Waste as a Resource

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From Waste to Wealth

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Chapter 13
Utilization of Agricultural Waste for Water and Wastewater Treatment Processes

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Abbreviations

AOP	Advanced oxidation processes
COD	Chemical oxygen demand.
GAC	Granular activated carbon
MF	Microfiltration
NF	Nanofiltration
PAC	Powdered activated carbon
RC	Reverse osmosis
TOC	Total organic carbon
UF	Ultrafiltration

13.1 Introduction

The utilization of agricultural waste for water and wastewater treatment processes has become increasingly important in recent years. This is due to its potential to solve two critical environmental issues: the disposal of agricultural waste and the treatment of water and wastewater (Khunt et al., 2019; Kumar et al., 2023). Agricultural waste includes byproducts from agricultural activities, such as crop residues, animal manure, and food processing waste. If not properly managed, these waste materials can cause environmental pollution and health hazards (Green, 2019; Siddiqua et al., 2022). Water scarcity and pollution are global problems that require innovative and sustainable solutions (He et al., 2021; Mulwa et al., 2021; Shemer

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et al., 2023). Traditional water and wastewater treatment methods often involve the use of chemicals and energy-intensive processes, which can be expensive and harmful to the environment. Therefore, the utilization of agricultural waste for water and wastewater treatment has emerged as a promising alternative (Harshwardhan & Upadhyay, 2017; Khunt et al., 2019). Various methods and technologies harness the potential of agricultural waste for water and wastewater treatment (Elbeshbishy et al., 2012). These methods not only effectively treat water and wastewater but also utilize agricultural waste as a valuable resource. For example, biofiltration uses microorganisms present in agricultural waste to remove pollutants from water and wastewater. Anaerobic digestion decomposes organic matter in the absence of oxygen, producing biogas and nutrient-rich digestate. Biochar, produced through the pyrolysis of agricultural waste, can effectively adsorb pollutants from water and wastewater and improve soil fertility (Kamali et al., 2021; Mota et al., 2023). The utilization of agricultural waste for water and wastewater treatment offers a sustainable and cost-effective solution to address agricultural waste management and water pollution challenges. By implementing these innovative approaches, there will be a contribution to a more sustainable and circular economy while protecting our water resources and the environment.

This chapter aims to explore the utilization of agricultural waste for water and wastewater treatment processes, including its types, properties, challenges, and opportunities. It will also discuss various methods and technologies using agricultural waste for water treatment and present case studies. Additionally, it will highlight the advantages, limitations, and future perspectives of utilizing agricultural waste for water treatment.

13.2 Agricultural Waste as a Resource

13.2.1 Types of Agricultural Waste

There are various agricultural waste types suitable for water and wastewater treatment (Chang & Li, 2019; Koul et al., 2022; Rao & Rathod, 2019). Crop residues like corn stalks, rice straw, wheat straw, and sugarcane bagasse can be used as a filter medium or a carbon source for biological treatment (Pandey & Soccol, 2000). Manure from animals, including pigs, cows, and poultry, offers valuable nutrients and organic matter (Bicudo & Goyal, 2003). Fruit and vegetable peels, husks, and shells are examples of food processing waste that can supply nutrients and carbon (Esparza et al., 2020). Then, waste from food manufacturing and animal dung can both be used in biological treatment systems. Aquaculture waste, such as fish scales, fish waste, and shrimp shells, can serve as a carbon and nutrient source in biological treatment processes(Mirabella et al., 2014). Certain bioenergy crops like switchgrass and miscanthus offer their residues, such as leaves and stalks, for water and wastewater treatment. Biogas digestate, a byproduct rich in nutrients and organic matter from biogas production, can be used as a fertilizer or carbon source in wastewater treatment (Al Seadi et al., 2013). Proper management of agricultural runoff is crucial to prevent water pollution and safeguard water resources. The choice of agricultural waste depends on local practices and available resources.

13.2.2 Properties and Composition of Agricultural Waste

Agricultural waste refers to the byproducts and residues generated during agricultural activities, including crop production, livestock farming, and food processing. It is predominantly composed of organic matter such as plant materials, animal manure, and food residues, which provide valuable nutrients and can be used for composting and energy production (Adeyi, 2010; Titiloye et al., 2013). The moisture content of agricultural waste varies widely, with high moisture content leading to issues such as microbial growth and increased decomposition rates. Essential nutrients like nitrogen, phosphorus, and potassium can be found in significant amounts in agricultural waste, derived from plant residues, animal manure, and fertilizers. The carbon-to-nitrogen (C/N) ratio is an important parameter that determines the rate of decomposition and nutrient availability in agricultural waste (Adeyi, 2010). Different types of waste have varying C/N ratios, with lower ratios indicating a higher nitrogen content and faster decomposition rates. Agricultural waste can have diverse physical characteristics, influencing its handling, storage, and processing (Xue et al., 2016). Contaminants such as pesticides, herbicides, and heavy metals can be present in agricultural waste due to the use of agricultural chemicals or environmental pollution. Proper management and treatment of agricultural waste are crucial to minimize the potential negative impacts of these contaminants. It is important to consider regional factors, agricultural practices, and specific waste management strategies when assessing and managing agricultural waste in a particular context (Naeem et al., 2020).

13.2.3 Challenges and Opportunities in Utilizing Agricultural Waste

The utilization of agricultural waste in water and wastewater treatment faces several challenges. One of the main challenges is the variability of agricultural waste (Table 13.1), which makes it difficult to develop standardized treatment processes (Chilakamarry et al., 2022; Koul et al., 2022). Additionally, limited infrastructure and technology in regions that generate significant amounts of agricultural waste hinder efficient waste management and treatment. Contamination and safety concerns also pose risks to human health and the environment if agricultural waste is not properly managed and treated (Chilakamarry et al., 2022; Koul et al., 2022). Moreover, the cost-effectiveness of developing and implementing treatment processes is a significant challenge, especially in regions with limited financial resources.

Table 13.1 Characterization of agricultural waste

Agricultural waste	Chemical composition (% w/w)			Ash (%)	References
	Hemicellulose	Cellulose	Lignin		
Soy stalks	34.5	24.8	19.8	10.4	El-Tayeb et al. (2012)
Wheat straw	32.8	38.0	8.9	1.4	Bjerre et al. (1996)
Corn stalks	42.7	23.3	17.5	9.8	Qu et al. (2011)
Rice straw	41.9	25.6	0.8	16.5	Wang et al. (2021)
Palm oil trunk	39.9	21.2	22.6	1.9	Yuliansyah et al. (2010)
Rice husk	32.7	31.7	18.8	16.3	Dizaji et al. (2019)
Sugarcane bagasse	30.2	56.7	13.4	1.9	El-Tayeb et al. (2012)
Palm oil frond	31.5	19.2	14.0	12.3	Hong et al. (2012)

However, there are several opportunities associated with utilizing agricultural waste in water and wastewater treatment. Agricultural waste is a renewable and abundant resource that can reduce reliance on traditional fossil fuel-based treatment processes (Chilakamarry et al., 2022; Koul et al., 2022; Puglia et al., 2021). Nutrient recovery from agricultural waste can be utilized as fertilizers in agricultural practices, closing the nutrient loop and reducing the need for synthetic fertilizers. Certain agricultural waste can be used to generate renewable energy, reducing reliance on fossil fuels. The utilization of agricultural waste in water and wastewater treatment can also contribute to a circular economy approach, where waste is viewed as a resource (Chilakamarry et al., 2022; Koul et al., 2022; Puglia et al., 2021). Lastly, it can create opportunities for local economic development, including job creation and the development of value-added products from agricultural waste.

13.3 Water Treatment Processes

These include physical, chemical, and biological processes.

13.3.1 Physical Treatment Processes

Sedimentation and Filtration

These processes can be implemented in both small-scale and large-scale wastewater treatment systems. Sedimentation is the process of allowing suspended solids to settle down under gravity. Settling basins are large tanks where water is allowed to sit, allowing solids to settle at the bottom. Agricultural waste, such as straw or hay, can be added to enhance the sedimentation process by providing surfaces for solids to adhere to (Harshwardhan & Upadhyay, 2017; Khunt et al., 2019). Inclined plate settlers use inclined plates to increase the surface area available for solids to settle.

Agricultural waste can be used as a media on the plates to enhance the sedimentation process (Moayedi et al., 2011). Filtration is the process of passing water through a medium to remove suspended solids and other impurities. Slow sand filtration involves passing water through a bed of sand at a slow rate. Agricultural waste, such as rice husks or coconut shells, can be added to the sand bed to improve filtration efficiency (Karić et al., 2022). Rapid sand filtration is similar but with a higher flow rate and the addition of coagulants or flocculants. Agricultural waste can be used as a pretreatment media to remove larger particles. Membrane filtration processes use membranes with different pore sizes to remove suspended solids and contaminants (Hoslett et al., 2018). Agricultural waste, such as activated carbon derived from agricultural byproducts, can be used as a pretreatment step. Biofilters, using agricultural waste materials, support the growth of beneficial bacteria and microorganisms that break down organic pollutants and contaminants in the water (Hoslett et al., 2018).

Adsorption

The use of agricultural waste materials as adsorbents in water treatment processes is a cost-effective and environmentally friendly method that can be easily implemented in both rural and urban areas. Common agricultural waste materials such as rice husk, coconut shell, sugarcane bagasse, corn cob, and sawdust have been successfully used for adsorption purposes (Dai et al., 2018; Harshwardhan & Upadhyay, 2017). These materials possess excellent adsorption properties due to their high silica content, surface area, natural carbon, porous structure, and adsorption capacity. To implement the adsorption process, the waste material is pretreated, dried, and grounded into a suitable particle size before being mixed with contaminated water (Dai et al., 2018).

Membrane Filtration

Membrane filtration processes for water and wastewater treatment can be achieved using agricultural waste through various methods. Examples include microfiltration (MF), ultrafiltration (UF), nanofiltration (NF), and reverse osmosis (RO). MF utilizes membranes with pore sizes ranging from 0.1 to 10 micrometers to remove suspended solids, bacteria, and some viruses (Mateo et al., 2021). Low-cost membrane filters for MF can be developed using agricultural waste such as rice husks or coconut shells. UF uses membranes with smaller pore sizes (0.001–0.1 micrometers) to remove colloidal particles, proteins, and larger organic molecules. Agricultural waste-based membranes can be utilized to enhance filtration efficiency and reduce costs. NF membranes have even smaller pore sizes (0.001–0.01 micrometers) and can remove divalent ions, organic matter, and certain smaller molecules (Mateo et al., 2021). Agricultural waste-based membranes can be modified to achieve the desired separation properties for NF. RO is a high-pressure filtration process that uses a semipermeable membrane to remove dissolved salts, heavy metals, and other contaminants from water (Xiang et al., 2022). Agricultural waste-based membranes can be developed for RO applications, providing a cost-effective and sustainable solution. However, to utilize agricultural waste for membrane filtration, the waste material needs to be processed and converted into a suitable membrane material. Techniques such as carbonization, activation, or modification of the waste material may be required to enhance its filtration properties (OboteyEzugbe & Rathilal, 2020). Proper pretreatment of water or wastewater may also be necessary to prevent fouling and prolong the membrane's lifespan.

13.3.2 Chemical Treatment Processes

Coagulation and Flocculation

Coagulation and flocculation are crucial steps in water and wastewater treatment, involving the addition of chemicals to destabilize and aggregate suspended particles for their removal (Ukiwe et al., 2014). However, these processes can be made more cost-effective and sustainable by utilizing agricultural waste. One such example is the use of Moringa seeds, which contain natural coagulants that effectively remove suspended particles from water (Camacho et al., 2017). The seeds are crushed and mixed with water to extract the coagulant, which is then added to the water or wastewater, followed by gentle mixing. Moringa seeds contain cationic proteins that act as coagulants and have been widely studied and used in water treatment due to their excellent properties. They can remove suspended solids, turbidity, bacteria, and even some heavy metals (Shan et al., 2017). Another agricultural waste product that can be used as a coagulant is chitosan, derived from the chitin found in crustaceans like shrimp and crabs. It is biodegradable and renewable, effectively removing organic matter, heavy metals, and certain dyes from water (Camacho et al., 2017; Shan et al., 2017). Tannins, naturally occurring polyphenolic compounds found in various plant sources, also possess coagulation properties and effectively remove turbidity, color, and organic matter from water (de Oliveira et al., 2022; Ibrahim et al., 2021; Tomasi et al., 2022). Rice husk ash, a byproduct of rice milling, contains silica particles that neutralize the charge on suspended particles, promoting their aggregation and settling. It has been used to remove turbidity, color, and heavy metals from water (Anjitha & George, 2016; Nigusie, 2019). Similarly, banana peel, coconut coir, corn starch, and okra mucilage can all be used as natural coagulants in water treatment, effectively removing suspended solids, turbidity, and even heavy metals (Lee et al., 2014).

Precipitation

Various precipitation processes can be employed for water and wastewater treatment utilizing agricultural waste. These processes utilize agricultural waste materials to facilitate the precipitation and elimination of impurities from water. For instance, agricultural waste materials like plant extracts or byproducts can serve as natural coagulants and flocculants. These materials contain organic compounds that can bind with suspended particles and form larger flocs, which can then be easily removed through sedimentation or filtration (Lee et al., 2014). Additionally, certain agricultural plants possess the ability to absorb and accumulate heavy metals and other contaminants from water. These plants, known as hyperaccumulators, can be cultivated in constructed wetlands or other treatment systems to eliminate pollutants through their root systems. Biochar, a type of charcoal derived from agricultural waste, can also be utilized as an adsorbent material to remove organic contaminants from water (Ghosh et al., 2023). With its high surface area and porosity, biochar effectively adsorbs and retains pollutants (A. Kumar & Bhattacharya, 2021; McKay et al., 2022). Furthermore, agricultural waste materials like crop residues or animal manure can be employed as carbon sources in biological nutrient removal processes, providing a food source for microorganisms that can eliminate excess nitrogen and phosphorus from water through processes such as denitrification and phosphorus uptake (Bicudo & Goyal, 2003). Lastly, agricultural waste materials can be utilized in the construction of wetland systems for water and wastewater treatment, creating a natural environment where various physical, chemical, and biological processes can occur to remove contaminants (Verhoeven & Meuleman, 1999).

Oxidation-Reduction Reactions

Agricultural waste can play a significant role in various oxidative and reductive processes used for water and wastewater treatment. Advanced oxidation processes (AOPs) involve the production of highly reactive oxidizing species like hydroxyl radicals, which can degrade organic pollutants (Khunt et al., 2019). Rice husks or corn cobs can serve as precursors for the generation of these oxidizing species. AOPs include processes such as Fenton's reaction, ozonation, and photocatalysis. Electrochemical oxidation utilizes an electric current to generate oxidizing agents like chlorine or ozone, which can degrade organic pollutants. Agricultural waste can be used as an electrode material or as a source of organic matter, enhancing the degradation efficiency. Biological oxidation utilizes agricultural waste as a carbon source for microorganism growth in biological treatment systems. These microorganisms can degrade organic pollutants through aerobic or anaerobic processes, with examples including activated sludge systems, biofilters, and anaerobic digesters (Kumar et al., 2023).

13.3.3 Biological Treatment Processes

Aerobic and Anaerobic Digestion

Aerobic and anaerobic digestion processes are commonly used in water and wastewater treatment to break down organic matter and reduce the concentration of pollutants. These processes are also effective in utilizing agricultural waste as a feedstock.

Aerobic digestion is a biological process that occurs in the presence of oxygen. It involves the use of aerobic microorganisms to decompose organic matter and convert it into carbon dioxide, water, and microbial biomass. Agricultural waste such as crop residues, animal manure, and food processing waste can be used as a substrate for aerobic digestion. The process involves pretreatment to remove any large solids or contaminants, digestion in an aerobic digester where the waste is mixed with air or oxygen, microbial decomposition by aerobic microorganisms, and management of resulting sludge which can be further processed or used as a fertilizer (Gavrilescu & Macoveanu, 1999).

On the other hand, anaerobic digestion is a biological process that occurs in the absence of oxygen. It involves the use of anaerobic microorganisms to convert organic matter into biogas and digestate. Agricultural waste, including crop residues, animal manure, and food waste, can be utilized as a substrate for anaerobic digestion. The process involves pretreatment to remove any large solids, contaminants, or inhibitors; introduction of the waste into an anaerobic digester; biogas production through biochemical reactions by microorganisms; and management of the remaining digestate, which can be used as a fertilizer or further processed for nutrient recovery (Kiyasudeen et al., 2016).

Both aerobic and anaerobic digestion processes have their advantages and limitations. Aerobic digestion is faster and more efficient in terms of organic matter removal, but it requires a constant supply of oxygen and energy for aeration. Anaerobic digestion, on the other hand, produces biogas as a valuable byproduct but requires longer retention times and careful control of operating conditions.

Constructed Wetlands

Constructed wetlands are an innovative and sustainable approach to water and wastewater treatment, harnessing the natural purification abilities of wetland plants and microorganisms. By incorporating agricultural waste, these wetlands offer an effective and environmentally friendly solution to water treatment challenges. The process begins with pretreatment, where large solids and debris are removed from the incoming water or wastewater to prevent clogging and damage to the wetland system (Vymazal, 2011). Next, the subsurface flow wetland comes into play, as the wastewater flows horizontally through a bed of porous media, such as gravel or sand, that is planted with wetland vegetation. This vegetation absorbs nutrients like nitrogen and phosphorus from the water, reducing their concentrations. Additionally, agricultural waste can be used to provide nutrients to plants, promoting their growth and enhancing nutrient uptake. Beneath the wetland vegetation, anaerobic or facultative bacteria break down organic matter present in the wastewater, aiding in the removal of pollutants and organic compounds. The porous media in the wetland bed acts as a filter, trapping suspended solids and particulate matter, while the wetland plants and microbial activity further aid in the removal of pollutants and contaminants (Omondi et al., 2020). Oxygenation is crucial for the survival of aerobic bacteria responsible for organic matter degradation and pollutant removal. To ensure sufficient oxygen supply, some constructed wetlands incorporate mechanisms like surface aeration or alternating wet and dry periods. After passing through the wetland bed, the treated water undergoes a final polishing process, which may include disinfection using UV light or chlorination to further reduce pathogens and meet quality standards (Vymazal, 2011). Finally, the treated water can be discharged into bodies of water or reused for irrigation or industrial processes, depending on the achieved quality. Constructed wetlands with agricultural waste integration provide a natural and sustainable solution for water treatment, benefiting both the environment and communities.

13.4 Methods and Technologies Utilizing Agricultural Waste for Water and Wastewater Treatment

These include processes such as adsorption, coagulation and flocculation, membrane filtration, and biological treatments.

13.4.1 Adsorption

Activated Carbon from Agricultural Waste

Activated carbon is a highly effective material for water and wastewater treatment, known for its strong adsorption capacity. To produce activated carbon, various methods and technologies utilize agricultural waste (Fig. 13.1).

One such method is pyrolysis, which involves heating agricultural waste materials like rice husks, coconut shells, or sugarcane bagasse in the absence of oxygen. This process thermally decomposes the waste, leaving behind a carbon-rich residue that can be activated to create activated carbon (Bumajdad & Hasila, 2023; Farah, 2023). Chemical activation is another method that treats agricultural waste with a chemical agent, like an alkali metal hydroxide or acid, to create activated carbon (Farah, 2023). The waste is impregnated with the chemical agent and then heated, creating a porous structure with a high surface area for enhanced adsorption

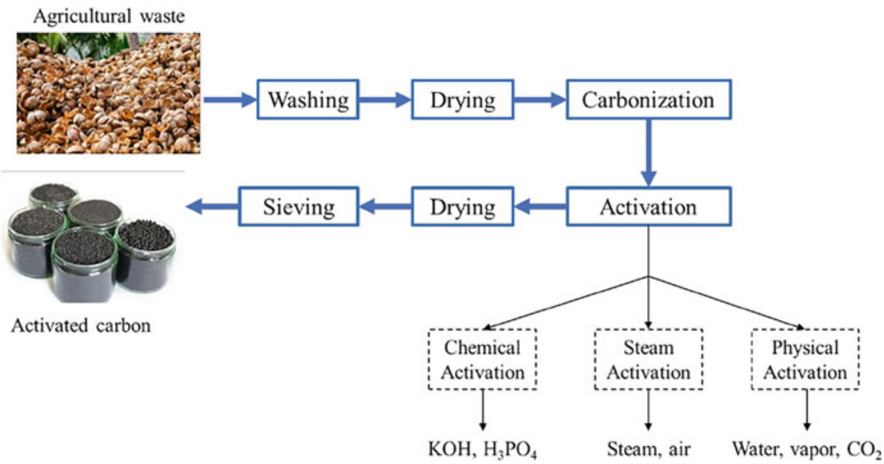

Fig. 13.1 A schematic diagram illustrating the process of producing activated carbon from agricultural waste

capacity. Physical activation, on the other hand, subjects agricultural waste to physical processes like steam activation or carbonization (Farah, 2023). Steam activation exposes the waste to high-temperature steam, while carbonization involves heating the waste in the absence of oxygen (Molina-Sabio et al., 1996). Some methods combine both chemical and physical activation processes to produce activated carbon. Once activated carbon is produced, it can be applied in various adsorption technologies for water and wastewater treatment, such as fixed-bed adsorption, fluidized-bed adsorption, granular activated carbon (GAC) filtration, and powdered activated carbon (PAC) dosing (Jjagwe et al., 2021). These methods offer a sustainable and cost-effective solution for utilizing agricultural waste and improving water and wastewater treatment processes(Farah, 2023).

Biochar

Biochar is a carbon-rich material that is produced through the process of pyrolysis, which involves heating biomass (such as agricultural waste) in the absence of oxygen. It is a highly porous substance with a large surface area, making it effective for various applications, including water and wastewater treatment. There are several methods and technologies that utilize agricultural waste for the production of biochar for water and wastewater treatment(D. Wang et al., 2020).

One method is slow pyrolysis, which involves heating agricultural waste at temperatures ranging from 300 to 700 °C in a slow and controlled manner (Fig. 13.2). This allows for the production of high-quality biochar with enhanced adsorption properties (Wang et al., 2020). Another method is fast pyrolysis, which

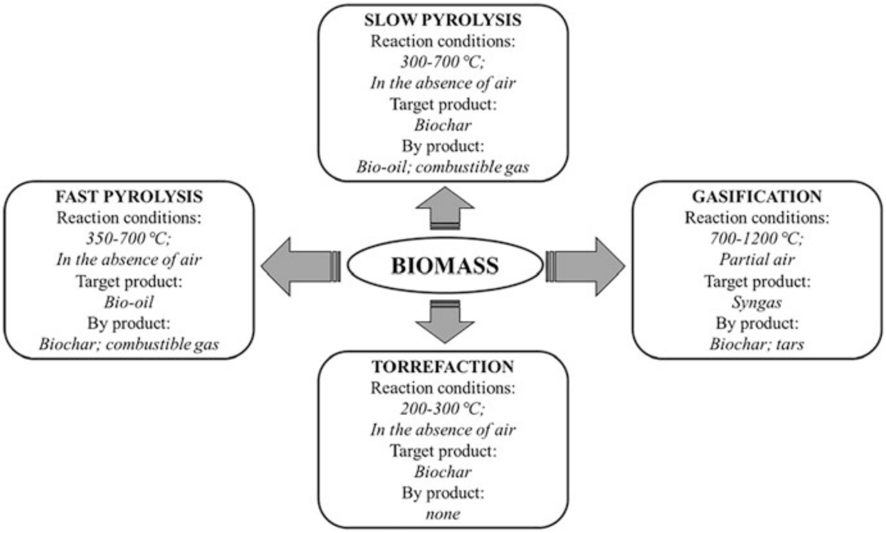

Fig. 13.2 Technologies for the thermochemical conversion of biomass to produce biochar

involves rapid heating of agricultural waste at temperatures above 350 °C (Wang et al., 2020). Fast pyrolysis is often used for large-scale biochar production (Fig. 13.2). Gasification (Fig. 13.2) is another method that involves the partial oxidation of agricultural waste at high temperatures (700–1200 °C), producing a syngas that can be further processed to obtain biochar. Gasification is known for its high energy efficiency and versatility in handling various types of biomass (D. Wang et al., 2020). Hydrothermal carbonization is a relatively fast process that involves the conversion of agricultural waste into biochar under high-pressure, high-temperature conditions in the presence of water. It can be used to produce biochar from wet biomass.

These methods can be combined with various agricultural waste materials to produce biochar. Once produced, biochar can be used in different water and wastewater treatment processes. It has a high adsorption capacity, making it effective in removing organic pollutants, heavy metals, and other contaminants from water (Hama Aziz & Kareem, 2023; Jagadeesh & Sundaram, 2023a). Biochar can also be used as a filtration medium to remove suspended solids and particulate matter. Additionally, it can be used to remove nutrients from agricultural runoff or wastewater and adjust the pH of water or wastewater due to its alkaline nature (Enaime et al., 2020; Jagadeesh & Sundaram, 2023b; Jha et al., 2023).

13.4.2 Coagulation and Flocculation

Natural Coagulants from Agricultural Waste

Natural coagulants derived from agricultural waste are increasingly being explored as alternative options for water and wastewater treatment due to their numerous advantages over conventional chemical coagulants. To extract and utilize these natural coagulants, several methods and technologies are employed. The first step is the extraction of active compounds from agricultural waste through techniques such as grinding, crushing, or boiling. The extracted material is then filtered to remove impurities and solid particles, ensuring the purity of the coagulant solution. The natural coagulant solution is added to the water or wastewater to be treated, causing destabilization of suspended particles and colloids, leading to the formation of larger flocs in a process called coagulation-flocculation. The mixture is then allowed to settle, with the flocs settling to the bottom and forming a layer of sludge, while the clarified water is separated. In some cases, additional filtration may be performed to remove any remaining suspended particles or impurities (Badawi et al., 2023). After the coagulation and filtration processes, the treated water may undergo disinfection to eliminate any remaining pathogens or microorganisms. Common agricultural waste materials used for natural coagulant production include Moringa oleifera seeds, tamarind seeds, banana peels, papaya seeds, and various plant extracts, which contain natural coagulant compounds such as proteins, polysaccharides, and tannins (Abujazar et al., 2022). These sustainable and eco-friendly alternatives have proven to be effective in removing impurities and contaminants from water.

Composite Coagulants

Composite coagulants derived from agricultural waste offer an innovative and sustainable solution for water and wastewater treatment (Balbinoti et al., 2023). These coagulants are created by combining agricultural waste materials with traditional coagulants like alum or ferric chloride, resulting in improved performance and reduced environmental impact. The production and utilization of composite coagulants involve several methods and technologies. First, agricultural waste materials such as rice husks, coconut shells, or corn cobs are collected and processed. These readily available materials are carbonized to eliminate impurities and transform them into carbon-rich substances. The carbonized waste is then activated to enhance its surface area and porosity, thereby increasing its adsorption capacity. The activated carbonized agricultural waste is then mixed with traditional coagulants in specific ratios to form composite coagulants. The combination of agricultural waste and traditional coagulants enhances the coagulation and flocculation properties of the composite coagulant. When added to water or wastewater, the composite coagulant destabilizes suspended particles and colloids, causing them to aggregate and form larger flocs. These flocs can be easily separated from the water through sedimentation or filtration. Following coagulation and flocculation, the water or wastewater undergoes filtration to remove the larger flocs and any remaining particles. Depending on specific requirements, disinfection processes like chlorination or UV treatment may be employed to eliminate harmful microorganisms. Using composite coagulants from agricultural waste offers several benefits, including sustainability, cost-effectiveness, enhanced performance, and versatility in adapting to local agricultural resources and waste streams (Badawi et al., 2023; Balbinoti et al., 2023).

13.4.3 Membrane Filtration

Membranes Modified with Agricultural Waste

Utilizing agricultural waste technology, modified membranes offer a sustainable and cost-effective approach to water and wastewater treatment (Samavati et al., 2023; Shrivastava & Singh, 2022). By leveraging materials like rice husks, coconut shells, and corn cobs, the surface properties of membranes can be enhanced, improving their filtration performance. One method involves incorporating agricultural waste into the membrane matrix during fabrication, where materials like activated carbon or biochar, derived from agricultural waste, are mixed with the membrane material (J. He et al., 2017). This modification enhances the membrane's adsorption capacity, effectively removing organic pollutants and heavy metals from water and wastewater. Another approach entails coating the membrane surface with a thin layer of agricultural waste-derived materials, which enhances hydrophilicity, antifouling properties, and selectivity towards specific contaminants (Ahmad et al., 2022; Shahkaramipour et al., 2017). Chitosan, a natural polymer derived from shrimp and crab shells, can be used for this purpose, improving fouling resistance and antimicrobial properties. Additionally, agricultural waste can serve as a precursor for nanoparticle synthesis, which, when incorporated into the membrane structure, enhances separation efficiency and antimicrobial properties. For instance, silver nanoparticles synthesized from agricultural waste materials inhibit the growth of bacteria and microorganisms within the membrane (Abdelghany et al., 2018; Garg et al., 2020).

Bio-inspired Membranes

Bio-inspired membrane technology involves the creation of membranes that imitate the structure and function of natural biological membranes, aiming to enhance the efficiency and effectiveness of water and wastewater treatment (Abaie et al., 2021). One way to achieve this is by utilizing agricultural waste materials, such as crop residues, animal manure, and food processing byproducts, which can be processed and transformed into membranes suitable for water and wastewater treatment (Abaie et al., 2021). Various methods can be employed to create bio-inspired membranes from agricultural waste, including extracting cellulose from the waste and using it as a base material for membrane fabrication (Ehsani et al., 2022). Cellulose, a biodegradable and renewable polymer, can be modified to enhance its filtration properties (Morales-Jiménez et al., 2023). Another approach involves coating membranes with chitosan, a natural polymer sourced from crustacean shells, which not only improves membrane performance and durability but also possesses antimicrobial properties (Kaushal & Singh, 2023). Additionally, bio-inspired membranes can incorporate natural structures found in biological membranes, such as nanopores created using nanotechnology, enabling more efficient separation and filtration processes. These bio-inspired membranes offer several advantages over traditional ones, including their environmentally friendly nature, reliance on renewable resources, and potential cost-effectiveness due to the availability and affordability of agricultural waste materials (Ehsani et al., 2022; Kaushal & Singh, 2023; Morales-Jiménez et al., 2023).

13.4.4 Biological Treatment

Anaerobic Digestion

Anaerobic digestion is a biological process that breaks down organic materials without oxygen, producing biogas and nutrient-rich effluent (Fig. 13.3).

This technology is effective for water and wastewater treatment, particularly for agricultural waste(Uddin & Wright, 2023). The process involves several steps. First, agricultural waste such as crop residues, animal manure, and food waste is collected and prepared as feedstock. Then, an anaerobic digester is designed and constructed according to the waste characteristics and treatment requirements (Xu & Li, 2017). Different types of digesters are available, including covered lagoons, plug flow digesters, complete mix digesters, and fixed film digesters.

The prepared feedstock is loaded into the digester and mixed to ensure uniform distribution and microbial activity. The anaerobic digestion process occurs in stages, starting with hydrolysis, followed by acidogenesis, and ending with methanogenesis. The produced biogas, mainly composed of methane and carbon dioxide, is collected and stored for energy generation. The effluent still contains nutrients and organic matter, which can be further treated for water quality standards. Benefits of anaerobic digestion include energy generation, waste management, nutrient recovery, and greenhouse gas reduction (Uddin & Wright, 2023; Xu & Li, 2017).

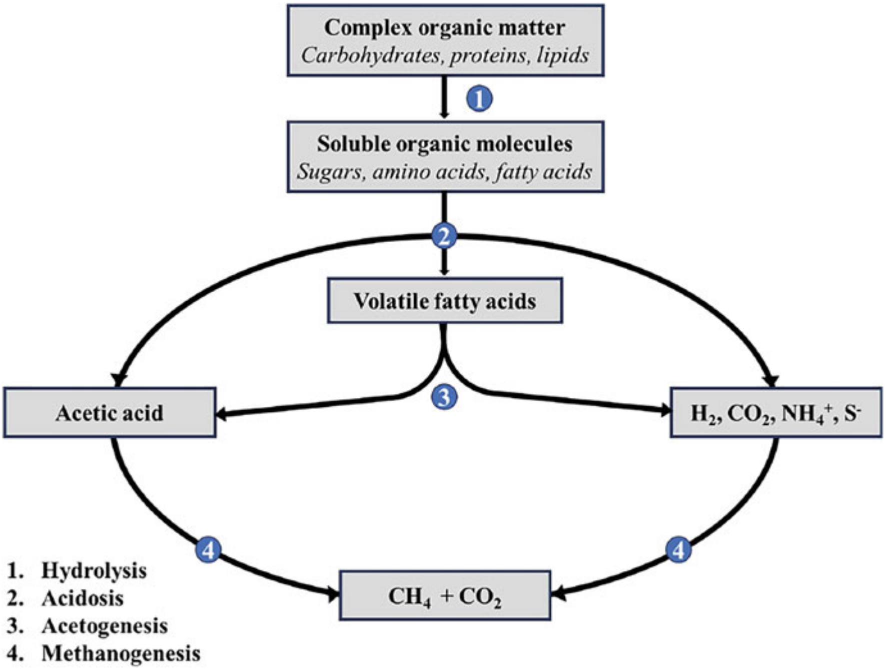

Fig. 13.3 Stages of anaerobic digestion

Constructed Wetlands

Constructed wetlands utilize natural processes to improve water quality by removing pollutants. They consist of shallow basins or channels filled with wetland plants like reeds, cattails, and bulrushes. The wetland cells are lined to prevent seepage. In subsurface flow wetlands, polluted water passes through a gravel or rock bed beneath the plants, where microorganisms break down organic matter and remove pollutants. Surface flow wetlands involve water flowing over the plants' surface, enhancing pollutant removal through plant uptake and microbial processes. Treatment mechanisms include sedimentation, filtration, adsorption, plant uptake, microbial decomposition, and denitrification. Constructed wetlands effectively remove pollutants in agricultural waste, but require regular maintenance and monitoring (Hadidi, 2021). They are cost-effective, energy-efficient, and provide additional benefits like habitat creation and biodiversity conservation. However, they may not remove certain contaminants completely, and efficiency can vary depending on design and environmental conditions (Hadidi, 2021).

13.5 Case Studies

13.5.1 Utilization of Agricultural Waste for Adsorption

Removal of Heavy Metals

Researchers conducted case studies to investigate the potential of different waste materials as adsorbents for removing heavy metals from water and wastewater.

- In Case Study 1, banana peel waste was collected, processed into powder, and mixed with water samples containing heavy metals. The results demonstrated that banana peel waste effectively removed heavy metals, indicating its potential as a low-cost and sustainable adsorbent (Leong, 2018).
- In Case Study 2, rice husk ash, a byproduct of rice milling, was processed into a fine powder and mixed with water samples containing heavy metals, showing high adsorption capacity (Lata & Samadder, 2014).
- In Case Study 3, coconut shell-activated carbon was tested, showing a high adsorption capacity for heavy metals in water samples (Amuda et al., 2007).

Removal of Organic Pollutants

- In Case Study 1, researchers in India utilized rice husk, an agricultural waste material, to remove organic pollutants from wastewater at a treatment plant. By treating the wastewater with varying concentrations of rice husk, the researchers observed its effectiveness in reducing the concentration of organic pollutants, including dyes and heavy metals. The study revealed that rice husk had a significant adsorption capacity for these pollutants (Madhav et al., 2022).
- Similarly, in Case Study 2, coconut shell, another agricultural waste material, was used to remove organic pollutants from water at a treatment plant. The study demonstrated that coconut shells had a high adsorption capacity for organic pollutants like pesticides and pharmaceuticals, effectively reducing their concentration in the water. The researchers also noted that the adsorption capacity increased with a longer contact time between coconut shells and water (Madhav et al., 2022).

13.5.2 Utilization of Agricultural Waste for Coagulation and Flocculation: Removal of Suspended Solids and Turbidity

In two separate case studies, agricultural waste materials were utilized for the removal of suspended solids and turbidity in water and wastewater treatment.

- In the first case study conducted in India, rice husk was collected from local rice mills, washed, dried, and ground into a fine powder. This rice husk powder was then used as a coagulant in the water treatment process, where it was added to contaminated water, stirred, and allowed to settle. The treated water was then filtered to remove any remaining particles, resulting in a significant reduction in suspended solids and turbidity levels (Adams & Mulaba-Bafubiandi, 2014; Ezekoye, 2017).
- Similarly, in the second case study, banana peels were collected from local plantations, prepared, and used as a coagulant in the water treatment process. The banana peel powder was added to contaminated water, mixed, and allowed to settle before filtration. This also led to a notable decrease in suspended solids and turbidity levels. In both cases, the natural properties of the agricultural waste materials facilitated the aggregation and settling of particles, ultimately improving the quality of the water (Azamzam et al., 2022; Mokhtar et al., 2019).

13.5.3 Utilization of Agricultural Waste for Membrane Filtration

Removal of Microorganisms

The researchers examined the application of agricultural waste materials in water and wastewater treatment for microorganism removal in two distinct case studies.

- In the first study, rice straw was used as a natural adsorbent material in a membrane filtration system. The researchers prepared the rice straw by washing, drying, and cutting it into small pieces, which were then packed into a filtration column. The system effectively removed bacteria, viruses, and fungi from the wastewater, with a high removal efficiency for certain microorganisms.
- In the second study, coconut shell-activated carbon was incorporated into a membrane filtration system for water treatment. The activated carbon, prepared by carbonizing and activating coconut shells, demonstrated a high removal efficiency for bacteria, algae, and protozoa (Crites et al., 2014; Smarzewska & Morawska, 2021).

Removal of Organic Matter

- In Case Study 1, rice straw was utilized as agricultural waste material for membrane filtration in water treatment. A composite membrane was developed by incorporating rice straw particles into a polymeric matrix. Its efficiency in removing organic matter from water was tested, resulting in a high removal efficiency for organic matter, with significant reductions in chemical oxygen demand (COD) and total organic carbon (TOC) levels. The membrane also demonstrated good stability and durability during filtration (Hassan et al., 2020).

- Similarly, in Case Study 2, banana peel was used as agricultural waste material for membrane filtration in wastewater treatment. The composite membrane, developed by incorporating banana peel particles into a polymeric matrix, showed excellent performance in organic matter removal, with significant reductions in COD and TOC levels. The membrane also exhibited good mechanical strength and stability during filtration (Ahmad & Danish, 2018; Datta et al., 2012; Farias et al., 2023).

13.5.4 Utilization of Agricultural Waste for Biological Treatment

In this case study, a rural farm successfully implemented an anaerobic digestion system to treat water and wastewater generated from animal manure. The main objective was to utilize agricultural waste and produce biogas as a renewable energy source. With a large number of livestock, the farm faced the challenge of significant daily animal manure production, leading to environmental pollution and foul odors from traditional open lagoon storage. To address these issues and make beneficial use of the waste, the farm installed a series of tanks for anaerobic digestion. This process involved the decomposition of organic matter by bacteria in the absence of oxygen, resulting in the production of biogas and nutrient-rich digestate (Hamilton, 2009; Song et al., 2023). The captured biogas was then used for heating, electricity generation, and as fuel for farm vehicles, reducing the farm's reliance on fossil fuels and lowering their carbon footprint. The nutrient-rich digestate was utilized as a fertilizer for agricultural crops, providing a sustainable source of nutrients and minimizing environmental pollution from synthetic fertilizers. The implementation of the anaerobic digestion system not only improved water and wastewater treatment but also provided economic benefits by reducing energy costs and expenses associated with synthetic fertilizers, while enhancing the overall sustainability of the farm's operations (Hamilton, 2009; Rekleitis et al., 2020; Song et al., 2023).

13.6 Advantages and Limitations

13.6.1 Advantages of Utilizing Agricultural Waste for Water Treatment

Utilizing agricultural waste for water treatment offers several advantages.

- First, it is a cost-effective solution as agricultural waste, such as crop residues or animal manure, is readily available and inexpensive. This reduces the cost of traditional treatment methods.
- Second, repurposing agricultural waste for water treatment promotes sustainability by minimizing the environmental impact of waste disposal and contributing to a circular economy.
- Third, agricultural waste contains valuable nutrients that can be recovered during the treatment process, reducing the need for synthetic alternatives and promoting sustainable agriculture (Green, 2019). Additionally, many agricultural waste materials act as natural filters, promoting biological treatment processes that break down organic pollutants in water and reduce the need for chemical treatment. Moreover, utilizing agricultural waste for water treatment requires less energy compared to conventional methods, especially in biological treatment processes (Crites et al., 2014).
- Lastly, engaging local communities in rural areas where agriculture is a primary economic activity fosters a sense of ownership and promotes environmental stewardship.

13.6.2 Limitations and Challenges

The utilization of agricultural waste for water treatment presents numerous limitations and challenges. First, the composition of agricultural waste varies greatly, including crop residues, animal manure, and food processing byproducts, making it difficult to establish standardized treatment processes. Additionally, agricultural waste may not effectively remove certain contaminants, such as heavy metals or persistent organic pollutants, depending on the specific waste used and the targeted contaminants (Crites et al., 2014; Smarzewska & Morawska, 2021). Furthermore, the availability and scalability of agricultural waste for water treatment can be limited due to factors like seasonal variations, agricultural practices, and geographical location. Some agricultural waste treatment technologies may also require sophisticated equipment or infrastructure, which can be impractical or financially burdensome, particularly in rural areas or developing countries with limited resources. Moreover, the utilization of agricultural waste for water treatment can have unintended environmental consequences, such as the release of excess nutrients leading to eutrophication and ecosystem disruption. Additionally, agricultural waste may contain pathogens, pesticides, or other harmful substances, posing health and safety risks if not properly managed during the treatment process. Adequate precautions must be taken to ensure the safety of workers and the public (Crites et al., 2014; Green, 2019; Smarzewska & Morawska, 2021). Lastly, the utilization of agricultural waste for water treatment may be subject to varying regulatory requirements and policies across jurisdictions, posing compliance challenges, particularly for small-scale or informal treatment systems.

13.6.3 Future Perspectives and Research Directions

The utilization of agricultural waste for water treatment is a promising field with various future perspectives and research directions. With the increasing water scarcity and pollution worldwide, it is crucial to find sustainable and cost-effective methods for water treatment. Agricultural waste, including crop residues, animal manure, and food processing byproducts, can serve as a valuable resource in this regard. One potential future perspective involves the development of innovative technologies that effectively utilize agricultural waste for water treatment. For instance, researchers can explore the use of biochar, a carbon-rich material derived from the pyrolysis of agricultural waste, as a filtration medium to remove contaminants from water. Biochar has shown excellent adsorption properties, effectively eliminating heavy metals, organic pollutants, and nutrients from water. Another research direction involves optimizing treatment processes by enhancing the adsorption capacity and performance of agricultural waste through proper pretreatment methods. Additionally, researchers can investigate the integration of agricultural waste-based treatment systems with other technologies like membrane filtration or electrochemical processes to enhance overall treatment efficiency. Furthermore, it is essential to assess the environmental impacts of utilizing agricultural waste for water treatment, including the potential release of harmful substances or byproducts and their effects on the environment. Understanding the fate and transport of contaminants in agricultural waste-based treatment systems will aid in designing sustainable and environmentally friendly water treatment processes. Moreover, economic feasibility studies are necessary to evaluate the cost-effectiveness of utilizing agricultural waste for water treatment. Researchers can explore ways to optimize the production of agricultural waste-based materials and technologies, making them more affordable and accessible, especially in developing countries where water treatment infrastructure is often inadequate.

13.7 Conclusion

The utilization of agricultural waste for water and wastewater treatment offers advantages and opportunities. It can be a valuable resource for sustainable treatment technologies. Agricultural waste is suitable for various treatment processes. Physical processes like sedimentation, filtration, and adsorption can remove solids and pollutants. Chemical processes can be enhanced using natural and composite coagulants from agricultural waste. Biological processes like digestion and wetlands can degrade organic matter and remove nutrients. Methods and technologies have been developed for water treatment using agricultural waste. Adsorption with activated carbon and biochar removes heavy metals and pollutants. Coagulation and flocculation remove solids and turbidity. Membrane filtration with modified membranes removes microorganisms and matter. Anaerobic digestion and wetlands treat wastewater. Successful case studies include adsorption for heavy metal and pollutant removal, coagulation and flocculation for solids and turbidity removal, membrane filtration for microorganism and matter removal, and anaerobic digestion and wetlands for wastewater treatment. Utilizing agricultural waste has advantages like using renewable and local resources, cost-effectiveness, and environmental sustainability. However, challenges include waste composition variability, pretreatment and modification, and potential contaminant release. Future research should focus on efficient and cost-effective technologies, parameter optimization, exploring new waste types, and evaluating long-term environmental impacts.

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