**Progress and future prospects in biochar composites: application and reflection in the soil environment**

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**Supplementary Materials**

**Table S1. Recent progress in biochar and biochar composites and environmental applications**

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| ***Biochar composites*** | ***Biomass*** | ***Agents/ metal oxides/ Nanomaterials*** | ***Development conditions*** | ***Surface area******/N2 (m2/g)*** | ***Basic properties*** | ***Contaminant/Application area*** | ***Ref.*** |
| ***Pre-Pyrolysis*** |
| magnetic biochar/ colloidal Nano sized γ-Fe2O3 particles | 1. Cotton wood
2. Pine wood
 | Ferric chloride | 600°C /1h | - | - | As(V) (Aqueous) | (Ming Zhang et al., 2013) |
| Novel graphene/biochar composite | Wheat straw | Graphene-pretreated biomass | 600°C /1h | G/BC-1%- 17.3 | - | 1. Hg(II)
2. Phenanthrenei

(Aqueous) | (Tang, Lv, Gong, & Huang, 2015) |
| HC-SDBS-CNT and BC-SDBS-CNT | 1. Hickory chips
2. sugarcane bagasse
 | CNTs | 600°C /1h | 1. HC-SDBS-CNT -359
2. BC-SDBS-CNT -336
 | 1. HC-SDBS-CNT -77.69
2. BC-SDBS-CNT -84.30
 | 1. Pb(II)
2. Sulfapyridine

(Aqueous) | (Inyang, Gao, Zimmerman, Zhou, & Cao, 2015)([Inyang et al., 2015](#_ENREF_7)) |
| Biochar-supported magnetic MnFe2O4 nanocomposite | corn straw | egg whiteFe(NO3)3·9H2OMn(NO3)2 | 500 °C/5h | BC/FM- 38.05 | - | Pb(II)-154.94 Cd(II)-127.83  | (L. Zhang et al., 2019) |
| CS450 and ADPCS450 | Corn straw | without and with ammonium dihydrogen phosphate (ADP) | 450°C /4h | 1. CS450-44.966
2. ADPCS-450356.010
 | 1. CS450-75.17
2. ADPCS-67.07
 | Atrazine (Aqueous) | (Zhao et al., 2013) |
| Clay-biocharcomposites | 1. Bamboo, bagasse,
2. hickory chips
 | 1. Montmorillonite
2. Kaolinite suspensions
 | 600 °C | 1. Unmodified -375.5
2. Modified -408.1
 | 1. Unmodified -80.9
2. Modified -83.3
 | Methylene blue(Aqueous) | (Yao et al., 2014) |
| Porous MgO-biochar nanocomposites | 1. sugar beet tailings (SBTs),
2. sugarcane bagasse (SB),
3. cottonwoods (CWs),
4. pine woods (PWs),
5. peanut shells (PSs)
 | Magnesium chloride hexahydrate (MgCl2⋅6H2O)  |  600 °C /1 h | 1. SBT70.0
2. CW50.1
3. SB 122.5
4. PS18.9
5. PW2.8
 | - | 1. Phosphorus
2. nitrates

(Aqueous) | (Ming Zhang, Gao, Yao, Xue, & Inyang, 2012) |
| Magnetite-modified water hyacinth biochar | water hyacinth | 1. Ferrous chloride
2. Ferric chloride
 | 250-450 °C/1 h | 1. MW2501- 69
2. MW4501-37.2
 | - | As(Aqueous) | (F. Zhang, Wang, Xionghui, & Ma, 2016) |
| Magnetic biochar prepared from pinewood and natural hematite | loblolly pine | Hematite suspension | 600 °C/1h | 1. PB- 209.6
2. HPB- 193.1
 | 1. PB-85.7%
2. HPB-51.7%
 | 1. As(Aqueous)
 | (Shengsen Wang, Gao, Zimmerman, et al., 2015) |
| Biochar/Mg–Al assembled nanocomposites | brown marine macro algae(Laminaria japonica) | Magnesium chloride | 600 °C/1h | 14.1 | - | phosphate (887 mg/ g) (Aqueous) | (K.-W. Jung, Jeong, Hwang, Kim, & Ahn, 2015) |
| Nano-cerium oxide wood chip biochar composites | Pine wood chip | CeCl3 | 600 °C/30 min | 1. WCC28 412
2. WCC21 297
3. WB 312
 | 1. WCC28 35.8
2. WCC21 53.2
3. WB-85.6
 | levofloxacin(Aqueous) | (S. Yi et al., 2018) |
| Magnetic biochar’s  | Orange peel | 1. Ferrous chloride
2. Ferric chloride
 | 250°C, 400 °C /700 °C | MOP400-23.4 | MOP400-29.4% | 1. Naphthalene
2. p-nitro toluene
3. phosphates

(Aqueous) | (B. Chen, Chen, & Lv, 2011) |
| ***Post-Pyrolysis*** |
| Magnetic oak wood and oak bark | oak wood and oak bark | Ferric sulfateferrous sulfate | 400~450°C / 30 min | 1. MOWBC-6.1
2. MOBBC-8.8
 | MOWBC-69.025%MOBBC-56.145% | 1. MOBBC- Pb2+: 30.2 and Cd2+: 7.4 mg/g2. MOWBC- Pb2+ 10.13 and 2.87 mg/g(Aqueous)  | (Mohan, Kumar, Sarswat, Alexandre-Franco, & Pittman, 2014) |
| Manganese oxide-modified biochar’s | Pinewood | MnCl2·4H2O | 600°C /1h | 1. PB-209.6
2. MPB-463.1
3. BPB-67.4
 | 1. PB-85.68
2. MPB-78.95
3. BPB-61.54
 | 1. Pb(II)
2. As(V) (Aqueous)
 | (Shengsen Wang, Gao, Li, et al., 2015) |
| Biochar/AlOOH nanocomposite | Cottonwood | AlOOH | 600°C /1h | - | - | As(V) (Aqueous) | (Ming Zhang & Gao, 2013)([Zhang and Gao, 2013](#_ENREF_36)) |
| Ca and Fe modified biochar’s | Rice Husk | calcium oxideiron powder <150 μm | 300 °C | - | - | 1. Arsenic (As5+)
2. chromium (Cr6+)

(Aqueous) | (Agrafioti, Kalderis, & Diamadopoulos, 2014) |
| Mg-biochar nanocomposite | Mg-enrichedtomato leaves | potassium phosphatemonobasic (KH2PO4) | 600 °C | - | - | Phosphorus(Aqueous) | (Yao, Gao, Chen, & Yang, 2013) |
| magnetic biochar composites | Paper mill sludge | CTMB solution | 700°C | 1. Paper mill sludge-4.8
2. Biochar -67
3. ZVI-MBC-101.23
 | - | Pentachlorophenol(Aqueous) | (Devi & Saroha, 2014) |
| magnetic Biochar  | 1. Nut shield
2. Wheat straw
3. grape stalk
4. grape husk
5. plum stone
 | iron oxide particles | 600°C /30min | 1. NSBC -365
2. WSBC-334
3. GSBC-80.5
4. GHBC-127
5. PSBC-363
 | - | 1. Pb(II)
2. Cu(II)

(Aqueous) | (Trakal et al., 2016) |
| Aluminum-modified crop straw-derived biochar’s | 1. Rice straw,
2. peanut straw,
3. soybean straw
 | AlCl3 | 350 °C /4 h | 1. SSB-1.0 ± 0.2
2. PS-2.1 ± 0.5
3. RSS -19.3 ± 1.1
 | 1. SSB-541 ± 3.3 g/kg
2. PS-410 ± 2.5 g/kg
3. RSS -425 ± 3.1 g/kg
 | As5+(Aqueous) | (Qian, Zhao, & Xu, 2013) |
| Chitosan-modified biochar’s | 1. Bamboo(BB-C)
2. sugarcane bagasse(BG-C)
3. hickory wood(HC-C)
4. peanut hull(PN-C)
 | chitosan homogenous suspensionNaOH (1.2%) solution | 600 °C/2h | 1. BB-C- 166.9
2. BG-C- 123.7
3. HC-C- 2.6
4. PN-C- 0.2
 | 1. BB-C- 71.60
2. BG-C- 69.61
3. HC-C- 66.69
4. PN-C-65.40
 | 1. Pb2+
2. Cu2+
3. Cd2+

(Aqueous) | (Zhou et al., 2013) |
| Magnetic Biochar Decorated with ZnS Nanocrystals | Rice hull | ZnS nanocrystals(NCs)  triethylene glycolFe(acac)3 | 275°C/0.5 h | - | - |  Pb (II) 367.65 mg g–1(Aqueous) | (Yan, Kong, Qu, Li, & Shen, 2015) |
| Iron oxides biochar | Eucalyptus leaf | ZnCl2FeCl3·6H2O | 400°C /1h | 1. MELRC (ELBC)-473.50
2. ELBC-562.12
 | 1. MELRC (ELBC)-38.38
2. ELBC-46.21
 | Cr(VI) (Aqueous) | (Sheng-ye Wang et al., 2014) |
| Fe-Mn modified biochar composite | corn straw | KMnO4 | 600 °C/2 h | FMBC1 208.0 ± 1.2 FMBC27.53 ± 0.06  | 67.3 ± 0.253.8 ± 0.6 | As (soil) | (Lin, Li, Liu, Qiu, & Song, 2019) |
| Mg−biochar nanocomposites | Sugarbeet tailings | - | 600 °C /2h | - | DSTC-30.81%STC -50.78% | Phosphorus(Aqueous) | (Yao et al., 2011) |
| Magnetic porous carbon from waste hydro char | rice-husk | acid and alkali | 449 -499 oC | 1. Acid-treated -46.8
2. Alkali-treated-117.8
 | 1. Acid-treated C-43.6
2. Alkali-treated C-76.4
 | TCE(Aqueous) | (Zhu et al., 2014)[1] |
| Fe-impregnated biochar | Hickory chips | Iron hydroxide particles | 600°C /2h | 16.0 | 84.7 | As(V) (Aqueous) | (Hu, Ding, Zimmerman, Wang, & Gao, 2015)([Xin et al., 2015](#_ENREF_32)) |
| MnO/NiO-biochar compositeNi/Mn-LDH-modified biochar (NMMB) | loblolly pine | 1. Ni(NO3)2·6H2O
2. MnCl2
 | 600°C /1h | 1. NMMF-125
2. NMMB-282.8
 | 1. NMMF-55.142. NMMB-54.90 | As(V) (Aqueous) | (Shengsen Wang, Gao, & Li, 2016) |
| MnOx-loaded biochar | Corn straws | KMnO4 | 600 °C/3 h | 1. BC -61.0
2. 2.5%MBC 23.8
3. 10%MBC 3.18
4. 60%MBC 2.28
 | 1. BC (85.3)
2. 2.5%MBC (79.7)
3. 10%MBC (73.0)
4. 60%MBC (48.6)
 | Cu2+(Aqueous) | (Song et al., 2014) |
| zinc-loaded pine cone biochar | Pine cone | Zn-OH | 500°C /1h | 1. Raw PC biochar-6.60
2. Zn-loaded PC biochar -11.54
 | 1. Raw PC biochar- 67.88%
2. Zn-loaded PC biochar - 71.21%
 | As(III) (Aqueous) | (Van Vinh, Zafar, Behera, & Park, 2015)([Vinh et al., 2015](#_ENREF_22)) |
| Cobalt-coated adsorbent (Co-MBC) | Bamboo | CoO,Co3O4 | - | Co-MBC 263 | - | Cr(VI) (Aqueous) | (Y. Wang et al., 2012) |
| N-biochar and O-biochar  | Pine chip | NaOH | 300°C /15 min | 1. N-biochar- 1360
2. O-biochar- 1151
 | 1. N-biochar- 72.6
2. O-biochar- 83.8
 | 1. Diclofenac,
2. naproxen
3. ibuprofen

(Aqueous) | (C. Jung et al., 2015) |
| Carbon nanotubes on low-cost bamboo biochar | Moso bamboo | CNTs  | 800 °C/2 h | - | - | Pb(II) (Aqueous) | (Huang, Zhang, Wang, Lv, & Kang, 2012) |
| Fe-biochar (Fe-biochar), | Rice straw | FeCl2/NaClO  | 450 °C/1 h | - | - | CD and As (soil) | (D. Yin, Wang, Peng, Tan, & Ma, 2017) |
| Chemically modified biochar (Mg(OH)2) | Conocarpus wastes | Mg(OH)2 | 600°C/30 min | 154.9  | 76.18% | Fe(II) (Aqueous) | (Usman et al., 2013) |
| Modified Biochar’s Derived from Bamboo | Bamboo | KMnO4, HNO3, or NaOH | 550 °C | 1. BC-Raw-42.8
2. BC-KMnO4-27.2
3. BC-HNO3-0.5
4. BC-NaOH-0.4
5. BC-Heat-494.2
 | 1. BC-Raw-63.5
2. BC-KMnO4-60.7
3. BC-HNO3-56.7
4. BC-NaOH-59.5
5. BC-Heat-70.7
 | Furfural(Aqueous) | (Y. Li et al., 2014) |
| iron-coated biochar’s (IBs) | Wheat straw | FeCl3 .6H2O | 450 °C | 1. WB-9.47
2. 6HWB-14.58
3. DIB2-48.98
4. DIB4-138.56
5. DIB5-64.91
 | 1. Wheat Straw -43.06%
2. WB -47.20%
3. 6HWB-47.93%
4. DIB2 -25.91%
5. DIB4 -27.14%
6. DIB5-17.29%
 | 1. Nitrate 2.47 mg/g
2. Phosphate16.58 mg/g

(Aqueous) | (J. H. Li et al., 2016) |
| Mongolian scotch pine tree sawdust char (MMSC) | Pine tree sawdust | Phosphoricacid | 550 °C /microwave method | 1. MSC-7.68
2. MMSC-389.5
 | 1. MSC-59.76%
2. MMSC-61.93%
 | 1. 885 m/ kg for F− (Aqueous) | (Guan et al., 2015) |
| Environmental-friendly montmorillonite-biochar composites | bamboo powder | montmorillonite  | 300~500°C /1h | 1. Bamboo-4.694
2. Biochar-400-2.272
3. MBC-300-9.844
4. MBC-350-13.399
5. MBC-400-19.928
6. MBC-450-26.233
7. MBC-500-18.046
 | 1. Bamboo-48.31%
2. Biochar-400-76.05%
3. MBC-400-64.01%
 | 1. NH4+
2. PO43−

(Aqueous) | (L. Chen et al., 2017) |
| CuO-MnOx-modified pinecone biochar | pinecones | hydrogen peroxide Mn(NO3)2Cu(NO3)2·3H2O | 500 °C/ 90 min | 12%CuMn/HBC-320.98 | - | 1. Formaldehyde
2. elemental mercury

(Aqueous) | (Y. Yi et al., 2018) |
| Magnetic nano ferromanganese oxides modified biochar | pine sawdust | FeCl2KMnO4 | 500 °C/ 2h | 1. BC-13.08
2. MBC-666.2
3. EBC-466.66
 | - | tetracycline hydrochloride(Aqueous) | (Liang et al., 2019) |
| Nanoscale zero-valent iron/magnetite carbon composites | Yellow pine | Fe(NO3)3 | 700, 800, 900°C/1 hr | 1. NZVI/MC700-304.3
2. VI/MC800-193.1
3. NZVI/MC900-185.9
 | - | 1. U(VI) (Aqueous) | (Lv et al., 2018) |
| Eggplant-Derived Biochar-Halloysite Nanocomposite | Greenhead of eggplant | H2SO4Pd(OAc)2N‐methylimidazole(3‐chloropropyl)trimethoxysilane | 200 °C/ 15 h | 1. Hal-51
2. Char-22
3. Hal-Char-20
4. Hal-Char-IL-11
5. Hal-Char-SO3H-36
6. Hal-Char-CD-19
 | - | catalytic activity for the hydrogenation of nitroarenes | (Sadjadi, Akbari, Léger, Monflier, & Heravi, 2019) |
| Ag-Biochar composite | banana peel | Azadirachta indica leaf extractAgNO3. 2H2O | 300 °C/1 h | Ag-BBc- 142.5 | - | Congo Red Dye | (Kaushal, Saharan, Kumar, Sharma, & Umar, 2019) |
| BC-Gl-NSi nanocomposite | Liquidambar styraciflua fruit char | Silica gel | 450 °C/20 min | BC-Gl-NSi nanocomposite-60.754 | - | U(VI) | (Mahmoud et al., 2019) |
| Biochar-supported zero valent iron nanocomposite | Corn Stover | FeCl3 solution | 550 °C/ 120 min | 1. BC - 61.9
2. nZVI-BC- 16.7
 | 1. BC -85.9%
2. nZVI-BC-71.9%
 | Anaerobic digestion (AD)methane production from sewage sludge | (Min Zhang, Li, & Wang, 2019) |
| Novel Crayfish Shell Biochar Nanocomposites Loaded with Ag-TiO2 Nanoparticles | crayfish shell | 1. Tetra-n-butyl titanate (Ti(OC4H9)(4))
2. silver nitrate (AgNO3)
 | 450 °C/2 h | - | - | Antibacterial activities of the nanocomposites to E. coli. | (Y. Zeng, Xue, Long, & Yan, 2019) |
| Algal biochar@La/Cu/Zr trimetallic nanocomposite | alga | 1. lanthanum nitrate
2. sodium citrate
 | 400 °C/7h | Algal biochar@La/Cu/Zr trimetallic nanocomposite -107.2 | - | malachite green94% degradation at 4 h | (Sharma et al., 2019) |
| *g*-MoS2 decorated biochar | Rice straw | 1. sodium molybdate
2. thioacetamide
 | 500 °C/2h | g-MoS2 decorated biochar- 176.8 | - | TC | (Z. Zeng et al., 2019) |
| Sawdust Biochar/Fe3O4 Nanocomposites | sawdust | ferric sulfateferric chloride | 300 °C/3h | - | - | textile dye Reactive Blue 21 (RB21) -75% | (Nadeem et al., 2019) |
| Novel attapulgite/biochar (ATP/BC) nanocomposite | Rice straw | ZnCl2 | 450 °C/1h | 1. BC-11.13
2. ATP-104.42
3. ATP/BC-203.38
 | 1. BC-40.07
2. ATP-18.10
3. ATP/BC-51.10
 | 17 beta-estradiolATP/BC 154.23 mg/g | (Z. Yin et al., 2019) |
| Waste sludge biochar | petroleum waste sludge | R-sludge | 850 oC/1h | SBC0-143SBCa-561SBCb-569 | SBC0-23.6SBCa-64.3SBCb-85.4 | petroleum refinery wastewater (PRW)TOC | (C. Chen et al., 2019) |

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