Converting waste into a resource: ethylenediamine modification of iron blast furnace slag to fabricate a cost-effective adsorbent for effective Pb(II) removal

Wesam Abd El-Fattah[a], Ahlem Guesmi[a,*], Rana Yahya[b], Ahmed M. Alharbi [c], Naoufel Ben Hamadi [a,*], Ahmed M. Eldesoky[c], Reda F. M. Elshaarawy [d, *]

[a] Chemistry Department, College of Science, Imam Mohammad Ibn Saud Islamic University (IMSIU), P.O. Box 5701, Riyadh 11432, Saudi Arabia

[b] University of Jeddah, College of Science, Department of Chemistry, Jeddah, Saudi Arabia

[c] Department of Chemistry, Faculty of Sciences, Umm Al-Qura University, Makkah, Saudi Arabia

[d] Department of Chemistry, Faculty of Science, Suez University, 43533 Suez, Egypt.

Corresponding authors

RFME: reda.elshaarawy@suezuniv.edu.eg; Orchid: 0000-0003-2100-8928

AG: amalkasme@imamu.edu.sa; Orchid: 0000-0002-7552-4146

1. Chemicals

Chemicals were utilized just as they were provided.

2. Characterization

FT-IR spectra were recorded on a BRUKER Tensor-37 FTIR spectrophotometer in the range of 400–4000 cm^{-1} as KBr disc with 2 cm^{-1} resolution. For signal intensities the following abbreviations were used: br (broad), sh (sharp), w (weak), m (medium), s (strong), vs (very strong).NMR-spectra were obtained with a BrukerAvance DRX200 (200 MHz for ^{1}H) or BrukerAvanceDRX500 (125MHz for ^{13}C) spectrometer with calibration to the residual proton solvent signal in DMSO-d_6 (^{1}H NMR: 2.52 ppm, ^{13}C NMR: 39.5 ppm), $CDCl_3$ (^{1}H NMR: 7.26 ppm, ^{13}C NMR: 77.16 ppm) against TMS (δ = 0.00 ppm) for ^{1}H and ^{13}C. Multiplicities of the signals were specified ass (singlet), d (doublet), t (triplet), q (quartet) or m (multiplet). Scanning electron microscope (SEM) was carried on JEOL-JSM-6510 LV.

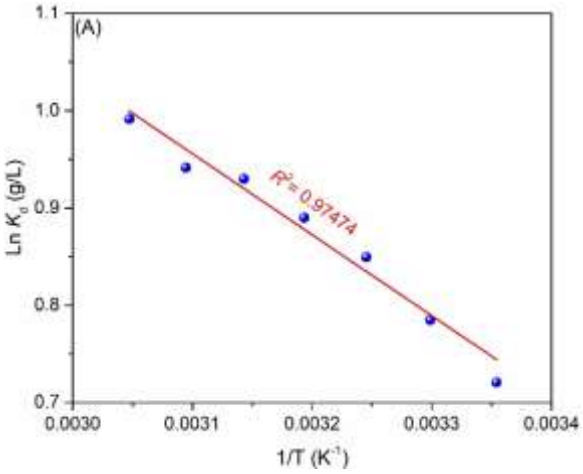

Figure S1: Van't Hoff plot for adsorption of Pb(II) by NN@slag adsorbent.

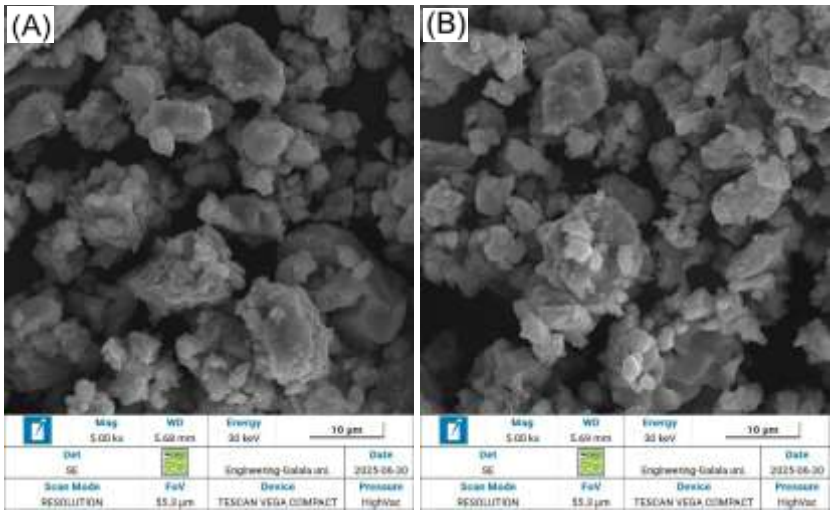

Figure S2: SEM microimages of the (A) nascent ethylenediamine-functionalized slag (NN@Salg) adsorbent and (B) recovered adsorbent (R NN@Salg) after Pb(II) desorption.

Table S1: Linear and non-linear mathematical formula for the adsorption isotherms and kinetic models used in this work (Experimental conditions: CMCSB-SCB dose = 15.0 mg, pH = 4.6, contact time = 30 min, T = 308 K)

Model	Linear formula	Non-linear formula
Langmuir isotherm [a]	$\frac{1}{q_e} = \left(\frac{1}{q_{max}}\right) + \frac{1}{q_{max} b C_e}$ **Eq. 1**	$q_e = \frac{q_{max} b C_e}{(1 + bC_e)}$ **Eq. 4**
Freundlich isotherm [b]	$\log q_e = \log K_f + \frac{1}{n} \log C_e$ **Eq. 2**	$q_e = K_f C_e^{1/n}$ **Eq. 5**
Tenkin isotherm [c]	$\ln(\frac{q_e}{q_{max} - q_e}) = \ln K_S + \frac{1}{n_s} \ln C_e$ **Eq. 3**	$q_e = \frac{q_{max} (K_s C_e)^{1/n_S}}{(1 + (K_s C_e)^{1/n_S})}$ **Eq. 6**
Pseudo-1st-order kinetic [d]	$\log (q_e - q_t) = \log q_e + \frac{k_1 t}{2.303}$ **Eq. 7**	$q_t = q_e(1 - e^{-k_1 t})$ **Eq. 10**
Pseudo-2nd-order kinetic [d]	$\frac{t}{q_t} = \left(\frac{1}{k_2 q_e^2}\right) + \frac{t}{q_e}$ **Eq. 8**	$q_t = \left(\frac{q_e^2 k_2 t}{1 + k_2 q_e^2 t}\right)$ **Eq. 11**
Intraparticle diffusion kinetic [d]	$q_t = k_{id} t^{1/2} + C$ **Eq. 9**	

[a] q_e and q_{max} are the amounts (mg/g) of the adsorbed phosphate ions per unit mass of membrane at equilibrium and to form amonolayer of phosphate ions on the membrane surface, respectively, *C*e is the residual phosphate ions (mg/L) at equilibrium, and b is Langmuir coefficient (L/mg).

[b] K_f and n are Freundlich adsorption coefficients.

[c] K_s and n_s are Sips adsorption coefficients.

d q_t and q_e are the adsorption capacities (mg g^{-1}) of the MPM at at time t (min) and equilibrium , respectively; k_1 (min^{-1}), k_2 (g mg^{-1} min^{-1}), and k_{id} (mg g^{-1} $min^{-0.5}$) are the adsorption rate constants for the Lagergren pseudo-1st-order, pseudo-2nd-order, and intraparticle diffusion kinetic models; C (mg g^{-1}) is the thickness of the boundary layer.