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UTILIZATION OF AGRO–WASTES DERIVED BIOCHAR/MODIFIED BIOCHAR AS EFFICIENT ADSORBENTS IN WASTEWATER TREATMENTS – A REVIEW

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Abstract: Wastewater has been seen as one of the global environmental issues recently. Untreated wastewater left environment polluted and tends to cause health issues. The rate at which environmental contaminants are discharged into our environment are alarming and there is need to seek for solutions to address these issues towards achieving eco–sustainability of the environment in promoting SDG–3 (Ensure healthy lives and promote well–being for all at all ages) through efficient implementation of SDG–6 (Ensure availability and sustainable management of water and sanitation for all). As a result of this, there is need to seek for sustainable adsorbents through utilization of Green Chemistry Principle #7 (Use of Renewable Feedstocks) to address global issues of water scarcity. Utilization of agro–wastes is in frontline towards achieving environmental wastes and as well to produce value–added products such as Activated carbons, Biochar, renewable and eco–friendly chemicals from agro–wastes. Therefore, this mini–review present recent overviews of agro–waste derived adsorbents (biochar) as catalytic materials for the environmental remediation of wastewater

Keywords: Agro–wastes, Biochar, Wastewater, Sustainable Development Goals (SDGs), Circular Economy

INTRODUCTION

Biochar as a renewable and eco–sustainable material obtained from renewable sources with green credentials are gaining attention recently (Afolalu et al., 2022; Li et al., 2022). Biochar is a material suitable for various environmental and energy applications (Li et al., 2022). Biochar is being employed and studied as material with multipurpose in various fields (see Figure 1). Biochar is obtainable from biomass. As we already know that the entire world is facing various issues of which consumption of non–renewable resources is fundamental to it, utilization of non–renewable materials such as petroleum derived materials (Afolalu et al., 2022). Reckless utilization of petroleum derived materials has led to various issues ranging from climate changes to pollution of various types (Aderemi Timothy Adeleye et al., 2021) Petroleum derived materials are not equally distributed equally in all global geographical regions, therefore, there is crisis in continuous using without back–up or sourcing source of renewable materials to complement it (Timothy et al., 2020). Biomass as a material renewable in nature, equally distributed almost across the world and eco–sustainable compliance without environmental degradation are suitable for the synthesis of various materials that are equally obtainable from petroleum such biofuels (e.g ethanol, biodiesel), recently Ning Li et al synthesized biojet fuels from lignocellulose biomass (Timothy et al., 2020). Biomass has also been used for the synthesis of activated carbon (Aderemi Timothy Adeleye et al., 2021), it has been employed as catalytic materials for the synthesis of various materials such value–added chemicals (Chi et al., 2021), for sensor application and as adsorbents for various applications (Li et al., 2022). It is an important renewable feedstock owing to its environmental–friendliness and renewability credentials (Afolalu et al., 2022). Therefore, this is the reason they are being explored for various uses. Agro–wastes are from biomass and are suitable for the applications enumerated above (Aderemi T. Adeleye et al., 2020). This review work is specifically based on the utilization of agro–wastes for the synthesis of biochar as adsorbents for the treatment of wastewater. An environmental and sustainable approach to optimize the use of vast agro–wastes is to use them for the production of value–added materials (Timothy et al., 2020). This will really help in the reduction of accumulated wastes around the globe and further serve as source of income which can as well create job opportunities while agro–economics receive positive boosts (Aderemi T. Adeleye et al., 2020). Apart from plant–derived biomass, biochar can also be synthesized from animal wastes such as bone. For instance, Adeniyi and his colleagues' metal oxide–based biochar from bone via pyrolysis. The biochar synthesized was reported to be suitable as low–cost adsorbent for the treatment of wastewater and catalytic materials to produce biofuel as alternative fuel at lower cost (Chi et al., 2021). The entire production was said to be low–cost and eco–friendly (Li et al., 2022).

The published reports by the United Nations (UN) in 2017 revealed that not less than 2.2 billion people have no access to safe drinking water because of the presence of contaminants in the source of water (Kingsley I. John, Omorogie, Bayode, Adeleye, & Helmreich, 2022).

According to recent report by the year 2030 more 700 million people could be displaced because of inability to have access to potable drinking water.

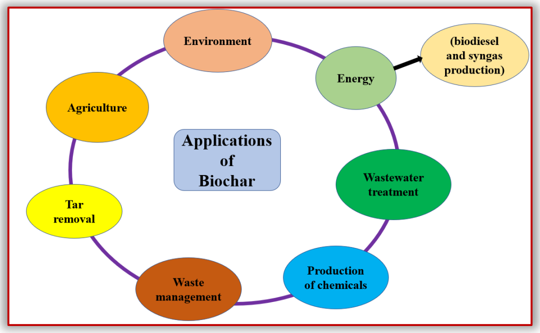

Figure 1. Applications of biochar in various field

According to the United Nations (UN) report, as of 2017, approximately 2.2 billion people were short of safely managed drinking water due to contamination by pollutants (Igenepo John et al., 2021). In order to address this issue in accordance with the SDG–6 (Ensure availability and sustainable management of water and sanitation for all) and SDG–3 (Ensure healthy lives and promote well–being for all at all ages) various techniques have been employed for the treatment of wastewater (Kingsley Igenepo John et al., 2021). Figure 2 shows the current and existing applicable wastewater treatment techniques (Kingsley Igenepo John et al., 2021; Kingsley Igenepo John, Malachy Obu, et al., 2022).

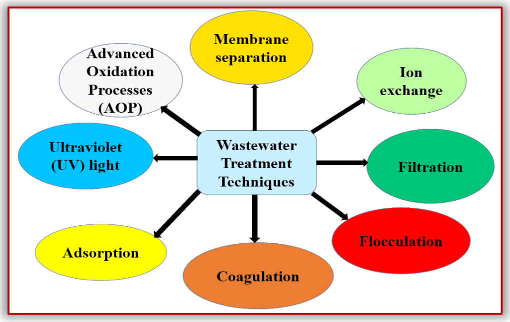

Figure 2. Applicable wastewater treatment techniques

Improper and continuous discard of a large number of organic and inorganic contaminants such as dyes, heavy metals, surfactants, pharmaceuticals, pesticides, and personal care products from households, industries and municipalities into the sources of water have contributed to the scarcity of water for various uses across the globe(Kingsley Igenepo John, Daniel Agbor, et al., 2022). The fact about these contaminants is that they are significantly persistent and recalcitrant in nature thereby causing continuous degradation of our environment in various form. This is a concern and solutions are urgently needed to avert subsequent consequences specially to keep the environment habitable for the future generation while we take care of the present with the available technologies for the wastewater treatment toward achieving sustainable development (Igenepo John et al., 2021). Apart from the wastewater techniques shown in Figure 2, other conventional technologies are applied worldwide for the removal of wastewater contaminants in a single manner or in combination to achieve the purpose efficient treatment. Such as coagulation–flocculation, reverse osmosis, chemical precipitation, ion–electrochemical treatment, solvent extraction, and flotation for the removal of inorganic pollutants (Sarayu & Sandhya, 2012). Though these treatment techniques have pros and cons. Some are inefficient in nature or not cost–effective due to the cost of the required equipment and maintenance, sometimes high consumption of energy made them unaffordable(Rout, Zhang, Bhunia, & Surampalli, 2021). Therefore, efficiency and viability of the method adopted for the treatment must be considered if they are economical affordable, environmental compliance and potential to scale up to industrial adoption. With these credentials treatment approaches could decrease the unaffordable treatment cost and increase the efficiency features of process of the water treatment (Adeyemi, Ajiboye, & Onwudiwe, 2021). The synthesis of biochar is not performed via pyrolysis or thermal decomposition of the employed precursors (i.e carbonaceous biomass) under a limited amount, or absence of oxygen (Fischer et al., 2019). Generally, almost all carbonaceous precursors are suitable to produce biochar precursor such as lignocellulosic biomass, agricultural biomass (i.e., plant or animal derived biomass or even manure), industrial residue, and activated sludge (Fischer et al., 2019). Recently biochar has attracted the attention of the researchers owing to their cost–effectiveness and other characteristic features such presence of oxygen–containing functional groups, interesting high surface areas, high cation exchange capacity and alkalinity (Jung, Lee, Choi, & Lee, 2019), these characteristic features have made them suitable candidates as efficient and sustainable adsorbents in wastewater applications (Fischer et al., 2019). It has been employed as an adsorbent for the remediation of emerging contaminants such as microplastics (Mujtaba Munir et al., 2021), pharmaceuticals (Ihsanullah, Khan, Zubair, Bilal, & Sajid, 2022), dyes, trace metals, pesticides and heavy–metals (Amusat, Kebede, Dube, & Nindi, 2021). Sajjadi B. et al, 2019 (Sajjadi et al., 2019)and Mandal S. et al, 2020 attributes the interesting high sorption feature of biochar to existing disordered valence sheets that engineer incompletely saturated valences and unpaired electrons, that facilitate an improved high number of active sites for adsorption (Mandal et al., 2021; Sajjadi et al., 2019). The presence of a large amount of delocalized π electrons result to a negative charge of the biochar surface; therefore, causes it to act like a Lewis base which subsequently attract Lewis acid via processes of physi– and chemisorption (Mandal et al., 2021). Furthermore, availability of oxygen–containing and nitrogen–containing functional groups on the biochar surface enhances adsorption through acid/base interactions and hydrogen–bond formation (Sajjadi et al., 2019). In addition to that, as biochar possesses carbon matrix, structural defect sites, and various surface functional groups, it is suitable for efficient use in photocatalytic reactions. Biochar has remarkable electrical conductivity, leading to its decreased electron/hole recombination rate during the photocatalytic process, thus enhancing the oxidation rate of the target compound (Mandal et al., 2021; Sajjadi et al., 2019). All of these features make biochar an interesting alternative to activated carbon in the fields of adsorption and photocatalysis (Matos, 2016). Katiyar and his colleagues emphasized on limitations of biochar. Pristine biochar reveals an excellent adsorption capacity for organic substances, it exhibits a very limited adsorption capacity for anionic pollutants (Katiyar et al., 2022). Moreover, raw biochar requires a long equilibrium time, due to its limited surface functional groups and porous structure (Amusat et al., 2021). Additionally, the biomass source, reaction media, and processing conditions determine the biochar properties (Afolalu et al., 2022; Ihsanullah et al., 2022) which means that biochars will differ in the range of molecular structure and topology. Therefore, numerous studies have been conducted to improve biochar properties, including chemical and physical approaches (Amusat et al., 2021; Ihsanullah et al., 2022). To improve its properties for environmental applications, chemical processes such as acid and base modification, metal salt or oxidizing agent modification, and carbonaceous material modification are most often selected (Amusat et al., 2021).

APPLICATION OF BIOCHAR–BASED CATALYST TO WASTEWATER TREATMENT

— Industrial wastewater remediation

Biochar–based catalysts have been used in the treatment of industrial effluent, which composes majorly heavy metals and organic contaminants. Biochar–based catalyst has the potential to be used efficiently as an adsorbent for the adsorption of heavy metals in industrial wastewater(Jung et al., 2019). For instance, Rajapaksha A.U et al emphasized that a successful adsorption of heavy metals (Cu, Pb, As, Cd and other heavy metals) from industrial wastewater using chitosan/ biochar is dependent on the combination ratio of chitosan/ biochar materials (Rajapaksha et al., 2015). Biochar made from bagasse was as well employed to absorb lead from the effluent of the battery production sector to the tune of 13 mg/g, and the adsorptive activity depended on the moderate pH value, contact time, and concentration (Qian, Kumar, Zhang, Bellmer, & Huhnke, 2015). Pan et al. prepared biochar (from peanut, soybean, canola, and rice husk) and showed that adsorption capacity increases as functional groups on biochar increase, suggesting complexation with functional groups as the controlling remediation mechanism for trivalent chromium (Pan, Jiang, & Xu, 2013). Further studies from Chen et al. observed there was a correlation between the absorbed Cr (III) and the released Ca2+ and Mg2+ cations into solution during adsorption. At lower pH (<2.5), surface biochar becomes negatively charged, and trivalent chromium species remains positively charged leading to electrostatic interaction and the removal of the chromium. Majorly, the application of biochar–based catalyst in adsorbing contaminants from industrial wastewater have been carried out in a laboratory environment; however, additional study and deployment in the actual situation are required (Chen, Zhou, Xu, Wang, & Lu, 2015).

— Wastewater treatment in the agricultural sector

Agricultural pollution is unbecoming due to rapid development of new technologies in the agriculture sector. This has led to the release of agro–chemicals containing toxic heavy metals into the environments in large quantities (Amusat et al., 2021). Pesticides such as atrazine and pentachlorophenol are two of the most often used in agriculture. Corn straw and soybean biochars both exhibit strong atrazine reduction potentials, with the adsorption efficiency owing mostly to the pH value and pore volume of the biochars (Fischer et al., 2019). Steam–activated biochar is efficient at eliminating sulfamethazine, and the rate at which it absorbs the substance is dependent on the pH value (Afolalu et al., 2022; Li et al., 2022).

— Data Evaluation of Adsorbents

≡ Calculation of Equilibrium Adsorption Amount of Contaminants

The equilibrium adsorption amount can be calculated using Equation (1):

$$q_e = \frac{(C_0 - C_e)}{m} \tag{1}$$

where qe (mg/g) is the adsorption capacity of the Cm on contaminants, V (mL) refers to the volume of contaminants added, Co (mg/L) represents the initial addition concentration of contaminants solution, Ce (mg/L) denotes the concentration of contaminants solution after adsorption, and m (g) is the weight of the sample (Liu et al., 2022).

≡ Fitting of Contaminants Adsorption Isotherms

Three isothermal adsorption models can be selected on the basis of the adsorption isotherm trend, and the isothermal equation (Equations (2)– (4)) such as follows:

$$q_e = \frac{q_m K_L C_e}{1 + K_L C_e} \tag{2}$$

$$q_e = K_F C_e{}^{\frac{1}{n}} \tag{3}$$

$$q_e = K_H C_e \qquad (4)$$

where qm indicates the maximum adsorption amount of contaminants, mmol/kg; and KL, KF, and KH are the Langmuir (eqn. 2), Freundlich (eqn. 3), and Henry adsorption (eqn.4) equilibrium constants of the contaminants adsorption, which can be used to measure the affinity of adsorption (Liu et al., 2022). In the study conducted by Liu et.al., and his colleagues where acid–base modified biochar was employed for adsorption removal of pharmaceutical compound (Chlortetracycline, CTC) by purple soil, the variation of the CTC adsorption capacity of different soil samples with temperature is represented in Figure 3, the sorption capacity of each amended soil for CTC increased with increasing temperatures, showing that the sorption was an endothermic form in nature.

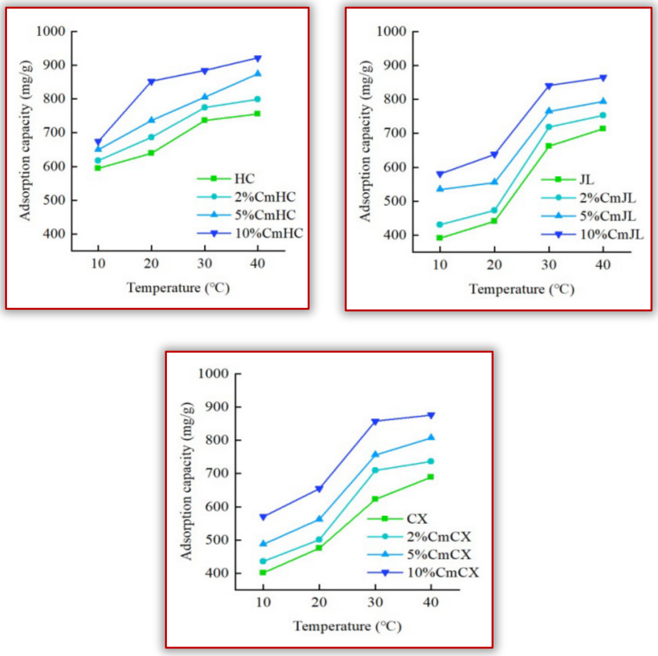

Figure 3: Adsorption capacity of CTC on different soil samples at various temperatures (Liu et al., 2022)

According to the author with the increase in temperature, the adsorption process was more spontaneous because of the thermal movement of molecules, and the collision between the biochar used as adsorbent and CTC was more violent at a high temperature (Liu et al., 2022). A previous study also showed that the adsorption capacity of tetracycline (TC) for different amended soil samples increased with temperature, thereby showing the positive effect of increasing temperature (He et al., 2019)

CHALLENGES AND PROSPECTS OF BIOCHAR CATALYST TO WASTEWATER TREATMENT

Biochar–based catalysts has proven beneficiary in useful applications to catalytic processes and various specific/functional organic reactions. However, all these are currently in their infancy and must be scaled up. Biochar production systems must be set up on an industrial scale to enable the scaling up of these processes. Stephen O. et al. identified to major inhibitors to scaling up biochar production, which are multiple competing end–users, as well as the collection and transportation of raw materials to the facilities that manufacture biochar (Stephen Okiemute, Ifeanyi Michael Smarte, Jeremiah, & Sammy Lewis, 2022). Homagain studied the sensitivity of transportation distance and distinct carbon offset values and found that the system is financially viable at 200 km with good biomass availability (Homagain, Shahi, Luckai, & Sharma, 2016). In addition, the seasonal biomass production cycle makes it difficult to maintain a steady supply of sustainable and reliable fuel. Again, moisture content and particle size are other critical parameters in the synthesis of biochar, because biochar production method requires a lot of energy to drain the moisture and reduce the size. The investigation of high surface area, active sites, and optimal pores is critical to managing the combined impacts of important production process variables (e.g., reagent gas, duration, heating rate, and temperature) and activation process variables (e.g., chemical, and physical) (Amusat et al., 2021; Ihsanullah et al., 2022)

CONCLUSION

This review systematically presented an overview of the emergence of biochar and its significance, different biochar production techniques, characteristics and inherent properties that permit its adsorption capacity, preparation of biochar–based catalysts and its modification mechanisms to enhance its adsorption and absorption properties toward organic and inorganic emerging contaminants, prospective applications to wastewater treatment, present challenges, prospects and recommendations. Therefore, biochar–based catalysts have strong potential for replacing costly and non–renewable conventional catalysts. The versatility characteristics of biochar–based catalysts has been demonstrated effective in remediation of contaminated wastewater, including the adsorption of toxic heavy metals, organic and inorganic elements from effluent, as a support for catalysts, as an immobilization support media for microorganisms and adsorbent of inhibitive compounds during anaerobic digestion.

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