Magnetite-supported sulfonic acid: a retrievable nanocatalyst for Ritter reaction and multicomponent reactions

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General methods and experimental procedures

All commercial reagents were used as received unless otherwise mentioned. For analytical and preparative thin-layer chromatography, Merck, 0.2 mm and 0.5 mm Kieselgel GF 254 percoated were used, respectively. The spots were visualized using UV light.

The X-ray powder diffraction pattern was obtained using a conventional powder diffractometer RIGAKU, model: MiniFlex™ II benchtop X-ray Diffractometer; X-ray tube: Cu-Kα (30 kV / 15 mA) radiation operating in Bragg-Brentano (θ/2θ) geometry. (Sample preparation: grinding when needed and compression in the sample holder with a flat glass. The sample area in the sample holder is about 2 cm^2). Transmission electron microscopy (TEM) experiments were performed on a Hitachi H8100 microscope, with a ThermoNoran light elements EDS detector and a CCD camera for image acquisition. The Fe_3O_4-OSO_3H fine powder was placed on carbon stub and the images were recorded at 5-15 kV using LFD detector under low vacuum.

Scanning electron microscopy images were acquired using a JEOL JSM7001F FEG-SEM. Elemental analysis was performed using a light elements EDS detector from Oxford. The Fe_3O_4-OSO_3H powder was spread on a double-sided carbon tape and analyzed using 25kV acceleration voltage. Infrared spectra were recorded on a Perkin Elmer spectrum 1000.

Proton NMR spectra were recorded on a Bruker, 400, 5 mm probe at 300 MHz. ^1H shifts are reported relative to internal TMS.

Preparation of Fe_3O_4 MNPs[1-4]

$FeCl_3.6H_2O$ (5.4 g) and urea (3.6 g) were dissolved in water (200 mL) at 85 to 90 ºC for 2 h. The solution turned brown. To the resultant reaction mixture cooled to room temperature was added $FeSO_4.7H_2O$ (2.8 g) and then 0.1 M NaOH until pH 10. The molar ratio Fe^{III} to Fe^{II} in the above system was nearly 2.00. The obtained hydroxides were treated by ultrasound in the sealed flask at 30 to 35 ºC for 30 min. After ageing for 5 h, the obtained black powder (Fe_3O_4) was washed, and dried under vacuum.

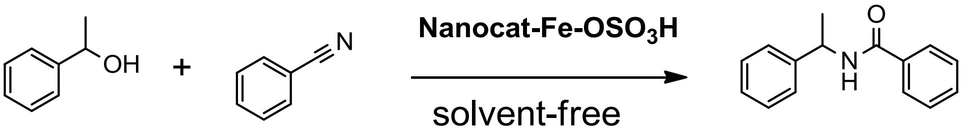
Preparation of Fe_3O_4-OSO_3H (Nanocat-Fe-OSO_3H)

In a two neck round bottom flask, equipped with a constant-pressure dropping funnel and a gas inlet tube for conducting HCl gas over an adsorbing solution (i.e. water) was used. Magnetite (Fe_3O_4) (2 g) was stirred in round bottom flask and neat chlorosulfonic acid added (0.5 mL) drop wise over a period of 5 min at room temperature. HCl gas immediately evolved from the reaction vessel. After addition, the mixture was shaken for 30 min and solid material was collected as a brown solid of magnetic sulfonic acid (Nanocat-Fe-OSO_3H)
(2.35 g).

Optimization of reaction conditions.

Using Fe_3O_4 and under catalysts-free conditons, the reaction did not proceed (Table, 1, entries 1 and 2). Depending on the amount of Nanocat-Fe-OSO_3H the yield increased from 35 to 84% (Table 1, entries 3 to 3). Indeed, increasing the quantity of catalyst from 50 mg to 100 mg led to an increase in the yield of reaction. However, we found a 100 mg catalyst is enough to catalyze the reaction under solvent-free conditions.

Table 1. Optimization of reaction conditions



No.	Catalyst	Catalyst Amount (mg)	Time (h)	Isolated Yield (%)
1	No catalyst	....	12	NR
2	Fe_3O_4	100	12	NR
3	Nanocat-Fe-OSO_3H	50	5	35
4	Nanocat-Fe-OSO_3H	75	5	65
5	Nanocat-Fe-OSO_3H	100	5	84

Reactions condition = 1-phenyl ethanol (1mmol), benzonitrile (1 mmol), under solvent-free condition at 90 ^{o}C.

Experimental procedure for Ritter reactions

In a pressure tube, alcohol (1 mmol), nitrile (1 mmol) and Nanocat-Fe-OSO_3H (100 mg) were heated at 90 °C under solvent-free conditions for respective time (see Table 1 in paper). After completion of reactions, monitored by thin layer chromatography, 5 mL of ethyl acetate was added to the reactions mixture and the catalyst separated magnetically. The organic solvent was concentrated under reduced pressure and the crude material subjected to column chromatography with ethyl acetate and hexane as eluent. All compounds are well reported and characterized in the literature.[5]

Some selected proton NMR of corresponding compounds depicted below,

N-(1-phenylethyl)benzamide (entry 1) : ^{1}H NMR (300 MHz, $CDCl_3$): δ 7.80 (d, 2H, J = 6.9 Hz), 7.59-7.20 (m, 8H), 6.47 (br s, 1H, D_2O exchangeable), 5.40 (m, 1H), 1.63 (d, 2H, J = 6.9 Hz)

2-chloro-N-(1-phenylethyl)acetamide (entry 5); ^{1}H NMR (300 MHz, $CDCl_3$): δ 7.30-7.06 (m, 5H), 6.75 (br s, 1H), 5.10-5.00 (m, 1H), 3.95 (s, 2H), 1.46 (d, 3H, J = 6.9 Hz)

N-(1-phenylethyl)benzamide (entry 6) ; ^{1}H NMR (300 MHz, $CDCl_3$): δ 7.75 (d, 2H, J = 7.8 Hz), 7.44-7.26 (m, 8H), 6.84 (br s, 1H, D_2O exchangeable), 4.55 (d, 2H, J = 5.7 Hz)

N-benzyl-4-bromobenzamide (entry 7); ^{1}H NMR (300 MHz, $CDCl_3$): δ 7.68 (d, 2H, J = 8.4 Hz), 7.55 (d, 2H, J = 8.4 Hz), 7.40-7.27 (m, 5H), 6.51 (br s, 1H, D_2O exchangeable), 4.64 (d, 2H, J = 5.7 Hz)

N-cyclohexylbenzamide (entry 9); ^{1}H NMR (300 MHz, $CDCl_3$): δ 7.69-7.67 (d, 2H, J = 7 Hz), 7.42-7.30 (m, 3H), 6.03 (br s, 1H, D_2O exchangeable), 3.91- 3.84 (m, 1H), 1.95 (m, 2H), 1.68-1.55 (m, 3H), 1.40-1.28 (m, 2H), 1.22-1.09 (m, 3H)

4-bromo-N-cyclohexylbenzamide (entry 10); ^{1}H NMR (300 MHz, $CDCl_3$): δ 7.56 (d, 2H, J = 8.4 Hz), 7.47 (d, 2H, J = 8.4 Hz), 6.03 (br s, 1H, D_2O exchangeable), 3.91- 3.85 (m, 1H), 1.95 (d, 2H, J = 6.6 Hz), 1.70-1.56 (m, 3H), 1.39-1.27 (m, 2H), 1.21-1.09 (m, 3H)

Preparation of 2-(4-fluorophenyl)-2-(piperidin-1-yl)acetonitrile (2)[6]

A mixture of 4-flurobenzaldehyde (1 mmol), piperidine (1.5 mmol), and Nanocat-Fe-OSO_3H (50 mg) was stirred at room temperature for 1 min.Then TMSCN (1.2 mmol) was added and the mixture stirred for another 30 min. When TLC showed completion of the reaction the reaction mixture was diluted with ethyl acetate (20 ml) and water (20 ml). The nanocatalyst was separated by use of a magnet. The organic layer was separated and aqueous layer was re-extracted with ethyl acetate (2 X 20 ml). The combined organic layer was dried over anhydrous sodium sulphate and concentrated under reduced pressure to give the desired product which was subsequently purified by column chromatography with ethyl acetate and hexane as eluent.

2-(4-fluorophenyl)-2-(piperidin-1-yl)acetonitrile (2) obtained in 93 % yield; ^{1}H NMR (300 MHz, $CDCl_3$): δ 7.70-7.67 (d, 2H), 7.04-6.98 (t, 2H), 4.72 (s, 1H), 2.64 (s, 4H), 1.52-1.18 (m, 6H)

Synthesis of 3,3-dimethyl-9-phenyl-3,4-dihydroacridin-1(2H)-one (3)[7]

In a glass tube a mixture of 2-amino benzophenone (1mmol), 5,5-dimethyl-1,3-cyclohexandione (1 mmol), and Nanocat-Fe-OSO_3H (50 mg) was irradiated in microwave (300 W) at 130 ◦C for 3h. After completion of reaction monitored by TLC, the reaction mixture was cooled to room temperature, and ethyl acetate (20 mL) was added to separate the catalyst by an external magnet. The organic layer was washed with water (10 mL) dried over anhydrous sodium sulphate and concentrated under reduced pressure to get the crude product which was subjected to crystallization with ethanol.

3,3-dimethyl-9-phenyl-3,4-dihydroacridin-1(2H)-one (3) obtained in 92 % yield ; ^{1}H NMR (300 MHz, $CDCl_3$): δ 8.22 (br s, 1H), 7.91(br s, 1H), 7.64 (br s, 5H), 7.10 (br s, 2H), 3.64 (s, 2H), 3.01 (s, 2H), 1.30 (s, 6H)

XRD of Nanocat-FeOSO$_3$H and Fe_3O_4

The XRD spectra of Fe_3O_4 and Nanocat-Fe-OSO$_3$H are depicted in Figure 1. The XRD spectrum of Fe_3O_4 clearly matches with the literature data from the Joint Committee on Powder Diffraction System (JCPDS 79-0419). Notably, same peaks were also observed in Nanocat-Fe-OSO$_3$H XRD spectra, with slightly changes in nature of peaks, it could be due presence of sulfonic acid on the surface of Fe_3O_4. The crystallite size of Nanocat-Fe-OSO$_3$H catalyst, was determined by the Debye Scherrer equation, and found to be 18 nm.

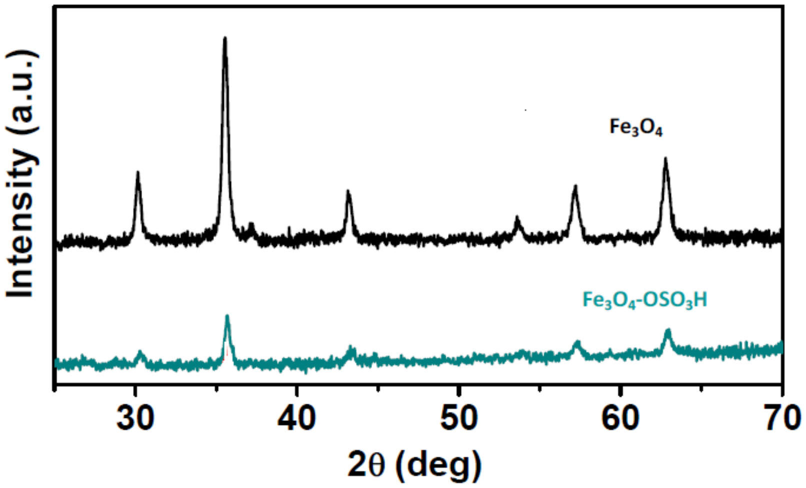


Figure 1 XRD spectra of Fe_3O_4 and Nanocat-Fe-OSO$_3$H MNPs

Infrared spectra of Fe_3O_4 and Nanocat-Fe-OSO$_3$H

The infrared spectra of Fe_3O_4 and Nanocat-Fe-OSO$_3$H are depicted in Figure 2 a. The band observed at 560 cm^{-1}, confirms the structure of Fe-O group, while for nanocat-Fe-OSO$_3$H, the characteristics peaks from the -OSO$_3$H group of chlorosulfonic acid were observed at 3367 cm^{-1} (O-H stretching). Also detectable are the bands at 1614 and between 1200 and 980 cm^{-1} corresponding to S=O and S-O stretching which clearly indicates the presence of -OSO$_3$H group over magnetite surface. The infrared spectra of reused catalyst after five runs is depicted in

Figure 2 b. It is important to note that all corresponding peaks are intact without any change in characteristics. It indicates that structure of catalyst doesn't change even after 5 cycles.

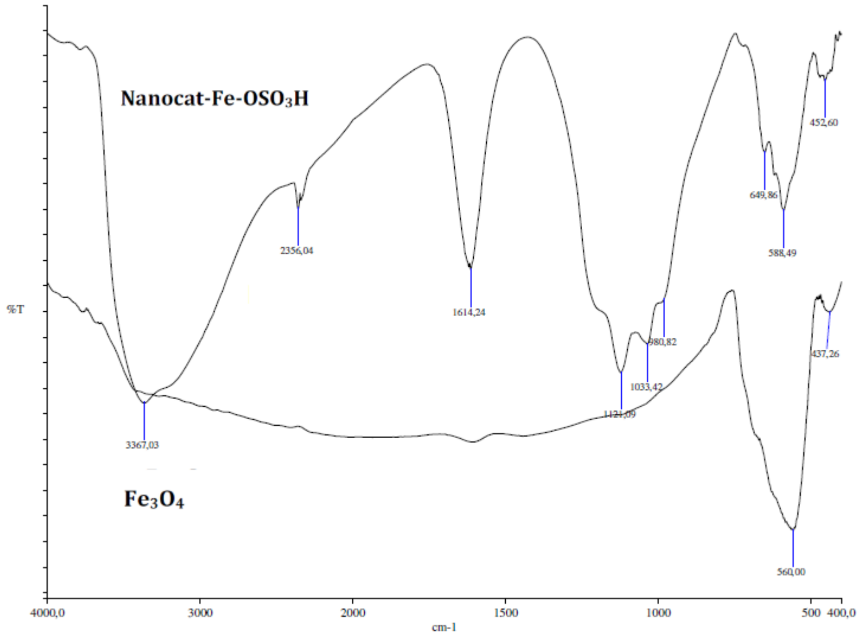


Figure 2. a) FT infrared spectrum of Fe_3O_4 and Nanocat-Fe-OSO_3H

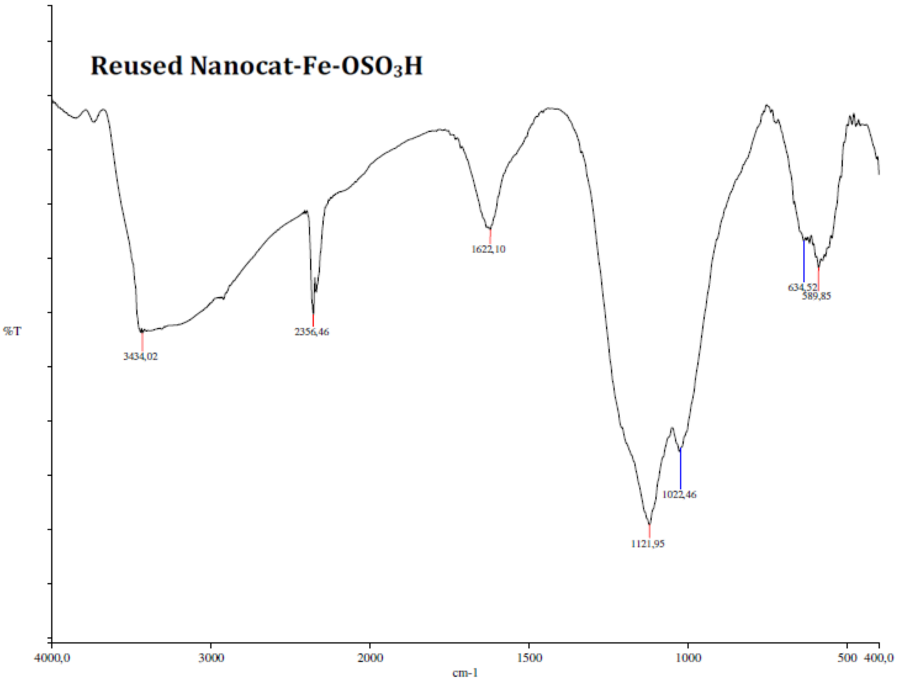
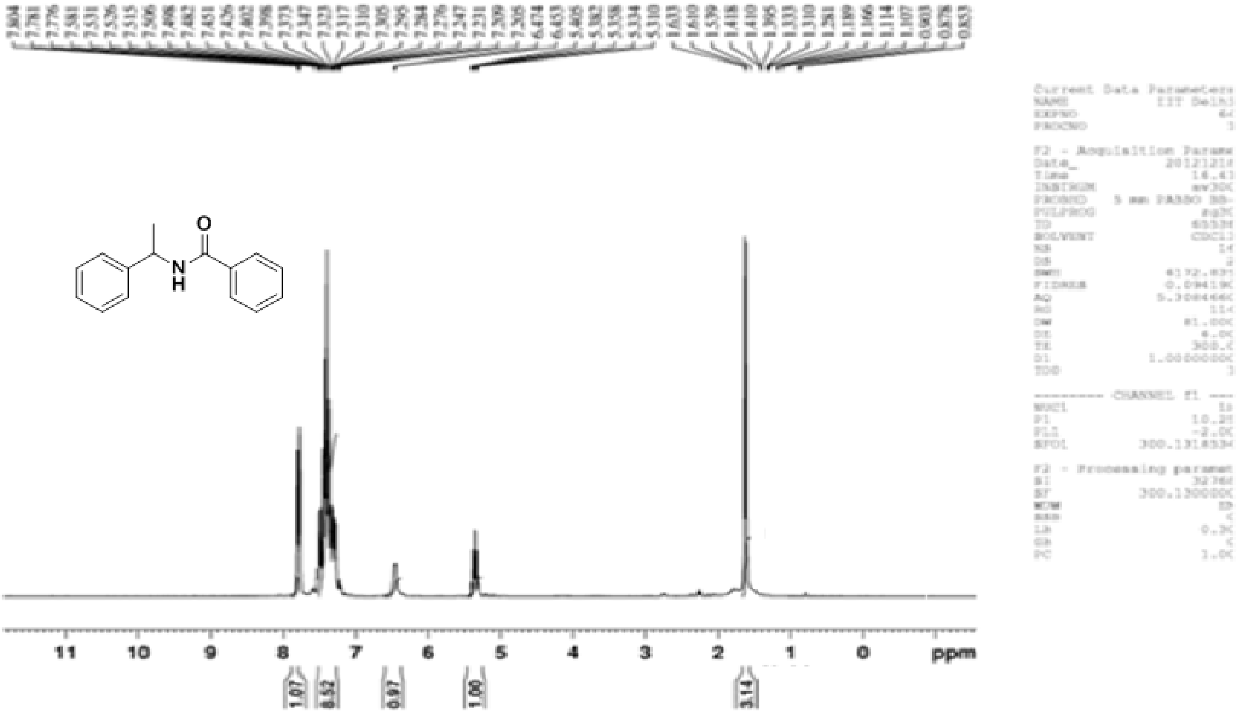
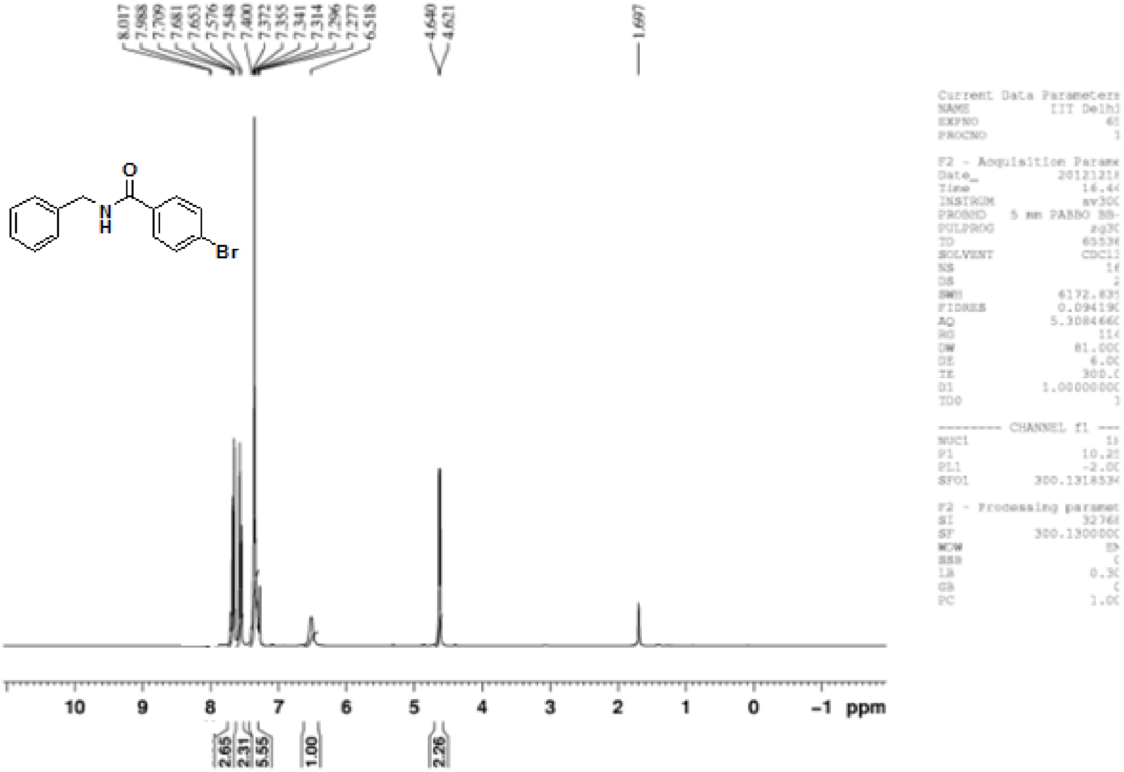
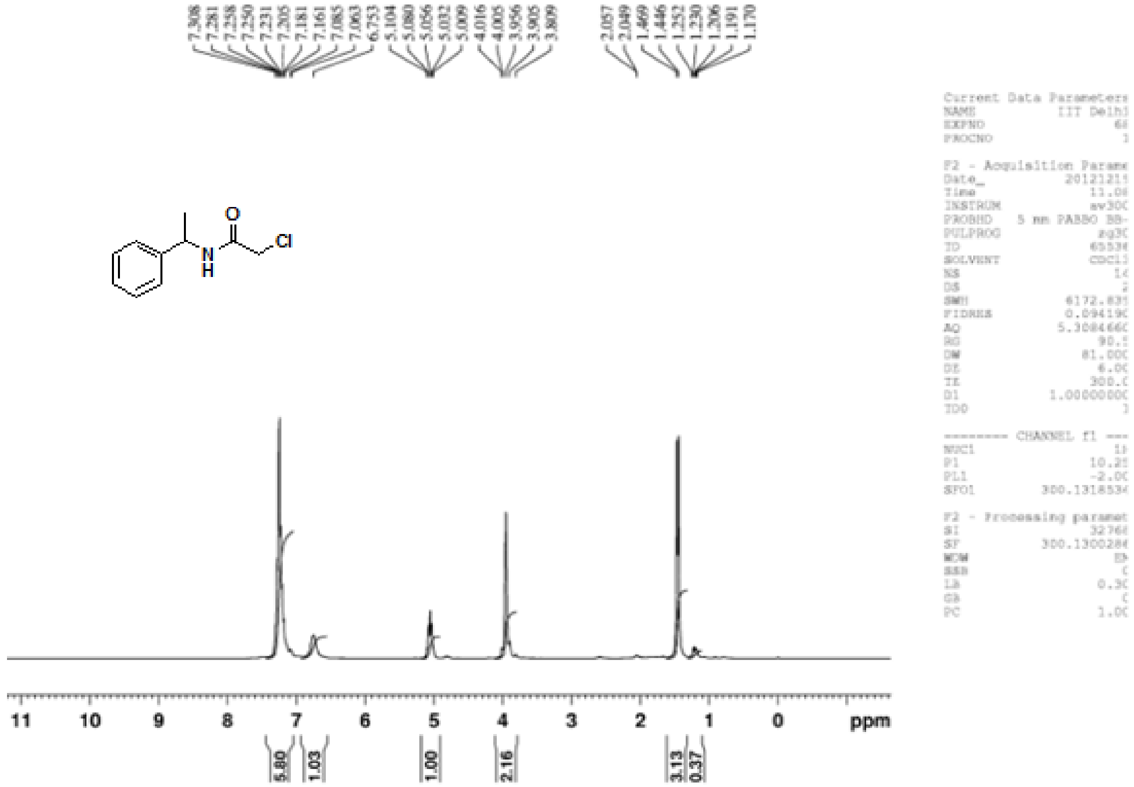


Figure 2. b) FT infrared spectrum of reused Nanocat-Fe-OSO_3H

Proton NMR spectra



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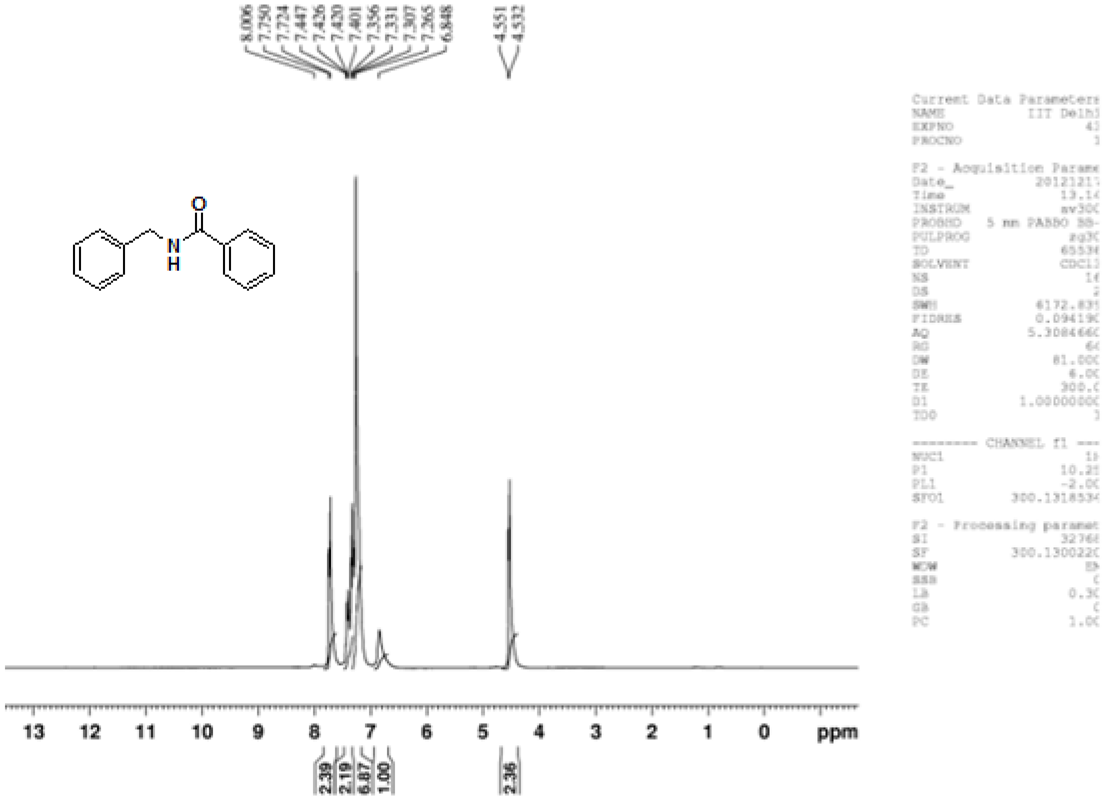
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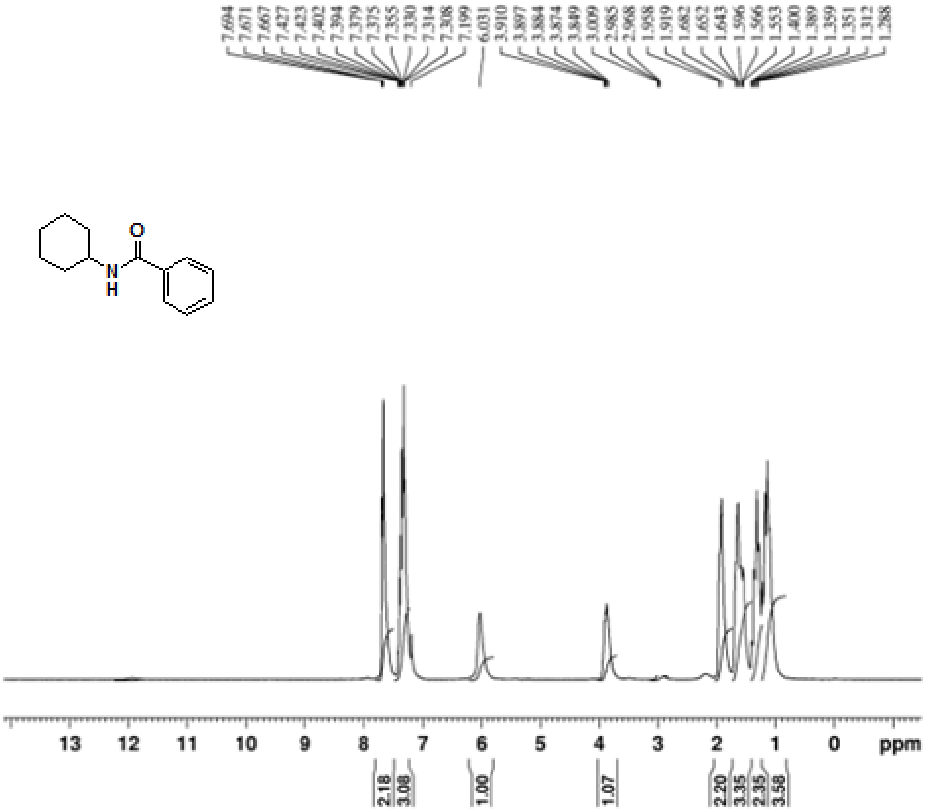

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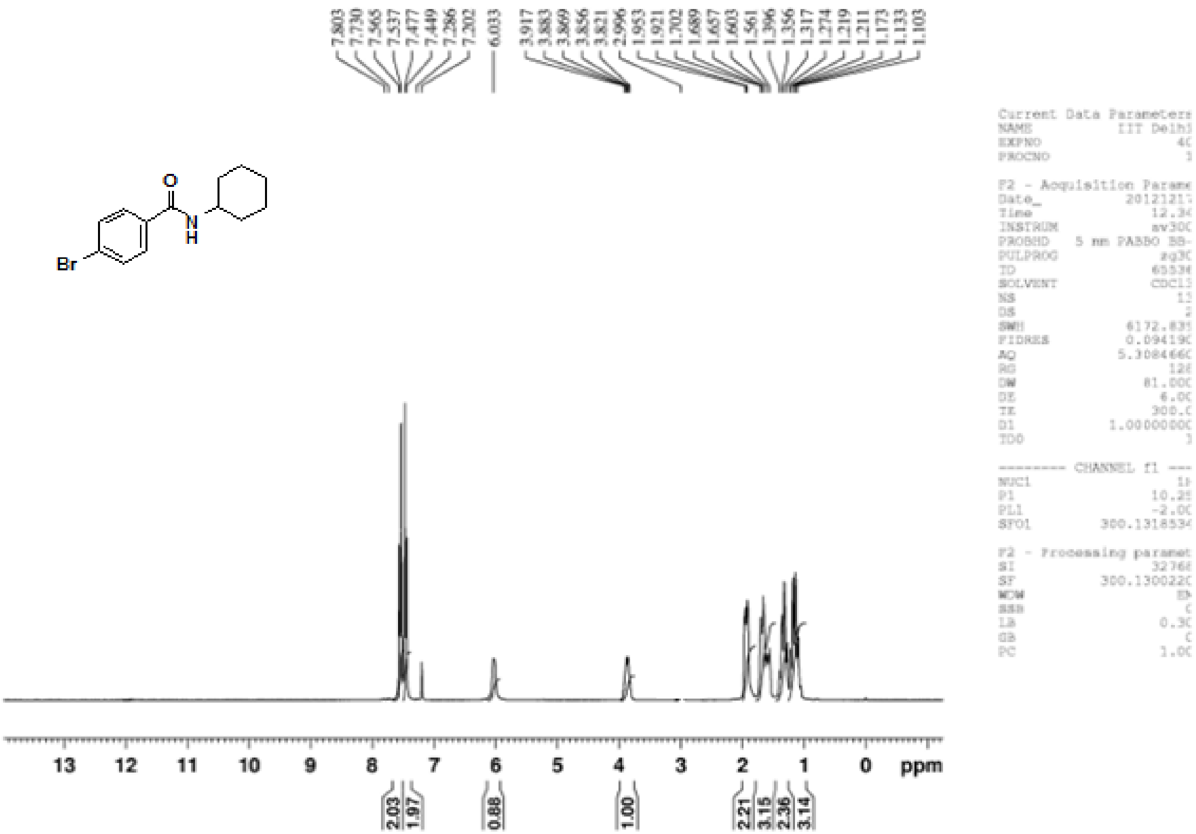
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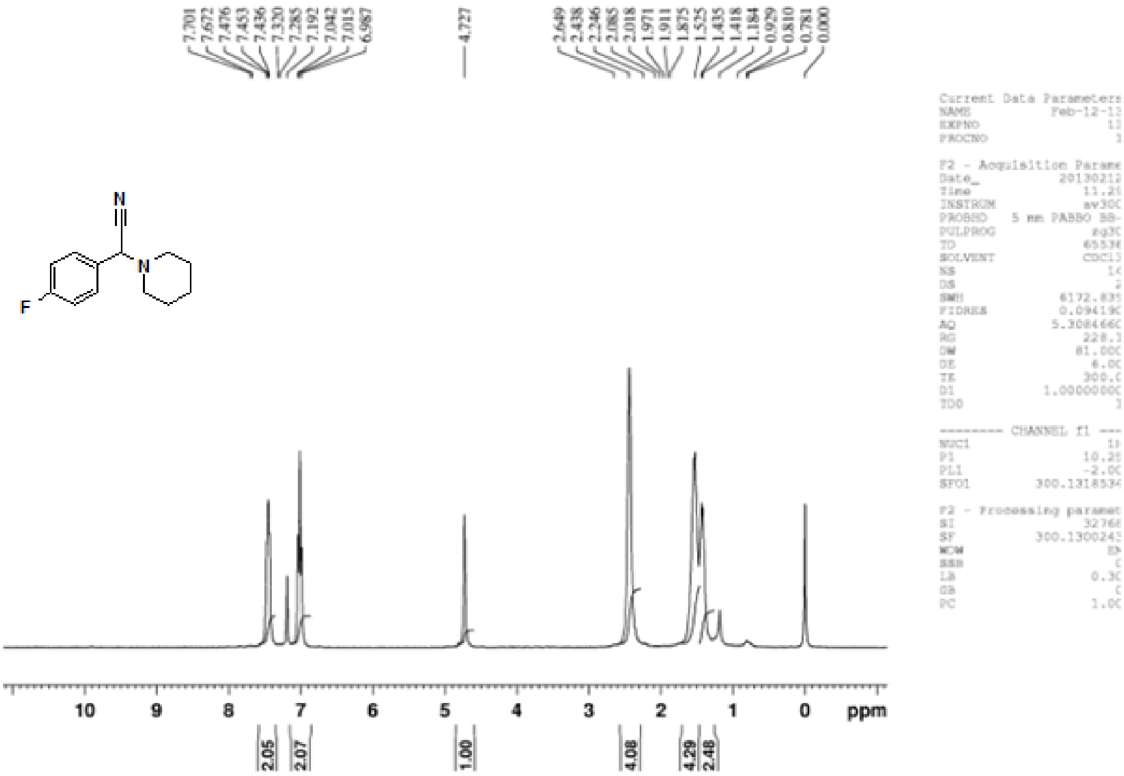
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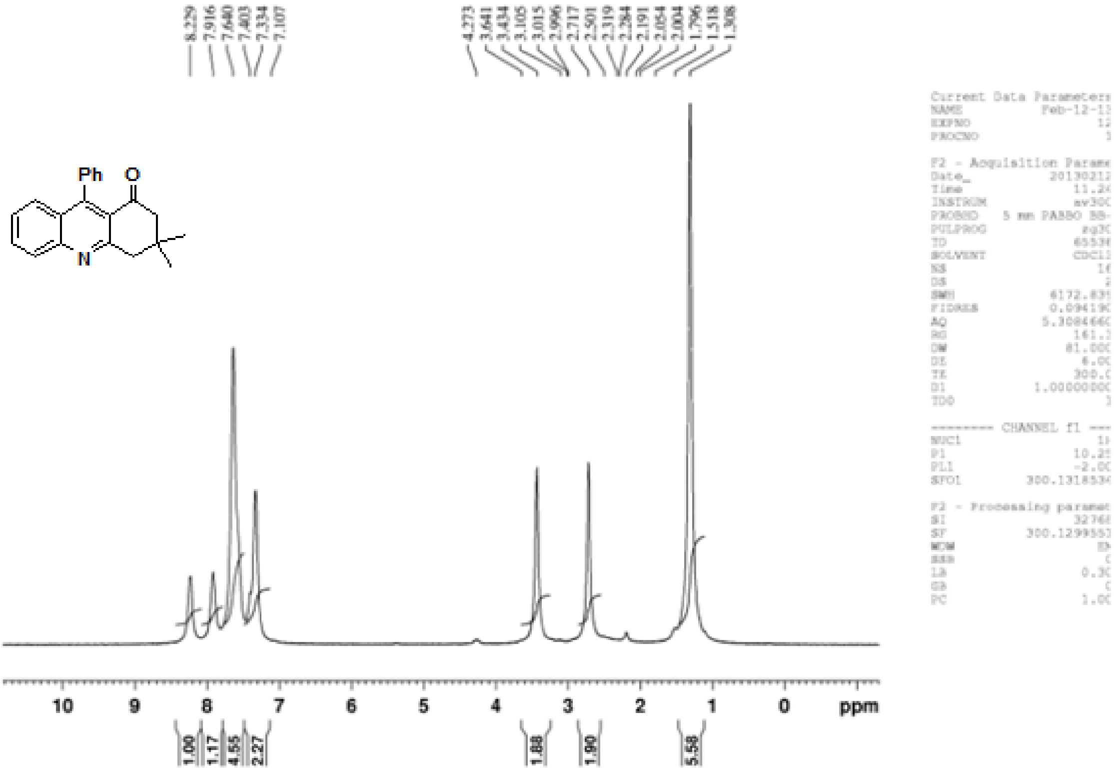
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