magnetochemistry

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Article

A Novel Magnetic Nano-Adsorbent Functionalized with Green Tea Extract and Magnesium Oxide to Remove Methylene Blue from Aqueous Solutions: Synthesis, Characterization, and Adsorption Behavior

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Text S1. Characterization techniques.

The surface morphology of the prepared materials were examined by SEM (TM4000Plus II, Hitachi, Tokyo, Japan) attached with an energy dispersive spectrometer (EDS). Prior to observation, the samples were crushed, dispersed in ethanol, dispersed by ultrasound, and deposited on copper mesh.

The phase structure and crystallinity was measured by XRD (PANalytical X'Pert Powder, Spectris Pte. Ltd., Almelo, the Netherlands) using Cu Kα radiation (40 kV, 40 mA, λ=1.5406 Å). Scan range: 2θ of 10° to 80°; Step size: 0.026°.

The infrared spectrum of prepared samples was recorded by FTIR (IRTracer100, Shimadzu, Kyoto, Japan) with the KBr pellet technique.

The composition of elements in the prepared materials was analyzed by XPS (ESCALAB250Xi, Thermo Fisher, Waltham, Massachusetts, USA). With a 400 μm spot size, 12 kV operating voltage, and 6 mA filament current, the full-spectrum scanning fluence energy was 150 eV in 1 eV steps, whereas the narrow-spectrum scanning fluence energy was 50 eV in 0.1 eV steps.

The magnetic properties were measured in a commercial PPMS DynaCool 9 (Quantum Design, San Diego, California, USA).

The point of zero charge of the catalyst was determined with zetasizer nano ZS90 apparatus (Malvern, London, UK).

The pore texture parameters and surface areas were analyzed using automatic multistation specific surface and aperture analyzer (Quadrasorb 2MP, Quantachrome, Boca Raton, Florida, USA). The pore texture parameters were obtained from the corresponding N_2 adsorption–desorption isotherms. The pore size distribution was obtained through the classical Barrett–Joyner–Halenda method based on a modified Kelvin adsorbent. The specific surface areas were estimated by the Brunauer–Emmet–Teller method using the adsorption branch of the isotherms.

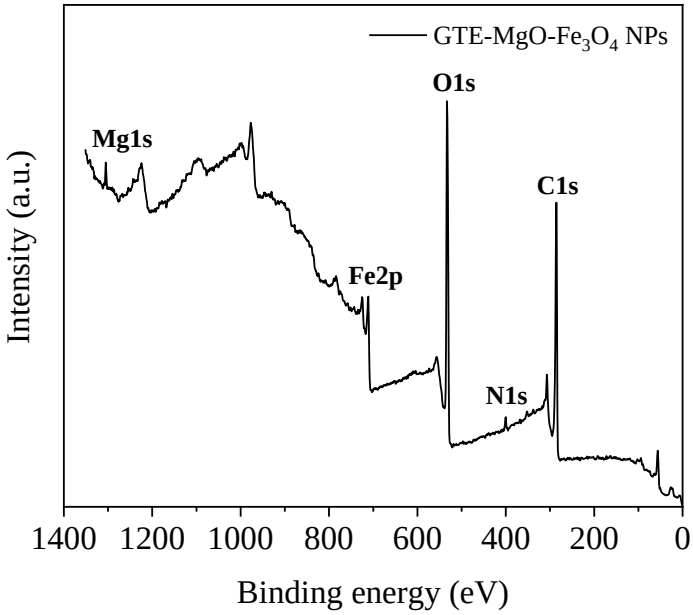

Figure S1. The XPS fully scanned spectra of GTE-MgO-Fe_3O_4 NPs.

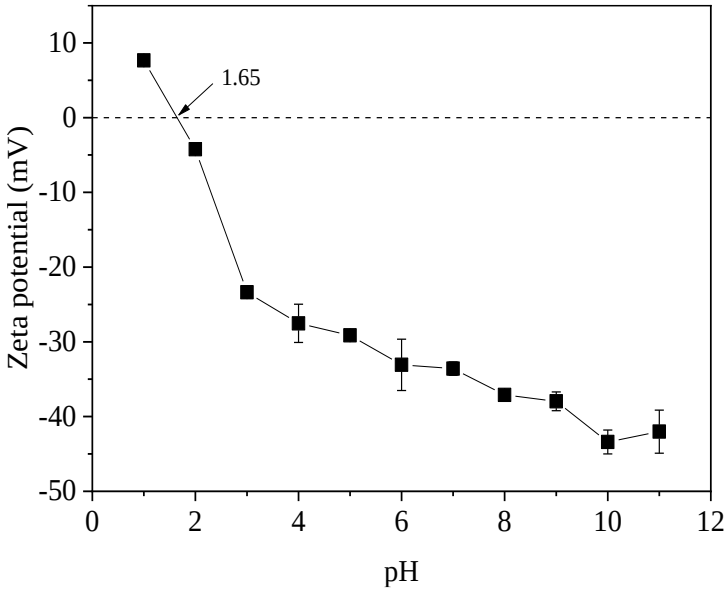

Figure S2. Zeta potential curve for GTE-MgO-Fe_3O_4 NPs in the pH range of 1-11.

Table S1. Kinetic model parameters for the MB adsorption by GTE-MgO-Fe_3O_4 NPs.

kinetic model	parameters	Initial concentration of methylene blue (mg L^{-1})			
		10	20	40	60
PFO	q_e (mg g^{-1})	32.37	62.76	107.16	126.41
	k_1 (min^{-1})	0.570	0.293	0.189	0.166
	R^2	0.90	0.95	0.95	0.94
PSO	q_e (mg g^{-1})	33.76	66.57	115.46	136.83
	k_2 (g mg^{-1} min^{-1})	0.0305	0.0068	0.0023	0.0017
	R^2	0.99	0.99	0.99	0.99

Table S2. Isotherm model parameters for the MB adsorption by GTE-MgO-Fe_3O_4 NPs.

Model	**Parameters**	**288.15 K**	**298.15 K**	**308.15 K**	**318.15 K**
Langmuir	q_m (mg g^{-1})	146.33	139.60	170.94	170.46
	k_L (L mg^{-1})	5.57	2.60	0.11	0.07
	R^2	0.66	0.67	0.92	0.97
Freundlich	k_F ((mg g^{-1})(L $mg^{-1})^{1/n}$)	95.63	86.42	33.70	26.06
	n	6.51	6.32	2.60	2.34
	R^2	0.99	0.99	0.99	0.99
Temkin	b_T (J mol^{-1})	157.82	154.52	83.75	80.21
	f (L mg^{-1})	996.05	293.97	1.96	1.05
	R^2	0.96	0.98	0.94	0.97

Table S3. Thermodynamic parameters for the MB adsorption by GTE-MgO-Fe_3O_4 NPs.

temperature (K)	pH	ΔG° (kJ mol^{-1})	ΔH° (kJ mol^{-1})	ΔS° J mol^{-1}k^{-1}
288.15	6.0	−44.10	−123.62	−276.14
298.15	6.0	−43.74		
308.15	6.0	−37.11		
318.15	6.0	−37.01		

Table S4. The maximum adsorption capacities (q_{max}) of various adsorbents for MB.

Adsorbents	q_{max} (mg g^{-1})	R%	Ref
Fe_3O_4@GTPs NPs	7.25	95	[37]
γ-Fe_2O_3@GL	91.74	99	[38]
magnetic-biochar nanocomposite derived from avocado peel	62.1	–	[39]
$NiFe_2O_4$@GO	76.34	–	[40]
CMC-coated Fe_3O_4@SiO_2	22.7	–	[41]
Chitosan/Fe_3O_4 nanocomposite	45.37	–	[42]
Fe_3O_4@Ag/SiO_2	128.5	99.6	[43]
TTGTW500	69.01	98.07	[44]
GTE-MgO-Fe_3O_4 NPs	174.93	99.78	This work