

Supplementary Material

The Influence of The Textural Characteristics of The Hierarchical Porous Carbons on The Removal of Lead and Cadmium Ions From Aqueous Solution

Turki N. Baroud

Department of Mechanical Engineering, King Fahd University of Petroleum and Mineral, Dhahran, 31261, Saudi Arabia.

Corresponding authors. Email: turkibaroud@kfupm.edu.sa (Turki N. Baroud)

Table S1. CCD matrix of the experiment showing the factor combination and the responses.

STD	RUN	Initial Conc.(mg/L)	Adsorbent Dosage (g/L)	pH	Cd ²⁺ Exp (mg/g)	Cd ²⁺ Pred.(mg/g)	Pb ²⁺ Exp (mg/g)	Pb ²⁺ Pred.(mg/g)
18	1	55	3	5	7.389	7.463	16.28	15.96
2	2	100	1	3	7.029	7.099	18.36	17.81
9	3	10	3	5	2.886	2.829	4.85	4.95
14	4	55	3	7	8.415	8.248	15.96	16.28
5	5	10	1	7	5.259	5.312	6.30	6.11
1	6	10	1	3	0.720	0.730	2.77	2.70
11	7	55	1	5	6.753	6.424	10.59	11.59
16	8	55	3	5	7.316	7.463	16.12	15.96
3	9	10	5	3	2.019	2.015	6.82	6.89
6	10	100	1	7	7.691	7.846	17.81	17.46
4	11	100	5	3	7.243	7.243	48.42	48.91
8	12	100	5	7	10.591	10.591	86.49	87.36
17	13	55	3	5	7.389	7.463	15.80	15.96
12	14	55	5	5	9.025	9.025	29.96	28.50
19	15	55	3	5	7.171	7.463	16.28	15.96
10	16	100	3	5	6.686	6.554	24.05	24.78
20	17	55	3	5	7.389	7.463	16.44	15.96
7	18	10	5	7	5.641	5.641	6.30	6.36
13	19	55	3	3	7.463	7.243	16.44	16.95
15	20	55	3	5	7.389	7.463	16.44	15.96

Table S2. ANOVA result for Cd²⁺ adsorption.

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	7.26	12	0.6047	536.17	< 0.0001	significant
A-Initial Conc (mg/L)	0.3489	1	0.3489	309.35	< 0.0001	
B-Adsorbent Dosage (g/L)	0.3019	1	0.3019	267.73	< 0.0001	
C-pH	0.0081	1	0.0081	7.16	0.0318	
AB	0.0709	1	0.0709	62.82	< 0.0001	
AC	0.8038	1	0.8038	712.72	< 0.0001	
BC	0.0557	1	0.0557	49.36	0.0002	
A ²	0.8318	1	0.8318	737.53	< 0.0001	
B ²	0.0013	1	0.0013	1.16	0.3175	

C²	0.0039	1	0.0039	3.45	0.1055
ABC	0.1956	1	0.1956	173.44	< 0.0001
A²C	0.2237	1	0.2237	198.36	< 0.0001
AB²	0.0377	1	0.0377	33.43	0.0007
Residual	0.0079	7	0.0011		
Pure Error	0.0007	5	0.0001		
Cor Total	7.26	19			

Table S3. ANOVA result for Pb²⁺ adsorption.

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	11.63	12	0.9692	351.92	< 0.0001	significant
A-Initial Conc (mg/L)	1.29	1	1.29	469.14	< 0.0001	
B-Adsorbent Dosage (g/L)	2.03	1	2.03	735.41	< 0.0001	
C-pH	0.0005	1	0.0005	0.1781	0.6857	
AB	0.3404	1	0.3404	123.59	< 0.0001	
AC	0.0043	1	0.0043	1.55	0.2525	
BC	0.0096	1	0.0096	3.50	0.1034	
A²	0.3593	1	0.3593	130.46	< 0.0001	
B²	0.0519	1	0.0519	18.86	0.0034	
C²	0.0050	1	0.0050	1.81	0.2199	
ABC	0.2833	1	0.2833	102.86	< 0.0001	
A²C	0.0509	1	0.0509	18.49	0.0036	
AB²	0.0295	1	0.0295	10.71	0.0136	
Residual	0.0193	7	0.0028			
Pure Error	0.0010	5	0.0002			
Cor Total	11.65	19				

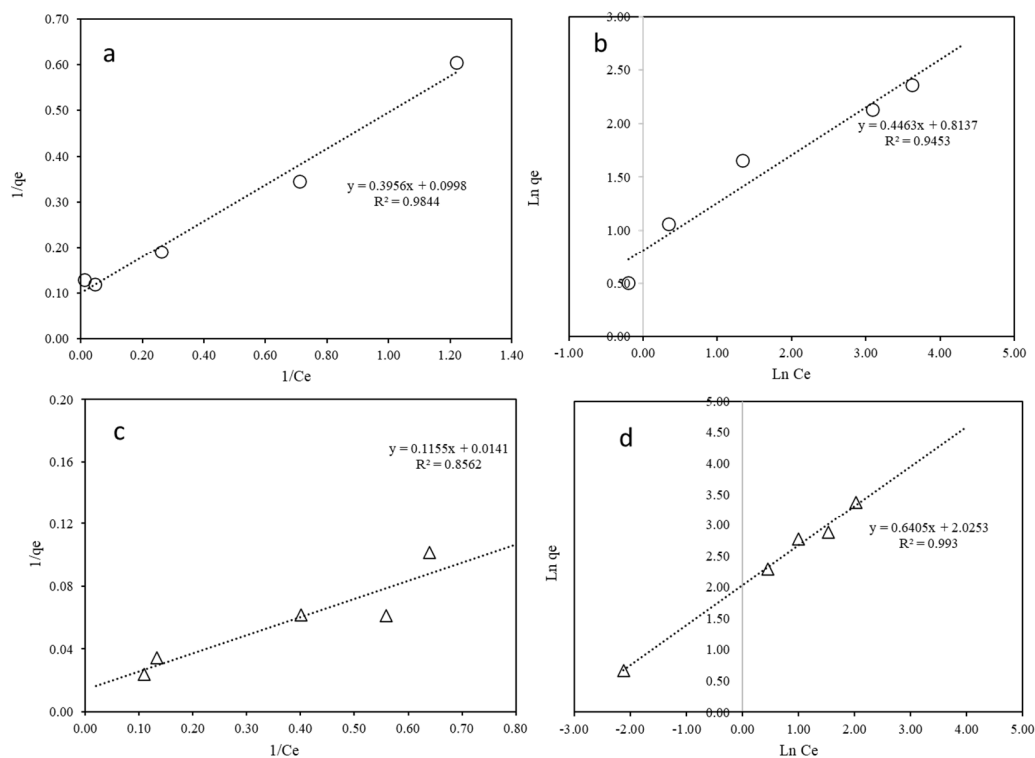


Figure S1. Langmuir and Freundlich isotherm plot for Cd²⁺ (a,b), and Pb²⁺ (c,d) adsorption.

Table S4. Isotherm parameters.

Isotherm Model	Cd ²⁺	Pb ²⁺
Langmuir Isotherm		
q_m (mg/g)	10.02	70.92
K_L (L/mg)	0.2522	0.122
R^2	0.9844	0.8562
Freundlich Isotherm		
n	2.24	1.56
k_F	2.26	7.58
R^2	0.945	0.993

Table S5. Comparison of adsorption capacities of some non-functionalized carbon adsorbents for Cd²⁺ and Pb²⁺.

Adsorbent Type	Surface area (m ² /g)	Micropore area (m ² /g)	Total pore volume (cm ³ /g)	Micropore volume (cm ³ /g)	Average pore size (nm)	Cd ²⁺ q _e (mg/g)	Pb ²⁺ q _e (mg/g)	Ref.
Activated Carbon from waste tire	265	187	0.3	0.09	5	49.7	10.40	[1]
Activated carbon (AC) derived from	479.0	479.0	0.14	0.14	N/A	N/A	78.84	[2]

waste coconut buttons								
Banana peel activated carbon	456.54	N/A	N/A	N/A	2.77	30.7	45.6	[3]
Olive stone activated carbon	1280.71	379	0.604	N/A	4.63	11.72	N/A	[4]
Pine cone activated carbon	1094.1	613	1.09	0.39	N/A	N/A	27.53	[5]
Coffee residue activated carbon	890	N/A	0.772	N/A	N/A	N/A	63	[6]
mesoporous carbon derived from SBA-15 and sucrose								
Commercial activated carbon (Chemviron Carbon)	4273	3697	2.66	2.4	4.48	17.23	16.84	[8]
Cashew nut shell activated carbon	1026	N/A	0.5789	N/A	22.57	14.29	28.9	[9]
Saw dust activated carbon	696.7	617.4	0.405	0.284	2.53	NA	58.25	[10]
Tire activated carbon	131.6	62.89	0.619	0.029	2.81	N/A	50.48	
Acrylic fiber activated carbon	781.3	650.5	1.334	0.299	2.23	N/A	31.25	
Rice husk activated carbon	1014.4	886.1	0.713	0.410	2.25	N/A	59.73	
HPC1221	907	112	2.8	0.05	12	12.3	89	This work

N/A: information is not available

References

1. Nieto-Márquez, A.; Pinedo-Flores, A.; Picasso, G.; Atanes, E.; Kou, R.S. Selective adsorption of Pb²⁺, Cr³⁺ and Cd²⁺ mixtures on activated carbons prepared from waste tires. *J. Environ. Chem. Eng.* **2017**, *5*, 1060–1067, doi:10.1016/j.jece.2017.01.034.
2. Anirudhan, T.; Sreekumari, S. Adsorptive removal of heavy metal ions from industrial effluents using activated carbon derived from waste coconut buttons. *J. Environ. Sci.* **2011**, *23*, 1989–1998, doi:10.1016/s1001-0742(10)60515-3.

3. Li, Y.; Liu, J.; Yuan, Q.; Tang, H.; Yu, F.; Lv, X. A green adsorbent derived from banana peel for highly effective removal of heavy metal ions from water. *RSC Adv.* **2016**, *6*, 45041–45048, doi:10.1039/c6ra07460j.
4. Alslaibi, T.M.; Abustan, I.; Ahmad, M.A.; Abu Foul, A. Cadmium removal from aqueous solution using microwaved olive stone activated carbon. *J. Environ. Chem. Eng.* **2013**, *1*, 589–599, doi:10.1016/j.jece.2013.06.028.
5. Momčilović, M.; Purenović, M.; Bojić, A.; Zarubica, A.; Randelović, M. Removal of lead(II) ions from aqueous solutions by adsorption onto pine cone activated carbon. *Desalination* **2011**, *276*, 53–59, doi:10.1016/j.desal.2011.03.013.
6. Boudrahem, F.; Aissani-Benissad, F.; Aït-Amar, H. Batch sorption dynamics and equilibrium for the removal of lead ions from aqueous phase using activated carbon developed from coffee residue activated with zinc chloride. *J. Environ. Manag.* **2009**, *90*, 3031–3039, doi:10.1016/j.jenvman.2009.04.005.
7. Lu, L.; Zhao, H.; Yan, L.; Wang, G.; Mao, Y.; Wang, X.; Liu, K.; Liu, X.; Zhao, Q.; Jiang, T. Removal characteristics of Cd(II) ions from aqueous solution on ordered mesoporous carbon. *Korean J. Chem. Eng.* **2015**, *32*, 2161–2167, doi:10.1007/s11814-015-0150-7.
8. Asuquo, E.; Martin, A.; Nzerem, P.; Siperstein, F.; Fan, X. Adsorption of Cd(II) and Pb(II) ions from aqueous solutions using mesoporous activated carbon adsorbent: Equilibrium, kinetics and characterisation studies. *J. Environ. Chem. Eng.* **2017**, *5*, 679–698, doi:10.1016/j.jece.2016.12.043.
9. Tangjuank, S.; Insuk, N.; Tontrakoon, J.; Udeye, V. Adsorption of Lead (II) and Cadmium (II) ions from aqueous solutions by adsorption on activated carbon prepared from cashew nut shells. *World Acad. Sci. Eng. Technol.* **2009**, *3*, 110–116.
10. Song, M.; Wei, Y.; Cai, S.; Yu, L.; Zhong, Z.; Jin, B. Study on adsorption properties and mechanism of Pb²⁺ with different carbon based adsorbents. *Sci. Total Environ.* **2018**, *618*, 1416–1422, doi:10.1016/j.scitotenv.2017.09.268.