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(Review Article)

# A review on techniques for the cleaning of wastewater

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## Abstract

The review thoroughly examines current approaches to wastewater treatment, addressing the urgent worldwide issues of water contamination and shortage. Given that the majority of Earth's surface is covered by water, only a small portion of it is really appropriate for consumption. As a result, billions of people are at risk of experiencing water shortages on a yearly basis. The research examines several therapeutic strategies, including physical, chemical, and biological approaches, with a specific emphasis on their effectiveness, constraints, and current advancements. Adsorption and membrane technology are physical technologies that use developments in nano-sized materials to improve the removal of contaminants. Coagulation/flocculation procedures encounter difficulties in de-colorization and sludge generation, notwithstanding their effectiveness. Chemical techniques such as electrochemical and photo-electrochemical oxidation, Fenton's oxidation, and ozonation demonstrate sophisticated oxidation mechanisms that have the ability to break down pollutants. Nevertheless, the need for continuous improvement arises due to problems such as energy expenses and the generation of by-products. The use of microorganisms for the breakdown of organic colorants is a promising ecologically acceptable solution in the field of biology. Biofilm applications show potential in the treatment of sewage water, highlighting the capacity of microorganisms to adapt and their enzymatic activity. This review highlights the urgent need for ongoing research and technological advancements in order to address the global issue of water scarcity. It emphasizes the importance of incorporating sustainable, cost-effective, and environmentally friendly wastewater treatment solutions into worldwide water management strategies, in order to ensure a resilient future.

**Keywords:** Wastewater treatment; Adsorption; Membrane technology; Advanced oxidation; Biological treatment

## 1. Introduction

The availability of clean water is essential to human health and well-being [1]. An environment that promotes cleanliness and provides access to uncontaminated drinking water are fundamental prerequisites for maintaining good health. Purified water is a vital component for household use and is necessary for industrial and agricultural use [2]. The escalated water use would eventually result in greater volumes of wastewater discharge [3]. An integral part of the ecosystem is water [4]. It is the mother of all living things [5]. Despite the fact that over 70% of the Earth's surface is covered with water, just a mere 3% of it is acceptable for human consumption, with the other 97% consisting of saline water [6]. Approximately four billion people globally experience water shortage for a minimum of one month every year [7]. The use of harmful chemicals in agricultural and industrial operations, as well as population increase, is continually putting pressure on this essential resource, leading to the depletion of aquifers [8]. Appropriate water supplies are necessary for human consumption, industry, agriculture, and enjoyment. Typically, many forms of pollution take away this inherent blessing from us and compel us to confront more difficult surroundings [9]. Water contamination may originate from several sources such as mining, industrial waste, livestock [10], sewage, pesticides, and agricultural fertilizers [11]. The primary pollutants found in wastewater effluents include halogenated hydrocarbons, heavy metals, dyes, surfactants, organic compounds, salts, and soluble bases [12, 13].

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In response to the environmental issues caused by water pollution, several researchers have focused their efforts on developing innovative methods for treating wastewater [14]. Various approaches have been devised so far to reduce wastewater discharges and address the risks posed by contaminants. These methods include adsorption, membrane filtration, coagulation/flocculation, oxidation, and biological treatment, among others [15]. The treatment of wastewater sometimes incurs significant expenses due to the need of thoroughly eliminating the contaminants in order to render the water clean and suitable for reuse [14]. Nevertheless, the design of these wastewater treatment procedures primarily focuses on the characterization of effluents and purification needs, disregarding their influence on the overall treatment performance and the environment [16]. Current traditional treatment procedures do not completely eliminate pollutants; rather, they either concentrate them or transform them into another form [17]. Adsorption is often regarded as a very effective technology for wastewater treatment compared to other methods, since it has various advantageous qualities that are lacking in other approaches [18].

In recent times, several researchers have focused their efforts on finding adsorbents that possess expansive surface areas, are cost-effective, and environmentally friendly. The researchers discovered a method to create effective adsorbents using nano-sized materials. These materials have been identified as crucial for removing dyes, heavy metals, organic compounds, and other substances from wastewater [14]. This review will thoroughly examine the methodologies used in wastewater treatment and ultimately determine the best effective strategy for water purification.

## 2. Methods used for the purification of wastewater

Progressively developmental achievements are being accomplished in order to develop new strategies for wastewater treatment and fulfill the requirements of clean water [19]. However, it has been challenging to treat discharged water containing pollutants thoroughly with available methods [20]. Literature reports various techniques for wastewater treatment, including physical, chemical, and biological processes, which are effective in various ways, as illustrated in Figure 1. Their selection depends on various factors like dye concentration, sewage composition, cost of the process, or the additional impurities present in wastewater [20]. Treatment methods with high installation and running costs, increased processing time, low output, and toxic byproducts are often less significant for industrial applications [21]. Hence, it is crucial to find an alternative treatment system that can completely degrade or remove contaminants [17], as shown in Figure 1.

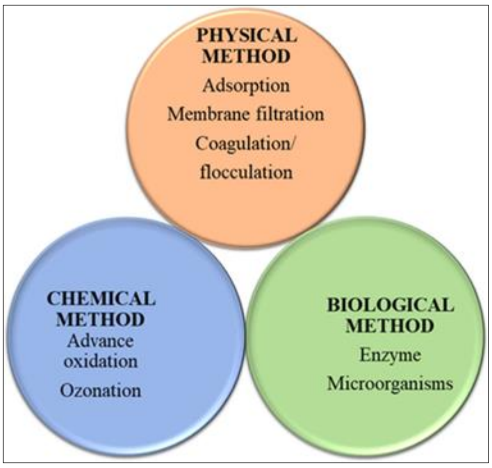

**Figure 1** Conventional and advanced techniques used for wastewater treatment [3]

### 2.1. Physical method

The foundation of physical pollution removal strategies is in the mass transfer approach [122]. Its likelihood of use is higher because of its simplicity, flexibility, high efficiency, and capacity to recycle pollutants [23]. An additional benefit of this strategy is the reduced chemical requirements. Physical therapy is considered more dependable than other therapies due to its independence from live creatures [22]. In recent years, researchers have increasingly used adsorption as a physical approach due to its notable efficacy and economical operation [23], as shown in Figure 2.

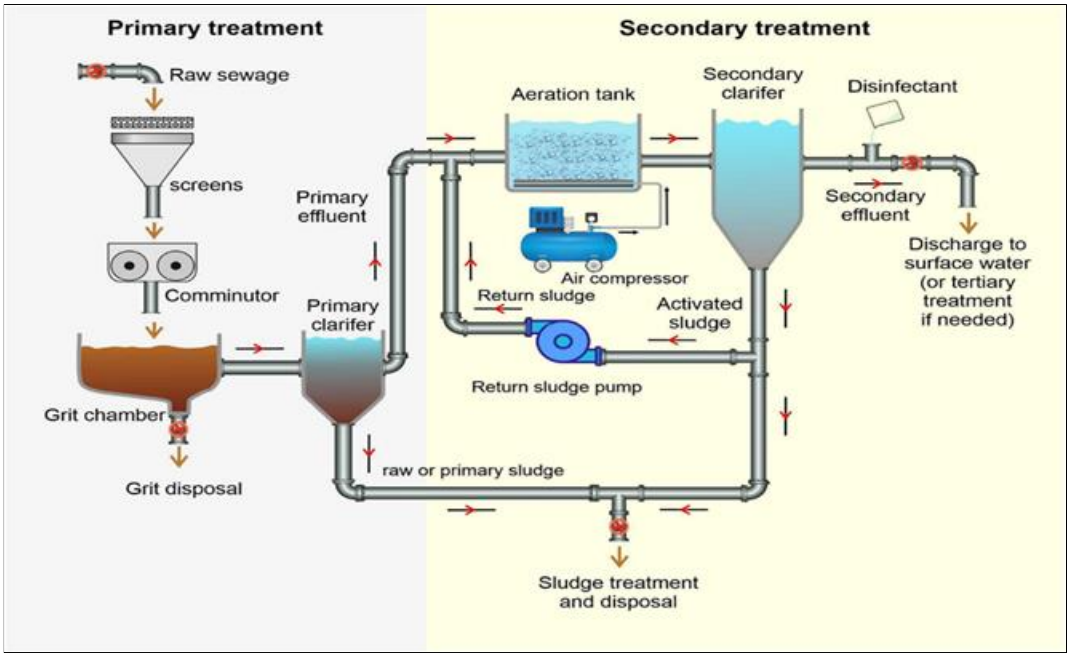

**Figure 2** Physical treatment for EC removal [24]

### *2.1.1. Adsorption process*

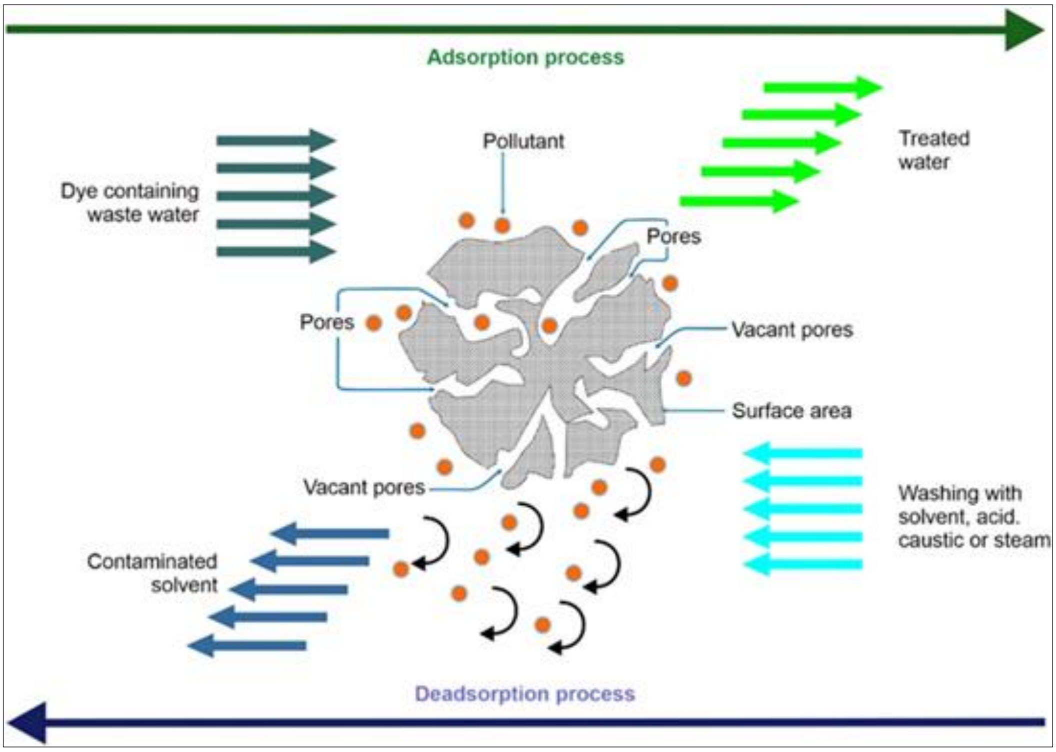

**Figure 3** Wastewater treatment techniques of adsorption and de-adsorption [25]

Adsorption is the physical phenomenon in which soluble molecules are eliminated by adhering to solid surfaces [26]. Adsorption is a prominent physical treatment method that relies on the exceptional surface area of adsorbents to be effective. Prior to use, it is necessary to activate this particular surface area by eliminating the adsorbents from the adsorbents. Hence, activated carbon is often used to achieve a more efficient and effective activation of the adsorbents [27]. The adsorption technique may effectively remove a wide range of organic, inorganic, and hazardous pollutants. The adsorption capacity is influenced by factors such as the size of the pollutants, their concentration, temperature, molecular mass, and other chemical parameters. Activated carbons have superior efficacy in selectively removing emerging contaminants (ECs) compared to other adsorbents such charcoal and carbon nanotubes [28]. The adsorption-based treatment mechanism may be readily integrated with other robust wastewater treatment methods to enhance the efficiency of removing ECs. Currently, in order to guarantee the environmental sustainability of the adsorption process (as shown in Figure 3), micro plastics and ECs obtained from a separate system are being used as adsorbents [29]. Hence, it is essential to investigate the adsorption capacity of alternative materials for the effective removal of ECs.

### *2.1.2. Membrane technology*

Membrane technology is a method of physically removing pollutants by passing them through a membrane, which is selected depending on the size and qualities of the contaminants, as shown in Figure 3. The primary determinant of membrane filtration is the hydrostatic pressure exerted in the vicinity of the membrane [30]. While membrane-based separation is a commonly used method for removing pollutants, there have been recent advancements in this field to enhance the efficiency of contaminant removal. These advancements include regular upgrades and the addition or exclusion of certain components [31]. shown in Figure 4. The membrane technology or filtration might vary based on the pore size of the membrane. As an example, the pore size range for microfiltration (MF) ranges from 0.001 to 0.1 µm, whereas for ultrafiltration (UF).

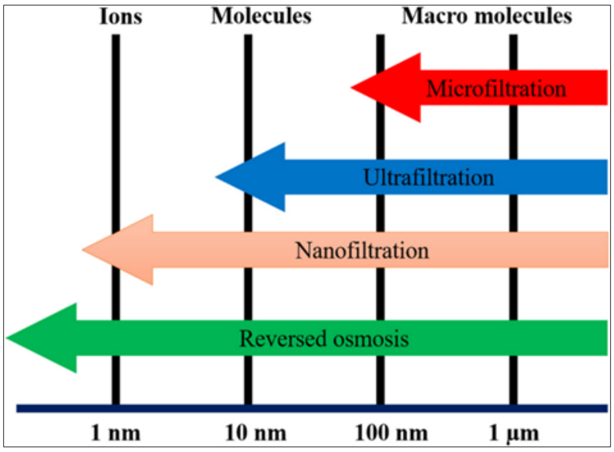

**Figure 4** Wastewater treatment using membrane technology [32]

Nano filtration has a pore size smaller than 0.001 µm; the pore size for Nano filtration (NF) ranges from 1 to 10 nm and so on. Furthermore, in the context of reverse osmosis (RO), the use of a semipermeable membrane aids in the elimination of particles that are smaller than 1 nm [33]. The effectiveness of particular filtering technologies may be regulated by the kind of membrane or the type of pollutants present. In addition to membrane-based filtration, a typical granular filtering method may be beneficial for removing EC at a lesser scale. Water flows through the granular filter beds of this system, where pollutants are trapped and separated. Therefore, the process of passing wastewater through a membrane or granules aids in the separation and extraction of ECs [34].

### *2.1.3. Coagulation/flocculation*

Coagulation-flocculation techniques are effective for removing color from wastewater that contains dispersion dyes. Their de-colorization effectiveness for reactive and vat dye effluent is poor. These approaches often have restricted use because of their inadequate ability to remove color and their substantial production of sludge [35]. Coagulation is the destabilization of dye solution systems, resulting in the formation of flocs and agglomerates. Flocculation is a process that causes the particles in a liquid to come together and form bigger clumps that eventually settle due to gravity's pull, as shown in Figure 5 [36].

Coagulation-flocculation technique neutralizes charges, creating gelatinous agglomerates for wastewater treatment in textile industries. Cost-effective, quick, and simple, it creates bridges between suspended particles [37]. These approaches include the use of coagulants such as lime ($Ca(OH)_2$), ferric chloride ($FeCl_3{\cdot}7H_2O$), ferric sulfate ($Fe_2(SO_4)_3{\cdot}7H_2O$), and aluminum sulfate ($Al_2(SO_4)_3{\cdot}18H_2O$) to bond with pollutants and dispersed colors [38]. The binding process in wastewater involves sorption, electrostatic force, and bridging, removing contaminants and coagulating colors through protonated amine groups and high molecular weight polymers, reducing chemical concentration [39].

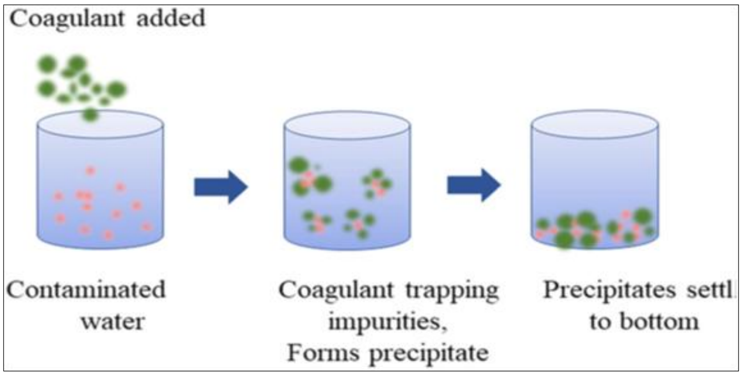

**Figure 5** General mechanism of coagulation/flocculation to remove contaminants [36]

## 2.2. Chemical method

Multiple chemical oxidation methods have been documented for various catalytic applications [40, 41]. The advanced oxidation process is widely regarded as a crucial method for treating wastewater. AOPs stands for Advanced Oxidation Processes, which include several techniques used in wastewater treatment that share the basic premise of creating oxidizing species, including hydroxyl radicals (•OH) [42]. Oxidation may occur via several processes, including electrochemical oxidation, photo-electrochemical oxidation, UV-assisted Fenton's oxidation, and ozonation. Catalysts and pH are crucial factors in the oxidation process [43]. Figure 6 illustrates the advanced oxidation techniques used for treating textile effluent.

**Figure 6** Textile wastewater treatment by advanced oxidation process [44]

### *2.2.1. Electrochemical oxidation*

Electrochemical advanced oxidation processes (EAOPs) are a promising technique for wastewater treatment, offering high efficiency, simple equipment, and easy handling. However, challenges include increased energy costs and lower oxidation efficiencies. Recent research has focused on improving electrode materials' stability and catalytic activity. Pulse electrolysis with pulse current supply is an exemplary method for energy efficiencies. This study treated Methyl Orange, Alizarin Red S, and Indigo Carmine with pulse mode, revealing that optimized operating parameters can save energy needs up to 47.9%, 41.0%, and 25.5% [45].

### *2.2.2. Photo-electrochemical oxidation*

Advanced oxidation processes (AOPs) are becoming more prevalent in achieving high removal efficiencies and degradation of pollutants. Among these processes, hydroxyl (•OH)-based electrochemical methods are gaining importance in maintaining pollution levels below legal limits [46, 47]. Photo-electro catalysis is a process where a semiconductor anode is irradiated with solar light to remove dyes like methyl orange (MO). OH radicals, generated by water oxidation, mediate the oxidation of MO, producing small molecules, aromatic ring-opening, and azo bond breakdown. High rates of dye removal can be achieved at high current and low primary concentrations, while high yields can be achieved at low concentrations and low current. This process reduces dye concentration and degrades them [46].

### *2.2.3. Fenton's oxidation*

Advanced oxidation processes (AOPs) may facilitate the total or partial breakdown of organic compounds or colors present in textile effluent. Oxidation processes produce free radicals, such as hydroxyl radicals, which have a higher potential for oxidation. Fenton's oxidation is widely regarded as a feasible and sophisticated technology for water treatment [48]. This technique utilizes ferrous sulfate ($FeSO_4$) and hydrogen peroxide ($H_2O_2$) to produce highly reactive hydroxyl radicals, which function as powerful oxidizing agents. •OH has been acknowledged for its elevated oxidative potential. Past studies have successfully used Fenton oxidation for the treatment of industrial wastewaters. During Fenton oxidation, the formation of many flocs of different sizes is seen. The formation of these tiny flocs is a result of chain reactions between hydroxide ions and ferrous ions, leading to the creation of ferric hydroxo-complexes. Settling these little flocs in wastewater is challenging due to their small size [49]. The following reactions depict the interaction between Fenton's reagent and any organic compound (RH):

$$H_2O_2 + Fe^{+2} \rightarrow Fe^{+3} + OH- + OH. \text{ ……………} (1)$$

$$RH + OH. \rightarrow H_2O + R\text{…………………..} (2)$$

$$R. + Fe^{+3} \rightarrow R+ + Fe^{+2}\text{……………….} (3)$$

$$R+ + H_2O \rightarrow ROH + H+\text{…………………….} (4)$$

Hydrogen peroxide ($H_2O_2$) generates hydroxyl radicals upon interaction with the iron ions, as hydrogen peroxide is not good enough for dye de-colorization alone at normal conditions [42].

### *2.2.4. Ozonation*

Ozone is a well-recognized potent oxidizing agent that may participate in chemical reactions with a diverse array of organic and inorganic substances [50]. The use of this chemical has been immensely significant in the field of wastewater treatment over the last decade due to the absence of any detrimental by-products in the ozone-involved reactions [51]. Ozonation is an intricate oxidation procedure that occurs by introducing ozone, resulting in a substantial enhancement in wastewater biodegradability. Multiple studies have consistently shown that ozonation is a very effective method for removing personal care and pharmaceutical goods, since the majority of these substances may be completely removed. Nevertheless, it is undeniable that ozone has a brief half-life. If its concentration above a certain threshold, around 23%, it is deemed a perilous hazard [52]. Recent research suggest that ozone has a poor utilization efficiency and its ability to oxidize and mineralize organic contaminants is not as effective as it is in the formation of harmful by-products [53]. The catalytic ozonation method has gained significant recognition as a very promising technique for wastewater treatment, provided that this issue can be minimized to a certain extent [54].

Figure 6 illustrates the process of catalytic ozonation for the degradation of contaminants. Ozone has the ability to produce hydroxyl radicals when it comes into contact with water, making it a recognized advanced oxidation process. Ozone may be used with complementary technologies such as $H_2O_2$, ultraviolet (UV), ultrasound (US), and others, in order to enhance the effectiveness of removing color or organic debris [42], as shown in Figure 7.

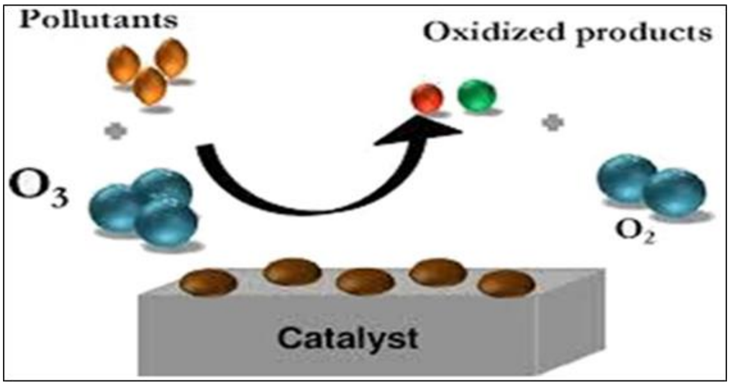

**Figure 7** Schematic illustration of catalytic ozonation [55]

### 2.3. Biological method

Microorganisms break down organic colorants in biological treatment by either aerobic or anaerobic processes [56]. Microorganisms use organic compounds as a source of energy via the process of degradation. Fig. 8 demonstrates the use of biofilms for the purpose of eliminating pollutants from sewage water. Several colors used in textile industries have detrimental effects on aerobic organisms and contribute to the formation of sludge via processes such as rising, flocculation, and sludge bulking. Thus, it has been shown that the aerobic pathway is inadequate for the degradation of textile colors, particularly azo dyes [57]. In addition, the anaerobic treatment of textile colors necessitates a larger physical area and a longer hydraulic retention time, as well as a lengthier acclimatization period for anaerobic microbes. Under oxygen-deprived circumstances, the formation of harmful aromatic amines occurs. However, the combination of an oxygen-deprived system with an oxygen-rich system may successfully mitigate the impact of textile dyes [42].

Biological techniques for the degradation of textile wastewater provide environmental friendliness, economic effectiveness, less sludge generation, nonhazardous byproducts, and decreased water use in comparison to physical/oxidation techniques. The efficacy of these processes is contingent upon the flexibility of microorganisms and the activity of enzymes. The isolation and testing of different microorganisms, such as bacteria, fungus, and algae, for the purpose of dye degradation, is an intriguing biological element of treating textile effluent. The number [58].

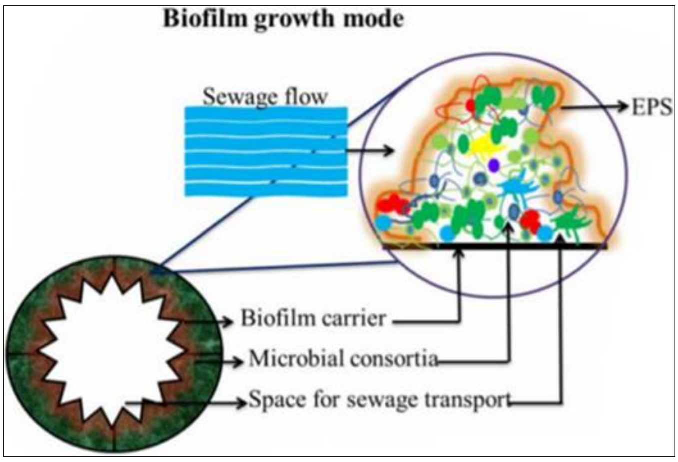

**Figure 8** Biofilm for sewage water treatment [59]

## 3. Conclusion

To summarize, this review explores the complex field of wastewater treatment methods, highlighting the urgent need for creative strategies in response to the growing problem of water pollution. The pervasive worldwide water shortage situation, which impacts more than four billion individuals each year, demands the implementation of comprehensive and efficacious measures to guarantee the accessibility of unpolluted and untainted water. The review comprehensively examines the physical, chemical, and biological techniques used in wastewater purification, providing insight into their individual benefits, constraints, and new progressions

Adsorption, membrane technology, and coagulation/flocculation are effective physical ways for removing pollutants. Adsorption, due to its use of large surface areas of nanoscale materials, is very successful in treating a wide range of pollutants. The significance of improving contaminant removal efficiency is highlighted by membrane technology, which offers a variety of pore diameters tailored to individual contaminants. Coagulation/flocculation procedures encounter difficulties such as restricted de-colorization capabilities and significant sludge generation, notwithstanding their effectiveness.

Chemical techniques such as electrochemical oxidation, photo-electrochemical oxidation, Fenton's oxidation, and ozonation use oxidation processes to effectively break down pollutants. The complex interaction between catalysts, pH, and reactive species highlights the adaptability of these approaches in addressing various compositions of wastewater. Nevertheless, the need for improvement remains evident due to obstacles including high energy expenses and the possible creation of detrimental side effects.

The use of microorganisms for the breakdown of organic colorants is a biologically-based approach that offers both environmental sustainability and economic efficiency. The use of biofilms shows potential in removing contaminants from sewage water, highlighting the need of microbial adaptability and enzyme function in biological wastewater treatment.

Amidst a swiftly changing climate where water supplies are under strain, the study emphasizes the need of continuous research and technical progress in creating sustainable, economical, and eco-friendly techniques for treating wastewater. It is crucial to include these techniques into global water management frameworks to guarantee a healthier and more resilient future for communities throughout the globe.

## Compliance with ethical standards

### *Disclosure of conflict of interest*

No conflict of interest to be disclosed.

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