A Review on Biochar Produced from Biomass Waste-Its Removal Mechanism and Adsorption Capabilities for Pollutants in Industrial Water

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***Abstract*- In present times, due to the increasing growth of industrialization and urbanization in developing countries, a large amount of wastewater is produced from industries. As a result, the wastewater not only imports significant dangers to the environment as well as to the people's health, but it also affects the economy of any country if it is not treated properly at the earliest. As a result, the government and scientists are paying closer attention to the development of a sustainable low-cost wastewater treatment system. The current analysis focuses on recent biochar applications for eliminating organic and inorganic contaminants from industrial effluents. The most modern methods of synthesis physicochemical characteristics and adsorption mechanisms of biochar in the removal of organic and inorganic industrial contaminants are also thoroughly discussed here. Biochar exhibited up to 80% adsorption of industrial dyes. It also describes the most current use and mechanism of biochar-supported photocatalytic materials for organic pollutant degradation in wastewater. Here the study showed possible optimizations (such as pyrolysis temperature and solution pH) that could boost biochar adsorption capacities and lead to organic pollutants removal, likewise, increasing the pyrolysis temperature of the biochar increases its surface area while decreasing the number of functional groups that contain oxygen, which causes a reduction in the media's capacity to adsorb metal (loid) ions. Finally, the review suggests that more research be conducted to optimize the major components involved in the creation of biochar. Future efforts should be focused on process engineering in order to improve the adsorption capacity and hence boost the economic benefits of its implementation.**

***Keywords*: Biochar, Adsorption, Biochar-supported photocatalysts materials, Organic pollutants, Inorganic pollutants.**

I. INTRODUCTION

Every day, a large amount of wastewater is produced by industry (coal and steel industries, non-metallic minerals industries, and industries for metal surface processing such as iron picking and electroplating), which has an immense effect on the environment (Inyang, 2012). As a result, several ways to treat industrial wastewater have been used, including advanced oxidation processes (AOPs), reverse osmosis, adsorption, ion exchange, ozonation, precipitation, filtration with coagulation, and coagulation process (Park, 2011). However, the majority of these processes have large operational and capital expenses. This has been identified as the main barrier to their use in both developed and developing nations for the removal of potentially harmful chemicals from polluted waterways (Giannakis, 2017; Lou, 2017; Ambaye, 2020). Biochar is a solid formed from the pyrolysis of biomass at temperatures below 700°C under low or no oxygen (Park, 2011). As a result, wastewater pollutants both organic and inorganic can be removed because of th5rterteryte solid's high carbon content and promising adsorption capacity. Various waste materials such as straws, faces, and sludge have been tested as raw materials for biochar production.

Many scientists investigated the viability of biochar made from animal dung, plant residues, and biosolids (Downie, 2009; Joseph, 2010; Sun, 2014) for the adsorption of pesticides, medications, hormones, and potentially harmful metals. They demonstrated that, as compared to activated carbons, biochar exhibited significant efficiency for adsorbing contaminants. In their investigations employing biochar made from plant biomass to eliminate endocrine-disrupting disrupting organic compounds from aqueous solutions, (zçimen and Karaosmanolu, 2004) and (Hossain, 2011) obtained the same results. They found that organic contaminants such as triazine herbicide, -ethinylestradiol, atrazine, and bisphenol may be removed by biochar by up to 60%. They came to the conclusion that the physiochemical characteristics of both the pollutant and the biochar as well as the preparation of the feedstock affect the absorption capacity of biochar to remove contaminants. Two dyes, safranin, and methylene blue, were removed using rice husk (Inyang, 2014). According to (Peng, 2011), the adsorption constants for the two dyes were 838 and 312 mg/g, respectively.The capacity of orange peel to absorb dye and remove it from home and commercial effluents has been thoroughly researched. It has been investigated how certain physicochemical factors, such as the dosage of biochar, the medium's acidity, the reaction time, and the dye concentration, may impact absorption efficacy. Within the first 15 minutes at an initial pH of 2, direct red 23 and 80 showed adsorption capabilities of 10.72 and 21.05 mg/g (Fuertes, 2010). New research articles (Inyang, 2016, Rizwan, 2016, O'Connor, 2018, Wei, 2018) demonstrated the efficacy of the biochar adsorption method in removing heavy metals from wastewater. For typical industrial wastewater pollutants such as potentially harmful metals, organic pollutants, phosphorus, and nitrogen compounds, this material has a good ability for adsorption. Due to its excellent phosphorus and nitrogen adsorption capability, as previously documented (Chen, 2011a, b; Yao, 2011a, b 2013a, b; Zhang, 2013a, b), biochar can be employed as a release regulating agent in fertilizers. As biochar is an environment-friendly absorbent, it is currently of greater interest to understand its physicochemical properties and to have complete knowledge of the adsorption mechanism. The adsorption

mechanism of biochar to remove organic and inorganic contaminants can mainly be based on the processes like the interaction of electrostatic charges, ion exchange, pore blocking, and precipitation. This is determined by the biochar's physiochemical properties, including dosage, pyrolysis temperature, and medium/effluent pH (Pellera, 2012; Ahmad, 2014; Lam, 2016; Mubarak, 2016; Vithanage, 2016;Younis,2016; Rehman, 2017; Qayyum, 2017).

In this paper, Various biochar sorbing materials for the removal of contaminants from industrial wastewater are reviewed. The preparation processes, biochar characterization, and various pollutant adsorption mechanisms are discussed.Additionally, its economic and environmental benefits are examined, particularly when applied on a big scale. The analysis also identifies areas for future research, particularly in relation to biochar's uses in the environment.

II. PROPERTIES OF BIOCHAR

1. Procedures for Making Biochar

Different techniques were utilized to make the biochar. (Table.1) Summarises some of the preparation circumstances, part of the preparation techniques, and the absorption yield of freshly made biochars. It appears that pyrolysis is a key technique for producing biochar. Decomposition that occurs at a high temperature without oxygen is known as pyrolysis. Based on the temperature and the length of the reaction, it can be classified as rapid, slow, or "flash" pyrolysis (Downie,2009; Sun,2014). Slower heating rates and lower pyrolysis temperatures might result in solid products.

Hydrothermal carbonization (HTC) is another important method for creating biochar. The biochar produced by HTC is better suited for the adsorption of contaminants in aqueous systems. This technique doesn't produce any harmful compounds. According to Van Zwieten, (2010), the method's main drawbacks are the high-pressure requirement required by the high temperature, as well as the reactor's cost. It could also be time-consuming, which raises the cost (Van Zwieten, 2010) and delays its practical use. However, Recent research demonstrated that employing HTC to treat sewage sludges and digestate can overcome its energy constraint when compared to other thermochemical methods. According to (Parmar and Ross 2019), the hydrochar that can be created with this procedure was shown to be more stable. Because of this, HTC hydrochar can enhance soil amendment and remediation as well as biogas production. For potential large-scale applications, more study is required on the coupling of HTC with the anaerobic digestion of process fluids (Parmar and Ross, 2019).

Table. 1: Biochar is created using traditional methods (Downie,2009; Novak,2009; Sun,2014).

Preparation methods	Temperature (°C)	Heating rate	Yield (%) Solid	liquid	Gas
Slow pyrolysis	<700	Slow	35	30	35
Fast pyrolysis	<1000	Fast	10	70	20
Flash pyrolysis	775-1025	Faster	10-15	70-80	5-20
Hydro-carbonization	<350	Slow	10	5	85
Gasification	700-1500	Faster	50-80	-	-

2. Different types of biochar

The source of the biomass and the method of preparation have a major effect on the physicochemical characteristics of biochar. Biochar can be made from various biomasses with various physical, chemical, and structural properties.

Theoretically, any kind of biomass can be used to create biochar. A variety of feedstocks, including agricultural, aquatic, or forest products, could be used to make biochar (Sun, 2014). Different biowastes, such as husks, sawdust, shells, and hulls, can also be transformed or processed to create biochar. Figure 1 depicts additional biomass sources, such as manures, municipal solid wastes, and sewage sludge (Zhang, 2017). The physicochemical properties of biochar can be affected by a variety of circumstances. The kinds of raw materials used and the size of the substrate are two factors that influence the qualities of biochar. The kind of pyrolysis (slow, quick, or fast), temperature, heating rate, and pyrolysis time can all have a significant impact on the final biochar's quality (Downie,2009; Peng,2011; Thies and Rillig 2009).

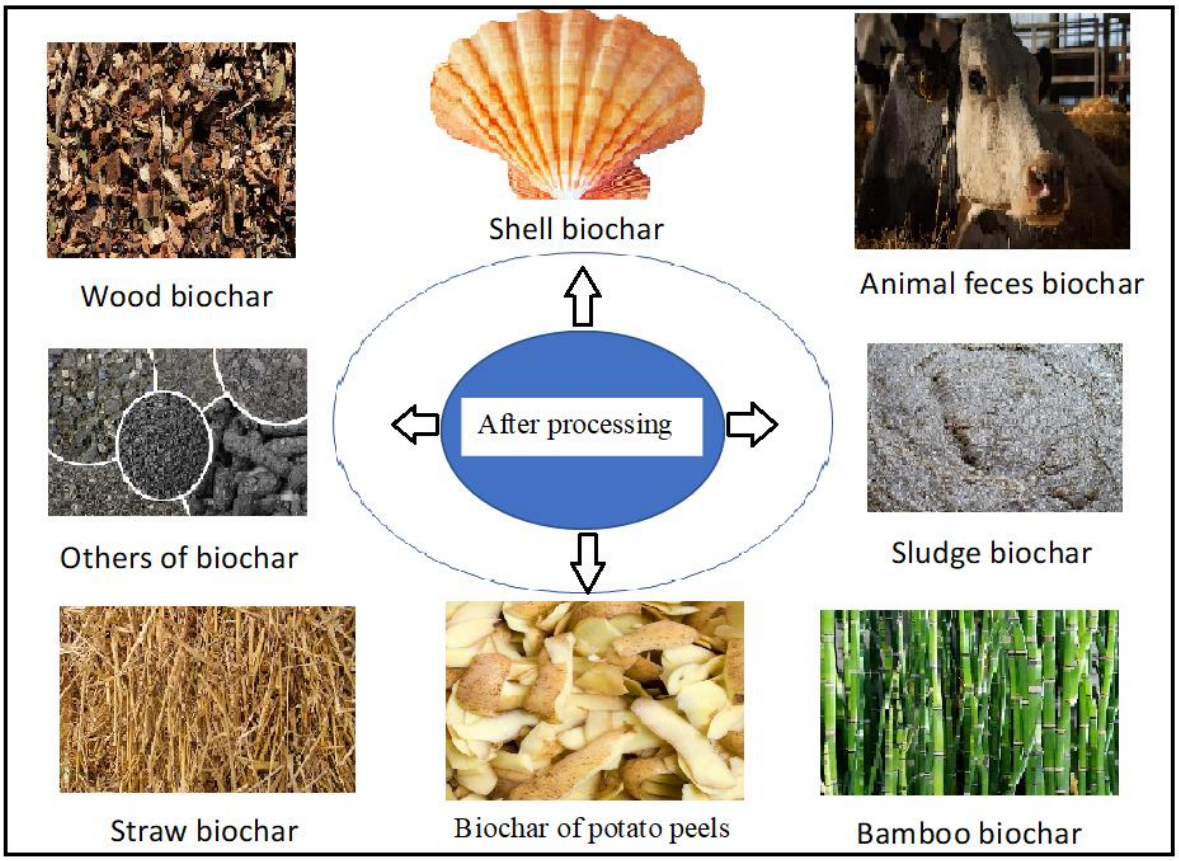


Fig.1: Sources of different types of biochar.

2.1 The Characteristics of Biochar Regulating Its Activity

The features of biochar are defined by the pyrolysis temperature, residence time, feedstock consideration, and thermal conversion process, as stated before. These factors also influence the effectiveness of various contaminants' removal (Chen, 2012). (Chen and Chen 2009) studied the adsorption of organic contaminants using biochar made from pine needles at temperatures ranging from 100 to 700°C, demonstrating that the biochar's pore size and specific surface areas increase proportionally with the pyrolysis temperature. (Chen, 2012) and (Ahmad, 2012) proposed that the presence of carbonized mat may also influence the removal of various contaminants. Optimizing the pyrolysis temperature can also help metal elements that could be hazardous to humans interact with biochar more efficiently. (Kim, 2012) investigated the effects of pyrolysis temperatures above 500 °C on the pH and surface area of biochar. They used biochar to help with the Cd adsorption in aqueous environments. In contrast, (O'Connor, 2018) demonstrated that utilizing biochar made from coconut, increasing the pyrolysis temperature resulted in a decrease in the removal of Cr (VI) in aqueous media. The latter caused Cr (VI) to be converted to Cr (III).

Due to its pH dependence, this reduction reaction poses a major threat to the environment. In situ, reduction of Cr (VI) was attempted by (Ludwig, 2007) using sodium dithionite and ferrous sulfate. The delayed reduced kinetics prevented this approach from being used in practice right away.

Accordingly, it has been noted that raising the pyrolysis temperature of biochar results in an increase in the material's surface area while a decrease in the number of functional groups that contain oxygen. As can be seen in Fig. 2, the latter results in less hazardous metals being adsorbed in aqueous systems. These findings agreed with those made by (Inyang, 2011). According to (Inyang, 2011), the Pb adsorption on biochar dropped from 21 mg/L as the pyrolysis temperature of bagasse biochar climbed from 250 to 600 °C. They explained this by not having as many oxygen-containing groups when the temperature is high.

The composition of the feedstock is another factor that influences the adsorption capabilities of biochar (Sun, 2014). Since these minerals can help form additional active sorption sites and enhance the adsorption of potentially toxic metals from wastewater, their presence or absence in the feedstock can affect the adsorption capacity of the resulting biochar (Cao, 2009).

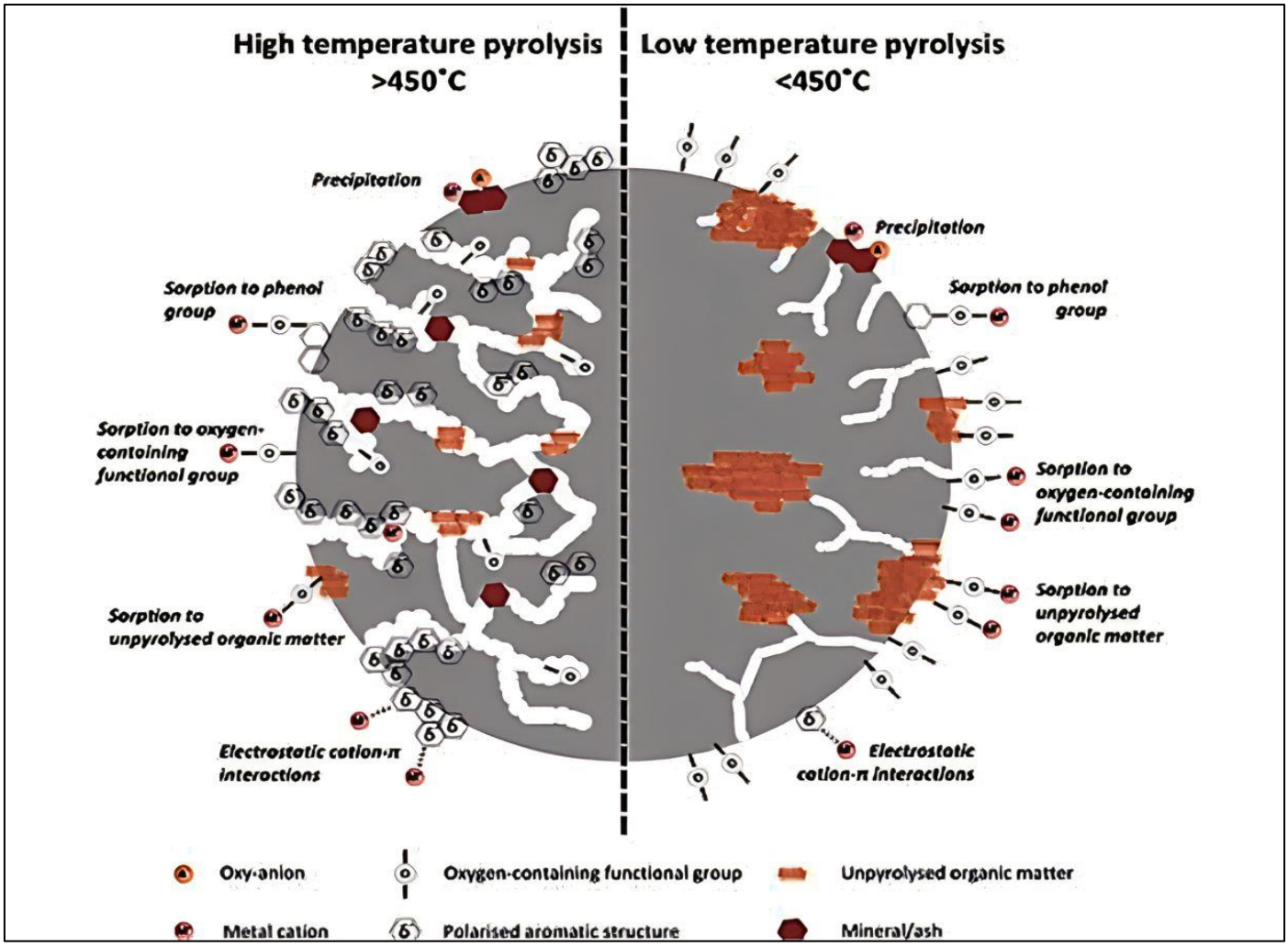


Fig. 2: Mechanisms of metal cation and oxyanion sorption to biochar produced by pyrolysis at high temperature (>450°C) and low temperature (450°C) include Cd^{2+}, Cu^{2+}, Hg^{2+}, Pb^{+}, Zn^{2+}, and oxyanions (e.g. PO_4^3, AsO_4^3). Ambaye, T.G., Vaccari, M., van Hullebusch, E.D. (2021).

2.2 Mechanisms of Adsorption by Biochar

Adsorption occurs when the adsorbate becomes connected with the adsorbent's surface until equilibrium is reached. Adsorption involves three steps: (i) physical adsorption, in which the adsorbate settles on the adsorbent's surface; (ii) precipitation and complexation, in which the adsorbate deposits on the adsorbent's surface; and (iii) pore blocking, in which the adsorbate is condensed into the adsorbent's pore (Fagbohungbe, 2017). The three steps of this process, which are divided into three zones, are as follows: the clean zone is the initial stage, during which no adsorption happens. The mass transfer zone, where the adsorption is taking place, is the second step. The tired zone, which is the final step, is where equilibrium is reached (de Ridder, 2012). During the process, the clean zone shrinks while the saturated or exhausted zone grows. If the concentration of the adsorbate is elevated, the mass transfer zone is impacted; otherwise, it is unaffected. Such a pattern continues until the adsorbent reaches the saturation point (Moreno-Castilla 2004).

2.2.1 *Toxic Metal Adsorption Mechanism*

Surface sorption, ion exchange, electrostatic interaction, precipitation, and complexation are the several mechanisms involved in the elimination of toxic heavy metals.

a) ***Surface Solubility***:

It is a physical process in which chemical bonds are created as a result of the metal ions diffusing within the pores of the sorbent. The carbonization temperature affects the volume of the pores and the surface area of the sorbent (biochar). (Kumar, 2017) investigated the uranium adsorption onto pinewood-derived biochar at temperatures between 300 and 700°C. Their findings demonstrated that uranium can be entirely removed from biochar prepared at a high temperature as opposed to one prepared at a low temperature. They explained this by pointing out that biochar's surface area and pore volume are increased by significant carbonization. Another study described by (Wang, 2015) looked at the harmful metals' capacity to bind to biochar made from hickory wood and KMnO4 treatment. According to their findings, the biochar they produced displayed 153.1 mg g^{-1} Pb adsorption, 34.2 mg g^{-1} Cu adsorption, and 28.1 mg g^{-1} Cd adsorption. This variation in adsorption might be caused by the abundance of various metals, which have different valences towards the biochar.

b) Metals' Electrostatic Interactions with Biochar

To prevent the mobilization of potentially harmful metals, this method uses the electrostatic interaction of charged biochar and metal ions (Mukherjee, 2011). For instance, according to (Qiu, 2009), the attraction of the positively charged Pb and negatively charged biochar results in a high removal of Pb from the aqueous solution when Pb is removed using biochar made from rice and wheat. Additionally, they asserted that raising the pyrolysis temperature above 400°C can improve biochar carbonization and boost the biochar's ability to adsorb pollutants through electrostatic contact. The key process involved in the elimination of potentially harmful metals, electrostatic contact, was previously described by (Keiluweit, 2009), (Dong,2011), (Agrafoti, (2014), and (Igalavithana, 2017). However, the pH of the solution and the biochar's point of zero charges both affect this immobilization process.

c) Capacity For Cation/Ion Exchange

The main concept of this mechanism is the exchange of protons and ionized cations with dissolved salts on the surface of biochar. The contaminated size and surface functional group of the biochar influence its adsorption capacity to remove heavy metals (Rizwan, 2016). According to (Ali, 2017), the higher the cation exchange capacity of the biochar, the greater the metal adsorption. However, once pyrolysis temperatures exceed 350°C, the cation exchange capability decreases. (El-Shafey, 2010) examined the removal of Hg^{2+} and Zn^{2+} from polluted water using rice husk biochar at a pyrolysis temperature of 180°C. They found that Hg ions absorbed significantly more than Zn ions. (Trakal, 2016) investigated Cd and Pb removal using biochar made from several feedstocks such as wheat straw, graph stalk, grape husk, plum stone, and nutshell. The authors observed greater Pb and Cd removal efficiencies for feedstocks containing iron oxides. The addition of iron in the biochar feedstock was found to improve the biochar's cation exchange capacity.

d) Precipitation

It is one of the main methods for removing inorganic pollutants from biochar. It entails the formation of mineral precipitates in the solution or on the surface of the sorbing material, particularly for biochar. It has an alkaline quality and is created by the pyrolysis of cellulose and hemicelluloses at temperatures higher than 300°C (Cao and Harris 2010) As well as (Puga, 2016) discovered that biochar made from sugarcane and straw dust can increase the precipitation of Cd and Zn. However, they claimed that the efficiency of surface precipitation of biochar is dependent on the pyrolysis temperature, implying that more research into optimizing the pyrolysis temperature is required in the future.

e) Complexation

This metal complexation technique involves the production of multi-atom complexes via the interaction of specific metal ligands. Because functional groups include oxygen in their structure, such as phenolic, lactonic, and carboxyl, biochar formed at low temperatures can bind with heavy metals. This oxygen content can promote the surface oxidation of biochar, resulting in increased metal complexation (Mohan and Pittman 2007; Liu and Zhang, 2000) when compared to animal-derived biochar such as dairy manure and chicken litter (Cao, 2009; Zhang, 2017). They came to the conclusion that plant-derived biochar has strong surface complexation and ion exchange capacities. However, further research is required to establish the development of biochar metallic complexes was investigated utilizing advanced spectroscopic techniques such as X-ray photoelectron spectroscopy (XPS) and Fourier transform infrared spectroscopy (Zhou, 2014).

2.2.2 The Mechanism Involved in Organic Pollutant Adsorption

Pore blocking, Interaction between hydrophobic molecules, Partitioning, Interaction of electrostatic charges, and Interaction of electron donors and acceptors (EDA) are the several mechanisms involved in organic pollutants adsorption.

a) Partitioning

During this stage, the adsorbate material diffuses into the pores of the biochar's non-carbonized portion. This part easily interacts with the organic adsorbate, resulting in sorption. However, the adsorption of organic pollutant chemicals is dependent on the properties of non-carbonized biochar (crystalline or amorphous carbon) and carbonized crystalline and graphene biochar fractions. (Cao, 2009) and (Zhang, 2013a, b) revealed that organic carbon (OC) fractions of biochar generated from swine and dairy dung at pyrolysis temperatures of 200 and 350°C demonstrate high sorbate partitioning of atrazine contaminant. (Sun, 2011) found similar results, showing that organic components of biochar generated from wood and grass can improve norfurazon and fluridone adsorption by partitioning. In general, when biochar has a high volatile matter content and a high concentration of organic pollutants, the partitioning process is more evident and efficient (Keiluweit, 2010).

b) Pore Blocking

This is a process in which organic pollutants accumulate on the surface of biochar, which contains mesopores (2-50 nm) and micropores (2 nm). The polarity of the organic contaminant, the type of biochar, and the environment all have an impact the pore fling mechanism. According to (Kasozi, 2010), biochar generated from gamma grass, oak, and loblolly for catechol sorption utilizing the micropore blocking mechanism is more dominant than other adsorption methods. In general, for this pore-blocking process to be efficient, the biochar must contain a limited quantity of volatile matter and occur at low concentrations of organic pollutants.

c) Interaction of Electrostatic Charges

This is the most significant mechanism, which entails the electrostatic interaction-mediated adsorption of ionizable organic molecules to the positively charged surface of the biochar. The pH and ionic strength of the aqueous solution determine how well

it attracts or repels contaminants (Ahmad, 2014; Zheng, 2013). When the pH of the aqueous solution is high, the surface of the biochar bears a negative charge, according to research by (Mukherjee, 2011) on the impact of pH on the electrostatic interaction between organic pollutants and biochar. This suggests that the pH of the solution or effluent controls the net charge of the biochar's surface. The ionic strength of the aqueous solution is affected by the electrostatic interaction of organic pollutants with biochar. (Inyang, 2014) demonstrated that increasing the ionic strength of the sorbate solution from 0.01 to 0.1 M NaCl reduced methylene blue adsorption from 4.5 to 3 mg g^1 in their experiment on the elimination of methylene blue using carbon nanotubes (CNT)-infused biochar made from bagasse. This was attributable to an increase in the sorbent-sorbate repulsive electrostatic interaction.

d) Interaction of Electron Donors and Acceptors

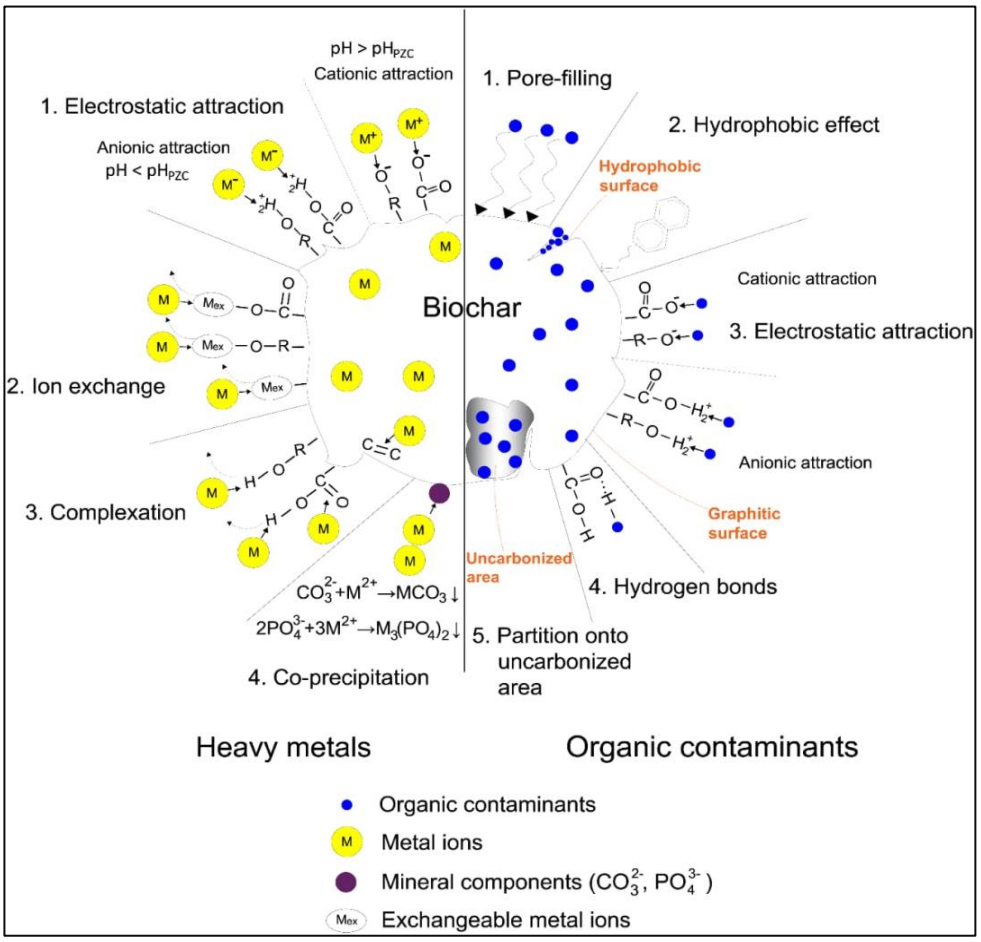
The electron donor and acceptor interaction mechanism is commonly used in the adsorption of aromatic chemicals on graphene-like charcoal. A temperature of more than 1100°C should be attained during biochar processing to achieve complete graphitization (Spokas, 2010). However, the temperature of the biochar during pyrolysis determines whether the electron density of the biochar will produce deficient or enriched electrons, therefore if the temperature of the biochar is less than 500 °C, the aromatic system of the biochar acts as an electron acceptor, and if the temperature is greater than 500°C, the biochar acts as a donor (Sun, 2014; Zheng, 2013). (Zheng, 2013) tried to adsorb sulfamethoxazole using reed charcoal mixed with -electron graphene on its surface. The aniline protonated rings of sulfamethoxazole and the graphene surface of biochar showed high sorption. Furthermore, they stated that the -electron donor/acceptor interaction on the surface of biochar between the electron-withdrawing substituent of chlorine and aromatic carbon improves atrazine adsorption.

e) Interaction between Hydrophobic Molecules

Through partitioning and hydrophobic interaction mechanisms, this mechanism can be employed for the adsorption of hydrophobic and neutral organic molecules. The hydrophobic contact method requires less energy than the partitioning procedure. Furthermore, the hydrophobic interaction is the primary pathway for the adsorption of organic contaminants on the surface of the graphene structure (Zhu, 2005). According to (Li, 2018), the main mechanism for the adsorption of ionizable organic contaminants such as benzoic acid, o-chlorobenzene acid, and chlorobenzene acid is hydrophobic contact. (Chen, 2011a, b) examined the sorption of perfluoro octane sulfonate on maize straw biochar. Due to the organic pollutant's high hydrophobicity, elimination was accomplished by hydrophobic interaction. The adsorption of perfluoro octane sulfonate molecules increased as the pyrolytic temperature increased. This was connected to the pyrolysis temperature causing a decrease in the number of polar groups on the biochar surface. The methods of organic and inorganic adsorbate removal including sorption onto biochar are displayed in Fig. 3. On biochar, metals are mostly adsorbed by precipitation, ion exchange, and electrostatic attraction to the surface of the adsorbent, while organic molecules are adsorbed using van der Waals forces, hydrogen bonds and electrostatic attraction, and hydrophobic interactions to the adsorbent's surface as shown in Fig. 3. Hydroxyl, carboxyl, carbonyl, and amine functional groups promote the abundance of organic molecules and their adsorption on the surface of biochar. Based on the uneven distribution of electrons between the functional groups of the organic chemical and the adsorbent (biochar), this adsorption mechanism is an electron donor/acceptor type. It is important to note that at this level, there --is very little interaction between organic compounds with nitro- and chloro-substituent groups and the adsorbent. As the high electron acceptor character of the compound's substituent group (Atkinson, 2010), the electrostatic interaction between the organic molecule and the biochar is increased (Mu'azu, 2017)

Fig. 3: Adsorption mechanisms for organic and inorganic pollutants in different biochar (adapted from Ahmad et al. 2014).

3. Factors affecting pollutant sorption onto biochar



3.1 Effect of the pH

The sorption of pollutants onto biochar has been considered to be dependent on the pH of the aqueous solution. The oxygen-containing functional groups, which depend on pH, are related to this. Because of this, the surface charge and ionization of the biochar are pH-dependent, which differentiates their ability to remove pollutants by adsorption (Zhang, 2013a, b). When the pH of the aqueous solution rises, the functional groups deprotonate. As a result, biochar's ability to bind to cationic metals is increased. However, as the pH falls, protons and metal ions in the aqueous solution experience greater electrostatic repulsion forces. As a result, competition amongst cations for the biochar's adsorption sites may develop (Lu, 2012), decreasing the material's ability to adsorb metal ions.

In their study using biochar produced from hardwood and maize straw to adsorb metals such as copper, zinc, and lead, (Dong ,2011) found that the metallic cations' capacity for adsorption enhanced while pH rose from 2.0 to 5.0. As the hydroxide complex formation occurred at pH values higher than 5.0, the adsorption capacity decreased. (Tong, 2011) and (Lu, 2012) reported similar findings. However, (Zhang, 2013a, b) suggested that lowering the pH of the solution enhances the ability of anions, such as Cr (VI) metal ions, to adsorb. This results from electrostatic interactions between the positive charge of the biochar functional group and the negative charge of the chromate ion at low pH. Increasing the pH, on the other hand, was observed to cause a reduction in the Cr adsorption on the biochar surface by removing Cr (VI). This was explained by the OH species' fight with Cr (VI) species for the active/charged locations on the surface of the biochar. As (Shang, 2017) reported, the pH thus controlled the elimination of Cr (VI).

3.2 The Quantity of Biochar

The quantity of biochar has an impact on the adsorption capacity as well. The removal of potentially harmful elements (Cd, Cu, Pb, and Zn) from industrial effluent using biochar made from hardwood and corn straw was examined by (Che, 2011a, b). When the biochar content rose from 0.5 to 5 g/L, they noticed an improvement in the hazardous metals' ability to be adsorbed. It was explained by an increase in surface area and active sites caused by applying more biochar. The outcomes of (Lalhruaitluanga, 2010), (Tsai and Chen 2013), and more recently (Lu, 2017) are all in agreement with the results of this study. Sun (2013a, b) reported that increasing the amount of biochar (made from swine dung) in the solution from 1 to 8 g/L improved the availability of active sites for methylene blue adsorption (Wang, 2018) reported comparable outcomes when they increased the amount of biochar used for the adsorption of organic contaminants. The adsorption of organic contaminants and potentially hazardous substances benefits from a high biochar content. Finding the ideal dose would therefore be helpful because it is essential to reducing the cost of producing biochar in light of its industrial use.

4. The treatment for Removing Typical Pollutants

Biochar has been thoroughly investigated for water/wastewater treatment due to its ability to adsorb contaminants in the liquid phase (Chen, 2011a, b). It is mostly employed for the adsorption of potentially harmful metals (46%) and organic contaminants (39%), according to (Chen, 2011a, b). It can also be used to adsorb nitrogen and phosphorus (13%). Due to its substantial specific surface area, porous structure, and surface functional groups, the remaining 2% is for the adsorption of additional contaminants.

4.1 Isotherm for Adsorption

It's getting a global issue to release organic and inorganic pollutants in artificial backwaters. To exclude these dangerous pollutants from waterless results, scientists used biochar. The operation of biochar for the adsorption of pollutants in water is outlined in Table 2. Adsorption isotherms at constant ambient temperature must thus be used to quantify and ameliorate the commerce between the adsorption capacity of the biochar and the adsorbates (Fan, 2017; Goh, 2008; Koodyska, 2012). To characterize the equilibrium of organic and inorganic pollutant adsorption to biochar, colorful empirical equilibrium models similar to Temkin equations, Langmuir- Freundlich, Freundlich, and Langmuir were used. These models take into account only one subcaste of adsorbate adsorption on the homogenous face of the adsorbent during the list (Aydn and Aksoy 2009). (Chen 2011a, b) examined the Langmuir- Freundlich model for Cu^2 and Zn^2 adsorption at colorful attention. When compared to the Freundlich model (R2 were 0.86-0.94), the Langmuir model fit the experimental data better (R2>0.998). At the time of the list affinity, this model takes into consideration one single point of the adsorbate binding with one patch of adsorbate in a homogenous face. According to Freundlich isotherm, the model assumed one patch with multiple types of spots during the affinity of the adsorbate on the adsorbent. Another study (Zhang 2013a, b) investigated the adsorption of Pb^2 and Cr^3 using wastewater sludge biochar. This biochar showed that the adsorption of Pb^2 fitted the Langmuir model, whereas the adsorption of Cr^3 fitted the Freundlich model. This result indicates that Freundlich isotherm has multiple spots, as well as it, isn't confined to one point like Langmuir for the adsorption of adulterants.

4.2 Adsorption kinetics

The chemical and physical characteristics of biochar can have a significant impact on its adsorption behaviour towards organic and inorganic contaminants. These features influence the kinetics of adsorption as well as the mechanisms involving chemical binding and mass transfer (Boutsika, 2014; Inyang, 2012; Xu, 2013). (Reddy and Lee 2013) reported that the intra-particle diffusion model is essential to knowing the adsorbent surface area, diffusion mechanisms, and chemical reaction involved in the adsorption process in order to apply biochar on a large scale for the removal of organic and inorganic pollutants from wastewater. As a result of a rate-limiting step involving chemical sorption, the majority of kinetic parameters examined for pollutant removal-mediated biochar fit a pseudo-second-order kinetic model (Mohan,2011).(Lu, 2012) employed biochar generated from sewage sludge to adsorb Pb^{2+} from water with a pH ranging from 2 to 5. They demonstrated that the kinetics, because of the chemisorption of Pb^{2+} on the biochar, the pseudo-second-order model fit. (Liu and Zhang 2009) investigated the adsorption mechanism of Pb^{2+} on biochar made from pinewood and rice husk biomass. Because chemical adsorption was deemed the rate-limiting step, their mechanism demonstrated that their kinetics fit the pseudo-second-order model (Jia, 2013). Similarly, oxytetracycline and methylene blue sorption on biochar formed from palm bark, maize straw, and eucalyptus biomass was observed to deviate from the pseudo-second-order kinetic model (Sun, 2013a, b).

Table. 2: lists the different kinds of biochars' capabilities for adsorbing inorganic pollutants from wastewater from industries.

Different types of biochar	Temperature(°C)	pH	Inorganic Pollutants	Conc.(mg/l))	Adsorption Capacity(mg/g)	References
Corn straw	22	5	Hg^{2+}	140	5.03	Wang, (2018)
Banana peels	25	5	Cu^{2+}	60-80	38.2	Ahmad and Gao (2018)
Pinewood char	25	5	Pb^{2+}	2-1036	4.13	Mohan, (2011)
Cow manure biochar	20	5	Zn^{2+}	0.06-0.2	58.11	Kolodynska, (2012)
Orange peel biochar	25	_	PO_4^{3-}	0-12	0.007	Chen, (2011)
Rice husk	24	5	Cu^{2+}	1-20	3.49	Pellera, (2012)

4.3 Toxic heavy metals

Heavy metals are the most major industrial contaminants, and even relatively modest concentrations of metals like Cd, Cu, Zn, and Pb in wastewater can have a big impact on the environment. Before heavy metals enter the environment, their concentration can be decreased by adsorbing them on substances like biochar before releasing the treated water. On the basis of many interaction processes, including physical adsorption, precipitation, ion exchange, and electrostatic attraction, biochar has a high capacity to adsorb inorganic contaminants, such as heavy metals. Figure 2 describes the processes that lead to the adsorption of heavy metals and their interaction, and Table. 2 lists the different types of biochar's capabilities for adsorbing heavy metals.

(Dong, 2011) examined the processes through which Cr (VI) interacts with sugar beet charcoal to create Cr (III). They showed how the negative charge of Cr (VI) species is electrostatically attracted to the positive charges of biochar. Additionally, they showed that the biochar's hydrogen ions play a role in the conversion of Cr (VI) to Cr (III). In an aqueous solution, the functional groups of the biochar interact with the reduced Cr (III) to produce a complex of Cr (III). Similar results were reported by (Lu, 2012) who studied the removal of Pb^{2+} from wastewater using biochar made from sewage sludge. They showed that the functional groups of the biochar

are essential for building a complex with Pb. In order to adsorb Hg (II) using biochar derived from soybean stalk and Cd (II) using biochar made from maize straw, (Kong, 2011) and (Sun, 2014) demonstrated similar mechanisms.

4.4 Organic pollutant treatment

Organic contaminants such as phenols, antibiotics, and herbicides can be strongly adsorbed onto charcoal (Chen, 2011a, b). Similar organic contaminants and pollutants are always found in animal effluent; as a result, biochar has become a major emphasis in agricultural resources and the environment. Table. 3 Summarises the adsorption abilities among different biochars for organic pollutants in industrial wastewater and Fig. 3 shows the numerous mechanisms involved.

Table. 3: Adsorption abilities among different biochars for organic pollutants in industrial wastewater.

Different types of biochar	Temperature(°C)	pH	Organic Pollutants	Conc.(mg/l))	Adsorption Capacity(mg/g)	References
Peanut straw char	25	5-9	Methyl violet	40-816	104.61	Xu ,(2011)
Rice straw-derived char	30	5	Malachite green	25-300	128.14	Han, (2015)
Rice husk biochar	40	_	Phenol	100-15,000	409.8	Liu, (2011)
P(acrylamide)-wood biochar	25	_	Phenol	5-50	23.14	Karakoyun, (2011)
Sugarcane bagasse biochar	25	7	Malachite green	3000	_	Vyavahare, (2018)
Kenaf fiber char	30	8.5	Methylene blue	50-200	18.18	Xu, (2011)

After pyrolyzing at 350 °C, (Liu and Zhang 2009) created biochar from several raw materials (cole, peanut, and rapeseed straw). Their biochar had a methyl violet adsorption capacity of between 123.5 and 195.4 mg/g. At room temperature, rapeseed straw exhibited the highest levels of adsorption. Zeta potential and FTIR analyses confirmed that methyl violet and charcoal were electrostatically attracted to one another. The outcomes showed that the hydrophilic and COO sites were where the majority of the methyl violet was adsorbed. (Mohan, 2014) used biochar made from anaerobic digestion waste, palm bark, and tree to achieve methyl blue removal efficiencies of 99.5, 99.3, and 86.1%, respectively. The organic components were pyrolyzed for 30 min. at 400 °C under the following conditions: pH 7, 40 °C, and 4 mg/L of the dye. The treatment of methyl violet was shown to be significantly impacted by the pyrolysis temperature.

The maximum adsorption capacities of the biochar produced by (Mohn, 2014) from peanut shells and wheat straw were 58.82 mg/g and 20.61 mg/g, respectively. At 400 and 600 °C, these organic compounds undergo pyrolysis, respectively. The maximal adsorption capabilities for two herbicides, simazine, and atrazine, were determined to be 1066 and 1158 mg/g, respectively, for biochar made from mixed wood wastes that were pyrolyzed at 450 °C for 1 hour (Qiu, 2009). The authors asserted that acidic conditions led to maximum adsorption performances.

4.5 Treatment of Phosphorus and nitrogen pollution

In addition to the organic and heavy metal contaminants mentioned above, biochar has been studied to extract nitrogen and phosphorus from industrial effluent in order to lessen the impact of eutrophication on the ecosystem. The digestate produced as a result of this procedure can be utilized to produce high-quality fertilizer (Zhang, 2013a, b; Hale, 2012). Using cow dung biochar to remove PO_4-P and NH_4-N from wastewater.

(Wang, 2014) reported a large adsorption capacity. They also discovered that the charcoal feedstock influenced the adsorption capacity for nitrogen and phosphorus. As a result, biochar has a high ability to remove PO_4-P and NH_4-N, allowing nutrients to be discharged to boost soil fertility, which adds to increased crop output.

5. A biochar-supported catalyst is utilized in wastewater treatment.

In order to benefit from the exceptional qualities of catalytic nanoparticles, such as their high electrical conductivity, chemical stability, the presence of easily-tunable functional groups, and distinctive surface properties, biochar can be used as a support for the particles (Cuong, 2019; Liu, 2015; Xia and Larock, 2010). (Kim and Kan 2016) looked at how TiO_2 photocatalysts assisted by biochar may break down sulfamethoxazole in wastewater. Results showed that when compared to commercial nanoparticles, charcoal coated with TiO_2 has a higher sulfamethoxazole adsorption efficiency. This was explained by the fact that the biochar's electron conductivity prevented electron/hole pairs from recombining during photocatalysis. Additionally, this improves the charge balance of the biochar's surface (functional groups) to better absorb different pollutants from the wastewater. As a result, researchers created a variety of biochar-supported photocatalysts, including TiO_2 hybrids with Miscanthus straw pellets and softwood pellets, TiO_2-corn cob, TiO_2-waste plum, and TiO_2-wheat husks, TiO_2-chitosan, TiO_2-reed straw, TiO_2-bamboo, graphitic carbon nitride/ $FeVO_4$-pine needles, graphitic carbon nitride-chestnut, ZrO_2-wheat husks, BiOX-biochar, and TiO_2-wood charcoal. These combinations and others showed that the biochar-supported photocatalytic nanoparticles were highly effective at degrading various pollutants when exposed to visible light. Such hybrid materials have been described as having both high chemical stability and high recollection ability (Colmenares, 2016; Kalaivani and Suja 2016; Khataee, 2017a, 2017b; Kim and Kan 2016; Kumar, 2017; Li, 2016; Lisowski, 2017; Liu, 2017; Luo, 2015).

5.1 Organic pollutants from wastewater can be eliminated using biochar-supported catalysts.

There are several uses for materials that have photocatalytic activity aided by biochar. One of the most promising applications for photocatalytic material supported by biochar is the elimination of organic pollutants from wastewater. The large surface area and highly reactive oxidative radicals that promote adsorption during photodegradation may be the reason for this. As shown in Table.4, there are several kinds of biochar-supported photocatalysts, and during the past ten years, numerous studies for the removal of organic pollutants have been carried out. The results showed that the degradation of sulfamethoxazole, phenol, and methylene blue was highly effective. When compared to nanoparticles alone, its adsorption capability is 400 ppm, 50 ppm, and 10 ppm. They also indicated that TiO_2 backed by biochar can function as electrodes and as a water splitter during the synthesis of hydrogen. (J. Matos, 2016) published a comparison of the Au-TiO_2 supported by biochar's efficacy in degrading organic contaminants. It showed that the Au-TiO_2 composite supported by biochar has a greater effectiveness for the breakdown of organic contaminants than the nanoparticles alone.

The biochar can be treated with nanoparticles.:

- improve the nanoparticles' physicochemical characteristics,
- increase their active sites,
- electrons are shuttled through a graphene-like skeleton,
- act as electron reservoir which conducts away the electron from the e^-/h^+,
- When compared to bare catalytic nanoparticles, carbon or other non-metal doping (impurities or dangling bonds) reduces the bandgap energy and improves charge separation.

As a result, it performs well at degrading and absorbing organic contaminants in aqueous solutions. The use of various biomass and nanoparticles, heating/operating conditions, the ratio of biomass to nanoparticles, and the use of other waste materials like manure and sewage sludge composite with nanoparticles are some aspects that need to be further investigated in the future for the development of highly efficient biochar supported photocatalysts. These improvements may enhance the efficiency of photocatalysts supported by biochar in their ability to degrade and remove resistant/emerging organic contaminants from aqueous solutions.

Table. 4: Application of different photocatalysts supported by biochar.

Various biochar-supported photocatalysts	Pollutants	Conc (mg/l)	References
Corn cob-TiO_2	Sulfamethoxazole	160-10	Zhang, (2017)
Pinewood- TiO_2	Bisphenol	50-20	Luo, (2015)
Sludge/Wheat husks-TiO_2	Reactive Blue 69	1-20	Khataee, (2017a)
Bamboo-TiO_2	Methylene blue	200-30	Wu, (2015)

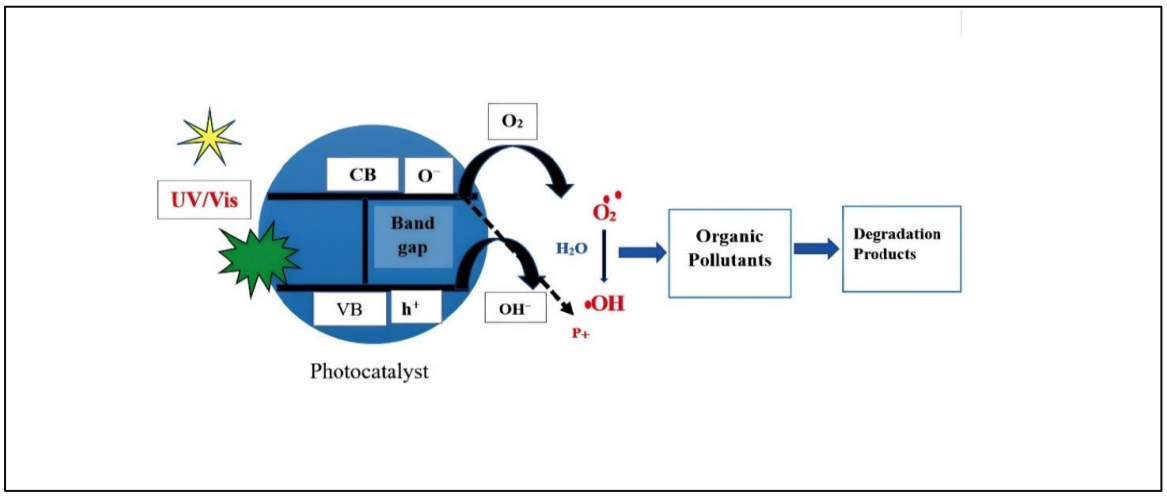


Fig .4: Fundamentals of reactive oxygen species photo-degradation of organic pollutants.

6. Analyses of Economic And Environmental Benefits

According to the studies, biochar has great application potential in the elimination of industrial pollutants. However, prior to large-scale application, some parameters, such as the type of biochar, local availability of the source material, pyrolysis temperature, availability of industrial-scale reactors, regeneration method, and life span, should be optimized to improve the process's economic viability.

(Dai, 2019) showed that biochars generated using slow and fast pyrolysis conditions have costs of 18.30 and 8.14 US$/ton, respectively, giving maximum benefit to users and long-term manufacturing for the industry. (Dai, 2019) showed that biochars produced by slow and fast pyrolysis conditions have costs of 18.30 and 8.14 US$/ton, respectively, giving maximum benefit to users and long-term manufacturing for the industry.

In addition, according to a 2013 survey performed by the International Biochar Initiative (IBI), the average price of biochar globally ranges from 80.00 US$/ton to 13,480.00 US$/ton at sellers' companies. However, a recent survey from 23 biochar companies in the USA found that the average cost per tonne was 2512 US dollars. According to recent research by (Dai, 2019), the International Biochar Initiative and the European Biochar Certificate are now developing a standards chart for the development of biochar.
The application of biochar to remove organic or inorganic impurities and other environmental activities, on the other hand, is dependent on the type of biochar utilised. Mainly it is based on the pyrolysis of biomass, biochar has been proved to produce biogas, sequester carbon in soil, and absorb CO_2 from the atmosphere. Biochar must be able to stay in the soil for an extended period of time in order to achieve carbon sequestration. This stability is mostly due to the biochar's mineralization over many years. The relationship between the preparation process/conditions, the feedstock, the microstructure, and the lifetime of biochar must be observed. Many techniques, such as infrared spectroscopy, biomarkers, nuclear magnetic resonance, and others, can be used to evaluate biochar mineralization over time (Weldon, 2019;Medyska-Juraszek, 2020). The ecotoxicological hazards that may come from the mineralization of the biochar itself must be ignored, though. Deep research must be done on this particular issue.

III. FUTURE DISCUSSION

It has been shown that biochar is a promising substance for the upkeep and restoration of agricultural soil fertility. Studies on the role of biochar in the removal of contaminants from wastewater, the impact of various feedstock sources on the quality of the biochar, and the physicochemical parameters affecting the efficiency of the removal of the contaminants are all still in the early stages.
As a result, the following research fields ought to be taken into account soon:
Creating the model for an altered biochar adsorption mechanism. According to the application, it is essential to adjust the porosity and surface functionality. To achieve this, techniques like amination, sulfonation, surface oxidation, and pore structure modification can offer novel perspectives on the production of particular biochar materials.

1. Applying modified methods to increase adsorption efficiency. Many trials should be conducted to investigate different modifiers or activators that affect the efficacy of biochars in removing organic and inorganic contaminants.
2. Today, the economic visibility of biochar and its regeneration, as well as conventional operating procedures for removing harmful pollutants from industrial effluent, is required. More research is needed before biochar's pre-treatment for hazardous chemical elimination and subsequent biological treatment may be used on a broad scale.
3. When compared to nonactivated biochar, activated biochar had a higher adsorption capacity to remove contaminants. However, the methods of absorption require further exploration.
4. In general, only a few studies have been completed in these areas, so more research is needed on themes such as the link between raw materials, processing parameters, and biochar regeneration to prevent environmental hazards, as seen in **Fig. 5.**

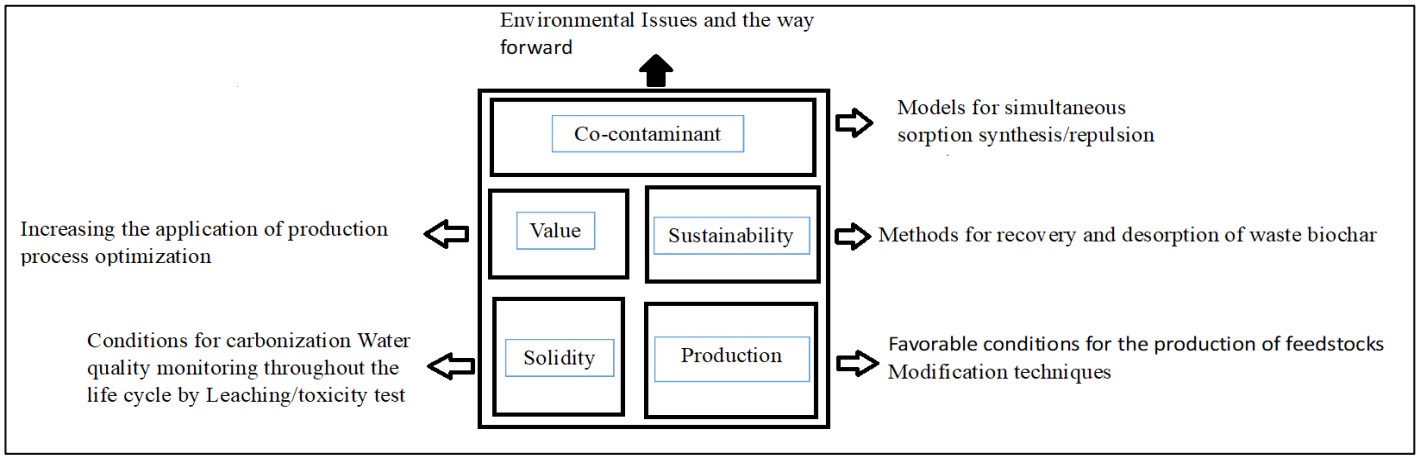


Fig. 5: illustrates a future study plan for using biochar.

IV. CONCLUSION

According to the review, biochar has a wide range of applications for the removal of common organic and inorganic contaminants found in industrial wastewater. It's a fascinating adsorbent with high efficiency. Because of its wide surface area, charged surface, and functional groups, it is an eco-friendly sorbing material. Biochar showed a high potential for adsorption of inorganic and organic pollutants through a variety of mechanisms including pore blocking, interactions of electrostatic charges, ion exchange, precipitation, and surface sorption, all of which are affected by physiochemical properties of biochar such as biochar dosage, pyrolysis temperature, and the pH of the treated matrix. The study discovered that the physical and surface characteristics of biochar, such as its appropriateness for a specific application, heavily depend on surface functional groups, pore volume, area, etc. As well as the study also demonstrated that the biochar adsorption technique removes pollutants from aqueous solutions more effectively and economically than several traditional methods. Consequently, biochar wastewater treatment is scalable. The cosmetic business is increasingly using activated biochar as a unique material. Charcoal is a common tooth cleaner in many countries.

Additional research is still required to: (1) create a new low-cost, high-efficiency biochar modification technology; (2) expand the use of biochar in wastewater treatment, particularly in industrial and municipal wastewater treatment; and (3) further enhance the biochar's capacity to bind heavy metals, organic pollutants, nitrogen, and phosphorus.

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