Wastewater Treatment Technologies

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1 Introduction

Industrialization and urbanization are the backbone of economic growth in various countries of the world. This process, however, has led to the generation of wastewater in large quantities. The need for wastewater purification is paramount due to the scarcity of water, hence, the need to treat and re-use for human consumption. Wastewater generally refers to water which contains various pollutants generated from various anthropogenic activities such as commercial, agricultural, domestic,

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as well as runoff water from other sources (Edokpayi et al. 2017). Wastewater have varying physical and chemical properties which differ based on their chemical compositions as well as flow conditions as this is a feasible parameter for the design of specific waste treatment plants. The conditions of flow in wastewater differ depending on the specific seasons since it is during the wet season that there is inflow of run-offs. The inorganic and organic contaminants present in wastewater are employed and functional indicators of the physicochemical properties of the wastewater. Some of the paramount characteristics such water include pH, total phosphorus, total nitrogen, chemical oxygen demand, and biochemical oxygen demand (Englande et al. 2015).

The treatment of wastewater also known as sewage treatment involves the removal of various impurities from sewage or wastewater before it gets into natural bodies (oceans, lakes, river, or estuaries) or aquifers. It is a process employed for the removal of various pollutants from wastewater and the conversion into effluents which can be released back to the water cycle. When returned into the water cycle, the effluents have acceptable impacts on the ecosystems and entire environment and can be re-used for different purposes (Talabi and Kayode 2019; Shah 2020). Basically, water is considered to be polluted when it has high amount of impurities thereby making it unsuitable for a specific usage such as swimming, fishing, or drinking. Even though the quality of water is influenced by natural conditions, pollution is commonly used with regards to anthropogenic influence as pollution source. The pollution of water, therefore, is brought about by the draining of polluted wastewater into groundwater or surface water and treatment of wastewater is a prominent feature of water pollution monitoring and control. When trace quantity of sewage is released into a body of flowing water, a natural mechanism is involved in the self-cleansing of the water. However in populated areas, a large amount of sewage is generated thereby affecting the self-purification processes, hence, wastewater treatment becomes paramount prior to disposal or re-using. Most of these techniques for water treatment comprise basically of physical and chemical processes which have emerge over time (Patel et al. 2019).

There is pressing need for the development of novel methods for the mitigation of the effects of wastewater on the environment that is currently degrading. Fresh water has become a very scarce resource with high demand most especially in developing countries where contamination is high. Various researchers have documented numerous technologies for the treatment of wastewater. One of the prominent reason responsible for the emergence of new technologies in the treatment of wastewater is the hefty fines and legislation that go with the disposal of wastewater that do not meet the permissible limits based on standards. Such impact with its financial implication on the industry has given rise to the emergence of more improved technology for the treatment of wastewater (Ahmed et al. 2021; Shah 2021). There are different technologies available for the treatment of wastewater. The use of conventional approaches in the treatment of wastewater is highly limited due to the inherent limitations of some of these techniques. The current trend of emerging contaminants in wastewater further engenders many challenges. Various groups of contaminants are generated from anthropogenic activities such as agriculture, and industrial production

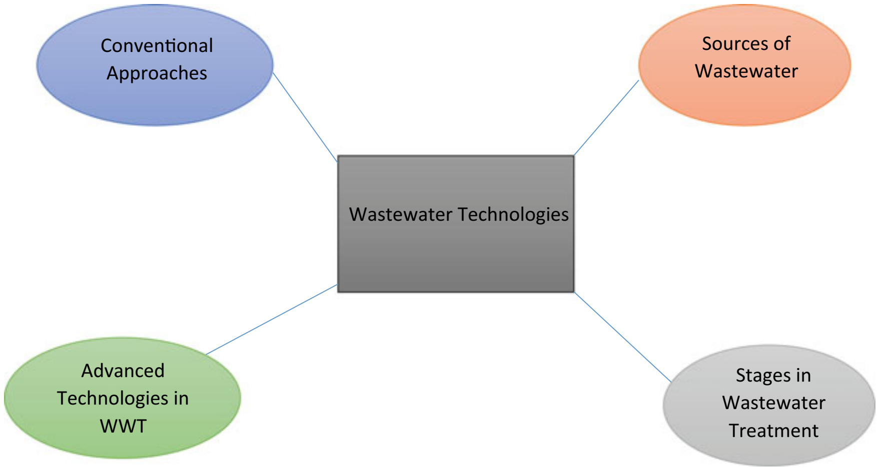

Fig. 1 Schematic representation of chapter

processes, among others (Bunce et al. 2018). Some of the existing techniques have evolved over time with the advent of new classes of environmental contaminants. The choice of technology to be adopted is determined by the nature and compositions of the wastewater. It is therefore paramount for efficient characterization of the wastewater prior to selection of appropriate technology for its treatment (Armah et al. 2020).

This chapter discusses the various technologies employed for the treatment of wastewater. It also highlights the sources, composition, and stages involved in the treatment of wastewater as schematically represent in Fig. 1.

2 Contaminants in Wastewater

2.1 Metals

There are various categories of metals in wastewater mainly from various activities such as mining, manufacturing, and textile industries, among others. Some of the metals present in wastewater include chromium, copper, lead, tin, arsenic, mercury, potassium nickel, aluminum, etc. They are generated from industries such as iron, steel, textiles, and micro-electronics. The presence of metals in wastewater brings about a rise in the cost of treatment (Hughes et al. 2020).

2.2 Nitrogen and Phosphorus Compounds

There are various nutrients of plants that are found in wastewater. These usually occur in the form of ammonia and nitrate from fertilizers producing companies. The total nitrogen is a combination of organic and inorganic nitrogen as well as ammonia present in wastewater. They exist as nitrite, nitrate, ammonium, and organic compounds that are dissolved in water.

2.3 Total Solids

This is made of organic and inorganic materials; settle-able substances dissolved and suspended matter, and volatile solids, among others. Although physical methods of separation are suitable for the removal of suspended solid materials, some of these particles still find their way into the environment. The total dissolved solids continue to increase as a result of chemicals from cleaning, washing, and processes of production (Jasim and Aziz 2019).

2.4 Microorganisms

There various groups of microorganisms that are found in wastewater. Various classes of bacteria, protozoa, and viruses have been documented in wastewater. Bacterial and viral infections due to water borne outbreaks are commonly linked with the areas with the release of wastewater. The presence of enteric viruses in wastewater has been associated with diseases such as hepatitis, respiratory tract infection, and gastroenteritis.

2.5 Pharmaceutical Compounds

There are also groups of emerging pollutants in wastewater which have long-term impacts on aquatic habitants and humans. Such compounds include antibiotics, analgesics, anti-cancer agents, lipid regulator, and hormones, among other. Their presence is also due to the fact that humans' drugs are released either in metabolized or their original forms. The various compositions of wastewater are presented (Fig. 2).

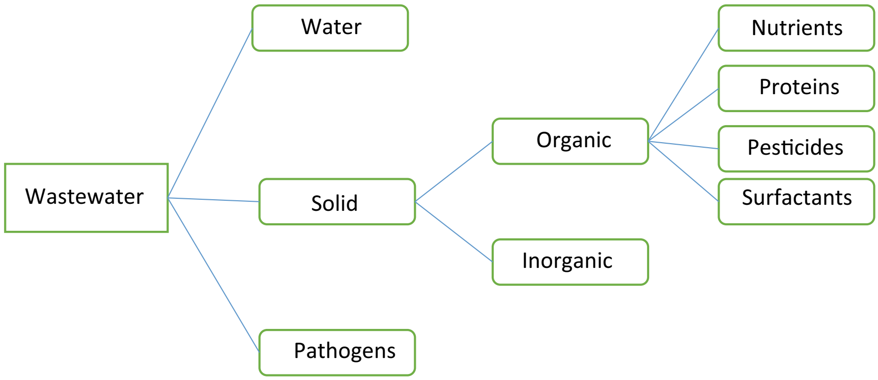

Fig. 2 Compositions of wastewater

3 Stages in the Treatment of Industrial Wastewater

Wastewater from industries contains various inorganic and organic materials in different concentrations depending on the activities within the industries. Some of the materials present are not readily acted upon by activities of microorganisms. The treatment of wastewater occurs in stages.

The traditional processes for the treatment of wastewater consist of preliminary steps, primary stage, secondary stage, and tertiary procedure which function on the basis of biological, chemical, and physical processes. The most prominent primary process involves the treatment with activated sludge. Wastewater treatment involves the conduction of the activated sludge stage such as the use of biofiltration. Such processes have proven effective in the removal of compounds. The efficiency the process in the removal of drugs varies within different investigations and is depended on the efficient construction and design of the wastewater facility for treatment. The conventional approaches are highly limited, hence, other processes such as ozonation, reverse osmosis, as well as advanced oxidative processes are more promising in the treatment of wastewater (Loucks and Beek 2017).

3.1 The Primary Stage

In the primary stage various solids matter, particulates, oils and other materials suspended are removed from the water. The primary stage basically involves the use of physical methods for the removal of these materials. It involves the use of oil separators for removing oil from the surface of the water, primary clarifiers for removing various materials and screens.

3.2 Secondary Stage

Secondary is considered as the heart of the process of wastewater treatment. It involves the biodegradation of various pollutants. Thus, biological processes involving the use of microorganisms such as bacteria are adopted. Activated sludge treatment using aerated system is also carried out here. The use of aerated activated sludge mechanism is highly promising and it is less complex, efficient in terms of cost, and highly efficient. The removal of many contaminants like organic pollutants and various soluble biodegradable substances is achieved through the use of aerobic and anaerobic treatment processes. There is also a rise in the use of membrane technologies for the treatment of wastewater. Various classical treatments involving the use of chemicals as well as the application of modern-advanced systems have been adopted in the efficient treatment of wastewater from industries.

3.3 Tertiary Stage

The tertiary stage in the treatment of wastewater involves the filter steps which is usually the final, finishing, and polishing stage such as the use of carbon filters made of activated materials. The tertiary stage is also referred to as the polishing stage during which the water is disinfected to the highest state. The stage is vital for the production of water of remarkable specification like the technical waters and for the treatment of wastewater use in public water system. The tertiary state of treatment includes chemical disinfection as well as UV disinfection. The disinfection using UV does not need the use of chemicals hence can be applied in the place of chemicals. The use of UV has no effect on the physical properties of the water such as smell, taste, appearance, and pH (Ahmed et al. 2021).

Stages	Activities	Processes involved	References
Primary	Various suspended solid materials are removed from the wastewater prior to passage to the other stage Removal of various activated sludge materials	Sedimentation and flocculation Smuts skimming Use of bioreactors, use of aerated ponds, biofillers, rotating biological contactors, and microbial induced oxidation ditches	Donald et al. (2022)
Secondary	Phosphate, nitrates, and other compounds are removed		Englande et al. (2015)
Tertiary	Other inorganic and organic nutrients are also removed	Use of chlorine, ozone, and other chemical substances Use of chloramines and chlorine dioxide	Milani and Bidhendi (2022)

3.4 Coagulation and Flocculation in Wastewater Treatment

Most industrial wastewater treatment plants consist of sedimentation in their treatment process. The sedimentation process also known as the clarification involves the lowering of the speed of the wastewater below the velocity of suspension, making it possible for the particles suspended to settle down as a result of the action of gravitational force. The wastewater then proceeds to the next stage of treatment after leaving the sedimentation tank. The efficiency of the overall performance of this stage is determined by temperature, details of tanks, and duration of retention, among others (Njewa et al. 2021). Coagulation is the process which involves the addition of various chemical compounds which speed up the sedimentation of some particles inside the tank. These coagulants consist of various inorganic and organic compounds such as aluminum hydroxide chloride, aluminum sulfate, and cationic polymers of high molecular weights. The primary essence of coagulant addition is for the removal of about 90% of the solids suspended in the wastewater in this stage.

4 Technologies for the Treatment of Wastewater

Technologies for the treatment of water have evolved over time in view to meeting the dynamic demands of this era. Several trends in water treatment techniques have been reported in different countries of the world. The production of wastewater is of environmental concern due to the presence of various classes of organic, inorganic, and biological contaminants in the water which poses health challenges to humans. Presence of new and emerging contaminants in wastewater has given rise to the need for advanced approaches to wastewater treatment. The traditional approaches to the treatment of wastewater are highly limited in the treatment and removal of some of these contaminants, and this could further worsen the existing challenges of water scarcity (Sathya et al. 2022).

4.1 Biotechnological Approaches in Wastewater Treatment

i. Microalgae technology
   This technique in the treatment of wastewater is autotrophic in nature with a remarkable potential of fixing the atmospheric carbon. This technology is commonly employed after the treatment of water in upstream as a secondary or in some other cases tertiary processes of treatment for various effluences containing organic materials and heavy metals contaminants in wastewater. It is an attractive dimension involved for the treatment of wastewater which also gives rise to the generation of biomass which has a high value that can be applied for various purposes. The application of microalgae in this regards gives rise to

highly minimal risk in terms of production of secondary contamination due to its potential of utilizing phosphorus and inorganic nitrogen for the purpose of growth and their unique ability for the removal of toxic organic substances and heavy metals.

ii. Microbial fuel cell technique
Microbial fuel cell (MFCs) this is one of the fastest growing technology involved in the treatment of wastewater. This approach makes use of the bioelectrical catalytic process of the microorganisms that are involved during the generation of electric power through the oxidation process of inorganic and organic material that are found in the wastewater. This technology offers two different goals since it permits the recovery of energy as well as the wastewater within a unit configuration.

iii. Aerobic and anaerobic-based technology
This approach has been recently adopted in the treatment of wastewater due to the fact that they are environmentally friendly and also cost effective. The anaerobic approach, however, has a clear cut above some of the other techniques most especially due to it lower energy demand. Various technologies based on the use of microorganisms have been employed for the treatment of wastewater. This has made it possible for the degradation of various organic contaminants under aerobic conditions. The biodegradation of organic contaminants under aerobic conditions is cheap, simple, and eco-friendly in the breakdown of waste. Some of the essential factors affecting the biodegradation of the various contaminants include moisture, nutrients, pH, temperature, rate of aeration, and aeration. Aerobic processes are basically employed as the primary means for the reduction of BOD in the wastewater due to the fastness of the anaerobic process of microbial reactions. Aerobic bioprocess, however, has its disadvantage in wastewater treatment which that it results to the production of large amount of sludge when compared to the anaerobic process (Chahal et al. 2016). A remarkably high concentration of biomass takes place in the aerobic bioreactor due to the yield of biomass for aerobic microbes is comparably high, about four times higher than that of anaerobic microorganisms. The sludge that is found inside the reactor effluents may have remaining BOD which makes it necessary to reduce them further in the subsequent processes.

4.1.1 Merits of Anaerobic Biodegradation of Contaminants

The anaerobic processes of microbial breakdown of contaminants in wastewater have the following merits: The byproducts generated are useful for various purposes such as generation of methane gas, it is relatively cheap and limited cost during the passage of oxygen into the reactor, it can be operated even at a high toxicity of contaminants and higher waste BOD, and it has a relatively lower formation rate of the sludge. Aerobic processes, however, have certain delimitations such as it high operating cost and restricted during the treatment of wastewater in streams of low rate of flow (Shevtsov et al. 2022).

4.2 Role Membrane Technology in Wastewater Treatment

This approach to wastewater treatment includes various interconnected scientific and engineering approaches for the movement of species, components, or materials through a membrane. This technology is used generally for the explanation of the mechanical phenomena for the separation of liquid or gases streams. Membranes are grouped as thin layers boundary for differential separation based on sizes of the substances. The membranes are mostly integrated with biological and chemical treatments or as a system standing-alone during the secondary treatment of contaminated water. In a typical system of membrane separation, a driving force exists such as a selectively permeable boundary which is capable of controlling the speed of movement of the various components through fractional permeation and also rejection through the varying sizes pores. The selective rejection and permeation are determined by the chemical affinity and pore sizes of the membrane (Naidoo and Olaniran 2013).

Some of the typical types of membrane technology are as follows:

i. Microfiltration (MF)
This makes use of a mechanism for sieving for the retention of macromolecules or some other particles that have sizes than are bigger than 0.1 micro meters, of specially, within the range of 0.1 to 10 μm. The transmembrane pressure in the both side of these membranes is low due to the retaining of the smaller particle components. Bigger pore sizes of the membrane filtration boundaries tend to limit the process of removing various suspended materials, viruses, bacteria, and organic colloids, among others that are within the region.
ii. Ultrafiltration (UF)
This approach to wastewater treatment has gained remarkable attention in recent times due to its application in bioreactors and desalination processes. It uses sieving process as its mechanisms of separation. The sizes of the pores used in UF range from 0.05 μm to 1 nm, the cutoff based on molecular weight varies from 1 to 500 kDa with an operational pressure of 1 to 7 bar. The use of UF has progressively gained popularity in industrial applications. It has been used as pretreatment process for nanofiltration and reverse osmosis technology. There is extreme distinguishing of fouling in UF utilization, as a result of the large molecular weight of the different fractions that are retained with respect to the small differential osmotic pressure. The configurations on the applications of UF are affected by cost implication (Inobeme et al. 2023).
iii. Ion exchange membrane

A membrane is said to be an anion exchange membrane if its polymeric matrix has a fixed charged group enclosed within it, and the other way round for a cation exchange membrane where there is permeation of cations/anions and also the rejection of anions/cations. There are various processes that involve the exchange of ionic particles across membrane between solutions, such as diffusion dialysis, reverse electrodialysis, and Donnan membrane technique.

iv. Reverse and forward osmotic process
This is commonly referred to as a membrane that is tight and has been broadly employed in the treatment of wastewater. It has also been reported to be vital for the desalination of water with better results when compared to the traditional thermal flashing. Hypertonic feed is employed for the generation of high pressure from the external region, within range of 15 to 150 bars, and this external pressure is higher than the osmotic pressure. This pressure is applied for the retaining of the dissolved solute which prevent and permit for the permeation of solvent. Reverse osmosis has certain advantages which include simplified configuration, low energy consumption, low membrane fouling occurrence, and high rejection of various ranges of pollutants (Nasir et al. 2022).

v. Electrodialysis
This is an approach that combines the various principles of generation of electricity and ion permeable boundary for the separation of dissolved ions present in water. The differences in the potential are responsible for the movement of ions into a concentrated solution from a dilute solution through a membrane that is permeable to ions.

4.2.1 Advantages of Membrane Technologies

Membrane technology has several merits in its application in wastewater treatment which include: energy saving potential, its clean and environmentally friendly nature, its potential of replacing some of the existing approaches such as ion exchange, filtration, chemical treatment and distillation, it unique ability of giving rise to products that are of high quality, and its remarkable flexibility with respect to design of the system. Due to its high flexibility and its multidisciplinary potential of applications, it has been adopted in various industries (metallurgy, biotechnology, chemical, and pharmaceutical) for the treatment of sewage water (Tetteh et al. 2018).

4.3 Chemical Oxidation Processes in Wastewater Treatment

Oxidation is a process during which electrons are shifted from a substance to another resulting to a potential commonly expressed as volt. The use of chemical oxidation seems to be a potential solution which complies with wastewater policies and legislations. This is commonly used after the secondary stage of wastewater treatment for the breakdown of various compounds that cannot be acted upon by microorganism. A primary parameter of reference in the oxidation processes for wastewater treatment is the chemical oxygen demand (COD). Wastewater that contains a small COD can be easily treated using these processes because a higher COD contents would need the utilization of high quantity of reactants that are expensive (Armah et al. 2020).

4.4 Advanced Oxidation Process (AOPs)

AOPs refer to the processes of treating wastewater that involve the formation of highly reactive intermediates such as free radicals and hydroxyl species under ambient pressure and temperature. The free radicals are generated in such concentrations that they can induce the purification of the contaminated water. This approach has been found highly promising approach in the remediation of contaminated ground water, wastewater, and surface water that contain a high amount on organic contaminants that are non-biodegradable. The hydroxyl radicals formed are very reactive and capable of attacking most of the organic compounds present in the wastewater resulting to their breakdown.

The use of AOPs, however, has certain limitations. It is difficult applying AOPs in permanent operations and also difficult applying it in a whole site. In some big critical treatment sectors, AOPs are needed for the purpose of dealing with peak COD so as to meet the treatment levels. AOPs are also efficient during the conversion of recalcitrant substances into intermediate species that can easily be acted upon by microorganism, through their transfer into the biological units where they are mineralized. Among the various types of AOPs, Fenton has been reported to be highly effective for the efficient treatment of wastewater breaking down pesticide residues, surfactants, dyes, and aromatic amines. The Fenton reagents have the advantage that it does not require energy input for the activation of the peroxide (Kesari et al. 2021).

5 Conclusion and Future Trends

Wastewater treatment is an issue of global concern. Wastewater is a serious challenge for different countries of the world as a result of the rising contents of unknown and undesired contaminants which are toxic to human health. It has been generally recognized that the challenges associated with the treatment of wastewater have serious effect on several other sectors such as energy, water, and food. In this work, we have highlighted the various technologies for the treatment of wastewater.

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