Potential of Biochar as Cost Effective Adsorbent in Removal of Heavy Metals Ions from Aqueous Phase: A Mini Review

Lata Rani1,2*, Jyotsna Kaushal1 and Arun Lal Srivastav3

1Centre for Water Sciences, Chitkara University Institute of Engineering & Technology, Chitkara University, Punjab-140401, India
2School of Basic Sciences, Chitkara University, Himachal Pradesh-174103, India
3Chitkara University School of Engineering & Technology, Chitkara University, Himachal Pradesh-174103, India

*Email: lata.rani@chitkarauniversity.edu.in

ARTICLE INFORMATION
Received: November 29, 2018
Revised: January 25, 2019
Accepted: February 18, 2019
Published online: March 06, 2019

ABSTRACT
Due to industrialization and increasing population, wastewater treatment has become a big challenge. There are numerous techniques such as ion-exchange, adsorption, membrane filtration, coagulation, flocculation, floating and electrochemical approach developed for the remediation of contaminants from wastewater. But, now it is necessary to develop an approach which should has high efficiency, less expensive and environmental friendly, so that limitation of existing techniques can be overcome. Recent developments of biochar have attracted the researchers into this area. Different methods are discovered to synthesized biochar for the removal of pollutants from wastewater. In this review, biochar are elaborated and critically discussed which have reported for the removal of metallic pollutants present in waste water.

Keywords: Adsorption, biochar, heavy metals ions, contaminated water, Purification

DOI: 10.15415/jce.2019.52003

1. Introduction
Today, environmental pollution has become one of the most global problem. Out of which water pollution is also a big concern because of rapid industrialisation and urbanisation. Approximately 1 billion people of the world do not get safe water and about 2 million losses their life every year due to polluted water (Gleick et al., 2003). Moreover World Health Organisation (WHO) specified that climate change will increase this problem of potable water for the half of the global people (World Health Organization). According to United Nation scheme world would have shortage of 40% water next 15 years. Polluted water is also very hazardous for water bodies as every year it causes death of 1 million marine, according to UNESCO (WWAP 2015).

Water pollution is caused by various pollutants such as organic, inorganic which are added by the industries. Among them heavy metal ions are the greatest threats to the environment, a living organism because these cannot be biodegraded and they are highly venomous nature (Shannon et al., 2008; Range et al., 2012). There are various natural and anthropogenic sources of heavy metals in aqueous solution, as shown in Figure 1. Discarding of heavy metals increased water pollution day by day throughout the world. The existence of heavy metals ion in the water sources (river, ponds, lakes and sea) caused serious threat to both flora and fauna. They are not contaminated surface but also caused the contamination of ground water (via leakage or rain) (Keiluwei et al., 2009). So earth water consist different hazardous heavy metals. Therefore to reduced the risk of heavy metals, its essential to remediate heavy metals from the aqueous solution. To remediate heavy numerous technologies such ion exchange, reverse osmosis, membrane filtration, coagulation, flotation and adsorption. Amongst these techniques adsorption is optimize techniques due to low cost, easy operation and high efficiency (Kumar et al., 2011). The utilization of low cost adsorbent such as biochar is the innovative method to remediate heavy metals from the aqueous solution. Biochar is a black carbon produced by thermal decomposition (pyrolysis) of biomass, which consist high amount of carbon in the absent of oxygen or oxygen deficient environment. Biochars playing a numerous function due to which researcher attracted towards utilization of biochars as less expensive adsorbent for the remediation of heavy metals. Biochars mainly removed
2. Mechanism

Heavy metals can be removed from the water by different mechanism for example complexation, electrostatic interaction, physical sorption and precipitation. Due to surface heterogeneity biochars shows higher sorption capacity for removal of heavy metal as activated carbon. In literature number of biochars given which have higher surface area as well as perfectly distributed pore network together with mesopores (2-50nm), macropores (>50nm) and micropores (<2nm) (Mukherjee et al., 2011). Biochars shows higher affinity towards heavy metal due to higher pore volume and surface the reason behind this the metallic ion may be sorbed physically on the surface of biochar and retained inside the pore. There are number of biochars which carry negative charge and have ability to adsorbed positively charged metal by electrostatic interaction. Biochars carried functional group and specific ligands may be attracting with many metals to form complexes otherwise their solid minerals phase precipitated (Cao et al., 2009; Inyang et al., 2012; Kim et al., 2013).

3. Application of Biochar for Water Treatment

Biochars possess high porous volume, greater surface area, efficiently remove contaminant from the water and functional group with unique characteristics. On the basis of the literature survey about 45% biochars utilized to remove heavy metals from the aqueous solution. In the current world the contamination of aqueous solution with heavy metals has been become a big issue. Therefore today researcher attracted towards the utilization of biochar to remediate heavy metals from aqueous solution. Examples of the most toxic heavy metals are arsenic (As), zinc (Zn), mercury (Hg), nickel (Ni), cadmium (Cd), (Cr), copper (Cu), lead (Pb), uranium (U), chromium and aluminum (Al) Sun et al., 2011; Hollister et al., 2013).
## 4. Literature Survey

| Year of Publication | Title                                                                 | Remarks                                                                 | Reference                      |
|---------------------|-----------------------------------------------------------------------|------------------------------------------------------------------------|--------------------------------|
| 2019                | Biobased magnetic metal-organic framework nanocomposite: Ultrasound-assisted synthesis and pollutant (heavy metal and dye) removal from aqueous media. | Adsorbent: Metal organic frameworks (Fe₃O₄@ESM)  
Methods of Synthesis: Low temperature co precipitation  
Adsorbate: Cu(II) and BIR 18 dye.  
Raw material: Eggshell  
Parameters: pH, equilibrium time, adsorbent dose.  
Characterization techniques: FTIR, ESM, XRD  
Adsorption capacity: 344.8 mg/g for Cu(II) and 250.8 mg/g for BIR 18 dye. | (Mahmoodi et al., 2019) |
| 2019                | Adsorption of metal ions with biochars derived from biomass wastes in a fixed column: adsorption isotherm and process simulation. | Adsorbent: Biochar  
Methods of synthesis: Pyrolysis  
Adsorbate: Cr(III) and Cu(II)  
Raw material: Wood and water caltrop shell  
Parameters: Temperature, pH, contact time, adsorbent dose.  
Characterization techniques: FTIR, AAS, ESM, XRD  
Adsorption capacity: Wood biochar and water caltrop shell biochar shows 67.7 mg/g and 78.5 mg/g, respectively for Cr and Cu 49.8 mg/g and 48.5 mg/g for Cu. | (Zhang et al., 2019) |
| 2018                | Synthesis of highly-efficient functionalyzed biochars from fruit industry waste biomass for the removal of chromium and lead. | Adsorbent: Biochars  
Methods of Synthesis: Pyrolysis  
Adsorbate: Cr(III) and Pb(II)  
Raw material: Fruit  
Parameters: Temperature, pH, contact time adsorbent dose.  
Characterization techniques: FTIR, BET, SEM and XRD  
Adsorption capacity: 28.7 mg/g and 23.8 mg/g by using PSuA and ASuA respectively for Pb and 28.7 mg/g and 23.8 mg/g by using PSuA and ASuA respectively for Cr. | (Pap et al., 2018) |
| 2018                | Removal of Cu(II), Cd(II) and Pb(II) ions from aqueous solutions by biochars derived from potassium rich biomass. | Adsorbent: Biochar.  
Methods of Synthesis: Pyrolysis  
Adsorbate: Cu(II), Cd(II) and Pb(II)  
Raw material: Banana pell and cauliflower  
Parameters: Temperature, pH, equilibrium time adsorbent dose.  
Characterization techniques: ICP–OES, Carlo-Erba NA-1500, BET, SEM, EDS-AMETEX and XRD  
Adsorption capacity: BB shows efficiency for Pb(II), Cu(II) and Cd(II) 98.2, 46.4 and 7.4% respectively while CB shows 74.6, 34.2 and 6.4% respectively. | (Ahmad et al., 2018) |
| 2017                | Stabilization of nanoscale zerovalent iron (nZVI) with modified biochar for Cr(VI) removal from aqueous solution. | Adsorbent: Biochar (nZVI@HCl-BC)  
Method of Synthesis: Pyrolysis  
Adsorbate: Cr(VI)  
Raw material: Cronstalk.  
Parameters: Temperature, pH, contact time adsorbent dose.  
Characterization techniques: FTIR, BET, SEM, XRD.  
Adsorption (%): 70% | (Dong et al., 2017) |
| 2017                | Enhanced lead and cadmium removal using biochar-supported hydrated manganese oxide (HMO) nanoparticles: Behavior and mechanism. | Adsorbent: Biochar-supported hydrated manganese oxide (HMO) nanoparticle.  
Adsorbent Synthesis: Slow pyrolysis  
Adsorbate: Cd(II) and Pb(II)  
Raw material: Peanuts shell  
Parameters: Temperature, pH, equilibrium time.  
Characterization techniques: FTIR, BET, TEM, EDS, SEM.  
Adsorption (%): For Pb(II) and Cd(II) 84% and 87% respectively. | (Wan et al., 2017) |
| Year | Title                                                                 | Adsorbent                      | Methods of Synthesis          | Adsorbate          | Raw material     | Parameters                          | Characterization techniques                      | Adsorption | Authors and Year |
|------|-----------------------------------------------------------------------|--------------------------------|-------------------------------|--------------------|------------------|------------------------------------|-----------------------------------------------|------------|------------------|
| 2016 | Sorption Process of Date Palm Biochar for Aqueous Cd (II) Removal: Efficiency and Mechanisms. | Biochar.                       | Slow pyrolysis                | Cd(II).            | Date palm        | Adsorbent dose, pH, equilibrium time.  | FTIR, BET, TEM, EDS, SEM.                      | 43.58 mg/g | (Usman et al., 2016) |
| 2016 | Effectiveness of Sunflower Seed Husk Biochar for Removing Copper Ions from Wastewater: a Comparative Study. | Biochar.                       | Pyrolysis                     | Cu(II).            | Sunflower seed husk | Adsorbent dose, pH, temprature.     | FTIR, BET, TEM, SEM.                          | 81%        | (Saleh et al., 2016) |
| 2015 | Manganese oxide-modified biochars: preparation, characterization, and sorption of arsenate and lead. | Manganese oxide-modified biochars. | Slow pyrolysis                | Cd(II).            | Pine wood stock  | Adsorbent dose, pH, equilibrium time.  | FTIR, BET, TEM, EDS, SEM.                      | 91%        | (Wang et al., 2015) |
| 2014 | Arsenic and chromium removal from water using biochars derived from rice husk, organic solid wastes and sewage sludge. | Biochars.                      | Pyrolysis                     | As(V).             | Rice husk        | Adsorbent dose, pH, equilibrium time.  | FTIR, BET, TEM, SEM.                          | 95%        | (Agrafioti et al., 2014) |
| 2014 | Biochar pyrolytically produced from municipal solid wastes for aqueous As(V) removal: Adsorption property and its improvement with KOH activation. | Biochar.                       | Slow pyrolysis                | As(V).             | Pine Municipal solid wastes. | Equilibrium time, pH.                 | FTIR, BET, TEM.                               | 53%        | (Jin et al., 2014) |
| 2013 | Chemically Modified Biochar Produced from Conocarpus Wastes: An Efficient Sorbent for Fe(II) Removal from Acidic Aqueous Solutions. | Modified .                     | Pyrolysis                     | Fe(II).            | Pine wood stock  | Adsorbent dose, pH, equilibrium time.  | FTIR, BET, TEM, EDS, SEM.                      | 91%        | (Usman et al., 2013) |
4. Concluding Remarks

Adsorption is the best techniques for the elimination of heavy metals from contaminated water due to its low cost, easy to operate and environmentally friendly. Recently, an urgent need has arisen to develop efficient, economically and green adsorbent for the elimination of arsenic ion. Therefore, biochar as an adsorbent are considered the promising adsorbents owing to their unique characteristics like greater surface area, highly porous structure and better functionality. This review focused on systematically development of different biochar for heavy metals ions removals. Adsorption data is best fitted in pseudo second order kinetic model and Langmuir and Freundlich isotherm model. By critically analyzing biochar give information about the further research in the field of nanoadsorbents. In nutshell, this review discussed the recent progress and better understanding of biochar to remediate heavy metals ions efficiently.

Reference

Agrafioti, E., Kalderis, D. & Diamadopoulos, E. (2014). Arsenic and chromium removal from water using biochars derived from rice husk, organic solid wastes and sewage sludge. *J. Environ. Manag.*, 133, 309–314. https://doi.org/10.1016/j.jenvman.2013.12.007

Ahmad, Z., Gao, B., Mosa, A., Yu, H., Yin, X., Bashir, A., Ghoveisi, H. & Wang, S. (2018). Removal of Cu(II), Cd(II) and Pb(II) ions from aqueous solutions by biochars derived from potassiumrich biomass. *J. Clean. Prod.*, 99, 19–23. https://doi.org/10.1016/j.jclepro.2018.01.133

Cao, X., Ma, L., Gao, B. & Harris, W. (2009). Dairy-manure derived biochar effectively sorbs lead and atrazine. *Environ. Sci. Technol.*, 43, 3285–3291. https://doi.org/10.1021/es803092k

Demir, S., Drouiche, N., Aouabed, A., Benayad, T., Dendene-Badache, O. & Sensami, S. (2016). Cadmium and nickel: Assessment of the physiological effects and heavy metal removal using a response surface approach by L. gibba. *J. Ecolog. Eng.*, 61, 426-435. https://doi.org/10.1016/j.j.ecoleng.2013.10.016

Dong, H., Deng, J., Xie, Y., Zhang, C., Jiang, Z., Cheng, Y., Hou, K. & Zeng, G. (2017). Stabilization of nanoscalezerovalent iron (nZVI) with modified biochar for Cr(VI) removal from aqueous solution. *J. Hazard. Mater.*, 332, 79–86. https://doi.org/10.1016/j.jhazmat.2017.03.002

Gleick, P.H. (2003). Global freshwater resources: soft-path solutions for the 21st century. *Science*, 302, 1524–1528. https://doi.org/10.1126/science.1089967

Hollister, C.C., Bisogni, J.J. & Lehmann, J. (2013). Ammonium, nitrate, and phosphate sorption to and solute leaching from biochars prepared from corn stover (L.) and oak wood (spp.). *J. Environ. Qual.*, 42(1), 137–144. https://doi.org/10.2134/jeq2012.0033

Inyang, M., Gao, B., Yao, Y., Xue, Y., Zimmerman, A.R., Pullammanappallil, P. & Cao, X. (2012). Removal of heavy metals from aqueous solution by biochars derived from anaerobically digested biomass. *Bioresource Technology*, 110, 50–56. https://doi.org/10.1016/j.biortech.2012.01.072

Jin, H., Capareda, S., Chang, Z., Gao, J., Xu, Y. & Zhang, J. (2014). Biochar pyrolytically produced from municipal solid wastes for aqueous As(V) removal: Adsorption property and its improvement with KOH activation. *Bioresour. Technol.*, 169, 622–629. https://doi.org/10.1016/j.biortech.2014.06.103

Keiluweit M. & Kleber M. (2009). Molecular-Level Interactions in Soils and Sediments: The Role of Aromatic pi-Systems. *Environ. Sci. Technol.*, 43(10), 3421–3429. https://doi.org/10.1021/es8033044

Kim, W.K., Shim, T. Kim, Y.S., Hyun, S., Ryu, C., Park, Y. K. & Jung, J. (2013). Characterization of cadmium removal from aqueous solution by biochar produced from a giant Miscanthus at different pyrolytic temperatures. *Bioresour. Technol.*, 138, 266–270. https://doi.org/10.1016/j.biortech.2013.03.186

Kolodyńskaa R.D., Wnętrzak, R., Leahy, J.J., Hayes, M.H. B., Kwapiński, W . & Hubicki, Z. (2012). Kinetic and adsorptive characterization of biochar in metal ions removal. *Chem. Eng. J.*, 197, 295–305. https://doi.org/10.1016/j.cej.2012.05.025

Kumar, S., Loganathan, V.A., Gupta, R.B. & Barnett, M.O. (2011). An Assessment of U(VI) removal
from groundwater using biochar produced from hydrothermal carbonization. *J. Environ. Manag.*, 92(10), 2504–2512. https://doi.org/10.1016/j.jenvman.2011.05.013

Mahmoodi, N.M., Taghizadeh, M., Taghizadeh, A., Abdi, J.H., Bagher & Shekarchi, A.A. (2019). Biobased magnetic metal-organic framework nanocomposite: Ultrasound-assisted synthesis and pollutant (heavy metal and dye) removal from aqueous media. *Appl. Surf. Sci.*, 480, 288–299. https://doi.org/10.1016/j.apsusc.2019.02.211

Mukherjee, A., Zimmerman, A.R., and Harris, W. (2011). Surface chemistry variations among a series of laboratory-produced biochars. *Geoderma.*, 163(3-4), 247–255. https://doi.org/10.1016/j.geoderma.2011.04.021

Pap, S., Bezanovic, V., Radonic, J., Babic, A., Saric, S., Adamovic, D., Sekulic, M.T. (2018). Synthesis of highly-efficient functionalized biochars from fruit industry waste biomass for the removal of chromium and lead. *J. Mol. Liq.*, 268, 315–325. https://doi.org/10.1016/j.molliq.2018.07.072

Saleh, M.E., El-Refaey, A.A. & Mahmoud, A.H. (2016). Effectiveness of sunflower seed husk biochar for removing copper ions from wastewater: a comparative study. *Soil and Water Research*, 11, 53–63. https://doi.org/10.17221/274/2014-SWR

Sun, K., Keiluweit, M., Kleber, M., Pan, Z. & Xing, B. (2011). Sorption of fluorinated herbicides to plant biomass-derived biochars as a function of molecular structure. *Bioresour. Technol.*, 102(21), 9897–9903. https://doi.org/10.1016/j.biortech.2011.08.036

Usman, A., Sallam, A., Zhang, M., Vithanage, M., Ahmad, M., Al-Farraj, A., Ok, Y.S., Abduljabbar, A. & Al-Wabel, M. (2016). Sorption Process of Date Palm Biochar for Aqueous Cd (II) Removal: Efficiency and Mechanisms. *Water Air Soil Pollut.*, 227, 449–460. https://doi.org/10.1007/s11270-016-3161-z

Wan, S., Wu, J., Zhou, S., Wang, R., Gao, B. & He, F. (2017). Enhanced lead and cadmium removal using biochar-supported hydrated manganese oxide (HMO) nanoparticles: Behavior and mechanism. *Sci. Total Environ.*, 616-617, 1298–1306. https://doi.org/10.1016/j.scitotenv.2017.10.188

Wang, S., Gao, B., Li, Y., Mosa, A., Zimmerman, A. R., Ma, L. Q., Harris, W. G. & Migliaccio, K. W. (2015). Manganese oxide-modified biochars: preparation, characterization, and sorption of arsenate and lead. *Bioresour. Technol.*, 181, 13–17. https://doi.org/10.1016/j.biortech.2015.01.044

World Health Organization. Drinking-Water Fact-Sheet. http://www.who.int/mediacentre/factsheets/fs391/en/.

WWAP (United Nations World Water Assessment Programme). Water for a Sustainable World; The United Nations World Water Development Report: UNESCO:Paris 2015; pp 1–67.

Zhang, Y.P., Adi, V.S.K., Huang, H.L., Lin, H.P. & Huang, Z.H., 2019. Adsorption of metal ions with biochars derived from biomass wastes in a fixed column: adsorption isotherm and process simulation. *J. Ind. Eng. Chem.*, 76, 240–244. https://doi.org/10.1016/j.jiec.2019.03.046