

Table S1: Comparison table summarizing the Cr(VI) adsorption performance of BC1 biochars

Parameter	BC1
Adsorption Capacity ( $\text{mgg}^{-1}$ ) (t = 1440 min)	8.12
Equilibrium Time	24 h
Maximum Adsorption at pH 5 (mg/g)	4.328
Adsorption at pH 8 (mg/g)	1.204
% Removal at pH 5 (10 g/L adsorbent dose)	78.1%
Lowest % Removal (pH 8)	Decreased
Effect of Temperature (293-308 K) on Adsorption Capacity (mg/g)	7.2 $\rightarrow$ 9.8
Adsorption Capacity vs. Adsorbent Dose (mg/g)	1.352 $\rightarrow$ 0.781
% Removal vs. Adsorbent Dose	33.8 $\rightarrow$ 78.1%
Effect of Initial Concentration (1-100 mg/L) on Adsorption Capacity (mg/g)	0.293 $\rightarrow$ 8.12

Table S2: Comparison table summarizing the Cr(VI) adsorption performance BC2 biochars

Parameter	BC2
Adsorption Capacity ( $\text{mgg}^{-1}$ ) (t = 1440 min)	9.49
Equilibrium Time	24 h
Maximum Adsorption at pH 5 (mg/g)	5.13
Adsorption at pH 8 (mg/g)	2.672
% Removal at pH 5 (10 g/L adsorbent dose)	84.6%
Lowest % Removal (pH 8)	Decreased
Effect of Temperature (293-308 K) on Adsorption Capacity (mg/g)	8 $\rightarrow$ 10.8
Adsorption Capacity vs. Adsorbent Dose (mg/g)	1.46 $\rightarrow$ 0.846
% Removal vs. Adsorbent Dose	36.5 $\rightarrow$ 84.6%

Effect of Initial Concentration (1-100 mg/L) on Adsorption Capacity (mg/g)	0.333 → 9.49
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Table S1: Isotherm models error functions for Cr(VI) adsorption on BC1

<b>Isotherm Models</b>	<b>Parameters</b>	<b>20°C</b>	<b>25°C</b>	<b>30°C</b>	<b>35°C</b>	
<b>Langmuir</b>	HYBRID	4.179041	13.436896	12.555820	15.864142	
	ARE	-3.482534	12.778785	12.527740	17.082734	
	MPSD	10.356963	29.115361	25.162058	32.453456	
	EABS	0.386345	1.831765	2.439280	3.930675	
	SSE	0.019502	0.412122	0.687912	1.546393	
	$\Delta q$ (%)	9.874976	27.760408	23.991081	30.943157	
	$x^2$	0.027068	0.387527	0.392496	0.838847	
	$R^2$ (adj)	0.999726	0.995539	0.994531	0.986234	
	<b>Freundlich</b>	HYBRID	-6.327302	3.383727	-3.311736	-6.449441
		ARE	5.272752	6.989083	2.759780	5.374534
MPSD		12.122464	14.228041	7.401612	6.492077	
EABS		1.034388	1.237538	0.824955	2.990116	
SSE		0.128862	0.165591	0.085785	0.762862	
$\Delta q$ (%)		11.558316	13.565905	7.057160	6.189953	
$x^2$		0.076844	0.104540	0.042482	0.177224	
$R^2$ (adj)		0.998094	0.997600	0.999155	0.999304	
<b>BET</b>		HYBRID	4.552512	14.861375	13.859639	17.523336
		ARE	4.514248	12.716481	12.434113	16.980410
	MPSD	10.851867	30.640839	26.427685	34.109400	
	EABS	0.387508	1.814618	2.406598	3.893064	
	SSE	0.019254	0.406200	0.672789	1.518181	
	$\Delta q$ (%)	9.815883	27.715681	23.904740	30.853113	
	$x^2$	0.026689	0.384851	0.386867	0.828856	
	$R^2$ (adj)	0.999693	0.995043	0.993974	0.984766	

Table S2: Isotherm models error functions for Cr(VI) adsorption on BC2

<b>Isotherm Models</b>	<b>Parameters</b>	<b>20°C</b>	<b>25°C</b>	<b>30°C</b>	<b>35°C</b>
<b>Langmuir</b>	HYBRID	8.421740	14.917176	3.749028	9.779490
	ARE	-7.018117	13.992366	-3.124190	-8.149575
	MPSD	16.405843	29.115361	11.842298	25.910269
	EABS	1.277395	2.053504	1.534002	1.333490
	SSE	0.217041	0.453776	0.316089	0.199762
	$\Delta q$ (%)	15.642358	29.607270	11.291188	24.704472
	$x^2$	0.165282	0.463132	0.073871	0.251463
	$R^2$ (adj)	0.997928	0.996927	0.997357	0.998745
	<b>Freundlich</b>	HYBRID	-2.515937	6.483987	-12.279487
ARE		2.096614	7.023723	10.232906	3.474605
MPSD		10.387146	14.228041	24.145098	16.975721
EABS		0.712751	0.668154	3.038091	2.657099
SSE		0.065653	0.072016	1.140948	0.732034
$\Delta q$ (%)		9.903755	20.148105	23.021448	16.185715
$x^2$		0.056242	0.157691	0.408770	0.333675
$R^2$ (adj)		0.999199	0.999254	0.990963	0.994064
<b>BET</b>		HYBRID	9.261312	16.508313	4.076760
	ARE	-6.945984	-12.381235	-3.057570	-8.089345
	MPSD	17.201452	31.013250	12.419310	27.272254
	EABS	1.264243	2.036325	1.532925	1.312838
	SSE	0.214223	0.447995	0.316762	0.193304
	$\Delta q$ (%)	15.559299	29.569974	11.233689	24.668682
	$x^2$	0.163207	0.460237	0.073724	0.249324
	$R^2$ (adj)	0.997681	0.996956	0.997019	0.998630

Table S5: Kinetic models error functions for Cr(VI) adsorption on BC1

<b>Pseudo-first order</b>						
HYBRID	8.092208	2.876414	3.789594	3.521094	3.573143	3.572992
ARE	8.320169	5.744815	6.801132	7.409008	6.578011	6.593305
MPSD	11.633269	10.101110	11.957229	13.037105	11.876800	11.952325
EABS	0.339821	0.542882	0.900026	1.930983	3.269909	5.392262
ERRSQ	0.000519	0.019535	0.056870	0.260220	0.748347	2.050316
$\Delta Q$	11.322992	9.831698	11.638312	12.689386	11.560028	11.633538
$\chi^2$	0.036619	0.037344	0.079274	0.192391	0.280091	0.470158

R <sup>2</sup> (adj)	0.994198	0.986037	0.987911	0.973317	0.983451	0.983026
<b>Pseudo-Second order</b>						
HYBRID	0.354821	-0.759392	0.033220	0.350728	-0.000583	0.026553
ARE	0.960449	1.172956	0.216025	1.304822	0.084174	0.106116
MPSD	1.858799	2.823527	0.530865	1.827275	0.159327	0.177671
EABS	0.027115	0.077434	0.023176	0.405398	0.045184	0.111286
ERRSQ	0.000060	0.000818	0.000074	0.012291	0.000231	0.001850
ΔQ	1.809222	2.748219	0.516706	1.778539	0.155077	0.172932
χ <sup>2</sup>	0.000343	0.002637	0.000174	0.007313	0.000079	0.000288
R <sup>2</sup> (adj)	0.999599	0.999409	0.999977	0.998639	0.999994	0.999983
<b>Ritchie's second order equation</b>						
HYBRID	0.354814	-0.759447	0.033459	0.350763	-0.000528	0.026402
ARE	0.960506	1.172958	0.215966	1.304845	0.084203	0.106080
MPSD	1.859044	2.823435	0.530879	1.827340	0.159326	0.177592
EABS	0.027114	0.077439	0.023167	0.405397	0.045210	0.111284
ERRSQ	0.000060	0.000818	0.000074	0.012291	0.000231	0.001850
ΔQ	1.809461	2.748130	0.516720	1.778602	0.155076	0.172855
χ <sup>2</sup>	0.000343	0.002637	0.000174	0.007313	0.000079	0.000288
R <sup>2</sup> (adj)	0.999599	0.999409	0.999977	0.998639	0.999994	0.999983
<b>Pseudo-nth order</b>						
HYBRID	0.567400	-0.203851	-0.048246	-0.512026	0.020286	-0.024513
ARE	1.091363	0.610606	0.248685	1.033060	0.088375	0.107538
MPSD	2.356552	1.275938	0.585562	2.267287	0.183183	0.177047
EABS	0.027083	0.062130	0.023852	0.226359	0.042382	0.116224
ERRSQ	0.000056	0.000442	0.000060	0.005940	0.000221	0.001690
ΔQ	2.229075	1.206916	0.553886	2.144639	0.173274	0.167470
χ <sup>2</sup>	0.000370	0.000999	0.000131	0.004568	0.000071	0.000256
R <sup>2</sup> (adj)	0.999604	0.999644	0.999980	0.999300	0.999994	0.999984

Table S6: Kinetic models error functions for Cr(VI) adsorption on BC2

<b>Pseudo-first order</b>						
HYBRID	1.500878	5.038794	3.063115	3.393132	3.735521	3.467629
ARE	3.751326	0.582200	6.176427	6.247247	6.586204	5.927025
MPSD	7.902029	17.427991	12.274170	12.264573	12.416061	12.057393
EABS	0.162216	0.039171	0.988401	1.662585	3.561043	5.419433
ERRSQ	0.002254	0.022861	0.075665	0.205646	0.907348	2.301921
ΔQ	7.691271	7.828421	11.946800	11.937459	12.084906	11.735805

$\chi^2$	0.012564	0.193898	0.099512	0.160019	0.326751	0.510162
R <sup>2</sup> (adj)	0.985060	0.978799	0.985675	0.982863	0.984279	0.985867
<b>Pseudo-Second order</b>						
HYBRID	-0.237344	1.052238	0.162356	0.027904	0.191288	0.008945
ARE	0.478436	0.056243	0.534597	0.531972	0.558592	0.630197
MPSD	1.410215	6.809573	0.940542	0.864214	0.924401	0.857999
EABS	0.015320	0.002628	0.107092	0.216547	0.353066	0.957220
ERRSQ	0.000033	0.001048	0.001496	0.004744	0.011494	0.082429
$\Delta Q$	1.372603	2.433159	0.915456	0.841164	0.899746	0.835115
$\chi^2$	0.000301	0.009632	0.001249	0.002473	0.002969	0.010134
R <sup>2</sup> (adj)	0.999789	0.999018	0.999513	0.999554	0.999777	0.999426
<b>Ritchie's second order equation</b>						
HYBRID	-0.267340	-0.465089	0.162387	0.027733	0.191362	0.007597
ARE	0.489827	0.946977	0.534581	0.531800	0.558247	0.630202
MPSD	1.403223	2.499630	0.940503	0.864149	0.923664	0.857850
EABS	0.016185	0.083466	0.107091	0.216525	0.352900	0.957376
ERRSQ	0.000032	0.001048	0.001496	0.004744	0.011494	0.082429
$\Delta Q$	1.365797	2.432961	0.915418	0.841101	0.899028	0.834970
$\chi^2$	0.000298	0.002628	0.001249	0.002472	0.002968	0.010135
R <sup>2</sup> (adj)	0.999788	0.999018	0.999513	0.999554	0.999777	0.999426
<b>Pseudo-nth order</b>						
HYBRID	-0.121710	-0.500388	-0.136653	0.544886	0.321676	0.420671
ARE	0.312097	0.954878	0.546353	0.823702	0.611934	0.890923
MPSD	0.697555	2.604659	0.824745	1.397826	1.276695	1.745015
EABS	0.012873	0.083801	0.115660	0.253549	0.314338	0.868822
ERRSQ	0.000016	0.001048	0.001109	0.005448	0.010882	0.060824
$\Delta Q$	0.659821	2.463761	0.780131	1.322211	1.207633	1.650619
$\chi^2$	0.000094	0.002664	0.000926	0.003426	0.003455	0.010911
R <sup>2</sup> (adj)	0.999880	0.998958	0.999615	0.999516	0.999779	0.999559

Table S7: Kinetic models error functions for Cr(VI) adsorption onto BC1 with Boyd's internal diffusion model

C <sub>ini</sub> (mg L <sup>-1</sup> )	1	5	10	20	50	100
HYBRID	-51.195546	-35.515295	-46.954528	-25.033803	-37.662101	-36.701871
ARE	-46.075991	-31.963765	-42.259075	-22.530423	-33.895891	-33.031684
MPSD	74.105138	62.350240	71.925658	54.697818	64.943185	64.215350
EABS	74.482075	38.258037	67.234150	21.607470	44.546151	42.629220
ERRSQ	0.014197	0.114296	0.545333	1.522978	7.052269	18.785127

$\Delta Q$	197.993	141.901	188.113	106.641	153.119	149.788
$\chi^2$	0.264786	0.699832	1.277383	2.041735	4.319951	7.068514
$R^2$ (adj)	0.942151	0.937524	0.947451	0.939113	0.947455	0.947175

Table 8: Kinetic models error functions for Cr(VI) adsorption onto BC2 with Boyd's internal diffusion model

$C_{ini}$ (mg L <sup>-1</sup> )	1	5	10	20	50	100
HYBRID	-3.650153	-6.936646	-13.657657	-22.903350	-34.584028	-27.199653
ARE	-3.285137	-6.242981	-12.291891	-20.613015	-31.125625	-24.479688
MPSD	26.939964	31.359962	42.342595	52.021589	62.393093	56.010720
EABS	0.890049	1.986896	7.360020	18.292711	38.101802	24.640761
ERRSQ	0.021912	0.054783	0.506009	1.773053	8.711131	24.148363
$\Delta Q$	21.644	32.338	62.239	98.121	141.611	113.881
$\chi^2$	0.182713	0.505113	1.079133	1.981412	4.692037	7.474876
$R^2$ (adj)	0.956912	0.943652	0.949274	0.950922	0.949425	0.952692

Table S9; Kinetic models error functions for Cr(VI) adsorption onto BC1 with the Weber-Morris Intra-particle diffusion model(IPD)

$C_{ini}$ (mg/L)	1	5	10	20	50	100
<i>Stage I</i>						
HYBRID	-38.442	-30.097	-38.070	-17.854	-30.784	-29.848
ARE	27.156	22.985	27.090	17.505	22.587	21.851
MPSD	72.084	59.117	74.083	40.597	60.959	59.673
EABS	0.035	0.151	0.157	0.495	0.629	0.982
ERRSQ	4.230E-04	5.503E-03	8.720E-03	5.508E-02	1.193E-01	3.072E-01
$\Delta Q$	64.473	52.876	66.262	36.311	54.523	53.373
$\chi^2$	2.577E-02	7.212E-02	1.267E-01	1.298E-01	3.796E-01	6.041E-01
$R^2$ (adj)	0.987737	0.983207	0.987838	0.970157	0.987682	0.988073
<i>Stage II</i>						
HYBRID	-0.004622	-0.003774	-0.013710	-0.006722	-0.008408	-0.006620
ARE	0.289391	0.401572	0.615975	0.500337	0.553151	0.493379
MPSD	0.493769	0.568434	0.883884	0.717891	0.793532	0.700568
EABS	0.002594	0.012375	0.026803	0.040789	0.091278	0.134112
ERRSQ	2.415E-06	3.853E-05	1.836E-04	4.261E-04	2.131E-03	4.525E-03
$\Delta Q$	0.403	0.464	0.722	0.586	0.648	0.572
$\chi^2$	1.084E-05	4.986E-05	1.691E-04	2.094E-04	5.175E-04	6.657E-04
$R^2$ (adj)	0.991633	0.969268	0.964447	0.957433	0.960939	0.967810

<i>Stage III</i>						
HYBRID	9.917E-04	-3.098E-03	-8.249E-03	-6.160E-03	-5.288E-03	-6.727E-03
ARE	0.452047	0.413934	0.623908	0.542396	0.534433	0.585678
MPSD	0.646470	0.545080	0.868006	0.766840	0.701696	0.797903
EABS	0.012566	0.035865	0.081428	0.126590	0.256961	0.460110
ERRSQ	2.517E-05	1.756E-04	1.004E-03	2.536E-03	8.930E-03	3.062E-02
$\Delta Q$	0.609	0.514	0.818	0.723	0.662	0.752
$\chi^2$	9.169E-05	2.043E-04	7.775E-04	1.092E-03	1.875E-03	3.947E-03
R <sup>2</sup> (adj)	0.948824	0.916742	0.901368	0.866982	0.909459	0.889564

Table 10: Kinetic model error functions for Cr(VI) adsorption onto BC2 with the Weber-Morris Intra-particle diffusion model(IPD)

C <sub>mi</sub> (mg/L)	1	5	10	20	50	100
<i>Stage I</i>						
HYBRID	11.346	7.172	-4.436	-15.571	-27.001	-19.981
ARE	-7.564	-4.782	2.957	10.381	18.001	13.320
MPSD	21.916	17.795	19.495	36.705	54.928	43.363
EABS	0.169	0.358	0.353	0.465	0.676	1.379
ERRSQ	9.245E-03	5.014E-02	3.324E-02	5.229E-02	1.437E-01	4.944E-01
$\Delta Q$	51.134	131.109	186.501	300.106	562.938	1035.307
$\chi^2$	3.896E-02	7.839E-02	5.180E-02	1.229E-01	3.710E-01	4.963E-01
R <sup>2</sup> (adj)	0.864062	0.884598	0.960763	0.977466	0.987073	0.983800
<i>Stage II</i>						
HYBRID	0.075385	1.765579	2.069629	-0.000984	-0.033757	2.935573
ARE	-0.037693	-0.882789	-1.034815	0.000492	0.016879	-1.467787
MPSD	0.539744	8.722453	9.531579	0.414021	1.684997	13.072404
EABS	0.003829	0.187110	0.318522	0.025352	0.210090	2.697850
ERRSQ	6.063E-06	1.067E-02	3.091E-02	1.816E-04	1.222E-02	2.303E+00
$\Delta Q$	28.692	164.134	287.774	297.345	725.549	2162.826
$\chi^2$	1.880E-05	1.274E-02	2.368E-02	7.886E-05	2.631E-03	2.803E-01
R <sup>2</sup> (adj)	0.417555	0.564881	0.783408	0.979530	0.859587	0.953761
<i>Stage III</i>						
HYBRID	-2.005E-03	-1.453E-01	-1.013E-03	-2.563E-03	-4.438E-03	-3.808E-03
ARE	0.001604	0.116230	0.000811	0.002050	0.003550	0.003046
MPSD	0.129749	0.668648	0.299052	0.495098	0.648095	0.612398
EABS	0.003010	0.037913	0.033456	0.090025	0.254641	0.427889
ERRSQ	1.467E-06	2.767E-04	1.453E-04	1.266E-03	9.665E-03	2.556E-02
$\Delta Q$	1151.813	1293.083	1375.617	1811.693	333.748	651.974
$\chi^2$	4.445E-06	3.146E-04	1.019E-04	4.982E-04	1.801E-03	2.769E-03
R <sup>2</sup> (adj)	0.891177	0.869376	0.960041	0.856655	0.898851	0.848862

Table 11S: Error functions for thermodynamics parameters of Cr(VI) adsorption on BC1 & BC2

	<b>BC1</b>	<b>BC2</b>
Temp range	20-35°C	20-35°C
HYBRID	0.246	0.356
ARE	-0.123	-0.178
MPSD	0.724	0.359
EABS	1.010	0.398
ERRSQ	4.881	2.010
$\Delta Q$	0.640	2.494
$\chi^2$	7.238	1.473
R <sup>2</sup>	0.999	0.998
R <sup>2</sup> -adj	0.998	0.995