
2-MeTHF, ee% = 92



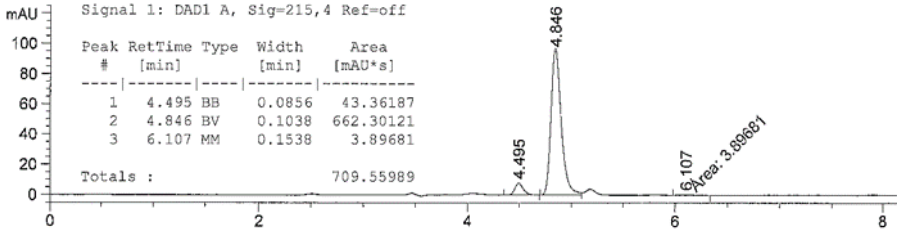
6
Si-CPN A
2-MeTHF, ee% = 87



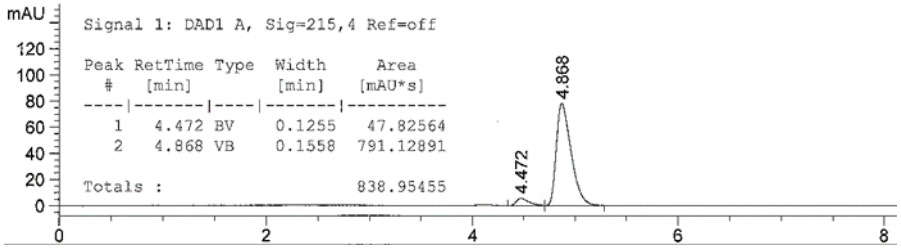
7
Si-CPN B
2-MeTHF, ee% = 77



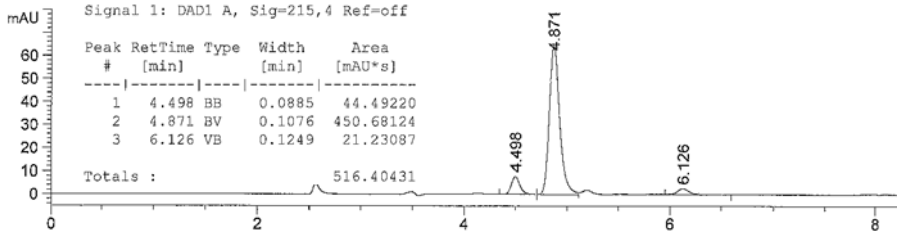
8
Si-CPN C
2-MeTHF, ee% = 88



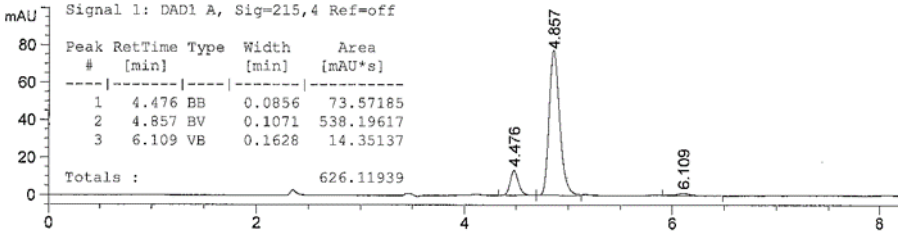
9
CPN
EtOAc, ee% = 89



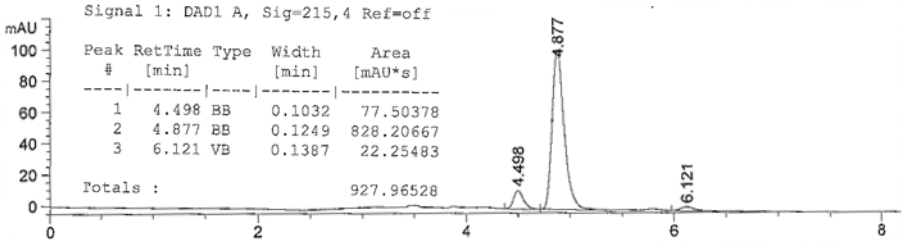
10
Si-CPN A
EtOAc, ee% = 82



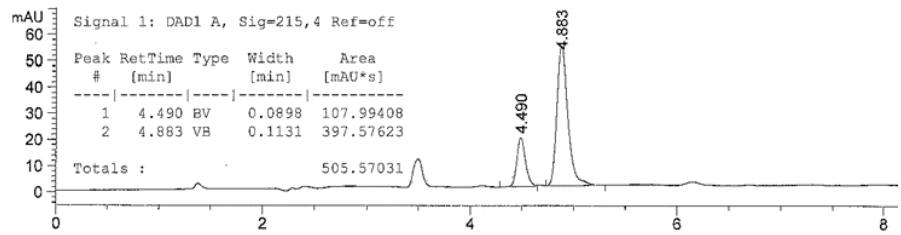
11
Si-CPN B
EtOAc, ee% = 76



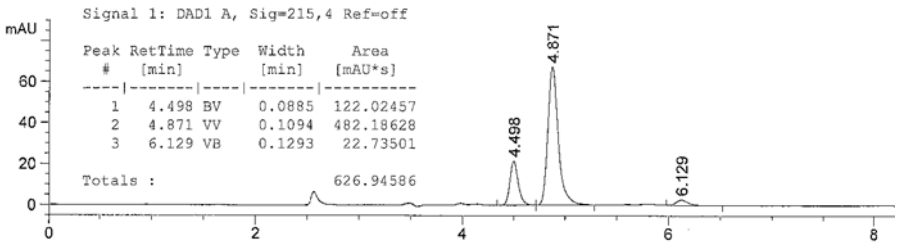
12
Si-CPN C
EtOAc, ee% = 83



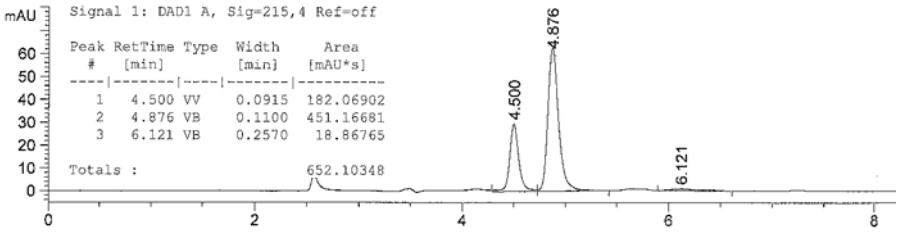
13
CPN
EtOH, ee% = 57



14
Si-CPN A
EtOH, ee% = 60



15
Si-CPN B
EtOH, ee% = 42



16
Si-CPN C
EtOH, ee% = 54