

Supplementary

Table S1. Experimental conditions verified and used in bromide adsorption experiments.

Experiment	Initial concentration, C_0 (mg L ⁻¹)	Solution volume, V (L)	Adsorbent mass, m (g)	Adsorbent dosage, m/V (g L ⁻¹)	Variable investigated
Effect of pH	20	0.025	0.10	4	pH (2–10)
Adsorbent dosage	30	0.025	0.05–1.50	2–60	Adsorbent dosage
Contact time	30	0.025	0.10	4	0–120 min
Agitation speed	30	0.025	0.10	4	50–250 rpm
Initial bromide concentration	5–200	0.025	0.10	4	Initial concentration
Temperature	30	0.025	0.10	4	25–55°C
Coexisting ions	30	0.025	0.10	4	Ion type

Table S2. Proposed FTIR band assignments and changes after Br⁻ adsorption

Assignment	Before adsorption (cm ⁻¹)	After adsorption (cm ⁻¹)	Interpretation
O–H stretching	3431	3419	Shift and intensity change indicating modification of hydroxyl and hydration environments
Carbonyl-related vibration	1799	1799	No significant change
Carbonate asymmetric stretching	1424	1419	Change in the local environment of calcium- and carbonate-containing sites
Si–O–Si / Si–O–Al / C–O–C stretching	1031	1028	Possible involvement of aluminosilicate and oxygen-containing groups
Low-wavenumber lattice feature	—	615	New feature attributed to perturbation of mineral-lattice vibrations
Secondary low-wavenumber feature	—	495	Weak shoulder associated with changes in the inorganic framework

Table S3. Effect of coexisting ions on adsorption capacity (q_e) and removal efficiency (%R).

Coexisting ion	q_e	R %	Note
Control	6.800	90.667	No competition
Cl ⁻	6.613	88.167	Weak competition
NO ₃ ⁻	6.475	86.334	Moderate competition
CO ₃ ²⁻	6.200	82.667	carbonate effect
SO ₄ ²⁻	5.975	79.667	Strong competition
PO ₄ ³⁻	5.650	75.334	Strongest single-ion competition
Mixed ions	5.350	71.334	Matrix suppression
Range	5.35–6.80	71.33–90.67	

Table S4. Effect of operational parameters, including pH, agitation speed, initial concentration (C_0), adsorbent dosage, temperature, and contact time, on adsorption capacity (q_e) and removal efficiency (%R).

Experiment	Condition	q_e (mg g ⁻¹)	Removal (%)	q_e range (mg g ⁻¹)	Removal range (%)
pH	2	4.667	93.340	1.803–4.867	36.067–97.336
	3	4.800	96.004		
	4	4.834	96.670		
	5	4.867	97.336		
	6	3.468	69.366		
	7	2.136	42.727		
	8	2.003	40.063		
	9	1.870	37.399		
	10	1.803	36.067		
	0.05	9.1	60.667		
Adsorbent dosage (g)	0.1	5.775	77	0.467–9.100	60.667–93.400
	0.2	3.4	90.667		
	0.5	1.388	92.5		
	1	0.699	93.4		
	1.5	0.467	93.167		
Contact time (min)	0	2.5	33.334	2.500–6.895	33.334–91.933
	5	3.8	50.667		
	10	4.775	63.667		
	20	5.7	76		
	30	6.288	83.834		
	45	6.638	88.5		
	60	6.8	91.5		
	90	6.863	91.733		
	120	6.88	91.933		
	50	5.95	79.334		
Agitation speed (rpm)	100	6.713	89.5	5.950–6.820	79.334–90.933
	150	6.8	90.667		
	200	6.82	90.933		
	250	6.788	90.5		
	5	1.117	89.345		
Initial concentration, C_0 (mg L ⁻¹)	10	2.234	89.345	1.117–39.997	79.994–93.784
	15	3.217	85.793		
	20	4.401	88.013		
	25	5.584	89.345		
	30	7.034	93.784		
	50	10.968	87.746		
	72	15.29	84.942		
	100	21.157	84.629		

Temperature (°C)	150	30.947	82.525	6.445–6.743	85.932–89.900
	200	39.997	79.994		
	25	6.743	89.9		
	30	6.702	89.359		
	35	6.661	88.818		
	40	6.614	88.187		
	45	6.567	87.556		
	50	6.506	86.744		
	55	6.445	85.932		

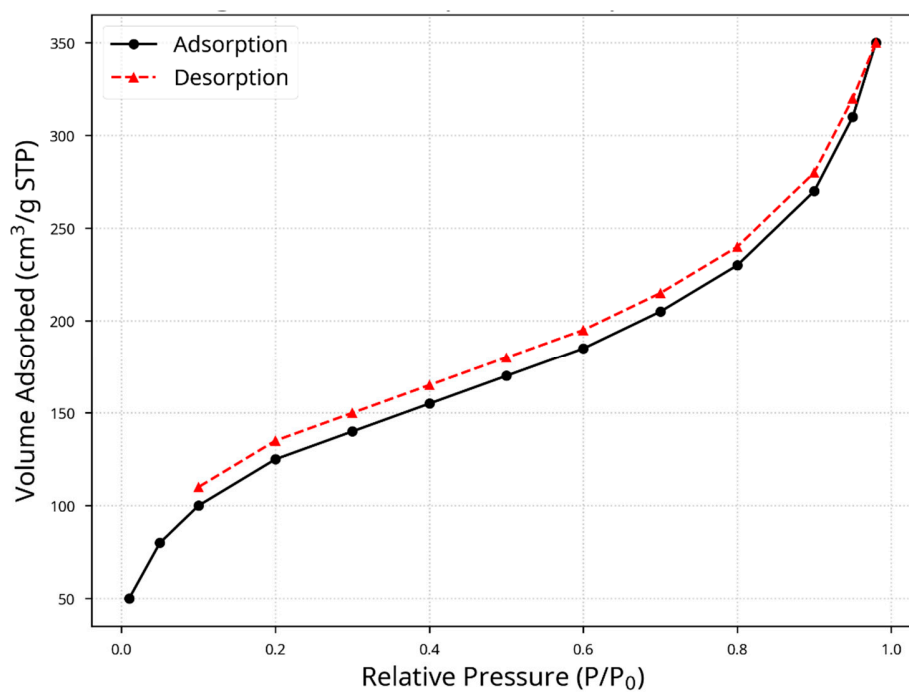
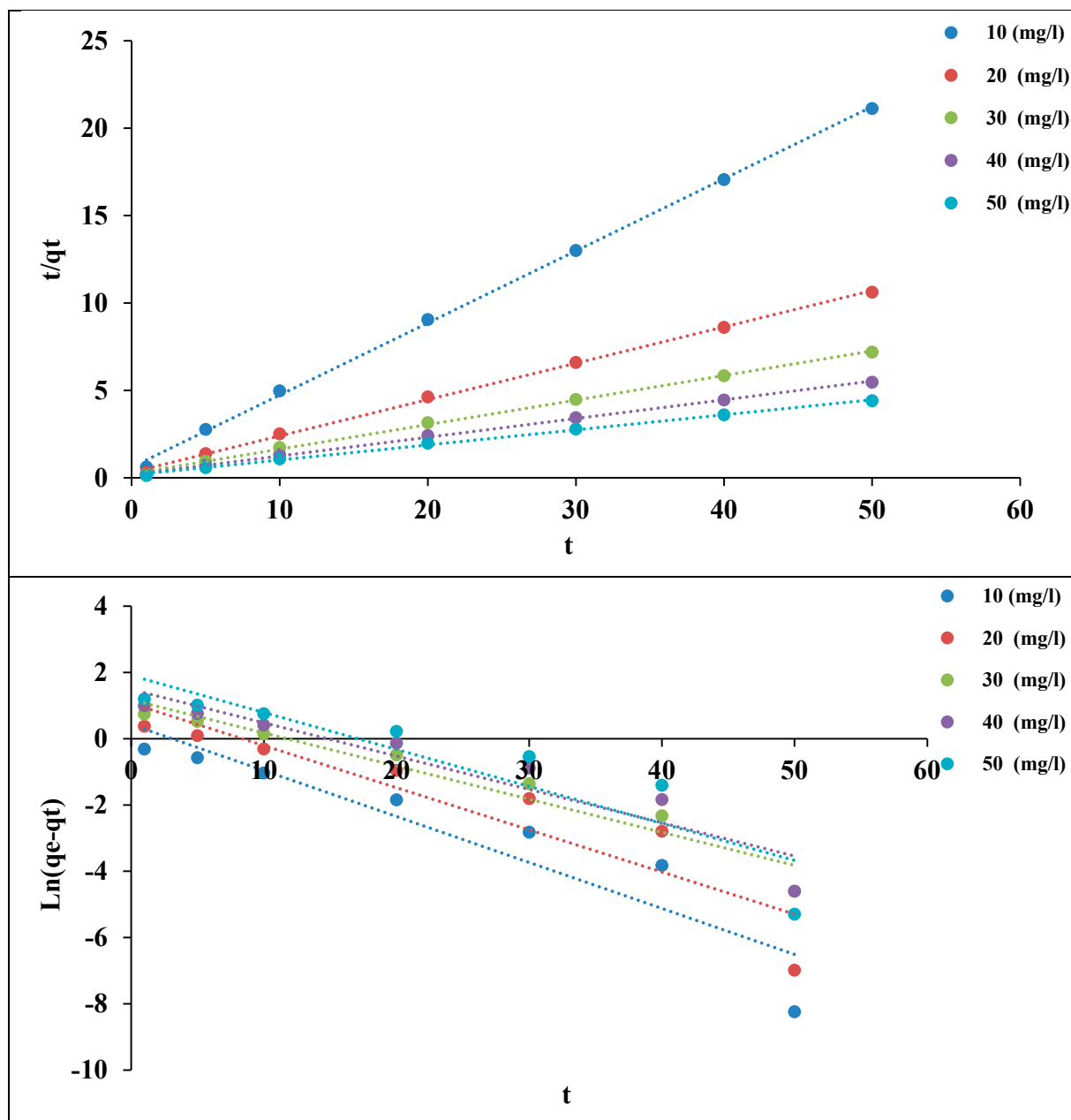


Figure S1. Nitrogen adsorption–desorption isotherm of the CAKS composite at 77 K, showing a Type IV profile with a distinct hysteresis loop, indicative of a predominantly mesoporous structure.



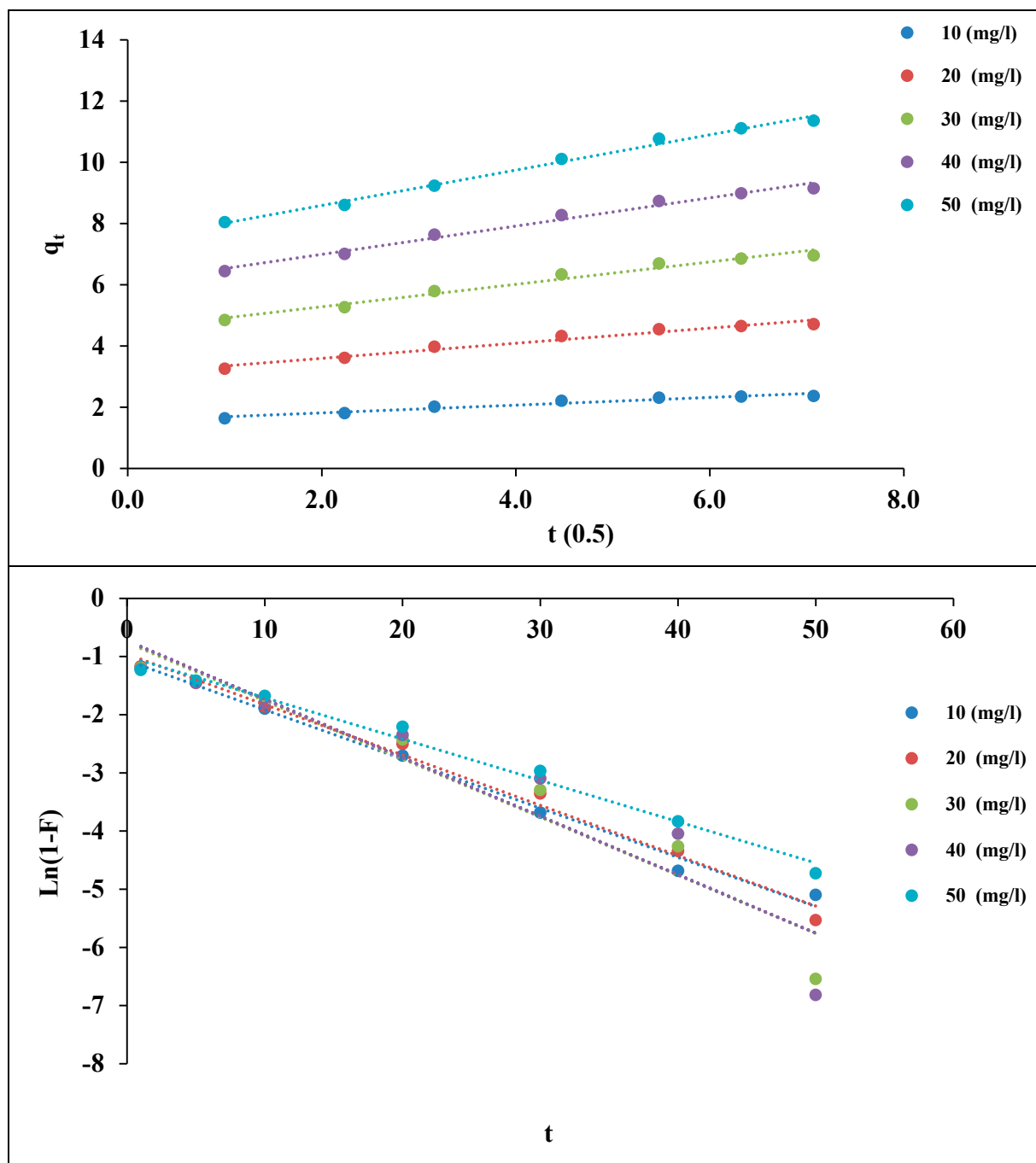


Figure S2. Kinetic analysis of bromide adsorption onto the CAKS composite at different initial concentrations: pseudo-first-order model, pseudo-second-order model, intraparticle-diffusion model, and film-diffusion model.