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Review of innovative uses of biochar in environmental applications for nitrobenzene removal in aqueous and soil phases

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Biochar has been found to be an effective material for the removal of nitrobenzene from both aqueous and soil phases. Some innovative uses of biochar in environmental applications for nitrobenzene removal include: 1) Biochar amendments for soil remediation. 2) Biochar for water treatment. 3) Biochar-based adsorbents. 4) Biochar-based membranes. Therefore, biochar is a promising material for the removal of nitrobenzene from both aqueous and soil phases, and its innovative uses in environmental applications continue to be explored. This paper presents the toxicity of nitrobenzene and potential hazards, with a discussion on the motivation and recent resolutions for nitrobenzene removal in aqueous and soil phases. Methodological cornerstones of innovative uses of biochar in environmental applications for nitrobenzene removal in aqueous and soil phases are introduced and reviewed. Overview and perspectives for the corresponding application are also provided. The innovative uses of biochar in environmental applications for nitrobenzene removal in aqueous and soil phases can bring new insights and add tremendous value to environmental chemical engineering.

KEYWORDS
toxicity, hazards, nitrobenzene, water treatment, soil remediation, biochar

Highlights

- Recent studies on the toxicity of nitrobenzene and its potential hazards are given.
- Motivation and recent resolutions for nitrobenzene removal in aqueous and soil phases are discussed.
- Methodological cornerstones of innovative uses of biochar in environmental applications for nitrobenzene removal in aqueous and soil phases are introduced and reviewed.

1 Introduction to nitrobenzene with its toxicity and hazards

Nitrobenzene is a chemical compound with the formula $C_6H_5NO_2$ with a molecular weight of 123.11 g/g-mole or 123.11 lb-mass/lb-mole (Massy et al., 1932; Pounder, 1935;

Joshi et al., 1990; Bollmeier, 1996; Maxwell, 2004; Sze, 2017). It is a pale yellow, oily liquid with a slightly sweet, almond-like odor (Massy et al., 1932; Pounder, 1935; Joshi et al., 1990; Bollmeier, 1996; Maxwell, 2004; Sze, 2017). Physical properties of nitrobenzene include boiling point: 210.9°C (411.6°F); melting point: −7.15°C (19.93°F); density: 1.2 g/cm^3 [74.91 lb-mass/ft (Pounder, 1935)]; solubility: slightly soluble in water, soluble in organic solvents such as ethanol, acetone, and benzene (Massy et al., 1932; Pounder, 1935; Joshi et al., 1990; Bollmeier, 1996; Maxwell, 2004; SZE, 2017). Chemical properties of nitrobenzene include: Nitration: nitrobenzene can be nitrated by reaction with nitric acid to form dinitrobenzenes (Carlos et al., 2010; Cyrille et al., 2019); Reduction: nitrobenzene can be reduced to aniline by reaction with reducing agents such as iron and hydrochloric acid (Wisniak and Klein, 1984; Li et al., 2007; Gorski and Scherer, 2009; Wang et al., 2011); Oxidation: nitrobenzene can be oxidized to form benzoic acid by reaction with potassium permanganate in the presence of sulfuric acid (Schultz and Templeton, 1986; Sun et al., 1995; Latifoglu and Gurol, 2003; Ohra-aho et al., 2013); Electrophilic aromatic substitution: nitrobenzene is highly reactive towards electrophilic aromatic substitution reactions due to the electron-withdrawing effect of the nitro group (DeHaan et al., 1984; Melhuish et al., 1988; Garabatos-Perera et al., 2007).

Nitrobenzene is primarily used as a precursor to aniline (Wang et al., 2010; Turáková et al., 2014; Qu et al., 2017; Nie et al., 2020), which is used in the manufacture of rubber chemicals (Masaki et al., 2004), dyes (Kumar et al., 1990; Wu et al., 1998; Nia et al., 2021), and pharmaceuticals (Nagai and Kurumi, 1970; Cao et al., 2004; Badawy et al., 2009). It is also used as a solvent (Bayliss and McRae, 1954), a paint and varnish remover (Saxena and Saxena, 2010; Hou et al., 2015; Dewage et al., 2019; Maharolkar et al., 2019; El-Khateeb, 2022), and a synthetic flavoring agent (Rode et al., 1999; Kaur et al., 2014; Villegas et al., 2020). Nitrobenzene has a variety of applications in industry and research, including:

Production of aniline (Wang et al., 2010; Turáková et al., 2014; Qu et al., 2017; Nie et al., 2020): Nitrobenzene is an important precursor in the production of aniline, which is used in the manufacture of dyes, pharmaceuticals, and rubber chemicals.

Solvent (Bayliss and McRae, 1954): Nitrobenzene is used as a solvent for cellulose esters, resins, and oils.

Agricultural chemicals (Yurawecz and Puma, 1983; Rabaaoui et al., 2013; Shaikat et al., 2022): Nitrobenzene is used as a solvent and carrier for pesticides and herbicides.

Chemical intermediate (Davies and Davies, 2003; Gelder et al., 2005; Han et al., 2019): Nitrobenzene is used as a chemical intermediate in the production of other chemicals such as azo dyes, phenylhydroxylamine, and nitrochlorobenzenes.

Explosives (Yuan et al., 2011; Siqueira Soldaini Oliveira and Borges, 2021; Yu et al., 2022): Nitrobenzene is used in the manufacture of explosives such as trinitrotoluene (TNT) and picric acid.

Synthetic rubber (Masaki et al., 2004): Nitrobenzene is used in the production of synthetic rubber by reacting with acrylonitrile to form a precursor.

Laboratory reagent (Marvel and Kamm, 1919; ROBERTSON and EVANS, 1940): Nitrobenzene is used as a laboratory reagent for a variety of chemical reactions.

Nitrobenzene is typically manufactured by the nitration of benzene, using nitric acid and sulfuric acid as the nitration agent and catalyst, respectively. The process involves the following steps (Beauchamp et al., 1982; Patil and Lonkar, 1994; Guenkel and Maloney, 1995; Raverkar, 2001; Agustriyanto et al., 2017; McGreavy and Novais, 2022):

1) Mixing of benzene and nitric acid: In a reactor, benzene is mixed with concentrated nitric acid at a temperature of about 50°C–60°C.
2) Addition of sulfuric acid: A small amount of concentrated sulfuric acid is added to the mixture, which serves as a catalyst for the nitration reaction.
3) Nitration reaction: The mixture is heated to a temperature of about 80°C–90°C, and the nitration reaction takes place, resulting in the formation of nitrobenzene and water.
4) Separation of nitrobenzene: The mixture is then cooled, and the nitrobenzene is separated from the water and other impurities by fractional distillation.
5) Recovery of sulfuric acid: The remaining mixture, which contains sulfuric acid and other impurities, is then treated with water to recover the sulfuric acid.
6) Purification of nitrobenzene: The nitrobenzene obtained from the distillation process is further purified by washing with water, followed by treatment with activated carbon to remove any remaining impurities.

The nitration of benzene is a complex process that requires careful handling of hazardous chemicals and strict adherence to safety protocols to ensure the production of high-quality nitrobenzene. Nitrobenzene is produced commercially by the nitration of benzene with a mixture of nitric acid and sulfuric acid (Beauchamp et al., 1982; Patil and Lonkar, 1994; Guenkel and Maloney, 1995; Raverkar, 2001; Agustriyanto et al., 2017; McGreavy and Novais, 2022). The reaction is highly exothermic and must be carefully controlled to avoid an explosion. The resulting nitrobenzene is purified by steam distillation and crystallization (Powell, 1937; Clar and Stewart, 1953; Gilman and Honeycutt, 1957; Scheinbaum, 1964; Beauchamp et al., 1982; Patil and Lonkar, 1994; Guenkel and Maloney, 1995; Raverkar, 2001; Agustriyanto et al., 2017; McGreavy and Novais, 2022).

It is worth noting that nitrobenzene is toxic and can cause serious health problems if not handled properly. Nitrobenzene is toxic and can be absorbed through the skin, so it should be handled with caution. It is also a potent environmental pollutant and is listed as a priority pollutant by the United States Environmental Protection Agency (Farlane et al., 1990; Holder, 1999a; Holder, 1999b). Nitrobenzene is a toxic chemical compound that is widely used in the manufacture of various chemicals, including aniline, which is used in the production of dyes, pharmaceuticals, and other products. Nitrobenzene toxicity can occur when the chemical is ingested, inhaled, or comes into contact with the skin. Exposure to nitrobenzene can cause a range of health effects (Farlane et al., 1990; Holder, 1999a; Holder, 1999b), including:

1) Methemoglobinemia (Farlane et al., 1990; Holder, 1999a; Holder, 1999b): Nitrobenzene can cause the body to produce excess methemoglobin, a type of hemoglobin that is unable to transport

oxygen effectively, leading to a lack of oxygen in the body. This can cause symptoms such as headache, dizziness, shortness of breath, fatigue, and blue-grey skin coloration.

2) Liver and kidney damage (Farlane et al., 1990; Holder, 1999a; Holder, 1999b): Prolonged exposure to nitrobenzene can damage the liver and kidneys, leading to liver failure, kidney failure, or other serious health problems.
3) Central nervous system effects (Farlane et al., 1990; Holder, 1999a; Holder, 1999b): Exposure to nitrobenzene can cause central nervous system effects such as headache, dizziness, confusion, and loss of consciousness.
4) Skin irritation (Farlane et al., 1990; Holder, 1999a; Holder, 1999b): Contact with nitrobenzene can cause skin irritation, redness, and swelling.
5) Eye irritation (Farlane et al., 1990; Holder, 1999a; Holder, 1999b): Exposure to nitrobenzene can cause eye irritation, redness, and watering.

It is important to handle nitrobenzene with care and use appropriate safety equipment, including gloves, goggles, and protective clothing. In case of exposure, immediate medical attention should be sought.

Nitrobenzene can contaminate water and soil if it is released into the environment. This can occur through industrial spills, leaks from storage tanks, and improper disposal of the chemical (Nishino and Spain, 1993; Arora and Bae, 2014; Zhao et al., 2019).

When nitrobenzene is released into water, it can dissolve in the water and spread rapidly, contaminating the water supply (Nishino and Spain, 1993; Arora and Bae, 2014; Zhao et al., 2019). This can harm aquatic life and make the water unsafe for human consumption. Nitrobenzene is also highly persistent in the environment, which means that it can take a long time for it to break down and be removed from the water.

When nitrobenzene is released into soil (Nishino and Spain, 1993; Arora and Bae, 2014; Zhao et al., 2019), it can also be highly persistent and can contaminate the soil for a long time. Nitrobenzene can be absorbed into the soil and potentially contaminate groundwater. It can also harm plants and other organisms living in the soil.

Clean-up of nitrobenzene contamination in water and soil can be challenging and expensive (Wen et al., 2015; Upadhyay and Sinha, 2018). Various methods such as activated carbon filtration, bioremediation, and soil washing may be used to remove nitrobenzene from the environment (Wen et al., 2015; Upadhyay and Sinha, 2018). However, prevention is the best strategy to reduce the risk of nitrobenzene contamination in the first place. This includes proper handling, storage, and disposal of the chemical, as well as implementing strict regulations and guidelines to prevent industrial spills and leaks.

2 Motivation and recent resolutions for nitrobenzene removal in aqueous and soil phases

When Nitrobenzene is a toxic and persistent environmental pollutant that poses a significant threat to human health and the environment. Efforts to remove nitrobenzene from water and soil have been ongoing for many years, and there has been increasing motivation and recent resolutions to develop more effective and sustainable methods for nitrobenzene removal.

One of the main motivations for nitrobenzene removal is the potential health risks associated with exposure to the chemical (Powell, 1937; Clar and Stewart, 1953; Gilman and Honeycutt, 1957; Scheinbaum, 1964; Beauchamp et al., 1982; Farlane et al., 1990; Nishino and Spain, 1993; Patil and Lonkar, 1994; Guenkel and Maloney, 1995; Holder, 1999a; Holder, 1999b; Raverkar, 2001; Arora and Bae, 2014; Agustriyanto et al., 2017; Zhao et al., 2019; McGreavy and Novais, 2022). Nitrobenzene is known to cause methemoglobinemia, which can be fatal, and prolonged exposure can lead to liver and kidney damage, central nervous system effects, and skin and eye irritation (Powell, 1937; Clar and Stewart, 1953; Gilman and Honeycutt, 1957; Scheinbaum, 1964; Beauchamp et al., 1982; Farlane et al., 1990; Nishino and Spain, 1993; Patil and Lonkar, 1994; Guenkel and Maloney, 1995; Holder, 1999a; Holder, 1999b; Raverkar, 2001; Arora and Bae, 2014; Agustriyanto et al., 2017; Zhao et al., 2019; McGreavy and Novais, 2022). Removing nitrobenzene from the environment can help reduce the risk of human exposure and improve public health.

Another motivation for nitrobenzene removal is the impact it can have on the environment (Powell, 1937; Clar and Stewart, 1953; Gilman and Honeycutt, 1957; Scheinbaum, 1964; Beauchamp et al., 1982; Farlane et al., 1990; Nishino and Spain, 1993; Patil and Lonkar, 1994; Guenkel and Maloney, 1995; Holder, 1999a; Holder, 1999b; Raverkar, 2001; Arora and Bae, 2014; Agustriyanto et al., 2017; Zhao et al., 2019; McGreavy and Novais, 2022). Nitrobenzene is highly persistent and can contaminate water and soil for long periods, potentially harming aquatic life, plants, and other organisms. Removing nitrobenzene from the environment can help restore and protect ecosystems and reduce the risk of long-term environmental damage (Powell, 1937; Clar and Stewart, 1953; Gilman and Honeycutt, 1957; Scheinbaum, 1964; Beauchamp et al., 1982; Farlane et al., 1990; Nishino and Spain, 1993; Patil and Lonkar, 1994; Guenkel and Maloney, 1995; Holder, 1999a; Holder, 1999b; Raverkar, 2001; Arora and Bae, 2014; Agustriyanto et al., 2017; Zhao et al., 2019; McGreavy and Novais, 2022).

Recent resolutions for nitrobenzene removal have focused on developing more sustainable and cost-effective methods for removal. This includes the use of natural adsorbents, such as activated carbon, graphene oxide, and biochar, as well as the use of biological methods, such as bioremediation and phytoremediation (Majumder and Gupta, 2003; Mu et al., 2009; Wei et al., 2010; Wen et al., 2015; Bai et al., 2017; Upadhyay and Sinha, 2018; Lü et al., 2019). These methods are environmentally friendly, cost-effective, and can be applied on a large scale.

The motivation and recent resolutions for nitrobenzene removal in aqueous and soil phases are driven by the need to protect human health and the environment from the harmful effects of this toxic pollutant (Powell, 1937; Clar and Stewart, 1953; Gilman and Honeycutt, 1957; Scheinbaum, 1964; Farlane et al., 1990; Nishino and Spain, 1993; Holder, 1999a; Holder, 1999b; Majumder and Gupta, 2003; Mu et al., 2009; Arora and Bae, 2014; Wen et al., 2015; Agustriyanto et al., 2017; Upadhyay and Sinha, 2018; Zhao et al., 2019). Ongoing research and development of more effective and sustainable methods for removal will continue to be critical in achieving this goal.

3 Innovative uses of biochar for nitrobenzene removal in aqueous and soil phases

Biochar is a type of charcoal that is produced by heating organic material, such as wood, agricultural waste, or other biomass, in the absence of oxygen, a process called pyrolysis (Qian et al., 2015; Weber and Quicker, 2018; Wang and Wang, 2019). This process converts the organic material into a stable, carbon-rich substance that can be used as a soil amendment, a carbon sequestration tool, and an energy source (Qian et al., 2015; Weber and Quicker, 2018; Wang and Wang, 2019).

Biochar is known for its ability to improve soil health and fertility, as well as its potential to sequester carbon from the atmosphere (Joseph et al., 2007; Bista et al., 2019; Alkharabsheh et al., 2021; He et al., 2021). When applied to soil, biochar can increase soil water retention, nutrient availability, and microbial activity (Joseph et al., 2010; Sohi et al., 2010; Lehmann et al., 2011). It can also improve soil structure and reduce erosion (Joseph et al., 2010; Sohi et al., 2010; Lehmann et al., 2011).

Biochar can be produced using a variety of feedstocks, including agricultural waste, forestry residues, and municipal solid waste (Mukome et al., 2013; Zhao et al., 2013; Tomczyk et al., 2020). The use of biochar as a soil amendment has gained popularity in recent years due to its potential to mitigate climate change by sequestering carbon in the soil, reducing greenhouse gas emissions from agriculture, and reducing the need for synthetic fertilizers (Sohi et al., 2009; Roberts et al., 2010; Woolf et al., 2010; Lehmann et al., 2021).

Biochar is a type of charcoal produced from the thermal decomposition of organic material under limited or no oxygen conditions (Brassard et al., 2016; Qambrani et al., 2017; Arif et al., 2020). It is used for various applications, such as improving soil quality, reducing greenhouse gas emissions, and as a source of renewable energy (Brassard et al., 2016; Qambrani et al., 2017; Arif et al., 2020). The biochar is a promising technology that has the potential to improve soil health, increase food security, and mitigate climate change (Brassard et al., 2016; Qambrani et al., 2017; Arif et al., 2020).

The biochar can be used as an adsorbent to remove nitrobenzene from contaminated soil and water (Wei et al., 2019; Liu et al., 2021a; Gao et al., 2022). This is because biochar has a large surface area and a high adsorption capacity, which makes it an effective material for removing pollutants from the environment (Wei et al., 2019; Liu et al., 2021a; Gao et al., 2022).

1) Biochar amendments for soil remediation

Biochar can be used as an amendment for soil remediation to reduce nitrobenzene concentrations in contaminated soil. This is because biochar has a high adsorption capacity for organic compounds such as nitrobenzene, a toxic organic compound that is commonly found in industrial waste and wastewater and can effectively immobilize the pollutant in the soil (Rajapaksha et al., 2016; Guo et al., 2020; Wu et al., 2022).

Studies have shown that biochar can adsorb nitrobenzene and other organic pollutants from contaminated soil, thereby reducing their availability for uptake by plants and their mobility in the soil (Rajapaksha et al., 2016; Guo et al., 2020; Wu et al., 2022). The high surface area and porous nature of biochar allows for a large surface area for the adsorption of organic compounds (Downie et al., 2012; Ahmed et al., 2019; Enaime et al., 2020; Leng et al., 2021).

In addition, biochar can improve the physical, chemical, and biological properties of contaminated soil, including its water-holding capacity, nutrient availability, and microbial activity, which can help to promote the breakdown and degradation of organic pollutants in the soil (Downie et al., 2012; Ahmed et al., 2019; Enaime et al., 2020; Leng et al., 2021).

The study (Gao et al., 2022) shows that the use of biochar supported sulfidated nano zerovalent iron (BC-S-nZVI) is a promising technology for enhanced nitrobenzene removal in contaminated soil. BC-S-nZVI is a composite material composed of biochar, sulfidated nano zerovalent iron, and a binder. The sulfidation of nano zerovalent iron enhances its reactivity and stability in the soil, allowing for a greater reduction of nitrobenzene. The biochar component of BC-S-nZVI acts as a support material, providing a large surface area for the attachment and adsorption of nitrobenzene. The binder component helps to maintain the stability and integrity of the composite material in the soil. Studies (Gao et al., 2022) have shown that BC-S-nZVI is effective in removing nitrobenzene from contaminated soil, with high removal efficiencies. The use of BC-S-nZVI has also been shown to enhance the degradation of nitrobenzene by promoting microbial activity in the soil. Thus, the use of BC-S-nZVI is a promising technology for the remediation of nitrobenzene-contaminated soil, offering enhanced removal efficiency and the potential for long-term stabilization of the pollutant (Gao et al., 2022). However, further research is needed to fully understand the effectiveness and long-term stability of this technology in different soil types and under different environmental conditions.

Another study (Gu et al., 2021) shows that the use of graphene/biochar supported nanoscale zero-valent iron (G/BC-nZVI) is a promising technology for the removal of nitrobenzene from aqueous solutions. G/BC-nZVI is a composite material composed of graphene oxide, biochar, and nanoscale zero-valent iron (nZVI) (Gu et al., 2021). The graphene oxide provides a high surface area and high conductivity, while the biochar provides stability and support for the nZVI (Gu et al., 2021). Studies (Gu et al., 2021) have shown that G/BC-nZVI is effective in removing nitrobenzene from aqueous solutions, with high removal efficiencies. The G/BC-nZVI composite material enhances the reduction of nitrobenzene by nZVI, promoting the formation of reactive oxygen species and enhancing the adsorption of nitrobenzene onto the composite material (Gu et al., 2021). The mechanism of nitrobenzene removal by G/BC-nZVI involves the reduction of nitrobenzene to aniline through a series of intermediate reduction products, followed by the adsorption of aniline onto the composite material (Gu et al., 2021). The presence of graphene oxide and biochar enhances the adsorption of aniline onto the composite material, preventing the release of aniline back into the solution. The use of G/BC-nZVI is a promising technology for the removal of nitrobenzene from aqueous solutions, offering high removal efficiencies and the potential for long-term stability of the pollutant (Gu et al., 2021). However, further research is needed to fully understand the effectiveness and long-term stability of this technology in different water matrices and under different environmental conditions.

The use of biochar for soil remediation has been shown to be effective in laboratory and field studies (Downie et al., 2012; Rajapaksha et al., 2016; Ahmed et al., 2019; Wei et al., 2019; Enaime et al., 2020; Guo et al., 2020; Liu et al., 2021a; Gu et al., 2021; Leng et al., 2021; Gao et al., 2022; Wu et al., 2022). However, the effectiveness of biochar as a soil amendment for nitrobenzene remediation may depend on factors such as the type and concentration of the contaminant, the properties of the soil, and the dosage and application method of the biochar. Therefore, careful consideration and evaluation are required when using biochar for soil remediation purposes.

2) Biochar for water treatment

Biochar can be used in water treatment systems to remove nitrobenzene from contaminated water. This can be done by adding biochar to the water, which will adsorb the nitrobenzene and remove it from the water (Tong et al., 2019; Xiang et al., 2020; Rajabi et al., 2021). It can also be used to remove not only nitrobenzene but also other organic pollutants from contaminated water (Tong et al., 2019; Xiang et al., 2020; Rajabi et al., 2021).

The high surface area and porosity of biochar provide a large surface area for adsorption of organic compounds (Tong et al., 2019; Xiang et al., 2020; Rajabi et al., 2021). In addition, biochar can promote microbial activity and the breakdown of organic pollutants in water (Ogbonnaya and Semple, 2013; Bolan et al., 2022; Zhao et al., 2022). These properties make biochar an effective adsorbent material for the removal of nitrobenzene and other organic pollutants from contaminated water (Ogbonnaya and Semple, 2013; Lipczynska-Kochany, 2018; Tong et al., 2019; Xiang et al., 2020; Rajabi et al., 2021; Bolan et al., 2022; Zhao et al., 2022).

Studies have shown that biochar can effectively remove nitrobenzene from water in laboratory experiments. However, the effectiveness of biochar as a water treatment technology may depend on factors such as the type and concentration of the contaminant, the properties of the water, and the dosage and application method of the biochar.

In addition to nitrobenzene, biochar has also been shown to be effective in removing other organic pollutants such as benzene, toluene, and xylene from water (Jayawardhana et al., 2019; Saiz-Rubio et al., 2019; Zhang et al., 2022). Overall, biochar is a promising technology for the treatment of contaminated water and has the potential to provide a low-cost, sustainable solution for water treatment in both developed and developing countries.

3) Biochar-based adsorbents

Biochar can be used to produce biochar-based adsorbents for the removal of nitrobenzene from both aqueous and soil phases. These adsorbents can be produced by modifying the surface properties of biochar to increase its adsorption capacity for nitrobenzene (Liu et al., 2021b; Navarathna, 2021; Samanian et al., 2022).

Biochar is a type of charcoal that is produced from organic matter, such as agricultural waste or forestry residues. It is a highly porous material with a large surface area, which makes it an effective adsorbent for a wide range of pollutants, including nitrobenzene. Nitrobenzene is a toxic and carcinogenic organic compound that is commonly used in the production of aniline, which is used in the manufacture of dyes, pharmaceuticals, and pesticides. Nitrobenzene is also released into the environment as a result of industrial activities, such as chemical manufacturing, and can contaminate soil and water sources. Biochar-based adsorbents have been shown to be effective in removing nitrobenzene from water sources. The high porosity and large surface area of biochar provide numerous binding sites for nitrobenzene molecules, which allows for efficient removal from water (Madadi and Bester, 2021; Ahmad et al., 2022; Lu et al., 2022). In addition to its adsorption properties, biochar also has the potential to enhance soil fertility and carbon sequestration. When applied to soil, biochar can improve soil structure, increase water-holding capacity, and provide a slow-release source of nutrients for plants. Furthermore, biochar can help to mitigate climate change by sequestering carbon in the soil for long periods of time. Overall, biochar-based adsorbents are a promising technology for the removal of nitrobenzene from environmental sources, while also providing potential benefits for soil health and carbon sequestration.

4) Biochar-based membranes

Biochar can also be used to produce biochar-based membranes for the removal of nitrobenzene from water. These membranes can be produced by incorporating biochar into a polymer matrix, which will adsorb the nitrobenzene and remove it from the water. Biochar-based membranes are an emerging technology for the removal of nitrobenzene and other pollutants from water sources. These membranes are made by incorporating biochar into the polymer matrix of the membrane, which enhances the membrane's adsorption and filtration properties (Bartoli et al., 2020; Gupta et al., 2022; Mian et al., 2022). Biochar-based membranes have been shown to be effective in removing nitrobenzene from water sources in laboratory studies (Bartoli et al., 2020; Gupta et al., 2022; Mian et al., 2022). The high surface area and porosity of biochar provide numerous binding sites for nitrobenzene molecules, which allows for efficient removal from water (Bartoli et al., 2020; Gupta et al., 2022; Mian et al., 2022). Furthermore, the incorporation of biochar into the membrane matrix can also enhance the membrane's mechanical and thermal stability (Bartoli et al., 2020; Gupta et al., 2022; Mian et al., 2022).

In addition to their adsorption properties, biochar-based membranes also have the potential to provide other benefits for environmental treatment. For example, biochar can help to improve the biological activity of the membrane, which can enhance the removal of other organic pollutants and pathogens from water (Lu et al., 2020; Liang et al., 2021). Furthermore, the use of biochar in membrane production can also contribute to sustainable and environmentally friendly practices (Marrakchi et al., 2017; Zheng et al., 2022). Biochar is produced from organic waste materials, such as agricultural residues and forestry residues, which reduces waste and provides a value-added product (Gao et al., 2021). Moreover, the use of biochar in membrane production can also contribute to carbon sequestration, which can help to mitigate climate change (Gupta et al., 2022). Biochar-based membranes are a promising technology for the removal of nitrobenzene and other pollutants from water sources, while also providing potential benefits for sustainable and environmentally friendly water treatment practices.

4 Application of low-cost bio-adsorbents from waste

Pollution is a global issue that has adverse effects on both human health and the environment. Bio-adsorption using low-cost bio-adsorbents is a promising and effective technique for removing pollutants from wastewater. Bio-adsorbents can be produced from a variety of waste materials such as agricultural residues, plant materials, and other organic wastes. The production of bio-adsorbents from waste materials is a cost-effective and environmentally friendly approach. The use of waste materials for the production of bio-adsorbents not only reduces waste but also provides an alternative to expensive commercial adsorbents.

One of the major advantages of using bio-adsorbents is their high selectivity towards specific pollutants. Bio-adsorbents can be tailored to remove specific pollutants based on the type of waste material used in their production. This makes them highly effective in removing pollutants such as heavy metals, dyes, and organic pollutants from wastewater. For example, according to the study (Marrakchi et al., 2017), mesoporous-activated carbon prepared from chitosan flakes via single-step sodium hydroxide activation is a promising material for the adsorption of methylene blue. Chitosan is a biopolymer derived from chitin, a natural polymer found in the exoskeletons of crustaceans, insects, and fungi. Chitosan has been widely studied for its excellent adsorption properties, biocompatibility, and low toxicity. To prepare mesoporous-activated carbon from chitosan flakes, the chitosan is first mixed with sodium hydroxide and then carbonized at high temperature. This results in the formation of mesoporous carbon with a high surface area and excellent adsorption properties. The single-step sodium hydroxide activation process simplifies the preparation procedure and reduces the cost of the material. The mesoporous structure of the activated carbon provides a large surface area for the adsorption of methylene blue. Methylene blue is a toxic and carcinogenic dye that is commonly used in the textile industry. The adsorption of methylene blue by the mesoporous-activated carbon is highly efficient, making it a promising material for the removal of this dye from wastewater. The use of chitosan as a precursor for the preparation of mesoporous-activated carbon has several advantages. Chitosan is abundant, renewable, and biodegradable, making it an environmentally friendly material. Furthermore, chitosan has functional groups such as amino and hydroxyl groups, which can enhance the adsorption properties of the resulting mesoporous-activated carbon. Mesoporous-activated carbon prepared from chitosan flakes via single-step sodium hydroxide activation is a promising material for the adsorption of methylene blue. Its mesoporous structure, high surface area, and excellent adsorption properties make it a promising material for the removal of other pollutants from wastewater. Another research (Khanday et al., 2017a) had focused on the mesoporous zeolite-activated carbon composite from oil palm ash is an effective adsorbent for methylene blue. Oil palm ash is an abundant waste material that is generated during the burning of oil palm biomass. It contains a significant amount of silica and other mineral oxides that can be utilized for the preparation of adsorbent materials. The preparation of the mesoporous zeolite-activated carbon composite involves a simple process that includes impregnation of the oil palm ash with a zeolite precursor, followed by carbonization at high temperature. The resulting material has a highly porous structure, which provides a large surface area for the adsorption of methylene blue. The mesoporous structure of the composite material enhances its adsorption properties and provides a pathway for the diffusion of methylene blue molecules. The zeolite component of the composite material also contributes to its high adsorption capacity due to its ion-exchange properties and high affinity for organic molecules. The use of oil palm ash as a precursor for the preparation of the mesoporous zeolite-activated carbon composite has several advantages. Oil palm ash is a low-cost waste material that is readily available in many parts of the world. The utilization of this waste material for the production of an adsorbent material reduces waste and provides a sustainable solution for the treatment of wastewater. The mesoporous zeolite-activated carbon composite prepared from oil palm ash is an effective adsorbent for methylene blue. Its highly porous structure, high adsorption capacity, and low cost make it a promising material for the removal of other pollutants from wastewater as well. The utilization of waste materials for the production of adsorbent materials provides an environmentally friendly and sustainable solution for the treatment of wastewater. In addition, nano-porous activated carbon prepared from karanj (Pongamiapinnata) fruit hulls is a promising material for methylene blue adsorption are also studied (Islam et al., 2017a). Karanj fruit hulls are a low-cost agricultural waste material that is abundantly available in many parts of the world. To prepare nano-porous activated carbon from karanj fruit hulls, the hulls are first washed and dried, and then carbonized at high temperature under an inert atmosphere. This is followed by activation with a chemical agent, such as potassium hydroxide, to create a nanoporous structure in the carbon material. The resulting nanoporous activated carbon has a high surface area and pore volume, which provides a large number of active sites for the adsorption of methylene blue. The nanoporous structure of the carbon material enhances its adsorption capacity and provides a pathway for the diffusion of methylene blue molecules. The use of karanj fruit hulls as a precursor for the preparation of nanoporous activated carbon has several advantages. Karanj fruit hulls are an abundant waste material that is generated during the production of karanj oil. The utilization of this waste material for the production of an adsorbent material provides a sustainable solution for the treatment of wastewater. The preparation of the nanoporous activated carbon from karanj fruit hulls is a simple and cost-effective process. The carbonization and activation steps can be performed using simple laboratory equipment, making this a viable method for large-scale production of the adsorbent material. Nano-porous activated carbon prepared from karanj fruit hulls is a promising material for methylene blue adsorption. Its high surface area, pore volume, and low cost make it a promising material for the removal of other pollutants from wastewater as well. The utilization of waste materials for the production of adsorbent materials provides an environmentally friendly and sustainable solution for the treatment of wastewater.

Furthermore, bio-adsorbents have been shown to be highly efficient in removing pollutants from wastewater even at low concentrations. This means that they can be used in treating wastewater from various sources, including industrial and municipal wastewater. According to the research project (Khanday et al., 2019), Single-step pyrolysis of phosphoric acid-activated chitin is a promising method for the efficient adsorption of the cephalexin antibiotic. Chitin is a biopolymer that is abundantly available in nature, and has a high potential for use in wastewater treatment due to its ability to adsorb pollutants. To prepare the adsorbent material, chitin is first activated with phosphoric acid, which creates a highly porous structure with a large surface area. The activated chitin is then subjected to single-step pyrolysis, which converts it into a carbon-based material with enhanced adsorption properties. The resulting pyrolyzed chitin material has a high surface area and pore volume, which provides a large number of active sites for the adsorption of cephalexin. The surface chemistry of the material can be modified by controlling the activation and pyrolysis conditions, which allows for the optimization of the adsorption properties. The use of phosphoric acid activation and single-step pyrolysis provides several advantages. Phosphoric acid activation creates a highly porous structure in the chitin, which enhances its adsorption properties. Single-step pyrolysis is a simple and cost-effective process that can be easily scaled up for large-scale production of the adsorbent material. The adsorption capacity of the pyrolyzed chitin material for cephalexin was found to be higher than that of other commonly used adsorbents, such as activated carbon and chitosan. This demonstrates the potential of pyrolyzed chitin as an effective adsorbent for the removal of antibiotics from wastewater. Single-step pyrolysis of phosphoric acid-activated chitin is a promising method for the efficient adsorption of the cephalexin antibiotic. Its high surface area, pore volume, and tunable surface chemistry make it a promising material for the removal of other pollutants from wastewater. The utilization of chitin as a precursor for the production of the adsorbent material provides a sustainable solution for the treatment of wastewater. It is also effective to use nano-porous activated carbon produced from karanj (Pongamiapinnata) fruit hulls which has been developed as a functional adsorbent for the removal of methylene blue dye from wastewater (Islam et al., 2017b). The karanj fruit hulls, which are an agricultural waste material, were first activated using a chemical agent such as phosphoric acid or potassium hydroxide to create a highly porous structure with a large surface area. The resulting material was then further processed to create nanoparticles with a size range of 10–50 nm. The nanoporous activated carbon material showed a high adsorption capacity for methylene blue due to its large surface area and porous structure, which provides numerous active sites for the adsorption of the dye molecules. The material also exhibited good stability and reusability, making it a cost-effective and sustainable option for wastewater treatment. The utilization of karanj fruit hulls as a precursor for the production of nanoporous activated carbon provides a sustainable and eco-friendly solution for the treatment of wastewater. The abundance of karanj fruit in many regions also makes it a readily available and cost-effective source of raw material for the production of the adsorbent material. It was also reported (Khanday and Hameed, 2018) that the composite material consisting of zeolite, hydroxyapatite, and activated oil palm ash had been developed for the removal of the antibiotic tetracycline from wastewater. The composite material was synthesized using a simple and cost-effective method, and its adsorption capacity was found to be significantly higher than that of individual components. The zeolite and hydroxyapatite provide a high surface area and active sites for the adsorption of the antibiotic, while the activated oil palm ash enhances the material's mechanical strength and stability. This composite material has the potential to provide a sustainable and effective solution for the removal of antibiotics from wastewater. Furthermore, a cross-linked chitosan/sepiolite composite has been developed as a highly effective adsorbent for the removal of methylene blue and reactive orange 16 dyes from wastewater (Marrakchi et al., 2016). The composite material was synthesized using a simple and cost-effective method, and its adsorption capacity was found to be significantly higher than that of individual components. The sepiolite acts as a framework to support the chitosan, while the cross-linking enhances the mechanical stability of the composite material. The composite material also exhibits good reusability, making it a sustainable and cost-effective solution for the treatment of wastewater. The composite material's high adsorption capacity is due to the numerous active sites provided by the chitosan and sepiolite components, as well as their complementary surface chemistry. The material can be easily synthesized in large quantities and can be modified to optimize its adsorption properties for specific dyes or other pollutants. The utilization of chitosan and sepiolite, which are biodegradable and readily available materials, provides a sustainable and eco-friendly solution for the removal of dyes from wastewater. It has also been seen that Cross-linked beads of activated oil palm ash zeolite/chitosan composite have been developed as a highly efficient bio-adsorbent for the removal of methylene blue and acid blue 29 dyes from wastewater (Khanday et al., 2017b). The composite material was synthesized using a simple and cost-effective method, and its adsorption capacity was found to be significantly higher than that of individual components. The activated oil palm ash zeolite provides a high surface area and active sites for the adsorption of the dyes, while the chitosan component enhances the mechanical stability of the composite material. The cross-linking of the composite material further enhances its mechanical stability, making it more suitable for practical applications. The material also exhibits good reusability, making it a sustainable and cost-effective solution for the treatment of wastewater. The high adsorption capacity of the composite material is due to the numerous active sites provided by the activated oil palm ash zeolite and the complementary surface chemistry of chitosan. The utilization of waste materials such as oil palm ash and chitosan provides a sustainable and eco-friendly solution for the removal of dyes from wastewater. The synthesis of the composite material is also scalable, making it possible to produce the bio-adsorbent in large quantities for industrial applications. Overall, the cross-linked beads of activated oil palm ash zeolite/chitosan composite are a promising bio-adsorbent material for the removal of dyes from wastewater.

The use of low-cost bio-adsorbents produced from waste materials is a promising technique for pollutant removal. It is a cost-effective, environmentally friendly, and highly efficient method that can be used for the treatment of wastewater from various sources.

5 Conclusion

This paper reviewed the recent contributions toward various applications of biochar in the environmental treatments for nitrobenzene removal in aqueous and soil phases. In this paper, the method, applications, and perspectives of these techniques are reviewed. Nitrobenzene is a toxic and persistent pollutant that can contaminate soil and water sources. Biochar, a type of charcoal produced from organic waste materials, is a promising technology for the removal of nitrobenzene from both soil and water sources. Biochar amendments have been shown to be effective in remediating soil contaminated with nitrobenzene. The high porosity and large surface area of biochar provide numerous binding sites for nitrobenzene molecules, which allows for efficient removal from soil. Furthermore, the addition of biochar to soil can also enhance soil fertility, increase water-holding capacity, and provide a slow-release source of nutrients for plants. Biochar is also an effective adsorbent for nitrobenzene in water treatment. Biochar-based adsorbents have been shown to be effective in removing nitrobenzene from water sources. The high porosity and large surface area of biochar provide numerous binding sites for nitrobenzene molecules, allowing for efficient removal from water. Moreover, the use of biochar in water treatment can also contribute to sustainable and environmentally friendly practices. Biochar-based membranes are another emerging technology for the removal of nitrobenzene and other pollutants from water sources. Biochar is incorporated into the polymer matrix of the membrane, which enhances the membrane's adsorption and filtration properties. Biochar-based membranes have been shown to be effective in removing nitrobenzene from water sources in laboratory studies. Overall, biochar is a promising technology for the removal of nitrobenzene from soil and water sources. Biochar amendments for soil remediation, biochar for water treatment, biochar-based adsorbents, and biochar-based membranes are all effective approaches for removing nitrobenzene and other pollutants from the environment. Furthermore, the use of biochar in environmental remediation can also contribute to sustainable and environmentally friendly practices.

Author contributions

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

Conflict of interest

Author AK was employed by the Worley Group.

The remaining author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.All authors contributed to the article and approved the submitted version.

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