

Supporting Information

Construction of oxygen vacancies of Zr doped CeO₂ with enhanced dye adsorption performance

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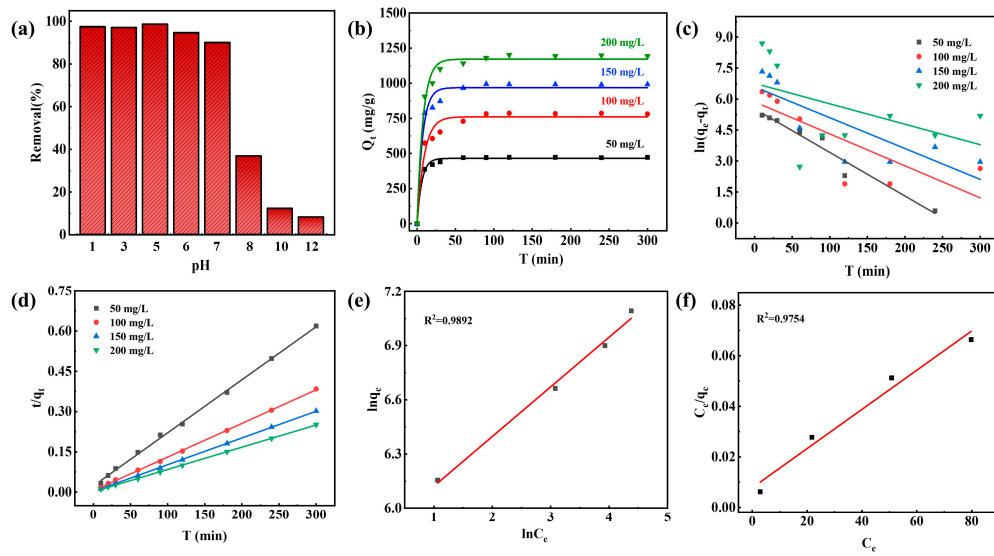


Figure S1. Performance of ZC0 in different pH (a), the effect of contact time. (b), Pseudo-first adsorption model (c), Pseudo-second adsorption model (d), Langmuir (e), Freundlich (f).

Table S1. Kinetic parameters for the adsorption of Congo Red on ZC0.

C_0 (mg/L)	$q_{e,exp}$ (mg/g)	Pseudo-first-order			Pseudo-second-order		
		K_1	q_e	R^2	K_2	q_e	R^2
50	484.91	0.02215	294.60	0.644	1.64×10^{-4}	507.61	0.9985
100	783.55	0.01758	350.72	0.621	2.76×10^{-4}	800.00	0.9995
150	995.11	0.01747	727.78	0.657	3.47×10^{-4}	1003.86	0.9998
200	1201.23	0.01349	871.31	0.249	3.71×10^{-4}	1207.77	0.9997

Table S2. Isothermal adsorption model of CR molecules on ZC0.

$T(^{\circ}C)$	Langmuir isotherm			Freundlich isotherm		
	q_m	b	R^2	K_f	$1/n$	R^2
25	1289.49	0.0872	0.9631	345.84	0.2748	0.9928

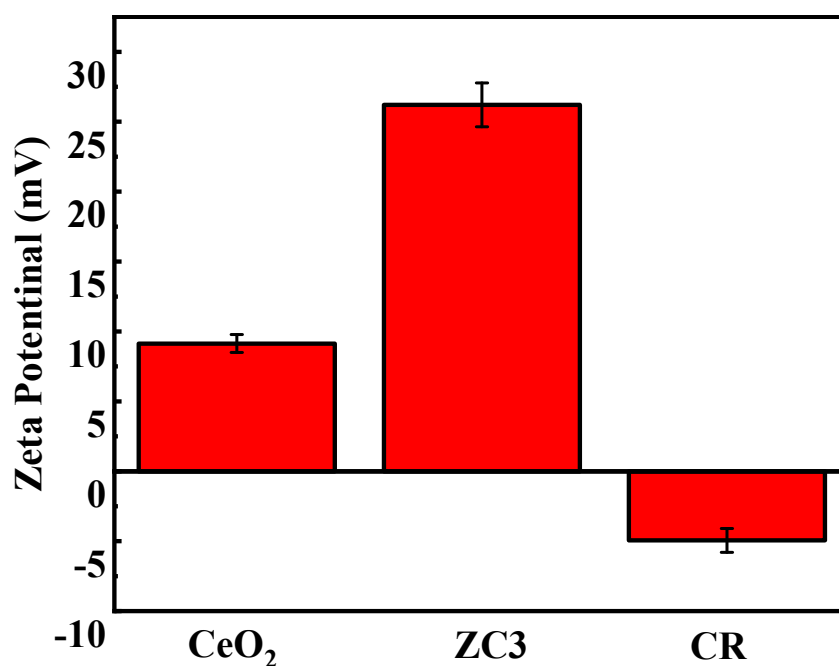
**Figure S2.** Dispersion of zeta potential in a neutral aqueous environment for CeO₂, ZC3 nanoparticles, and CR.

Table S3. Comparison of adsorption performance in this study with previous Congo red dye adsorbent in literature works.

Adsorbents	Dye	Qm (mg/g)	References
Imperata cylindrica	CR	1666.70	[1]
CoFe-MOF	CR	1649.3	[2]
CeO ₂ nanotube	CR	362.32	[3]
Porous rod-like MgO	CR	3236	[4]
Composite aerogels	CR	1567	[5]
Sodium alginate aerogel	CR	3568	[6]
NiO hollow microspheres	CR	526.3	[7]
Nitrogen-doped biochar	CR	1360	[8]
CuO–ZnO/SiO ₂ fibrous membranes	CR	141.8	[9]
Hierarchically porous carbon	CR	2519.2	[10]
ZC0	CR	1289.49	This work
ZC3	CR	3642.05	This work

Reference

1. Bello, O.S.; Akinwale, F.T.; Agboola, O.S.; Ibrahim, A.O.; Adesina, O.O. Liquid-phase adsorption of Congo red dye using modified spear grass (*Imperata cylindrica*) root as adsorbent. *Biomass Convers. Biorefin.* 2022, doi:10.1007/s13399-022-03078-9.
2. Liu, Y.; Qiu, G.; Liu, Y.; Niu, Y.; Qu, R.; Ji, C.; Wang, Y.; Zhang, Y.; Sun, C. Fabrication of CoFe-MOF materials by different methods and adsorption properties for Congo red. *J. Mol. Liq.* 2022, 360, 119405, doi:10.1016/j.molliq.2022.119405.
3. Wu, J.; Wang, J.; Du, Y.; Li, H.; Jia, X. Adsorption mechanism and kinetics of azo dye chemicals on oxide nanotubes: a case study using porous CeO₂ nanotubes. *J. Nanopart. Res.* 2016, 18, 191, doi:10.1007/s11051-016-3497-8.
4. Bai, Z.; Zheng, Y.; Zhang, Z. One-pot synthesis of highly efficient MgO for the removal of Congo red in aqueous solution. *J. Mater. Chem. A* 2017, 5, 6630-6637, doi:10.1039/c6ta11087h.
5. He, Z.; Wu, F.; Guan, S.; Liu, L.; Li, J.; Huang, Y. Polyamide amine/aramid nanofiber composite aerogels as an ultra-high capacity adsorbent for Congo red removal. *J. Mater. Chem. A* 2021, 9, 13320-13331, doi:10.1039/D1TA02801D.

6. Feng, Y.; Wang, H.; Xu, J.; Du, X.; Cheng, X.; Du, Z.; Wang, H. Fabrication of MXene/PEI functionalized sodium alginate aerogel and its excellent adsorption behavior for Cr(VI) and Congo Red from aqueous solution. *J. Hazard. Mater.* 2021, 416, 125777, doi:<https://doi.org/10.1016/j.jhazmat.2021.125777>.
7. Zhang, P.; Ma, X.; Guo, Y.; Cheng, Q.; Yang, L. Size-controlled synthesis of hierarchical NiO hollow microspheres and the adsorption for Congo red in water. *Chem. Eng. J.* 2012, 189-190, 188-195, doi:<https://doi.org/10.1016/j.cej.2012.02.055>.
8. Zhang, X.; Tran, H.N.; Liu, Y.; Yang, C.; Zhang, T.; Guo, J.; Zhu, W.; Ahmad, M.; Xiao, H.; Song, J. Nitrogen-doped magnetic biochar made with $K_3[Fe(C_2O_4)_3]$ to adsorb dyes: Experimental approach and density functional theory modeling. *J. Cleaner Prod.* 2023, 383, 135527, doi:<https://doi.org/10.1016/j.jclepro.2022.135527>.
9. Wang, C.; Liu, K.; Wang, D.; Wang, G.; Chu, P.K.; Meng, Z.; Wang, X. Hierarchical CuO–ZnO/SiO₂ Fibrous Membranes for Efficient Removal of Congo Red and 4-Nitrophenol from Water. *Adv. Fiber Mater.* 2022, 4, 1069-1080, doi:10.1007/s42765-022-00142-x.
10. Hou, Z.; Lan, H.; Zhu, K.; An, X.; Liu, H.; Qu, J. Hierarchically porous carbon derived from pore remodeling of waste polymeric membranes for high-efficiency adsorption applications. *Resour. Conserv. Recycl.* 2023, 190, 106845, doi:<https://doi.org/10.1016/j.resconrec.2022.106845>.