**Figures**



Figure S1: A sustainable scenario for meeting the long term future phosphate demand by efficient use and recovery of phosphate [19].

**Tables:**

**Table S1:** Summary of the reported studies on phosphate removal from water with modified BCs

|  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Adsorbent/ feedstock | Details on BC modification/  impregnation | Pyrolysis conditions (Temperature and time) | Studied phosphate concentration (mg/L) | N2 Surface area (m2/g) | PZC | *Qm* (mg/g) | Kinetic model | Isotherm | Adsorbent dose D (g/L),  Optimum pHopt Equilibrium time (T) | Mechanism of adsorption | Ref |
| Porosity enhanced MgO modified Laminaria  Japonica BC | Biomass treated with MgCl2 solution, ratio 1:10 (Solid to liquid ratio) | 600 ℃, 1 h | 1 – 2500 (P) | - | - | 620 (P) at 20 ℃ | - | L-F | D: 1  pHopt: -  T: - | - | [69] |
| Metals (Fe, Zn, Cu, Mn) modified water hyacinth BC | Feed stock was irrigated with 100 mg/l of each ion for 45 days | 450 ℃, 2 h | 5 – 200 (PO43-) | FeBC: 155.91  ZnBC: 95.65  CuBC: 62.11  MnBC: 34.34 | - | FeBC 31.55  ZnBC 22.03  CuBC 16.81  MnBC 12.17  (PO43-) at 25 ℃ | PSO | F | D: 2  pHopt: -  T: Mn/Cu 24 h, Fe/Zn 48 h | Surface precipitation Electrostatic interactions; Complexation; | [72] |
| Montmorillonite (Mt) bamboo composite BC | Mass ratio of raw materials 1:1 | 400 ℃, 1 h | 20 – 6000 (PO43-) | 19.928 | - | 105.28 (PO43-) at RT | Nth order, n=6.205 | RP | D: 10  pHopt: -  T: 40 h | Electrostatic interactions | [73] |
| CaO-MgO poplar tree wood sawdust  BC composite | Mass ratio 5:3 (sawdust to dolomite) | 900 ℃, 1 h | 10 - 450 (P) | 169.33 | - | 207.79 (P) at RT | PSO | L | D: 1.25  pHopt: 3 – 11  T: 60 min | Surface crystallization, precipitation, electrostatic attraction | [74] |
| Phosphogypsum modified distillers grains BC | Mass ratio 1:2 (Phosphogypsum to grains) | 600 ℃ | 5 – 500 (PO43-) | - | 7.74 | 102.4 (PO43-) at pH 6, RT | PSO | L, F | D: 1.25  pHopt: 6  T: 24 h | Electrostatic adsorption, surface precipitation and ligand exchange | [75] |
| Mg(OH)2 bentonite rice husk BC composite | Mass ratio 7:3 (bentonite to rice husk) in 100 ml of 1.25 M MgCl2 | 450 ℃, 2 h | 60 (P) | 68.66 | 11.62 | 125.36 (PO43-) at 25 ℃ | PSO, Intra particle diffusion | - | D: 0.3  pHopt: 8  T: 240 min | Surface crystallization, co-precipitation, ion exchange, electrostatic interaction and inner-sphere complexation. | [76] |
| Bentonite modified cotton straw BC | 90 wt% cotton straw, 10 wt% bentonite | 600 ℃, 2 h. | 500 (PO43-) | 134.06 | - | 245.56 (PO43-) at neutral pH, 25 ℃ | Nth order, n=1.742 | - | D: 2  pHopt: -  T: 5 h | Surface precipitation | [77] |
| Magnetic water hyacinth BC | - | 450 ℃, 6 h | 0.186 – 150 (P) | 37.2 | 2.75 | 5.07 (P) at pH 7, RT | PSO | L-F | D: 5  pHopt: 2  T: 4 h | Ligand exchange,  electrostatic interactions | [86] |
| Fe-modified fly ash/pinewood BC | Mass ratio 5:1, pinewood to fly ash or coal gangue, then 30 g of BC activated with 200 ml of 0.05 M FeCl3 | 500 ℃, 1 h | 10 – 50 (PO43-) | 80.73 |  | 3.076 (PO43-) at pH 6, 25 ℃ | PSO | F | D: 12  pHopt: 3, 12  T: 240 min | Surface precipitation | [87] |
| Fe-modified coal gangue/ pinewood BC | 75.86 |  | 3.196 (PO43-) at pH 6, 25 ℃ | PSO | L | D: 12  pHopt: 12  T: 240 min |
| Fe-impregnates corn cob BC | Pyrolyzed BC treated with Fe(NO3)3.  Fe content in the produced BCs;  Corn cob: 21.85 mg/g  Garden wood: 39.46 mg/g  Wood ships: 18.87 mg/g | 500 ℃, 2 h | 10 – 200 (PO43-) | 6.19 | - | 1.99 (PO43-) at 24 ℃ | Nth order | L, F | D: 33.33  pHopt: 4.5 – 5.5  T: 24 h | Electrostatic interactions,  ion exchange | [88] |
| Fe-impregnates garden wood waste BC | 9.42 | 2.75 (PO43-) at 24 ℃ |
| Fe-impregnates wood chip BC | 11.08 | 3.20 (PO43-) at 24 ℃ |
| Fe-modified coconut shell BC | Biomass was immersed in 0.5 M of FeCl3, produced BC has Fe content of 106.6 mg/g. | - | 2 – 100 (PO43-) | 547 | 7.6 | 65.32 (PO43-) at pH 7, 45 ℃ | Nth order, n=2.652  Intra particle diffusion | L-F | D: 2.5  pHopt: 3  T: 24 h | Ligand exchange, electrostatic attraction, surface precipitation, and inner-sphere complexation | [89] |
| Fe-impregnated bagasse and bamboo BC | - | - | 2.5 – 6.5 (PO43-) | - | - | Bagasse: 4.06  Bamboo: 2.32 (PO43-) at pH 7.4 | Intra particle diffusion | Bagasse: F  Bamboo: Timken | D: 2  pHopt: 7.4  T: 20 h | Electrostatic interactions | [91] |
| Magnetic orange peel powder BC | - | 250 ℃, 6 h | 0 – 12 (P) | 41.2 | - | 0.512 (P) | - | F | D: 6.25  pHopt: -  T: - | Electrostatic interactions,  ligand exchange | [41] |
| Magnetic Douglas fir BC | BC treated with iron chloride/ sulfate. Produced BC has Fe content of 26.2 wt% | - | 5 – 1500 (PO43-) | 312.6 | 6.55 | 91 (PO43-) at pH 3, 35 ℃ | - | L, F | D: 4  pHopt: 2 – 3  T: 2 min | Electrostatic interactions | [80] |
| Fe-loaded wheat straw BC | 10 g of BC treated with 125 ml of 0.1 M FeCl3 | 450 ℃ | 40 – 100 (P) | 138.56 | - | 16.58 (P) at RT | - | L | D: 4  pHopt: 6  T: - | Inner and outer sphere complexes by electrostatic interactions | [92] |
| Fe-modified waste activated sludge BC | 1 g of BC treated with 30 ml solution containing 2.18 g of FeCl3.6H2O | 550 ℃ | 5 – 1000 (PO43-) | 254.4 | ~6.2 | 111 (PO43-) at pH 7, 22 ℃ | PSO | F | D: 2  pHopt: 2  T: 500 min | Electrostatic interactions, ion exchange and ligand exchange | [93] |
| Ferric oxide doped Cotton stalk BC | - | 350 ℃ | 20 (PO43-) | 219 | - | 0.963 (PO43-) at 25 ℃ | PFO | - | D: 10  pHopt: -  T: 25 h | Electrostatic interactions,  ion exchange | [94] |
| Fe-modified granulated cotton straw BC | - | 350 ℃ | 10 – 50 (PO43-) | - | 3.85 | 1.76 (PO43-) at 45 ℃ | - | F | D: 20  pHopt: 4  T: - | Electrostatic interactions and ion exchange | [95] |
| Magnetite modified coconut shells BC | Dispersion of 5.0 g BC, 2.8 g FeCl2∙4H2O, and 7.6 g FeCl3∙6H2O in 100 ml of water.  Fe content on BC: 20.75 wt% | 900 ℃ | 5 – 100 (PO43-) | 759 | 2.48 | 9.408 (PO43-)  at pH 2 | PSO, Intra particle diffusion | L, F | D: 2  pHopt: -  T: 180 min | Electrostatic attraction, ligand exchange | [96] |
| Ferrihydrite modified coconut shells BC | Dispersion of 5.0 g BC, 10.0 g Fe(NO3)3∙9H2O were dispersed  in 50 mL water.  Fe content on BC: 24.22 wt% | 864 | 2.72 | 18.49 (PO43-) at pH 2 | L | D: 2.5  pHopt: -  T: 120 min |
| Goethite modified coconut shells BC | Dispersion of 5.0 g BC, 10 g of  FeCl3∙6H2O in 100 mL water with (7.4 g NaOH).  Fe content on BC: 18.81 wt% | 691 | 3.27 | 22.14 (PO43-) at pH 2 | L | D: 2  pHopt: -  T: 60 min |
| Hematite modified coconut shells BC | Dispersion of 5.0 g BC, 10.0 g Fe(NO3)3∙9H2O in 50 mL water.  Fe content on BC: 27.61 wt% | 752 | 2.37 | 13.81 (PO43-) at pH 2 | L, F | D: 2.5  pHopt: -  T: 120 min |
| Fe-loaded corn straw BC | BC immersed in I M of FeCl4-, ratio of solid/ solution is 1:20 | 500 ℃, 1 h | 1 – 100 (P) | 18.71 | - | 35.43 (PO43-) at pH 3, 25 ℃ | PSO, Intra particle diffusion | L | D: 1  pHopt: -  T: 125 min | Electrostatic interactions | [97] |
| Fe-modified corn straw BC | 40 g straw was dispersed into 1 L of 1 M ferrous sulfate | 400 ℃, 2 h | 2.2 – 12 (P) | 4.18 | - | 0.56 (P) at 25 ℃ | - | F | D: 10  pHopt: 8 – 12  T: - | - | [98] |
| α-Fe2O3/ Fe3O4 coated bamboo wood BC | Bamboo wood was immersed in 1.2 M of ferrous nitrate.  Fe content on BC  45.51–47.02% | 600 ℃, 3 h | 2 – 50 (P) | 198.1 | 3.1 | 2.85 (P) at pH 3, 25 ℃ | Intra particle diffusion | L | D: 10  pHopt: 3  T: 1080 min | Electrostatic interactions | [99] |
| Magnetic Neurospora crassa BC | Biomass was grown in iron containing coagulation backwash.  Fe content in the BC: 45% | 700 ℃ | 4 – 90 (P) | 51.6 | - | 23.9 (P) at 25 ℃ | - | F | D: 2  pHopt: -  T: - | Ion exchange | [100] |
| Magnetic rice husk BC | 50 g of BC was added to a solution containing 38.5 g ferrous sulfate.  Fe content in BC:  Rice BC: 21.59 wt%  Wood BC: 23.65 wt% | 600 ℃ | 25 – 150 (PO43-) | 3.178 | - | 24.9 (PO43-) at  pH 8, 25 ℃ | PSO | F | D: 10  pHopt: -  T: 300 min | Electrostatic interactions, surface precipitation, ligand exchange | [78] |
| Magnetic wood BC | 50.66 | - | 27.6 (PO43-) at pH 8, 25 ℃ | PSO | F |
| Ferric oxide hydrate modified wheat straw BC | Biomass dispersed in 0.8 M FeCl3, mass to volume ratio 1:10.  Fe content in BC: 15.97% | 500 ℃, 3 h | 10 – 1000 (P) | - | - | 53.83 (P) at 35 ℃ | PSO | F | D: 3  pHopt: -  T: 24 h | Hydrogen bond interactions | [101] |
| Ca-Mg loaded Corncob BC | Consecutive treatment of Corncob by MgCl2 and CaCl2 solutions at a mass to volume ratio of 1:3 | 600 ℃, 3 h | 30 – 4000 (P) | 487.5 | - | 326.6 (P) at pH 8.3, 30 ℃ | PFO | F | D: 10  pHopt: 8 – 9  T: 360 min | - | [102] |
| Mg-modified corn BC | Corn was dispersed in MgCl2 solution with a mass to volume ratio 1:3 | 600 ℃, 3 h | 84 – 2600 (P) | 490.3 | - | 239 (P) at pH 7.8, 30 ℃ | PSO | L-F | D: 10  pHopt: 9  T: 30 min | Electrostatic interactions | [44] |
| Ca-impregnated Ramie Boehmeria nivea BC | 10 g of biomass added to 200 ml of water containing 5.6 g CaCl2.2H2O | 500 ℃ for 2 h | 10 – 400 (PO43-) | 14.973 | 2.3 | 105.41 (PO43-) at 26 ℃ | PSO, Intra particle diffusion | L | D: 2  pHopt: 8 – 10  T: 840 min | Electrostatic interactions,  surface precipitation | [103] |
| Ca(OH)2 coated dairy manure BC | 20 g of BC was mixed with 400 ml of 2 M CaCl2 | 500 ℃ | - | 2.6 | 8.7 | 13.61 (P) at pH 8.5, 20 ℃ | PSO | F | D: 5  pHopt: 8.5  T: ~400 min | Surface precipitation, electrostatic interactions | [104] |
| MgO modified wheat straw BC | 100 g of biomass immersed in 1 L of water containing 12.7 g MgCl2·6H2O | 550 ℃, 1 h | 2 – 300 (PO43-) | 187.65 | 8.2 | 31.3 (PO43-) pH 4, 22 ℃ | PSO | L | D: 2.5  pHopt: 3  T: 180 min | Electrostatic attraction and surface precipitation | [105] |
| Ca-alginate beads Laminaria japonica BC | 2 g of BC dropped  into 4% (w/v) calcium chloride solution | 584.1 ℃, 1 h | 25 – 2000 (PO43-) | 177.52 | 7.78 | 394.35 (PO43-) at 30 ℃ | PSO, Intra particle diffusion | Sips | D: 2.5  pHopt: 4  T: 24 h | Electrostatic interactions,  ion exchange | [106] |
| MgO magnetic walnut  shell BC | 30 g of biomass dispersed into 400 ml solution of 0.04 M FeCl2.4H2O of and 0.08 M of MgCl2.6H2O | 600 ℃, 1 h | 5 – 400 (PO43-) | 231.1 | 9.1 | 6.95 (PO43-) at 30 ℃ | PSO | L-F | D: 2  pHopt: 3  T: - | Electrostatic interactions | [107] |
| Mg modified soybean straw BC | Biomass was dispersed in Mg solution (190 g/l) at a solid to liquid ratio of 1:7 g/mL.  Mg content in BC: 17.74% | 500 ℃, 2 h | - | 291.08 | 9.7 | 74.47 (PO43-) at pH 6, 25 ℃ | PSO | - | D: 2  pHopt: -  T: 2 h | Electrostatic interactions | [70] |
| Mg-laden Moso bamboo BC | 2 g of bamboo mixed with 20 ml of 2 M MgCl2.6H2O  Mg content in the BC: 44.2% | 600 ℃, 1 h | 19.7 - 498 (PO43-) | 399 | 10 | 370 (PO43-) at 25 ℃ | PSO | L, F | D: 1  pHopt: 2.5 – 5.5  T: 80 h | Ligand exchange, inner-sphere surface complexes, electrostatic attraction | [108] |
| MgO containing sugar  beet tailings BC | Biomass was mixed with 60 ml water containing 40 g of MgCl2.6H2O.  MgO content in BC: 26.1% | 600 ℃, 1 h | 1 – 1600 (PO43-) | 70, N2  253.4, CO2 | - | 835 (PO43-) at 22 ℃ | - | L | D: 2  pHopt: -  T: - | Electrostatic interactions | [109] |
| MgO-impregnated Sugarcane harvest residue BC | 50 g of biomass mixed with 1 L of MgCl2 solution.  Mg content in BC: 20% | 550 ℃, 1 h | 1 – 500 (P) | 40.6 | - | 398 (P) at pH 4, 22.5 ℃ | PSO | L | D: 1.25  pHopt: 4  T: 1 h | Surface crystallization, electrostatic attraction | [110] |
| MgO-modified wood waste BC | Biomass treated with 2.3 M of MgCl2 solution. | 600 ℃ | - | - | - | 117.4 (P) at pH 8.92, 25 ℃ | Nth order, n=4.757 | L | D: 2  pHopt: -  T: 24 h | Surface precipitation, surface adsorption | [111] |
| MgO-engineered cow dung BC | 10 g of biomass mixed with 50 ml of 3.28 mg/l MgCl2 solution  Mg content in BC: 11.52 wt% | 700 ℃, 1 h | 200 – 600 (P) | 20.51 | - | 345 (P) at RT | - | - | D: 0.06  pHopt: -  T: | Surface precipitation | [112] |
| Black liquor Ca-functionalized rice straw BC | 10 g of biomass mixed with 10 g of Ca(OH)2.  Ca content in BC: 31% | 800 ℃, 2 h | 0 – 200 (P) | 28.9 | 3.17 | 197 (P) at pH 7, 25 ℃ | PSO | L | D: 0.25  pHopt: 5 – 13  T: 5 h | Surface precipitation and ligand exchange. | [113] |
| Ca-doped biosolids BC | Biosolids were mixed 20 wt% of Ca(OH)2.  Ca content on the BC: 11.52% | 700°C, 20 min | 100 - 1500 (P) | 54.4 | - | 147 (P) at  pH 4.5, 22 ℃ | PSO | L | D: 10  pHopt: 3  T: 8 h | Surface precipitation | [114] |
| Ca-decorated flour BC | Ca(OH)2 to flour mass ration 2:1 | 500 ℃, 2 h | 100 – 600 (P) | - | - | 314.2 (P) at 25 ℃ | PSO | L | D: 1  pHopt: -  T: 2 | Surface crystallization | [115] |
| Mg-modified wood waste BC | Biomass treated with 1.4 M MgCl2 solution.  Mg content in the BC: 12.41% | 600 ℃ | - | - | - | 118 (P) at 25 ℃ | PSO | L | D: 2  pHopt: 7 – 9  T: 5 min | Surface precipitation | [116] |
| MgO modified peanut  shells BC | 50 g of BC treated with 1 M MgCl2 solution.  Mg content of the BC: 6.81% | 600 ℃ | 8 – 200 (PO43-) | - | 10.9 | 18.94 (PO43-) pH 7.5, 25 ℃ | PSO | F | D: 4  pHopt:  T: 35 min | Electrostatic attraction, surface precipitation | [117] |
| MgO decorated magnetic sugarcane harvest residue BC | 50 g of biomass treated with 500 ml of Fe and Mg solutions.  Mg/Fe content in the BC;  Fe: 3.21%  Mg: 20.47% | 550 ℃, 1 h | 5 – 500 (P) | 27.22 | - | 121.25 (P) at pH 4, 23 ℃ | - | L | D: 2.5  pHopt: 3 – 4  T: - | Electrostatic attraction, surface precipitation and surface inner-sphere complexation | [118] |
| MgFe2O4 Undaria pinnatifida roots BC | 5 g of biomass mixed with 100 ml water containing 0.2 M of MgCl2.4H2O and 0.4 M FeCl3.6H2O | 800 ℃, 1 h | 5 – 500 (PO43-) | 172.81 | 8.52 | 579.81 (PO43-) at pH 3, 30 ℃ | PSO, Intra particle diffusion | Sips | D: 2  pHopt: 3  T: 10 h | Electrostatic interactions | [119] |
| Mg-alginate modified Thalia dealbata BC | Biomass treated with 1 M of MgCl2 solution | 500 ℃, 2 h | 0 – 100 (PO43-) | 46.19 | ~2 | 46.56 (PO43-) at pH 7, 28 ℃ | PFO | L | D: 2  pHopt: 3 – 10  T: 24 h | Precipitation ligand exchange | [120] |
| Mg-chitosan modified  Thalia dealbata BC | 1:1 mass ratio of BC and chitosan | 14.72 | 8.85 | 11.53 (PO43-) at pH 7, 28 ℃ | PSO | F |
| La(OH)3-modified magnetic pineapple BC | Pyrolyzed BC treated with Fe solutions followed by treatment with La at a ratio of 10 mmol/g. | 300 ℃, 1 h | 100 - 400 (P) | 84.89 | 7.16 | 101.16 (P) at 30 ℃ | PSO | L | D: 1  pHopt: 2  T: - | Surface precipitation, electrostatic interaction, ligand exchange and  inner-sphere complexation | [121] |
| La-doped magnetic Phragmites australis BC | La/Fe content in BC;  La: 4.04 wt%  Fe: 9.85 wt% | 600 ℃, 20 | 5 – 75 (P) | 236.02 | 5 | 10.82 (P)  at pH 8, 25 ℃ | PSO | F | D: 1  pHopt: 2  T: 5 h | Inner-sphere complex and electrostatic attraction | [83] |
| Ce-doped magnetic Phragmites australis BC | Ce/Fe content in BC;  Ce: 4.01 wt%  Fe: 7.68 wt% | 279.16 | 4.6 | 7.89 (P)  at pH 8, 25 ℃ | D: 1  pHopt: 2  T: 10 h |
| NaLa(CO3)2 decorated magnetic corn straws BC | - | 800 ℃, 2 h | 50 – 400 (PO43-) | 20.61 | 5.59 | 330.86 (PO43-) at pH 7, 35 ℃ | PSO | L | D: 0.4  pHopt: 5.6 – 8  T: 6 h | Electrostatic attraction and inner-sphere complexation via ligand exchange | [122] |
| Chitosan/ammonium/La modified wheat straw BC | 1 g of La(NO3)3·6H2O mixed with 0.4 g of the pretreated BC | 550 ℃, 30 | 25 – 300 (P) | - | - | 108.86 (P), at pH 3, 15 – 45 ℃ | PSO | L | D: 0.5  pHopt: 2.5 – 7  T: 0.5 – 2 h | Electrostatic interaction, ligand exchange, and Lewis acid-base interaction | [123] |
| MgFe2O4-Phragmites australis BC based La alginate beads | Biomass was treated with 0.225 M MgCl2 and 0.375 M FeCl3, then treated with 5% w/v) LaCl3 solution | 600 ℃, 2 h | 5 – 50 (P) | 158.8 | 5.7 | 26.83 (P) at pH 5.3, 25 ℃ | PSO | L | D: 0.6  pHopt: 2.8  T: 800 – 950 min | Ligand exchange, inner-sphere complexation, followed by electrostatic attraction | [124] |
| La-loaded oak chips BC | 30 g of biomass treated with 1 L of 0.1 M of La solution | 500 ℃ | 1 – 400 (P) | 45.79 | - | 46.37 (P) at | PSO | L | D: 2  pHopt: 3  T: 24 h | Surface precipitation, ligand exchange and complexation interactions | [125] |
| La(OH)3 modified rice husks BC | La to BC mass ratio of 0.2.  La content in the BC: 9.2 wt% | 800 ℃, 1 h | 5 – 100 (P) | 455.7 | 9.7 | 45.62 (P)  at 25 ℃ | PSO, Intra particle diffusionn | L | D: 0.3  pHopt: 3 – 10  T: 300 min | Electrostatic interaction, ligand exchange, inner-sphere complexation and surface precipitation. | [126] |
| La-containing oak sawdust BC | 40.0 g of biomass was dispersed in 1 L of 0.1 M of LaCl3 solution | 500 ℃, 30 | 3 – 3000 (PO43-) | - | - | 142.7 (PO43-) at 25 ℃ | PFO | L | D: 2  pHopt: -  T: 4 h | Electrostatic interactions | [45] |
| La-doped cattail BC | La content in the BC: 12.1% | 491 °C, 67 | 5 – 500 (PO43-) | 8.11 | 5.6 | 36.06 (P) at pH 7, 25 ℃ | PSO, Intra particle diffusion | L | D: 2  pHopt: 3  T: ~7.5 h | Ligand exchange, electrostatic attraction, and complexation mechanisms | [127] |
| La-modified platanus ball fiber BC | 300 mg of the pyrolyzed BC was mixed with 50 ml of 0.2 M La(NO3)3·6H2O | 600 ℃, 2 h | 30 – 100 (P) | 77.02 | 8.7 | 148.11 (P) at pH 6, 35 ℃ | PSO, Elovich, Intra particle diffusion | L | D: 0.4  pHopt: 3 – 9  T: 180 min | Electrostatic adsorption, ligand exchange, and complexation | [82] |
| AlOOH modified cotton wood composite BC | Biomass was dissolved in 60 g of water containing 40 g of AlCl3.6H2O | 600 ℃, 1 h | 1 – 1600 (PO43-) | - | - | 135.04 (PO43-) at 22 ℃ | - | L | D: 2  pHopt:  T: 6 h | - | [128] |
| Al-doped poultry manure BC | - | 350 ℃ | 0 – 3000 (P) | - | - | 701.65 (P) | - | L | D: 2  pHopt: -  T: - | - | [129] |
| Al-doped sugarcane straw BC | 758.96 (P) |
| AlOOH modified Laminaria  Japonica BC | Electrochemical modification by an aluminum electrode | 584.1 ℃, 1 h | 25 – 2000 (PO43-) | 290.21 | 8.23 | 460.28 (PO43-) at pH 6, 30 ℃ | PSO | Sips | D: 1  pHopt: 6  T: 24 h | Electrostatic interactions | [46] |
| AlOOH modified Laminaria  Japonica BC | Electrochemical modification by an aluminum electrode | 450 ℃, 2 h | 5 – 200 (PO43-) | 45.46 | - | 31.28 (P) at pH 7, 20 ℃ | - | L-F | D: 1  pHopt: -  T: - | - | [130] |
| Mg-Al modified Laminaria  Japonica BC | Electrochemical modification by an aluminum electrode and MgCl2 solution as an electrolyte.  Biomass added to the electrolyte at a solid/liquid ratio of 1:10 | 600 ℃, 1 h | 5 – 2500 (PO43-) | 14.1, N2  386.5, CO2 | - | 887 (PO43-), at pH 6, 30 ℃ | PFO, Intra particle diffusion | L-F | D: 1  pHopt: 6  T: 12 h | Electrostatic interactions | [131] |
| Al-modified poplar chips BC | Al content in the BC: 22.51% | 550 ℃, 2 h | - | 418.14 | - | 57.49 (PO43-) at pH 6, 25 ℃ | PSO | L-F | D: 2  pHopt: <6  T: 24 h | Electrostatic interactions, surface precipitation | [132] |
| Mg-Al modified wheat straw BC | Pyrolyzed BC mixed with 0.5 M solutions of Mg and Al at a solid to liquid ratio of 1:20 g/ml.  Mg/Al content in the BC;  Mg: 10.35%  Al: 16.77% | 600 ℃, 2 h | 10 – 2000 (PO43-) | 268.51 | 7.6 | 153.4 (PO43-) at pH 6 | PSO | L | D: 7  pHopt: 6 – 8  T: 6 h | Electrostatic interactions, , ion exchange and surface precipitation | [84] |
| Fe-Al hydroxides modified Corn stalk BC | Fe/Al content in the BC:  Fe: 0.5 (w/w)  Al: 0.241 (w/w) | 500 ℃, 2 h | 20 – 300 (P) | 258.6 | 7.23 | 208 (PO43-) at pH 6, 25 C | PSO | L | D: 2  pHopt:  T: 60 min | Co-precipitation, electrostatic interactions | [133] |
| Fe-Al hydroxides modified almond shell BC | Fe/Al content in the BC:  Fe: 0.295 (w/w)  Al: 0.143 (w/w) | 137.2 | 7.3 | 180 (PO43-) at pH 6, 25 C | PSO | L |
| Fe-Al hydroxides modified dairy manure BC | Fe/Al content in the BC:  Fe: 0.267 (w/w)  Al: 0.130 (w/w) | 227.8 | 7.35 | 215 (PO43-) at pH 6, 25 C | PSO | L |
| Mn-Al double oxygen sewage sludge BC | 2.5 g of biomass treated with 0.01 and 0.02 M of Mn and Al chlorides solutions.  Mn/Al content in the BC;  Mn: 12.2 wt%  Al: 10.3 wt% | 180 ℃, 12 h | 20 - 300 (P) | 104.67 | 7.3 | 55.08 (P) at pH 3, 25 ℃ | PSO, Intra particle diffusion | L | D: 1  pHopt: 3  T: 36 h | Inner-sphere surface complexation, surface precipitation, electrostatic interactions | [134] |
| Mg-Al LDH loaded cotton wood BC | 10 g of BC treated with 100 ml aqueous solution containing  0.03 M ZnCl2 and 0.01 M AlCl3 | 600 ℃, 1 h | 10 – 800 (PO43-) | - | - | 410 (PO43-) at 22 ℃ | PSO | L, F, L-F | D: 2  pHopt:  T: 1 h | Interlayer anion exchange | [135] |
| Mg-Al LDH loaded sugarcane leaves BC | 10 g of BC was  mixed with 300 ml of aqueous solution containing 0.3 M Mg(NO3)2 and 0.075 M Al(NO3)3.  Mg/Al content in the BC;  Mg: 14.55%  Al: 4.02% | 550 ℃, 1 h | 5 – 500 (P) | 12.25 | 9.3 | 81.83 (P) at pH 3, 23 ℃ | PSO | L | D: 2.5  pHopt: 3  T: 12 min | Ion exchange, electrostatic attraction and surface inner-sphere complex formation | [136] |
| Mg-Al LDH loaded Bamboo BC | Pyrolyzed BC immersed in 100 ml of water containing 0.03 MgCl2 mol of and 0.01 mol of AlCl3 | 600 ℃, 2 h | 5 – 600 (P) | - | - | 172 (P) at pH 6.5, RT | PSO | L, F | D: 2  pHopt: -  T: 1 h | Interlayer anion exchange, surface precipitation | [137] |
| Mg-Al LDH loaded Chinese cabbage BC | 5 g of biomass treated with 100 ml solution containing 1.250 mol/L Mg2+ and 0.625 mol/L Al3+ | 500 ℃, 2 h | 5 – 500 (PO43-) | 124 | 11.81 | 127.2 (PO43-) at pH 2 | PSO | L | D:  pHopt: 2 – 10  T: 30 min | Electrostatic attraction, surface complexation, and anion exchange | [138] |
| Mg-Al LDH loaded Brassia campestris BC | 184 | 11.57 | 132.8 (PO43-) at pH 2 | PSO | L |
| Mg-Al LDH loaded magnetic Caragana korshinskii BC | Mg/Al content in the BC:  Mg: 18.97 wt%  Al: 7.09 wt% | 600 ℃, 2 h | 5 – 500 (P) | 27.1 | 8.21 | 252.88 (PO43-) at pH 3 25 ℃ | PSO, Intra particle diffusion | L-F | D: 1  pHopt: 3  T: 2 h | Anion exchange, electrostatic attraction, and ligand exchange. | [79] |
| Zn-Al LDH loaded Corn stalks BC | 3 g of biomass treated with 300 ml solution containing 0.4 M of ZnCl2 or FeCl3·6H2O, or MgCl2 and 0.2 M of AlCl3 | 600 ℃, 1 h | 10 – 200 (PO43-) | 29.8 | - | 64.9 (P) at 25 ℃ | Elovich | L, F, RP | D: 0.25  pHopt: 5  T: 12 h | Electrostatic interaction, ion exchange, and ligand exchange | [85] |
| Mg-Al LDH loaded Corn stalks BC | 13.2 | 152.1 (P) at 25 ℃ | D: 0.25  pHopt: 5  T: 12 h |
| Ni-Fe LDH loaded Corn stalks BC | 56.1 | 78.3 at 25 ℃ | D: 0.25  pHopt: 3  T: 12 h |
| Mg-Al LDH loaded rice husk BC | 1 g of biomass treated with 80 ml solution containing 2:1 (Mg:Al) molar concentration.  MgAl content in the BC:  Mg: 13.5 Atomic%  Al: 6.63 Atomic% | 500 ℃ | 5 – 500 (PO43-) | 246.12 | - | 155 (PO43-) at 35 ℃ | PSO, Intra particle diffusion | Sips | D: 1.25  pHopt: -  T: 24 h | Memory effect, outer- and inner-sphere surface complexes via electrostatic interactions | [139] |
| Mg-Al LDH loaded date palm BC | 5 or 10 g of BC treated with 7.69 g Mg and 3.75 g Al, (3:1 molar ratio of Mg to Al) | 700 ℃, 4 h | 10 – 50 (PO43-) | 441.06 | 10.2 | 177.97 (PO43-) at pH 6, 35 ℃ | PFO | L | D: 0.125  pHopt: 4 – 6  T: 800 min | Ligand exchange, electrostatic interactions, inner and outer sphere complexes | [140] |
| Cerium oxide functionalized Maize straw BC | 20 g of biomass treated with 200 ml of CeCl3 solution.  Ce content in the BC: 21.13% | 300.6 ℃, 99.9 min | 21 – 350 (PO43-) | - | - | 77.52 (PO43-) at 25 ℃ | PSO | L | D: 2  pHopt: -  T: 60 – 90 min | - | [141] |
| Bismuth impregnated wheat straw BC | 10 g of biomass treated with 100 ml solution containing Bi2O3 | 500 ℃, 60 min | 60 – 1800 (PO43-) | 190.4 | - | 125.4 (P) at pH 3 | PSO, Intra particle diffusion | L | D: 2  pHopt: 3  T: 120 min | - | [142] |
| Ca-impregnated sewage sludge BC | Ca content in the BC: 18.56 wt% | 600 ℃, 3 h | 30 – 600 (PO43-) | - | - | 153.85 (P) at pH 7, 25 ℃ | PSO | L | D: 2  pHopt: -  T: 24 h | Surface precipitation | [143] |
| Multifunctional raw corncobs BC | DETA used for functionalization and the ratio 13.5:1 used for amine to BC for nitrogen groups | 400 ℃, 1 h | 20 – 240 (PO43-) | 78.7 | 5.73 | 57.47 (P) at pH 5, 25 ℃ | PFO | L | D: 2  pHopt: -  T: 75 min | Electrostatic interactions | [144] |
| Mg-enriched tomato tissues BC | - | 600 ℃, 1 h | 3.1 – 588.1 (PO43-) | - | - | 103.8 (P) at pH 5.2, 22 ℃ | Nth order n =1.74 | L-F, RP | D: 2  pHopt: -  T: 24 h | Surface precipitation | [145] |
| SiO2 modified algae BC | 10 g of biomass treated with vermiculite as a source of SiO2 | 500 ℃, 3 h | 0 – 100 (PO43-) | 42.43 | 4.8 | 159.4 (PO43-) at pH 5, 25 ℃ | PSO | L | D: 1  pHopt: 5  T: 5 – 10 h | Electrostatic interactions | [146] |