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A Critical Review on Pharmaceutical Wastewater Using Catalytic Oxidation Processes

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Abstract

Wastewater is any water that has been used for various purposes, such as domestic, agricultural, and industrial activities and is now discharged or disposed of. This article aims to explain the elucidate how pollution affects both the natural world and individuals as well as the significance of wastewater treatment, and current trends and technologies used in wastewater treatment. Pharmaceutical industries are vital to the healthcare sector, but their production processes generate wastewater containing harmful contaminants. The environment and human health could be seriously harmed by the release of such wastewater without adequate treatment. Advanced oxidation process (AOP) with catalysts is a promising technique for treating pharmaceutical wastewater. This article covers the different facets of employing AOP and catalysts to treat the pharmaceutical industry effluent.

Introduction

Wastewater is any water that has been contaminated by human, animal, or industrial activities and is no longer suitable for its original intended use [(Rueda-Marquez, 2020)]. This can include water from toilets, sinks, showers, and other sources in homes, businesses, and industries [(Akpan, 2011)]. Wastewater typically contains a range of pollutants, including organic matter, pathogens, nutrients, and chemicals [(Lin, 2017)]. If untreated or poorly treated, wastewater can pose significant risks to public health and the environment, including the spread of disease, contamination of water sources, and harm to aquatic ecosystems [(Mustafa, 2020)]. Effective wastewater management involves treating and disposing of wastewater in a way that minimizes its impact on human health and the environment [(Yan, 2018)]. This can involve a range of approaches, including physical, chemical, and biological treatment methods, as well as the use of wastewater for irrigation, energy production, or other purposes [(Bartolomeu, 2018)].

TABLE 1. Various Wastewater and their Sources

Sr. No	Types	Area of Sources
1	Residential Sewage	The kitchen, bathroom, and toilet water are all included in the household wastewater that is generated.
2	Industrial Wastewater	This is the wastewater produced by industrial processes, and it may be full of infections, toxic metals, inorganic as well as organic compounds, and other pollutants.
3	Wastewater from Farming	It refers to wastewater produced by farming operations like irrigation and animal husbandry, and it may be contaminated with fertilisers, chemical fertilisers, and other pollutants.

4	Stormwater	This is the wastewater generated from rainwater runoff, which can contain pollutants from urban and industrial areas, as well as natural sources such as soil erosion.
5	Groundwater	This is the water found underground and can become contaminated with pollutants from various sources, such as leaking underground storage tanks or agricultural activities.
6	Greywater	Wastewater that is produced by irrigation appliances other than toilets, such as sinks and showers, and can be reused for certain purposes, such as irrigation or toilet flushing.
7	Blackwater	This is the sewage produced by toilets and contains impurities that need to be treated specifically, including human waste.

Each type of wastewater has its own unique characteristics and may require specific treatment methods to effectively remove pollutants and make it safe for discharge or reuse [(Sgroi, 2020)].

Pharmaceutical wastewater refers to any wastewater that contains residues of prescription and over-the-counter medications, as well as personal care products, are included in, as well as cosmetic and hygiene products [(Zhang, 2020)]. Pharmaceutical wastewater can be generated by various sources, including pharmaceutical manufacturing facilities, hospitals, households, and livestock farms where animals are treated with drugs. The discharge of pharmaceutical wastewater into the environment can result in the contamination of water sources and potential risks to human and environmental health [(Hussain, 2020)]. Pharmaceutical wastewater treatment typically involves advanced treatment methods that can effectively remove PPCPs, like improved oxidation techniques, membrane filtering, and activated carbon adsorption [(Iovino, 2016)]. However, the complexity of pharmaceutical wastewater and the wide range of compounds involved make the treatment of pharmaceutical wastewater challenging. In addition to treatment, efforts are being made to limit the quantity of pharmaceuticals that get up in wastewater in the first place through source control methods [(Khalaf, 2020)]. This can involve improved pharmaceutical waste management practices, as well as promoting the appropriate use of pharmaceuticals and more advanced technology sustainable drug products [(Kolosov, 2018)].

Wastewater treatment refers to the process of treating wastewater to remove contaminants and make it safe for discharge or reuse [(Lekkerkerker-Teunissen, 2012)]. Physical, approaches such as chemical and biological commonly used in the treatment process to remove pollutants from wastewater [(Bereketoglu, 2020)]. The first stage of wastewater treatment is usually primary treatment, which involves the physical removal of solids and organic matter using processes such as sedimentation and screening [(Aydin, 2019)]. The second stage of treatment is secondary treatment, which involves biological processes such as aeration and the use of microorganisms to break down and remove dissolved organic matter [(Adityosulindro, 2017)]. In some cases, To further cleanse the wastewater and get rid of further contaminants, you could need a tertiary treatment stage, such as nutrients or trace contaminants [(Ewadh, 2019)]. This may involve processes such as advanced oxidation, membrane filtration, or chemical treatment [(Fatta-Kassinos, 2011)]. After that, the ecosystem may receive the cleansed wastewater. or used again for a variety of tasks, including chemical reactions aquaculture, or groundwater recharge [(Ganiyu, 2015)]. The specific treatment approach will depend on the quality of the wastewater, the discharge standards and regulations in the area, and the intended reuse of the treated water [(Guo, 2018)]. Due to the significant threats that improperly or poorly treated wastewater poses to the environment and public health, effective wastewater treatment is necessary [(Guo Y. Z., 2020)].

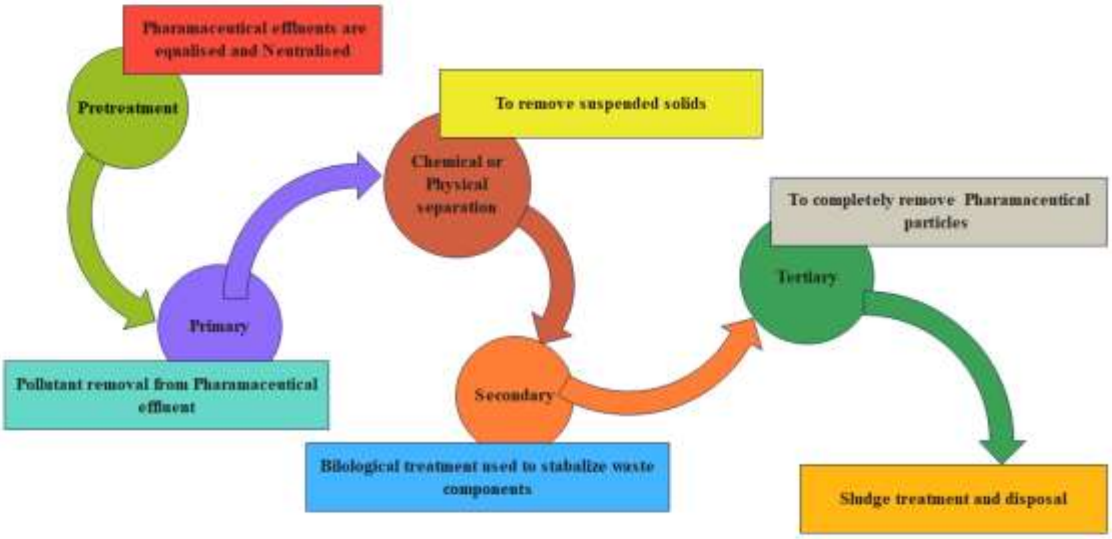

Figure 1. Pharmaceutical Wastewater Treatment Overview

Wastewater degradation refers to the breakdown or elimination of removing pollutants from wastewater through physical, chemical, or biological processes [(Hofman-Caris, 2011)]. Pollutants in wastewater must be degraded if Environmental factors and public health are to be safeguarded, since untreated or inadequately treated wastewater may contain dangerous contaminants that endanger aquatic life and ecosystems, as well as pose risks to human health. Physical processes for wastewater degradation include sedimentation, filtration, and membrane separation, which remove solid and suspended particles from wastewater [(Luo, 2014)]. These Techniques can also eliminate some Heavy metals and other dissolved contaminants and certain organic compounds [(Minella, 2019)]. Chemical processes for wastewater degradation involve the use of chemical agents or reactions to break down pollutants [(Yu, 2019)]. Examples of chemical processes include ozonation, chlorination, and advanced oxidation processes, which produce hydroxyl radicals with a high degree of reactivity, which can disintegrate a variety of contaminants into lesser, less harmful molecules [(Wang, 2018)]. Wastewater treatment by biological means degradation use microorganisms to degrade pollutants [(Uslu, 2012)]. Examples of biological processes include activated sludge processes, anaerobic digestion, and constructed wetlands [(Villanueva-Rodríguez, 2019)]. These processes can be effective in eliminating organic toxins and water-borne nutrients, but they can be sensitive to environmental conditions and require careful management to maintain optimal performance [(Thokchom, 2015)]. The wastewater's properties and the sorts of pollutants present will determine which degrading technique is most appropriate for a certain wastewater [(Tanveer, 2019)]. To obtain the best possible degradation of contaminants in wastewater, It is possible to use a mix of processes that are biological, chemical, and physical in nature [(Ternes, 2003)].

AOPs are a class of water treatment techniques that use chemical reactions to remove pollutants from wastewater. [(udhakaran, 2013)]. AOPs are often utilised to treat wastewater This is difficult to handle using conventional techniques because it contains persistent organic compounds or additional elements that are resistive to degradation [(Scheers, 2012)]. AOPs function by producing hydroxyl radicals (•OH), which are extremely reactive and capable of oxidizing and dissolving a variety of contaminants into smaller, less hazardous molecules. This is achieved through various chemical reactions, such as Fenton's reaction, photochemical reactions, or ozonation [(Rivera-Utrilla, 2013)].

Common AOPs for wastewater treatment include the following.:

1. Ozone-based processes: These processes use ozone (O_3) to generate hydroxyl radicals and oxidize pollutants.

2. UV-based processes: These processes use ultraviolet (UV) radiation to generate hydroxyl radicals and break down pollutants.

3. Heterogeneous photocatalysis: This process uses a catalyst, such as titanium dioxide, to accelerate the breakdown of pollutants in the existence of UV radiation.

4. Fenton-based processes: These processes use iron (Fe) and hydrogen peroxide (H_2O_2) to produce hydroxyl radicals, which oxidise contaminants.

pesticides, goods for personal care and prescription drugs, Persistent organic contaminants, among others, can be effectively utilising to remove from wastewater AOPs. However, they can also be expensive and energy-intensive compared to conventional treatment methods, and the treatment conditions need to be carefully controlled to ensure optimal performance [(Ren, 2021)].

The Water (Prevention and Control of Pollution) Act authorised the establishment of the Central Pollution Control Board (CPCB), a statutory body in India. The CPCB is in charge of organising and carrying out policies that aim to avoid, control, and reduce all types of pollution in the nation, including wastewater pollution. The CPCB sets standards for the level of wastewater quality that can be discharged into water bodies, and also monitors and regulates industries to ensure compliance with these standards. The CPCB also conducts research and development activities related to wastewater treatment and pollution control and provides technical assistance and training to industries and government agencies. In order to enforce its policies, the CPCB has created a network of state pollution control boards (SPCBs) and pollution control committees (PCCs) its programs at the state and local levels. The SPCBs and PCCs are responsible for monitoring and regulating pollution in their respective states and regions, and for enforcing the standards set by the CPCB. In addition to regulating industrial wastewater, the CPCB also focuses on promoting the use of wastewater treatment technologies and practices that can help reduce pollution and conserve water resources. The CPCB utilises industries and other stakeholders to develop and promote sustainable wastewater management practices, such as the use of treated wastewater for irrigation or industrial processes [(Preis, 2014)].

Pharmaceutical wastewater can encompass a wide range of o chemical compounds, including active pharmaceutical ingredients (APIs), solvents, acids, alkalis, heavy metals, and other contaminants. Pharmaceutical wastewater has distinct characteristics that depend on things like the type of manufacturing process, the kinds and quantities of pharmaceuticals produced, and the particular pollutant removal procedures utilised [(Paul, 2014)].

2. Pharmaceutical wastewater characteristics

2.1 Characteristics of pharmaceutical wastewater

2.1.1. Exceptionally high levels for both the chemical and biological oxygen demands, pointing to a high level of organic chemicals that require oxygen to break down [(Aydin, 2019)].

2.1.2. Presence of antibiotics, hormones, and other pharmaceutical compounds, which is potentially dangerous to aquatic organisms and humans if not properly removed [(Yu, 2019)].

2.1.3. Extremely high total suspended particle levels can lead to the clogging of pipes and equipment in sewage treatment facilities [(R, 2009)].

2.1.4. substances with high nitrogen and phosphorus concentrations can cause eutrophication in receiving waters and lead an adverse algal bloom [(Wang Z. S., 2019)].

2.1.5. the presence of hazardous chemicals that can harm both people and aquatic life, such as cadmium, lead, and mercury [(Wang J. D., 2019)].

2.1.6. Presence of solvents, acids, and alkalis, which can be corrosive and cause damage to equipment in treatment facilities for sewage [(Yan P.-F. Y.-H.-Q., 2019)].

Overall, pharmaceutical wastewater can pose a significant environmental and public health risk if not properly managed and treated. Effective treatment processes are necessary to remove contaminants and ensure that discharged wastewater meets regulatory standards for safe disposal or reuse [(Zhang W. S., 2020)].

2.2 Characteristics of Secondary Effluent

A biological treatment facility's supplemental effluent is treated wastewater that has undergone this procedure. It is the final product of the treatment prior to usage or Environment-friendly release for other purposes. Some of the common characteristics of secondary effluent include [(Yu H.-W. P., 2019)].

2.2.1. Lower levels of organic matter: The secondary treatment procedure significantly reduces the quantity of organic matter in the wastewater, which lowers the effluent's parameters for chemical and biochemical oxygen demand (BOD and COD).

2.2.2. Lower levels of suspended solids: The overall suspended solids levels of the effluent are reduced on account of secondary treatment, which also eliminates a large portion of the suspended particles from the wastewater.

2.2.3. Nutrients may be present in the effluent even when the secondary treatment procedure lowers the quantities of organic matter. Examples of these nutrients are nitrogen and phosphorus. In receiving waterways, these nutrients may lead to eutrophication and the appearance of algae.

2.2.4. Presence of disinfectants: To further cleanse the secondary effluent and get rid of any leftover germs, disinfectants like chlorine or ultraviolet (UV) radiation may be employed in some circumstances.

2.2.5. Neutral pH: The pH of the secondary effluent is usually close to neutral, which is typically around 7.0. This is because the wastewater treatment process usually involves pH adjustment to improve the elimination of contaminants.

Overall, Secondary effluent is a generally high-quality treated wastewater that may will be the ecosystem after being released or utilized for a variety of tasks, including irrigation, business operations, and, with additional treatment, drinking water. However, it is important to ensure that the effluent meets regulatory standards and does not cause any harm to the environment or public health [(Zwiener, 2020)].

3. Pharmaceutical wastewater Advanced Treatment Techniques

Pharmaceutical wastewater must undergo advanced treatment to get rid of impurities that can't be efficiently eliminated by standard treatment methods. In order in order to handle pharmaceutical waste in an advanced manner, a number of procedures are frequently employed, including [(Tanveer M. G., 2019)].

3.1. Membrane filtration: Utilising a membrane is part of membrane filtration to physically separate contaminants from the wastewater. Colloidal particles, certain chemical molecules, and suspended solids can all be removed with this technique. There are several membrane filtering techniques, such as Nanofiltration, ultrafiltration, and reverse osmosis (RO, NF, UF) [(Sudhakaran, 2013)].

3.2. Adsorption: Adsorption involves using an adsorbent material to remove contaminants from the wastewater. Due to its enormous surface area and adsorption capability, activated carbon is a frequently utilised adsorbent in order to handle pharmaceutical wastewater [(Fukahori, 2012)]. Other adsorbents such as zeolites and chitosan may also be used.

3.3. Advanced oxidation processes (AOPs): AOPs involve using oxidizing agents, such as ozone, hydrogen peroxide, or UV radiation, to break down organic compounds in the wastewater. AOPs can be effective in removing pharmacological substances and other recalcitrant contaminants [(García-Araya, 2010)].

3.4. Biological treatment: Utilising microorganisms to remove nutrients and organic materials from wastewater is known as biological treatment. The batch reactor sequencing process, which uses a series of programmed cycles for aeration, mixing, and settling to remove contaminants, is one popular form of biological treatment for pharmaceutical wastewater [(García-Espinoza, 192)].

3.5. Electrochemical treatment: Electrochemical treatment involves using an electric current to remove contaminants from the wastewater. While electrocoagulation may use to get rid of suspended particles and heavy metals, electrochemical oxidation can be utilised to degrade organic molecules. [(Garcia-Segura, 2018)].

Overall, the removal of many contaminants and the creation of high-quality effluent that satisfies regulatory criteria for safe release or reuse are both possible with sophisticated treatment procedures for pharmaceutical wastewater. The precise features of the wastewater and the treatment objectives, however, determine which approach is most suited [(Ghafoori, 2015)].

4. Advance Oxidation Process treatment

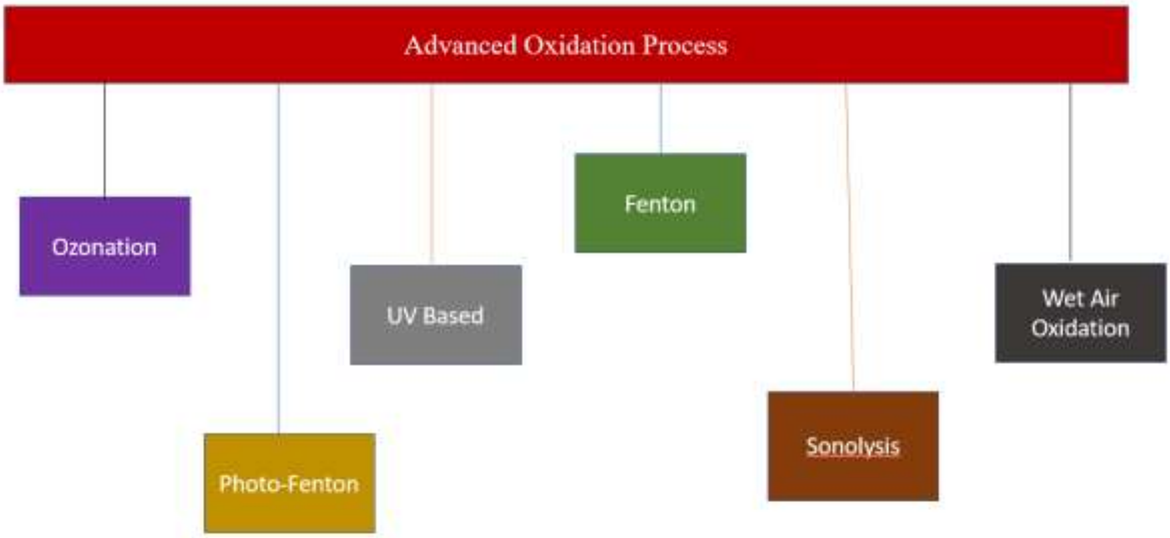

Figure 2. Types Of Advanced Oxidation Process

4.1 Photocatalytic Processes

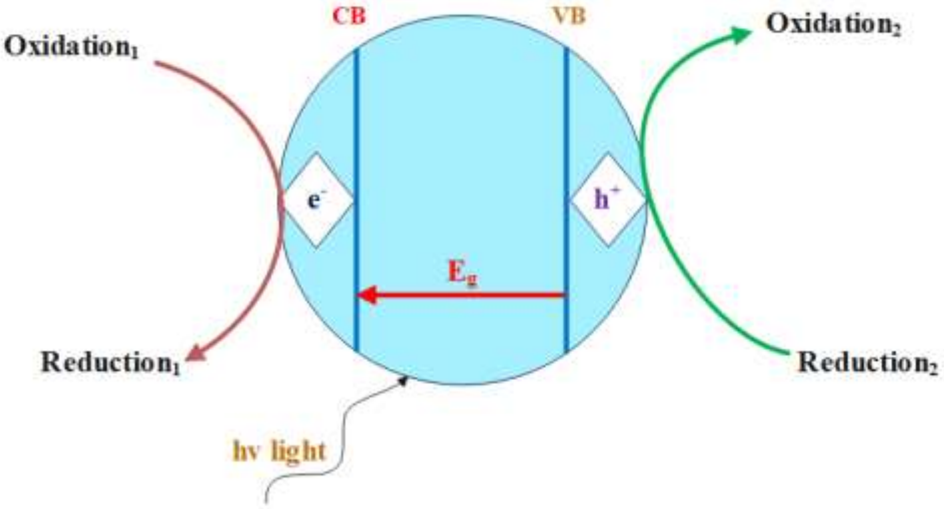

Figure 3. Photocatalytic Oxidation

Photocatalytic processes refer to chemical reactions that are driven by light energy and a catalyst. In these processes, a catalyst material is activated by light energy, typically in the ultraviolet range, to start a chemical process. The catalyst material absorbs the light energy and uses it to promote a reaction between two or more molecules, resulting in the formation of new chemical products.

Photocatalytic processes have many applications in environmental remediation, such as the treatment of air and water pollutants. TiO_2 is frequently used as a photocatalyst to break down organic contaminants in water and the air, making it one of the most popular photocatalytic processes. When TiO_2 is exposed to ultraviolet light, it generates highly reactive oxygen species that can break down organic compounds into simpler, less harmful molecules.

Other photocatalytic processes include the use of photocatalysts to produce hydrogen from water, to convert carbon dioxide into useful chemicals or fuels, and carry out photochemical synthesis reactions in organic chemistry. New photocatalytic materials and techniques are being developed, and they have the potential to solve multiple environmental and energy-related problems [(Friedmann, 2010)].

4.2 Fenton Process

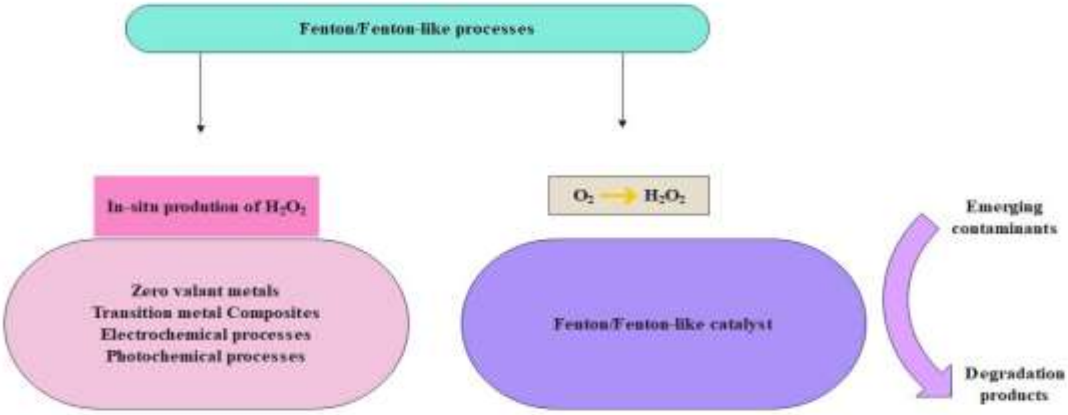

Figure 4. Fenton Like Oxidation

The Fenton process is a popular treatment method for pharmaceutical wastewater, which contains a variety of organic pollutants that, if not properly handled, might be dangerous to both the environment and human health.

A Fenton reagent, which is hydrogen peroxide and a mixture of and ferrous ion (Fe^{2+}), is added to is part of the wastewater of the Fenton process. The Fenton reagent produces hydroxyl radicals (•OH), They can oxidise organic contaminants into less dangerous compounds like water and carbon dioxide since they are extremely reactive.

The Fenton process has several advantages for treating pharmaceutical wastewater. several types of organic contaminants, particularly those that are challenging to breakdown using conventional techniques, may be effectively treated using it. Additionally, the process does not generate harmful byproducts and can be operated at ambient temperatures and pressures.

However, Using the Fenton method costly and requires careful management of the Fenton reagent to prevent excessive consumption and the production of unwanted byproducts. It also requires proper handling and disposal of the treated wastewater and the spent Fenton reagent, which can be hazardous if not managed properly. Overall, the Fenton process is a promising treatment option for pharmaceutical wastewater, but its implementation requires careful consideration of the specific wastewater characteristics and operational parameters [(2017)].

4.3 Electrochemical Process

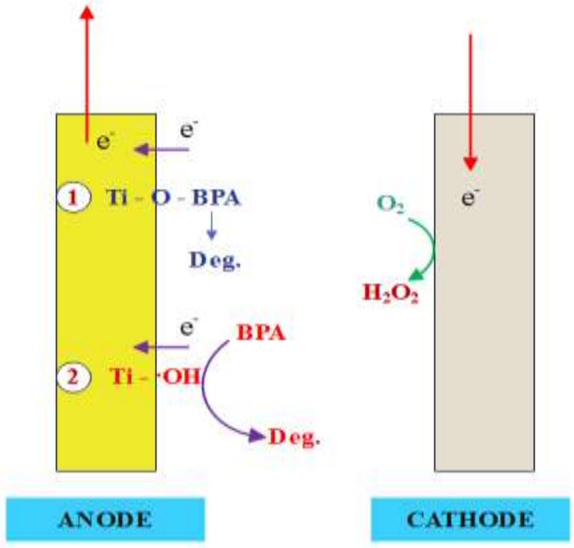

Figure 5. Electrochemical Oxidation

Pharmaceutical wastewater contains different organic contaminants that, if not adequately treated, possibly harmful to both the environment and people's health. A promising method in order to accomplish this effluent is electrochemical oxidation. To produce oxidising agents like hydroxyl radicals (•OH) or ozone (O3) that can oxidise organic pollutants into less harmful substances like water and carbon dioxide, the electrochemical oxidation process uses an electrode, which is typically made of materials like graphite, platinum, or diamond that has had boron incorporated into it. The ability to treat a variety of organic contaminants, including those that are challenging to degrade using conventional techniques, is one benefit of electrochemical oxidation. Additionally, the procedure may be carried out at ambient pressures and temperatures, which eliminates the requirement for pressurisation or heating that consumes a lot of energy.

However, electrochemical oxidation can be costly and may require complex electrode designs and materials. Additionally, the process can generate unwanted byproducts such as chlorinated compounds or nitrogen oxides, that might be damaging to the environment and need further medical attention. Generally speaking, electrochemical oxidation is a method that shows promise for treating pharmaceutical wastes, but its implementation requires careful consideration of the specific wastewater characteristics, operational parameters, and the potential for the development of harmful byproducts [(Loos, 2018)].

4.4 Photo-Fenton Process

An improved oxidation method for treating wastewater including organic contaminants is the photo-Fenton reaction. This approach combines photocatalysis with the Fenton reaction. A photocatalyst, such as titanium dioxide, is employed in the photo-Fenton process to produce hydroxyl radicals (•OH) if there is UV light present. By enhancing the generation of hydroxyl radicals, the combination of ferrous ions and hydrogen peroxide accelerates the oxidation process. Considering their great responsiveness, hydroxyl radicals may oxidize a variety of organic contaminants into less damaging ones like water and carbon dioxide. Many different kinds of organic contaminants, including those that are resistant to conventional treatment options, can be effectively treated using the photo-Fenton reaction. The photo-Fenton reaction has the benefit of operating at ambient pressure and temperature, eliminating the requirement for energy-intensive heating or pressurisation. The technique also produces no toxic byproducts, and the effluent after treatment may be properly repurposed or the ecosystem after being discharged.

However, the photo-Fenton reaction can be costly and requires careful management of the reagents to prevent excessive consumption Moreover, the creation of unwanted byproducts. Additionally, the effluent's quality might have an impact on the process. and the presence of certain contaminants such as chloride ions. Overall, the photo-Fenton reaction is a potential advanced oxidation a process for treating organic contaminants in wastewater, but its application needs careful evaluation of the unique wastewater properties and operating parameters [(Ata, 2019)].

4.5 Ozone Oxidation

Waste from pharmaceutical industries treated using ozone oxidation cutting-edge oxidation process. The method uses ozone gas as an oxidising agent to convert organic contaminants in wastewater into less dangerous ones. A vast variety organic and inorganic substances can be oxidised by the extremely reactive gas known as ozone. When ozone is added to pharmaceutical wastewater to cause the organic pollutants to react, intermediate oxidation products such aldehydes, ketones, and carboxylic acids are just a few examples of what is produced. These intermediate products are then further oxidized by ozone to produce less harmful substances such as water and carbon dioxide. Ozone oxidation has several advantages over other treatment methods. Numerous organic contaminants, particularly those that are challenging to breakdown using conventional techniques, can be effectively treated using it. There is also no need for energy-intensive heating or pressurisation because the process doesn't produce any toxic byproducts and may run under standard pressure and temperature.

However, ozone oxidation can be costly, and the ozone gas must be carefully managed to prevent excessive consumption and the creation of undesirable byproducts. Additionally, the effectiveness of the procedure may be impacted by the wastewater and the presence of certain contaminants such as bromide ions, which can result during the creation of harmful byproducts such as bromate. In general, ozone oxidation is a promising method for the treatment of pharmaceutical wastewater, but its application necessitates careful consideration of the unique wastewater properties and operating requirements [(Aydin, 2019)].

4.6 Wet Air Oxidation

Pharmaceutical wastewater has been treated using a form of advanced oxidation technique called wet air oxidation (WAO). To transform organic contaminants in wastewater into simpler and less dangerous chemicals, a procedure using oxygen and pressure and temperature that are high is used. The WAO process involves mixing air with the pharmaceutical wastewater and heating it to temperatures between 180 and 300 °C while applying pressures between 20 and 150 bar. The intense heat and pressure conditions cause the organic compounds in the wastewater to react with oxygen, generating water, carbon dioxide, and other safe byproducts. The WAO procedure is efficient in removing a variety of organic substances from wastewater, including hazardous and persistent pollutants.

Compared to other Processes for treating wastewater, the WAO process has several advantages. A highly efficient process that can achieve high levels of removal for a wide range of organic pollutants. It also has low operating costs; Not require the use of expensive catalysts or reagents.

However, the WAO process also has some drawbacks. The intense heat and pressure conditions required for the process can lead to high expenditures for equipment and energy consumption. In addition, the process may generate acidic byproducts, which can require additional treatment or disposal. The WAO process is a possible approach to managing pharmaceutical wastewater. It appeals to enterprises looking to enhance their wastewater treatment procedures due to its efficiency and cheap running costs [(Luo, 2014)].

4.7 Sonolysis

Sonolysis therapy is an effective strategy. for treating pharmaceutical wastewater. It includes dissolving organic contaminants and removing them from wastewater using ultrasonic waves.

In sonolysis treatment, high-frequency sound waves are applied to the wastewater, causing cavitation bubbles to form. These bubbles collapse rapidly, producing extreme pressures and temperatures that result in the production species that are particularly reactive like hydroxyl radicals and hydrogen peroxide. Pharmacies are one of the numerous organic contaminants that these reactive species can break down. Sonolysis treatment has several advantages over conventional treatment methods for pharmaceutical wastewater. It is a non-thermal process, meaning it does not require the addition of heat or chemicals. It is also a low-energy process, making it a cost-effective alternative for treating wastewater. Additionally, sonolysis treatment is effective at removing persistent and hazardous organic substances that may not be removed by other treatment methods.

However, Sonolysis therapy has several restrictions as well. The kind and quantity of contaminants present in the wastewater determine the treatment's efficacy. The approach might not be suitable for large-scale therapy because to the poor treatment capacity of current sonolysis equipment. Sonolysis treatment offers a lot of potential as a method for handling pharmaceutical effluent. To improve the procedure and make it more useful for large-scale therapeutic applications, further research and development are required [(Sudhakaran, 2013)].

5. Catalyst Types

By lowering the energy required for a chemical reaction to occur, catalysts are compounds that can speed up chemical processes. Catalysts come in a variety of forms, including

5.1. Homogeneous catalysts: They can be with the help of liquids, gases, or solids and are concurrent with the reactants in phase. if the reactants and catalyst disappear in identical amounts solvent during a solution-phase reaction, homogeneous catalysts are commonly employed.

5.2. Heterogeneous catalysts: These catalysts, which are generally employed in gas-phase or solid-phase processes, differ from the reactants in their phase. Heterogeneous catalysts are frequently solid particles that are spread throughout the mixture of reactants.

5.3. Enzymes: In living things, enzymes are biological catalysts that speed up certain biochemical processes. Enzymes are perfect for many industrial applications because they are extremely selective and can catalyse reactions under benign circumstances.

5.4. Acid catalysts: Acid-catalysed processes containing functional groups like alcohol and carbonyl groups are sped up using acid catalysts. Acid catalysts including sulfuric acid, hydrochloric acid, and p-toluene sulfonic acid are frequently used.

5.5. Base catalysts: functional groups that are catalysed by bases, such as Amphetamines and carboxylic acids, are utilised to speed up processes involving these functional groups. Triethylamine, sodium and potassium hydroxides are common bases as catalysts.

5.6. Metal catalysts: Metal catalysts are often used in heterogeneous catalysis and can be of metals or metal oxides. Some common metal catalysts include platinum, palladium, and nickel.

The selection of the appropriate catalyst depends on the specific reaction being catalysed and the desired reaction conditions the reaction temperature, among other things, pressure, and reactant concentrations can all influence the choice of catalyst [(Zwiener, 2020)].

6. Catalyst Preparation Methods

Catalyst preparation can be done in a variety of ways, including:

6.1. Impregnation method: In this method, a support material, such as alumina or silica, is soaked in a solution containing the desired catalyst precursor. The support material absorbs the precursor, which is then calcined to form the catalyst.

6.2. Co-precipitation method: In this method, the catalyst precursor and the support material are both dissolved in a solvent. The solution is then mixed, and a precipitant is added to induce the process through which the catalyst. The resulting mixture is then calcined to form the catalyst.

6.3. Sol-gel method: In this method, a precursor solution is mixed with a solvent, such as water or alcohol, to form a sol. The sol is then aged and gelled to form a solid material, which is then calcined to form the catalyst.

6.4. Spray-drying method: In this method, a solution containing the catalyst precursor is sprayed into a hot drying gas. The droplets dry and form small particles, which are then calcined to form the catalyst.

6.5. The catalyst precursor and the support material are combined in a solution and cooked under intense pressure in an autoclave when using the hydrothermal technique. The catalyst is formed more quickly under conditions of high pressure and temperature.

The selection of the appropriate catalyst preparation method depends on several factors, including the desired properties of the catalyst, the specific catalyst precursor, and the support material. Different preparation methods can result in catalysts with different particle sizes, surface areas, and pore structures, this may have an impact on catalytic activity and selectivity of the catalyst [(Khalaf, 2020)].

Table 2: Experimental setup and rate of contaminants degradation for oily wastewater with various techniques.

Method	Catalyst\Electrod	Contaminant	Optimal experimental conditions	Efficiency	References
Oxidation by photocatalysis	$Ga_{1.0}S_{5.0}$@ZnO@rGO	Acetaminophen (ACT)	50 mg/L concentration, 1 g/L catalyst dose, 5.4 pH, and 1 hour of visible light	Reduction in ACT: 100% 61% of ACT is mineralized.	(Jafarisani, 2020)
Photocatalytic oxidation	NFC(Nitrogen-Fluorine-Carbon) doped TiO_2	Antibiotics	Concentration: Uncommon, dose of 3%w(g)/V(mL), pH is sewage dependant, Time: 7 h, clear light	Decline in COD: 62% to 79% Degradation of TOC: 62%e86% leftover antibiotics 99%e 100% removal	(Ata, 2019)
Photocatalytic oxidation	MWCNT/TiO_2 Ration: 1.5(w/w%)	Tetracycline (TC)	10 mg/L concentration, 0.2 g/L catalyst dose, and pH of 5 Time: 5 h, Wavelength of light: 240 nm	100 minutes of TC elimination, 100%; 83% of TC mineralization.	(Ahmadi, 2017)
Catalytic ozonation	Iron foam	Raw pharmaceutical wastewater	Iron foam dosage: 80 g/L, pH: 8.4, Ozone concentration: 9 mg/L, DOC: 40 to 50 mg/L, Time: 2 h	Removal of DOC: 53% (21% more than ozonation)	(Huang, 2020)
Catalytic ozonation	NiO/Al_2O_3	2,4,6-trichlorophenol(2,4,6-TCP)	Ozone flux: 225 mg/h, pH: 4, 75 mg/L for the initial concentration, 5 g/L for the catalyst 40 minutes	Removal of 2,4,6-TCP: 84.3% to 86.58%	(Kruanak, 2019)
Electrochemical oxidation	Electrode: Iron	Raw landfill leachate	1.42 mA/cm2, 400 mg/h of ozone, and a pH of 3 are the current density values. Time: 2 h	Elimination of COD: 11,387.2 146.12 / 3381.9 mg/L	(Ghahrchi, 2020)
Electro-Fenton oxidation	Anode and cathode: Aluminum	Semi aerobic landfill leachate	pH: 3, doses of Fe_2 and H_2O_2 are 0.01 M and 2 A, respectively. 28 degrees Celsius, : 30 minutes	Decolorization (93%), elimination of COD (92%),	(Mohajeri, 2019)
photocatalytic oxidation	Raw landfill leachate	ungsten (W)-Carbon (C)- co-doped titanium dioxide (TiO_2)	starting COD of 550 mg/L, 40 W of light, 1 L/min of leachate flow, and 10.59 g/m2 of coating surface density. Time: 40 h	Removal of COD: 84%	(Azadi, 2020)

Photo-Electrochemical oxidation	Anode: Ti/SnO_2eSb, Cathode: Carbon black air diffusion	norfloxacin (NOR)	UV light, 5.2 mA/cm_2 current density, 20 mg/L NOR concentration, and 21.3 g/L Cl concentration Time: 2 h	100% of NOR degradation (4 minutes), 83.9% of TOC elimination	(Yu H. D., 2020)
Ozonation	H_2O_2, O_3	Mature landfill leachate	600 mg/L of H_2O_2, 8 g/h of ozone flowing through the system, 202 C, and a pH of 7 are the parameters. Time: 1 h	Removal of COD was 63% and TOC was 53%.	(Cortez, 2010)
Photocatalytic oxidation	UV-TiO_2	Mature landfill leachate	UV: 254 nm; 2 g/L; pH: 4; Catalyst dose 1.5 L/min air flow, 72 hours.	60% of COD, 70% of DOC, and 97% of the colour are removed.	(Jia, 2011)
Fenton reaction-neutralization-ultrafiltration (UF)	Fe^{2+}, H_2O_2	Mature landfill leachate	pH is 3, the amount of Fe^{2+} is 1 g/L, and COD is 4. 50 litres per hour for permeate flow Time: 2 h	Removal of COD: 80%	(Primo, 2008)

7. Advanced Oxidation Processes (AOPs) and Catalyst-Supported

To breakdown organic impurities in water, AOPs create a lot of hydroxyl radicals (•OH). Strong oxidants (such hydrogen peroxide or ozone) combine with water molecules to form these radicals. It is possible to eliminate a a range of organic pollutants, even those that are resistant to standard treatment techniques, thanks to the highly reactive nature of •OH. However, the procedure might be laborious and needs a large quantity of oxidant.

The use of a catalyst in catalyst-supported AOPs to increase Whether the is successful AOP procedure by providing a surface for the •OH to interact with organic contaminants on, the catalyst speeds up the rate of degradation. The outcome is, the process becomes more efficient and the volume of oxidant needed decreases. The two categories of catalyst-supported AOPs are homogeneous and heterogeneous, respectively. While heterogeneous catalysts are supported on a solid surface, homogeneous catalysts are dissolved inside the response media.

In conclusion, AOPs might be sluggish and require a lot of oxidants, even if they are excellent in reducing organic pollutants in water. Catalyst-supported AOPs boost the process' efficiency by utilising a catalyst to speed up degradation and lower the need for oxidizer. [(Yan Z. Z., 2018)].

8. Conclusion

The process of wastewater treatment is crucial to preserving a healthy and sustainable ecosystem. It helps protect our health, conserve water resources, and promote economic growth. To increase the effectiveness of wastewater treatment, it is crucial to solve the problems and implement new technology. Pharmaceutical wastewater is a complicated and difficult form of wastewater to treat because of the high concentration of medicines, complex combination of pollutants, and the advent of new contaminants. To preserve the environment, protect the public's health, and recover priceless resources, pharmaceutical wastewater must be properly treated. Advanced Oxidation Process with catalysts is an efficient and promising technique for treating pharmaceutical wastewater. It can help reduce the release of harmful contaminants into the surroundings and protect public health.

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