Abstract No: TA 20

Correlation and the Impact of Feedstock Type and Production Conditions on Heavy Metal Adsorption by Biochar: A Comprehensive Meta-Analysis

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Biochar (BC) is a ubiquitous, porous, carbonaceous solid produced by the pyrolysis of biomass under anaerobic conditions, which can be used as a fuel as well as an adsorbent. Although the potential use of biochar in aqueous systems to adsorb heavy metals has gained attention recently, no studies have been conducted to evaluate and correlate its specific impact on the adsorption of Cu^{2+}, Cd^{2+} and Pb^{2+} metal cations. In this study, the correlation between pyrolysis temperature, pyrolysis method, feedstock type, modifications applied, and physiochemical properties of BC and their statistical significances were evaluated considering the adsorption of Cu^{2+}, Cd^{2+} and Pb^{2+} metal cations. For the statistical analysis, over 500 individual data entries were extracted from 172 peer-reviewed articles that were published in the years 2014 to 2018, and the correlation studies were done using the R programming language in RStudio. Biochar used in the adsorption of Cu^{2+}, Cd^{2+} and Pb^{2+} exhibited moderate positive correlations with specific surface area and pyrolysis temperature (r_{Cu}= 0.47, r_{Cd} = 0.37 and r_{Pb} = 0.49) whereas pore size and ash content exhibited negative or negligible correlations. Both aromaticity (r_{Cu}= -0.48, r_{Cd} = -0.53 and r_{Pb} = -0.34) and polarity (r_{Cu}= -0.33, r_{Cd} = -0.37 and r_{Pb} = -0.51) were negatively correlated with pyrolysis temperature for all three metal cations. The maximum sorption capacity (MSC) and pyrolysis temperature showed a statistically significant, weak positive correlation ($r=0.26$, $p\leq0.05$) for Cu^{2+} adsorption, whereas for both Cd^{2+} and Pb^{2+} it was found to be negligible (r_{Cd} = -0.02, r_{Pb} = 0.08). Pyrolysis method did not show any statistically significant relationship for MSC with Cu^{2+} and Cd^{2+} ($p\geq0.05$) but it was statistically significant for MSC with Pb^{2+} ($p=0.01$). Sludge based BC showed the highest variability for MSC with Cu^{2+} and Pb^{2+} whereas fungi based BC exhibited the highest variability for MSC with Cd^{2+}. Magnetized, oxidized and base modified BC showed the highest variability for MSC with Cu^{2+}, Cd^{2+} and Pb^{2+} respectively. Therefore, an insight was gained on what factors should be considered when selecting pyrolysis conditions and feedstock types, in order to produce BC with useful physiochemical properties that will specifically aid in the adsorption of Cu^{2+}, Cd^{2+} and Pb^{2+} metal cations from aqueous systems.

Keywords: Biochar, Heavy metals, Pyrolysis conditions, Feedstock type, Meta-analysis, Physiochemical properties