

**Explorations on thermodynamic and kinetic performances of various cationic
exchange durations for synthetic clinoptilolite**

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Electronic Supplementary Information

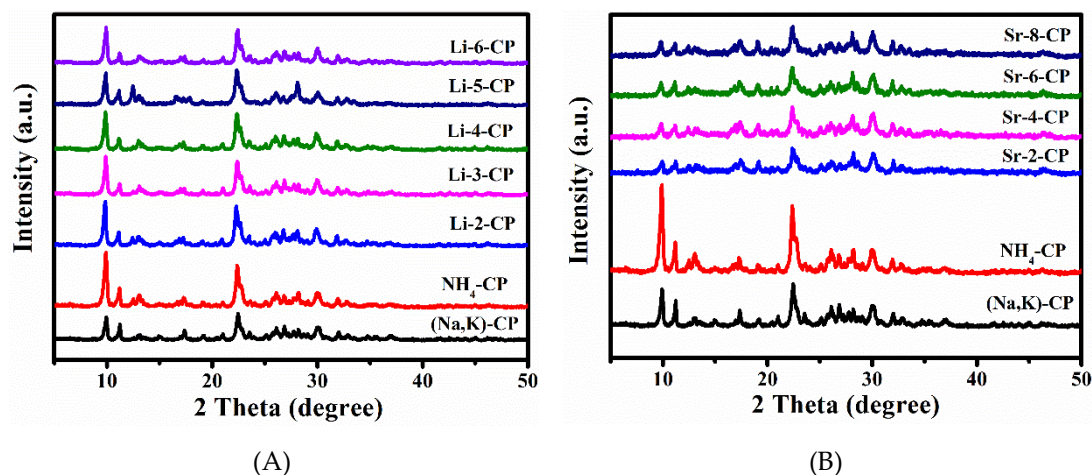


Figure S1. XRD patterns of Li-x-CP (A) and Sr-x-CP (B).

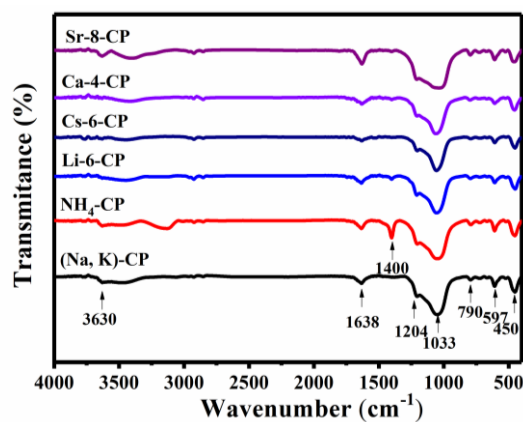
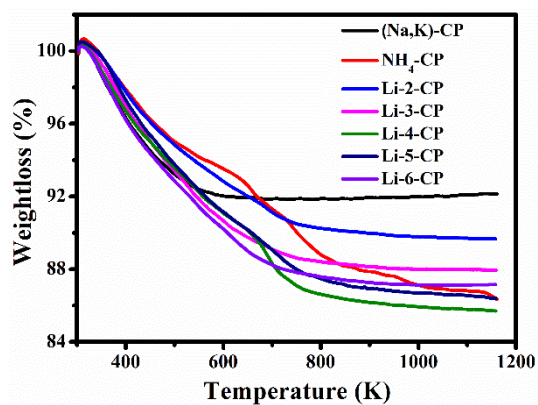
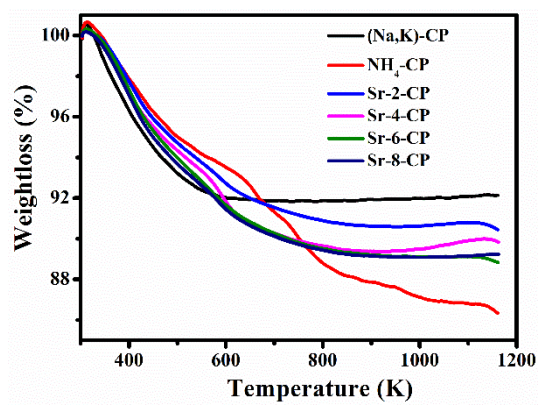


Figure S2. FT-IR spectra of various CPs.

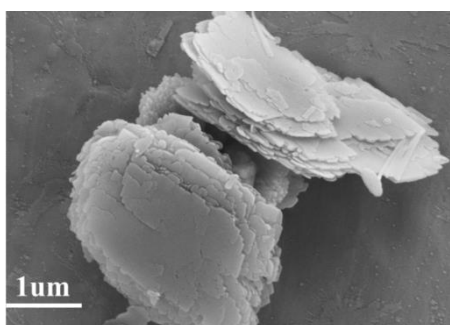


(A)

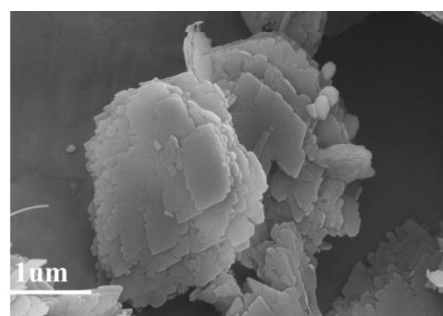


(B)

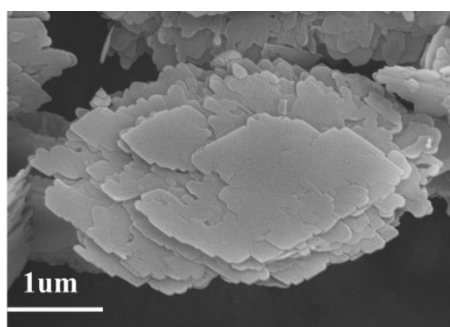
Figure S3. TG profiles of Li-x-CP (A) and Sr-x-CP (B).



(A)



(B)



(C)

Figure S4. SEM images of (Na, K)-CP (A), Cs-6-CP (B), and Ca-4-CP (C).

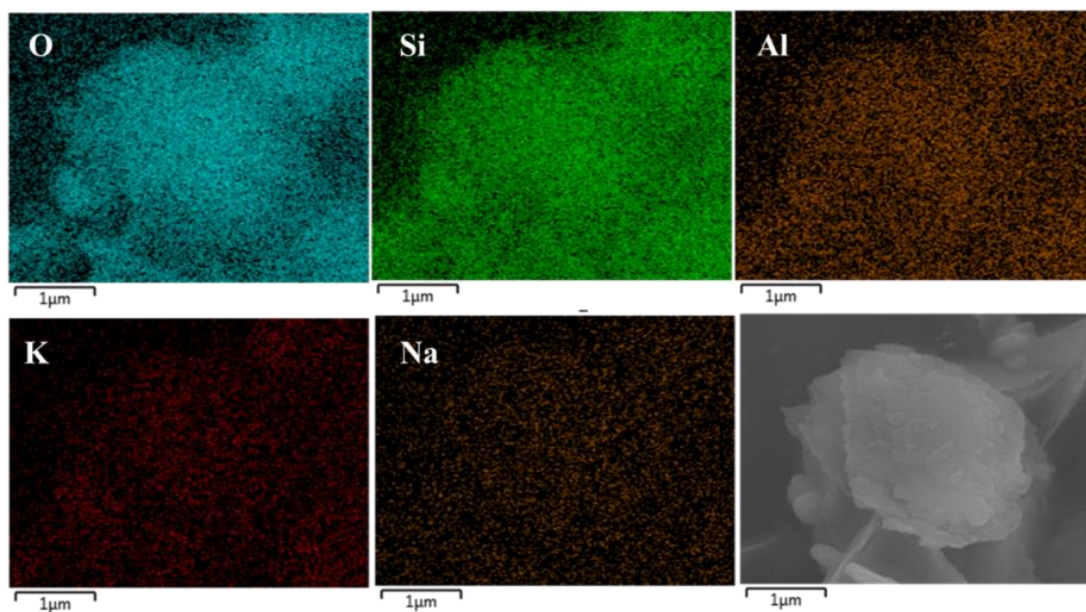


Figure S5. SEM elemental mappings of (Na, K)-CP.

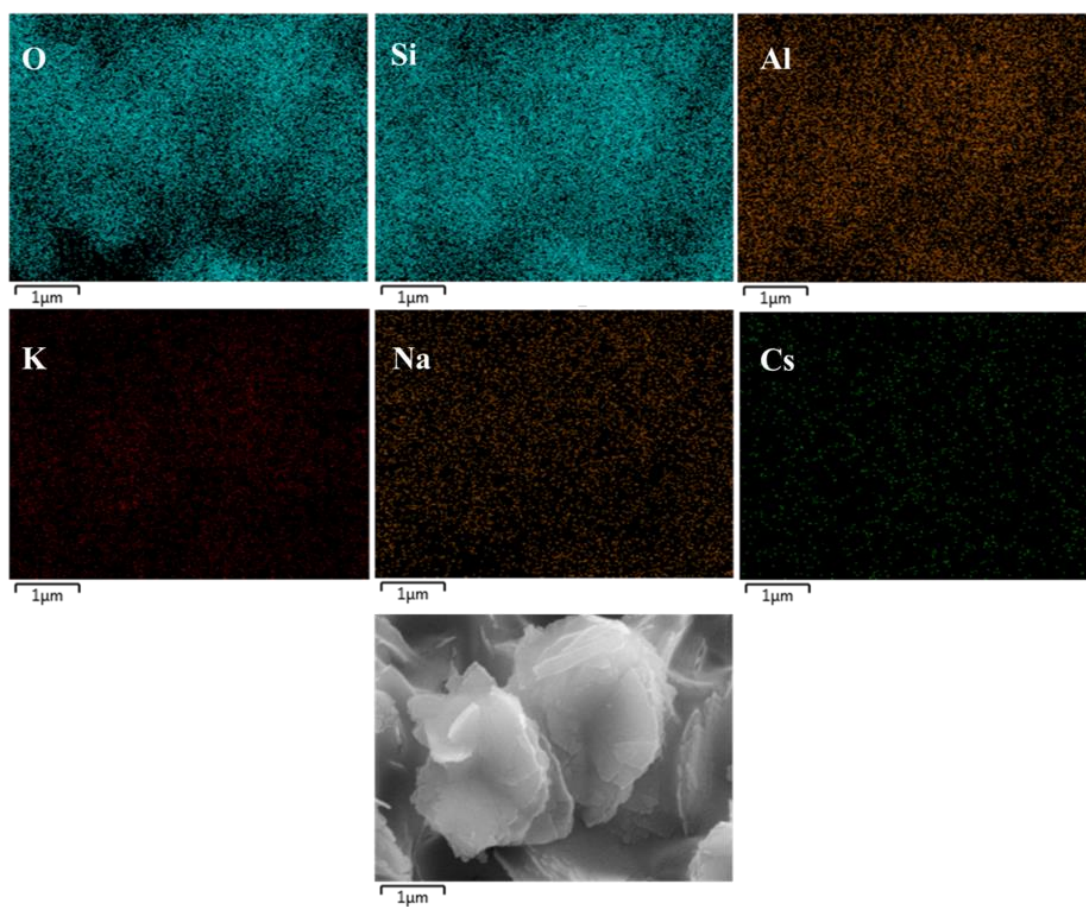


Figure S6. SEM elemental mappings of Cs-6-CP.

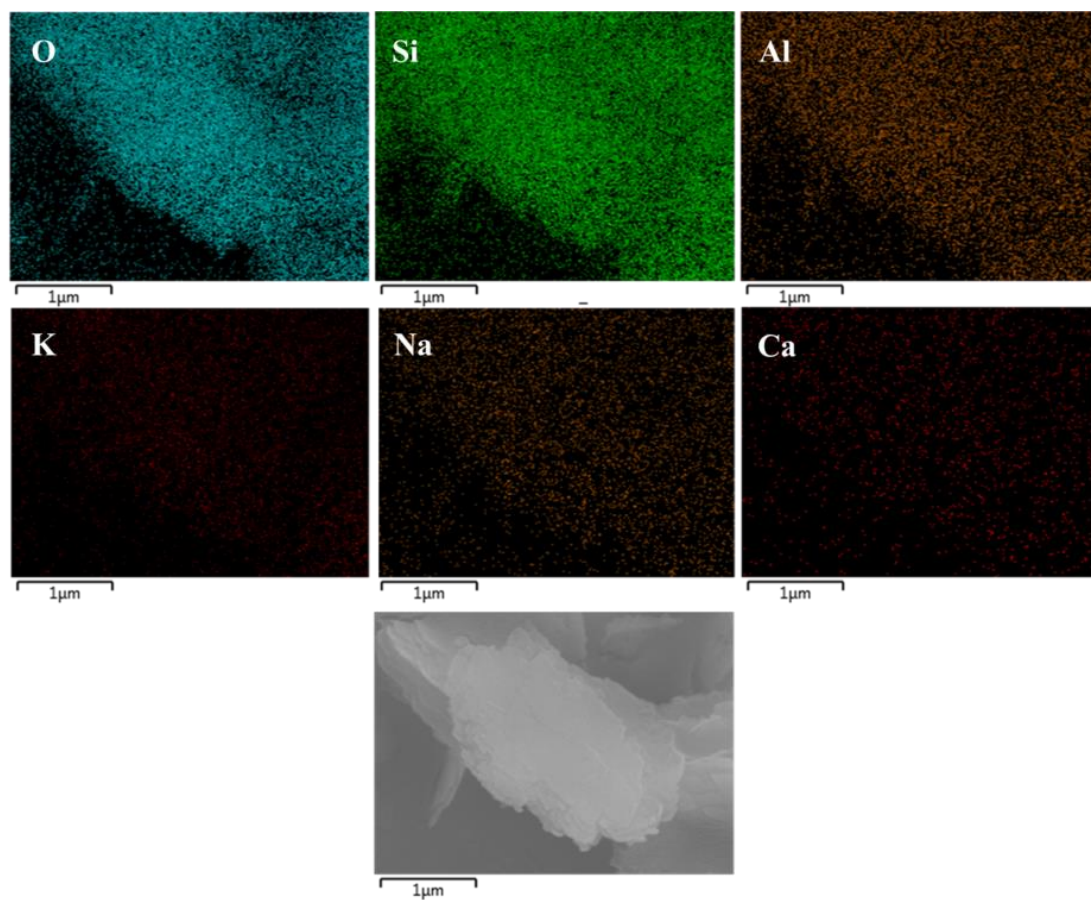
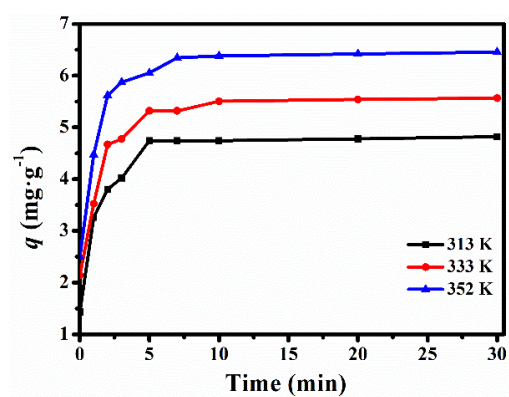
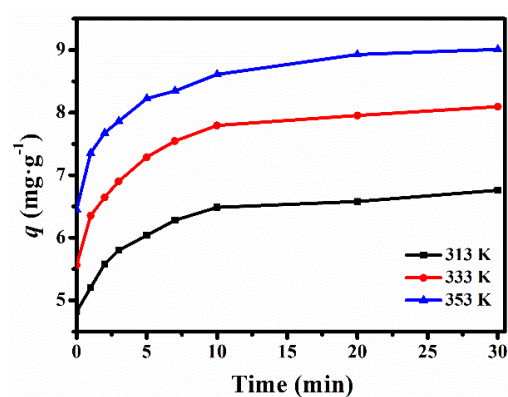


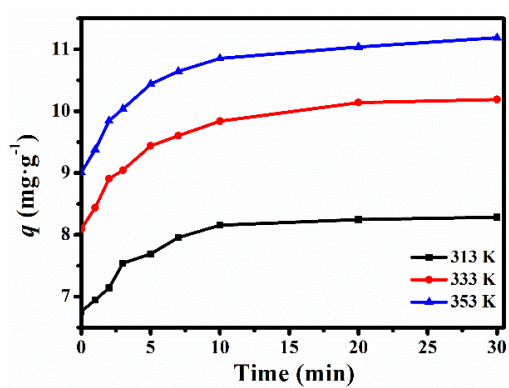
Figure S7. SEM elemental mappings of Ca-4-CP.



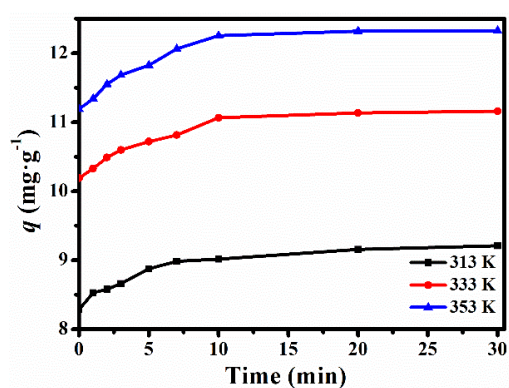
(A)



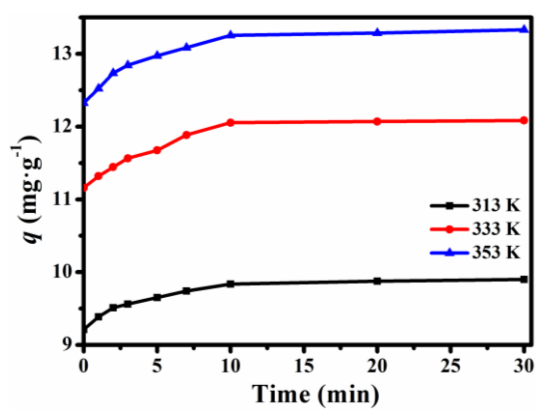
(B)



(C)



(D)



(E)

Figure S8. Exchanged kinetic curves of Li-x-CP at 313 K, 333 K, and 353 K. x = 2 (A), 3 (B), 4 (C), 5 (D), and 6 (E).

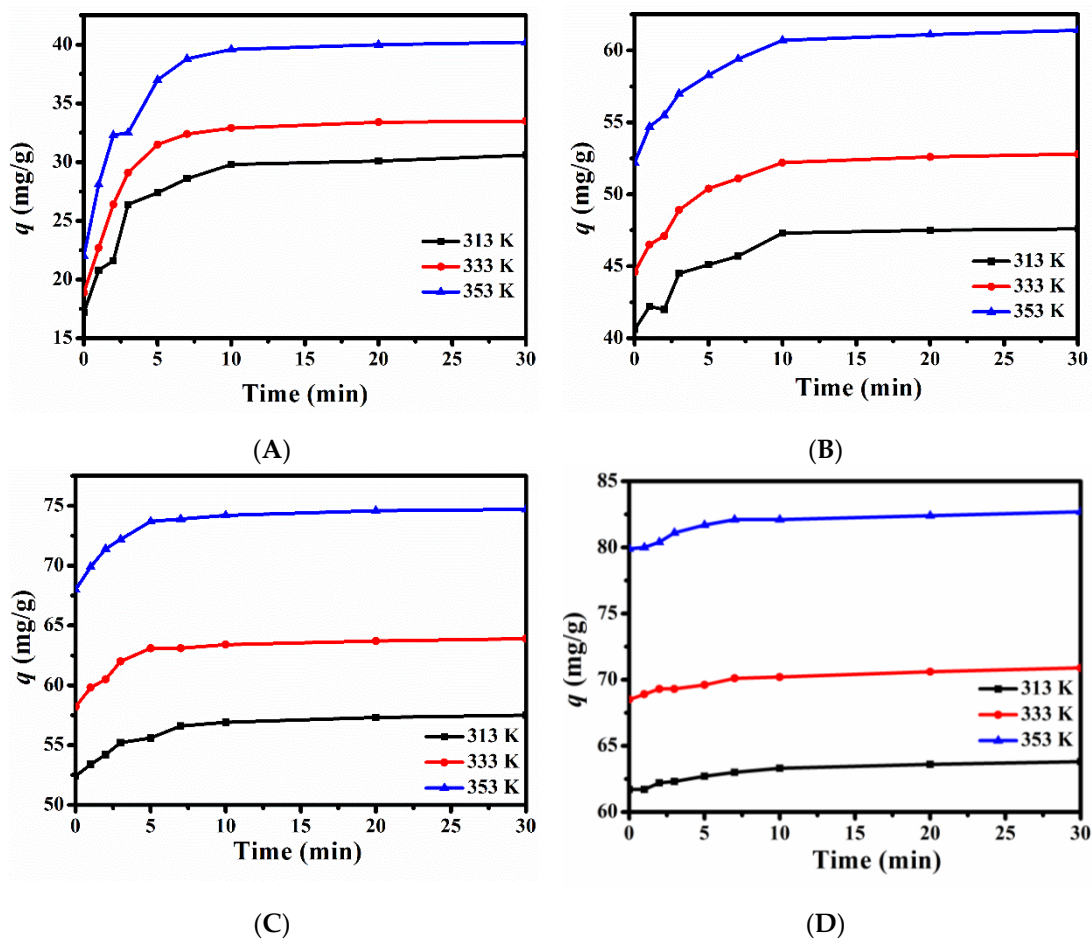


Figure S9. Exchanged kinetic curves of Sr- x -CP at 313 K, 333 K, and 353 K. $x = 2$ (A), 4 (B), 6 (C), and 8 (D).

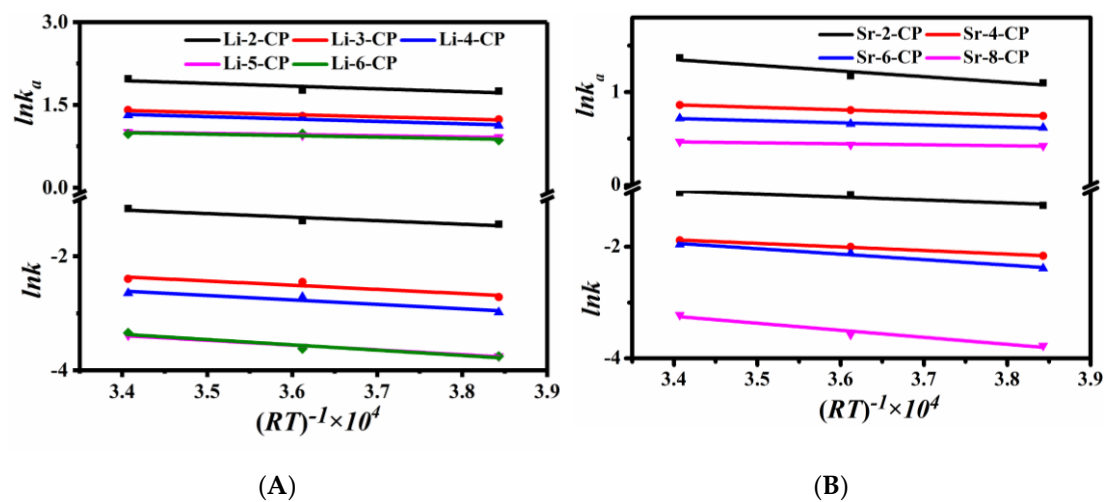


Figure S10. Relationship between $\ln k_a$ and $(RT)^{-1} \times 10^4$, as well as $\ln k$ and $(RT)^{-1} \times 10^4$ for Li- x -CP (A) and Sr- x -CP (B).

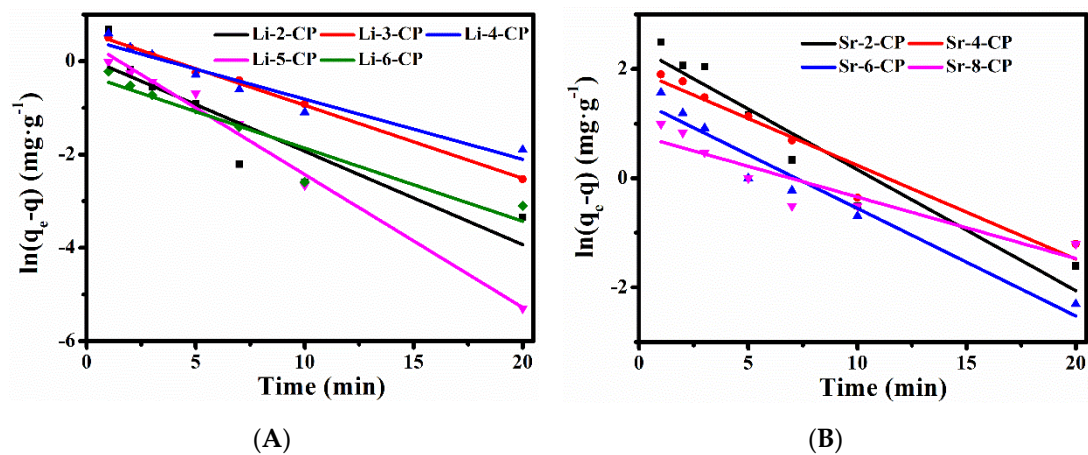


Figure S11. Pseudo-first-order model fit for Li-x-CP (A) and Sr-x-CP (B).

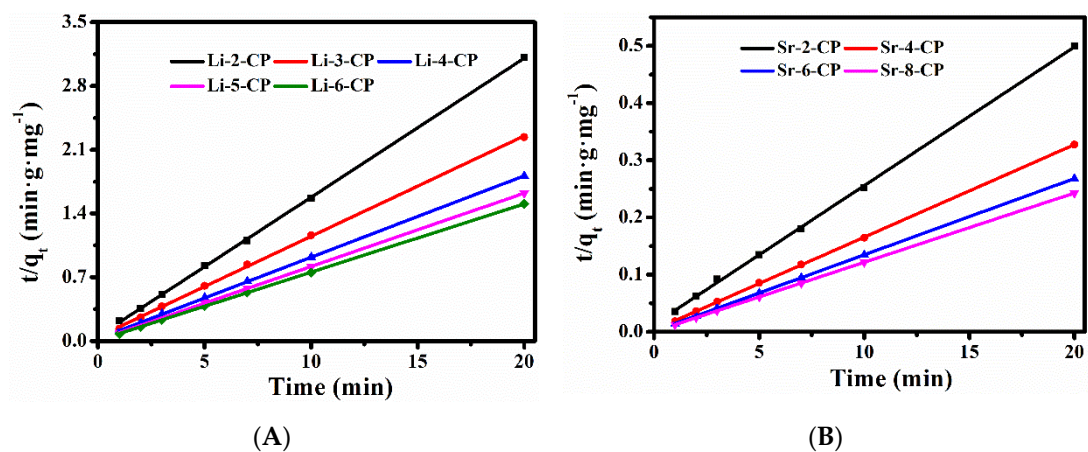


Figure S12. Pseudo-second-order model fit for Li-x-CP (A) and Sr-x-CP (B).

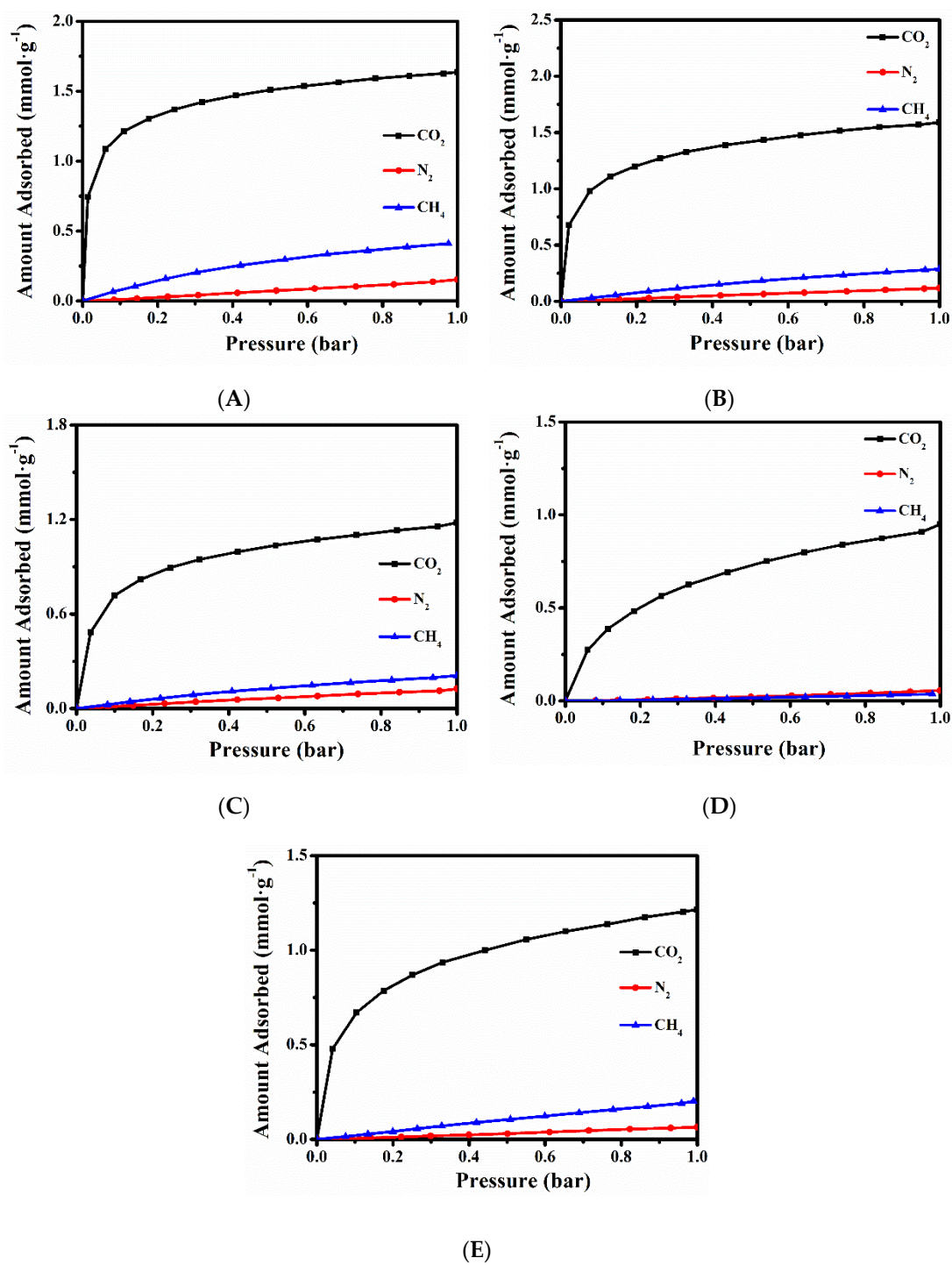


Figure S13. Adsorbed isotherms of (Na, K)-CP (A), Li-6-CP (B), Cs-6-CP (C), Ca-4-CP (D), and Sr-8-CP (E) using CO₂, N₂ and CH₄ as adsorbate at 298 K.

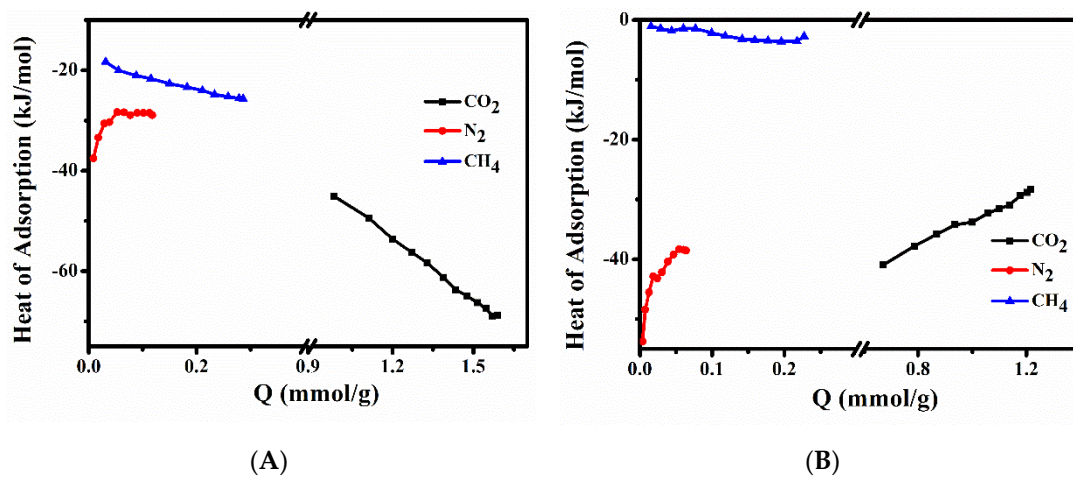


Figure S14. Adsorption heat of CO₂, N₂ and CH₄ of Li-6-CP (A) and Sr-8-CP (B).

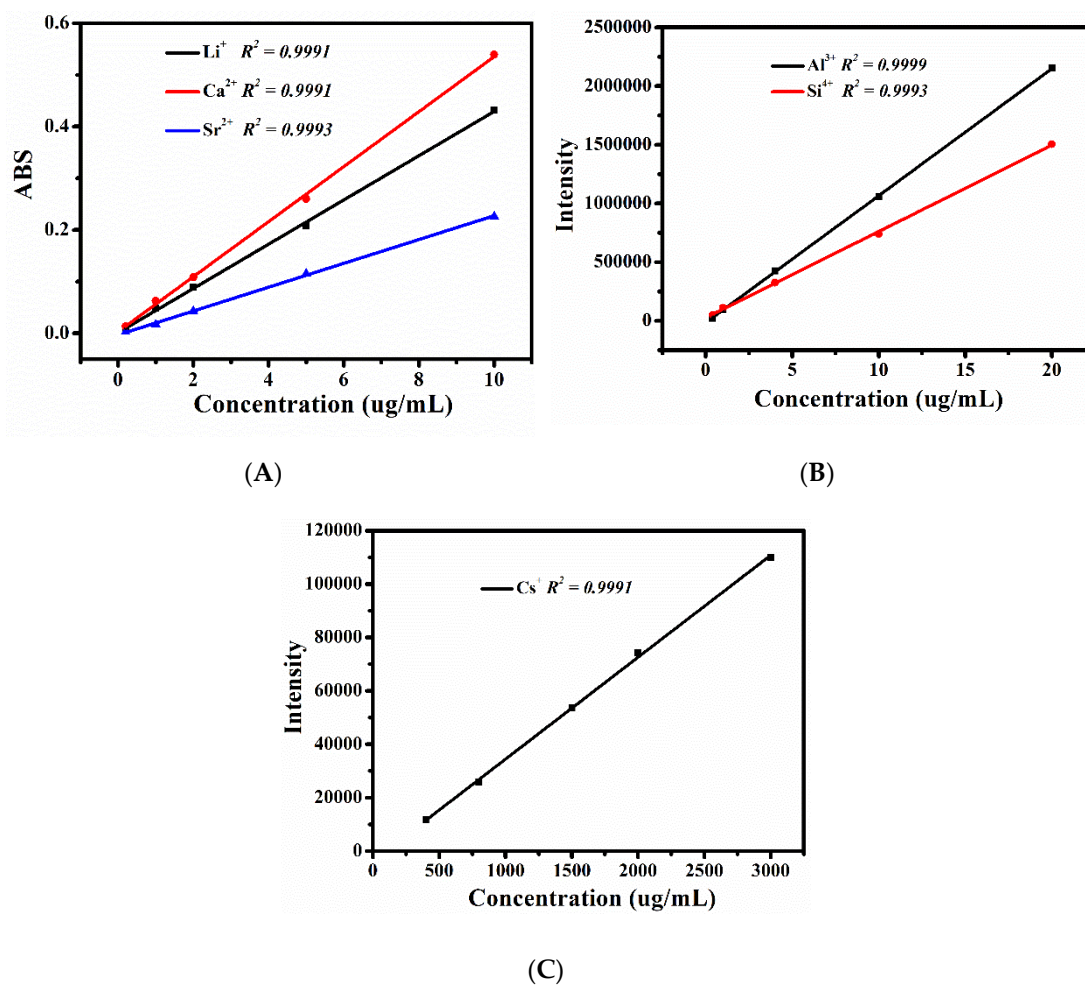


Figure S15. The standard curves of Li⁺, Ca²⁺, Sr²⁺ (A), Al³⁺, Si⁴⁺ (B), and Cs⁺ (C).

Table S1. Summaries for the d (nm) spacing values of the obtained M-x-CPs corresponding to different spatial planes.

Samples	<i>020</i>	<i>200</i>	<i>111</i>	<i>13-1</i>	<i>131</i>	<i>22-2</i>	<i>42-2</i>	<i>151</i>	<i>530</i>	<i>061</i>
CP	8.909	7.892	5.104	4.637	3.959	3.402	3.160	2.970	2.796	2.725
NH ₄ -CP	8.927	7.909	5.132	4.648	3.976	3.414	3.162	2.980	2.800	2.734
Li-2-CP	8.982	7.963	5.133	4.666	3.976	3.427	3.173	2.988	2.802	2.728
Li-3-CP	8.946	7.950	5.139	4.651	3.979	3.416	3.175	2.965	2.801	2.730
Li-4-CP	8.927	7.907	5.109	4.633	3.963	3.411	3.166	2.974	2.799	2.730
Li-5-CP	8.984	7.953	5.145	4.649	3.983	3.429	3.175	2.988	2.807	2.730
Li-6-CP	8.962	7.907	5.105	4.642	3.973	3.414	3.166	2.984	2.803	2.735
Cs-2-CP	9.055	7.996	5.169		4.005	3.432	3.173	2.996	2.817	2.743
Cs-3-CP		8.025			4.005	3.432	3.177	3.002	2.819	2.746
Cs-4-CP	9.020	8.065			4.004	3.438	3.177	3.013		2.746
Cs-5-CP	9.157	8.007	5.164	4.709	4.001	3.435	3.179	2.998		2.751
Cs-6-CP		8.025			4.005	3.432	3.177	3.002	2.819	2.746
Ca-2-CP	8.983	7.937	5.121	4.661	3.973	3.424	3.182	2.961	2.797	2.730
Ca-3-CP	8.965	7.922	5.115	4.649	3.973	3.422	3.173	2.963	2.796	2.726
Ca-4-CP	8.944	7.906	5.082	4.647	3.952	3.411	3.169	2.961	2.787	2.735
Sr-2-CP	8.876	7.866	5.087	4.628	3.952	3.412	3.160	2.959	2.791	2.720
Sr-4-CP	8.965	7.921	5.099	4.643	3.973	3.421	3.171	2.968	2.798	2.730
Sr-6-CP	8.990	7.948	5.122	4.657	3.976	3.424	3.173	2.965	2.801	2.733
Sr-8-CP	9.035	7.908	5.105	4.643	3.969	3.417	3.175	2.972	2.800	2.734