Supplementary Materials

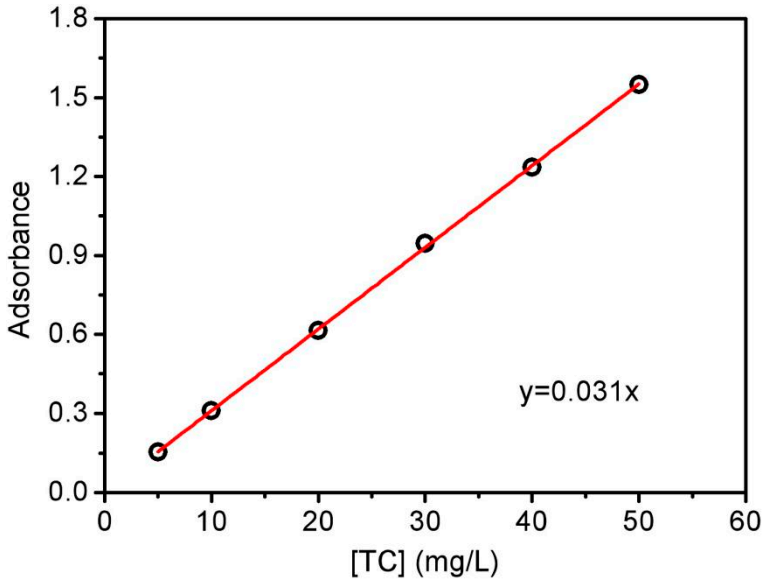

Figure S1. The calibration curve of absorbance at 360 nm versus tetracycline concentration [TC] measured in the UV–visible spectrometer.

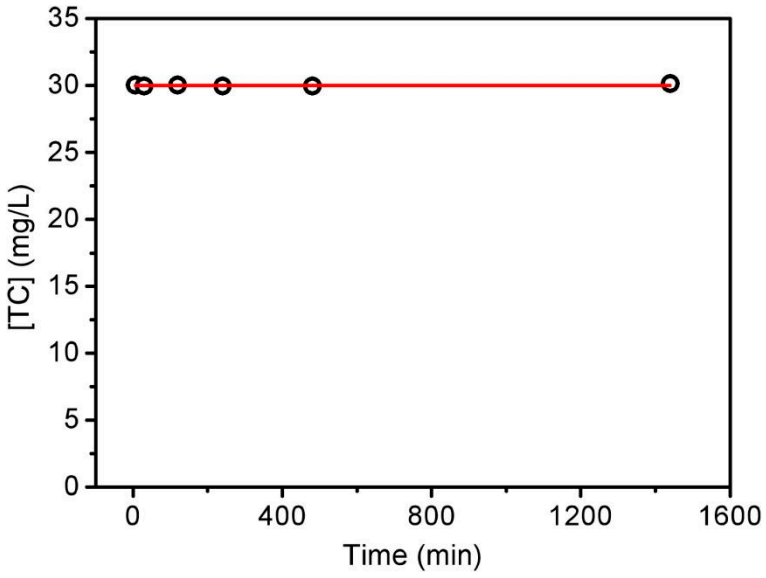

Figure S2. The variation of tetracycline concentration [TC] with time by using residual solid (microwave-assisted hydrothermal treated tobacco stalk) as adsorbent.

Table S1. The effects of heating temperature (A) and holding time (B) on the carbohydrate yield (mg/g) after extraction from tobacco stalk powder sample.

Run	A (°C)	B (min)	Y (mg/g)
1	135	20	256.71
2	135	40	245.00
3	135	20	256.84
4	135	20	262.95
5	90	40	210.04
6	135	20	259.83
7	180	20	177.60
8	90	20	217.83
9	135	20	251.15
10	135	0	243.85
11	180	0	143.71
12	180	40	139.36
13	90	0	203.20

Table S2. Analysis of variance and regression coefficients of the response surface model.

Source	Sum of squares	df	Mean square	F value	p-value
Model	22442.52	5	4488.5	87.41	< 0.0001
A	4839.36	1	4839.36	94.25	< 0.0001
B	2.21	1	2.21	0.043	0.8416
AB	31.3	1	31.3	0.61	0.4605
A^2	11626.74	1	11626.74	226.43	< 0.0001
B^2	912.05	1	912.05	17.76	0.004
Residual	359.44	7	51.35		
Lack of Fit	282.93	3	94.31	4.93	0.0787
Pure Error	76.51	4	19.13		
Cor Total	22801.96	12			
R^2	0.9842				
Adjusted R^2	0.9730				

Table S3. The identified benzene products from the pyrolysis of residual solid at different temperature conditions.

Compound	Retention time (min)	Reference retention index	Actual retention index	Peak area (Semiquantitative proportion %)		
				700 °C	500 °C	300 °C
1-Ethyl-4-methoxy Benzene	18.309	1237±2	1238	2032961 (3.92%)	564219 (1.55%)	
1-Indanone	19.469	1289±8	1279	940742 (1.81%)	432831 (1.19%)	
3-Methylindole	22.374	1393±6	1386	539088 (1.04%)		

Table S4. The identified phenol products from the pyrolysis of residual solid at different temperature conditions.

Compound	Retention time (min)	Reference retention index	Actual retention index	Peak area (Semiquantitative proportion %)		
				700 °C	500 °C	300 °C
Phenol	10.421	980±4	984	2494376 (4.81%)	1869113 (5.15%)	396689 (3.16%)
2-Methyl-Phenol	12.746	1054±9	1056	1416010 (2.73%)	716961 (1.97%)	
4-Methyl-Phenol	13.465	1075±5	1078	3646671 (7.03%)	1542043 (4.25%)	185175 (1.48%)
Guaiacol	13.707	1090±3	1086	974556 (1.88%)	723319 (1.99%)	
2,6-Dimethyl-Phenol	14.389	1108±4	1107	452022 (0.87%)		
2-Ethyl-Phenol	15.356	1139±3	1139	646091 (1.24%)		
2,4-Dimethyl-Phenol	15.705	1150±2	1150	1229474 (2.37%)	436417 (1.20%)	
4-Ethyl-Phenol	16.258	1169±3	1168	3377339 (6.51%)	1447536 (3.99%)	
3,5-Dimethyl-Phenol	16.542	1171±4	1178	695000 (1.34%)		
2-Methoxy-4-methyl-Phenol	16.891	1193±3	1189	570816 (1.10%)	649384 (1.79%)	

Table S4. continued. The identified phenol products from the pyrolysis of residual solid at different temperature conditions.

Compound	Retention time (min)	Reference retention index	Actual retention index	Peak area (Semiquantitative proportion %)		
				700 °C	500 °C	300 °C
3,4-Dimethyl-Phenol	17.069	1193±4	1195	407569 (0.79%)		
4-Ethyl-2-methyl-Phenol	18.959	1236±17	1261	798461 (1.54%)		
2,4,5-Trimethyl-Phenol	19.179	1276±1	1268	249511 (0.48%)		
4-Ethyl-Guaiacol	19.319	1282±4	1273	656387 (1.26%)	454233 (1.25%)	
4-Hydroxy-3-methylacetophenone	20.360	1323	1310	1501069 (2.89%)	730592 (2.01%)	
2-Methoxy-4-propenyl-Phenol	23.964	1450±14	1448	717909 (1.38%)	544100 (1.50%)	136809 (1.09%)
2,4-Di-tert-butyl-Phenol	25.446	1511±13	1507	513661 (0.99%)	198657 (0.55%)	137372 (1.09%)

Table S5. The identified heterocycle products from the pyrolysis of residual solid at different temperature conditions.

Compound	**Retention time (min)**	**Reference retention index**	**Actual retention index**	**Peak area (Semiquantitative proportion %)**		
				700 °C	**500 °C**	**300 °C**
Methyl 2-furoate	10.136	979±4	976	622292 (1.20%)	924401 (2.55%)	
1,4:3,6-Dianhydro-alpha-d-glucopyranose	17.611	1207±8	1214	1831919 (3.53%)	2217289 (6.11%)	2302681 (18.35%)
Nicotine	21.322	1361	1346	7654004 (14.75%)	3773591 (10.39%)	2363332 (18.84%)

Table S6. The identified alkane products from the pyrolysis of residual solid at different temperature conditions.

Compound	Retention time (min)	Reference retention index	Actual retention index	Peak area (Semiquantitative proportion %)		
				700 °C	500 °C	300 °C
Pentadecane	25.252	1500	1499	222039 (0.43%)		
Eicosane	36.025	2000	2000	541575 (1.04%)		
Docosane	39.665	2200	2199	637473 (1.23%)		
Heptacosane	47.608	2700	2699	2986183 (5.75%)	3063785 (8.44%)	1485679 (11.84%)
Nonacosane	50.400	2900	2899	1815935 (3.50%)	1728816 (4.76%)	

Table S7. The identified alkene products from the pyrolysis of residual solid at different temperature conditions.

Compound	Retention time (min)	Reference retention index	Actual retention index	Peak area (Semiquantitative proportion %)		
				700 °C	500 °C	300 °C
2-Methyl-2-cyclopenten-1-one	7.902	913±8	907	238251 (0.46%)		
2-Hydroxy 2-cyclopenten-1-one	8.509	926±1	926	1226116 (2.36%)	4088321 (11.26%)	
2-Hydroxy-3-methyl-2-cyclopenten-1-one	11.752	1034±4	1025	3394486 (6.54%)	3002752 (8.27%)	1666973 (13.29%)
2,3-Dimethyl-2-cyclopenten-1-one	12.080	1040±5	1035	776345 (1.50%)	696783 (1.92%)	129034 (1.03%)
3-Ethyl-2-hydroxy-2-cyclopenten-1-one	14.652	1091±17	1116	1067814 (2.06%)	807008 (2.22%)	415401 (3.31%)
Neophytadiene	32.770	1837±5	1836	840114 (1.62%)	650077 (1.79%)	399753 (3.19%)

Table S8. The identified other products from the pyrolysis of residual solid at different temperature conditions.

Compound	Retention time (min)	Reference retention index	Actual retention index	Peak area (Semiquantitative proportion %)		
				700 °C	500 °C	300 °C
Methyl palmitate	34.569	1926±2	1925	745352 (1.44%)	559340 (1.54%)	264174 (2.11%)
2,7,11-Cembratriene-4,6-diol	37.136	2073±21	2059	1305582 (2.52%)	1058180 (2.91%)	869228 (6.93%)
9-Octadecen-amide	42.361	2334	2359	2133699 (4.11%)	3422932 (9.43%)	1794278 (14.3%)

Table S9. The tetracycline adsorption (Q_t) at predetermined time point on the obtained biochar at different pyrolysis temperature.

Run	Tetracycline (mg/L)	Pyrolysis Temperature	Time (min)	Q_t (mg/g)
1	30	300 °C	5	3.607 ± 0.669
2	30	300 °C	30	4.686 ± 0.554
3	30	300 °C	120	6.120 ± 0.467
4	30	300 °C	240	7.882 ± 0.594
5	30	300 °C	480	8.884 ± 0.441
6	30	300 °C	1440	10.047 ± 0.282
7	30	500 °C	5	8.764 ± 0.701
8	30	500 °C	30	14.573 ± 1.355
9	30	500 °C	120	16.450 ± 1.535
10	30	500 °C	240	18.002 ± 0.602
11	30	500 °C	480	18.880 ± 0.273
12	30	500 °C	1440	19.005 ± 1.412
13	30	700 °C	5	5.584 ± 0.860
14	30	700 °C	30	7.346 ± 0.769
15	30	700 °C	120	9.924 ± 0.918
16	30	700 °C	240	11.121 ± 0.525
17	30	700 °C	480	12.117 ± 0.796
18	30	700 °C	1440	12.595 ± 1.384
19	10	500 °C	480	7.746 ± 0.282
20	20	500 °C	480	12.994 ± 1.174
21	40	500 °C	480	25.265 ± 0.435
22	50	500 °C	480	28.707 ± 1.087

Table S10. Kinetic parameters of tetracycline adsorption on the biochar obtained at different pyrolysis temperature using pseudo-first order and pseudo-second order models.

Models	Pyrolysis Temperature	Parameters	
Pseudo-first order: $Q_t = Q_e(1 - \exp(-k_1 t))$	300 °C	Q_e (mg/g)	8.316
		k_1 (1/min)	0.0317
		R^2	0.775
	500 °C	Q_e (mg/g)	17.547
		k_1 (1/min)	0.1231
		R^2	0.950
	700 °C	Q_e (mg/g)	11.205
		k_1 (1/min)	0.0594
		R^2	0.845
Pseudo-second order: $Q_t = Q_e^2 k_2 t/(1 + Q_e k_2 t)$	300 °C	Q_e (mg/g)	9.029
		k_2 (g/mg/min)	0.00477
		R^2	0.869
	500 °C	Q_e (mg/g)	18.436
		k_2 (g/mg/min)	0.00871
		R^2	0.988
	700 °C	Q_e (mg/g)	11.655
		k_2 (g/mg/min)	0.00946
		R^2	0.931

Table S11. Kinetic parameters of tetracycline adsorption on the biochar obtained at different pyrolysis temperature using intraparticle diffusion and Chrastil's diffusion models.

Models	Pyrolysis Temperature	Parameters	
Intraparticle diffusion: $Q_t = k_{id}t^{0.5} + C_d$	300 °C	k_{i1} (mg/g/min$^{0.5}$)	1.613
		C_1 (mg/g)	0
		R^2	1
		k_{i2} (mg/g/min$^{0.5}$)	0.317
		C_2 (mg/g)	2.854
		R^2	0.974
	500 °C	k_{i1} (mg/g/min$^{0.5}$)	3.920
		C_1 (mg/g)	0
		R^2	1
		k_{i2} (mg/g/min$^{0.5}$)	0.342
		C_2 (mg/g)	12.698
		R^2	1
	700 °C	k_{i1} (mg/g/min$^{0.5}$)	2.498
		C_1 (mg/g)	0
		R^2	1
		k_{i2} (mg/g/min$^{0.5}$)	0.380
		C_2 (mg/g)	5.418
		R^2	0.953
Chrastil's diffusion: $Q_t = Q_e(1 - \exp(-k_C A_0 t))^x$	300 °C	Q_e (mg/g)	10.758
		k_C (L/g/min)	0.002
		x	0.224
		R^2	0.989
	500 °C	Q_e (mg/g)	18.785
		k_C (L/g/min)	0.018
		x	0.226
		R^2	0.991
	700 °C	Q_e (mg/g)	12.710
		k_C (L/g/min)	0.006
		x	0.204
		R^2	0.998

Table S12. Isotherm parameters of tetracycline adsorption on the biochar obtained at different pyrolysis temperature using Langmuir, Freundlich and Sips models.

Models	Pyrolysis Temperature	Parameters	
Langmuir: $Q_e = K_L C_e Q_m/(1 + K_L C_e)$	500 °C	Q_m (mg/g)	90.094
		K_L (L/mg)	0.0134
		R^2	0.985
Freundlich: $Q_e = K_F C_e^{1/n}$	500 °C	K_F ($mg^{(1-n)}L^n/g$)	1.802
		n	1.280
		R^2	0.986
Sips: $Q_e = (Q_m K_S C_e^{(1/y)})/(1 + K_S C_e^{(1/y)})$	500 °C	Q_m (mg/g)	186.879
		K_S (L/mg)	0.0083
		y	1.149
		R^2	0.980

Table S13. Comparison of the maximum adsorption capacity and other parameters of some previously reported biochar from different biomass for removal of tetracycline.

Adsorbent	Pyrolysis Temperature	pH	Adsorption Temperature	Maximum adsorption capacity	References
Biochar from sludge with no additive	750 °C	6.0	25 °C	13.9 mg/g	Yang et al. (2016)
Biochar from sludge activated by ferric	750 °C	6.0	25 °C	54.5 mg/g	Yang et al. (2016)
Biochar from rice straw with no additive	400 °C 600 °C	5.0	25 °C	8.2 mg/g 14.2 mg/g	Wang et al. (2018)
Biochar from swine manure with no additive	400 °C 600 °C	5.0	25 °C	6.5 mg/g 8.1 mg/g	Wang et al. (2018)
Biochar from spent coffee ground with no additive	500 °C	7.0	25 °C	39.2 mg/g	Nguyen et al. (2021)
Biochar from spent coffee ground activated by NaOH	500 °C	7.0	25 °C	113.6 mg/g	Nguyen et al. (2021)
Biochar from peanut shell with no additive	400 °C 700 °C	Not mentioned	25 °C	26.4 mg/g 33.4 mg/g	Shi et al. (2023)
Biochar from tobacco stalk waste with no additive	500 °C	7.0	25 °C	90.1 mg/g	This work

References

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2. Wang et al., *RSC Adv.* 2018, 8, 16260-16268
3. Yang et al., *Bioresour. Technol.* 2016, 211, 566-573
4. Shi et al., *Sustainability* 2023, 15, 874.