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10 Physical and Biological Removal of the Mass Load of Emergent Pollutants from Waste Treatment Facilities

Linda U. Obi, Frances N. Olisaka, Felix C. Onyia, Israel H. Innocent, Paschaleen Onyemaechi

10.1 INTRODUCTION

One of the major effects of climate change is the difficulty in accessing water, and a broad and joint approach must be used to manage this limited resource if we are to increase resilience against climate change and provide for a growing population. According to the United Nations (UN) 2030 Agenda for Sustainable Development, Sustainable Development Goal (SDG) 6, which focuses on water and sanitation, also incorporates issues related to the management of water, wastewater, water resources, and ecosystems (Patel et al., 2020).

Contaminants of emerging concern (CECs) are also referred to as emergent pollutants (EPs); they are compounds that are introduced into the environment but for which there are currently no recognized restrictions (Wiest et al., 2021). Wiest et al. (2021) also explained that due to the increase in the global population and socioeconomic development in various sectors, such as industries, agriculture, and health, coupled with the prevailing changes in climatic conditions, increased water consumption has led to the generation of significant quantities of waste. Urban wastewater and effluent discharged from wastewater treatment facilities represent prominent sources of most emergent pollutants in aquatic ecosystems, and these EPs are toxic and typically persist in the environment, which makes them potentially dangerous to ecosystems and to the general public's health (Wiest et al., 2021). Emergent pollutants are naturally occurring or of synthetic origin, and they include pesticides, hormones, microplastics, personal care products, pharmaceuticals, and surfactants (Mahmood et al., 2022). The need for their removal is essential since these wastes are persistent in the environment and can bioaccumulate. To manage the accruing waste and mitigate the challenges of potential contamination of the surrounding

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ecosystem and destruction of habitats for wildlife, wastewater treatment facilities are constructed to treat and remove these wastes.

The treatment or removal of EP waste from treatment facilities involves four (4) distinct stages/levels, including preliminary, primary, secondary, and tertiary stages as described by Mahmood et al. (2022). The preliminary and primary phases are the initial phases that deal with screening and basic removal of physical wastes while the secondary phase is the implementation of techniques that will remove EPs that escaped the primary treatment phase. The tertiary treatment level removes about 85%–95% of suspended solids and 50%–90% of dissolved solids. While some municipal wastewater treatment facilities use a tertiary stage of treatment for EPs, the majority use primary and secondary levels of treatment (Mahmood et al., 2022).

Waste treatment facilities utilize some conventional technologies in their management of EPs resident in wastewater, and these include physical, chemical, and biological technologies. The use of just one technique for wastewater treatment is typically insufficient to provide the best results (Srivastava et al., 2021). According to Srivastava et al. (2021), Combining multiple procedures and performing them in sequence could have a favorable outcome. However, environmental sustainability depends on waste removal techniques that use both physical and biological methods. The physical techniques focus on straightforward design and cost-effectiveness. However, the selection of a physical removal process is based on the type of waste and its properties. Although cost-effective and efficient, biological techniques are inefficient for some EPs such as synthetic dyes; this is due to the ability of such EPs to resist aerobic biodegradation (Srivastava et al., 2021).

Nevertheless, chemical treatments typically have toxic by-products and are ineffective (Mahmood et al., 2022). Physical strategies for the removal of EPs from treatment facilities include sedimentation, filtration, stabilization/solidification, floatation, coagulation, etc. Sedimentation is a physical water treatment strategy that employs the force of gravity in the removal of suspended materials from water. A subsequent waste removal technique, filtration removes solid particles from a liquid or gaseous fluid by passing it through a filter membrane (Shen et al., 2021). The biological waste removal strategies employ the degradation potentials of microorganisms, and they encompass activated sludge, trickling filters, etc.

This chapter focuses on the stages of EP treatment as well as the techniques used to physically and biologically remove EPs from waste facilities. The potential challenges and prospects for the effective removal of EPs from waste treatment plants were also addressed.

10.2 ORIGIN AND TYPES OF EMERGING POLLUTANTS

Emerging pollutants are usually introduced into the environment through human activities. These emerging pollutants (EP) are made up of substances such as pharmaceuticals, personal care products (PCPs), surfactants, plasticizers, pesticides, industrial chemicals, additives, endocrine disruptors, microbeads, etc. (Patel et al., 2020).

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10.2.1 Pharmaceuticals

A variety of chemical substances have been used to formulate certain products to meet human satisfaction. These products include cosmetics, pharmaceuticals, personal care products, pesticides, insect repellents, synthetic hormones, artificial sweeteners, as well as cleansing products (Kolpin et al., 2002).

Pharmaceuticals are chemical compounds that are either naturally secreted or artificially blended with the ultimate intention of preventing the spread of disease, curing the disease, or enhancing human life (Maletz et al., 2013). Different compounds associated with these pharmaceutical products have been detected in both fresh and wastewaters worldwide (Vulliet and Cren-Olive, 2011). Based on therapeutic use, pharmaceutical drugs in circulation include antibiotics (ciprofloxacin), antimicrobials (penicillin), anti-epileptic (carbamazepine), anti-diabetics, anti-inflammatories, analgesics, anti-histamines, anti-ulcer, anti-anxiety (diazepam), and lipid regulators (clofibrate) (Kanakaraju et al., 2014). The main classes of pharmaceutical drugs that are prevalently available in water bodies include nonsteroidal anti-inflammatory drugs, anticonvulsants, antibiotics, and lipid regulators (Mompelat et al., 2009). Pharmaceutical products are compromised by their chronically toxic effects because their compounds are biologically undegradable and water-insoluble, thus are available in both waste and freshwater bodies.

10.2.2 Personal Care Products (PCPs)

These are products produced from different substances, both active and inert. These substances include both prescribed and non-prescribed pharmaceuticals which are used by humans for personal care purposes and animals for veterinary purposes (Jiang et al., 2013). These products include synthetic hormones, cosmetics, preservatives, toiletries, fragrances, insect repellent, shampoos, lipid regulators, steroids, as well as analgesics as described by Jiang et al. (2013). Most of these products are routinely used and, thus, common to us. However, they are not ingested like pharmaceutical products; rather, they are used topically (Jiang et al., 2013). Personal care products can be grouped into two, these include polycyclic musks as well as parabens (Fawell and Ong, 2012). Many consumer products, such as hand soaps, air fresheners, lotions, toothpaste, etc., are manufactured with disinfectants like chloroprene and triclosan (Fawell and Ong, 2012).

Recently, there has been the identification of personal care products (PCPs) (in their original or transformed state) from water bodies, including water treatment plants due to their incessant usage by the populace. They end up in the community water system and soil after being introduced from leached farmland manure/sewage treatment plants, swimming, bathing, and showering (Parra-Saldivar et al., 2020). These PCPs are fully converted into harmless substances such as carbon dioxide and water, while the lipophilic and non-biodegradable products get attached to other hydrophilic compounds as they get absorbed partially into sedimentation sludge (Jiang et al., 2013). The more abundant substances in the environment are the quantity of the PCPs that are introduced either in their originality or transformed/metabolized state in the wastewater treatment plants.

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10.2.3 Endocrine Disruptive Chemicals (EDCs)

Certain compounds have been identified to interrupt the function of hormones secreted by the endocrine gland. These compounds are referred to as 'endocrine-disrupting compounds/modulators' (Ferguson et al., 2013). These compounds are available in products such as cosmetics, plastic bottles, detergents, children's toys, etc. These have been documented to have caused harmful effects on the endocrine systems of aquatic life including fish, and these chemicals modify the body physiology as well as trigger the basic regulatory function in the body fluid (Ferguson et al., 2013). These effects may be transgenerational as well as irreversible (Patel et al., 2020). These compounds could be introduced into the environment both synthetically (through organic chemicals from some anthropogenic activities like bisphenol A) and naturally (through estrones, androgens, gestagens) (Patel et al., 2020). In a study by Tremblay et al. (2018), it was discovered that the basic source of steroid estrogens is crop residues and that estrogens are present in soil drainages, streams, stock grazing fields, runoff from dairy wastes, groundwater, and lands

10.2.4 Antiseptics

Antiseptics such as triclosan are known to be present in household appliances, toothpaste, soaps, clothing, fabrics, etc. When present in tap water, they yield chloroform as a chlorinated by-product (Gwenzi et al., 2018). Triclosan is broken down into dioxins in the environment. These include 2,4-dichlorophenol and 2,8-dichlorodibenzo-p-dioxin. Triclosan has been discovered in many water bodies in the United States, and its complete removal has not been achieved even with the conventional treatment methods; thus, its safety standards in drinking water are yet to be established (Gwenzi et al., 2018).

10.2.5 Perfluorinated Compounds (PFCs)

These compounds are found in paints, polishes, waxes, electronics, food packages, etc. Examples include perfluorocarbon sulfonic acids (PFSAs), perfluorinated carboxylic acids (PFCAs), perfluoro octane sulfonate (PFOS), and perfluorooctanoic acid (PFOA), while the last two are most commonly in use (Bai et al., 2018). There is detection of PFOA in drinking and treated water sources, possibly due to their release from industrial facilities and non-point sources (Bai et al., 2018). Their existence has also been observed in drinking water wells through contaminated groundwater. PFOA can gain access to groundwater through the atmosphere from close industrial sites up to 20 miles away before being deposited onto soil and seepage into underground water (Zhu and Kannan, 2019).

10.2.6 Disinfection By-products (DBPs)

Drinking water treatment plants have been observed to be the basic source of disinfection by-products (Stalter et al., 2020). Halogenic acetic acids (HAAs) and trihalomethane (THMs) were discovered to account for 38.1% and 42.6% of all DBPs, respectively, in all treated samples. Depending on the water source, the level of DBPs in

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drinking water has been observed to vary with surface water having the highest levels, mixed water sources, and groundwater having the lowest levels (Stalter et al., 2020).

10.2.7 Pesticides

The possible means of introducing pesticides into drinking water is a result of carelessness such as sizeable accidental spills, siphoning, and application in lawns (Srivastav et al., 2020). The metabolites of pesticides have been observed to be heavily released in the soil through leaching, and most of these metabolites in water matrices showed prevalent wide usage in city centers (Gallé et al., 2020).

10.3 POSSIBLE EFFECTS OF EMERGING POLLUTANTS ON THE ECOSYSTEM

Adverse effects of emerging pollutants have become a serious concern to the entire populace because of being implicated in causing cancer and disruption of the endocrine system. Endocrine disruption chemicals negatively affect the hormones of living organisms (Jiang et al., 2013). The normal hormone level could be negatively affected by this disruption, thereby resulting in abnormal regulation of hormone secretion and metabolism as stated by Afshan et al. (2020). The sexual development of a mother's offspring can be negatively affected when she gets exposed to any of these endocrine-disrupting compounds such as bisphenol A and alkylphenol ethoxylate, (Afshan et al., 2020). Secondary metabolites are generated when the pharmaceutical and personal care products (parent compounds) present in our environment are biotransformed, and the impact of these metabolites could be more toxic than the parent compounds with an unclear adverse effect on non-target organisms (WHO, 2015). Prolonged exposure of living organisms (including aquatic life) to these compounds endangers their lives heavily as a result of acute toxicity.

The possible ecological threats posed by antibiotics in marine ecosystems cannot be over-emphasized.

Lin et al. (2024) investigated the impact of two antibiotics, levofloxacin (LEV) and norfloxacin (NOR), on the cell growth parameter and eventual physiological variation of the marine microalgae *Skeletonema costatum* after exposure. It was observed that both drugs repressed the growth of *S. costatum* at all concentrations except at 10 mg/L for NOR. Another study by Pradit et al. (2024) discovered the abundance of heavy metals and microplastics in lagoon sediments. This may serve as a source of toxicity to marine organisms and humans, as it will greatly affect the food chain of the marine habitat.

10.4 DIFFERENT PHASES INVOLVED IN THE TREATMENT OF EMERGENT POLLUTANTS

10.4.1 Preliminary Phase of Treatment of Emergent Pollutants

The removal of large organic and inorganic debris present in flowing water, such as huge wood, boulders, plastics, dead animals, and tree branches, is part of the

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preliminary treatment of emerging contaminants in wastewater (Oakley and Von Sperling, 2017). It is the first treatment operation used in the removal of emerging pollutants in wastewater and has no direct benefit in terms of improving water purity; rather, its main importance is in protecting the water treatment equipment and infrastructure from clogging while also ensuring their long-term viability. Over time, the accumulation of debris in the treatment facility can erode it and cause wear and tear (Metcalf and Eddy, 2014). This phase consists of two major processes.

10.4.1.1 Screening

The screening procedure involves removing huge floating or suspended material from moving waters. If not removed, this debris could clog the pipes and inhibit efficient water treatment in the primary, secondary, and tertiary phases of treatment (Oakley and Von Sperling, 2017). Screens for this treatment range from coarse to fine, and they are often made of steel set parallel to one another or iron bars with small apertures of approximately an inch. Mesh screens with fewer apertures could be used to make other varieties. They are normally installed in chambers and face the direction of the flowing water. The debris is trapped at the screen's surface and can be cleaned both manually and mechanically (Oakley and Von Sperling, 2017). For large-scale wastewater treatment plants, a device called a comminutor or a barminutor is utilized in large-scale treatment plants. These devices capture and chop huge and heavy garbage to make collection easier (Oakley and Von Sperling, 2017). After being filtered, the wastewater is routed into the grit chamber for further treatment.

10.4.1.2 Grit Removal

Grits are heavy inorganic solids with specific gravities ranging from 2 mm to 2.65 mm, such as sands, gravel, heavy sticks, and metal bits. Allowing the water to settle causes tiny particles with a higher mass compared to the particles surrounding them to be gravity-sorted, or drop to the bottom of the mixture (Lee et al., 2020). Here, grit chambers are used to collect particles and transport them to a precise spot where they may be securely and effectively removed. Grit removal will be accomplished by automated gear in larger water treatment plants, although smaller plants may do so manually. Grit collection over time may cause excessive wear and abrasion at various treatment phases and must consequently be eliminated by utilizing grit chambers. After collecting these grits, they are either buried or utilized as manure (Oakley and Von Sperling, 2017)

10.4.2 Primary Phase of Treatment of Emergent Pollutants

The primary step of emergent pollutant treatment comprises filtration and sedimentation to remove a percentage of the suspended solids (scum) and organic matter from wastewater to decrease debris for further downstream treatment procedures (Metcalf and Eddy, 2014). It is sometimes referred to as primary sedimentation. The primary treatment's goal is to settle material by gravity, eliminate floatable debris, and minimize pollutants to make later treatment easier. The primary goal of wastewater treatment is to minimize the biochemical oxygen demand (BOD) and total

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suspended solids (TSS). BOD refers to the amount of dissolved oxygen consumed by aerobic microorganisms when organic matter is decomposed in water, while TSS refers to suspended particles in wastewater. The sediment, known as primary sludge, is highly decomposable and must be cleaned from the bottom of the sedimentation tank that holds the wastewater regularly (Oakley and Von Sperling, 2017). This is generally accomplished by anaerobic digestion as described in Figure 10.1. In this phase, two fundamental therapies are used.

10.4.2.1 Biological Treatment

Anaerobic digestion is the biological treatment used in this phase of treatment. Following digestion, the sludge is moved to the digester, a large enclosed tank where the main sludge is digested using facultative bacteria such as Proteobacteria, Firmicutes, Bacteroides, and Actinobacteria (Marín et al., 2015). Anaerobic bacteria use the organic nutrients in the sludge to generate carbon dioxide and methane gas. According to Oakley and Von Sperling (2017), the action of these microbes makes it safe to dispose of this sludge to the environment by lowering the cell biomass present and enhancing its dewaterability (eliminating water existing in it or removing moisture) for later treatment. To do this, the digester is heated to 35–37 degrees Celsius, and the digestion takes 15–28 days with optimum mixing to promote mass transfer. The digested gas contains 35% carbon dioxide and 65% methane, and it is utilized to power the treatment facility (i.e. large-scale treatment plants).

10.4.2.2 Chemical Treatment

This is also known as chemically enhanced primary therapy (CEPT) or advanced primary treatment (APT) (APT). They are used to boost sludge treatment performance (anaerobic digestion) as described by Metcalf and Eddy/AECOM (2014). The CEPT treatment used flocculation as well as traditional primary sedimentation. Flocculation is the process by which particles in water collide and attach, resulting in the formation of flakes, whereas APT treatment employs coagulation-flocculation with a high-rate lamellar settler for substantially shorter hydraulic retention durations (Metcalf and Eddy/AECOM, 2014). Before the effluent is disposed of, chemical treatment such as pH correction or pre-reduction of a high organic load may be necessary.

10.4.2.3 Secondary Phase of Treatment of Emergent Pollutant

The secondary treatment employed in the treatment of emergent pollutants in wastewater is the removal of biodegradable organic matter from wastewater. Secondary treatment is said to eliminate roughly 85% of the water's biochemical oxygen demand (BOD). The majority of their treatment is done through biological approaches. This therapy employs two types of biological systems.

10.4.2.4 Activated Sludge Treatment

This is a biological wastewater treatment that involves the mixture of microorganisms in a bioreactor. It is an aerobic method that uses a high biomass of microorganisms, mostly bacteria, protozoa, and fungus, to remove the clumped organic

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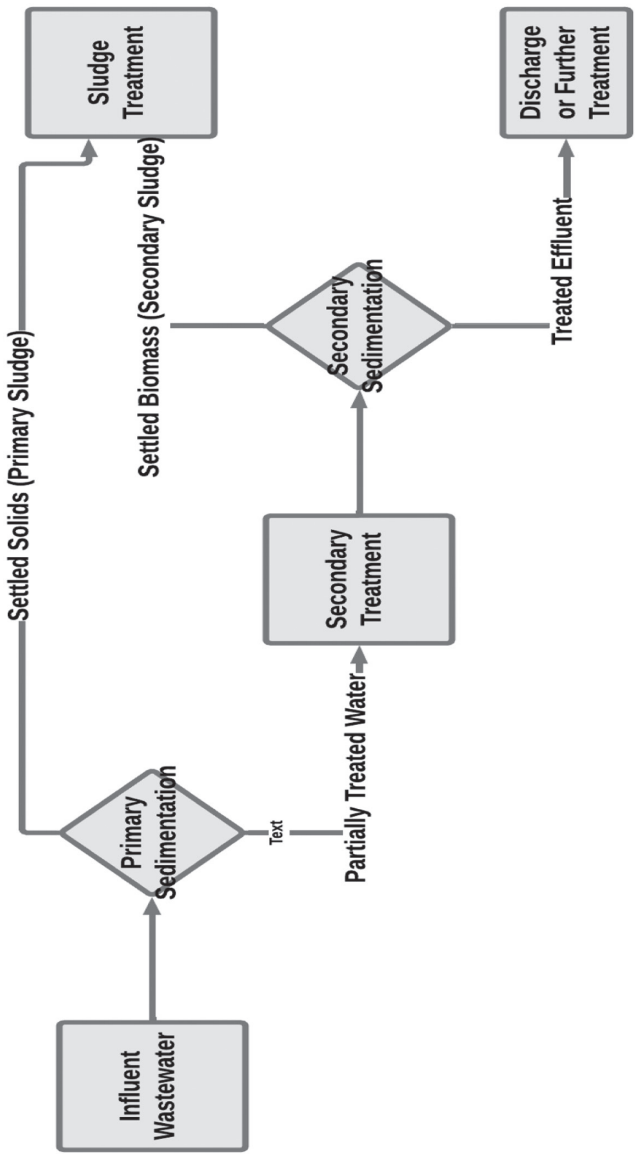


FIGURE 10.1 Description of primary sedimentation during primary and secondary treatment of wastewater and sludge management.

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materials in the wastewater (Marin et al., 2015). By agitation and aeration, the main effluent from the primary treatment phase is thoroughly mixed with microorganisms as documented by Marin et al. (2015). This technology includes injecting air into the bioreactor with adequate mixing to allow oxidation to occur. The biological flocs (sedimented sludge) are then allowed to settle in a settling tank, separating the sludge from the clear treated water. A portion of the waste sludge is recycled and transferred to the aeration tank, while the remainder is collected for further treatment and disposal, either directly into the soil or by burial. Diffused aeration, surface aerators (cones), and in rare cases, pure oxygen aeration are all ways of aeration. The benefits of utilizing activation sludge treatment include a decreased ammonia level, the possibility of utilizing it in tiny places, and the fact that it is typically odor-free (Drewnowski et al., 2019). Aside from the benefits of this technology, the high energy required to operate the aeration tank has an impact on utilization (Drewnowski et al., 2019). The availability of oxygen, temperature, and the characteristics of the treated wastewater are all factors that influence the activation sludge system (Kolev, 2017).

10.4.2.5 The Use of Trickling Filters

Trickling filters treat wastewater by carrying a large population of microorganisms on a stable surface and removing organic materials aerobically with the organisms attached to a media (usually rocks or plastic). As the wastewater travels over the medium, microorganisms in the water cling to the rock, slag, or plastic surface and form a film (Naz et al., 2015a). The organic material is then digested by aerobic microbes in the slime layer's outermost region. As the slime layers thicken due to microbial activity, oxygen cannot permeate, and anaerobic organisms form and lose their capacity to adhere to the medium, causing some of the slime to slip off the filter into the wastewater (Naz et al., 2015a). This is referred to as sloughing. The biomass consumes oxygen-demanding compounds as the wastewater flows through the media, and the water leaving the media is significantly cleaner. However, some biomass sloughs off the medium and must settle in a secondary treatment tank. The subsurface drainage system collects the slime and transports it to the clarifier for disposal (Oakley and Von Sperling, 2017). The secondary treatment effluents are subjected to further treatment to minimize the microbial burden. The advantages of this system include the fact that it is appropriate for regions where large areas of land are not accessible, that it is successful in treating high concentrations of organic waste depending on the medium used, that it is durable, and that it has minimal power needs. The disadvantages of this treatment technique include the following: it necessitates the operator's continual attention, the incidence of clogging is quite high, there are vector and odor issues, and flexibility and control are restricted when compared to activated-sludge procedures (Oakley and Von Sperling, 2017)

10.4.2.6 Tertiary Phase of Treatment of Emergent Pollutants

After secondary treatment, tertiary treatment of wastewater entails several additional procedures to further eliminate pathogenic bacteria, non-biodegradable chemicals, heavy metals, and some residual inorganic dissolved solids (Hu et al., 2017). In this treatment, wastewater satisfies a higher standard than the secondary treatment's

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effluent. The majority of methods include some form of physicochemical treatment, such as coagulation, filtration, organic activated carbon adsorption, reverse osmosis, and further disinfection. Others involve the application of UV radiation. This is the most sophisticated therapy used to tackle emerging contaminants (Hu et al., 2017). UV radiation is one of the most regularly utilized treatment methods (Hu et al., 2017).

10.4.2.7 Ultrafiltration

Ultrafiltration is a method intermediate between microfiltration and nanofiltration. Ultrafiltration membranes typically have holes ranging from 10A to 1,000A. Larger particles move through the membrane less easily when the pore diameters are smaller. As a result, the rate of fluid filtration is determined by the pore size of the membrane (Kim et al., 2018). According to Kim et al. (2018), pressure is the driving factor for mass transfer in ultrafiltration, as it is in reverse osmosis, nanofiltration, and microfiltration. The pressure differential for the ultrafiltration process is typically in the range of 2 to 5 bars, and it is applied to the system via the pump and the feed solution. Solvent molecules and tiny dissolved solids move across the membrane under these circumstances, whereas bigger molecules and colloidal particles are trapped and remain behind them. The purpose of using this approach is to deal with the phenomena of concentration polarization and membrane fouling.

10.4.2.7.1 Nanofiltration and Microfiltration

The membranes used in nanofiltration contain pores close to or lower than a nanometer, and the size is usually around 0.5 nm to 1.5 nm. It is a process between ultrafiltration and reverse osmosis. The holes of nanofiltration membranes are near to or less than a nanometer in size, typically ranging from 0.5 nm to 1.5 nm. Kim et al. (2018) described microfiltration, on the other hand, as a filtration technique that uses porous membranes to separate suspended particles with diameters ranging from 0.9 microns to 90 microns from the flow of gases and fluids. This method's acceptable benefits include the appropriate specification of the external product (output), simple operating circumstances, the membrane process's capacity to combine with other processes (adsorption, chemical, and biological features), and the system's simpler control.

10.4.2.7.2 Reverse Osmosis

Reverse osmosis is a method that separates minerals from wastewater using membranes that are permeable to water but not to minerals (Collivignarelli et al., 2018; Kim et al., 2018). By exerting pressure from the feeding side, mineral-containing water is forced through the membrane, and solute-free water is collected as the leaking flow. Under pressure, water is forced through a succession of semipermeable membranes. External pressure exceeds normal osmotic pressure. The bigger molecules are then cleansed as they pass in a lateral flow along the membrane. Because these holes hinder the passage of molecules bigger than water molecules, as a result, the smaller molecules can pass through the pores of the membrane, whereas the bigger ones cannot (Kim et al., 2018). The bigger molecules are then cleansed as they pass in a lateral flow along the membrane. Because these pores prohibit molecules bigger than water molecules from passing through, permeated water flows from one side and concentrated water (brine) flows from the other.

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Reverse osmosis can remove 90% to 99% of all TDS and colloidal particles from water. Sodium, potassium, sulfate, bicarbonate, silicate salts, bacteria, viruses, and other wastewater-soluble entities are examples of these salts. According to Kim et al. (2018), emerging contaminants from pharmaceutical goods such as ciprofloxacin may be eliminated using a reverse osmosis membrane under continuous pressure.

10.4.2.7.3 Ultraviolet Radiation

According to Collivignarelli et al. (2018), this form of treatment is employed particularly for disinfection since it does not produce undesired disinfection by-products. UV light is employed because it destroys the DNA of bacteria and also produces a photooxidation by-product that kills or damages any diseases or germs present. Photooxidation is a chemical process that happens when light is absorbed in the presence of oxygen. Some bacteria are known to be resistant to UV radiation, while others can mend and recover from its effects (Collivignarelli et al., 2018).

In terms of effluent quality, simplicity of operation and maintenance procedures, cheap cost, and the small amount of operating space required, nanofiltration is superior to other traditional filtration technologies for processing medicines and personal care items (Hu et al., 2017; Mehran Abtahi et al., 2018). However, reverse osmosis is the most effective method of pesticide removal. In actuality, there are no universal principles since performance is dependent not only on the membranes employed and the pretreatments that the effluents go through but also on several criteria such as the complexity of the effluents, the type(s) of substance(s), or their concentration. As a result, several studies must be carried out before deciding on the membrane technology to be employed.

According to Mehran et al. (2018), the upsides of membrane filtration embody the availability of a wide variety of commercial membranes from numerous manufacturers, standard style, little footprint, easy and economical technologies, production of high-quality treated waste matter, no chemicals needed, low energy consumption, and well-known separation mechanisms.

10.5 CONTEMPORARY STRATEGIES FOR WASTE REMOVAL/ MANAGEMENT FROM TREATMENT FACILITIES

10.5.1 Physical Waste Removal Strategies

Physical waste removal methods employ mechanical properties for the separation and removal of solid particulate matter from wastewater.

10.5.2 Sedimentation

Sedimentation is the oldest and most commonly used technique in the treatment of wastewater Zabava et al., 2016). It refers to the process by which coagulated flocs are allowed to settle. A variety of chemical compounds are utilized in facilitating this process. These compounds may include salts of metals such as ferrous sulfate ($FeSO_4.7H_2O$), ferric chloride ($FeCl_3$), ferric sulfate ($Fe_2(SO_4)_3$), aluminum sulfate

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$(Al2SO_4)_3$, and calcium hydroxide ($CaOH_2$) (Bezirgiannidis et al., 2019). Numerous studies have been conducted to assess the application of sedimentation in wastewater treatment.

Bezirgiannidis et al. (2019) evaluated the use of chemically enhanced primary sedimentation/treatment (CEPT) in the treatment of municipal wastewater. After CEPT, significant improvements in pollutant parameters, including chemical oxygen demand (COD), 5-day biological oxygen demand (BOD5), nitrogen (NH4+-N), total suspended solids (TSS), volatile suspended solids (VSS), and phosphorus (PO43-P), were reported, characterized by removal efficiencies of 62%, 56%, 14%, 72%, 71%, and 71%, respectively.

In another study by Ren et al. (2020), chemical sedimentation, aimed at turbidity, organic and inorganic phosphorus removal from turbid wastewater was proposed. It involved the use of ferric chloride ($FeCl_3$) as a precipitant followed by the application of starch-based flocculant. This modified process led to a decrease in turbidity and total phosphorus of 95% and 90%, respectively, values higher than observed in traditional chemical sedimentation using just $FeCl_3$. Lin et al. (2017) developed a new strategy involving the use of $FeCl_3$ as a coagulant for chemically enhanced primary sedimentation (CEPS). It was aimed at improving the removal of nutrients, energy saving, and resource recovery in municipal wastewater treatment. At a concentration of 20 mg-Fe/L, the removal efficiencies of total organic carbon (TOC) and phosphorus (PO43-P) were 75.6% and 99.3%, respectively. Chen et al. (2019) demonstrated a dose-dependent action of $FeCl_3$ in the removal of pollutants from raw wastewater by sedimentation. 25 mg/L $FeCl_3$ was identified as the optimal dosage for pollutant recovery, as it led to about 78% of COD and 95% of phosphorus.

10.5.2.1 Filtration

Filtration is an important stage in water treatment. It involves the removal of suspended solid substances from water using various processes such as fine mesh screening, media filtration, and membrane filtration. Media filtration systems employ layers of filter media such as sand, anthracite, and gravel to separate suspended solids from incoming feed water (Liu et al., 2018). Different types of materials have been studied to determine their efficacy in the removal of various forms of waste materials from water. Liu et al. (2018) applied deep filtration processes in the removal of oils from oily wastewater using ZnO and octadecyltrichlorosilane-coated quartz sand filter media. It was observed that the filter media used in the process enabled a highly efficient filtration process and could potentially be applied in oily waste treatment. In another study, Shen et al. (2021) evaluated the efficiency of aluminosilicate filter media in the removal of microplastics from wastewater. The aluminosilicate filter media used was modified by cationic surfactant, and it was observed to have a significantly higher removal (>96%) of microplastics than rapid sand filters (63%).

Another media filtration method used in waste management is slow sand filtration (SSF), which is widely regarded as one of the most proficient strategies for the elimination of pathogens, particulate organic matter, and turbidity from wastewater (Amy et al., 2006). Kaetzl et al. (2020) evaluated the applicability of anaerobic biochar filters and slow sand filters in wastewater treatment. Their study revealed a

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significant extent of COD and TOC removal by both filters used but a higher removal in biochar filters than in sand filters. Additionally, biochar filters removed a significantly higher concentration of *E. coli* (1.35 ± 0.27 log10MPN·100 mL^{-1}) than sand filters (1.18 ± 0.31 log10MPN·100 mL^{-1}). In addition, Joel et al. (2018) demonstrated the use of slow sand filtration techniques in raw wastewater treatment. The filtered wastewater was observed to meet the recommended COD and TC standards set for irrigation purposes. The filtration mechanism was explained to be a combination of mechanical (absorption, diffusion, screening, and sedimentation) and biological processes as water percolated through the sand.

10.5.2.2 Solidification and Stabilization

Solidification and stabilization (S/S) are major treatment strategies for the management of industrial-generated hazardous wastes. It involves mixing a binding reagent into the contaminated media or waste (Hashemi et al., 2019). Solidification and stabilization are progressively efficient pretreatment techniques that encapsulate and immobilize hazardous waste materials to achieve a decrease in leaching of the toxic elements in landfills (Hashemi et al., 2019). It involves the application of chemical agents, in addition to water and other sludge components, to form stable solids. According to numerous publications, the most common S/S material is cement. Tajudin et al. (2016) conducted a review of various agents used in S/S processes, including ordinary Portland cement (OPC), quicklime, fly ash, rice husk ash, bottom ash, calcium aluminate cement (CAC), pozzolanic cement, sulfate-resistant Portland cement (SRC), montmorillonite, diatomite, and sepiolite, among others. In an earlier study, Malviya and Chaudhary (2006) extensively reviewed the application of solidification and stabilization processes in treating hazardous wastes. Parameters to evaluate solidification were highlighted as strength, setting time, and extent of hydration. Cement content, curing time, and water-to-solid ratio were also identified as factors known to affect the strength development of the solidified/stabilized matrix. It was further emphasized that the performance of S/S products could be enhanced using additives such as silica fume, sulfur polymer, $CaCl_2$, $Ca(OH)_2$, Na_2SO_4, and K_2SO_4.

Solidification/stabilization is described as one of the most desirable techniques for the remediation of soils polluted with heavy metals, owing to its convenience and effectiveness. Jiang et al. (2019) analyzed the application and mechanism of action of alkaline industrial wastes (soda residue, steel slag, carbide slag, and red mud) for the solidification/stabilization of soil contaminated with heavy metal. Soda residues, steel slag, and carbide slag were identified as potential agents for the solidification and stabilization of Pb, Cd, Zn, and Cu, while red mud was ascertained as a prospective agent for the stabilization of As. Hydration, precipitation, and adsorption were also noted as the mechanisms of action of the alkaline wastes. Also, a limitation in the implementation of remediation processes using these agents was underscored due to a lack of sufficient available information on the long-term effectiveness, synergistic effects, and implementation in multiple heavy metal-polluted soils.

Han et al. (2020) assessed the prospects of bacterial-induced mineralization (BIM) as an S/S strategy. The basis of its application is the production of acid anions by some bacteria which react with (heavy) metal ions in the soil to form stable metal salt precipitates. The precipitates are observed to promote consistency between

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solid particles in the medium, a process that is analogous to the binding effect in cement-facilitated S/S. Compared to the regular cement-based S/S procedure, BIM attained higher strength improvement capacity, water permeability, and durability. Additionally, Singh et al. (2023) evaluated the use of fly ash-based geopolymers (combinations of sodium silicate and alkaline compounds such as NaOH or KOH) as an alternative to cement for the environmentally friendly and cost-effective management strategy of hazardous wastes. The geopolymers were observed to confer significant compressive strength of 2 MPa–60 MPa in addition to total immobilization of heavy metals (such as Cr, Cd, and Pb).

10.5.3 Flotation

Flotation is a technique used in treating industrial wastes, involving the introduction of gas as the transport medium. It is applied in treating wastewater containing fine suspended solids and oily matter and is often used as an alternative to sedimentation. Types of flotation processes include dissolved air flotation, dispersed air flotation (or induced air flotation), plain gravity flotation, vacuum flotation, electrolytic flotation (or electroflotation), and biological flotation (Wang, 2006).

10.5.3.1 Dissolved Air Flotation (DAF)

Dissolved air filtration is a wastewater treatment process that involves the use of air to remove suspended matter, metals, oil, and grease. According to Rocha e Silva et al. (2018), it is a process that utilizes microbubbles injected from a saturator for the separation of suspended solids or oil droplets in water. Traditionally, DAF involves four stages: generation of microbubbles, chemical pretreatment of the wastewater, flotation, and sludge removal. The efficacy of DAF has prompted the incorporation of hybrid techniques which have had numerous applications in the removal of pollutants and adherence to environmental standards of turbidity, color, total suspended solids (TSS), chemical oxygen demand (COD), and biochemical oxygen demand (BOD) (Muñoz-Alegría et al., 2021).

One of the major applications of DAF is in the treatment of oily wastes, with oil contents that may range between 1% and 50% (Rocha e Silva et al., 2018). Studies have shown that regardless of the oil content, DAF is the best strategy for the treatment of oily wastes.

Lee et al. (2020) developed and reported a hybrid system for the treatment of industrial wastewater containing oils, volatile organic compounds (VOCs), and heavy metals. It applied principles of dissolved air flotation, electrochemical advanced oxidation process, and magnetic biochar. As a subpart of their study, a pilot-scale DAF system was employed in the treatment of laundry and food wastewater. From the results, it was observed that about 99.3% of the CODs and DOCs were removed from laundry, while 75% and 79% of the CODs and TOCs, respectively, were removed from the food wastewater.

Ortiz-Oliveros and Flores-Espinosa (2018) studied the simultaneous elimination of oil, total cobalt, and 60Co from radioactive liquid waste using dissolved air flotation. The results revealed a higher efficiency of DAF (94.84%) in the removal of oily wastes than total cobalt and 60Co (85.39% and 87.5%, respectively). Pereira et al.

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(2020) evaluated the performance of flocculants Tanfloc and polyacrylamide (PAM) in the treatment of dairy wastewater using dissolved air filtration. The results showed a turbidity removal of about 90%.

Ortiz-Oliveros and Flores-Espinosa (2020) proposed the use of a mobile dissolved air flotation system (MDF) for the treatment of liquid radioactive waste. Their results revealed a 95% turbidity removal using the proposed system, along with significant removals of other parameters ($SO_{4-}{}^{2}$, NO_3-, $PO_{3-}{}^{3}$, Ni, Cr, and Pb concentrations). Total solids, Co, and 60Co removal were reported to be about 85%–88%, 94%, and 75%, respectively. Additionally, Leite et al. (2019) demonstrated the use of DAF (preceded by coagulation) in retrieving microalgae cultivated in wastewater. Significant removal of turbidity (93.7%–96.2%), apparent color (91.7%–92.3%), total Kjeldahl nitrogen (TKN) (90.2%–92.6%), total phosphorus (89.4%–90.9%), and TSS (88.6%–92.5%) were observed. Additionally, Pooja et al. (2021) researched the treatment of wastewater from the electroplating industry using dissolved air flotation. It was aimed at the removal of toxic metals such as chromium, cadmium, nickel, lead, and copper from wastewater. Optimum conditions led to a total removal of 97.39% of all metals.

10.5.3.1.1 Dispersed Air Flotation

Dispersed air flotation (or induced air flotation) is a method involving the direct introduction of air into the wastewater through a revolving impeller, a diffuser, or an ejector at a pressure slightly higher than 1 atm for the generation of air bubbles (usually between 80 microns to over 1 mm in size) in high volumes under turbulent conditions (Wang, 2006). According to Alhattab and Brooks (2017), dispersed air flotation involves the production of bubbles by the injection of compressed air through the pores of a diffuser, with a diameter generally ranging between 60 µm and 655 µm and a bubble number of 2×105/cm3. The effectiveness of the dispersed air flotation process is reported to be dependent on the level of instability of the suspended particles, particle size, and extent of particle capture by bubbles. The addition of surfactants may also influence the efficiency of the procedure (see Figure 10.2 for pictorial illustration).

10.5.3.2 Coagulation/Flocculation

Water industries consider coagulation and flocculation to be the key treatment strategies for enhancing the overall efficiency and cost-effectiveness of wastewater treatment (Cui et al., 2020). Coagulation/flocculation involves the addition of compounds (coagulants) that stimulate the aggregation of minute flocs into larger flocs so that they can be more easily separated from the liquid part. As a result of an increase in the severity of environmental pollution problems and stringency in water quality demands, conventional coagulation/flocculation techniques have fallen short in their ability to meet requirements for water safety standards. This has led to the advent of enhanced coagulation and optimized coagulation which involve improved treatment processes to achieve the effect of enhanced wastewater treatment (Cui et al., 2020).

There is already existing information on enhanced coagulation and optimized coagulation techniques provided by many authors. Some of these technologies are discussed next.

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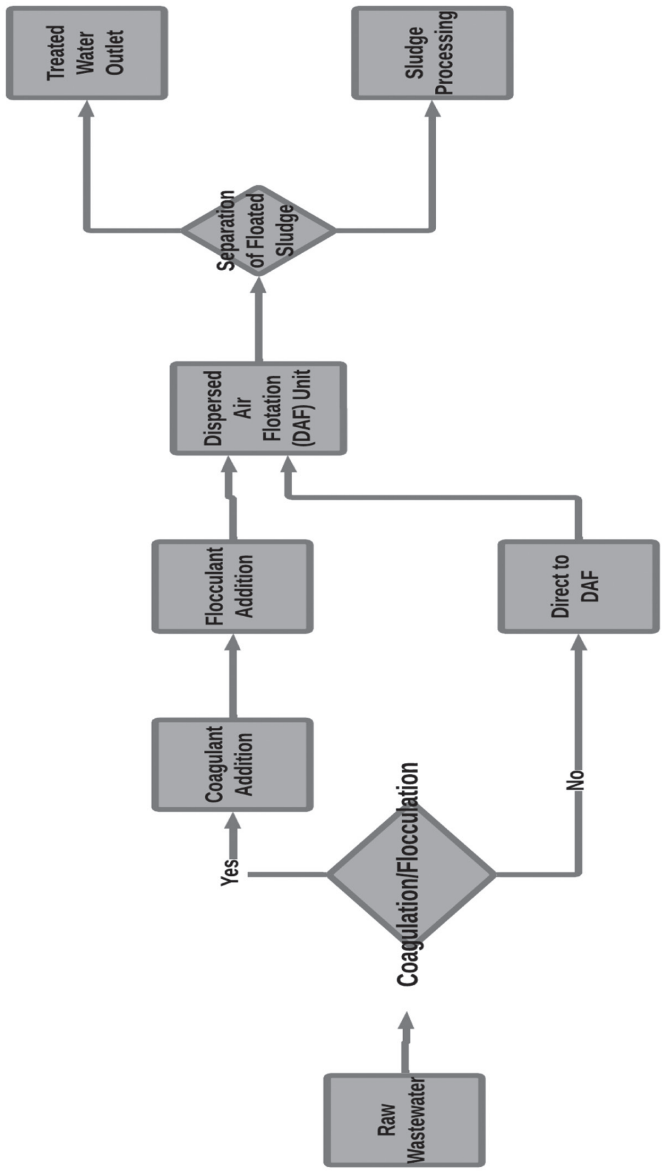


FIGURE 10.2 Flowchart describing the dispersed air flotation system in wastewater treatment.

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10.5.3.2.1 Ballasted Coagulation

Ballasted coagulation as an enhanced coagulation method has been extensively applied in wastewater treatment to facilitate the removal of organic matter, bacteria, color, and algae (Zhang et al., 2021). Gaikwad and Munavalli (2019) studied the efficacy of *Strychnos potatorum* and *Moringa oleifera* with and without a ballasting agent (micro sand) in stimulating flocculation. It was observed that sand-ballasted coagulation with the coagulants (SP and MO) increases flocculation and turbidity removal by 5%–10% when compared to conventional coagulation. This finding was in line with an earlier study by Mackie et al. (2016), who reported a significant enhancement in the removal efficiency of particulate and dissolved contaminants by the action of micros and as a ballasting agent.

10.5.3.2.2 Magnetic Separation Technology

Li et al. (2022) proposed an advanced strategy for the disposal of high arsenic wastewater using nano-zerovalent iron (nZVI) and ferric oxyhydroxide (FeOOH) combined with superconducting high-gradient magnetic separation (HGMS) technology. The results showed that 99.06% of arsenic was successfully removed from wastewater through magnetic flocculation. Additionally, Prot et al. (2019) used magnetic separation techniques to separate phosphorus in the form of vivianite ($Fe(II)_3(PO4)_2.8H_2O$) from wastewater. Vivianite is reported to be the major phosphorus sink in digested sewage sludge and may contain between 70%–90% of the total phosphorus. From the results, magnetic separation, coupled with alkaline treatment, led to a recovery of 16%–32% of phosphorus from the digested sludge. It was concluded that this technology could be feasibly implemented in the extraction of phosphorus from digested sludge.

10.5.3.2.3 Chemical Oxidation-Enhanced Coagulation

Zhao et al. (2013) assessed the action of chemical oxidants ozone and potassium permanganate on coagulation in micropolluted raw landscape lake water. Compared with coagulation by polyaluminium chloride (PAC), results showed that pre-oxidation using 2 mg/L of O3 for 20 minutes could significantly enhance the elimination rate of turbidity and total organic carbon (TOC 5.33% and 5.06%, respectively. Furthermore, Dong et al. (2022) reported enhancements in the use of a combination of permanganate (Mn(VII)) pre-oxidation and Fe(III)/peroxymonosulfate (PMS) coagulation process (Mn(VII)-Fe(III)/PMS) for the removal of dissolved organic carbon (DOC), turbidity, and micropollutants from raw water. Again, Qiu et al. (2021) studied a strategy for the effective removal of *Microcystis aeruginosa* and controlling algal organic matter from eutrophic water using Fe(II)/peroxymonosulfate (PMS) pre-oxidation–enhanced coagulation. The highest removal efficacy of *M. aeruginosa* (94.3% of an initial 1.0 × 10 6 cells/mL concentration) was observed at low PMS dosages of 20 mg/L and Fe(II) dosage of 4.5 mg/L.

Other enhanced coagulation methods include ultrasound-enhanced coagulation (Huang et al., 2021), inorganic polymer flocculants (Zhang et al., 2021; Yang et al., 2018), and biopolymer-based flocculants (Makhtar et al., 2020; Xia et al., 2018; Cunha et al., 2020).

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10.5.4 Biological Waste Removal Strategies

The biological waste management process employs microorganisms for the breakdown of waste materials into stable end products (Bressani-Ribeiro et al., 2018). Based on the presence of dissolved oxygen, biological waste treatment is divided into aerobic and anaerobic treatment practices.

10.5.4.1 Trickling Filter

The trickling filter (TF) is an aerobic treatment system that utilizes microorganisms attached to a medium to remove organic matter from wastewater. TFs are non-submerged aerobic biofilm reactors, consisting of a tank containing highly permeable material, onto which wastewater is applied through a distribution system (Bressani-Ribeiro et al., 2018).

Naz et al. (2015b) assessed the performance of a locally designed pilot-scale stone-media trickling biofilter for the treatment of municipal wastewater. The system was evaluated for its removal capacity of pollution indicators COD, BOD_5, NH_4, and fecal coliforms under conditions of increasing environmental temperature ranging from 20°C to 40.5°C over 40 days. The results showed a removal efficiency of 62.4%, 56.4%, and 33.8% for COD, BOD5, and NH4-N, respectively at 20°C on day one. At day 40, the removal efficiencies had increased to 98.1%, 98.6%, and 93.5% for COD, BOD5, and NH4-N, respectively, at 40.5°C. Additionally, an 88% reduction of fecal coliform was reported during the process.

Trickling filters have also been applied in the treatment of toxic raw chemicals. A study by Wu et al. (2016) was aimed at treating waste containing methyl acrylate gas. For the process, a three-layer laboratory scale biotrickling filter, packed with ceramic particles and immobilized with activated sludge, was established. The setup was designed to determine a relationship between the efficiency of the process, inlet concentration, temperature, time, and flow rate. The highest removal efficiency (>97%) was observed between day 29 and day 52 at a concentration of 4292.1 mg/m3. An increase in the flow rate at the same concentration did not lead to a decrease in the removal efficiency of the process until the 72nd day.

In a similar study, Yang et al. (2018) assessed the removal of n-butyl methacrylate from gas streams in two biotrickling filters (BTFs). One setup contained only ceramsite (BTFa), while the other contained ceramsite coated with activated carbon fiber (BTFb). The efficiencies of the two BTFs were assessed to determine the effect of the activated carbon fiber. The results revealed that the BTFb was 15.3% more efficient in the removal of n-butyl methacrylate than BTFa under empty bed residence time (EBRT) of 44s and inlet concentration of 500 mg/m3.

Zhao et al. (2022) investigated the application of a biotrickling filter packed with bamboo charcoal powder-based polyurethane (BC-PU) for the simultaneous treatment of n-hexane and dichloromethane (DCM). The highest removal capacity of n-hexane and DCM was 12.68 gm−3h−1 and 30.28 gm−3h−1 DCM, respectively. It was also observed that an increase in inlet loading (IL) of DCM led to a corresponding decrease in the removal efficiency of n-hexane. This inhibitory effect was explained to be a result of competition between enzymes produced by different microorganisms for substrate-active sites. It was concluded that BC-PU could be extensively applied in the treatment of hydrophobic pollutants.

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10.5.4.2 Membrane Filtration

Membrane filtration (MF) is a pressure-driven separation procedure that uses a membrane for the separation of particles and macromolecules (Benjamin and Lawler, 2013). Membrane filtration is considered a more effective pretreatment technique than traditional methods because in comparison with the latter, membrane systems necessitate less space and chemicals (Jeong et al., 2017). Membrane filtration technology is comprised of five major treatment techniques: reverse osmosis (RO), ultrafiltration (UF), microfiltration (MF), nanofiltration (NF), and electrodialysis (ED) (Azimi et al., 2017). An aspect of membrane filtration that has received significant attention recently is direct membrane filtration. It employs a micro-/ultrafiltration membrane for the removal of solids and pathogens from wastewater, leading to the generation of easily recovered water for a variety of purposes (Ruigómez et al., 2020).

As an advantage, direct membrane processes do not require an added activated sludge stage, leading to decreased energy requirements. A downside of the application of direct membrane processes in wastewater treatment is the occurrence of membrane biofouling (Hube et al., 2020). This limitation is overcome by the removal of available nutrients for microorganisms in the feed stream (in reverse osmosis systems) or by continuous or intermittent air/gas sparging and backwashing (Jeong et al., 2017; Ruigómez et al., 2020). Giagnorio et al. (2018) assessed the viability of nanofiltration to be used as a purification method for water polluted with chromium. From their results, membrane nanofilters, NF270 and NF90, successfully achieved 98.8% and 76.5% chromium removal.

Sandoval-Olvera et al. (2019) employed ultrafiltration membrane technology for the elimination of chromium from synthetic solutions. As a result of negative charges deposited due to modifications made on the membrane, it successfully repelled different anionic solutions of nitrate, acid chromate, chromate, and a mixture of acid/diacid phosphates. Katsou et al. (2011) examined the use of a sorbent-assisted ultrafiltration (UF) system for the removal of lead, copper, zinc, and nickel from industrial wastewater. The percentage reduction was 99.9%, 99.8%, 99.7%, and 99.6% for Pb, Cu, Zn, and Ni, respectively. Additionally, the total nitrogen, TOC, and COD removal ranged from 31% to 38%, 69% to 82%, and 72% to 86%, respectively.

10.5.4.3 Activated Sludge

The activated sludge (AS) process is currently the most widely used biological wastewater treatment process in the developed world (Scholz, 2015). It is a vital step in secondary wastewater treatment and involves two main steps: aeration and sludge settlement. The activated sludge is known to contain a large number of bacteria in it, the purpose of which is to help in breaking down organic matter and also in seeding bacteria. The main principle of activated sludge is the formation of flocs by bacteria as they grow in a liquid medium (Muralikrishna and Manickam, 2017). These flocs clump together and settle at the bottom of the tank, leaving a comparatively clear supernatant, void of suspended and organic matter. A mixture of the screened wastewater and recycled liquid (containing large amounts of microorganisms) is aerated and allowed to settle. The settled solid that results is called the activated sludge (Muralikrishna and Manickam, 2017).

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Lachheb et al. (2016) carried out a study aimed at decreasing the biological oxygen demand (BOD_5), chemical oxygen demand (COD), and total suspended solids (TSS) of urban wastewater using an activated sludge treatment method for reuse in irrigation. The results revealed a 90.20%, 89.79%, and 97.67% decrease in BOD_5, COD, and TSS, respectively, and a general improvement in the quality of treated water. In another study, Shivaranjani and Thomas (2017) studied the treatment of wastewater using activated sludge. From their results, BOD_5 was reduced at an efficiency of 93.7% to 40 mg/L and turbidity was reduced at 87.6% efficiency to 80 NTU. Thus, it was concluded that the activated sludge process was a very effective method for the treatment of Institutional wastewater for BOD and turbidity reduction.

Additionally, Shokoohi et al. (2020) conducted a study aimed at assessing the effectiveness of activated sludge and natural wastewater treatment systems for the treatment of municipal wastewater. Parameters (BOD_5, COD, and TSS) were measured and used to evaluate the effectiveness of the treatment methods. From the results, the COD removal efficiency of activated sludge ranged between 86.97% and 61.6%, while BOD5 removal efficiency ranged between 85.18% and 72.01%. These effluent characteristics complied with Environmental Protection Agency standards and so were deemed fit for reuse or discharge into water bodies. Furthermore, a study by Dharaskar (2015) was conducted to evaluate the viability of the activated sludge process to be used for the treatment of synthetic wastewater (containing glucose, urea, magnesium sulfate, potassium phosphate, calcium chloride, and ferric chloride). The percentage reduction in COD was used as an indicator to determine the total efficiency of the procedure. Optimum results correlating with a maximum COD removal efficiency of 94% were obtained at a mixed liquor volatile suspended solids (MLVSS) concentration of 3,000 mg/L after one hour.

El Moussaoui et al. (2019) performed an experimental pilot study evaluating the treatment of municipal sewage wastewater by an activated sludge process. The biomass growth, system performance, flocs settlement ability, and microbial hygienic parameters were determined and assessed. The results showed a percentage reduction of TSS, COD, BOD5, TKN, and TP of 92%, 94%, 97%, 85%, and 16%, respectively. The values obtained from the treated wastewater sufficiently met the regulatory requirements for direct discharge into the environment. Also of particular note was that microbiological comparison of raw and treated wastewater showed no significant decrease in total microbial count ($p>0.05$) post-treatment.

10.6 POSSIBLE CHALLENGES AND PROSPECTS FOR FURTHER STUDY

Water is a scarce natural resource, and this elevates the need for its conservation, as the increase in demand for water due to the increasing global population as well as climate change has contributed to its insufficiency. Subsequently, the conservation of water supports aquatic lives and the livelihood of a substantial amount of the earth's population while providing sources of food and clean energy for the populace. This propels the need for efficient and sustainable waste management techniques. Much attention has been drawn to the adverse effects of EPs on the environment, especially the aquatic ecosystem. To protect the environment and promote sustainability, waste

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management strategies usually strive to reduce challenges associated with ecological development. Presently, wastewater treatment is a challenging task since it significantly impacts the ecosystem and poses some socioeconomic challenges which are not limited potential production of secondary wastes that will require additional treatment, thereby elevating the cost-intensiveness. These wastes require comprehensive separation and removal due to their various behaviors, uneven sizes, and different physicochemical characteristics. The high cost of removing EPs via adsorption is an existing challenge. Incorporation of natural coagulation technology to the current adsorption techniques is an efficient, economical, and ecofriendly means of treating such wastes. There is a possibility of having incomplete mineralization or low mineralization efficiency, thus leading to the possible production of toxic intermediates. Finding a universal method to completely remove all contaminants from wastewater is challenging, as many biological and physical wastewater management technologies have been researched to eliminate emerging pollutants, but they have not been able to identify the most effective approach to achieve efficiency, environmental friendliness, and affordability. To improve removal and achieve desirable water quality, the prospects for effective removal of EPs from waste treatment facilities entail the implementation of innovative technology with high treatment efficiency when tackling the issues concerning emergent pollutants in wastewater. This includes combining or hybridizing effective treatment methods to achieve desired results while considering affordability and sustainability.

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