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Review Article

Biochar, an Eco-friendly Approach for the Treatment of Wastewater

Aparna Gunjal*, Srushti Rathod, Prajakta Ukirde

Department of Microbiology, Dr. D. Y. Patil, Arts, Commerce and Science College, Pimpri, Pune, Maharashtra, India

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Abstract

The agroindustry by-products viz., peanut shell, bagasse, corn cob, sawdust, rice and wheat straw, pressmud, etc. are produced in immense quantity which are directly burnt or disposed to the landfills. These agroindustry by-products can be used to make various value-added products. The agroindustry by-product can be used to prepare biochar, and such agroindustry by-product-based biochar can be used for the treatment of wastewater. As wastewater contains pathogens, total dissolved and volatile solids, the treatment of wastewater is very essential, and biochar can be the solution to it. The biochar can be prepared by pyrolysis at a high temperature (700 ^{o}C) in a limited supply of oxygen. This use of biochar for the treatment of wastewater is eco-friendly and economical and can be used for various purposes.

***Keywords*:** Agroindustry by-product, economical, eco-friendly, pathogens, pyrolysis, solids

Introduction

The wastewater is released from various industries such as sugar industries, electroplating, paint, etc. This wastewater contains various heavy metals, toxic dyes, phenolic compounds, solids such as total solids (TS), total suspended solids (TSS), total dissolved solids (TDS), total volatile solids (TVS), various pathogens, etc. (Ahmed et al., 2021). The pathogens such as *Escherichia coli* (*E. coli*), *Salmonella* sp., coliforms, etc. are present in the wastewater which causes diseases to the human, and this is a serious problem (Periasamy & Sundaram, 2013). This wastewater if enters soil or other water bodies will cause soil and water pollution. In the soil, beneficial bacteria are present which will get harmed. If wastewater enters water bodies, the solids, biological oxygen demand (BOD) and chemical oxygen demand (COD) will increase or decrease. The BOD and COD must be within the limits as per the guidelines of Maharashtra Pollution Control Board (MPCB) or Central Pollution Control Board (CPCB). The wastewater therefore needs to be treated. The use of chemicals to treat the wastewater is costly, causes pollution, and time consuming. Therefore, the solution of biochar to treat the wastewater is the best approach and novel.

Problems due to pathogens such as *E. coli* and coliforms in wastewater

E. coli

The human intestine contains several bacterial species, many of which are excreted as faeces (Numberger et al., 2019). Despite the fact that most of these bacteria are commensal and helpful to their hosts, some of them are pathogenic, and these enteric bacterial pathogens are the major pathogens present in wastewater Water contains pathogens *E. coli* which cause major serious effects on the human body. *E. coli* is present in concentrations of 10^5-10^{10} colony forming units (cfu) / lit of the sewage and are faecal contamination (Osuolale & Okoh, 2017). *E. coli* present in wastewater can cause serious effects of the human health such as diarrhoea, etc. Some strains of *E. coli* are known to produce toxins which can cause intestinal problems. In some cases, it can cause serious issues such as meningitis, haemolytic uremic syndrome, urinary tract infections, gastroenteritis, etc. (Anastasi et al., 2010).

Coliforms

Water quality is determined using indicator microorganisms present in wastewater. These are known as total faecal coliforms and are grouped in the family faeces. These coliforms are known to cause serious infections such as gastroenteritis and diarrhoea in the humans. The term "total coliforms" refers to all coliform bacteria and includes microorganisms from various sources. Due to their harmful effects on the human health, therefore it is very essential to reduce the no. of coliforms present in wastewater. And this treatment of wastewater can be the best possible using biochar.

Agroindustry by-products

There are various agroindustry by-products viz., peanut shell, corn cob, sawdust, paddy husk, pressmud, wheat straw, coconut husk, etc. These agroindustry by-products are produced in huge amount which are just disposed or burnt to the landfills. This causes environmental pollution which is harmful to the humans. Instead, they can be used to convert into value-added products viz., animal feed, biochar, compost, enzymes, fertilizer, enzymes, etc. These agroindustry by-products are very eco-friendly and economical. The agroindustry by-products can be used to make biochar also. This will also help in the management of agroindustry by-products which will avoid environmental pollution.

Corresponding author: aparnadyp@gmail.com

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Biochar and their advantages in wastewater treatment

Biochar can be prepared by heating at a very high temperature (> 700 ^{0}C) in the absence of oxygen or very limited amount of oxygen. This is also called as pyrolysis. The agroindustry by-products can be used which can be heated at a high temperature for the preparation of biochar (Fig. 1). The biochar has excellent property of adsorption and therefore is excellent in bioadsorption which makes it useful for the treatment of wastewater. The use of biochar as tertiary treatment is shown in Fig. 2. The research in the area on use of biochar for the treatment of wastewater is gaining immense interest. This is very simple, economical and eco-friendly approach for the treatment of wastewater. This is also a sustainable approach to avoid the environmental pollution and also prevent harmful effects on the humans or other living organisms. For the biochar different substrates can be used and can be pyrolyzed. The substrates can be bagasse, rice husk, wheat straw, sugar cane trash, coconut husk, etc.

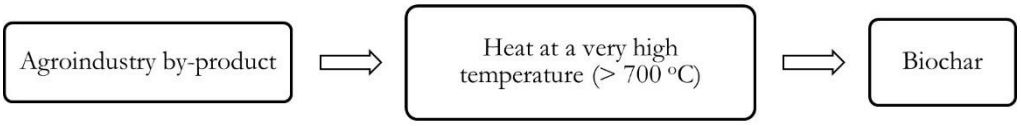

Figure 1. Preparation of biochar

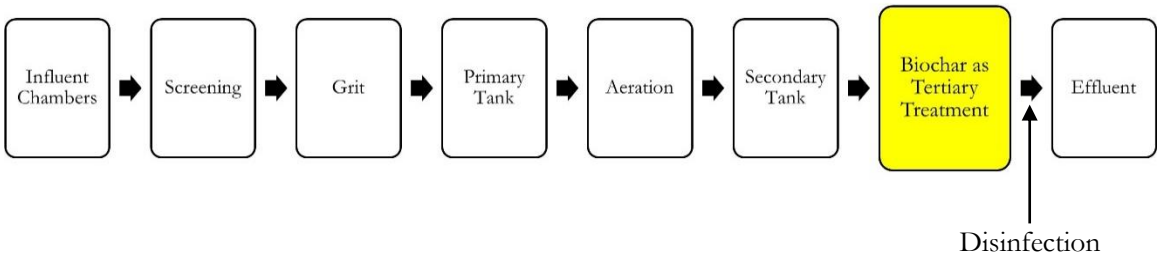

Figure 2. Biochar in treatment of wastewater

Bioadsorption property of biochar

The biochar has the excellent property of bioadsorption, which makes it very easy to remove the heavy metals, pathogens, various solids, etc. present in the wastewater. This will thus help in the clean-up of wastewater. The bioadsorption property can be due to various functional groups viz., -CH, -NH_2, -CH_2, -COOH, etc. present on the agroindustry by-products which is used to prepare biochar (Janu et al., 2021). It is reported that these functional groups can be responsible for the adsorption properties (Janu et al., 2021). The use of biochar for the treatment of wastewater is very easy to prepare, economical, fast and eco-friendly. The types of wastewater which can be treated by biochar are industrial, agricultural and domestic (Ahmed et al., 2021). Industrial wastewater can be released from various textile and petroleum refineries.

Biochar technology and its novelty

The biochar technology to treat various wastewaters is represented in Fig. 3. The novelty of biochar for the treatment of wastewater is it is extremely simple, fast, eco-friendly and economical.

Mechanisms for adsorption by biochar

In case of organic pollutants, adsorption can occur by electrostatic attraction, pore-filling, hydrogen bonding, complex adsorption and hydrophobic interactions (Ambaye et al., 2021). Soluble pollutants can attach to hydrophobic biochar in case they have hydrophobic functional groups. The surface of biochar has negative charge due to which interactions can occur with positively charged molecules. Adsorption can also occur due to hydrogen bonds which cause electrostatic repulsion between negative charged molecules and biochar. In case of removal of heavy metals by the biochar from wastewater, there are several mechanisms such as ion exchange, complexation, and electrostatic attraction between cations and anions. There are reports where biochar adsorption can occur due to a) electrostatic complexation due to metal exchange with cations, b) co-precipitation and complexation due to organic matter present in the biochar, c) complexation with functional groups and d) surface precipitation (Lu et al., 2012). The mechanisms by biochar for bioadsorption to remove inorganic and organic pollutants from wastewater are shown in Fig. 4 and 5, respectively.

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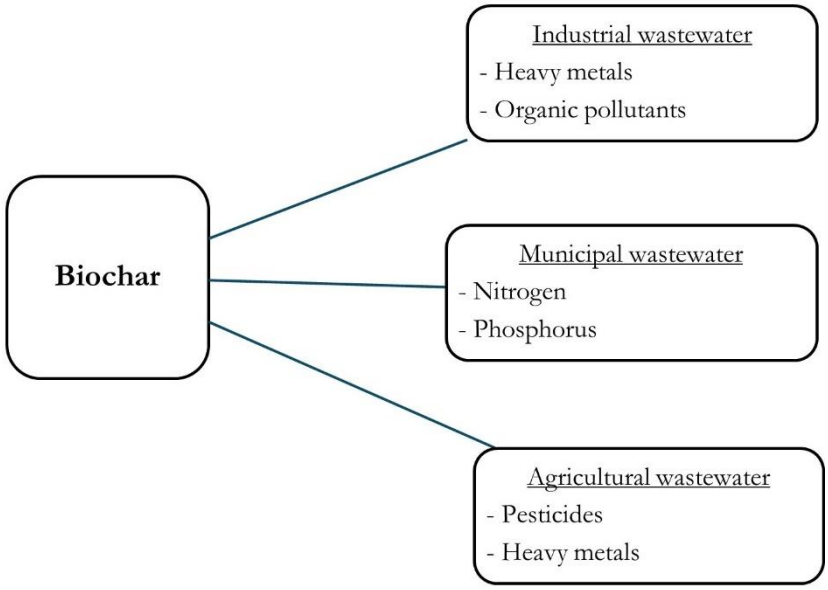

Figure 3. Biochar technology to treat wastewater

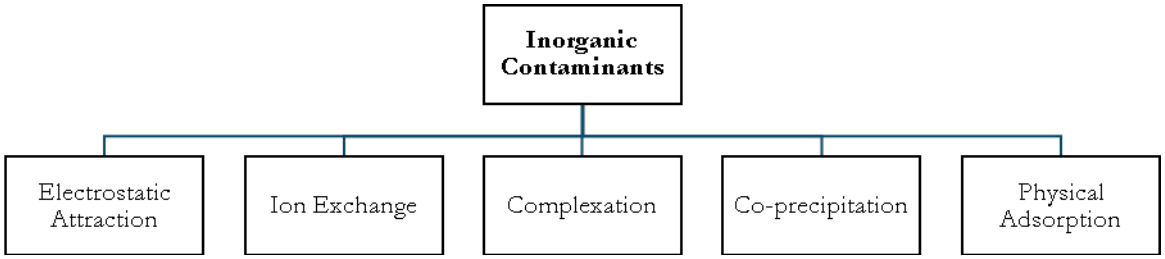

Figure 4. Mechanisms by biochar for bioadsorption to remove inorganic pollutants

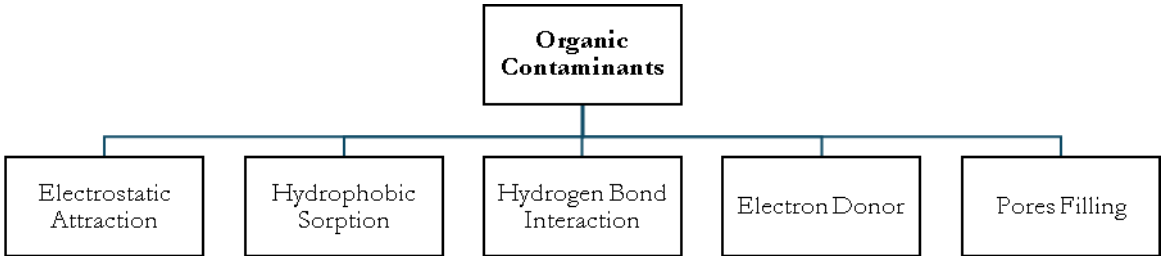

Figure 5. Mechanisms by biochar for bioadsorption to remove organic pollutants

Modification of biochar for adsorption

The biochar can be modified by use of acids such as hydrochloric (HCl), sulphuric (H_2SO_4), nitric (HNO_3), phosphoric (H_3PO_4), etc. (Li et al., 2017). This can increase the surface area and also make more adsorption sites available on the biochar for the adsorption to take place. The modification of biochar by acids can also result in change of the pore size (Zhou et al., 2017). The alkali such as potassium hydroxide (KOH), sodium hydroxide (NaOH) can also be used for the modification of biochar to enhance the adsorption capacity by biochar for the removal of pollutants from wastewater. The use of alkali for modification of biochar can increase functional groups and surface area of the biochar (Jing et al., 2014). This will also help in the removal of toxic dyes present in wastewater. The oxidizing agents can increase the functional groups present on the biochar (Tan et al., 2017).

Biofilm formation

Biochar has good surface area, porosity and inert properties. It can allow colonization and growth of biofilms. The microorganisms attach on the surface of biochar, and form biofilms with secretion of polymers as adhesive. This increases the viability of biochar owing to protection provided by biofilm (Hall-Stoodley et al., 2004). Biochar helps in adsorption due to the

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functional groups present, whereas microorganisms allow the degradation of complex compounds by their various metabolisms (Singh et al., 2006). This synergistic effect makes biotic biochar play important role in the treatment of wastewater. Biochar with biofilm assists in the degradation of organic pollutants (Sizmur et al., 2017). The biochar filter with biofilm for the removal of contaminants or pollutants removal from pharmaceutical wastewater has been reported (Dalameh et al., 2018).

Biochar in removal of heavy metals, toxic dyes and solids

There are different toxic heavy metals viz., zinc (Zn), cadmium (Cd), lead (Pb), nickel (Ni), chromium (Cr), etc. The biochar and their adsorption capacities are shown in Table 1. Different biochar can be used for the removal of these toxic heavy metals from wastewater (Inyang et al., 2016; Lopez et al., 2020). There is a report on application of biochar for the removal metals from aqueous solutions (Gholizadeh et al., 2021; Liu et al., 2022; Tan et al., 2015). Study is also done on removal of Cd form contaminated water by biochar with date seeds as raw material (Al-Tarawneh, 2022). Also, there is a report on spent coffee grounds-based biochar in removal of manganese (Mn), Pb and Cd (Chiwastowski et al., 2020). The heavy metal adsorbed by biochar is shown in Fig. 6.

Biochar for the removal of methyl violet from wastewater has been reported [30]. Biochar also acts as a filter and can remove various solids TS, TSS, TDS and TVS from the wastewater. This biochar filter can be thus useful in the clean-up of wastewater. There are studies done on biochar which can remove these solids from wastewater (Ambaye et al., 2021).

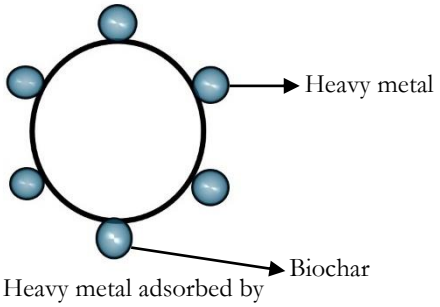

Figure 6. Heavy metal adsorbed by

Table 1. Biochar and their adsorption capacity

Biochar	Heavy metal removal	Adsorption (mg/g)	References
Peanut straw char	Cu	12.52	(Mubarak et al., 2013a; Mubarak et al., 2013b)
Dairy manure biochar	Cd	32.03	(Xu et al., 2013)
Oak wood char	Cr	3.03	(Mohan et al., 2014)
Banana peels	Cu	38.2	(Ahmad & Gao, 2018)
Corn straw	Hg	5.03	(Wang et al., 2018)
Banana peels	Pb	87.5	(Ahmed et al., 2018)

Biochar for the removal of pathogens

Biochar is a good medium so as to use in filtration systems to remove pathogens. This depends on adsorption ability of the filter material, the characteristics of the biofilm, and physical entrapment in the filter (Xu et al., 2011; Sasidharan et al., 2016). The straining mechanism helps to minimize the no. of pathogens which are large than the pores (Stevik et al., 2004). There are reports which show biochar can be used for the removal of pathogens from wastewater which is very essential.

Conclusions

The biochar technology is very effective for the treatment of wastewater. More research needs to be done on application of biochar for treatment of wastewater on a large-scale. Also, there is a need to find the exact mechanism behind the biochar filter to treat the wastewater. This is a very eco-friendly and economical way and there are no such technical barriers involved using this method to treat the wastewater.

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Data Availability Statement: The data of this study are available from the corresponding author, upon reasonable request.

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