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Advances in Biochar Engineering Methods

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Introduction

Biochar is currently used for various purposes, like environmental pollution treatment, heavy metal melioration, and nutrient stabilizers. Advancement in the properties of biochar increases its utility. Engineered biochar modification by researchers in terms of its absorption capacity, particle size, porosity, etc. The outcome of the properties of biochar mainly depends upon the feedstock properties as well as processes involved during biochar production. several engineering methods, ranging from physical or chemical to biological methods, which are based on modification of its physico-chemical properties (such as specific surface area, surface functional groups, and pore structures).

Biological modification

Biological modification mainly utilises two processes, which are anaerobic digestion and bacterial conversion. Bacteria like modified strains of Escherichia coli are used for anaerobic digestion of biomass to produce biochar. This method leads to higher surface area, pH, hydrophobicity, anion exchange capacity, and CEC. The use of such a technique might greatly improve the environmental and economic feasibility of biochar production by generating biogas. In general, biologically activated biochar might be used as an ion exchanger in environmental remediation to sequester negatively and positively charged ions such as heavy metals and phosphate.

Physical modification

Physical modification techniques enhance pore structure and provide oxygenic functional groups, as well as provide advantages over chemical methods in terms of cleanliness and ease of control. The physical alteration of modified biochar enhances its adsorption capacity by raising its specific surface area and producing more pores. Physical modification techniques use no additional contaminants and are low-cost. Steam or gas activation, ball milling, microwave modification, and magnetic modification are some of the physical modification processes for biochar.

Steam/gas activation

It is utilized for creating activated carbon and generally carbonization techniques that are created and modified by using CO_2 or steam. At temperatures ranging from 700 to 1100 °C, steam or gases expand and enhance the porosity in the carbonized material during carbonization. Steam activated biochar decomposes the carboxyl and phenol functional groups, which results in nearly doubling the surface area while lowering the polarity. The steam/gas activated biochars can be used to remove a variety of contaminants, including heavy metals, antibiotics, and greenhouse gases, and have played a key role in determining sulfamethazine sorption. This method can be utilized in industries for the preparation of biochar, but it has certain limitations due to the heterogeneity of biochar, difficulty in controlling the reaction temperature, local overheating, and non-uniform activation.

Ball milling processes

This methodology came up with an increase in the surface area by reducing carbon particle size through grinding, which increases corn stover biochar surface area by 60–194 $m^2 g^{-1}$. Feedstock ball milling can be done either through a physical or chemical method (alteration of extrinsic functional groups). A nano-sized particle was developed which had better contaminant absorbance capabilities due to a higher specific area than carbon nanotubes.

Microwave modification

Microwave pyrolysis is quite a recent method of pyrolysis that is typically more controlled, rapid, and allows a uniform distribution of internal temperature, as well as being energy and cost-effective. Thus, biochar modified through microwave contains more functional groups and has a higher surface area. Microwave pyrolysis can be carried out even at low temperatures, up to 200 °C, and has higher water holding capacity and cation exchange capacity and is more stable.

Magnetic modification

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Smaller particle size and less density make biochar difficult to separate from water, which restricts its application to a great extent. A mix of biochar and magnetic media allows for the solid-liquid separation, which is an excellent method to tackle the problem. Besides having better adsorption properties, magnetic biochar is easy to separate because of its magnetic properties. Generally, iron or iron oxides are used as media for linking the biochar, which has a wide range of applications in adsorption, environmental remediation, and purification. Because of Fe oxides in biochar, the CEC of magnetically treated biochar increases substantially.

Acid and alkali modification

Acids like sulphuric acid and nitric acid are used in the modification of biochars. Acid activated biochar changes the structure of biochar, which affects the adsorption performance of several metal ions. For example, acid activation by 30% sulfuric acid leads to an increase in the sorption of sulfamethazine. Acid activated biochars showed greater mobilisation of elements like Pb, Cu, and Zn.

In the case of alkali, NaOH and KOH are mostly used for biochar modification. NaOH modified biochar can be effectively used for creating activated carbons with greater surface area and micropore volumes, and it also shows a higher sorption capacity for Cd (II). KOH modified biochar is used for treating municipal solid wastes for the removal of harmful metals like arsenic and can also effectively adsorb methylene blue. Biochar that has been chemically changed can be used to remove both inorganic and organic pollutants from water, making it cleaner.

Chemical modification

The idea of different processes of biochar formation came into existence with the chemical nature of feedstock and fundamental chemical reactions. Pre-treated feedstock is brought for pyrolysis at oxidant availability. Oxidation of biochar can be done with certain acids and bases, which improves chemical properties, i.e., anionic and cationic exchange capacity of biochar as compared to Palestine biochar, leading to a magnificent increment of sorption capacity. Based on the availability of surface area functional groups, engineered biochar can be successfully used for the remediation of heavy metals. The cationic carboxyl group showed a positive force towards anionic metal ions.

Hydrogen peroxide modification

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By far the most well-known fact about H_2O_2 is its substantial oxidizing properties. By using this chemical nature, biochar was developed and comes up with an economically effective and environmentally sustainable approach. Hydrothermically produced biochar is capable of capturing heavy metals due to an increase in oxides at the surface, especially the carboxyl group. When batch hydro biochar was used to treat lead (22.82 mg g1), it absorbed 20 times more than lead that was not treated (0.22 mg g1).Meanwhile, when modified biochar is used as a filter in a packed column, it can successfully be capable of removing Pb with the same capacity. Other metals can also be removed from water, like Cu+2 > Cd^{+2} > Ni^{+2}. Some research also suggests that an increase in the oxide functional group over the surface capable of ammonium treatment when maple wood biochar modification is done by hydrogen peroxide. This happened due to an adjustment in the pH.

Acid and Alkali modification

Coating/Impregnation

Biochar exists due to the structure (internal and external) and properties (chemical and physical) it possesses. One of the main properties lies on the surface. The chemical groups occupied on the surface determine the use of biochar. For the suitable impregnation of the biochar surface, chemical treatment is done before (metal salts) or after (metal oxide nano-particle mixing) pyrolysis.

Various nanoparticle coating materials have been tested for different purposes. Nano particles, particularly used due to their specific surface area and functional groups, have high absorption affinity and can be used for bioremediation and water table treatment of heavy metals. Better thermal stability and porosity improve the efficiency of the biochar. Enhancement in the sorption of aqueous Pb^{2+} and Cd^{2+} was shown due to an increase in specific surface area when feedstock was treated with carbon nanotubes and graphene oxide. Graphene and surface aromatic molecules demonstrated interactions that enhanced methylene blue adsorption.

The bio accumulated biochar formation process starts with the cultivation of feedstock in which the feedstock is enriched with a specific element. Firstly, it is converted into nano metal oxide or hydroxide, and then pyrolysis is done. Tomato plants enriched with magnesium solution and their engineered biochar are used for the remediation of aqueous phosphate. as magnesium oxide and hydroxide particles over their surface. Hyper accumulator species have a higher potential for nanoparticle containing soil and water treatment.

Metal salts impregnated in biomass are pretreated, and pyrolysis converts these metal ions into hydroxides (AlCl3 to Al2O3, CaCl2 to CaO, KMnO4 to MnOx, MnCl2 to MnO, Zn(NO3)2 & ZnCl2 to ZnO). transformation increases specific reactive sites for heavy metal treatment by adsorption. which can accumulate the methodology developed. Lignin/Co biochar formed in a CO_2 environment can be used in bromate catalytic reactions and has a significantly higher surface area (approx. 100 times that of an N_2 environment). Similarly, when corn biomass is coated with FeCl3.6H2O and subjected to slow pyrolysis, it exhibits high precipitation and electrostatic attraction, resulting in higher As(V) absorption of 6.8mg g^{-1}.

Clay has a high surface area with an incredible absorption capability. Specifically, kaolinite clay minerals have a less negatively charged surface and surface area than montmorillonite. For the management of eutrophication and wastewater treatment, montmorillonite was used. Various attempts were made at clay impregnation before pyrolysis. Electrostatic attraction and ion exchange increased the absorption of dye (methylene blue) up to five times more than pristine biochar. It had a stable absorption capacity of 7.9 mg g^{-1}.