NiO nanocomposites/rGO as heterogeneous catalysis for imidazole scaffolds with their applications in inhibiting DNA binding activity

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Supplementary material file

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1. General experimental details and methods

Materials and Instruments

Graphite powder (~200 mesh, 99.9%) and 3-aminopropyltriethoxysilane (3-APTES) were purchased from Alfa Aesar, India. NiCl₂.6H₂O was obtained from SRL, India. All other materials were used of AR grade. All chemical and solvents were used for this work without any further distillation.

X-ray diffraction patterns were obtained using X-ray diffractometer (Model No. D8 DISCOVER). X-Ray photoelectron spectroscopy (XPS) (PHI 5000 Versa Prob II, FEI Inc.) with Auger electron spectroscopy module was used for obtaining XPS spectra. Morphological characterization was carried out using TECNAI 200 kV Transmission Electron Microscopy (TEM) (Fei, Electron Optics) equipped with digital imaging and 35 mm photography system and Field Emission Scanning Electron Microscope (FESEM) Model No.- ZEISS Gemini SEM-500. Raman spectra were recorded by Renishaw in ViaTM Reflex Micro-Raman spectrometer using 514 nm wavelength Ar⁺ laser for sample excitation. Fourier-transform infrared spectroscopy Model No. Spectrum RXI - Mid IR Perkin Elmer, FTIR spectrometer with ATR & Specular reflectance.

2. UV-visible spectra and FT-IR analysis of nano-catalyst

UV-visible spectra of GO and rGO-NiO-Nanocomposites were used to check the change in absorbance which takes place during the catalyst formation are shown in **Fig.** *S1*(a). The UV-visible spectrum of GO shows a strong absorption peak at 228 nm and another peak appears at about 391 nm which corresponds to the π - π * transitions of the graphitic C–C bonds and to the n- π * transitions of the C=O bonds, respectively. UV-visible spectra of the rGO-NiO-NCs show a similar peak to the GO but the peak at 402 nm indicates the presence of d–d transitions of the Ni (II), which support successful immobilization of NiO nanocomposites.



Fig. S1. (a) The UV spectra of the (i) GO (ii) rGO-NiO-NCs, **(b)** The FTIR spectra of the (i). GO, (ii) rGO-NH₂, and (iii) rGO-NiO-NCs nano-catalyst, and (c), (d) The FTIR before and after nano-catalyst rGO-NiO-NCs respectively.

FTIR spectroscopy technique was used to examine the chemical changes that occurred during the immobilization of nickel oxide nanoparticle onto the surface of functionalized rGO. The FTIR spectra of all GO, rGO-NH₂, rGO-NiO-NCs are given in **Fig. S1 (b)**. The FTIR spectrum of GO exhibited strong characteristics bands at 3395, 2924, 1729, 1619, 1407, 1211, and 1035 cm⁻¹, due to the presence of functional group such as hydroxyl, phenolic, carbonyl, carboxylic, epoxy. The FTIR spectrum of rGO-NH₂, exhibited a doublet at 2942 and 2873 cm⁻¹, corresponding to the symmetric and asymmetric -CH₂ of the alkyl chains. Moreover, the bands observed at and 1026 cm⁻¹ were attributed to and Si–O–C linkages. The bands at 1634 cm⁻¹, due to N–H, confirms the successful chemical reduction of GO to rGO-NH₂. The FTIR spectrum of NiO-NCs added to rGO-NH₂ the FTIR frequencies were slightly shifted to higher frequencies at 1626 cm⁻¹, compared to rGO-NH₂, which clearly shows the successful immobilization of NiO-Nanocomposites onto the surface of modified imine based rGO. The FTIR before **Fig. S1 (c)** and after **Fig. S1 (d)** of nano-catalyst rGO-NiO-NCs.

3. Calculation of green chemistry matrix



E-factor:

E-factor signifies the total amount of waste generated in a chemical reaction which can be calculated by reducing the amount of product formed from the number of raw materials then divided by the total amount of product. The ideal value of E-factor is zero.

E-factor = [total mass of raw materials - the total mass of product]/ mass of product.

E-factor of 7g = [(0.105 + 0.075 + 0.077) - 0.17]/0.17

= 0.511

Process mass intensity (PMI):

Process mass intensity can be calculated by dividing the amount of product formed from the total amount of reactants used in the reaction.

 $PMI = \sum (mass of stoichiometric reactants)/[mass of product]$

=(0.105+0.075+0.077)/0.17

= 1.51.

Reaction mass efficiency (RME):

Reaction mass efficiency can be calculated by dividing the total amount of reactants used in the reaction from the amount of product formed.

RME = [mass of product \sum (mass of stoichiometric reactants)] \times 100

 $= [0.17/(0.105 + 0.075 + 0.077)] \times 100$ = 66.14%

Atom economy (AE):

Atom economy signifies the percentage of atoms wasted in a chemical reaction. Higher the value of AE, greener is the reaction. The maximum value of atom economy is 100% which indicates that all the atoms present in reactants lie in the product.

AE = [MW of product] $\div \sum$ (MW of stoichiometric reactants) $\times 100$

$$= [(341.37)/(210.23+151.12+77.08)] \times 100$$

= 77.86%

Carbon efficiency (CE):

CE denotes the percentage of carbon in the reactants that remains in the product.

CE= [Amount of carbon in product/ Total carbon present in reactants] x 100

= [no. of moles of product x no. of carbons in product / (moles of 1a x carbons in 1a + moles of 2a x carbons in 2a + moles of 3a x carbons in 3a)] x 100

$$= [0.49 \text{ x } 21 / (0.5 \text{ x } 14 + 0.5 \text{ x } 7 + 1 \text{ x } 2)] \text{ x } 100$$

 $= [10.29 / (7+3.5+2)] \times 100$

= 82.32%

Turnover number (TON): The number of moles of substrate that converted by a mole of catalyst before its inactivation. TON is calculated for 5 cycles of the reaction with 25 mg of NiO.

TON = [No. of moles of product] ÷ [No. of moles of catalyst]

TON of compound: $[1 \text{ mmol } x \frac{96}{100}] / [0.039]$ TON of compound (**7g**): $[1 x \frac{96}{100}] / [0.039]$ TON of compound (**7g**): **23.5897**

4. Data of ¹H NMR, ¹³C NMR

Compound A1

¹H NMR (400 MHz, DMSO-d₆, ppm)δ: 8.05 (dd, J1= 8.5 Hz, J2= 1.4 Hz, 2H), 12.65 (s, NH, 1H), 7.1–7.9 (m, 13H) ppm. ¹³C NMR (400 MHz, DMSO d₆) 128.2, 128.7, 128.9, 130.9, 131.1, 131.3, 131.5, 132.0, 132.1, 133.1, 134.8, 137.3, 138.1, 145.3, 197.3 ppm.

Compound A2

¹H NMR (400 MHz, DMSO-d₆, ppm) δ : 7.87 (dd, J_{HH}= 12.4 Hz, 2H), δ : 6.8 (dd, J_{HH}= 9.2 Hz 2H) δ : 7.15–7.50 (m, 10H, ArH) δ : 9.66 (s, 1H, -OH) δ : 12.37 (s, 1H, -NH). ¹³C NMR (400 MHz, DMSO-d₆) 158.3, 146.6, 137.1, 135.9, 131.8, 129.2, 128.8, 128.7, 128.1, 127.9, 127.5, 127.4, 126.9, 122.1, 115.9.

Compound A3

¹H NMR (400 MHz, DMSO d₆) δ : 7.96 (dd, J_{HH}= 7.2 Hz, 1H), δ : 7.88 (dd, J_{HH}= 3.6 Hz, 1H), δ : 7.75 (t, J_{HH}= 7.6 Hz 1H), δ : 7.60 (t, J_{HH}= 0.8 Hz, 1H), δ : 7.48–7.40 (m, 6H, ArH) δ : 7.27 (t, J_{HH}= 7.6 Hz, 1H) δ : 7.19 (t, J_{HH}= 7.2 Hz, 1H), δ : 12.92 (s, 1H, -NH). ¹³C NMR (400 MHz, DMSO d₆) 147.8, 140.5, 137.0, 134.2, 131.6, 130.1, 129.2, 129.0, 128.3, 127.8, 127.5, 126.5, 126.2, 123.5 122.9.

Compound A4

¹H NMR (400 MHz, DMSO-d₆, ppm) δ : 8.01 (dd, J_{HH}= 8.4 Hz, 2H), δ : 7.90 (dd, J_{HH}= 7.2 Hz 1H) δ : 7.76 (t, J_{HH}= 8Hz, 1H), δ : 7.52 (d, J_{HH}=8.4Hz, 2H), δ : 7.59 (t, J_{HH}= 7.6Hz, 1H), δ : 7.52(d, J_{HH}= 8.8Hz, 2H) δ : 7.41 (t, J_{HH}= 7.6Hz, 2H), δ : 7.35 (d, J_{HH}=7.2 Hz, 1H), δ : 7.26 (t, J_{HH}= 7.6 Hz, 2H), δ : 12.7 (s, 1H, -NH), ¹³C NMR (400 MHz, DMSO d₆) 144.4, 137.3, 135.0, 131.7, 130.9, 129.5, 128.7, 128.6, 128.4, 128.2, 127.9, 127.1, 126.7, 121.4.

Compound A5

¹H NMR (400 MHz, DMSO d₆, ppm) δ : 8.05 (dd, J_{HH}= 8.4 Hz, 1H), δ : 7.76 (t, J_{HH}= 7.6Hz, 3H) δ :7.61–7.38 (m, ArH, 10H), ¹³C NMR (400 MHz, DMSO d₆) 194.9, 135.6, 132.3, 130.8, 129.7, 129.6, 128.7, 128.4, 128.3, 127.6, 127.2, 124.1, 122.2.

Compound A6

¹H NMR (400 MHz, DMSO d₆) δ : 8.05 (dd, J_{HH}= 8.4 Hz, 2H), δ : 7.52–7.45 (m, ArH, 6H) δ : 7.41 (t, J_{HH}= 7.2Hz, 2H) δ : 7.36 (dd, J_{HH}= 7.2 Hz, 1H) δ : 7.27 (t, J_{HH}= 7.6 Hz,

2H) δ : 7.21 (dd, J_{HH}= 7.2 Hz, 1H) δ : 12.75 (s, NH, 1H), $~^{13}C$ NMR (400 MHz, DMSO d_6) 143.9, 136.8, 134.5, 132.2, 130.4, 128.2, 127.9, 127.7, 126.6, 126.3.

Compound A7

¹H NMR (400 MHz, DMSO d₆) δ : 8.32 (dd, J_{HH}= 3.6 Hz, 2H), δ : 7.90 (dd, J_{HH}= 0.8Hz 1H) δ : 7.88 (dd, J_{HH}= 1.2Hz, 1H) δ : 7.78 (t, J_{HH}= 6.4 Hz, 1H) δ : 7.62 (t, J_{HH}= 8 Hz, 2H) δ : 7.53–7.48 (m, ArH, 3H) δ : 7.45 (t, J_{HH}= 5.2 Hz, 2H), δ : 7.31 (t, J_{HH}= 7.2 Hz, 2H) δ : 13.14 (s, NH, 1H), ¹³C NMR (400 MHz, DMSO d₆) 147.1, 143.9, 139.0, 136.1, 135.1, 132.7, 130.2, 130.1, 129.3, 129.1, 128.8, 127.7, 126.3, 124.8.

Compound A8

¹H NMR (400 MHz, DMSO d₆) δ : 8.06 (dd, J_{HH}= 8.4 Hz, 2H), δ : 7.58 – 7.52 (m, ArH, 4H) δ : 7.47 (t, J_{HH}= 6.8 Hz, 2H) δ : 7.41 (dd, J_{HH}= 7.2 Hz, 1H) δ : 7.33 (t, J_{HH}= 7.2 Hz, 2H) δ : 7.76 (dd, J_{HH}= 7.2 Hz, 1H) δ : 7.09 (dd, J_{HH}= 0.8 Hz, 2H), δ : 3.85 (s, -OCH3, 3H) δ : 12.54 (s, -NH, 1H), ¹³C NMR (400 MHz, DMSO d₆) 159.9, 146.1, 137.3, 131.8, 129.2, 128.9, 128.7, 127.6, 127.2, 123.6, 114.6.

Compound A9

¹H NMR (400 MHz, DMSO d₆) δ : 7.91 (dd, J_{HH}= 1.2 Hz, 2H), δ : 7.89 (dd, J_{HH}= 1.2Hz 2H) δ : 7.79 (t, J_{HH}= 1.2 Hz, 1H) δ : 7.77 (t, J_{HH}= 1.6 Hz, 2H) δ : 7.75 (t, J_{HH}= 1.2 Hz, 1H) δ : 7.60 (dd, J_{HH}= 4 Hz, 2H) δ : 7.41 (dd, J_{HH}= 7.2 Hz, 2H), δ : 7.26 (dd, J_{HH}= 7.6Hz, 2H) δ : 3.80 (s, -OCH3, 3H) δ : 12.65 (s, -NH, 1H), ¹³C NMR (400 MHz, DMSO d₆) 159.9, 146.1, 129.1, 128.8, 128.6, 128.7, 127.5, 127.2, 126.9, 123.6, 114.6.

Compound A10

¹H NMR (400 MHz, DMSO d₆) δ : 8.50 (dd, J_{HH}= 8Hz, 1H), δ : 7.91 (dd, J_{HH}= 4Hz, 2H) δ : 7.89 (dd, J_{HH}= 4Hz, 2H) δ : 7.77 (t, J_{HH}= 8Hz, 3H) δ : 7.60 (t, J_{HH}= 8Hz, 4H) δ : 7.44 (t, J_{HH}= 4Hz, 2H) δ : 7.29 (t, J_{HH}= 8Hz, 1H) δ : 13.09 (s, -NH, 1H), ¹³C NMR (400 MHz, DMSO d₆) 146.0, 142.8, 137.9, 136.0, 131.7, 131.6, 130.0, 129.1, 128.2, 128.0, 127.8, 126.6, 125.2, 123.8.

Compound A11

¹H NMR (400 MHz, DMSO d₆) δ : 7.66 (s, Ar-H, 1H) δ : 7.65 (s, Ar-H, 1H) δ : 7.53 (m, Ar-H, 8H) δ : 7.30 (s, Ar-H, 2H) δ : 7.07 (d, J_{HH} = 8Hz, 1H) δ : 3.85 (s, -OCH₃, 3H) δ : 3.81 (s, -OCH₃, 3H) δ : 12.91 (s, -NH, 1H), ¹³C NMR (400 MHz, DMSO d₆) 149.6, 149.3, 146.2, 129.2, 129.0, 128.7, 127.6, 123.7, 118.4, 112.3, 109.3, 56.1, 56.0.

Compound B1

¹H NMR (400 MHz, DMSO d₆) δ : 9.14 (d, J_{HH}= 8Hz, 1H) δ : 8.25 (d, J_{HH}= 8.4Hz, 1H) δ :8.16 (dd, J1= 8.4Hz, J2= 5.6Hz 2H) δ : 8.05 (d, J_{HH}= 8Hz, 1H) δ : 7.97 (t, J_{HH} = 16Hz, 4H) δ : 7.90 (d, J_{HH}= 1.2Hz, 2H) δ : 7.88 (d, J_{HH}= 1.2Hz, 2H) δ : 7.77 (t, J_{HH}= 1.2Hz, 1H) δ :7.73 (t, J_{HH}= 1.2Hz, 1H) δ : 7.70 (t, J_{HH}= 3.6Hz, 1H) δ : 13.1 (s, -NH, 1H), ¹³C NMR (400 MHz, DMSO d₆) 143.8, 137.5, 136.1, 136.0, 131.7, 131.4, 131.3, 130.2, 130.1, 129.6, 129.3, 128.9, 128.8, 128.5, 128.2, 128.2, 128.1, 127.8, 127.2, 126.6, 126.5, 126.1.

Compound B2

¹H NMR (400 MHz, DMSO d₆) δ : 8.81 (s, 1H), δ : 8.22 (t, J_{HH}= 4Hz, 1H) δ : 7.94 (t, J_{HH}= 4Hz, 1H) δ : 7.69 (d, J_{HH}= 1.6Hz, 1H) δ : 7.67 (d, J_{HH}= 0.8Hz, 1H) δ : 7.61–7.57 (m, Ar-H, 4H) δ : 7.46 (d, J_{HH}= 2Hz, 1H) δ : 7.44 (d, J_{HH}= 1.6Hz, 1H) δ : 7.38 (d, J_{HH}= 1.2Hz, 1H) δ : 7.36 (d, J_{HH}= 0.8Hz, 1H) δ : 7.34 (d, J_{HH}= 1.6Hz, 1H) δ : 7.27 (t, J_{HH}= 3.6 Hz 1H) δ : 8.13 (t, J_{HH}= 8Hz, 1H)) δ : 7.50 (t, J_{HH}= 4Hz, 1H) δ : 12.9 (s, -NH, 1H), ¹³C NMR (400 MHz, DMSO d₆) 146.1, 137.4, 136.1, 135.8, 134.2, 133.8, 132.8, 130.1, 130.0, 129.6, 129.3, 129.2, 128.9, 128.8, 127.8, 127.5, 127.2, 125.9, 124.7.

Compound B3

¹H NMR (400 MHz, DMSO d₆) δ : 8.64 (s, Ar-H, 1H) δ : 8.30 (d, J_{HH}= 2Hz, 1H) δ : 8.27 (d, J_{HH} = 1.6Hz 1H) δ : 8.03–7.92 (m, Ar-H, 4H) δ : 7.64–7.53 (m, Ar-H, 8H) δ : 7.49 (t, J_{HH}= 1.2Hz, 2H) δ : 12.89 (s, -NH, 1H), ¹³C NMR (400 MHz, DMSO d₆) 195.4, 146.0, 137.9, 136.1, 135.7, 133.5, 133.2, 132.8, 131.6, 130.1, 130.1, 129.2, 129.0, 128.8, 128.8, 128.6, 128.3, 128.3, 127.7, 127.2, 127.1, 124.2, 124.0.



Compound A1 ¹H NMR



Compound A1 ¹³C NMR



Compound A2 ¹H NMR



Compound A2 ¹³C NMR



Compound A3 ¹H NMR



Compound A3 ¹³C NMR



Compound A4 ¹H NMR



Compound A4 ¹³C NMR



Compound A5 ¹H NMR



Compound A5 ¹³C NMR



Compound A6 ¹H NMR



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Compound A7 ¹H NMR



Compound A7 ¹³C NMR



Compound A8 ¹H NMR



Compound A8 ¹³C NMR



Compound A9 ¹H NMR



Compound A10 ¹H NMR



Compound A11 ¹H NMR



Compound A11 ¹³C NMR



Compound B1 ¹H NMR



Compound B1 ¹³C NMR



Compound B2 ¹H NMR



Compound B2 ¹³C NMR



Compound B3 ¹H NMR



Compound B3 ¹³C NMR