Supporting Information for

Influence of Synthesis Methods on the High-Efficiency Removal of Cr(Vi) from Aqueous Solution by Fe-Modified Magnetic Biochars

Xiumei Jian*ª, Shan Liª, Yun Fengª, Xueru Chenª, Ruibin Kuangª, Bosong Liª, Yan Sun*ª,ª

ª Key Laboratory for Biobased Materials and Energy, Ministry of Education, South China Agricultural University, Guangzhou, Guangdong 510640, China

ª College of Materials and Energy, South China Agricultural University, Guangzhou, Guangdong 510640, China

ª Institute of Fruit Tree Research, Guangdong Academy of Agricultural Sciences, Key Laboratory of South Subtropical Fruit Biology and Genetic Resource Utilization (MOA), Guangdong Province Key Laboratory of Tropical and Subtropical Fruit Tree Research, Guangzhou, Guangdong 510640, China

ª Guangzhou Experimental Station, Chinese Academy of Tropical Agricultural Sciences, Guangzhou, Guangdong 510140, China

* Corresponding Email: silkcotton@scau.edu.cn

* Corresponding Email: simyan_sun@163.com
This file includes the descriptions of synthesis methods, equilibrium adsorption calculation equations, three kinetic models and three isotherm models, characterization methods, and discussions of BET, SEM & TGA characterization results, and 11 figures and 1 table.

**Figure S1.** N₂ adsorption-desorption isotherms and pore diameter curves for (a) unmodified biochars and (b) representative unmodified, pre-modified and post-modified biochars, and (c) pre-modified biochars pyrolyzed at different temperature, and (d) pre-modified biochars with various modifier ratios.

**Figure S2.** SEM images of unmodified biochars pyrolyzed at different temperatures. (a)BC@350 at 2000x, (b)BC@500 at 2000x, (c)BC@650 at 2000x, (d)BC@350 at 10000x, (e)BC@500 at 10000x, and (f)BC@650 at 10000x.

**Figure S3.** SEM images of pre-modified biochars pyrolyzed at different temperature. (a)5BC-Fe@A350 at 2000x, (b)5BC-Fe@B500 at 2000x, (c)5BC-Fe@B650 at 2000x, (d)5BC-Fe@B350 at 10000x, (e)5BC-Fe@B500 at 10000x, and (f)5BC-Fe@B650 at 10000x.

**Figure S4.** SEM images of pre-modified biochars with various modifier ratios. (a)1BC-Fe@B500 at 2000x, (b)5BC-Fe@B500 at 2000x, (c)10BC-Fe@B500 at 2000x, (d)1BC-Fe@B500 at 10000x, (e)5BC-Fe@B500 at 10000x, and (f)10BC-Fe@B500 at 10000x.

**Figure S5.** SEM images of post-modified biochars pyrolyzed at different temperature. (a)5BC-Fe@A350 at 2000x, (b)5BC-Fe@A500 at 2000x, (c)5BC-Fe@A650 at 2000x, (d)5BC-Fe@A350 at 10000x, (e)5BC-Fe@A500 at 10000x, and (f)5BC-Fe@A650 at 10000x.

**Figure S6.** SEM images of post-modified biochars with various modifier ratios. (a)1BC-Fe@A500 at 2000x, (b)5BC-Fe@A500 at 2000x, (c)10BC-Fe@A500 at 2000x, (d)1BC-Fe@A500 at 10000x, (e)5BC-Fe@A500 at 10000x, and (f)10BC-Fe@A500 at 10000x.

**Figure S7.** TG curves for (a) unmodified biochars, and (b) representative unmodified, pre-modified and post-modified biochars, and (c) pre-modified biochars pyrolyzed at different temperature, and (d) pre-modified biochars with various modifier ratios, and DTG curves for (e) unmodified biochars, and (f) representative unmodified, pre-modified and post-modified biochars, and (g) pre-modified biochars pyrolyzed at different temperature, and (h) post-modified biochars with various modifier ratios.

**Figure S8.** FTIR spectra of (a) unmodified biochars pyrolyzed at different temperatures, and (b) representative unmodified, pre-modified and post-modified biochars, and (c) pre-modified biochars pyrolyzed at different temperature, and (d) pre-modified biochars with various modifier ratios, and (e) post-modified biochars pyrolyzed at different temperature, and (f) post-modified biochars with various modifier ratios.

**Figure S9.** XRD patterns of (a) unmodified biochars pyrolyzed at different temperatures, and (b) representative unmodified, pre-modified and post-modified biochars, and (c) pre-modified biochars pyrolyzed at different temperature, and (d) pre-modified biochars with various modifier ratios, and (e) post-modified biochars pyrolyzed at different temperature, and (f) post-modified biochars with various modifier ratios.

**Figure S10.** Magnetization curves of (a) representative unmodified, pre-modified and post-modified biochars, (b) pre-modified biochars pyrolyzed at different temperature, and (c) pre-modified biochars with various modifier ratios.

**Figure S11.** Pearson correlations between Cr(VI) adsorption efficiency and properties of biochars with or without Fe-modification. (a) pH values of unmodified and modified biochars, (b) EC values, (c) BET surface areas, (d) ratio of micropore volume to total volume, (e) volume of micropores, (f) volume of total pores, (g) average pore diameters, (h) magnetization properties. The dots in blue ellipse were attributed to pre-modified biochars and those in black ellipse were attributed to post-modified and un-modified biochars.
Table S1. The removal efficiency of Cr(VI) and basic physicochemical characteristics of unmodified, pre-modified and post-modified biochars used in this study.
I. Discussion of BET, SEM & TGA characterization results

The pore distribution curves and N₂ adsorption-desorption isotherms of biochars, pre-modified biochars and post-modified biochars are depicted in Figure S1, and specific surface area and the porosity are shown in Table S1. According to IUPAC classification, unmodified biochars and modified biochars indicated a type IV isotherm with a type H3 hysteresis loops corresponding to narrow slit-like pores. Both types of modified biochars had surface area, total pore volume and pore size of 10.59–20.88 m²/g, 0.0141–0.0905 cm³/g, and 6.90–11.94 nm, respectively. These results indicate that all modified biochars contained mesoporous structures, which were beneficial to the accessibility of Cr(VI) to the adsorption sites, due to that the mesoporous structure could promote the transportation and diffusion of electrolyte ions. Also, there were no significant changes of pores characteristic between biochars and modified biochars. Additionally, the surface area is an important characteristic determining the adsorption capacity of metal ions, however the improvement in adsorption capacity can exceed the improvement in surface area due to improved surface functional groups.

The association of iron composites with biochar was confirmed from SEM images, as shown in Figs. S2–S6, respectively. Biochars exhibited a rough surface and inconspicuous pore structure. By contrast, as for pre-modified biochars, spherical particles with an uneven distribution onto corn straw fiber structure were observed, indicating the successful introduction of Fe₃O₄ on the surface of the carbonaceous material despite their slight aggregation. As for the post-modified biochars, the prepared ZVI was composed of fine spherical particles and was observed on the entire biochar surface, especially on 5BC-Fe@A650. This finding suggests that the inorganic salt FeCl₃·6H₂O or FeSO₄·7H₂O were successfully transformed to micro-particles onto pre-modified or post-modified biochar surface, respectively, resulting in magnetic carbonaceous materials as expected. The morphology noted in SEM images was consistent with the better adsorption of magnetic biochars, compared to unmodified biochars described in Figure 2.

Thermo-gravimetry was conducted to analyze the pyrolysis behaviors of the Fe-modified biochars in nitrogen environment. As shown in Figure S7, generally, there are four stages in the thermal degradation of biochar. In the first stage, loss of water was observed onto biochars and modified biochars at the temperature ranging from 25°C to 250 °C. The second stage extends to 450 °C, where the degradation of cellulose, lignin and hemicellulose occurred. In addition, the degradation of the FeCl₃ hydrates occurred at this stage. In the third stage, as the temperature increases from 450 °C to 800 °C, there was a steep and steady weight loss of the pre-modified magnetic biochars, due to the degradation of Fe₂O₃·HCl. The final stage ranging from 800-1000 °C could be assigned to the combustion of carbon matrix. Thus, there were obvious weight losses during the second stage and third stage in the DTG curves for the pre-modified biochars, indicating the better association of iron composite in the pre-modified biochars, compared to post-modified biochars. The pyrolysis behaviors of pre-modified biochars were in accordance with their higher acidity and greater Cr(VI) removal efficiency described in Table S1.

II. Synthesis methods for Fe pre-modified biochar and Fe post-modified biochar

xBC-Fe@B: For pre-modification, Fe₃O₄ particles were synthesized by transformation of FeCl₃·6H₂O. Briefly, 30 g of pre-treated feedstock (equivalent to 5 g of biochar) were mixed with 0.5 L of 9.64 g L⁻¹ FeCl₃·6H₂O solution (equivalent to 1 g of Fe³⁺) and this ratio of biochar to Fe was 5:1. The mixture was thoroughly stirred for 12 h at room temperature of 25 °C. The FeCl₃-treated corn straw were then filtered and oven-dried at 80 °C for 24 h. Pre-treated corn straw were then pyrolyzed at 500 °C for 2 h under oxygen-limited conditions. The biochar: Fe of mass ratio were set to 1:1, 5:1, and 10:1, respectively, and the HHT were set to 350, 500 and 650 °C, respectively. Generally, the letter B and x in sample name were referring to Fe modification before pyrolysis and the modifier ratio, respectively. Then, the pre-modified biochars with various mixing ratios were named 1BC-Fe@B500,
5BC-Fe@B500 and 10BC-Fe@B500, while pre-modified biochars with various HHT were referred to as 5BC-Fe@B350, 5BC-Fe@B500, and 5BC-Fe@B650.

XBC-Fe@A: For post-modification, ZVI particles were synthesized by reduction of FeSO₄·7H₂O using KBH₄. Biochar modified with ZVI were prepared through the following reduction procedure. The reduction process of the whole aqueous solution was purged with nitrogen gas (N₂). Briefly, 5 g FeSO₄·7H₂O (equivalent to 1 g of Fe²⁺) were firstly dissolved in 100 mL 20% ethanol solution. Then, 50 mL 20 g/L KBH₄ was added into the prepared solution by drop-wise addition and then ZVI particles were synthesized. With strong stirring and under N₂ atmosphere, 5 g biochars were deposited in ZVI particles solution and the mixture was stirred at 240 rpm for another 12 h under room temperature. This ratio of biochar to Fe was 5:1. The composite particles formed were settled and separated from the liquid phase. Then the solid was washed with 200 mL ethanol for several times, and finally vacuum dried at 80 °C for 24 h. The biochar: Fe of mass ratio were set to 1:1, 5:1, and 10:1, respectively, and the HHT were set to 350, 500 and 650 °C, respectively. The post-modified biochars were named based on the above denoting method, except for the letter A refereing to Fe modification after pyrolysis. All of experimental biochars were passed between the 80-mesh and 100-mesh sieve.

III Equilibrium adsorption calculation equations
The equilibrium adsorption capacity qₑ (mg/g) and the removal efficiency (%R) of Cr(VI) were calculated as follows.

\[ q_e = \frac{(C_0 - C_e)V}{m} \]  \hspace{1cm} (1)

\[ %R = \frac{(C_0 - C_e)}{C_0} \times 100\% \]  \hspace{1cm} (2)

where \( C_0 \) and \( C_e \) (mg/g) are the initial and equilibrium Cr(VI) concentrations in the aqueous solution, respectively, \( V \) (L) is the volume of the solution, and \( m \) (g) is the mass of the adsorbent. The error bars represent the standard deviation estimated from two determinations.

IV Kinetic models
In the present study, the kinetic response of Cr(VI) removal and its adsorption by modified biochar was validated with pseudo-first-order (Eq.3), pseudo-second-order (Eq.4) and intraparticle diffusion (Eq.5) kinetic models.

Pseudo-first-order model: \[ q_t = q_e (1 - e^{-k_1t}) \]  \hspace{1cm} (3)

Pseudo-second-order model: \[ \frac{t}{q_t} = \frac{1}{k_2q_e^2} + \frac{t}{q_e} \]  \hspace{1cm} (4)

Intraparticle diffusion: \[ q_t = k_3t^{0.5} + C \]  \hspace{1cm} (5)

where \( q_t \) and \( q_e \) (mg/g) are the amount of Cr(VI) adsorption per unit weight of biochar at time \( t \) (h) and equilibrium, respectively; \( k_0 \) (h⁻¹) and \( a \) (mg g⁻¹) are constants; \( k_1 \) (h⁻¹), \( k_2 \) (g mg⁻¹ h⁻¹) and \( k_3 \) (mg g⁻¹ h⁻₀.5) are rate constants of the pseudo-first-order, pseudo-second-order and intraparticle diffusion kinetics models, respectively.

V Isotherm models
Equilibrium isothermal experimental results were simulated with transformed liner Langmuir (Eq. (6)), liner Freundlich (Eq. (7)), and Temkin (Eq. (8)) isothermal models.
Langmuir model: 
\[
\frac{1}{q_e} = \frac{1}{k_L q_m} \times \frac{1}{C_e} + \frac{1}{q_m}
\] (6)

Freundlich model: 
\[
\ln q_e = \frac{1}{n} \ln C_e + \ln k_F
\] (7)

Temkin model: 
\[
q_e = B \ln C_e + B \ln A \quad \text{where} \quad B = \frac{RT}{b}
\] (8)

where \(q_e\) is the amount of Cr(VI) adsorption per unit weight of biochar at equilibrium, \(q_m\) (mg·g\(^{-1}\)) is the maximum amount of Cr(VI) adsorption corresponding to the monolayer, \(C_e\) is the equilibrium concentration; \(k_L\) (L·mg\(^{-1}\)) represents the Langmuir model constant, and \(k_F\) (mg\(^{1-n}\)·g\(^{-1}\)·L\(^n\)) and \(1/n\) represent the empirical constants of the Freundlich equation; \(R\) is the universal gas constant, 8.314 J/(mol·K); \(T\) is the adsorption temperature, K; \(A\), the equilibrium binding constant decided by maximum binding energies, L/g; \(b\), the Temkin isotherm constant.

VI Characterization of biochars

The specific surface area (\(A_{\text{BET}}\)) and pore characteristics (pore diameter and pore volume) were obtained by Micromeritics ASAP 2020 (USA) using N\(_2\)-BET adsorption method at 77 K. Prior to the BET surface area measurement, samples were degassed at 300 °C in a vacuum to 10\(^{-3}\) Torr. The morphology and microstructure of the magnetic adsorbent were analyzed by scanning electron microscopy (SEM, EVO18, Germany). Thermal degradation behaviour of biochars were determined by a thermogravimetric analyzer (TGA, Netzsch STA449C Jupiter) under nitrogen atmosphere. The pH and oxido reduction potential (ORP) were examined using Mettler-Toledo pH meter (FiveEasy Plus™, FE28) and the electrical conductivity (EC) was examined using EC meter (Leici, Shanghai, DDS-307A), at 1.0 g of biochar to 20 mL of deionized water ratio. The functional groups were evaluated using Fourier transform infrared (FTIR) spectra on a Bruker Tensor 27 spectrometer in the range of 400 to 4000 cm\(^{-1}\) with 32 scans per sample. The crystallographic structures were identified using an X-ray diffractometer (XRD, D8 advance, Germany) with a CuK\(_\alpha\) radioactive source (k = 0.154 nm) at 36 kV/30 mA with a scan speed of 4° min\(^{-1}\). The magnetic properties of modified biochars were evaluated by the MPMS-XL7 magnetometer (Quantum Design, USA) at 303 K.\(^{11}\)
Figure S1. $\text{N}_2$ adsorption-desorption isotherms and pore diameter curves for (a) unmodified biochars and (b) representative unmodified, pre-modified and post-modified biochars and (c) pre-modified biochars pyrolyzed at different temperature and (d) pre-modified biochars with various modifier ratios.
Figure S2. SEM images of unmodified biochars pyrolyzed at different temperatures. (a) BC@350 at 2000x, (b) BC@500 at 2000x, (c) BC@650 at 2000x, (d) BC@350 at 10000x, (e) BC@500 at 10000x, and (f) BC@650 at 10000x.

Figure S3. SEM images of pre-modified biochars pyrolyzed at different temperature. (a) 5BC-Fe@B350 at 2000x, (b) 5BC-Fe@B500 at 2000x, (c) 5BC-Fe@B650 at 2000x, (d) 5BC-Fe@B350 at 10000x, (e) 5BC-Fe@B500 at 10000x, and (f) 5BC-Fe@B650 at 10000x.
Figure S4. SEM images of pre-modified biochars with various modifier ratios. (a)1BC-Fe@B500 at 2000x, (b)5BC-Fe@B500 at 2000x, (c)10BC-Fe@B500 at 2000x, (d)1BC-Fe@B500 at 10000x, (e)5BC-Fe@B500 at 10000x, and (f)10BC-Fe@B500 at 10000x.

Figure S5. SEM images of post-modified biochars pyrolyzed at different temperature. (a)5BC-Fe@A350 at 2000x, (b)5BC-Fe@A500 at 2000x, (c)5BC-Fe@A650 at 2000x, (d)5BC-Fe@A350 at 10000x, (e)5BC-Fe@A500 at 10000x, and (f)5BC-Fe@A650 at 10000x.
Figure S6. SEM images of post-modified biochars with various modifier ratios. (a) 1BC-Fe@A500 at 2000x, (b) 5BC-Fe@A500 at 2000x, (c) 10BC-Fe@A500 at 2000x, (d) 1BC-Fe@A500 at 10000x, (e) 5BC-Fe@A500 at 10000x, and (f) 10BC-Fe@A500 at 10000x.
Figure S7. TG curves for (a) unmodified biochars, and (b) representative unmodified, pre-modified and post-modified biochars, and (c) pre-modified biochars pyrolyzed at different temperature, and (d) pre-modified biochars with various modifier ratios, and DTG curves for (e) unmodified biochars, and (f) representative unmodified, pre-modified and post-modified biochars, and (g) pre-modified biochars pyrolyzed at different temperature, and (h) pre-modified biochars with various modifier ratios.
Figure S8. FTIR spectra of (a) unmodified biochars pyrolyzed at different temperatures, and (b) representative unmodified, pre-modified and post-modified biochars, and (c) pre-modified biochars pyrolyzed at different temperature, and (d) pre-modified biochars with various modifier ratios, and (e) post-modified biochars pyrolyzed at different temperature, and (f) post-modified biochars with various modifier ratios.
Figure S9. XRD patterns of (a) unmodified biochars pyrolyzed at different temperatures, and (b) representative unmodified, pre-modified and post-modified biochars, and (c) pre-modified biochars pyrolyzed at different temperature, and (d) pre-modified biochars with various modifier ratios, and (e) post-modified biochars pyrolyzed at different temperature, and (f) post-modified biochars with various modifier ratios.
Figure S10. Magnetization curves of (a) representative unmodified, pre-modified and post-modified biochars, (b) pre-modified biochars pyrolyzed at different temperature, and (c) pre-modified biochars with various modifier ratios.
Figure S11. Pearson correlations between Cr(VI) adsorption efficiency and properties of biochars with or without Fe-modification. (a) pH values of unmodified and modified biochars, (b) EC values, (c) BET surface areas, (d) ratio of micropore volume to total volume, (e) volume of micropore, (f) volume of total pores, (g) average pore diameters, (h) magnetization properties. The dots in blue ellipse were attributed to pre-modified biochars and those in black ellipse were attributed to post-modified and un-modified biochars.
Table S1. The removal efficiency of Cr(VI) and basic physicochemical characteristics of unmodified, pre-modified and post-modified biochars used in this study.

| Adsorbents | Unmodified biochar | Pre-modified biochars with Fe-loading before pyrolysis | Post-modified biochars with Fe-loading after pyrolysis |
|------------|-------------------|--------------------------------------------------------|--------------------------------------------------------|
| Ratio of biochar to Fe | — | 5:1 | 5:1 | 5:1 | 1:1 | 5:1 | 10:1 | 5:1 | 5:1 | 5:1 | 1:1 | 5:1 | 10:1 |
| Pyrolysis Temperature (°C) | 350 | 500 | 650 | 350 | 500 | 650 | 500 | 500 | 500 | 350 | 500 | 650 | 500 | 500 | 500 |
| Removal efficiency (%) | 4.72 ± 0.66 | 7.61 ± 0.55 | 0.37 ± 0.52 | 95.54 ± 1.67 | 98.59 ± 0.30 | 98.52 ± 0.00 | 95.54 ± 0.78 | 14.80 ± 2.62 | 16.39 ± 2.78 | 21.60 ± 0.39 | 98.59 ± 0.23 | 50.70 ± 0.78 | 16.39 ± 2.78 | 21.60 ± 0.30 | 16.39 ± 2.78 |
| pH | 10.02 ± 0.01 | 10.34 ± 0.05 | 10.20 ± 0.01 | 2.1 ± 0.01 | 1.85 ± 0.08 | 1.85 ± 0.01 | 2.24 ± 0.08 | 3.01 ± 0.07 | 8.47 ± 0.04 | 9.23 ± 0.04 | 9.07 ± 0.08 | 8.52 ± 0.04 | 8.52 ± 0.08 | 9.23 ± 0.04 | 9.07 ± 0.08 | 9.23 ± 0.04 |
| ORP (mV) | -187.00 ± 1.41 | -228.50 ± 2.12 | -218.50 ± 3.54 | -237.00 ± 0.01 | -215.00 ± 0.08 | -225.00 ± 0.01 | -229.00 ± 0.08 | -251.00 ± 0.07 | -121.00 ± 2.83 | -164.50 ± 4.24 | -154.00 ± 2.83 | -124.00 ± 0.04 | -184.00 ± 0.04 | -124.00 ± 0.04 | -164.50 ± 0.04 | -184.00 ± 0.04 |
| EC (mS/cm) | 4.39 ± 0.13 | 3.03 ± 0.02 | 2.41 ± 0.03 | 4.56 ± 0.12 | 11.90 ± 0.71 | 3.41 ± 0.01 | 11.90 ± 0.68 | 2.04 ± 0.04 | 11.90 ± 0.68 | 0.79 ± 0.01 | 3.41 ± 0.04 | 11.90 ± 0.68 | 0.79 ± 0.01 | 3.41 ± 0.04 | 11.90 ± 0.68 | 0.79 ± 0.01 |
| A_{BET} (m²/g) | 13.72 ± 0.16 | 20.95 ± 0.01 | 17.26 ± 0.12 | 10.59 ± 0.14 | 12.03 ± 0.38 | 28.47 ± 0.02 | 24.76 ± 0.02 | 12.03 ± 0.14 | 28.47 ± 0.02 | 12.71 ± 0.01 | 28.47 ± 0.02 | 12.71 ± 0.01 | 28.47 ± 0.02 | 12.71 ± 0.01 | 28.47 ± 0.02 | 12.71 ± 0.01 |
| V_{total} (cm³/g) | 0.0131 ± 0.0160 | 0.0120 ± 0.0141 | 0.0141 ± 0.0384 | 0.0427 ± 0.0384 | 0.0427 ± 0.0384 | 0.0427 ± 0.0384 | 0.0427 ± 0.0384 | 0.0427 ± 0.0384 | 0.0427 ± 0.0384 | 0.0427 ± 0.0384 | 0.0427 ± 0.0384 | 0.0427 ± 0.0384 | 0.0427 ± 0.0384 | 0.0427 ± 0.0384 | 0.0427 ± 0.0384 | 0.0427 ± 0.0384 |
| D_{pore} (nm) | 7.92 ± 0.01 | 25.61 ± 0.01 | 9.82 ± 0.01 | 7.41 ± 0.01 | 11.94 ± 0.01 | 6.98 ± 0.01 | 8.41 ± 0.01 | 11.94 ± 0.01 | 6.07 ± 0.01 | 6.90 ± 0.01 | 6.07 ± 0.01 | 6.90 ± 0.01 | 6.07 ± 0.01 | 6.90 ± 0.01 | 6.07 ± 0.01 | 6.90 ± 0.01 |

Note: The data is represented as Mean ± SD (n =2).
References:

(1) Liu, J.; Jiang, J.; Aihemaiti, A.; Meng, Y.; Yang, M.; Xu, Y.; Gao, Y.; Zou, Q.; Chen, X. Removal of phosphate from aqueous solution using MgO-modified magnetic biochar derived from anaerobic digestion residue. J. Environ. Manage. 2019, 250, 109438.

(2) Zhu, Z.; Jiang, H.; Guo, S.; Cheng, Q.; Hu, Y.; Li, C. Dual Tuning of Biomass-Derived Hierarchical Carbon Nanostructures for Supercapacitors: the Role of Balanced Meso/Microporosity and Graphene. Sci. Rep.-UK. 2015, 5(1).

(3) Ajmani, A.; Shahnaz, T.; Subbiah, S.; Narayanasamy, S. Hexavalent chromium adsorption on virgin, biochar, and chemically modified carbons prepared from Phanera vahlii fruit biomass: equilibrium, kinetics, and thermodynamics approach. Environ. Sci. Pollut. R. 2019, 26(31), 32137-32150.

(4) Fan, Y.; Yang, R.; Lei, Z.; Liu, N.; Lv, J.; Zhai, S.; Zhai, B.; Wang, L. Removal of Cr(VI) from aqueous solution by rice husk derived magnetic sorbents. Korean J. Chem. Eng. 2016, 33(4), 1416-1424.

(5) Baig, S.A.; Zhu, J.; Muhammad, N.; Sheng, T.; Xu, X. Effect of synthesis methods on magnetic Kans grass biochar for enhanced As(III, V) adsorption from aqueous solutions. Biomass and Bioenergy. 2014, 71, 299-310.

(6) Yan, J.; Han, L.; Gao, W.; Xue, S.; Chen, M. Biochar supported nanoscale zerovalent iron composite used as persulfate activator for removing trichloroethylene. Bioresource Technol. 2015, 175, 269-274.

(7) Devi, P.; Saroha, A.K. Synthesis of the magnetic biochar composites for use as an adsorbent for the removal of pentachlorophenol from the effluent. Bioresource Technol. 2014, 169, 525-531.

(8) Thines, K.R.; Abdullah, E.C.; Mubarak, N.M.; Ruthiraan, M. Synthesis of magnetic biochar from agricultural waste biomass to enhancing route for waste water and polymer application: A review. Renewable and Sustainable Energy Reviews. 2017, 67, 257-276.

(9) Li, S.; Yang, F.; Li, J.; Cheng, K. Porous biochar-nanoscale zero-valent iron composites: Synthesis, characterization and application for lead ion removal. Sci. Total Environ. 2020, 746, 141037.

(10) Yang, F.; Zhang, S.; Sun, Y.; Cheng, K.; Li, J.; Tsang, D.C.W. Fabrication and characterization of hydrophilic corn stalk biochar-supported nanoscale zero-valent iron composites for efficient metal removal. Bioresource Technol. 2018, 265, 490-497.

(11) Yu, Y.; An, Q.; Jin, L.; Luo, N.; Li, Z.; Jiang, J. Unraveling sorption of Cr (VI) from aqueous solution by FeCl3 and ZnCl2-modified corn stalks biochar: Implicit mechanism and application. Bioresource Technol. 2020, 297, 122466.