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# Copper sulphate immobilized on P(AN-NIPAM-MBAM) terpolymer as a highly efficient catalyst for the selective reduction of nitro-arenes

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A new copper sulphate anchored to an acrylonitrile-N-isopropylacrylamide-bisacrylamide based P(AN-NIPAM-MBAM) terpolymer support has been employed as a catalyst for the hydrogenation of varied substituted nitro-arenes affording corresponding amines with excellent yield. Application of hydrogen source from $NaBH_4$ in combination with NaOH under water and/or methanol solvent system at 50-55°C has been investigated. The terpolymer and catalyst have been characterized by ICP-OES, FT-IR, TGA, SEM and EDAX analysis methods. Different parameters supporting chemo-selective hydrogenation such as concentration of $NaBH_4$, TP-$CuSO_4$, assisting base and solvents have been investigated. Controllable vigorous $H_2$ gas evolution, low-temperature requirement, feasibility under air atmosphere, low catalyst loading, use of non-toxic reagents and solvents, high isolated yield, easy work-up procedure, purification without involving tedious column or flash chromatographic separation techniques, makes this protocol highly significant from the implementation point of view.

**Keywords**: Copper sulphate, Nitro-arenes, Hydrogenation, Heterogeneous catalyst

In view of evolving awareness towards human health and environmental conservation, in recent years, the necessity for green methodologies and clean reagents in organic synthesis has enthralled progressive attention. The general areas of investigation in green chemistry include selections of feedstocks, solvents, reagents, catalysts, reaction conditions and the design of safer chemicals. The amino groups and amino derivatives are chief synthones for the manufacturing of most pharmaceutical drugs, agrochemicals, pigments, dyes, pesticides, explosives, fibers, photographic and rubber chemicals, *etc*. leading to the compelling necessity of accelerating the production capacity of aniline and other aromatic amines.

Numerous methods have been developed and employed to accomplish this transformation through hydrogen transfer catalysts aid, some include the stochiometric assistance of hydrochloric acid with iron[1], Sn (Ref. 2) as well as Zn/$NH_4Cl$ (Ref. 3), Zn/NaOH/EtOH (Ref. 4), Al/$NH_4Cl$/MeOH (Ref. 5), $Mo(CO)_6$ (Ref. 6) have also been used. Further, some techniques were circumscribed to the surrogacy of reducing reagents such as hydrazine/Raney nickel[7], hydrazinium monoformate/Zn (Ref. 8), $N_2H_4$/ $Ru(bpy)_2$/hν (Ref. 9), $N_2H_4.H_2O/Fe_2O_3$/MgO (Ref. 10), $TiCl_4$-dialkyl tellurid[11], $Ru_3(CO)_{12}$ (Ref. 12), $(C_2H_5O)_2$ PCl (Ref. 13), metal sulfides[14] like $Fe_3S_4$, $Co_3S_4$, NiS, CuS, ZnS and sodium borohydride with transition metals like Mn, Fe, Ni, Cu, Ru, Rh, Pd, Os, Ir, and Pt salts[15]. Perhaps employing molecular hydrogen and palladium or platinum catalyst or Raney Nickel[16] is one of the most reasonable and effective industrial practices, due to the fact that, no side products, except water, are formed in the reaction. However despite notable effectiveness, formerly discussed methodologies are plagued by major operational constraints like the requirement for elevated temperature-pressure, product isolation, handling and restraining highly flammable hydrogen may impose significant risk, water sensitivity, expensiveness of some of the equipments, reagents mentioned, considerable issue of heat removal at industrial scale, cascading dehydrogenation reactions and lack of the desired selectivity during transformation over other functionality is being encountered. Nevertheless, the literature precedents demonstrate many synthetic routes for such transformations, the exploration for new mild, chemoselective, cost-effective, facile, recyclable, and greener hydrogenation methodologies that dodge the exercise of pricey and hazardous

reagents/catalysts, is still highly desirable and is the subject of attention too.

In the past few decades, the studies of heterogeneous polymer-supported catalysts have achieved an enormous boost from their implementation leading to prompt various organic transformation[17], among the reductive reactions and more distinctively hydrogenation reactions mostly rely on homogeneous transition metals catalysts to give effectual output and the ligands being a part of the asymmetric version are often very expensive to produce or purchase. To date, the chief drawbacks associated with homogeneous catalysts are their own isolation from the reaction products and the recycling of the expensive chiral catalyst. A potential resolution to get rid of this obstacle can be achieved by "heterogenizing" a homogeneous transition metal-based catalyst system, either by using a liquid-liquid two-phase system or by anchoring the catalyst system on the insoluble solid support of various polymer matrix, thus one can enhance their industrial applicability. As a consequence of solid-phase synthesis, this hybrid class of polymer-bound catalyst has emerged, facilitating the effectual isolation of the substrate or catalyst from the product catalyzed. Hitherto, varied inorganic or organic polymer support having both porous and non-porous nature polymers such as silica gels[18], polystyrene beads[19], clays[20], active coal[21], NIPAM-based microgels[22], nanoparticles[23], *etc*. are reported, these traditional polymer supports were either plagued by decreased catalytic efficacy, loss of selectivity, tedious monomer functional group modification for the better anchoring of the groups to the metal complex or leaching of metals. Nevertheless, chemoselective complete hydrogenation of varied nitro substrates with or without competing functionalities *via* complete suppression of plausible toxic potential intermediates or self-condensed colored products utilizing polymer-bound catalyst interface is seldom documented. This exhilarated us to explore the possibility of utilizing a cross-linked amide functionalized hydrophobic terpolymer as polymer support derived from acrylonitrile (AN), *N*-isopropylacrylamide (NIPAM) and bisacrylamide (MBAM). This terpolymer can facilitate the nitro-amine transformation more efficiently under the surrogacy of coordinated copper metal, which gets immobilized onto the support upon reacting with its $CuSO_4$ salt. This terpolymer contrary to the unique swelling nature of NIPAM-based hydrophilic hydrogel shows remarkable swelling ability in DMSO and DMF solvents, whereas it remains in the shrunken state under non-compatible lower molecular alcohols or water solvents. Our philosophy lies in fishing in the right place and casting the net as broad as possible, herein, we endeavored to report the simplest preparation of exceptional ligand-free, cheaper, low-temperature required, hydrophobic P(AN-NIPAM-MBAM) based terpolymer support for copper sulphate immobilization and explore its catalytic capability and tolerance to hydrogenate varied nitro substrates to the corresponding amine over other reducible groups, in prompted time with excellent yield utilizing a base(NaOH) and sodium borohydride ($NaBH_4$) under mild reaction condition, using $H_2O$ like a green solvent, without undergoing chemical modifications of the monomers.

## Experimental Section

### Materials

Acrylonitrile (AN) and N-isopropylacrylamide (NIPAM, 99%, Sigma Aldrich) as monomers, N,N'methylenebisacrylamide (MBAM, 99%, Sigma Aldrich) as the crosslinker, azobisisobutyronitrile (AIBN, 99%, Spectrochem) as the initiator and dimethyl formamide (DMF, 99%, SRL) as a solvent were used as received without further purification. Further, copper sulphate (99%, anhydrous, HIMEDIA) as a metal ion source operational under dimethyl sulfoxide (DMSO, 99%, SRL) solvent was used for terpolymer supported copper(II) catalyst while sodium borohydride ($NaBH_4$, 99%, Sigma Aldrich) was used as a hydrogen surrogate for reduction. Double distilled water (DD water) was used throughout all experimental studies.

### Characterization methods

The loading of copper sulphate in terpolymer-supported copper(II)sulphate catalyst was determined by using ICP-OES (Optima 8000; Perkin Elmer, Singapore). FT-IR spectra of the terpolymer and terpolymer supported copper(II) sulphate catalyst were recorded using a Bruker ALPHA II FTIR Spectrometer and KBr pellets. The thermal properties and the amount of copper sulphate entrapped inside the polymer network were determined with TG measurements using a thermal Analyzer (SDT Q600 TA instrument, Germany) upon heating from ambient to 700°C, 10°C/min heating rate into dynamic nitrogen flow 10 mL/min. The morphology of the terpolymer and supported copper sulphate catalyst

was determined using a scanning electron microscope (SEM, JEOL, JSM-6510 LV). The anchoring of copper metal on the polymer matrix, Energy-dispersive spectra were performed on Inca Energy 350 analyzer (Oxford Company, Oxford, UK). Thin-layer chromatography (TLC, on aluminum plates precoated with silica gel, 60F, 0.25 mm thickness) (Merck, Darmstadt, Germany) was used for monitoring the progress of all the reactions. The melting points of all the titled compounds were determined by an open-tube capillary method and are uncorrected. UV radiation and/or ninhydrin, iodine, permanganate, and 2,4-dinitrophenylhydrazine stains were used as the visualizing agents. $^{1}$H and $^{13}$C NMR spectra were recorded in $CDCl_3$ and DMSO solvent on a Bruker Advance 400F (MHz) spectrometer (Bruker Scientific Corporation Ltd, Switzerland) using the residual solvent signal as an internal standard at 400 MHz and 100 MHz respectively. Chemical shifts are reported in parts per million (ppm).

**Synthesis of P(AN-NIPAM-MBAM) terpolymer**

P(AN-NIPAM-MBAM) terpolymer was synthesized by free radical polymerization. In a typical terpolymer synthesis procedure, the three-neck round bottom flask equipped with a Teflon-coated condenser, thermopocket, and magnetic needle containing, (1.59 g, 3.0 mmol) AN, (1.13 g, 1.0 mmol) NIPAM monomers and MBAM (0.77 g, 0.5 mmol) as crosslinker was dissolved in 10 mL DMF and heated at 60-65°C. After achieving the desired temperature, 1-2 mg of AIBN initiator was added and maintained for 70 min., and the resulting pale-yellow colored and spongy terpolymer was precipitated. Upon cooling at RT, the precipitated terpolymer allows their easy recovery by acquiring a simple filtration process with subsequent thrice MeOH rinsing. Finally, P(AN-NIPAM-MBAM) terpolymer was dried under a vacuum oven at 60°C until a constant weight was achieved (3.49 g) (yield -99%) and then further used as polymer support.

**Immobilization of Copper(II) ions on P(AN-NIPAM-MBAM) terpolymer (TP-$CuSO_4$)**

To obtain Cu(II) immobilized terpolymer catalyst, the samples of (3.0 g) P(AN-NIPAM-MBAM) terpolymer suspended in (15 mL) DMSO reaction solvent, were placed into the two-neck round bottom flask, equipped with a Teflon-coated condenser, thermopocket, magnetic needle was stirred for 1 h at 60°C heat. Then a suitable quantity of (1.0 g) anhydrous copper sulphate was added to the reaction flask with swollen terpolymer and allowed to stir for 12 h for complete complexation. Thus, the formed light sky-coloured complex was cooled to RT before filtration. The catalyst was isolated upon washing with 2×10 mL water and dried under vacuum at 60°C until a constant weight was achieved (3.69 g).

**General procedure for hydrogenation of nitro compounds**

The catalytic performances of the polymer immobilized Cu(II) complex were explored for the hydrogenation reaction of varied substituted nitro compounds presented in Table 1. The three-neck round bottom flask equipped with a Teflon-coated condenser, thermopocket, and magnetic needle containing nitro substrate (1 mmol) suspended in water and/or methanol (0.5 mL) was stirred and heated at 50-55°C under an atmospheric environment. To this stirred solution, NaOH (0.06 mmol) and terpolymer-supported copper(II) sulphate catalyst (5% W/W) was added. Sequentially $NaBH_4$ (2.5 mmol) was carefully added and maintained for 45 min, with the addition of $NaBH_4$, black granular precipitate formation with concomitant ($H_2$) gas evolution was observed. As per TLC observation, the starting material was completely consumed within 45 min. After reaction completion, the reaction mixture was filtered off to remove the black solid, then extracted with EtOAc (2×2 mL), and the combined organic layer was washed with water (2×2 mL) and dried over anhydrous sodium sulphate. After filtration, the solvent was removed under vacuo affording the desired amine. It was observed that the purity of the crude product was more than 99% by $^{1}$H NMR, henceforth, to obtain a pure product no column or flash chromatographic separation technique was needed.

**Spectral data of representative compounds**

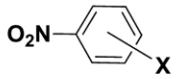
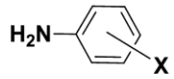
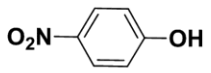
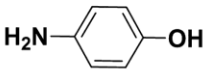
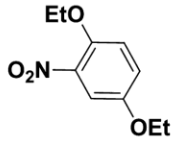
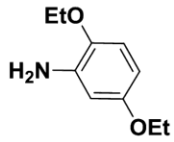
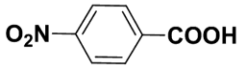
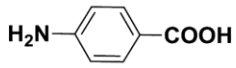
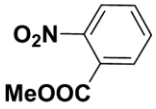
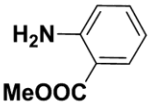
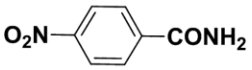
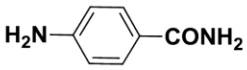
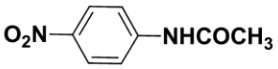
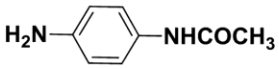
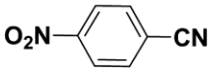
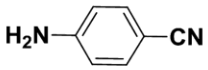
**2-Chloroaniline (Table 1, Entry-1a)** [24]

Pale yellow liquid. b.p. 208-210°C. Yield 98% (125 mg). $^{1}$H NMR (400 MHz, $CDCl_3$): δ 3.96 (br s, 2H, -$NH_2$), 6.69 (tt, 1H, *J*=7.8 Hz), 6.74 (dd, 1H, *J*=8 Hz), 7.06 (tt, 1H, *J*=7.6 Hz), 7.24 (dd, 1H, *J*=7.9 Hz); $^{13}$C NMR (100 MHz, $CDCl_3$): δ 116.04, 119.18, 119.44 (-*C*-Cl), 127.79, 129.57, 143.08 (-*C*-$NH_2$).

**4-Chloroaniline (Table 1, Entry-1b)** [25]

Colorless solid. m.p. 69-72°C. Yield 98% (125 mg). $^{1}$H NMR (400 MHz, $CDCl_3$): δ 3.57 (br s, 2H, -$NH_2$), 6.58 (d, 2H, *J*=8.6 Hz), 7.08 (d, 2H, *J*=8.6 Hz); $^{13}$C NMR (100 MHz, $CDCl_3$): δ 116.41, 123.31 (-*C*-Cl), 129.28, 145.14 (-*C*-$NH_2$).

Table 1 — Scope of TP-$CuSO_4$ catalyst [a]

| Sr. no. | Substrate | Product | Time (min.) | Conv. (%)/ Select. (%) [b] | Yield (%) [c] |
|---|---|---|---|---|---|
| 1 |  a: X= 2-Cl b: X= 4-Cl c: X= 4-Br d: X= 4-I |  a: X= 2-Cl b: X= 4-Cl c: X= 4-Br d: X= 4-I | a: 45 b: 45 c: 45 d: 45 | a: <99/<99 b: <99/<99 c: <99/<99 d: <99/<99 | a:98 b: 98 c: 96 d: 95 |
| 2 |  |  | 45 | <99/<99 | 97 |
| 3 |  |  | 45 | <99/<99 | 98 |
| 4 |  |  | 45 | <99/<99 | 92 |
| 5 |  |  | 45 | <99/<99 | 95 |
| 6 |  |  | 45 | <99/<99 | 99 |
| 7 |  |  | 45 | <99/<99 | 99 |
| 8 |  |  | 45 | <99/<99 | 96 |

[a] Reaction condition: 50-55°C, 45 min., 1 mmol of the substrate, the molar ratio of $NaBH_4$ to the substrate is 2.5, the molar ratio of NaOH to the substrate is 0.06, 5% w/w of catalyst, 0.5 mL of water and/or methanol, [b] Conversion (%) and selectivity (%) determined by $^1$H NMR

**4-Bromoaniline (Table 1, Entry-1c)** [25]

Colorless solid. m.p. 58-61°C. Yield 96% (165 mg). $^1$H NMR (400 MHz, $CDCl_3$): δ 3.55 (br s, 2H, -$NH_2$), 6.54 (dt, 2H, *J*=8.8 Hz), 7.22 (dt, 2H, *J*=8.8 Hz); $^{13}$C NMR (100 MHz, $CDCl_3$): δ 110.36 (-*C*-Br), 116.89, 132.18, 145.61(-*C*-$NH_2$).

**4-Iodoaniline (Table 1, Entry-1d)** [25]

Brown solid. m.p. 61-63°C. Yield 95% (208 mg). $^1$H NMR (400 MHz, $CDCl_3$): δ 3.66 (br s, 2H, -$NH_2$), 6.43 (d, 2H, *J*=7.9 Hz), 7.39 (d, 2H, *J*=7.9 Hz); $^{13}$C NMR (100 MHz, $CDCl_3$): δ 79.38 (-*C*-I), 117.37, 137.87, 146.13 (-*C*-$NH_2$).

**4-Aminophenol (Table 1, Entry-2)** [26]

Off-white solid. m.p.186-189°C. Yield 97% (105 mg). $^1$H NMR (400 MHz, DMSO-$d_6$): δ 4.36 (br s, 2H, -$NH_2$), 6.34-6.60 (m, 4H, -Ph), 8.35 (br s, 1H, -OH); $^{13}$C NMR (100 MHz, DMSO-$d_6$): δ 115.31, 115.58, 140.61 (-*C*-OH), 148.27 (-*C*-$NH_2$).

**2,5-Diethoxyaniline (Table 1, Entry-3)** [27]

Blackish-red solid. m.p. 85-87°C. Yield 98% (177 mg). $^1$H NMR (400 MHz, $CDCl_3$): δ 1.34 (t, 3H, *J*=7 Hz, $CH_3$), 1.37 (t, 3H, *J*=7 Hz, $CH_3$), 3.78 (br s, 2H, -$NH_2$), 3.92 (q, 2H, *J*=7 Hz, $CH_2$), 3.97 (q, 2H, *J*=7 Hz, $CH_2$), 6.20 (dd, 1H, *J*=8.7 Hz), 6.30 (d, 1H, *J*=2.9 Hz), 6.65 (d, 1H, *J*=8.7 Hz); $^{13}$C NMR (100 MHz, $CDCl_3$): δ 15.14 (-*C*$H_3$), 15.29 (-*C*$H_3$), 63.89 (-*C*$H_2$-), 64.78 (-*C*$H_2$-), 102.87, 103.17, 113.02, 137.65 (-*C*-$NH_2$), 141.19 (-*C*-OEt), 153.89 (-*C*-OEt).

**4-Aminobenzoic acid (Table 1, Entry-4)** [26]

White solid. m.p.186-189°C. Yield 92% (126 mg). $^1$H NMR (400 MHz, DMSO-$d_6$): δ 5.85 (br s, 2H, -$NH_2$), 6.54 (dt, 2H, *J*=8.7 Hz), 7.62 (dt, 2H, *J*=8.7

Hz), 11.94 (br s, 1H, -COOH); $^{13}$C NMR (100 MHz, DMSO-$d_6$): δ 112.55, 116.90 (-*C*-COOH), 131.19, 153.10 (-*C*-$NH_2$), 167.46 (-*C*OOH).

**Methyl 2-aminobenzoate (Table 1, Entry-5)** [28]

Pale yellow liquid. b.p. 255-257°C. Yield 95% (143 mg). $^1$H NMR (400 MHz, $CDCl_3$): δ 3.85 (s, 3H, $CH_3$), 5.33 (br s, 2H, -$NH_2$), 6.64 (td, 1H, *J*=7.6 Hz), 6.67 (dd, 1H, *J*=8.2 Hz), 7.25 (td, 1H, *J*=7.8 Hz), 7.84 (dd, 1H, *J*=8 Hz); $^{13}$C NMR (100 MHz, $CDCl_3$): δ 51.73 (-*C*$H_3$), 111.22 (-*C*-COOMe), 116.79, 117.10, 131.42, 134.29, 150.21 (-*C*-$NH_2$), 168.73 (-*C*OOMe).

**4-Aminobenzamide (Table 1, Entry-6)** [26]

Off-white solid. m.p.181-184°C. Yield 99% (135 mg). $^1$H NMR (400 MHz, DMSO-$d_6$): δ 5.58 (br s, 2H, -$NH_2$), 6.52 (dt, 2H, *J*=8.6 Hz), 6.83 (br s, 1H, -CONH), 7.51 (br s, 1H, -CONH), 7.58 (dt, 2H, *J*=8.6 Hz); $^{13}$C NMR (100 MHz, DMSO-$d_6$): δ 112.45, 120.97 (-*C*-$CONH_2$), 129.08, 151.62 (-*C*-$NH_2$), 168.04 ((-*C*$ONH_2$).

**N-(4-Aminophenyl)acetamide (Table 1, Entry-7)** [29]

White solid. m.p. 164-167°C. Yield: 99% (149 mg). $^1$H NMR (400 MHz, DMSO-$d_6$): δ 1.95 (s, 3H, $CH_3$), 4.80 (br s, 2H, -$NH_2$), 6.48 (dt, 2H, *J*=8.7 Hz), 7.19 (dd, 2H, *J*=8.7 Hz), 9.47 (br s,1H, -NH); $^{13}$C NMR (100 MHz, DMSO-$d_6$): δ 23.64 (-*C*$H_3$), 113.78, 120.83, 128.57 (-*C*-$NHCOCH_3$), 144.54 (-*C*-$NH_2$), 167.17 (-NH*C*$OCH_3$).

**4-Aminobenzonitrile (Table 1, Entry-8)** [30]

Off-white solid. m.p. 82-85°C. Yield 96% (113 mg). $^1$H NMR (400 MHz, $CDCl_3$): δ 4.20 (br s, 2H, -$NH_2$), 6.61 (dt, 2H, *J*=8.8), 7.36 (dt, 2H, *J*=8.8 Hz); $^{13}$C NMR (100 MHz, $CDCl_3$): δ 100.12 (-*C*-CN), 114.58, 120.37 (-*C*N), 133.93, 150.70 (-*C*-$NH_2$).

## Results and Discussion

Fig. 1 portrays a schematic representation of the P(AN-NIPAM-MBAM) terpolymer-supported copper sulphate catalyst preparation.

As shown in the figure, due to the electrostatic interaction between copper ions and cyano (-CN), amide (-$CONH_2$) functional groups of the P(AN-NIPAM-MBAM) terpolymer network, the copper ion can be loaded into the terpolymer. The amount of copper sulphate loaded in the terpolymer was determined by using ICP-OES, it was observed that 99.5 mg copper ion was absorbed by 1 g dry terpolymer.

The approaches of copper metal onto the polymer support were confirmed by relative divergence or compression of the FT-IR spectral bands of the polymer-supported copper catalyst over the polymer (Fig. 2a,b). Polymer exhibited a broad band at 3387 $cm^{-1}$ which is allocated to N-H (secondary amide) stretching frequency, while the position of this band is slightly shifted to 3384 $cm^{-1}$ and also shriveling of this band clearly suggests that the complexation of the N-H group to copper metal. The weak C-H stretching bands observed at 2974, 2935 $cm^{-1}$ also shifted to 2973, 2933 $cm^{-1}$respectively and shorten as well. The nitrile -C≡N stretching band at 2244 $cm^{-1}$ is slightly shifted to frequency 2242 $cm^{-1}$, and highly compressed due to the major involvement of this functional group in complexation. Interestingly, the characteristic amide C=O stretching band observed at 1656 $cm^{-1}$ is moderately short without changing its position. The intense overlapped broad band observed around 1280–1400 $cm^{-1}$ is confirming the presence of copper(II) ions[31]. Moreover, the presence of copper sulphate was confirmed by bands at 617, and 975 $cm^{-1}$ and also by overlapped broadband around 1095 $cm^{-1}$ [32].

The scanning electron micrographs of terpolymer (Fig. 3a) indicate the formation of porous material, while terpolymer supported copper sulphate catalyst Fig. 3b) clearly demonstrated the morphological change due to complexation and suggests the loading of copper sulphate.

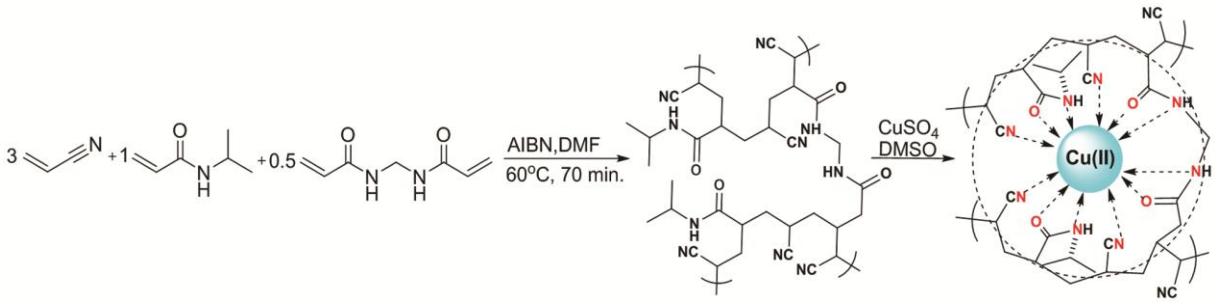



Fig. 1 — Schematic representation of the preparation of P(AN-NIPAM-MBAM) terpolymer and P(AN-NIPAM-MBAM) terpolymer supported copper sulphate catalyst

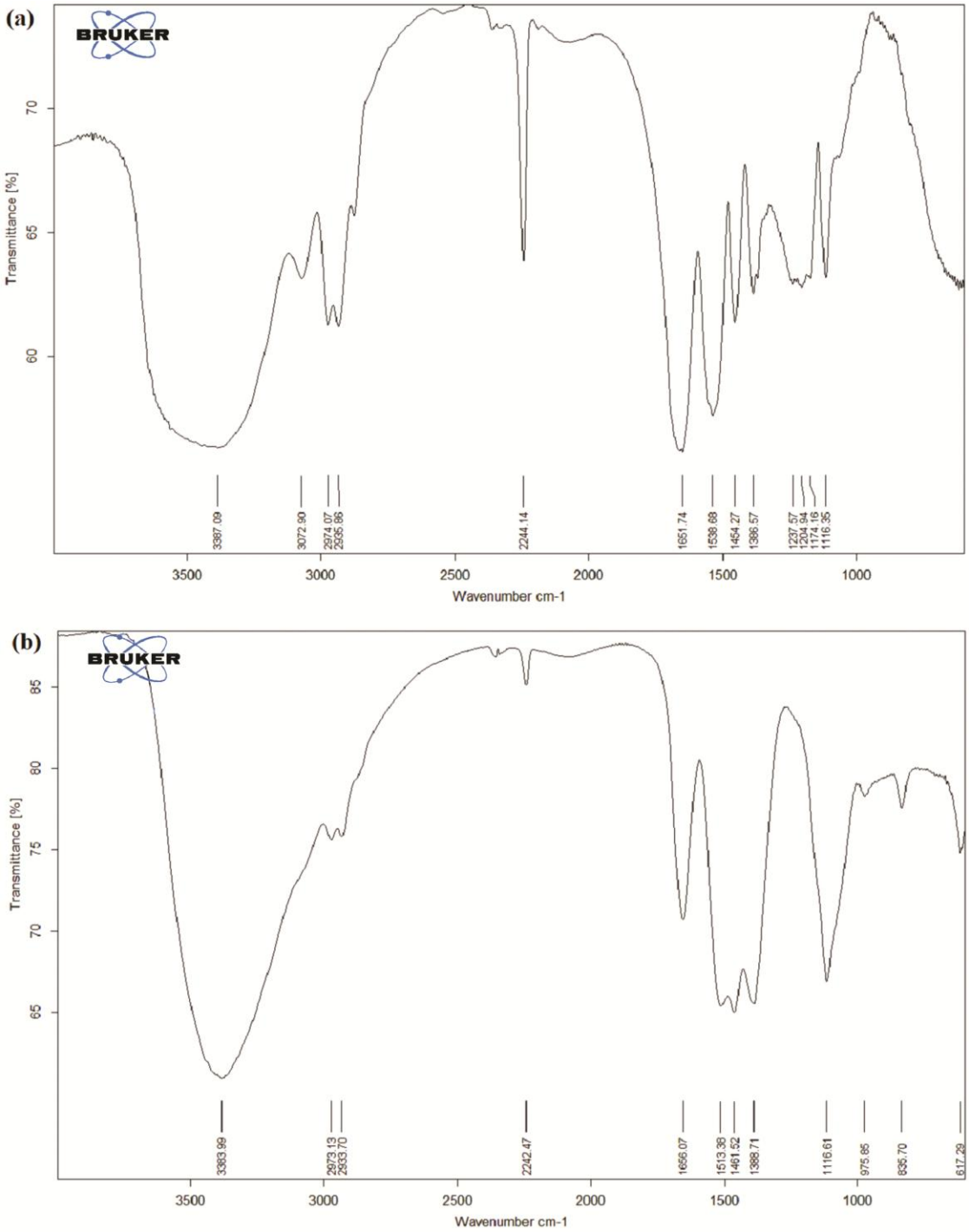



Fig. 2 — FT-IR spectra of (a) P(AN-NIPAM-MBAM) terpolymer and (b) P(AN-NIPAM-MBAM) terpolymer supported copper sulphate catalyst

The thermal properties and the amount of copper sulphate entrapped inside the polymer network determined by the thermogravimetric analyzer (TGA), were performed for pure and composite terpolymer.

About 2.394 mg terpolymer and 2.146 mg composite terpolymer were grinded and taken in the ceramic pan of the TGA and heated from ambient to 700°C, at a heating rate of 10°C/min into a dynamic nitrogen flow of 10 mL/min. Fig. 4a demonstrates TG-DTG curves of P(AN-NIPAM-MBAM) terpolymer, while Fig. 4b P(AN-NIPAM-MBAM) terpolymer supported copper sulphate catalyst. TG-

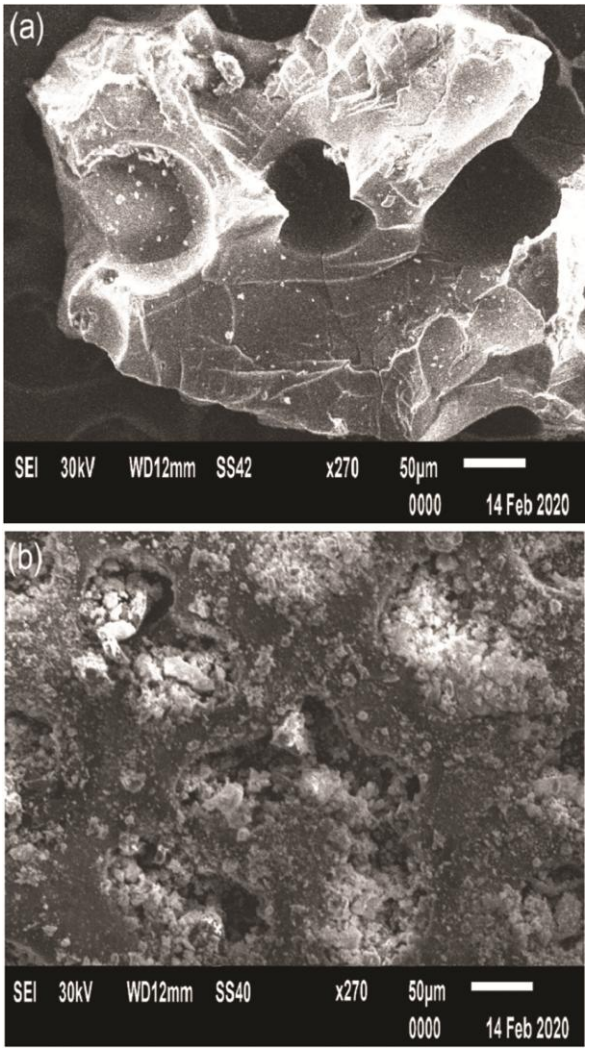



Fig. 3 — SEM images of (a) P(AN-NIPAM-MBAM) terpolymer and (b) P(AN-NIPAM-MBAM) terpolymer supported copper sulphate catalyst

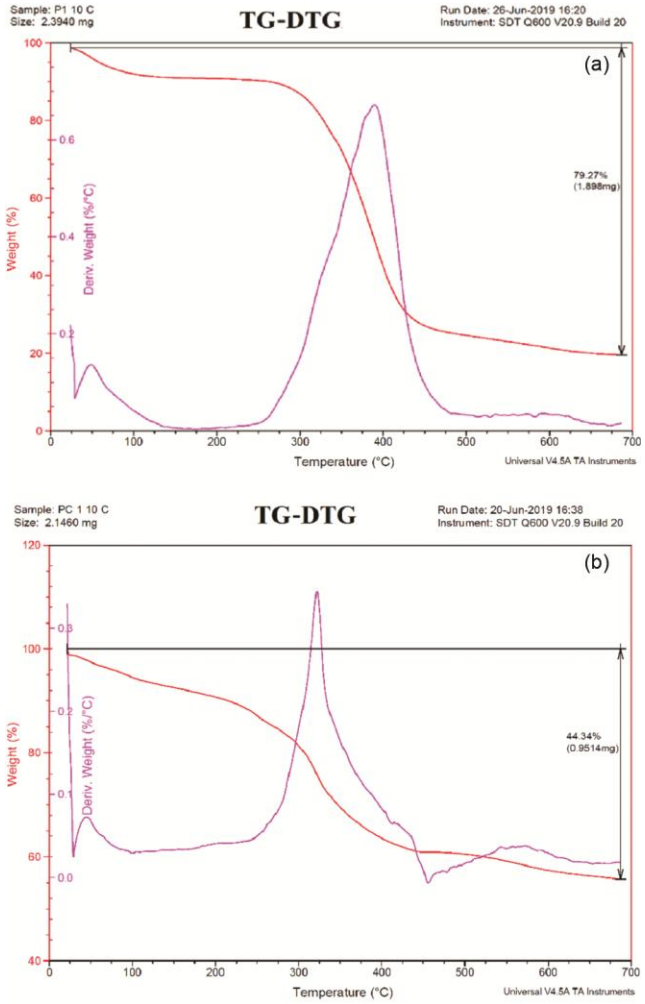
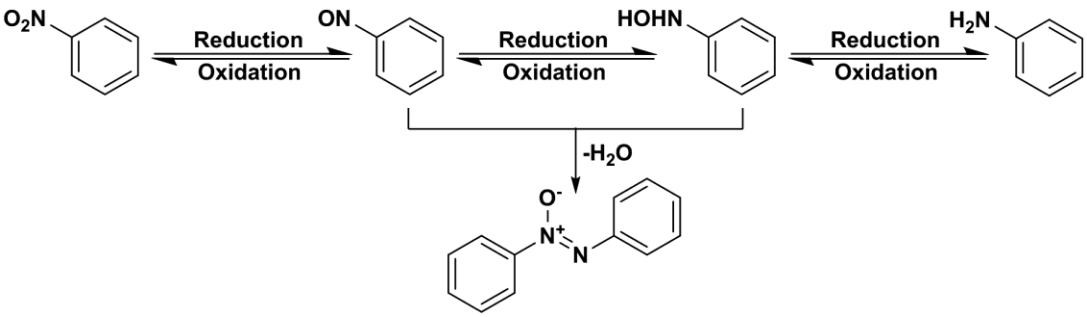



Fig. 4 — TG-DTG thermogram of (a) P(AN-NIPAM-MBAM) terpolymer and (b) P(AN-NIPAM-MBAM) terpolymer supported copper sulphate catalyst

DTG curves of pure and composite terpolymer clearly show that there were two degradation events of weight loss. The first is a minor event corresponding to around 9% and 13% weight loss, caused by water or volatile substances evaporation at less than 250°C for both pure and composite terpolymer. The second major event of weight loss occurred in the range of 250–500°C for both pure and composite terpolymer with the decomposition of around 66% and 27% respectively caused by the degradation of the polymer. However, A clear difference that has been observed in TG experiments is that composite terpolymer exhibits better thermal stability than pure terpolymer.

The energy-dispersive X-ray (EDX) analyses of P(AN-NIPAM-MBAM) terpolymer Fig. 5a and P(AN-NIPAM-MBAM) terpolymer supported copper sulphate catalyst Fig. 5b were investigated, which clearly indicates the presence of copper sulphate inside the terpolymer.

Catalytic reduction of aryl nitro compounds to corresponding amines is a significant transformation reaction in the field of synthetic organic chemistry. However, when other functional groups are located on an aryl ring or as a substituent of nitroarene, then selective hydrogenation of the nitro group becomes quite challenging, as it transforms through the involvement of aryl nitroso and aryl hydroxylamine intermediates[33], which can sometimes also be isolated. Whilst azoxybenzene intermediates may also be procured from *in situ* subsequent condensation of aforementioned intermediate species (Scheme 1) and to a vast extent, in dealing with hydrogenation of




Scheme 1 — Intermediates involved in the reduction of nitro compounds

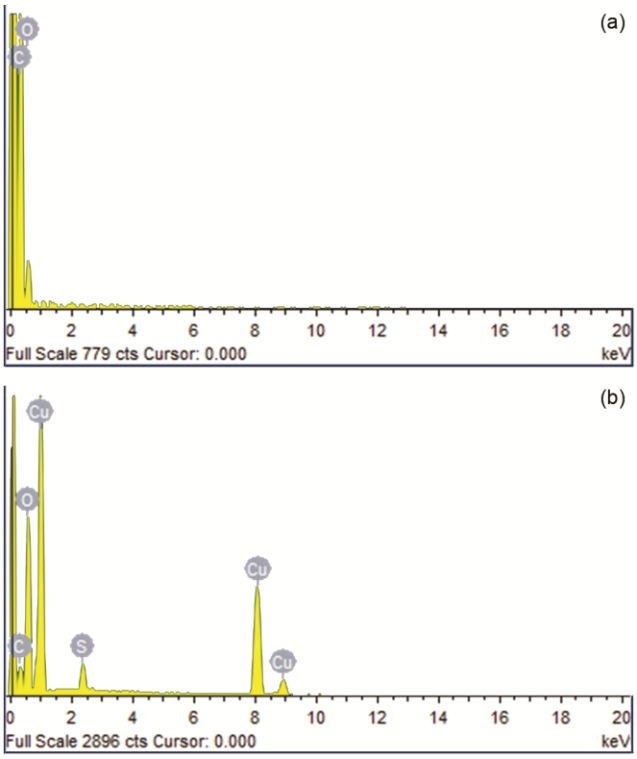



Fig. 5 — EDAX data of (a) P(AN-NIPAM-MBAM) terpolymer and (b) P(AN-NIPAM-MBAM) terpolymer supported copper sulphate catalyst

halogenated nitroarenes, there is a need to curb the dehalogenation issues too.

In synthetic chemistry and industrial fabrication of varied nitro-amine-based industrially essential products, the hydrogenation of substituted nitro-arene compounds to corresponding amines is an extremely crucial process. Certainly, the surrogacy of metal boron hydride (*i.e.*, $NaBH_4$) is the best alternative for the hydrogenation of nitro compounds under aqueous and/or alcoholic solution conditions. Sodium borohydride is soluble in protic solvents such as water and lower alcohols, and unstable in an acidic medium, it decomposes in neutral or acidic aqueous/alcoholic solutions but is stable at *p*H 14 (Ref. 34). In the presence of transition metals, it reacts with polar protic solvents leading to vigorous evolution of $H_2$ gas, it becomes more vigorous at a higher temperature (Equation 1) [35].

$$2Cu^{2+}(aq.) + 4BH_4^-(aq.) + 12\ H_2O \rightarrow 2Cu(s) + 14H_2 + 4B(OH)_3$$

Equation 1 — Degradation of $NaBH_4$ in the presence of copper metal and water

Therefore, the commercial application of sodium borohydride with transition metal catalysis is unviable. By adhering to the former fact that, sodium borohydride is stable at higher *p*H, it can be controlled by the addition of a proper base to increase the *p*H of reaction mass thus minimizing the vigorous $H_2$ gas evolution property without losing its reduction capability. However, the addition of a base decreases the rate of reaction, but it is quite necessary for the commercial applicability of the catalyst. In our experiment, we observed some valuable results listed in Table 2 and Table 3.

Hydrogenation of especially halogen-substituted nitroarenes is an extremely tedious transformation and it is well known that the use of alkali metal bases promotes dehalogenation, however, the controlled crucial quantity of these bases would not only enhance the catalytic effect but also be able to manage the vigorous effervescence effect of $NaBH_4$. The preliminary assessment of the catalyst performance was primarily carried out for the hydrogenation of nitrobenzene (Scheme 2) substrate under water and/or methanol solvent medium at 50-55°C. $NaBH_4$ (2.5 equiv. to the substrate), was used as the hydrogen source and the consequence of basic NaOH concentration over the reaction conversion and its selectivity were investigated first (Table 2).

It was observed that the hydrogenation of nitrobenzene under the presence of Cu-polymer catalyst and $CuSO_4$ was much facilitated upon increasing the molar ratio of NaOH from 0.01-0.06,

Table 2 — Influence of NaOH concentration on the reduction of nitrobenzene [a]

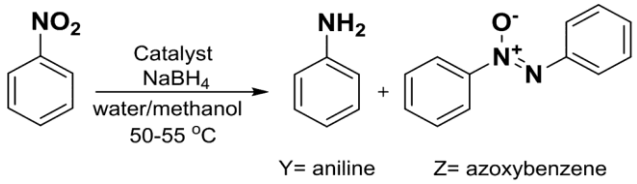
| Sr. no. | NaOH [b] | No-catalyst | | | $CuSO_4$ | | | TP-$CuSO_4$ | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Conversion (%) [c] | Selectivity (%) [d] | | Conversion (%) [c] | Selectivity (%) [d] | | Conversion (%) [c] | Selectivity (%) [d] | |
| | | | Y | Z | | Y | Z | | Y | Z |
| 1 | 0.01 | <05 | - | <05 | 66 | 31 | 35 | 81 | 72 | 09 |
| 2 | 0.02 | 08 | - | 08 | 57 | 25 | 32 | 86 | 78 | 06 |
| 3 | 0.03 | 12 | - | 12 | 48 | 20 | 28 | 91 | 87 | 03 |
| 4 | 0.04 | 16 | - | 16 | 40 | 15 | 25 | 95 | 94 | 01 |
| 5 | 0.05 | 19 | - | 19 | 32 | 11 | 21 | >99 | >99 | - |
| 6 | 0.06 | 24 | - | 24 | 24 | 7 | 17 | >99 | >99 | - |

[a] Reaction condition: 50-55°C, 45 min., 1 mmol of nitrobenzene, [b] the molar ratio of NaOH to the substrate, the molar ratio of $NaBH_4$ to the substrate is 2.5, 5% w/w of catalyst, 0.5 mL of water and/or methanol, [c, d] Conversion (%) and selectivity (%) determined by $^1$H NMR, Y=Aniline, Z=Azoxybenzene

Table 3 — Effect of various bases on the reduction of nitrobenzene [a]

| Sr. no. | Base [b] | No-catalyst | | | $CuSO_4$ | | | TP-$CuSO_4$ | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Conversion (%) [c] | Selectivity (%) [d] | | Conversion (%) [c] | Selectivity (%) [d] | | Conversion (%) [c] | Selectivity (%) [d] | |
| | | | Y | Z | | Y | Z | | Y | Z |
| 1 | - | | <01 | | >99 | >99 | - | >99 | >99 | -- |
| 2 | NaOH | 24 | <01 | 24 | 24 | 7 | 17 | >99 | >99 | -- |
| 3 | KOH | 23 | <01 | 23 | 25 | 7 | 18 | >99 | >99 | -- |
| 4 | $K_2CO_3$ | <1 | -- | -- | 95 | 95 | -- | 95 | 95 | -- |
| 5 | NaOAc | <1 | -- | -- | 96 | 96 | -- | 96 | 96 | -- |
| 6 | $NH_3$ | <1 | -- | -- | 71 | 49 | 22 | 88 | 81 | 07 |
| 7 | $EtNH_2$ | <1 | -- | -- | 76 | 52 | 24 | 91 | 86 | 05 |
| 8 | $Et_2NH$ | <1 | -- | -- | 65 | 40 | 25 | 89 | 83 | 06 |
| 9 | n-$Bu_3N$ | <1 | -- | -- | 35 | 35 | -- | 51 | 51 | -- |
| 10 | TEA | <1 | -- | -- | 36 | 36 | -- | 56 | 56 | -- |

[a] Reaction condition: 50-55°C, 45 min., 1 mmol of nitrobenzene, [b] the molar ratio of base to the substrate is 0.06, the molar ratio of $NaBH_4$ to the substrate is 2.5, 5% w/w of catalyst, 0.5 mL of water and/or methanol, [c, d] Conversion (%) and selectivity (%) determined by $^1$H NMR, Y=Aniline, Z=Azoxybenzene




Scheme 2 — The reduction of nitrobenzene

Nevertheless, the conversion and selectivity under the former condition were extremely outstanding than the latter condition. The 0.06 molar ratio of the NaOH base with the assistance of the TP-$CuSO_4$ catalyst leads to 99% conversion of nitrobenzene into aniline (Y) within 45 min whereas, under the latter condition, only 24% conversion was noted. Under the non-catalytic condition, the formation of azoxybenzene (Z) was observed as a major product with poor conversion. Under the influence of a minimum amount of NaOH, only 81% conversion was observed for the TP-$CuSO_4$ catalyzed reaction. Interestingly, under the presence of a $CuSO_4$ catalyst, the conversion to azoxybenzene than aniline declined with an increasing molar ratio of NaOH.

We further screened the efficacy of different bases (Table 3). It was observed that other inorganic bases such as KOH, $K_2CO_3$, NaOAc and $NH_3$ all though gave good selective conversion, but they failed in controlling the effervescence generated upon $H_2$ gas evolution. Under the administration of TP-$CuSO_4$ catalyst, like superior NaOH assistance, the simulation of KOH under reaction medium resulted in 99% conversion to aniline (Y) (Table 3, entry -2,3). However, under the influence of $CuSO_4$ salt, the same was not true. Under non-catalytic conditions, the former two bases lead to the formation of azoxybenzene (Z). $NH_3$ catalyzed reduction produced little amount of azoxy benzene (Z). Further influence of organic bases such as $EtNH_2$, $Et_2NH$, n-$Bu_3N$ and TEA have also been tested and it was noted that all of them under non-catalytic reaction conditions were reluctant towards hydrogenation with zero

conversion. However, under the persistence of $CuSO_4$ catalyzed reaction conditions, $EtNH_2$ and $Et_2NH$ resulted in a mixture of products, whereas n-$Bu_3N$ and TEA selectively afforded aniline (Y) as a major product with low conversion. In the case of the TP-$CuSO_4$ catalyzed reaction, selective conversion of aniline is pretty good but no remarkable governance on the $H_2$ gas effervescence was observed. From Table 3 we can clearly conclude that $CuSO_4$ gives good selective conversion of aniline in the absence of bases, but it loses selectivity and conversion probably due to complexation with base. However, in the case of TP-$CuSO_4$, it opposes the complexation and hence can give significant selectivity and conversion (Ta ble 3, entry-1). Among all bases, we choose NaOH with TP-$CuSO_4$, because it has a high capability to control $H_2$ gas effervescence using a very low amount of it. Hence, from the operational point of view, the assistance of the NaOH base along with $NaBH_4$ increases the applicability of this protocol at the industrial level.

Further, to establish the general applicability of our delight TP-$CuSO_4$ catalyst, our investigation tuned towards the screening of appropriate solvent under charisma of required $NaBH_4$ and NaOH concentration for hydrogenation reaction (Table 4).

It was witnessed that the solvent-less condition doesn't support the nitro-amine transformation reaction at all. The screening results revealed that water and methanol were the most promising solvent for the selective transformation into aniline (Y) with excellent conversion. The alcoholic solvents such as ethanol, 2-propanol, 1-propanol and PEG-400 facilitated the catalytic transformation into aniline (Y) with very low conversion. Whereas, a mixture of products was obtained with higher conversion (>99) under a 1-butanol solvent system Under perseverance of other polar aprotic solvent systems such as acetonitrile, DMF, DMSO and DMAC, remarkably supported the transformation to azoxy benzene (Z) as a major product during catalytic reduction. Nonetheless, the DMSO exhibited the highest conversion among them. The presence of non-polar solvents, ethyl acetate, toluene, cyclohexane, chloroform, DCM, THF and 1,4-dioxane, constrains the hydrogenation with no conversion at all.

The varied concentration of our TP-$CuSO_4$ catalyst was also the subject of further experimental investigation (Table 5). It was interestingly observed that the selectivity to aniline (Y) product with the excellent conversion from 20% to >99% was achieved progressively upon increasing the concentration of TP-$CuSO_4$ catalyst up to 5% w/w with respect to substrate quantity.

Table 5 — Influence of catalyst concentration on the reduction of nitrobenzene [a]

| Sr. no. | TP-$CuSO_4$ Conc. (% w/w) [b] | Conversion (%) [c] |
|---|---|---|
| 1 | 1.0 | $^{Y}$20 |
| 2 | 2.0 | $^{Y}$41 |
| 3 | 3.0 | $^{Y}$69 |
| 4 | 4.0 | $^{Y}$88 |
| 5 | 5.0 | $^{Y}$>99 |

[a] Reaction condition: 50-55°C, 45 min., 1 mmol of nitrobenzene, the molar ratio of $NaBH_4$ to the substrate is 2.5, the molar ratio of NaOH to the substrate is 0.06, 0.5 mL of water and/or methanol, [b] % w/w of catalyst, [c] Conversion (%) determined by $^1$H NMR, Y=Aniline, Z=Azoxybenzene

Table 4 — Effect of various solvents on the reduction of nitrobenzene [a]

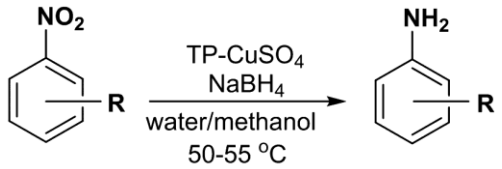
| Sr. no. | Solvents [b] | TP-$CuSO_4$ Conversion (%) [c] | Selectivity (%) [d] | |
|---|---|---|---|---|
| | | | Y | Z |
| 1 | No solvent | -- | -- | -- |
| 2 | Water | >99 | >99 | -- |
| 3 | Methanol | >99 | >99 | -- |
| 4 | Ethanol | 31 | 31 | -- |
| 5 | 2-Propanol | 07 | 07 | -- |
| 6 | 1-Propanol | 16 | 16 | -- |
| 7 | 1-Butanol | >99 | 82 | 17 |
| 8 | PEG-400 | 14 | 14 | -- |
| 9 | Acetonitrile | 32 | -- | 32 |
| 10 | DMF | 21 | -- | 21 |
| 11 | DMSO | >99 | -- | 99 |
| 12 | DMAC | 56 | -- | 56 |

[a] Reaction condition: 50-55°C, 45 min., 1 mmol of nitrobenzene, the molar ratio of $NaBH_4$ to the substrate is 2.5, the molar ratio of NaOH to the substrate is 0.06, 5% w/w of catalyst, [b] 0.5 mL of Solvent, [c, d] Conversion (%) and selectivity (%) determined by $^1$H NMR, Y=Aniline, Z=Azoxybenzene

Table 6 — Influence of $NaBH_4$ concentration [a]

| Sr. no. | $NaBH_4$ [b] | Conversion (%) [c] |
|---|---|---|
| 1 | 0.5 | $^{Y}23$ |
| 2 | 1.0 | $^{Y}48$ |
| 3 | 1.5 | $^{Y}72$ |
| 4 | 2.0 | $^{Y}91$ |
| 5 | 2.5 | $^{Y}>99$ |
| 6 | 3.0 | $^{Y}>99$ |

[a] Reaction condition: 50-55°C, 45 min., 1 mmol of nitrobenzene, [b] the molar ratio of $NaBH_4$ to the substrate, the molar ratio of NaOH to the substrate is 0.06, 5% w/w of catalyst, 0.5 mL of water and/or methanol, [c] Conversion (%) determined by $^1$H NMR, Y=Aniline, Z=Azoxybenzene




Scheme 3 — The selective reduction of nitro-arene

Next, we ought to screen the optimum concentration of $NaBH_4$ suitable for the catalytic reduction of nitrobenzene to aniline. In this transformation experiment, we inspected that with the assistance of a TP-$CuSO_4$ catalyst, the effectual quantity of $NaBH_4$ required for former hydrogenation with complete conversion was 2.5 molar equiv. to the substrate (Table 6). The selectivity and conversion remain unaffected upon further increasing the concentration of hydrogen surrogate.

Finally, to assess the general competence of this catalytic system, varied substituted nitroarene (Scheme 3) was tested (Table 1). Halogen-substituted nitroarenes are key intermediates in the pesticides, dyes, drugs, herbicides, *etc*. based industries. Generally, the traditional synthetic routes for such chemistry are very harmful to the environment and selective hydrogenation of aromatic halo-nitro compounds to the corresponding halo-amine is the most appealing and worthy methodology, however, the process is difficult because of extensive dehalogenation[36]. Here, the implementation of our catalytic system proficiently reduced varied halogenated nitroaromatic compounds with excellent yield without enduring any dehalogenated or condensed side products was achieved. (Table 1, entry-1).

Similarly, from synthetic aspects, 4-aminophenol is an important building synthone for paracetamol production. Conventionally, 4-aminophenol is afforded by iron–acid reduction of 4-nitrophenol. The chief shortcoming of the iron–acid reduction protocol is the generation of a bulk quantity of Fe–FeO sludge leading to severe pollution hitch[37]. Consequently, the literature is replete with varied studies on nitro-amino phenol transformation[38-40]. Our protocol efficaciously reduces 4-nitrophenol with appreciable yield (Table 1, entry-2). Furthermore, ether, acid, ester, amide, anilide and nitrile functionalities were compatible with our applied tandem hydrogenation technique, chemoselectively affording the corresponding amine in 96-99% yield (Table 1, entry-3-8) with outstanding conversion.

## Conclusion

We have developed a mild, stable, effectual, chemoselective hydrogenation methodology of industrially significant nitroarenes with appreciable conversion and yield *via* complete suppression of plausible toxic potential intermediates or self-condensed colored products, operational under water or methanol green solvents at 50-55°C. Moreover, this protocol efficiently manages $H_2$ gas effervescence, unlike traditional transition metals-$NaBH_4$ reduction which represents industrial applicability. The P(AN-NIPAM-MBAM) terpolymer support was ascertained to be an eminent anchor for the $CuSO_4$. The bands of $CuSO_4$ in FT-IR, undegraded weight in TGA, morphological change in SEM and peaks of Cu, S in EDAX analyses clearly demonstrated the loading of copper sulphate. The catalytic procedure proceeds without any requirement of flammable $H_2$ gas, or pricey Pt/Pd metal, which is commonly used under traditional methodology.

## Supplementary Information

Supplementary information is available on the website http://nopr.niscpr.res.in/handle/123456789/58776.

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## Conflicts of interest

The authors declare no conflict of interest.

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## References


1 Hazlet S E & Dornfeld C A, *J Am Chem Soc*, 66 (1944) 1781.
2 Yamabe S & Yamazaki S, *J Phys Org Chem*, 29 (2016) 361.
3 Kelly S M & Lipshutz B H, *Org Lett*, 16 (2014) 98.
4 Singh D & Bansal G, *J Chem*, 1 (2004), https://doi.org/10.1155/2004/728245.
5 Nagaraja D & Pasha M A, *Tetrahedron Lett*, 40 (1999) 7855.
6 Iyer S & Kulkarni G M, *Synth Commun*, 34 (2004) 721.
7 Yuste F, Saldaña M & Walls F, *Tetrahedron Lett*, 23 (1982) 147.
8 Gowda S, Gowda B K K & Gowda D C, *Synth Commun*, 33 (2003) 281.
9 Hirao T, Shiori J & Okahata N, *Bull Chem Soc Jpn*, 77 (2004) 1763.
10 Kumbhar P S, Sanchez-Valente J & Figueras F, *Tetrahedron Lett*, 39 (1998) 2573.
11 Suzuki H & Hanazaki Y, *Chem Lett*, 15 (1986) 549.
12 Alper H & Amaratunga S, *Tetrahedron Lett*, 21 (1980) 2603.
13 Fischer B & Sheihet L, *J Org Chem*, 63 (1998) 393.
14 Piña S, Cedillo D M, Tamez C, Izquierdo N, Parsons J G & Gutierrez J J, *Tetrahedron Lett*, 55 (2014) 5468.
15 Osby J O, Heinzman, S W & Ganem, B, *J Am Chem Soc*, 108 (1986) 67.
16 Augustine R L, *Heterogeneous Catalysis for the Synthetic Chemist*, (CRC Press, Taylor & Francis Group) 2020, p. 672.
17 Clapham B, Reger T S & Janda K D, *Tetrahedron*, 57 (2001) 4637.
18 Sankarshana T, Soujanya J & Kumar A A, *Int J Chem React Eng*, 11 (2013) 347.
19 Ren C, Zhu X, Zhao N, Shen Y, Chen L, Liu S & Li Z, *Eur Polym J*, 119 (2019) 130.
20 Nagendrappa G, *Appl Clay Sci*, 53 (2011) 106.
21 Iwanow M, Gärtner T, Sieber V & König B, *Beilstein J Org Chem*, 16 (2020) 1188.
22 Seto H, Imai K, Hoshino Y & Miura Y, *Polym J*, 48 (2016) 897.
23 Schatz A, Reiser O & Stark W J, *Chem A Eur J*, 16 (2010) 8950.
24 Dasgupta H R, Mukherjee S & Ghosh P, *Tetrahedron Lett*, 60 (2019) 151028.
25 Vijaykumar G & Mandal S K, *Dalt Trans*, 45 (2016) 7421.
26 Prathap K J, Wu Q, Olsson R T & Dinér P, *Org Lett*, 19 (2017) 4746.
27 Hwu J R, Wong F F, Hwu J R & Shiao M J, *J Org Chem*, 57 (1992) 5254.
28 https://www.sigmaaldrich.com/spectra/fnmr/FNMR003787.PDF.
29 https://www.sigmaaldrich.com/spectra/fnmr/FNMR000010.PDF.
30 Sharma S, Kumar M, Kumar V & Kumar N, *J Org Chem*, 79 (2014) 9433.
31 Pozdnyakov A S, Emel'yanov A I, Kuznetsova N P, Ermakova T G, Bolgova Y I, Trofimova O M, Albanov A I, Borodina T N, Smirnov V I & Prozorova G F, *Synlett*, 27 (2016) 900.
32 Haber V, *Chem Zvesti*, 31 (1977) 190.
33 Grirrane A, Corma A & García H, *Science*, 322 (2008) 1661.
34 Banfi L, Narisano E, Riva R, Stiasni N, Hiersemann M, Yamada T & Tsubo T, *Encycl Reagents Org Synth*, (2014) 1. https://doi.org/10.1002/047084289X.rs052.pub3.
35 Glavee G N, Klabunde K J, Sorensen C M & Hadjipanayis G C, *Langmuir*, 10 (1994) 4726.
36 Baltzly R & Phillips A P, *J Am Chem Soc*, 68 (1946) 261.
37 Bawane S P & Sawant S B, *Can J Chem Eng*, 83 (2005) 508.
38 Shin K S, Choi J Y, Park C S, Jang H J & Kim K, *Catal Letters*, 133 (2009) 1.
39 Zheng Y, Ma K, Wang H, Sun X, Jiang J, Wang C, Li R & Ma J, *Catal Letters*, 124 (2008) 268.
40 Sarhan I, El-Essawy T, El-Bellihi A & Selim M M, *Egypt J Chem*, 57 (2014) 45.