Supporting information

Mn-Ce oxide-modified activated carbon composites as efficient adsorbents for removing As(III) from water: Adsorption performance and mechanisms

Shengfeng Yang[a], Wei Fang[b], Qianwei Liang[c]*, Lin Lin[a], Mengqing Sun[a], Yujia Xing[a], Hanjin Luo[a,d]*

a School of Environment and Energy, South China University of Technology, Guangzhou 510006, China

b South China Institute of Environmental Sciences, Ministry of Ecology and Environment, Guangzhou 510655, China

c College of Geography and Environmental Sciences, Zhejiang Normal University, Jinhua 321004, China

d The Key Laboratory of Pollution Control and Ecosystem Restoration in Industry Clusters of Ministry of Education, Guangzhou 510006, China

*Corresponding author.

E-mail: qwliang@zjnu.edu.cn (Q. Liang); luohj@scut.edu.cn (H. Luo).

Text S1. Materials and chemicals

Active carbon (AC) powder (200 mesh) was purchased from Tianjinshi Baishi Chemical Co., Ltd. (Tianjin, China). Cerium nitrate hexahydrate ($CeN_3O_9 \cdot 6H_2O$) and Urea (CON_2H_4) were purchased from Aladdin (Shanghai, China). Potassium permanganate ($KMnO_4$) were purchased Guangzhou Chemical Reagent Factory (Guangzhou, China). Sodium arsenite ($NaAsO_2$) were purchased from Sigma-Aldrich Co., Ltd. (Germany). Cl^-, F^-, NO_3^-, SO_4^{2-} and PO_4^{3-} standard solution were purchased from Guobiao Testing & Certification Co., Ltd. (Beijing, China). All reagents used in the experiments are analytically pure reagents, and the water used in this work is deionized (DI) water.

Text S2. Characterization methods

Field emission scanning electron microscopy (FESEM, Merlin, Germany) were used to exam the morphologies and structural characterization of the samples. X-ray diffraction (XRD) analysis was conducted by using an X-ray powder diffractometer (Bruker D8, Germany) equipped with Cu Kα radiation at a scanning range from 5° to 90°, operated at voltage of 40 kV and applied potential current of 40 mA. The surface area of the sample was analyzed by Brunauer-Emmett-Teller (BET, Tristar II Plus, Micromeritics, USA) method by N_2 gas adsorption at 77.35 K using high-speed surface analyzer. Fourier transform infrared spectra (FT-IR, Nicolet-460, Thermo Fisher, USA) was used to measure the infrared spectra of these powders. The X-ray photoelectron spectroscopy (XPS, Escalab Xi+, USA) was recorded on the Escalab 250Xi spectrometer with monochromatic Al Ka radiation. The atomic absorption spectrometer (PinAAcle 900T, Perkin Elmer, Singapore) measured the leakage of loaded-Mn in the reaction system. Inductively coupled plasma emission spectrometer (iCAP 7200 Duo, Thermofisher Scientific, USA) measured the leakage of loaded-Ce in the reaction system.

Supporting figures

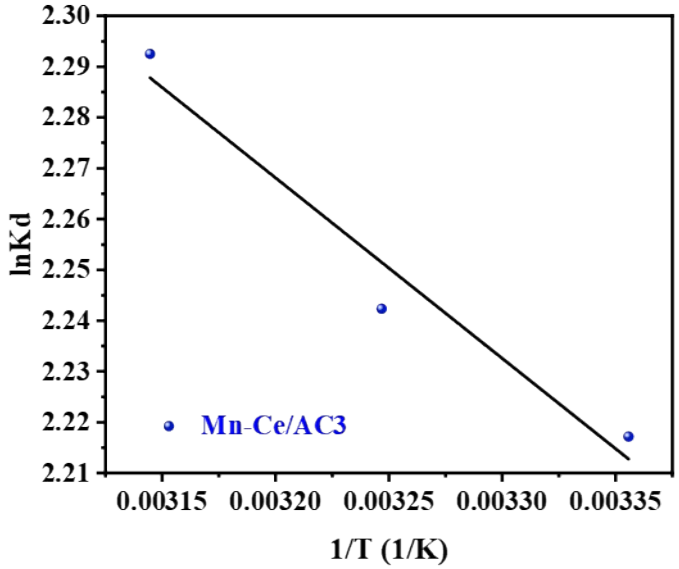

Fig. S1. Thermodynamic plot of As(III) adsorption by Mn-Ce/AC3.

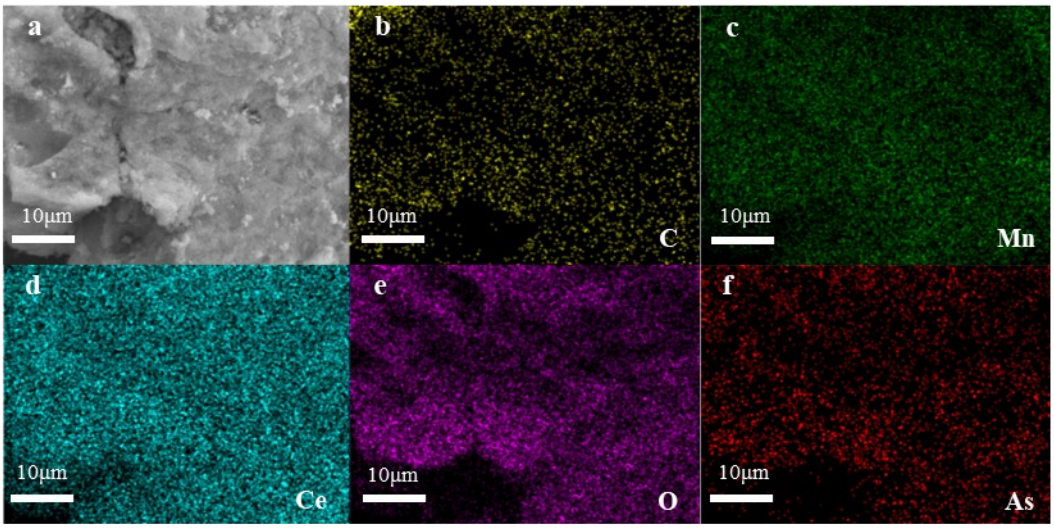

Fig. S2 Elemental mapping images of Mn-Ce/AC3-As(III).

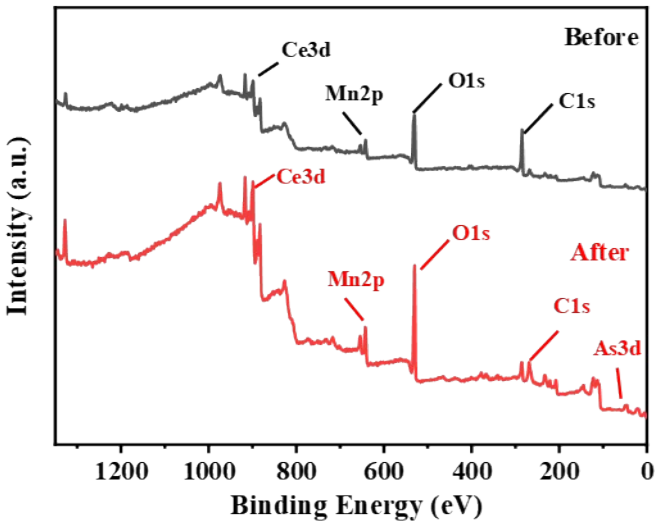

Fig. S3 Full-range XPS spectra of fresh Mn-Ce/AC3 and Mn-Ce/AC3 after adsorption of As(III).

Supporting tables

Table S1. BET surface area, total pore volume and average pore diameter of AC, Mn-Ce/AC1, Mn-Ce/AC3, Mn-Ce/AC5 and Mn-Ce/AC7.

Sample	Average pore size (nm)	BET surface area (m^2/g)	Pore volume (cm^3/g)
AC	7.33	9.63	0.01144
Mn-Ce/AC1	12.69	124.99	0.3725
Mn-Ce/AC3	10.33	213.25	0.5903
Mn-Ce/AC5	10.75	135.44	0.3253
Mn-Ce/AC7	13.82	53.16	0.1975

Table S2. Comparison of maximum arsenic adsorption capacities for different adsorbents.

Adsorbent	Maximum As(III) adsorption capacity (mg/g)	pH	References
Mn-Ce oxide-modified activated carbon	73.16	7.0	**Present study**
Fe–Mn–Ce oxide-modified biochar composite	8.74	3	1
Cerium oxide modified activated carbon	36.77	5.0	2
Cerium modified chitosan	57.50	8.0	3
Manganese oxide-coated-alumina (MOCA)	42.48	4~7.5	4
Ce-Mn binary oxide	97.70	8.0	5
Ti(IV)-Mn(IV) binary oxide	107.00	7.0	6
Mn-doped mesoporous iron oxides	59.44	3.0	7
Ce–Fe mixed oxide decorated multiwalled carbon nanotubes	28.74	7.5	8
Magnetic nanoparticles modified with Fe-Mn binary oxide	56.00	7.0	9
Starch-FeMnOx/RGO	78.74	7.0	10
Iron hydroxide/manganese dioxide doped straw activated carbon	75.82	3.0	11
MnOx and CeOx anchored on multi-walled carbon nanotubes	151.06	7.0	12

Table S3. Peak parameters for As, Mn, Ce and O in Mn-Ce/AC3.

Element	Species	Mn-Ce/AC3		Mn-Ce/AC3-As(III)	
		BE (eV)	Content (%)	BE (eV)	Content (%)
As	As(V)	----	----	44.30	43.2
	As(III)	----	----	45.24	56.8
Mn	Mn(IV)	654.5 642.2	43.94	654.5 642.2	40.83
	Mn(III)	654.1 641.8	37.88	654.1 641.8	41.67
	Mn(II)	653.0 641.2	18.18	653.0 641.2	17.50
Ce	Ce(IV)	882.53 889.03 896.43 901.01 907.80 916.70	75.19	882.68 889.07 896.84 901.21 907.82 916.90	63.80
	Ce(III)	881.24 884.79 898.40 903.20	24.81	880.64 884.78 898.70 903.23	36.20
O	H_2O	532.4	25.28	532.1	30.2
	-OH	531.4	37.73	530.8	25.57
	O^{2-}	529.5	36.98	529.6	37.4

References

1. X. Liu, M. Gao, W. Qiu, Z. H. Khan, N. Liu, L. Lin and Z. Song, *Environ Sci Pollut Res Int*, 2019, **26**, 17373-17382.
2. Y. Yu, C. Zhang, L. Yang and J. Paul Chen, *Chem Eng J*, 2017, **315**, 630-638.
3. L. Zhang, T. Zhu, X. Liu and W. Zhang, *J Hazard Mater*, 2016, **308**, 1-10.
4. S. M. Maliyekkal, L. Philip and T. Pradeep, *Chem Eng J*, 2009, **153**, 101-107.
5. J. Chen, J. Wang, G. Zhang, Q. Wu and D. Wang, *Chem Eng J*, 2018, **334**, 1518-1526.
6. W. Zhang, C. Liu, T. Zheng, J. Ma, G. Zhang, G. Ren, L. Wang and Y. Liu, *J Hazard Mater*, 2018, **353**, 410-420.
7. X. Xie, C. Lu, R. Xu, X. Yang, L. Yan and C. Su, *Sci Total Environ*, 2022, **806**, 150615.
8. B. Chen, Z. Zhu, J. Ma, Y. Qiu and J. Chen, *J Mater Chem A*, 2013, **1**, 11355-11367.
9. J. Nikic, M. A. Watson, M. K. Isakovski, A. Tubic, M. Solic, B. Kordic and J. Agbaba, *Environ Technol*, 2021, **42**, 2527-2539.
10. Z. Lou, Z. Cao, J. Xu, X. Zhou, J. Zhu, X. Liu, S. Ali Baig, J. Zhou and X. Xu, *Chem Eng J*, 2017, **322**, 710-721.
11. Y. Xiong, Q. Tong, W. Shan, Z. Xing, Y. Wang, S. Wen and Z. Lou, *Appl Surf Sci*, 2017, **416**, 618-627.
12. X. Liang, Q. Ye, Y. Zhao, Z. Yang and Q. Yang, *Surf Interfaces*, 2022, **30**.