Supplementary Information:

Adsorption of Cd^{2+} ions onto zeolites synthesized from mixture of coal fly ash and oil shale ash in aqueous media

Shuxia Bai[a], Zhibing Chang[b], Zhengchun Ren[a], Yongqin Zhao[c,*], Laixue Pang[d,*]

[a] School of Construction Machinery, Shandong Jiaotong University, 250357, Jinan, Shandong, China.

[b] School of Chemical & Environmental Engineering, China University of Mining and Technology (Beijing), 100083, Beijing, China.

[c] Jinan Preschool Education College, 250307, Jinan, Shandong, China.

[d] School of Traffic and Civil Engineering, Shandong Jiaotong University, 250357, Jinan, Shandong, China.

* Corresponding authors.

Email: lxpang@sdjtu.edu.cn (L. Pang), yongqin-zhao@outlook.com (Y. Zhao)

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Supplementary Tables

Tab. S1. Chemical composition of CFA and OSA

Component content (mass%)	SiO_2	Al_2O_3	CaO	Fe_2O_3	Na_2O	MgO	SO_3	TiO_2	K_2O	others	SiO_2/Al_2O_3
CFA	45.78	39.05	4.56	2.50	0.15	1.46	2.45	2.62	1.01	0.42	1.17
OSA	52.67	14.67	12.57	6.48	3.47	2.18	4.34	1.26	0.91	1.45	3.59

Tab. S2. Kinetics parameters for Cd^{2+} adsorption onto zeolites

Models	Samples	OSA100	OSA75	OSA50	OSA25	CFA100
Experiment	$q_{e,exp}$ (mg·g^{-1})	97.92	99.66	94.73	89.88	88.52
Pseudo-first-order	k_1 (min^{-1})	0.034	0.069	0.034	0.036	0.030
	$q_{e,cal}$ (mg·g^{-1})	24.19	43.99	27.66	23.25	31.89
	R^2	0.8879	0.9251	0.9684	0.9769	0.9708
Pseudo-second-order	k_2 (g·mg^{-1}·min^{-1})	0.0036	0.0047	0.0036	0.0041	0.0025
	$q_{e,cal}$ (mg·g^{-1})	99.70	101.52	96.15	92.94	91.58
	R^2	0.9997	0.9999	0.9998	0.9998	0.9999
Intraparticle diffusion (stage 1)	k_p (mg·g^{-1}·min$^{-1/2}$)	4.58	3.77	4.88	3.50	7.04
	C (mg·g^{-1})	62.25	70.96	59.24	61.72	39.53
	R^2	0.9474	0.7819	0.8508	0.7530	0.9559
Intraparticle diffusion (stage 2)	k_p (mg·g^{-1}·min$^{-1/2}$)	0.32	0.36	0.97	0.61	1.07
	C (mg·g^{-1})	93.91	95.56	83.40	82.86	76.42
	R^2	0.7181	0.9721	0.7466	0.8631	0.8602

The adsorption capacity (q_e) at equilibrium was calculated using Eq. (S1):

$$q_e = \frac{(C_0 - C_e)V}{m} \qquad \text{Eq. (S1)}$$

where C_0 (mg·L^{-1}) represents the initial Cd^{2+} concentration, C_e (mg·L^{-1}) is the Cd^{2+} concentration at equilibrium, V (L) is the volume of the solution, and m (g) is the mass of the adsorbent.

The uptake efficiency (E%) was calculated using Eq. (S2):

$$E\% = \frac{(C_0 - C_e) \times 100\%}{C_0} \qquad \text{Eq. (S2)}$$

where C_0 and C_e (mg·L^{-1}) are the initial and equilibrium Cd^{2+} concentrations, respectively.

The linear expressions for the pseudo-first-order, pseudo-second-order, and intraparticle diffusion models are given as follows:

$$\ln(q_e - q_t) = \ln q_e - k_1 t \qquad \text{Eq. (S3)}$$

$$\frac{t}{q_t} = \frac{1}{k_2 q_e^2} + \frac{1}{q_e} t \qquad \text{Eq. (S4)}$$

$$q_t = k_p t^{1/2} + C \qquad \text{Eq. (S5)}$$

In these equations, q_e and q_t ($mg \cdot g^{-1}$) denote the adsorption capacities at equilibrium and at any given time t, respectively. The rate constants k_1 (min^{-1}), k_2 ($g \cdot mg^{-1} \cdot min^{-1}$) and k_p ($mg \cdot g^{-1} \cdot min^{-1/2}$) correspond to the pseudo-first-order, pseudo-second-order, and intraparticle diffusion models, respectively. C ($mg \cdot g^{-1}$) represents the intercept of the plot of q_t as a function of $t^{1/2}$.

Tab. S3. Isotherm parameters for Cd^{2+} adsorption onto zeolites

Models	Samples	OSA100	OSA75	OSA50	OSA25	CFA100
Experiment	$q_{e,exp}$ ($mg \cdot g^{-1}$)	187.18	227.24	205.87	179.54	156.21
Langmuir	q_{max} ($mg \cdot g^{-1}$)	192.31	236.41	211.86	182.84	159.24
	K_L ($L \cdot mg^{-1}$)	0.13	0.09	0.10	0.07	0.10
	R^2	0.9908	0.9954	0.9961	0.9914	0.9928
Freundlich	K_F ($mg \cdot g^{-1}$)	60.59	60.66	57.10	50.78	52.05
	n_F	4.76	4.20	4.26	4.20	5.18
	R^2	0.7307	0.7908	0.7553	0.8469	0.7951
Dubinin-Radushkevich	q_{max} ($mg \cdot g^{-1}$)	129.14	153.30	143.54	126.23	116.51
	K_{DR} ($mol^2 \cdot J^{-2}$)	$5.67 \cdot 10^{-8}$	$1.03 \cdot 10^{-7}$	$1.17 \cdot 10^{-7}$	$5.14 \cdot 10^{-8}$	$6.48 \cdot 10^{-8}$
	R^2	0.4934	0.8385	0.7051	0.5701	0.8777
	E_{DR} ($kJ \cdot mol^{-1}$)	2.97	2.21	2.07	3.12	2.78

The Langmuir isotherm model, which assumes monolayer adsorption onto a homogeneous surface with a finite number of identical adsorption sites, is widely employed for modeling equilibrium data in solid-liquid systems. The linearized form of the Langmuir equation is expressed as:

$$\frac{C_e}{q_e} = \frac{1}{q_{max} K_L} + \frac{C_e}{q_{max}} \quad \text{Eq. (S6)}$$

where K_L ($L \cdot mg^{-1}$) is the Langmuir adsorption constant, which is related to the energy of adsorption, C_e ($mg \cdot L^{-1}$) is the equilibrium concentration of Cd^{2+} ions in the solution, q_e ($mg \cdot g^{-1}$) is the amount of Cd^{2+} ions adsorbed by the adsorbent at equilibrium, and q_{max} ($mg \cdot g^{-1}$) represents the maximum monolayer adsorption capacity of the adsorbent.

The Freundlich isotherm, an empirical model, is typically used to describe adsorption on heterogeneous surfaces. The equation for the Freundlich isotherm is expressed as:

$$\ln q_e = \ln K_F + \frac{1}{n_F} \ln C_e \quad \text{Eq. (S7)}$$

where K_F ($mg \cdot g^{-1}$) is the Freundlich constant, and n_F is the characteristic constant of the adsorption system.

The Dubinin-Radushkevich (D-R) isotherm is similar to the Langmuir isotherm but is more general as it does not assume a homogeneous surface or constant adsorption potential. The linear form of the D-R equation is expressed as:

$$\ln q_e = \ln q_{max} - K_{DR}\varepsilon^2 \quad \text{Eq. (S8)}$$

where q_{max} ($mg \cdot g^{-1}$) is the maximum adsorption capacity, and K_{DR} ($mol^2 \cdot J^{-2}$) is the affinity coefficient related to the adsorption energy $E = 1/(2K_{DR})^{1/2}$ ($kJ \cdot mol^{-1}$). The Polanyi potential ε is given by:

$$\varepsilon = RTln\left(1+1/C_e\right) \quad \text{Eq. (S9)}$$

where R ($J \cdot mol^{-1} \cdot K^{-1}$) is the ideal gas constant, T (K) is the absolute temperature, and C_e ($mg \cdot L^{-1}$) is the equilibrium concentration of the adsorbate in the solution.